Representativeness of the current NERM network sites in draft FMUs'

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Executive summary/ Whakarāpopototanga Matua

1 Bay of Plenty Regional Council (BOPRC) runs the Natural Environment Regional Monitoring Network (NERMN) programme, which began in 1989 to monitor state and trends of important physical, chemical and biological characteristics of the natural resources of the Bay of Plenty region. Amongst the NERMN programme are on-going assessments of freshwater invertebrate communities, water quality, lake cyanobacteria, lake aquatic plants, river periphyton, recreational bathing water quality and groundwater quality.

2 Under the National Policy Statement for Freshwater Management (NPS-FM) (2020), Regional Councils must monitor attributes identified in the National Objectives Framework. These attributes form the bulk of the current NERMN monitoring. The NPS-FM stipulates that monitoring must be conducted at a spatial scale of a Freshwater Management Unit (FMU) of which BOPRC has identified 13 (working draft) throughout the region. The NPS-FM also requires that monitoring sites in an FMU must be representative of the FMU (or relevant part of the FMU). This report consequently examines the representativeness of the current NERMN monitoring network within these draft FMUs.

3 Any assessment of representativeness needs to be specific to the attribute in question and realise that "representativeness" will vary between different attributes. We thus first defined appropriate ways to assess representativeness for our different NEMRN sampling programmes, and then described representativeness of the monitoring networks within a) the region, and b) each of the draft FMUs.

4 Representativeness was assessed by calculating the proportion of NERMN sampling sites in a particular classification class (for rivers) or the number of lakes to the total number of NERMN sites throughout the region (or draft FMUs). For attributes in rivers, the proportion of river lengths in each classification class in the region (or draft FMUs) was also calculated and expressed as a proportion to the total river length in the region (or FMU). For attributes in lakes, the number of lakes in specific classification classes was calculated and expressed as a proportion of the total number of lakes in the region (or FMU). The ratio of the first proportion to the second proportion gave us an estimate of the representativeness of the NERMN sites to other waterways within the region, or each FMU. A ratio between 0.7 and 1.3 was defined as being representative.

Invertebrate sampling

1 Representativeness of the current invertebrate monitoring programme was assessed for four classifications (biophysical class[1], land use[2], stream size, and a combined biophysical x land use classification) at both the regional level, and within the draft FMUs. The current monitoring network was representative or over-representative of the five land use classes throughout the region. It was representative of the V-LG biophysical class, while the V-HG class was over-represented, and the NV class was greatly under-represented.

2 Under-representation of NV streams may have implications for the successful implementation of the NPS-FM, as these streams covered about 30% of the region.

[1] Carter *et al.* (*in prep*) further developed three biophysical classes based on Snelder *et al.* (2016): Volcanic+High Gradient (V-HG); Volcanic+Low gradient (V-LG); Non-volcanic (NV).

[2] We used five land use classes from the BOPRC 2017 land use layer: Native Forest (IF); Exotic Forest (EF); Pasture (P); Pasture Intensive (PI); Urban (U).

3 From a regional perspective, the current monitoring network was significantly under-representative in three FMUs: the Waioeka-Otara, East Coast and Rangitāiki. The current monitoring network was not currently sampling one of the common land use classes in five of the draft FMUs: pasture catchments in the Waihī/Pongakawa FMU, pasture intensive catchments in the Kaituna, Waiōtahe, Waitahanui, and Whakatāne FMUs, exotic forest catchments in Kaituna and Waitahanui, and indigenous forest catchments in Waiōtahe.

4 Sample representativeness was also assessed according to both bio-physical classification and land use in each FMU. The current network was representative of the dominant land use in the dominant biophysical class in five FMUs and over-representative in four FMUs. The network was under-representative of dominant catchment land use in in Rotorua Te Arawa Lakes (PI), Tarawera (EF), and Waiōtahe (IF).

5 These findings suggest that the current network may have some functionality as a basis of ongoing monitoring for the Council to meet its NPS-FM obligations using these draft FMUs, although some modification would be required due to the number of underrepresented (or missing) classes, and some over representation. However, to obtain rigorous estimates of ecosystem 'state' of specific stream classes within an FMU, enough replicate streams also need to be sampled. Examination of the number of sites in each of the biophysical x land use classes shows that many of the biophysical x land use classes examined had insufficient site replication to properly infer ecosystem state. Thus, our analysis of sample representativeness is only telling part of the story, as many 'representative' sites do not have sufficient sample replication to make strong conclusions about their overall state. More work is thus needed to develop a potentially new invertebrate monitoring network that is both representative and statistically robust.

Water quality sampling

1 Representativeness of the current NERMN river water quality network excluded any 'impact' sites below point source discharges. Representativeness was assessed against four classifications; biophysical; land use; stream size; and temporal (flow and sample frequency). Assessments were made at the FMU level for all classifications and at regional level for the biophysical and land use classifications.

2 Four FMUs with the largest river length (Rangitāiki, East Coast, Whakatāne, and Waioeka-Otara) were under-represented. Although two of these (East Coast and Rangitāiki) had a relatively high number of monitoring sites (five and seven, respectively), the number of waterways (or stream length) in these FMUs was at least double that of any other FMU, so overall representativeness here was low.

3 Exotic forest, indigenous forest and pasture intensive land use were under-represented at a regional level. In contrast, there are two water quality monitoring sites classed as 'urban', which this analysis considers over-representative. While only 0.7% of large streams (third order or more) are classified as urban, this land use can have significant detrimental impacts on stream ecosystems, which the current network is not able to capture.

4 Regionally, the NERMN water quality sites are representative of the V-HG class, over-representative of the V-LG class, and under-representative of the NV class. Thus, although 30% of stream length in the region flows is classified as NV, the current network makes up only 17% of the sampling effort. Assessment at FMU level shows that while we are representing dominant biophysical classes, classes that still make up a significant portion of the FMU are often not represented

5 Only one common biophysical x land use class was representative (V-HG-IF), and one was over-representative (V-LG-P). Two common biophysical x land use classes were underrepresented (NV-IF and V-LG-EF). The remaining classes comprised <10% of stream length within each biophysical class. Of those, three were representative, three were over-representative, and five were under-representative, with four of those having no sites at all. This indicates that our ability to draw conclusions about the state of these land use classes in the associated biophysical class across the region is limited.

6 It is likely that we could infer conditions in other IF sites throughout the region where we are not monitoring as we have a reasonable number of sites (17) across the region under the IF classification. Inferring conditions from other 'like' areas therefore becomes more difficult as dominant land use and / or biophysical unit does not explain as much of the variation observed in water quality. Teasing apart a dominant influence or a standardised mix of influences (such as land use) to be able to relate to other areas would be a difficult and resource heavy task. In order to consider extrapolation in non-IF areas, a detailed exercise of investigating influences would need to be undertaken most likely on a case-by-case basis.

7 To inform our policies and plans and their effectiveness, one must be able to determine the state, trends and loads from the NERMN programme. The programme is temporally (flow and sample frequency) representative for state and trends, yet many of our FMUs are lacking monitoring sites in the upper parts of the catchments (i.e., medium sized tributaries), suggesting that the current water quality network is not representative of the state and trends of our rivers at this level. In contrast, the programme is not temporally representative for loads, but likely representative spatially with the majority of sites being at the base of catchments capturing inputs into sensitive receiving environments.

Dissolved oxygen

1 Bay of Plenty Regional Council is currently monitoring DO downstream of major industrial point source discharges in five rivers to meet the requirements of Table 7 in the NPS-FM. No major issues were identified in this monitoring.

2 An additional four-point source discharges have also been identified, but three of these are likely to be in tidal areas, which will greatly reduce any adverse effects of point source discharges due to the increased dilution. The fourth discharge is at the Matahīna Dam as part of the hydro-electric power scheme there. This discharge is from relatively shallow, oxygenated water from Lake Matahīna, so is highly unlikely to reduce DO in this river.

3 As such, the current DO monitoring is regarded as being representative of the major point source discharges in the region.

4 A further 240-point source discharges have also been identified however, further work is required to exclude insignificant or short-term discharges.

5 Apart from DO monitoring below point source discharges, BOPRC is not monitoring DO in other areas, as implied in Table 17 of the NPS-FM. It is likely that any new DO monitoring will, in the first instance, be informed by the current NERMN water quality monitoring sites, however, this does not preclude monitoring this attribute at other as yet unidentified sites.

Periphyton

1 Periphyton sites were originally selected from a subset of all waterways in the region to represent streams where algal blooms would be highest. These streams were typically unshaded, and in areas with coarse streambeds. Sites were also selected based on a combination of geological class, estimated nutrient status, and flood disturbance. Three FMU's (Rangitāiki, East Coast, Whakatāne) comprised the majority (68%) of suitable periphyton monitoring reaches. All other FMU's make up less than 10% of the total regional reach length per unit.

2 Monitoring sites in the Rangitāiki FMU are representative, however, the Whakatāne and Tauranga Moana FMU's were slightly over-represented, and the East Coast was underrepresented based on the existing monitoring programme.

3 Monitoring only occurs in two other FMU's, the Waioeka-Otara and Waiōtahe. The former was adequately represented, but the latter was grossly overrepresented, given the total reach length. This over-representation is a combination of the small size of the Waiōtahe FMU and the high number of current monitoring sites (4) there.

4 The Rotorua Te Arawa Lakes, Tarawera, and Kaituna FMU's were not represented at all by the monitoring programme, despite making up between 1% and 8% of the applicable regional reaches. However, this may have reflected the fact that field observations of selected waterways were found to have streams dominated by fine, unstable streambeds, despite being predicted to have coarser streambeds. This made them unsuitable for periphyton monitoring.

5 Three bespoke periphyton categories were over-represented throughout the region, two were under-represented, and one was within the bands of adequate representation. The VA_Hard Eutrophic Low category was under-represented by the current monitoring programme and theoretically should be high risk sites for periphyton biomass accumulation due to the high nutrient status and low flushing potential.

6 The only FMUs to have adequate representation of all major periphyton categories were the Whakatāne and Rangitāiki, which had a maximum of two major periphyton categories only. The East Coast and Waiōtahe FMU were well represented for the dominant periphyton category within each FMU, but under or over-represented for others, Waioeka-Otara was over-represented for its dominant category, and Tauranga Moana was over-represented for a secondary category and under-represented for others.

7 The current monitoring distribution over-represents the Indigenous Forest (IF) landuse category, and under-represents Pasture (P), Pasture Intensive (PI) and Exotic Forest (EF). This differs by FMU, with Whakatāne representing all land use classes, Waioeka-Otara, and Waiōtahe representing their dominant land use class, and Rangitāiki and Tauranga Moana over-representing the IF land use class.

Cyanobacteria

1 Ninety four percent of applicable Freshwater Recreational Survey Layer (FRSL)[3] sites were located within the Rotorua Te Arawa Lakes FMU, which contains 92% of BOPRC's cyanobacteria monitoring effort and was deemed representative of the distribution at a regional level. One additional site was present in the Kaituna FMU at the Trout Pool near Ōkere Falls.

2 One applicable FRSL site was identified in the Tauranga Moana FMU near Lake McLaren. This FMU contained only 3% of FRSL sites so was deemed represented with monitoring absence.

3 For those FMU's that had monitoring coverage, 54.5% of identified FRSL sites within the Rotorua Te Arawa Lakes were within 3 km of an existing cyanobacteria monitoring site. The Kaituna FMU was limited to swimming areas around Ōkere Falls and had 100% coverage from the Trout Pool site.

4 Lake specific analysis of the Rotorua Te Arawa Lakes FMU shows that more than 83% of identified FRSL sites within lakes with a TLI >3 (mesotrophic of greater) were within 3 km of an existing monitoring site.

5 Lakes Ōkāreka, Tikitapu, Tarawera, Ōkataina, and Rotomā were not covered by the cyanobacteria monitoring programme. Lake Tarawera is the highest risk of this group, which

[3] The Freshwater Recreational Survey Layer represents a GIS-based database of all recreational areas within the region.

had four FRSL sites and a history of mild, ad-hoc blooms. This lake is not monitored routinely due to access issues, and instead health warnings rely on information from the public or satellite imagery.

6 Routine cyanobacteria monitoring only operates from October to June the following year, to coincide with the productive summer growth season. Blooms have been known to occur outside of this season (e.g., Lake Rotorua in October 2020) and are currently unmonitored. This is mitigated somewhat by the use of high-resolution satellite imagery, and ad-hoc response based on public information. However, this could be eliminated by maintaining a scaled down version of the monitoring programme during the lower risk off season.

Bathing quality

1 The Tauranga Moana FMU contained the most riverine FRSL sites (29%) and was adequately represented by seven monitoring sites. Other examples of representative FMU's include: East Coast, Rangitāiki, Waihī-Pongakawa, and Whakatāne.

2 The Kaituna and Tarawera FMU's were under-represented for riverine bathing sites, and the Rotorua Te Arawa Lakes and Waioeka-Otara FMU's were over-represented.

3 Proximity analysis showed that 100% of riverine bathing sites situated in the Rotorua Te Arawa FMU were within 3 km of bathing monitoring site. This number was lower for the Kaituna, Tarawera, Whakatāne, and East-Coast FMU's, all of which had less than 50% of identified FRSL sites within 3 km of a bathing monitoring site.

4 Addition of monthly monitoring from NERMN river water quality sites increased the coverage of riverine FRSL sites by 50% or more for Waihī-Pongakawa, Tarawera, and East coast FMU's. Furthermore, the Kaituna and Waiōtahe was the only FMU to have less than 50% coverage once all available monitoring information was included. However, these additional sites are only monitored monthly so this information should be seen as secondary to information derived from bathing water quality sites.

5 97% of the 34 FRSL sites specific to lake bathing were identified in the Rotorua Te Arawa Lakes FMU, which contained all 25 lake bathing monitoring sites and was therefore deemed representative. The only other identified lakes FRSL site was located in Tauranga Moana at Lake McLaren, which is not currently considered a popular swimming spot.

6 Of the 33 identified lake specific FRSL sites in the Rotorua Te Arawa Lakes FMU, 75.6% were within 3 km of a lake bathing monitoring site, which can be considered as representing the ambient conditions at that site. This increased to 93.9% when all monthly monitoring data from NERMN lake water quality and river water quality sites were taken into account. The only identified FRSL site in the Tauranga Moana FMU was within 3 km of a bathing monitoring site, however results should be considered with caution as Lake McLaren is known to have significant bird populations that can elevate the level of faecal contamination over the downstream McLaren Falls monitoring site.

Lake water quality

1 The current lake water quality monitoring programme represents lakes within the Rotorua Te Arawa Lakes and Rangitāiki FMU's reasonably well but lacks coverage in the Tarawera and Tauranga Moana FMU's.

2 Twelve of the 13 lakes monitored by BOPRC are classified as being of the Volcanic geomorphic type, with dams being the only other type monitored.

3 Dams, riverine, and shoreline lakes are underrepresented, despite collectively comprising 43% of the lakes within the region. Volcanic lakes make up the other 57% and overrepresented by the current monitoring programme.

4 WONI's primary classification category shows that BOPRC's current monitoring programme overrepresents mild, deep, large lakes (category D), mild, moderate depth and size (category

E), and mild, shallow, small lakes (category F), at the cost of warm, shallow, moderate sized lakes (category A), and warm, moderately shallow, small lakes (category B).

5 Notable lakes that are omitted from the current monitoring programme and fall into under-represented categories include: Lake McLaren in the Tauranga Moana FMU, Thornton Lagoon in the Rangitāiki FMU, and Lakes Pūpūwharau, Rotoroa, and Tamurenui in the Tarawera FMU. However, the value of monitoring some of these is questioned, given their status as hydro-electric lakes (Lake McLaren), or part of the treatment ponds for the pulp and paper mills in Kawerau (Lake Rotoroa), or are generally inaccessible to the public (Lake Pūpūwharau).

6 Analysis of the spatial variation of chlorophyll-a using satellite imagery shows that concentrations are highly variable across lakes, but typically form more predictable patterns in larger lakes.

7 Results also show that Lakes Tarawera, Rerewhaakaitu, and Ōkaro are situated in areas that approximately represent the median chlorophyll-a concentration across each lake. Lakes Ōkāreka, Rotoehu, Rotomā, Rotomāhana, and Tikitapu likely overrepresent the overall median chlorophyll-a concentration, and Lake Ōkataina and the Rotoiti (east) site under-represent median chlorophyll-a concentrations

8 Remote sensing results are only presented for chlorophyll-a, and caution should be applied before extrapolating findings to other water quality variables that cannot be detected through remote sensing methods.

Lake macrophyte monitoring

1 Lake SPI surveys are routinely conducted in the 12 Te Arawa Rotorua lakes. Three other lakes (Matahīna, Aniwhenua, Pupuwharau) have also been surveyed once on an ad hoc basis, but no consistent monitoring is being done in these lakes. The restriction of LakeSPI to the 12 Te Arawa Rotorua lakes means that our assessment of representativeness of the LakeSPI programme is very similar to that of the water quality programme, with the exception that LakeSPI assessments are not routinely undertaken in Lake Matahīna.

2 Each lake is surveyed only at sites where aquatic plants can grow. The LakeSPI methodology is thus not considered to be fully representative of overall macrophyte development throughout individual lakes, but instead focusses on surveying areas where plant growth is maximised. In this regard, it is similar to the site selection process outlined for the periphyton monitoring programme, where only sites conducive to periphyton development were selected.

3 Based on the analysis of the lake water quality monitoring programme, the LakeSPI programme is over-representative of the Rotorua FMU, and under-representative in the Rangitiaki FMU. Furthermore, it is absent from the Tarawera and Tauranga-Moana FMUs. However, the lakes in the Tauranga_Moana FMU are part of the Ruahihi hydro-electric power scheme (HEPS) and are thus functionally more similar to rivers. The value of LakeSPI monitoring in these HEPS lakes is therefore questionable. Lack of LakeSPI monitoring in the Tarawera FMU is consistent with the fact that these lakes are either inaccessible, managed as wildlife reserves for gamebirds by Fish and Game, or are part of aeration pond infrastructure for the pulp and paper plants in Kawerau.

4 Routine LakeSPI monitoring is not occurring in Lake Matahīna. However, the value of routine monitoring there is questionable. Macrophyte development is naturally severely limited by the lakes' bathymetry, so macrophytes flourish in only a few locations. Furthermore, the one LakeSPI done showed the highly degraded state of the macrophyte community there, being dominated by highly invasive plants. These plants are found throughout the catchment (especially in Lake Aniwaniwa), making their control extremely difficult or impossible.

5 If LakeSPI assessments were to be done in the Rangitāiki FMU, an obvious choice would be in Lake Pouarua, at the headwaters of the catchment. No LakeSPI assessments have been conducted there to date, so its condition is unknown. It may thus be valuable to undertake at

least a one-off LakeSPI assessment here to determine its condition. Based on the results, it may be justifiable to add this lake to the routine LakeSPI monitoring programme.

6 At this stage it is thought that the current LakeSPI programme is providing adequate information about the ecological status of macrophyte communities in all the major lakes where macrophyte development may occur.

Groundwater

1 Representation of groundwater is examined at a hydrogeological scale (HGU) and is shown at the FMU level. Existing groundwater monitoring is referenced to the 13 HGUs, which are present in eight of the 12 FMUs.

2 Just under half (44%) of monitoring bores are in coastal or upland sedimentary basin HGUs. There is no groundwater monitoring representation in the East Coast, Waiōtahe, Ōhiwa, and Whakatāne FMUs. The more easily accessed water in these areas is in sedimentary basins, which are much smaller resources that other water bearing stratigraphy in the region, so this absence may be acceptable.

3 Other aquifers with shallow groundwater flow systems (i.e., the lower coastal and upper sedimentary HGUs), are fairly well represented, with the exception of the Pongakawa and Tauranga FMUs. Most of the lower coastal and upper sedimentary HGUs are under cultivated land, with the exception of some urban areas. As these shallow aquifers are the most vulnerable and responsive to changes in land use activities, a higher level of representation may be required, depending on monitoring objectives.

4 Upper Volcanic HGUs A, B and C along with Mamaku, Matahīna and Pokai, Chimp and Pokopoko (PCP) ignimbrites and pyroclastic deposits have poor representation, other western volcanics units have fair representation.

5 Mid-Pleistocene sediments are poorly represented. They are generally found 150 m below ground level along the coast and are situated below predominantly agricultural land use. Similarly, the Lower Volcanic B HGU is poorly represented, in contrast to the well represented Lower Volcanic A HGU. Greater representation is recommended for some areas if a draft nitrate-nitrogen attribute is to be implemented regionally to protect ground and surface waters. Bores associated with the detection of saline intrusion are limited to Tauranga and Waioeka-Otara FMUs but are being investigated further. Priority is for the Kaituna area.

6 Data collected by the BOPRC groundwater monitoring network could supplement and enhance knowledge around drinking water supplies. A risk assessment for drinking water supplies bores on a regional scale is to be undertaken.

Contents/Ngā Rārangi Take

Part 1: Introduction/Kupu Whakataki

1.1 Background/Kupu Whakamārama

Bay of Plenty Regional Council runs the Natural Environment Regional Monitoring Network (NERMN) programme, which began in 1989, to monitor the state and trends of important physical, chemical and biological characteristics of the natural resources of the Bay of Plenty region. Amongst the NERMN programme are on-going assessments of freshwater invertebrate communities, water quality, lake cyanobacteria (blue-green algae), lake macrophytes (aquatic plants), river periphyton (algae), recreational bathing water quality and groundwater quality. The NERMN programme was reviewed by Donald (2014), who found that the programme was (then) appropriate to adequately manage natural resources. However, the Donald review also noted that an increase in monitoring frequency and/or geographical coverage was required to meet future needs. The implementation of the NPS-FM (2020) from central government was thus a catalyst of this review.

Under the NPS-FM, regional councils must monitor a number of clearly defined attributes identified as part of the National Objectives Framework. Such monitoring is to be conducted at a spatial scale of a freshwater management units (FMU) which regional councils must identify. Every regional council must identify (if present) within an FMU, the sites to be used for monitoring. Monitoring sites for an FMU must be located at sites which are either (or both) a) representative of the FMU; b) representative of one or more primary contact sites.

Regional councils must set limits on resource use for certain attributes (in Appendix 2A) in order to achieve Target Attribute States (TAS) and may set them for other attributes. Regional councils must initiate action plans to achieve TAS for Appendix 2B attributes and for attributes where monitoring shows a deteriorating trend (and may initiate them for Appendix 2A attributes). Attributes requiring limits on resource use are based either on water quality (e.g., nutrients and sediments) or on attributes usually/generally tightly linked to water quality (e.g., phytoplankton and river periphyton). Attributes requiring action plans are more ecologically based, and include attributes describing submerged macrophytes in lakes, fish, and invertebrate communities. This means that if a particular monitoring site fails to meet required Target Attribute States, then either limits on resource use or action plans must be initiated to ultimately halt further degradation and improve the state of the water body in question.

Bay of Plenty Regional Council has recently developed a spatial framework of working draft FMUs[4], where 13 FMUs have been identified. With the exception of the Motiti Island FMU, all others are on the mainland within the Bay of Plenty's regional boundaries. Bay of Plenty Regional Council currently has no NERMN monitoring on Motiti Island (which in itself represents a gap in our current network), so this report only deals with the mainland sites.

This report consequently documents the representativeness of the current monitoring network in terms of the FMU spatial framework.

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[4] Bay of Plenty Regional Council (*unpublished*), Draft Freshwater Management Units for the Bay of Plenty Region for discussion. Bay of Plenty Regional Council, Whakatāne, New Zealand

1.2 Purpose/Take

This report fulfils Task 5 of the Surface Water Quality workstream brief[5] as part of the Essential Freshwater Policy Programme (EFPP) implementing the NPS-FM (2020) for BOPRC. Specific requests for advice and information were requested by Gemma Moleta at a meeting on the 5 February 2020, and these requests form the basis of this memorandum.

The main focus of this report is to assess the representativeness of our NERMN networks in respect to the locations of the individual sampling sites in each of the draft FMUs. It is also important to assess what we are currently monitoring for and whether this provides a representative picture of the state of our waterbodies. Under the NERMN programme, BOPRC is collecting data on many of the attributes identified in the NPS-FM (Table 1), as well as additional attributes recommended in BOPRC's review of attributes for implementation of the NPS-FM[6]. The basis for including additional attributes and the limited application recommended for some NPS-FM attributes is detailed in that review. This report assesses the representativeness only of those attributes we are currently monitoring and are used to interpret the state. Most of the compulsory and recommended NPSFM attributes are represented. Fish deposited fine sediment, continuous dissolved oxygen (at NERMN sites), temperature and heavy metals (Cu and Zn) are not currently monitored as required in the NPS-FM (or recommendations). However, for many of these, we do have data that can provide some indicative information but may not meet the monitoring requirements for that attribute e.g., spot measurement of dissolved oxygen and temperature.

Table 1 Attributes recommended from BOPRC review and whether we are currently monitoring them.

	Attribute	Currently monitoring - yes (✔) / no (✗)
Appendix 2A - Rivers and Streams	Periphyton (trophic state) (Table 2)	✓
	Ammonia (toxicity) (Table 5)	✓
	Nitrate (toxicity) (Table 6)	✓
	Dissolved oxygen - Below point source only (Table 7)	✓
	Suspended fine sediment (Table 8)	✓
	Escherichia coli (E. coli) (Table 9)	✓
	Cyanobacteria (planktonic) lake fed only (Table 10)	✓
Appendix 2A - Lakes	Phytoplankton (trophic state) (Table 1)	✓
	Total nitrogen (trophic state) (Table 3)	✓
	Total phosphorus (trophic state) (Table 4)	✓
	Ammonia (toxicity) (Table 5)	✓
	Escherichia coli (E. coli) (Table 9)	✓

[5] Water Quality Task Brief (Internal document): Objective ID A3629388

[6] Objective ID: A3797680

	Attribute	Currently monitoring - yes (✔) / no (✗)
	Cyanobacteria (planktonic) (Table 10)	✓
Appendix 2B - Rivers and Streams	Fish (Table 13)	✗
	Macroinvertebrates (Table 14)	✓
	Macroinvertebrates (Table 15)	✓
	Deposited fine sediment (Table 16)	No – see Obj A3614602 and Zygadlo *et al.*, (2022) report
	Dissolved oxygen (Table 17)	✗
	Dissolved reactive phosphorus and cl. 3.13 (Table 20)	✓
	Ecosystem metabolism (Table 21)	✗
	Escherichia coli (E. coli) (primary contact sites) (Table 22)	✓
Appendix 2B - Lakes	Submerged plants (natives) (Table 11)	✓
	Submerged plants (invasive species) (Table 12)	✓
	Lake-bottom dissolved oxygen (Table 18)	Limited application. See Obj A3741406.
	Mid-hypolimnetic dissolved oxygen (Table 19)	Limited application. See Obj A3741406.
	Escherichia coli (E. coli) (Table 22)	✓
Additional - Rivers and Streams	DIN	✓
	Temp	✗
	Benthic cyanobacteria	✓
	Copper	✗
	Zinc	✗
Additional - Lakes	TLI	✓

Part 2:
General methodology/Huarahi

2.1 Assessing representativeness/Te Aromatawai i te kupu Māngaitanga

Site selection is a critical part of a monitoring design. We acknowledge that it is impossible to measure all locations in the region (or, indeed in an FMU), so we need to understand what options are available for selecting a subsample of sites that are representative of the region (or FMU). Any assessment of representativeness thus needs to have a clearly articulated statement of the monitoring objectives. We also acknowledge that any monitoring programme needs to be commensurate with the scale of issues and risks. For example, urban land use represents only a small proportion of the total land area in the region, yet urban development can often have profound impacts on freshwater (and estuarine) ecosystems. As such, it may be justified to have monitoring sites in urban areas, even though these may be 'over-representative' of other land uses in the region. The opposite situation exists for streams draining indigenous forests (IF), where there are few anthropogenic pressures, and subsequently no issues. It could thus be justified for a sampling programme to be under-representative for this stream type, although the importance of monitoring these streams to provide information on "reference" conditions means that any sampling programme should include this land use class at a sufficient level of detail to draw conclusions.

At this stage though, we are exploring what our current monitoring sites do and do not represent, to inform how we go about setting Target Attribute States for freshwater bodies in FMUs and parts of FMUs. Section 35 of the RMA requires regional councils to monitor the state of the environment and the effectiveness and efficiency of policies, rules, or other methods in their policy statements and plans. The NPS-FM clause 3.7(3)(a) requires councils to monitor water bodies and freshwater ecosystems, and clause 3.18 states that councils must establish methods for monitoring progress towards achieving Target Attribute States and environmental outcomes. Although the Target Attribute States are clearly quantitative in nature, these high-level qualitative narratives about monitoring make it problematic to decide what the overall "sampling population" should be in a monitoring programme. However, a fundamental goal of any monitoring programme in site selection is to obtain a "representative" sample of the population to be monitored. If the sample is not representative, then the information produced will not provide a good estimate of environmental conditions, or state, within the monitored groups. It is thus important to be very specific about what is meant by a representative sampling design in a monitoring program before an assessment can be made whether the site selection process is consistent with the objectives.

One way of calculating representativeness is using techniques outlined in Snelder and Scarsbrook (2005). Briefly, this involves calculating the proportion of NERMN sampling sites of a particular classification class to the total number of NERMN sites throughout the region (or, in this case, the FMU). The proportion of river lengths in each class in the region (or each FMU) is also calculated and expressed as a proportion to the total river length in the region (or FMU). The ratio of the first proportion to the second proportion illustrates the representativeness of the NERMN sites to other waterways within the region (or FMU). Numbers close to one suggest that the number of sites in the NERMN network are similar to the ratio of waterway length in that class; numbers > 1 indicate an over representation of sites within the NERMN when compared to waterway length; numbers < 1 indicate under representation. We based our assessment of representativeness when the ratio was between 0.7 and 1.3. Note that this example is applicable only to rivers for attributes such as invertebrate communities or water quality.

For attributes in lakes, the classification class would obviously be different, and based on some form of lake classification. Under this circumstance, the proportion of NERMN sampling sites in a particular lake classification class is calculated and compared to the total number of NERMN lake sites in the region (or FMU). The number of lakes in the region (or each FMU) in each lake class is also calculated, expressed as a proportion to the total number of lakes in the region (or FMU). As with the river example, representativeness of the NERMN lake sampling programme is based on the ratio of the first proportion to the second proportion.

Note that all assessments of representativeness for the different attributes being monitored requires some form of appropriate classification (Table 2) in each FMU. These classifications differ between the attributes. Thus, representativeness of the invertebrate and river water quality monitoring programmes involve assessment of representation in different landuse and biophysical classifications, as well as stream size. Water quality sampling is also done monthly, and water quality varies with flow. Because of this, we also looked at the temporal representativeness of the timing of the water sampling programme, to make sure that it was not biased towards high or low flows. Representativeness of the lake monitoring programmes (water quality and LakeSPI) used similar classifications, as did the bathing and lake cyanobacterial monitoring programmes. The representativeness of the different NERMN monitoring programmes according to these classifications were subsequently assessed. When doing this, it was also important to keep the number of classification classes as low as possible, while still genuinely reflecting biophysical similarities/differences in freshwater bodies in the FMU/region. If the number of potential classification classes is large, then there would be a corresponding requirement for increased sampling to cover all the different classes. This is why, for example, stream size was grouped into three classes for the assessment of invertebrate representativeness. The following sections briefly outline the rationale behind the classifications used for this analysis.

Table 2 Summary of the nine major attribute classes, showing the appropriate classification classes that representativeness was assessed, both regionally and within each FMU.

Attribute	Waterbody (sites)	Classification	Representativeness	
			Region	FMU
Invertebrates	River (124 sites)+	Landuse	Y	Y
		Biophysical	Y	Y
		Biophysical x landuse	Y	Y
		Size		Y
Water quality	River (52 sites)++	Landuse	Y	Y
		Biophysical	Y	Y
		Biophysical x landuse	Y	
		Size		Y
		Temporal		Y
DO	River (5 sites)	Below Point Sources	Y	
Periphyton	River (27 sites)	Targeted site selection		Y
		Bespoke classification	Y	Y
		Landuse	Y	Y
Lake WQ	Lake (13 lakes)	WONI*_Primary classification		Y
		WONI_Geomorphic type		Y
		Within lakes		

Attribute	Waterbody (sites)	Classification	Representativeness	
			Region	FMU
LakeSPI	Lake (12 lakes)	WONI_Primary classification		Y
		WONI_Geomorphic type		Y
Lake Cyanobacteria	Lake (4 lakes + 2 in upper Kaituna)	FRSL** recreational sites		Y
Bathing water	Rivers (31 sites), Lakes (13 sites)	FRSL recreational sites		Y
Groundwater level and quantity	Groundwater (73 bores)	Hydrogeologic Unit		Y

*WONI = Waters of National Importance
**FRSL = Freshwater Recreational Suitability Layer
+Note that although 124 sites have been sampled for invertebrates throughout the region, only 121 sites have been sampled for the requisite minimum period of five years to allow Current State to be calculated (See Zygadlo *et al.,* 2022). However, these sites have been included here for completeness.
++ Note that there are 53 current water quality sites in total, however, the Mangakino at Rerewhakaaitu Road site is on a second order stream so has been excluded from this analysis as discussed in section 2.1.1.

2.1.1 Water quality and invertebrate monitoring

An obvious classification for a monitoring network for both water quality and invertebrate monitoring is based on land use, as this has profound effects on water quality and ecology. We thus used the current BOPRC 2017 Landuse Layer to represent the 'dominant' land use in the catchment (or FMU). The methodology to determine the land use classes, thresholds and general methodology is detailed in Carter *et al.* (*in prep*) but described briefly below.

The NERMN programme was not explicitly designed to determine the impact of particular land use (especially for water quality). However, given the often-dramatic effect that both water quality and ecological attributes are strongly determined by broad land use classes, an assessment of land use was considered useful in understanding how representative the NERMN network was (Table 2). We used the dominant land use classes of IF (Indigenous Forest), EF (Exotic Forest), P (Pasture), PI (Pasture Intensive) and U (Urban) from the BOPRC 2017 land use layer (amalgamation of land use classifications into these dominant classes are described in Carter *et al.* (*in prep*)) to assess representativeness of monitoring sites in terms of land use. Although most draft FMUs have only very small proportions of waterway draining urban areas (with the highest amount of only 5% of waterway length in the Rotorua Te Arawa Lakes), it was decided to include urban land use in this analysis reflecting its often-major effect on stream ecosystem health, even at low percentages of total land use within a catchment. Because of this, we assessed representativeness in each FMU based on the five common land-use classes. The dominant land use in each draft FMU was also identified, based on the length of waterway segments within a particular land use being the largest contribution of total segment length. This allowed us to focus on the sampling representativeness of any major land use classes within each FMU. As mentioned earlier, this is particularly important to determine whether we are adequately assessing dominant classes within each FMU.

Another obvious classification to examine representativeness included the geology/slope biophysical framework which incorporated the best available information including GNS geology and slope from the Snelder *et al.,* (2016) classification merged to REC2.5 watersheds (Carter *et al., in prep*). This divided the region into three classes: Non-Volcanic (NV); Volcanic+High Gradient (V-HG); Volcanic-Low Gradient (V-LG) (Figure 1). Non-volcanic streams were found mainly in catchments from the Waiōtahe River east, while V-HG catchments were found mainly in the Whakatāne and Tauranga catchments, the Whirinaki catchment in the Rangitāiki FMU, the Tarawera and Waitahanui FMUs, and parts of the Tauranga Moana FMU. The classification was subsequently used for the assessment of representativeness to both the invertebrate and water quality monitoring networks (Table 2).

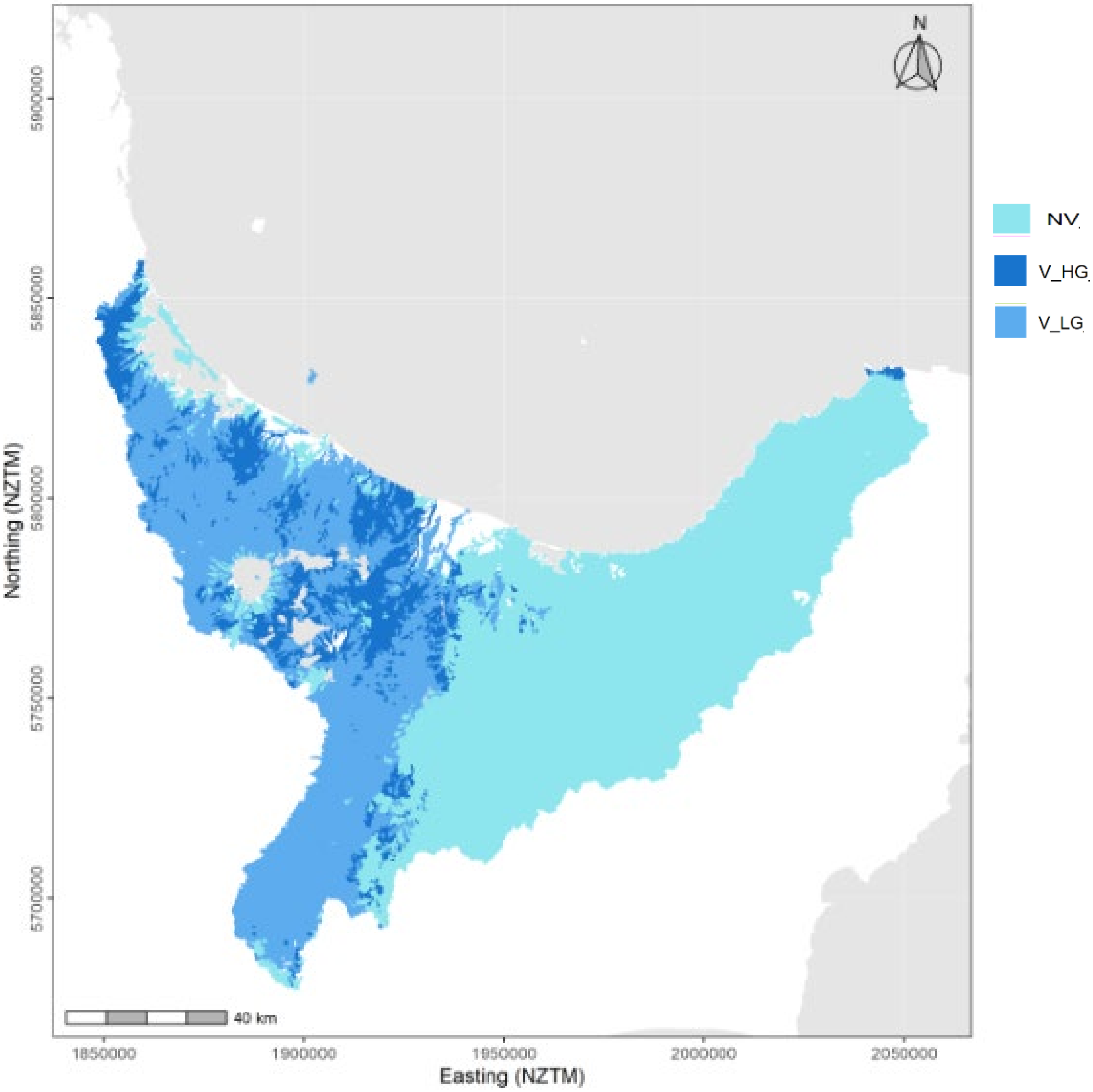


Figure 1 *Suggested biophysical classification of the Bay of Plenty drainage network based on geology and the average slope of the upstream catchment. The slope threshold differentiating the V-HG and V-LG classes was 10-degrees. (From Carter et al., in prep).*

We also considered stream order in our analysis of sample representation for some of the monitored attributes (Table 2), although our definition of representativeness differed depending on the attributes in question. For example, ecological sampling generally avoids large rivers, as it is difficult to collect samples from deep, fast flowing water[7]. In contrast, water quality sampling is generally in the lower parts of catchments in larger rivers, as these programmes were initiated to capture contaminant loads at the base of catchments. Thus, assessments of representativeness for water quality sampling were restricted to large rivers only (Third order and greater). Assessment of stream order (or size class) representativeness was performed only for invertebrates and water quality monitoring (Table 2).

Unlike invertebrate communities, which are monitored only annually, water quality is monitored monthly at 52 sites (53 sites including the one site monitored on a second order stream) throughout the region for the NERMN programme. Water quality is closely linked to flow, so we also examined the 'hydrological' representativeness of the current NERM water quality monitoring programme (Table 2).

Our assessments of the representativeness of the different attributes in each FMU was done for classifications deemed relevant for each attribute. To assist in the interpretation of the results, we created several tables that showed:

1 The cumulative length of waterways based on different classifications (e.g., biophysical and land use).

2 The number of sampling sites in each of these classifications.

3 The calculated representativeness of each attribute in each class. Representativeness was allocated to one of three classes: over-representative (orange shading); representative (green shading) and under-representative (red shading).

Although this analysis gave us information on the overall representativeness of our different monitoring networks in each FMU, we also attempted to identify both common and uncommon waterway types in each FMU. This was done as we wanted to emphasise that the *implications* of whether a site is representative or not also depends on how *common* a particular class was within an FMU, or the region. Having a sample network that is under-representative of sites in an uncommon class is not as major an issue in terms of assessing the overall environmental conditions of waterways within FMUs. However, if our sampling networks are under-representative of a particular waterway class that is common in an FMU (or the region), then our ability to assess the overall environmental conditions of those waterways is compromised. We thus defined waterways in a particular class as being 'common' if their combined NZSegment length was the largest percentage of total waterway length within a FMU. We also defined uncommon classes as being those with a cumulative length of <10%. Within the tables, common waterway classes were identified by the use of **BOLD** figures, while uncommon waterways were identified by grey shading.

[7] Note, however, that invertebrate sampling is done in some large East Coast rivers, where shallow riffles and runs are sampled

2.1.2 Periphyton monitoring

General methods used for the periphyton assessment were similar to that used for the water quality and invertebrate analysis, with the exception that a bespoke periphyton class was used as a classification, in addition to land use (Table 2). Representativeness was also assessed at a regional and FMU level. The bespoke periphyton class was originally developed in Suren and Carter (2016) and concatenated variables pertaining to biophysical class, nutrient status, and flood frequency.

2.1.3 Recreational bathing and cyanobacterial monitoring

Recreational bathing and cyanobacteria assessments used an alternative methodology based around the Freshwater Recreational Survey Layer (FRSL: Table 2). This layer is assumed to contain all known recreational sites within the region and was used to assess the representativeness of the current monitoring network. An additional analytical component was included in this analysis by adding an arbitrary 3 km buffer for each bathing or cyanobacteria site. Any identified FRSL site that fell within the 3 km buffer was assumed to be represented by the ambient conditions at the established monitoring site. More detailed methodology is included in relevant sections.

2.1.4 Lake water quality

The lake water quality used the Waters of National Importance (WONI) geospatial layer (Table 2), which forms part of the Freshwater Ecosystems of New Zealand (FENZ) database (Leathwick *et al.,* 2010). This layer included over 102 lakes greater than 1 ha in the Bay of Plenty Region. This number was reduced by applying a minimum 8 ha size limit and a maximum dimension >0.5 km, resulting in 30 lakes that could potentially justify a monitoring site. The associated classifications of ‘primary classification’ and ‘geomorphic type’ from the WONI layer were used to determine representativeness across the region. Comparisons were made between reference (WONI) sites and current monitoring sites using the same methodology as stated for other monitoring programmes above.

The second element of the lakes water quality analysis was simply a summary of relevant points from an article by Lehmann *et al.* (in press) that discusses the representativeness of BOPRC’s lake water quality monitoring sites relative to the spatial distribution of chlorophyll-a, as measured by remote sensing.

2.1.5 Groundwater

Unlike surface water, groundwater moves relatively slowly through the rock matrix which can mean changes to both water level and quality respond on a slower timescale than surface waters. Representation needs to provide information at relevant spatial and temporal scales to relate to monitoring objectives. Bay of Plenty Regional Council has recently identified hydrogeological units (HGU) and hydrostratigraphic units (HSU: Fernandez 2021) which provide the framework for hydraulically similar groundwater units, resulting in scale-independent, laterally extensive units that can be hydraulically connected (Table 3).

Development of HGU and HSU are the results of developing a conceptual regional model of groundwater systems on the basis of hydrological and hydrogeological information. The conceptual model provides the framework for groundwater monitoring and monitoring design. Using this framework an examination of the proposition of HGU being monitored in relation to FMUs is examined. As groundwater does not move as surface water, representation of groundwater is better achieved at a hydrogeological level, such as using the HGU framework. Representation is examined at the HGU and FMU scale across the region, examining the spatial extent of current groundwater monitoring (Table 2).

Table 3 Relationship of the proposed hydrogeological units to the major stratigraphic units in the Bay of Plenty (From Fernandes, 2020).

Western Bay of Plenty Stratigraphic Units	Tarawera-Rangitāiki-Whakatāne –Ōpōtiki Stratigraphic Units	Rotorua Stratigraphic Units	HGU Name	HGU	HSU	HSG
	Taupō Group		Tauranga- Kaituna Coastal Plains	Lowland sedimentary basins	Coastal Sedimentary	Coastal and Inland
Tauranga Group	Superficial non-marine sediments (outside Rangitāiki Plains)	Superficial sediments	Rangitāiki Plains			
	Q1 (Holocene) non-marine (Rangitāiki Plains)		Ōhope			
	Q1 (Holocene) marine (Rangitāiki Plains)		Waiōtahe			
	Q2–Q4 terrestrial (12–59 ka Pleistocene) (Rangitāiki Plains)		Ōpōtiki			
			Tirohanga			
	Q6–Q8 non-marine (186–245 ka Pleistocene) (Rangitāiki Plains)		East Cape			
			Galatea	Upland sedimentary basins	Inland Sedimentary	
			Waiohau			
			Waimana			
			Tāneatua			
			Lake Rotorua			
Rotoiti Formation			Upper Volcanic C	Upper Volcanic C	Regional One	Upper Volcanic
	OMER (Oruanui, Mangaone, Earthquake	OMER (Oruanui, Mangaone, Earthquake				

Western Bay of Plenty Stratigraphic Units	Tarawera-Rangitāiki-Whakatāne –Ōpōtiki Stratigraphic Units	Rotorua Stratigraphic Units	HGU Name	HGU	HSU	HSG
	Flat and Rotoiti formations)	Flat and Rotoiti formations)				
		Rotorua Basin Lake Sediments: Q3 Late Pleistocene, Q4–Q6 Middle Pleistocene	Lake Rotorua	Sedimentary A	Inland Sedimentary	Coastal and Inland
	Q1–Q4 undifferentiated pyroclastics		Upper Volcanic B	Upper Volcanic B	Semi-Regional	Upper Volcanic
	Youngest Okataina rhyolites					
		Post-caldera Rotorua rhyolites				
Mamaku Plateau Formation	Mamaku Plateau Formation	Mamaku Plateau Formation	Mamaku	Mamaku	Regional Two	
	Kāingaroa Formation		Kāingaroa	Kāingaroa		
	mQ to Q7 undifferentiated pyroclastics	mQ to Q7 undifferentiated pyroclastics?	Upper Volcanic A	Upper Volcanic A	Semi-Regional	
Rotorua rhyolites	Middle Okataina rhyolites	Middle Okataina rhyolites and other Pre-caldera Rotorua rhyolites				
Pokai, Chimp, Pokopoko Millar's Road ignimbrite	Pokai, Chimp, Pokopoko Millar's Road ignimbrite	Pokai, Chimp, Pokopoko Millar's Road ignimbrite	PCP	PCP	Regional Three	
Matahīna Ignimbrite	Matahīna Ignimbrite	Matahīna Ignimbrite	Matahīna	Matahīna	Regional Four	
	Rainbow Mountain dacite					
	Whakamaru group	Whakamaru group	Whakamaru	Whakamaru	Regional Five	
			Kaituna Pleistocene			Coastal and Inland

Western Bay of Plenty Stratigraphic Units	Tarawera-Rangitāiki-Whakatāne –Ōpōtiki Stratigraphic Units	Rotorua Stratigraphic Units	HGU Name	HGU	HSU	HSG
Mid-Pleisto mudstones and Early to Mid-Pleistocene sand and gravel			Eastern Rangitāiki Plains Pleistocene	Pleistocene Sedimentary	Pleistocene Sedimentary	
			Western Rangitāiki Plains Pleistocene			
			Tāneatua Pleistocene			
			Ōhope-Ōpōtiki Pleistocene			
Oldest Okataina rhyolites	Oldest Okataina rhyolites pre-Whakamaru includes Onepu/Caxton Formation from Kawerau	Oldest Okataina rhyolites	Lower Volcanic B	Lower Volcanic B	Regional Six	Lower Volcanic
Older volcanics including Pakaumanu Group	Old undifferentiated volcanics and sediments	Old undifferentiated volcanics and sediments				
Waiteariki Ignimbrite	Waiteariki Ignimbrite	Waiteariki Ignimbrite	Lower Volcanic A	Lower Volcanic A	Regional Seven	
Whitianga Group volcanics						
Aongatete Ignimbrite	Aongatete Ignimbrite	Aongatete Ignimbrite				
Basement undifferentiated	Basement undifferentiated	Basement undifferentiated	Basement	Basement Systems	Regional Eight	Basement

2.2 Limitations/Ngā here

Firstly, this assessment is based on a western-science perspective only. The assessment of representativeness is from a technical perspective only, not a cultural one. We acknowledge that representation of cultural attributes or locations of cultural significance will also need to be included in any future monitoring design and review. Any future advice on cultural attributes, monitoring and sites of significance is likely to come via our direct engagement with iwi Māori as per Te Hononga.

Secondly, clear definitions are required as to how 'representation' is defined, as this is likely to vary between the different attributes that BOPRC is measuring, even for the same classification (Table 2). For example, invertebrate communities are commonly collected in small, wadeable low order streams that are in intimate contact with their surrounding catchments. This reflects the fact that benthic invertebrates cannot be easily collected from larger rivers using the same techniques[8], and because metrics such as the MCI and QMCI that are used in the NPS-FM were developed based on data collected from wadable streams. Thus, taxa with low MCI tolerance scores were characteristically dominant in streams subject to a high degree of organic enrichment, while taxa with high MCI tolerance scores were found mainly in sites with little organic enrichment. Larger rivers are often dominated by a different suite of taxa than smaller rivers, and these taxa may be responding to stressors other than nutrient enrichment that the original MCI scores were based on. This may bring into question the original 'tolerance values' assigned to the different invertebrate taxa used in smaller streams. Therefore, it may be appropriate for any assessment of representativeness of invertebrate monitoring sites not to include larger rivers in the assessment particularly if these traditionally have not been sampled for valid technical reasons. In contrast, water quality sampling is usually restricted to larger higher order rivers, as these are generally located at the 'base' of catchments, and thus better represent total contaminant accumulation of all waterways upstream of these sampling points. This gives us a greater ability to understand the load of contaminants of water quality attributes (e.g., nutrients, bacterial sediment) leaving entire catchments, and entering receiving environments such as lakes or estuaries.

A third example of how assessments of representation will differ between attributes is for periphyton. It could be argued that 'site representativeness' for periphyton monitoring should not be based on assessing representativeness in relation to all individual waterway segments throughout the region, but instead be based only on-stream types where periphyton blooms are likely. Suren (2016) thus selected sites for a periphyton monitoring programme within the region that omitted all sites dominated by fine unstable substrates and with > 80% shade, as these conditions were not conducive to periphyton to grow. Stream order was also used to filter out unsuitable sites, with all waterways > 5th order being removed due to difficulties with sampling, and all 1st order waterways being removed reflecting the fact that many of these were likely to be ephemeral. In this way, any assessment of site representativeness for periphyton should be based only on intermediate sized waterways (2nd order to 4th order) unshaded sites with larger substrates.

[8] Although this is generally true, some larger rivers are still sampled as part of BOPRC's invertebrate monitoring network. These are generally gravel-bed braided rivers in the central-eastern part of the region, where only shallow gravel runs are sampled. Deeper and faster flowing habitats such as runs, pools and debris jams are not sampled.

Yet another important aspect to consider is representativeness will vary depending on whether we are assessing 'spatial' representativeness, or 'temporal' representativeness. The former reflects the importance of measuring a specific attribute at sites that are commonly found within a defined region (e.g., FMU), so that the 'current state' of a particular region can be described. For example, there is little point in only sampling steep forested streams in an area where at least 50% of waterways flow through lowland agricultural areas, as this will not allow us to make proper assessments of 'current state' within the region (or FMU). While annual sampling is sufficient for some attributes (e.g., invertebrate and/or fish communities), other attributes (e.g., water quality, river periphyton, lake cyanobacteria) require more frequent sampling, such as monthly, as they are tightly linked to antecedent hydrological conditions (Biggs 2000; Larnard *et al.,* 2017). Therefore, representativeness of water quality and river periphyton should also include some assessment of hydrological conditions on the day of, and prior to sampling to ensure that (for example) samples have not missed being collected during either floods or low flow events.

These, and other limitations specific to each attribute are discussed in each of the sections below.

2.2.1 Lake cyanobacteria limitations

While we recognise that most of the 12 Te Arawa Rotorua lakes are being monitored for cyanobacterial blooms, we also acknowledge that there is also a high degree of spatial variability within a lake. Some lakes have only a single sample location, while others have more. This may have implications for the ability to detect spatially restricted blooms within a lake. It is also acknowledged that the bathing cyanobacterial monitoring programme is only to monitor cyanobacterial blooms in the shallow lake margins – the areas where recreational use is expected to be highest. This focus on recreational monitoring is also the reason why the cyanobacterial monitoring is generally limited to the warmer months (November – May) where swimming may occur.

2.2.2 Periphyton limitations

Sites in the current periphyton monitoring programme were selected on the basis of being unshaded, and of having large substrates: conditions which are favourable for periphyton to grow. Any assessment of periphyton representativeness is thus based on the accuracy of the various models such as REC and the Freshwater Environments of New Zealand (FWENZ) models to accurately model shade and substrate size. Thus, a major limitation with assessment of periphyton representation is the accuracy of the various models. Although these models are extremely useful, field validation of predicted substrate categories have often shown them to be inaccurate. Therefore the 'true' number of reaches in the region that could sustain periphyton biomass accumulations may differ to that we have based our assessments on.

2.2.3 Bathing water quality limitations

The purpose of the recreational bathing water quality programme was to monitor and communicate the health risk that the community faces when interacting with freshwater resources throughout the region. The council is unable to monitor every freshwater bathing site in the region due to logistical and resource constraints, which means that sites are unofficially prioritised towards those that pose the greatest risk to the community. In this instance, risk can be defined as a combination of the magnitude of use and the water quality conditions at a site of interest.

To determine representativeness across the region, a census of bathing sites was required. This does not exist in a perfect form at present, however a student project carried out during the summer of 2019/2020 identified a significant number of recreational sites throughout the region[9]. This layer, called the Freshwater Recreational Site Layer (FRSL), is considered the closest source of recreational bathing site information to a regional census, and has therefore been used to represent all potential bathing sites for the purposes of this assessment.

While useful, the FRSL has known errors, including incorrect coordinates for some sites, and omission of a small number of bathing sites that form BOPRC's recreational bathing programme. This may imply that there are other sites missing throughout the region, which will have implications for the accuracy of this analysis. The FRSL could be significantly improved by raising public awareness, perhaps through an online website, or encouraging council staff to develop the dataset as they become aware of new bathing locations.

The FRSL also contains a qualitative assessment of the magnitude of public use. However, initial observations suggested that this diverged from reality in some locations (e.g., a number of high-profile sites that make up the BOPRC bathing water quality programme). Without accurate information then we cannot obtain an accurate estimate of risk and use this to prioritise site location.

2.2.4 Groundwater limitations

Bay of Plenty Regional Council maintains a database of groundwater well locations and well logs. A drilling programme designed to establish lithological and stratigraphical information has also been implemented at selected key sites. These sites also serve as a part of the council's groundwater monitoring network.

A key objective of the BOPRC drilling programme is to identify geological units and water bearing layers by using basic rock identification techniques and thin sections. Drill-hole information is instrumental in constructing conceptual 3D geological models but are limited by the accuracy and interpretation of lithologies by drilling companies as well as the robustness and availability of hydrological testing undertaken for a drill hole or series of drill holes. Hence, uncertainty and gaps exist within the available hydrogeological data for the FMUs which affects the current understanding of the groundwater system and contributes to uncertainty in predictions made with the groundwater models.

This report uses hydrogeological units (HGUs) for which several formations and lithostratigraphic units are combined into a hydrogeological unit. The hydrogeological units are further grouped into hydrostratigraphic units. Monitoring may occur in a HGU but is likely to be restricted locally to a water bearing lithostratigraphic unit (aquifer units) compared to aquitards (low permeability unit). A HGU may have several aquifer units but depending on the bore location and depth, as well as connectivity of the aquifer units between each other, the data collected from a bore may be limited to part of an HGU.

Water that has been in the ground only a short time is likely to be more variable in quality than older water. The processes of mixing, dispersion and attenuation that occur as the water and dissolved constituents travel through the groundwater system mean that any variability in water quality that has recently entered the ground will tend to decrease with time and distance travelled. Representing the temporal aspect of groundwater can in some cases be undertaken by aging techniques and, to a lesser extent, by chemical analysis. There are limitations to dating techniques for groundwaters and these

[9] See Internal Student report: Objective ID A3467512

techniques use mixing models to account for a range of differing groundwater contributions, which can result in a level in uncertainty. For this reason, as well as lack of data across the region, this temporal aspect of groundwater will not be discussed.

Regional scale monitoring programmes may not provide the level of detail necessary to evaluate local scale activities. Local and specific monitoring networks should be assessed to provide the information needed for management of such activities, which may add to knowledge of regional systems.

Part 3:
River invertebrate monitoring/ Ki te aroturuki i ngā awa tuaiwi-kore

3.1 Background/Kupu Whakamārama

Monitoring of river invertebrates within BOPRC first started in 1992, where 14 cobble-bottomed rivers in the eastern Bay of Plenty and four sites in the western Bay of Plenty were first monitored. These were the same sites where water quality monitoring was also initiated at the same time. In 2001 the invertebrate sampling programme was enlarged to a total of 118 sites, spread throughout the Bay of Plenty region, especially in the mid and western parts of the region. While some of these were hard-bottomed streams, many were soft-bottomed streams (i.e., had a streambed with >50% of soft sediments), which were typically found in the central-western part of the region. As far as can be ascertained, there was no documentation as to why streams were selected for sampling. A review of the NERMN monitoring scheme by Suren (2013) highlighted that EF streams were under-represented by the network at that time. This was rectified by sampling additional EF sites and dropping what was seen to be an 'excess' of pasture sites. Sites which were dropped were selected as being too difficult to sample due to either absence of continued access permission, health and safety issues, or the fact that some of these sites were dry on some years and were thus more ephemeral than perennial. A total of 124 sites are thus currently being sampled for freshwater invertebrates.

At each site, samples of aquatic invertebrates are collected using standard protocols developed for both hard and soft-bottomed streams (Stark *et al.,* 2001). Sampling is conducted annually between November and March. Sampling only annually is appropriate as most aquatic invertebrates have life cycles ranging from months to a year or so. They thus integrate all antecedent flow and water quality conditions, and their presence is also strongly controlled by small-scale habitat factors such as substrate size and deposited sediment, as well as overall rapid habitat assessments of factors including shade, flow heterogeneity, bank stability, and channel alteration (Snelder *et al.,* 2019). Aquatic invertebrates also have different sensitivities to hydrological disturbances, as well as changes to water quality (e.g., temperature, dissolved oxygen) or habitat conditions (e.g., deposited sediment smothering cobbles, or excess algal growth covering stones). Any environmental conditions occurring prior to sampling that would adversely affect sensitive invertebrates means that their densities would be reduced, or that they may be absent completely from a stream.

3.2 Assessment of site representativeness/Ki te aromatawai i te Māngaitanga

Assessment of site representativeness was restricted only to sites still currently being monitored (as of 2020-2021). It is also acknowledged that mix of 'ad-hoc' and stratified random sampling design may not be the best way to properly characterise regional condition in the future, as other methods such as a random probabilistic design network are arguably more robust in allowing more statistically accurate assessments to be made of the target population (Collier and Olsen, 2013). Furthermore, future changes to the monitoring network also have to include mātauranga Māori, and BOPRC has not sufficiently advanced its iwi engagement yet to have a clear view on this. A possible outcome of this analysis may thus be a redesign on the invertebrate monitoring network if this analysis shows too many cases of under-representative sampling in common waterways throughout different FMUs.

The assessment of site representativeness for invertebrate monitoring was based only on assessing the current NERMN monitoring locations. The majority of invertebrate monitoring sites (61%) are in first to third-order streams. However, a further 16% of the NERMN sites were in large rivers (5th order or greater), so it was decided to include all waterways in our assessment of site representativeness, even though the sampling design was a priori biased toward smaller streams. However, to simplify this analysis, all stream orders were classified into three classes:

- Small streams = orders 1 and 2
- Medium streams = orders 3 and 4
- Large streams = 5th order and above.

Representativeness was assessed for three classifications (biophysical class, land use and stream size) at both a regional level, and then within individual FMUs. We also created a combined biophysical x land use classification and assessed sample representativeness both regionally and within each FMU. We assessed representation firstly at a regional level, and then at the level of the proposed FMUs.

3.2.1 Regional representativeness

The current NERMN invertebrate monitoring programme collects samples annually from 124 sites, spread throughout the region (Figure 2). The length of time that these have been surveyed for ranges from five or fewer years (Six sites) to more than 20 years (12 sites). The majority of sites (84) have been sampled for between 15 and 20 years.

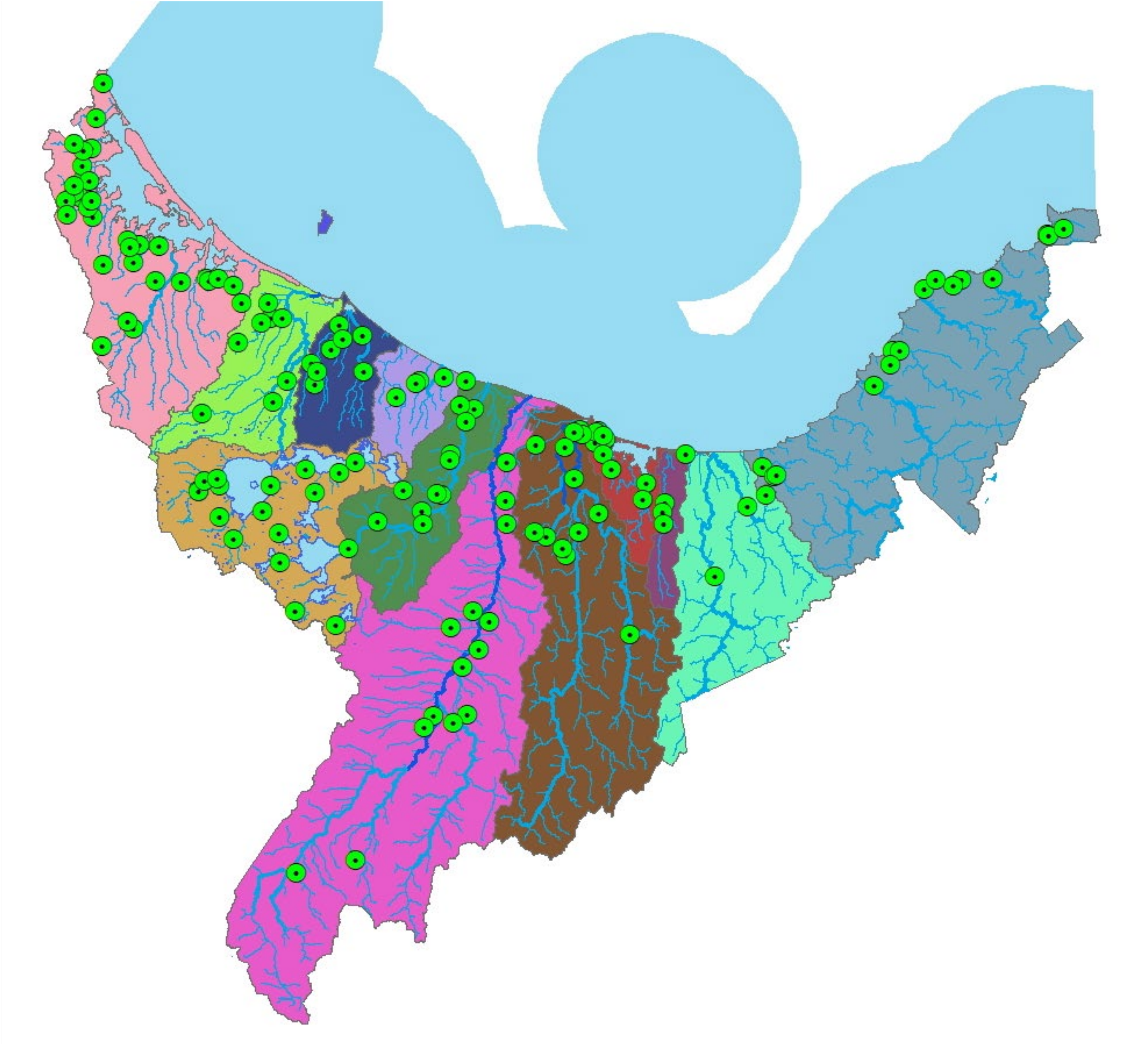


Figure 2 Map of the location of the 124 invertebrate monitoring sites around the Bay of Plenty region. Also shown are the draft FMUs, and all waterways > 3rd order, for simplicity.

3.2.2 Landuse classification

Within the region, the dominant landuse that streams flowed through was Indigenous Forest (46% of waterway length), followed by Exotic Forest (21%), Pasture (17%), and Pasture Intensive (15%). Urban land use contributed only 2% of total waterway length. Suren (2013) reviewed the invertebrate monitoring programme up to the end of the 2012-2013 sampling season. Examination of the representativeness in the Suren (2013) review of the invertebrate monitoring programme showed that pasture streams were over-represented. Based on this, a recommendation was made to drop some of the pasture sites and sample more sites in exotic plantation forests. As a result of this, three main land use classes are currently being sampled in a representative manner within the region, but pasture (P) is still slightly over-representative (Table 4). Urban streams, although contributing only 400 km to total waterway length, have eight NERMN sampling sites. This was over-representative but justified based on the often-profound negative effects that urban development has on freshwater ecosystems (Suren and Elliot 2005; Walsh *et al.,* 2005).

Table 4 Representativeness of the invertebrate monitoring network in the five land use classes in the region. Table shows the total segment length of waterways in each land use class, as well as the number of sites currently being monitored in the network. Representativeness was calculated as the ratio of the % of sites in each class being sampled to the % of waterway length. Over-represented sites = Orange shading; Under-represented sites = Red shading; Representative sites = Green shading. Where a particular waterway class exceeds 50% of total waterway length, the representativeness value is highlighted (bold); where this is less than 10% of waterway length, the class is shaded grey. NS = classes where no sites are being sampled

Land use classification	Total segment length (km)	Number of sites	Representativeness
Exotic Forest (EF)	4294	21	0.82
Indigenous Forest (IF)	9532	46	0.81
Pasture (P)	3465	33	1.59
Pasture Intensive (PI)	3048	16	0.88
Urban (U)	400	8	3.35

3.2.3 Biophysical classification

Within the region, the dominant geology-slope biophysical classification was for the V-LG class (40%), followed closely by the V-HG class (30%) and NV class (30%). Approximately 70% of the region was classified as having a volcanic-based geology, while only 30% of the region was classified as NV. The V-LG class was represented by the current invertebrate monitoring network, while the V-HG class was over-represented (Table 5). The NV class was greatly under-represented, with only 18 sites (or 15% of total sampling effort), despite this class representing about 30% of the total stream length in the region. This under representation may be justifiable, given the substantially less resource use and pressure in the eastern part of the region, so monitoring could be argued to be commensurate with the scale of issues and risks. Furthermore, one of the main rationales behind the biophysical classification approach was the realisation that ecological conditions in streams in a single biophysical class are likely to be similar, as they would have similar environmental drivers associated with the underlying geology and catchment slope. This means that there is expected to be a fairly large degree of uniformity within streams in each biophysical class.

Table 5 Representativeness of the invertebrate monitoring network in the three biophysical classes in the region. Conventions as per Table 4.

Bio-physical classification	Total segment length (km)	Number of sites	Representativeness
NV	6264	18	0.48
V-HG	6357	61	1.62
V-LG	8273	45	0.92

3.2.4 Biophysical x land use classification

Given the importance of both land use and the biophysical classification in explaining variability to invertebrate communities (Snelder *et al.,* 2016; Suren *et al.,* 2017), we next determined the representativeness of the invertebrate monitoring network using a biophysical x land use classification. This gave us 15 potential classes: three biophysical x five land use classes. This was important, as it allowed us to determine whether a particular biophysical class was under-represented by the monitoring network between the five dominant land use classes. If it was, then our ability to draw conclusions about the true state of stream health in that land use class in that biophysical class would be limited.

Four of the 15 biophysical x land use classes were representative, and three classes were under-representative (Table 6). Six of the classes represented <10% of the stream length and of these, four were over-representatively sampled. Of particular concern was the finding that the EF class in the V-LG class was under-represented, despite this being a dominant land use in this biophysical class. The NV class was common throughout the eastern part of the region, in the East Coast, Waioeka-Otara and Waiōtahe FMUs. However, the current NERM network was not sampling any sites in the IF land use class within the Waiōtahe FMU. V-HG-P and V-LG-P were over-representative. Although waterways in urban land use was uncommon (<10%) in each biophysical class, NV wasn't sampled at all, and the other two biophysical classes were over representative. However, as mentioned above, this over-representation of urban streams may be justifiable.

Table 6 Representativeness of the invertebrate monitoring network in a biophysical x land use classification. NV = Non-volcanic, V-HG = Volcanic-high gradient, V-LG = Volcanic-low gradient. Conventions as per Table 4.

	Total segment length (km)					Number of sites					Representativeness				
Geology-slope	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**
NV	393	4928	710	145	80	7	10	1	0	0	6.19	**0.71**	0.49	0.00	0.00
V-HG	1154	3741	897	461	30	8	30	14	7	2	0.71	**0.83**	1.61	1.57	6.79
V-LG	2747	863	1857	2442	289	6	6	18	9	6	**0.40**	1.27	1.77	0.67	3.78

3.3 FMU representativeness

After assessing regional representativeness of the NERM invertebrate monitoring network, we next wanted to assess how representative the current monitoring programme was in each of the 12 draft FMUs. We first assessed representativeness of the current sampling programme in each of the FMUs, with a particular emphasis to see which FMUs the current network was under-representing. Following on from this, we next assessed representativeness within each FMU according to land use and biophysical classes (and their combination), and stream size.

3.3.1 FMU classification

Sampling was significantly under-represented in three FMUs (Table 7), and in particular in the Waioeka-Otara, where only two sites are currently being sampled. Although relatively large numbers of sites were sampled in the East Coast and Rangitāiki FMU's, these FMUs were still under-represented, reflecting the fact that that these FMUs had the longest combined waterway length. Samples were overrepresented in six FMUs, while representative sampling was found in three FMUs. In general, larger FMUs were under-represented (with the exception of the Whakatāne), while smaller FMU's were either representative or over-representative. Having under-representative sampling within the large East Coast and Waioeka-Otara may not be a major issue given the dominance of undeveloped land in these FMUs. However, there is more land use development within the Rangitāiki FMU, so the under-representativeness of current NERMN network may be problematic for adequately describing ecological conditions within this FMU.

Table 7 Representativeness of the invertebrate monitoring network in the 12 mainland draft FMUs in the region. Conventions as per Table 4.

FMU_DRAFT	Total segment length (km)	Number of sites	Representativeness
East Coast	4035	12	0.50
Kaituna	992	6	1.02
Ōhiwa Harbour	284	7	4.15
Rangitāiki	4725	13	0.46
Rotorua Te Arawa Lakes	1749	15	1.44
Tarawera	1070	13	2.05
Tauranga Moana	2051	31	2.54
Waihī-Pongakawa	634	5	1.33
Waioeka-Otara	1861	2	0.18
Waiōtahe	248	4	2.72
Waitahanui	421	3	1.20
Whakatāne	2806	13	0.78

3.3.2 Landuse classification

The combination of Pasture and Pasture Intensive was the dominant land use class in six FMUs (Kaituna, Ōhiwa Harbour, Rotorua-Te Arawa Lakes, Tauranga Moana, Waihī-Pongakawa and Waitahanui), however, Waihī-Pongakawa was the only FMU where the P or PI class exceeded 50% of the stream length (Table 8). Indigenous forest (IF) was the dominant land use in four FMUs (East Coast, Waioeka-Otara, Waiōtahe, and Whakatāne; Table 8). Exotic forestry (EF) was the dominant land-use in Rangitāiki and Tarawera. Urban land use was generally low throughout the region, with the highest amounts being found in the Tauranga Moana (8.6%), Rotorua/Te Arawa Lakes (7.0%) and Kaituna (4.0%) FMUs (Table 8). The other FMUs each had less than 1% urban land use other than Tarawera (1.4%). This highlights the relatively low population density throughout the region, and the fact that, apart from the three main urban areas of Tauranga, Rotorua and Whakatāne, much of the Bay of Plenty presently has little urban development. Urban growth in the region is, however, likely to change, so future monitoring networks may need to consider these future changes.

Table 8 Percentage of total stream length in each draft FMU of waterways draining catchments assigned to one of five land use categories (EF (exotic forest), IF (indigenous forest), P (pasture), PI (pasture intensive) and U (urban). Dominant land use categories (greatest stream length) in each FMU are in bold text. These dominant classes also appear in tables of representativeness as bold values.

Draft FMU	%_EF	%_IF	%_P	%_PI	%_U
East Coast	7.21	**74.90**	15.90	1.96	0.03
Kaituna	16.28	8.78	**38.75**	32.21	3.99
Ōhiwa Harbour	18.76	23.12	21.02	**36.73**	0.36
Rangitāiki	**51.03**	27.77	8.04	12.88	0.28
Rotorua Te Arawa Lakes	18.78	22.80	**25.84**	25.57	7.01
Tarawera	**47.45**	18.84	9.01	23.28	1.43
Tauranga Moana	5.78	32.62	**38.42**	14.55	8.63
Waihī-Pongakawa	11.63	7.35	23.95	**56.51**	0.57
Waioeka-Otara	1.90	**75.57**	14.85	6.90	0.77
Waiōtahe	12.44	**57.29**	7.58	22.62	0.07
Waitahanui	22.73	11.14	**38.36**	27.61	0.15
Whakatāne	7.73	**77.28**	2.97	11.35	0.68

Examination of the representativeness of the current NERMN macroinvertebrate monitoring sites showed that only one dominant land use type was not monitored in each of the draft FMUs (Table 9). This occurs in the Waiōtahe FMU where there are no monitoring sites in its dominant land use, IF. The dominant land use in Tarawera, EF, was under-represented with only two monitoring locations. With regard to non-dominant land uses, four FMUs were under-representative for pasture and six with regard to pasture intensive. Exotic and indigenous forest land uses were under-represented in three FMUs each. Some potential reasons for this under-representativeness include:

- Some waterways in FMUs like the Waihī-Pongakawa and Waitahanui are too deep, and fast flowing to easily or safely sample, as they have a single-channel morphology with steep sided banks and a highly mobile pumice streambed.
- It is difficult to access some sites in indigenous forest in the Waioeka-Otara and Waiōtahe FMUs without accessing private land, as there are not many public roads in these poorly developed areas.
- Many waterways draining exotic plantation forest may appear as perennial on maps, but upon inspection are often dry, or too small to be sampled. Access to these sites is also often hampered by road access as well.

Sites were over-represented for 12 land use classifications, notably for indigenous forest (five FMUs; Table 9). Urban streams were particularly over-represented in the Whakatāne FMU, despite there being only a 'minor' land use, and despite having only one sampling site. However, given the continual urban growth within the region, and the dramatic effect that this can have on stream health, it is not recommended to reduce the numbers of urban streams currently being monitored. Similarly, even though exotic plantation streams are overrepresented in two FMU's, given the fact that this land use is so common throughout the region, and can have the potential to have relatively large short-term adverse effects on stream health, it is not recommended to reduce the numbers of streams being sampled.

Sites were considered representative of land use within each FMU for eight classifications. Moreover, five of these classifications represent the dominant land use type within each FMU (Table 9), indicating a good level of agreement between sample location and land use within these FMU's.

Table 9 Land use representativeness for NERMN invertebrate monitoring network in the 12 mainland draft FMUs in the region. Conventions as per Table 4.

	Total Segment Length (km)					Number of sampling sites					Representativeness				
FMU Draft	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**
East Coast	290.6	**3018.7**	640.8	79.0	1.2	4	7	1	0	0	4.62	**0.78**	0.52	0.00	0.00
Kaituna	160.9	86.7	**382.7**	318.1	39.4	0	1	5	0	0	0.00	1.90	**2.15**	0.00	0.00
Ōhiwa Harbour	52.9	65.2	59.3	**103.5**	1.0	1	3	1	2	0	0.76	1.85	0.68	**0.78**	0.00
Rangitāiki	**2410.3**	1311.6	379.8	608.5	13.4	6	2	2	3	0	**0.90**	0.55	1.91	1.79	0.00
Rotorua Te Arawa Lakes	306.3	371.9	**421.4**	417.0	114.4	2	1	6	3	3	0.71	0.29	**1.55**	0.78	2.85
Tarawera	**502.5**	199.5	95.4	246.5	15.1	2	6	3	2	0	**0.32**	2.45	2.56	0.66	0.00
Tauranga Moana	118.5	668.9	**787.7**	298.3	177.0	0	14	11	2	4	0.00	1.38	**0.92**	0.44	1.49
Waihī-Pongakawa	73.7	46.6	151.9	**358.4**	3.6	1	0	0	4	0	1.72	0.00	0.00	**1.42**	0.00
Waioeka-Otara	35.4	**1405.3**	276.2	128.3	14.4	0	2	0	0	0	0.00	**1.32**	0.00	0.00	0.00
Waiōtahe	30.9	**142.1**	18.8	56.1	0.2	3	0	1	0	0	6.03	**0.00**	3.30	0.00	0.00
Waitahanui	94.9	46.5	**160.2**	115.3	0.6	0	1	2	0	0	0.00	2.99	**1.74**	0.00	0.00
Whakatāne	216.8	**2168.4**	83.2	318.4	19.2	2	9	1	0	1	1.99	**0.90**	2.59	0.00	11.24

3.3.3 Bio-physical classification

Snelder *et al.* (2016) proposed a biophysical classification for streams within the Bay of Plenty based on dominant geology (Non-volcanic or Volcanic) and average upstream catchment slope (Hill catchments, > 10º slope, or Low catchments, < 10º slope). This biophysical classification was shown to explain considerable variability to both water quality, fish and invertebrate communities. As with the land use data, the dominant biophysical classification (containing the greatest waterway length) in each of the 12 FMU's was identified (Table 10). This showed that NV streams were dominant in the eastern FMUs in the region (East coast, Waioeka Otara, and Waiōtahe), while V-HG gradient streams were dominant in the Ōhiwa Harbour, Tarawera, Waitahanui and Whakatāne FMUs. V-LG streams were dominant in the other five FMUs (Kaituna, Rangitāiki, Rotorua-Te Arawa Lakes, Tauranga Moana, and Waihī–Pongakawa).

We also identified biophysical classes that had a secondary importance in each FMU, based on having > 10% of waterway length in each FMU. Thus, NV streams were of secondary importance in Whakatāne, while Volcanic-hill streams were of secondary importance in six FMUs (Kaituna, Rangitāiki, Rotorua Te Arawa Lakes, Tauranga Moana, Waioeka-Otara and Waiōtahe: Table 10). The V-LG streams were of secondary importance in four FMUs (Ōhiwa Harbour, Tarawera, Waiōtahe, and Waitahanui). Inclusion of these secondary biophysical classes in each FMU meant that we would be including > 80% of all waterway types in each FMU if we decided to include the secondary biophysical classes in our analysis of representativeness of the sampling network in waterways on each FMU.

Table 10 Percentage of total stream length in each draft FMU of waterways draining catchments in each of the three geology-slope biophysical classification classes. Dominant biophysical classes (greatest stream length) are identified (bold text).

Draft FMU	% NV	% V-HG	% V-LG
East Coast	**94.2**	3.6	2.2
Kaituna	2.5	15.9	**81.5**
Ōhiwa Harbour	0.3	**76.1**	23.6
Rangitāiki	7.4	27.2	**65.4**
Rotorua Te Arawa Lakes	0.9	28.8	**70.3**
Tarawera	0.9	**57.7**	41.4
Tauranga Moana	5.3	24.6	**70.2**
Waihī-Pongakawa	2.2	9.6	**88.2**
Waioeka-Otara	**78.0**	16.8	5.2
Waiōtahe	**65.2**	20.1	14.8
Waitahanui	0.2	**63.8**	36.0
Whakatāne	11.1	**79.4**	9.5

Examination of the representativeness of the current NERMN macroinvertebrate monitoring sites according to the dominant geology/slope classification (Table 11) showed that the current monitoring network was representative in eight of the 12 FMUs. Ōhiwa Harbour, Tarawera, and Waitahanui were slightly over-representative. Monitoring in the dominant geology/slope in Tauranga Moana was under-representative even with 15 sampling sites (Table 11); the V-LG class represented 70% of total waterway length in the FMU, so this under-representation could be considered relatively important in terms of limiting our ability to describe a common stream type in this area.

Table 11 Biophysical representativeness for the NERMN invertebrate monitoring network in the 12 mainland draft FMUs in the region. Conventions as per Table 4. (NV = Non-volcanic; V-HG = Volcanic+hill gradient; V-LG = Volcanic+low gradient).

FMU_Draft	Kilometers of NZSegments			Number of sampling sites			Representativeness		
	NV	V-HG	V-LG	NV	V-HG	V-LG	NV	V-HG	V-LG
East Coast	**3800.5**	146.0	88.6	12			**1.06**		
Kaituna	25.0	158.0	**808.7**		2	4		2.09	**0.82**
Ōhiwa Harbour	0.8	**215.8**	67.0		7			**1.31**	
Rangitāiki	350.0	1284.1	**3090.9**	1	4	8	1.04	1.13	**0.94**
Rotorua Te Arawa Lakes	16.4	503.1	**1229.5**		5	1		1.16	**0.95**
Tarawera	10.0	**617.5**	442.7		11	2		**1.47**	0.37
Tauranga Moana	107.8	504.2	**1439.2**		16	15		2.10	**0.69**
Waihī-Pongakawa	14.2	60.8	**559.3**			5			**1.13**
Waioeka-Otara	**1451.7**	312.5	96.6	2			**1.28**		
Waiōtahe	**161.6**	49.7	36.7	3		1	**1.15**		1.69
Waitahanui	0.7	**268.7**	151.5		3			**1.57**	
Whakatāne	311.7	**2228.4**	266.1		13			**1.26**	

3.3.4 Stream size

Unlike water quality sampling, which has traditionally focused on larger waterways at the base of catchments, invertebrate samples are mainly collected in small to medium-size waterways, although some sampling is still done in wadeable areas of larger waterways. In order to simplify the analysis of representativeness according to stream order, three waterway sizes were created: small streams = order 1 and 2; medium streams = order 3 and 4; larger streams = 5th order and greater.

In all FMUs, the majority of waterway length (ca 75%) comprised small streams, while medium streams made up approximately 20% of total waterway length. Larger streams contributed less than 5% on average to total waterway length in each FMU, although in some FMUs large waterways contributed over 6% (e.g., East Coast, Kaituna, Waioeka – Otara and Whakatāne).

With the exception of the Ōhiwa harbour, all FMUs were underrepresented in terms of sampling their small waterways (Table 12). In particular, no small waterways were sampled in three FMUs, which instead were over representative for large and medium waterways. Representative sampling was found only for medium waterways in the East Coast and Whakatāne FMU, and for small waterways in the Ōhiwa harbour FMU. Both medium and large waterways in other FMUs where present were all overrepresented by the current sampling protocol (Table 12).

Under representation of small sites in most FMUs is not surprising, and simply reflects the huge number of the small waterways throughout the region. However, many of these may be ephemeral in many parts of the region, and also located at sites inaccessible due to lack of roads or being on private land. The fact that the majority of medium and large streams where over-representative reflects the relatively low proportion of these size classes in each FMU in relation to the number of sample sites. Many of these were also sampled close to roads, which are often found in the lower, and more developed parts of the region. Note that no small or medium waterways were sampled in the Waioeka FMU, and only two sampling sites were from large rivers. This low amount of sampling in this FMU reflects the earlier finding (Table 7) of the low representativeness of sites here in general.

Table 12　Representativeness for the NERMN invertebrate monitoring network in the 12 mainland draft FMUs in the region when assigned to one of three stream size classes. Conventions as per Table 4.

	Kilometers of NZSegments			Number of sampling sites			Representativeness		
FMU	**Large streams**	**Medium streams**	**Small streams**	**Large streams**	**Medium streams**	**Small streams**	**Large streams**	**Medium streams**	**Small streams**
East Coast	247	828	**2960**	4	2	6	5.45	0.81	**0.68**
Kaituna	64	217	**710**	0	5	1	ns	3.81	**0.23**
Ōhiwa Harbour		60	**224**		3	4	ns	2.02	**0.73**
Rangitāiki	271	991	**3463**	3	8	2	4.02	2.93	**0.21**
Rotorua Te Arawa Lakes	51	307	**1391**	4	7	4	9.07	2.66	**0.34**
Tarawera	61	211	**799**	1	12	0	1.36	4.68	**ns**
Tauranga	24	430	**1597**	0	21	10	ns	3.23	**0.41**
Waihī-Pongakawa	13	149	**472**	1	4	0	10.08	3.40	**ns**
Waioeka-Otara	121	385	**1355**	2	0	0	15.37	ns	**ns**
Waiōtahe		57	**191**		2	2	ns	2.17	**0.65**
Waitahanui	8	108	**305**	0	3	0	ns	3.90	**ns**
Whakatāne	225	538	**2043**	5	5	3	4.80	2.01	**0.32**

3.3.5 Biophysical x land use classification

Finally, we assessed the representativeness of the current monitoring network according to a combination of the bio-physical classification and land use within each FMU. This analysis would have, in theory, resulted in 180 possible combinations (12 'mainland' FMUs x 3 biophysical classifications x 5 land use classes), represented by a table of 12 FMUs, each with three rows of biophysical classes and five columns of land use classes. Such a table would have been excessively complicated to present and interpret. Instead, we decided to filter out all the non-dominant biophysical classifications in each FMU in this analysis, so we were assessing the representativeness of the current monitoring network in the dominant biophysical classification in each FMU with regards to land use. This gave us a total of 93 sites: or 75% of the network being represented.

For the 12 draft FMUs, there were 60 possible combinations of the five land use classes and the three dominant biophysical class. Results of this analysis showed that nine of these combinations were representative, while 13 were under-representative (Table 13). A further nine classes were over-representative. The current NERM network was representative of the dominant land use class in five of the draft FMUs (East Coast, Rangitāiki, Tauranga Moana, Waioeka-Otara, and Whakatāne). A further four draft FMUs were over-representative (Kaituna, Ōhiwa Harbour, Waihī-Pongakawa, and Waitahanui) and the remaining three FMUs under-representative (Rotorua Te Arawa Lakes, Tarawera, and Waiōtahe); notably with no sampling being conducted in the dominant land use (IF) for the Waiōtahe.

The above analysis of the representativeness of the current invertebrate monitoring network in different land use classes in the dominant biophysical class of each FMU only represented 75% of the sites. To include as many sites as possible in this analysis, while still keeping the resultant table 'manageable', we next reanalysed the data to include the secondary biophysical classes (i.e., those with > 10% stream length in each biophysical class) in this analysis (Table 14). This analysis ended up capturing 123 out of the 124 sampling sites currently being monitored. There were 120 potential combinations for this analysis (12 FMUs x 2 biophysical classes x 5 land use classes), however, the East Coast FMU only contained a single biophysical class (NV) and Waiōtahe had two secondary classes.

The current invertebrate survey network was representative in 12 of the biophysical x land use classes with >10% stream length in the respective FMU, of which four classes were the dominant class (Table 14). An additional 12 classes were over-represented by the monitoring network, of which two classes were dominant. Thirty-four classes were under-represented by the monitoring network, including 26 classes where no sampling was being conducted. Of these 34 classes, eight were also in the dominant or sub-dominant class in each FMU.

Table 13 Biophysical x land use classes in each of the12 draft FMUs, showing representativeness of the NERM sampling network in the dominant biophysical class (greatest waterway length) in each FMU. Conventions as per Table 4.

		Total segment length (km)					Number of sites					Representativeness				
FMU	**Geology_slope**	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**
East Coast	NV	273	**2963**	531	33	0	4	7	1	0	0	4.34	**0.75**	0.60	ns	ns
Kaituna	V-LG	118	45	**308**	295	39	0	1	3	0	0	ns	4.43	**1.96**	ns	ns
Ōhiwa Harbour	V-HG	50	**65**	42	56	1	1	3	1	2	0	0.61	**1.41**	0.72	1.09	ns
Rangitāiki	V-LG	**2116**	137	329	500	8	5	0	2	1	0	**0.91**	ns	2.35	0.77	ns
Rotorua Te Arawa Lakes	V-LG	201	173	311	**394**	86	0	1	5	2	2	ns	0.67	1.87	**0.59**	2.71
Tarawera	V-HG	**339**	181	52	40	2	2	5	3	1	0	**0.33**	1.54	3.23	1.39	ns
Tauranga Moana	V-LG	65	408	**592**	246	129	0	3	7	1	4	ns	0.71	**1.14**	0.39	2.98
Waihī-Pongakawa	V-LG	55	39	128	**336**	1	1	0	0	4	0	2.04	ns	ns	**1.33**	ns
Waioeka-Otara	NV	35	**1234**	141	35	6	0	2	0	0	0	ns	**1.18**	ns	ns	ns
Waiōtahe	NV	23	**129**	4	6	—	3	0	0	0	—	7.05	**ns**	ns	ns	—
Waitahanui	V-HG	77	34	**118**	37	—	0	1	2	0	—	ns	2.59	**1.51**	ns	—
Whakatāne	V-HG	211	**1858**	61	92	6	2	9	1	0	1	1.63	**0.83**	2.79	ns	27.87

Table 14 Biophysical x land use classes in each of the 12 draft FMUs, showing representativeness of the NERM sampling network in both the dominant biophysical class (making > 50% of waterway length: red shading) and secondary biophysical class (with waterway length > 10%: orange shading) in each FMU. This combination covered 125 of the 126 sampling sites currently being monitored. Conventions as per Table 4.

		Total segment length (km)					Number of sites					Representativeness				
FMU	**Geology_slope**	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**
East Coast	NV	273	**2963**	531	33	0	4	7	1	0	0	4.65	**0.75**	0.60	0.00	0.00
Kaituna	V-HG	43	41	**68**	5	1	0	0	2	0	0	0.00	0.00	**2.30**	0.00	0.00
	V-LG	118	45	**308**	295	39	0	1	3	0	0	0.00	4.43	**1.96**	0.00	0.00
Ōhiwa Harbour	V-HG	50	**65**	42	56	1	1	3	1	2	0	0.61	1.41	0.72	**1.09**	0.00
	V-LG	3	0	17	**48**	0	0	0	0	0	0	0.00	0.00	0.00	**0.00**	—
Rangitāiki	V-HG	272	**878**	42	89	3	1	1	0	2	0	1.18	**0.37**	0.00	7.22	0.00
	V-LG	**2116**	137	329	500	8	5	0	2	1	0	**0.91**	0.00	2.35	0.77	0.00
Rotorua Te Arawa Lakes	V-HG	105	**198**	110	23	13	2	0	1	1	1	1.71	**0.00**	0.82	3.92	6.77
	V-LG	201	173	311	**394**	86	0	1	5	2	2	0.00	0.67	1.87	**0.59**	2.71
Tarawera	V-HG	**339**	181	52	40	2	2	5	3	1	0	**0.33**	1.54	3.23	1.39	0.00
	V-LG	163	18	44	**203**	6	0	1	0	1	0	0.00	11.86	0.00	**1.07**	0.00
Tauranga Moana	V-HG	14	**258**	185	42	4	0	11	4	1	0	0.00	**1.34**	0.68	0.74	0.00
	V-LG	65	408	**592**	246	129	0	3	7	1	4	0.00	0.71	**1.14**	0.39	2.98
Waihī-Pongakawa	V-LG	55	39	128	**336**	1	1	0	0	4	0	2.04	0.00	0.00	**1.33**	0.00
Waioeka-Otara	V-HG	1	**166**	114	31	0	0	0	0	0	0	0.00	**0.00**	0.00	**0.00**	—
	NV	35	**1234**	141	35	6	0	2	0	0	0	0.00	**1.18**	0.00	0.00	0.00
Waiōtahe	V-HG	8	13	8	**21**	0	0	0	0	0	0	0.00	0.00	0.00	**0.00**	—
	V-LG	0	0	7	**30**	0		0	1	0	0	—	0.00	5.61	**0.00**	0.00
	NV	23	**129**	4	6	0	3	0	0	0	0	7.05	**0.00**	0.00	0.00	—
Waitahanui	V-HG	77	34	**118**	37	0	0	1	2	0	0	0.00	2.59	**1.51**	0.00	—
	V-LG	17	12	42	**78**	0	0	0	0	0	0	0.00	0.00	0.00	**0.00**	—
Whakatāne	V-HG	211	**1858**	61	92	6	2	9	1	0	1	1.63	**0.83**	2.79	0.00	27.87
	NV	0	**302**	0	8	2	0	0	0	0	0	—	**0.00**	0.00	0.00	0.00

3.4 General discussion and summary/Matapakitanga

Having a monitoring network that is representative of FMUs or parts of FMUs in terms of specific classifications is a key requirement of the NPS-FM, which requires councils to monitor clearly defined attributes describing overall stream health such as the MCI, QMCI and ASPM at the spatial scale of an FMU. Monitoring sites for ecological purposes within an FMU must therefore be located at sites which are representative of the FMU. We assessed site representativeness of the NERMN invertebrate monitoring programme which collects samples from 124 sites throughout the region. Although the majority of monitoring sites are restricted to small first to third-order streams, about 10% of the sites are in large rivers. Because of this we decided to include all waterways in our assessment of site representativeness, even though the bulk of the invertebrate sampling was biased toward smaller streams.

Representativeness was assessed for three classifications (biophysical class, land use and stream size) at both a regional level, and then within individual FMUs. A fourth biophysical x land use classification was also created. Representativeness of the current network was assessed against this classification in all FMUs.

Having sites that are *representative* in terms of a specific classification means that they are sampled in proportion to their occurrence throughout an FMU. Having representative sites allows us to make accurate assessments of overall stream health of a particular stream class in an FMU, with the caveat that a minimum number of streams are being sampled to be able to draw statistical inferences from. Having a monitoring network with many sites which are *over-representative* of a particular class may reflect an unintended inefficiency of data collection, possibly at the expense of collecting more sites in classes which are underrepresented by a monitoring network. Clearly, monitoring networks where sites which are *under-representative* of particular stream classes highlight potential deficiencies with the monitoring network and may have implications in terms of enabling the Council to meet its obligations under the NPS-FM. There may, however, be cases where an under-representative network may be acceptable, such as where sites are flowing through catchments dominated by unmodified landuse, and where subsequent human pressures are minimal. Having a network that also under-represents small streams may also be acceptable, as it would be impossible to have a monitoring network that truly represents what amounts to the majority of a river network. Furthermore, many of these small first and second order streams are likely to be ephemeral, and therefore not suited for biological monitoring using the current sampling protocols (Stark *et al.,* 2001).

3.4.1 Regional representativeness

The current monitoring network is representative of exotic forest, indigenous forest, and pasture intensive land use classes throughout the region; urban and pastureland use classes were over-representative. Given the often-profound negative effects that urban development has on freshwater ecosystems, this over-representativeness of urban streams was deemed acceptable. The current invertebrate monitoring network was only representative of the V-LG biophysical class, while the V-HG class was over-represented. Here, 61 of the 124 sites (or 49%) were being sampled from this class, which contained 30% of total river length in the region. The NV class was greatly under-represented by the current monitoring programme, with only 18 sites (or 15%) being sampled in a class that contained 30% of total river length. Lack of sampling in NV streams may have implications for the successful implementation of the NPS-FM, in that a large area of the region is under-represented, mainly the eastern part. However, a large proportion of this biophysical class is in catchments dominated by IF, where pressures associated with landuse changes would be minimal, so this under-representation may not be of major significance.

This under-representative sampling of NV streams was also mirrored in the analysis of the biophysical x land use classes, where the IF class in the NV class was under-represented, despite this being a dominant land use in this biophysical class. In particular, the current NERM network did not sample *any sites* in the IF land use class within the Waihī-Pongakawa and Waiōtahe FMUs. However, as mentioned, this may not be of concern given the lack of human pressures in these catchments.

3.4.2 FMU representativeness

The current monitoring network was significantly under-representative of three FMUs, and in particular the Waioeka-Otara. Here, only two sites are being sampled (2% of the total number of sites in the network) in an FMU which contains 9% of total waterway length in the region. The East Coast and Rangitāiki FMU are also under-represented by the current monitoring network with only 10% of sites being sampled here, despite the fact that each FMU contributes approximately 20% of total waterway length. Indeed, these two FMUs have the longest combined waterway length in the region. Furthermore, the current monitoring network is under-representatively or not sampling dominant land use types in three of the draft FMUs. For example, although stream length through exotic forest catchments was 48% in the Tarawera FMU, it only contained two sites. Similarly, even though more than 50% of stream length flow through catchments dominated by indigenous forest (IF) in the Waiōtahe FMU, there are no sampling sites. This is a significant gap in our ability to properly characterise the health of these waterways in these FMUs. However, as noted above, much of these areas is dominated by IF where human pressures are minimal. Given this, their state may be inferred from other IF sites in nearby FMUs in the region. Making such inferences was one rationale behind the creation of the biophysical framework of Snelder *et al.* (2016). Using this framework, the ecological conditions of a stream in a NV catchment dominated by IF can be inferred from the measured conditions of a similar stream in another NV catchment.

The representativeness of the current NERMN macroinvertebrate monitoring sites according to the dominant geology/slope classification showed that the current monitoring network was representative (or over-representative) in eight of the 12 FMUs. Notably, the V-LG class in the Tauranga Moana FMU, which was under-represented. This class represented 41% of total waterway length in the FMU, so this under-representation could be considered relatively important in terms of limiting our ability to describe a relatively common stream type in this area. However, it may be possible to infer the ecological conditions of these streams in other V-LG stream classes of similar landuse in other parts of the region.

3.4.3 Stream size

All FMUs were dominated by small streams, while medium streams made up approximately 20% of total waterway length. With the exception of the Ōhiwa Harbour, all FMUs were under-represented in terms of sampling small waterways. However, medium and large waterways in other FMUs where present were either sampled representatively or were over-represented by the current sampling protocol.

Under-representation of small sites in most FMUs is not surprising, and simply reflects the huge number of the small waterways throughout the region. Moreover, many of these small first order streams are in fact ephemeral, and so could not form part of the aquatic invertebrate monitoring programme, which is restricted to perennial streams only. Given the numerical dominance of small streams throughout the region, achieving representative sampling would require an unrealistic sampling effort, for arguably little information gain. Instead, any sampling programme should ensure that at least the mid-size streams are sampled representatively, as this becomes a more realistic goal.

Note that although it would be informative to sample larger rivers in a representative manner, they are complicated by the fact that not all larger rivers can be sampled or have wadeable habitats in them that are conducive to sampling. Having a network that is under-representative of large streams is more a reflection of inherent methodological constraints with ecological sampling in these rivers.

Biophysical x land use classification

The current NERM monitoring network was representative of the dominant land use class in five of the 12 FMUs (East Coast, Ōhiwa Harbour, Rangitāiki, Tauranga Moana, and Whakatāne). A further five FMUs were over-representative (Kaituna, Rotorua Te Arawa Lakes, Waihī-Pongakawa, Waioeka-Otara, and Waitahanui). Tarawera and Waiōtahe were both under-representative of their dominant land use, with no sampling occurring in IF in Waiōtahe. The ecological condition in Tarawera may be reasonably inferred from other non-volcanic streams in EF dominated catchment.

The representativeness of the current monitoring network according to a combination of the bio-physical classification and land use within each FMU was also assessed. This assessment was done firstly on only the dominant biophysical class in each FMU (containing the greatest waterway length), and then with both dominant and secondary classes. For the analysis of dominant biophysical classes only, we found that the current network was representative of the dominant land use in all but four FMUs. The Ōhiwa Harbour, Tarawera, and Waitahanui each had their dominant land use class x dominant biophysical class sampled over-representatively. Tauranga Moana was under-representative of its V-LG class, even with 15 monitoring sites. The current network was under representative of EF in the Tarawera FMU and did not sample IF in the Waiōtahe FMU. The current network was also over representative of different land uses in eight FMUs. As discussed above, the ecological condition of EF streams in the Tarawera FMU is likely to be reasonably inferred from other streams in a similar biophysical class in catchments dominated by EF land use.

A similar picture was found when assessing representativeness of the monitoring network according to land use categories when both the dominant and secondary biophysical classes were used in each FMU. We found 12 of the common land use x biophysical classes to be representative by the current monitoring network, and a further 13 classes to be over representative. The current network was under representative of 33 classes, of which no samples were collected from eight of these dominant classes. Eight under-representative classifications occur in the indigenous forest class, which has been noted to have little human impact and so may not warrant a high level of sampling.

One reason for the under-representativeness of many sites is that the biophysical classification was only very recently revised (2021) revised and the classification of pasture was further separated to pasture and pasture intensive. Accordingly, the monitoring network was not designed with these newer classifications in mind. Because of the revised landcover classification system, the current monitoring network may warrant further investigation to see if it can still enable Council to meet its NPS-FM obligations if these draft FMUs become adopted.

3.4.4 Dealing with under-representative streams

Given that councils need to monitor sites within an FMU with a network that is representative of conditions within the FMU, any classifications that are under-representative of a particular class in an FMU may be counter to the over-arching objectives of the NPS-FM. Our analysis has shown that the current network is under-representative of NV streams within the region, and also shows an absence of monitoring dominant land use (IF) within the Waioeka-Otara FMU.

Part of monitoring attributes is to find out whether they are falling below a desired state or are displaying negative trends over time. Under such circumstances, councils must initiate action plans if monitoring shows a particular ecological attribute (e.g., MCI, QMCI or ASPM) below a desired state, or is showing a degrading trend within an FMU. Although the under-representativeness of IF sites, for example, may not be fully aligned with the need to have sites that are fully representative of a FMU, the need to monitor sites dominated by IF with negligible changes in land use activities may be questioned. Afterall, if there are no activities occurring in the IF land use class, is it a good use of resources to implement a monitoring programme in these stream types?

While it may be tempting to assume that monitoring sites in catchments dominated by IF seems unnecessary, it is important to note that these sites represent the “reference condition”, where (in theory) the only “stressor” on invertebrate communities reflects climatic changes. Reference condition streams are an important component of monitoring, as they allow us to describe the standard against which the current condition of other streams can be compared. Indeed, the use of reference streams to help interpret the overall condition of other streams is common in many overseas areas such as the United States of America, Australia, and the European Union as a whole, where the concept of reference condition is codified in legislation aimed at protecting and improving the ecological condition of streams (Stoddard *et al.,* 2006; Yates and Bailey 2009). Thus, lack of monitoring in reference condition streams throughout the region may be problematic in terms of putting any observed trends to biotic metrics into context. For example, a declining trend in MCI scores at pasture streams could simply be explained by a reduction in, for example, annual rainfall as a result of large-scale climatic cycles such as El Nino, which can cause stronger or more frequent westerly winds in summer, leading to drier-than-normal conditions in east coast areas such as the Bay of Plenty. If no monitoring was being undertaken in reference sites, then any potential negative trend in MCI scores in (for example) pasture streams may result in council implementing “action plans” to counteract these negative pressures. However, if the same negative trend was observed in reference condition streams, then it could be argued that such negative trends in the pasture catchments could instead be attributed to these climatic effects. Any future monitoring network design would therefore need to include some IF sites in each of the biophysical classes.

We also acknowledge that it may not be necessary to monitor reference condition sites in all FMUs, or even in all of the biophysical classes in each FMU. The idea behind the biophysical classification of Snelder *et al.* (2016) is that all streams within the same biophysical class display a certain degree of similarity in their physiographic drivers of water quality and quantity. Thus, it may be that as long as we are monitoring streams draining NV catchments dominated by native vegetation in some FMUs, then under-representation of these stream types in other FMUs does not necessarily prevent us from inferring their condition from similar streams in other spatially disjunctive locations. A qualifier to this statement is that our ability to make statistically valid inferences about the state of waterways within a specific class, or to infer the state of waterways in other FMUs is strongly dependent on the number of replicate streams being sampled. This is discussed in further detail below.

3.4.5 Need for maintaining minimum sample sizes

The above analysis of sample representativeness was based on examining the ratio of the percentage of sampling sites in a particular classification to the total number of sampling sites, to the percentage of waterway length in that classification to the total waterway length in an FMU. We set a nominal ratio between 0.7 - 1.3 to indicate representativeness. Having a monitoring network with many sites that were under representative of particular classifications was highlighted as potentially limiting the Council's ability to fulfil the obligations of the NPS-FM, while having a network with sites that are over representative of a particular classification suggests a degree of inefficiency in the network.

However, it must be remembered that to obtain rigorous estimates of ecosystem "state" of specific stream classes within an FMU, enough replicate streams need to be sampled. Examination of the number of sites in each of the land use x biophysical classes shows a somewhat concerning picture. For example, 52 of the 60 potential land use x dominant biophysical classes examined across the 12 FMUs had fewer than five sampling sites: indeed, 12 classes were represented by only a single site and 24 with no sampling sites. Under these conditions, the ability of BOPRC to adequately infer environmental state is severely limited. This means that our analysis of sample representativeness is not telling the complete story, as many of the representative sites may not have sufficient sample replication to allow council to draw strong conclusions about any monitoring results. The difficulty in capturing the full picture will also increase when a classification increases the number of categories, as more of these will need to be sampled with sufficient replication to properly infer state.

For example, the dominant land-use in the Waitahanui V-HG FMU is pasture, representing 44% of total stream length in the dominant biophysical class or 28% of the whole FMU. Only three sites are being sampled in the Waitahanui, of which two are in pasture streams - equating to 66% of sampling effort here. This means that the calculated representativeness of these sites is 66% / 44% = 1.5 (over-representative). However, it could be unreasonable for Council to expect that they could accurately describe the state of pasture streams in the Waitahanui Volcanic+ High gradient FMU on the basis of just two streams. This would be even more problematic if one of these two streams was below a desired attribute state, or showing a negative trend, as councils are obligated to implement action plans when this happens. Furthermore, the mechanisms behind a decline in ecological condition are many and varied, and can include reductions in small-scale habitat conditions, changes to water quality, and changes to hydrological regimes. This is likely to further complicate the ability for councils to implement action plans without further investigative work to determine the cause of the decline. But, in this example, it would be unwise to assume that other pasture streams in the same V-HG class in the Waitahanui are also degraded, based on a sample size of only two.

Given the large number of potential land use x biophysical classes across the 12 FMUs where sample replication is severely restricted, any further decision as to the ongoing value of the current invertebrate monitoring network in being suitable for implementation of the NPS-FM needs to consider both representativeness and site replication. However, it is also acknowledged that one of the strengths of the biophysical classification is the acknowledgement that streams in each of the three biophysical classes are likely to be controlled by the same overarching hydrological and physical processes. This means that we should be able to infer the ecological condition of a stream of a particular land use x biophysical class in one FMU across to a spatially disjunct FMU. This ability to infer stream condition may help us meet the requirements of both sample representativeness and site replication. It is envisaged that more work will be done on this as part of developing a potentially new invertebrate monitoring network throughout the region. The value of predictive models to infer current state in un-monitored streams also needs to be considered, and Clapcott *et al.,* (2016) have developed models to predict at least one of the NPS-FM attributes (the MCI) in all NZSegments throughout the country.

Part 4:
River water quality monitoring/ Ki te aroturuki i te kounga wai

4.1 Background/Kupu Whakamārama

The river and stream water quality monitoring network has been operating since 1989 and the results are used for a number of reasons, such as:

- Reporting on the state of the environment in terms of water quality of rivers and streams.
- Comparing measured water quality parameters against water quality classifications, guidelines and standards.
- Detecting water quality trends in the interests of maintaining and/or enhancing water quality.
- Identifying specific water quality issues.

Water quality sampling has traditionally been focused on larger waterways at the 'base' of catchments to capture cumulative impacts of upstream activities. First-order streams are often ephemeral making them unsuitable for water quality monitoring year-round. Second-order streams are also generally small and drain relatively small catchments. As a result, only one of our NERMN water quality monitoring sites are in first or second order streams. First and second order streams were excluded from this analysis in order to be more representative of the traditional approach to a water quality SoE network. The Mangakino at Rerewhakaaitu Road site is located on a second order stream. This site was therefore excluded for this analysis of representativeness.

A total of 46 (excluding the Mangakino site) river and stream sites are monitored by the Regional Council as part of the NERMN network, with a further six sites being monitored by NIWA. Within the broader monitoring network are 'impact' sites that are located downstream of significant point source discharges, and therefore are beyond the purposes of SoE monitoring. These 'impact' sites were thus excluded from this analysis, resulting in 53 sites being used in this assessment (Figure 3). The sites cover a range of land uses and catchment land cover and include most of the major rivers and streams in the Bay of Plenty.

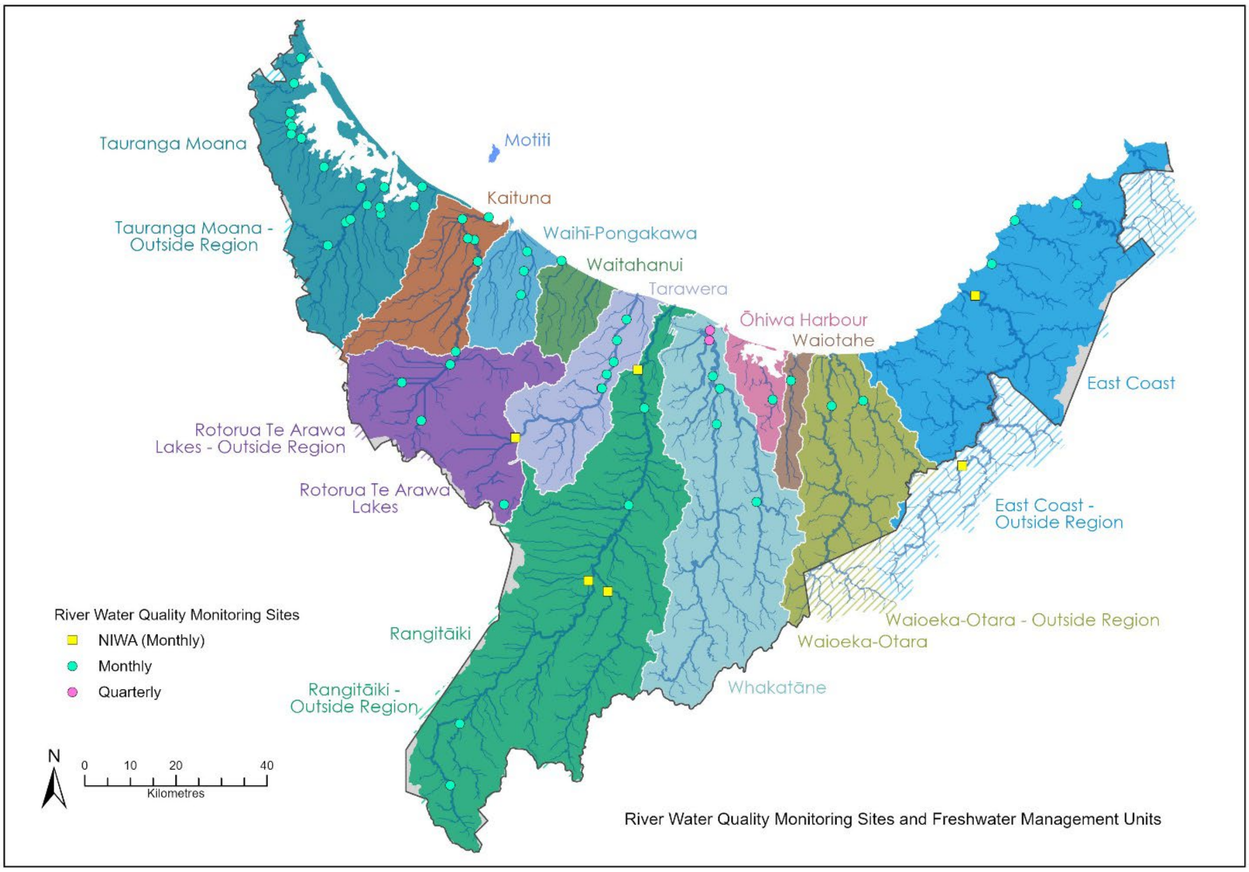


Figure 3 Map of the location of the 52 river water quality monitoring sites around the Bay of Plenty region. Also shown are the draft FMUs, and all waterways > 3rd order, for simplicity.

4.2 Assessment of representativeness/Te Aromatawai i te kupu Māngaitanga

Our assessment of representativeness for NERMN water quality sites was limited to current BOPRC and NIWA sites, excluding the 'impact' sites that are located downstream of point source discharges. Representativeness was assessed against four classifications:

- Biophysical,
- Land use,
- Stream size, and
- Temporal (hydrological, and sample frequency).

Biophysical and land use was assessed at both a regional level, and then within individual FMUs. We also created a combined biophysical x land use classification and assessed sample representativeness at the regional level. Combining classifications multiplies the number of sub-classes, hence this combined assessment was limited to these two classifications based on their identified importance in explaining variability in water quality (Snelder *et al.*, 2016). This combination allows us to determine whether a particular biophysical class is under-represented by the monitoring network between the four dominant land use classes.

Stream size was assessed at the individual FMU level. In order to simplify the analysis of representativeness according to stream order, two waterway classes were created: medium streams = orders 3 and 4; larger streams = 5^{th} order and greater, consistent with the ecological analysis above (excluding small streams of 1^{st} and 2^{nd} orders).

Flow representativeness was assessed for individual sites covering all but one FMU (Waiōtahe). This approach was taken as information on flow regimes across the region is varied. NERMN sites where there was water quality and continuous flow rating were identified initially (BOPRC and NIWA sites). This provided coverage across eight of the 12 FMUs with at least one site in each of those FMUs. Three FMUs (Whakatāne, Rotorua Te Arawa Lakes, and Waitahanui) used continuously rated sites that were close to a NERMN water quality site. Field gauging results at these three water quality sites were checked against the flow for the same time at the continuously rated site and found to be representative enough for the purposes of this assessment. No suitable site could be found in the Waiōtahe FMU for flow representation.

Flow duration curves (FDC) were obtained from Aquarius, the council's environmental database, and flow quartiles extracted from this data. The measured flow on the day of sampling was appended to the water quality sample using the in-house Aquarius package in R, and then grouped into associated flow quartiles. Hydrological representativeness was then calculated as the ratio of the % of samples in the flow quartile divided by 25% (a quartile).

4.3 Regional representativeness/Ngā māngaitanga ā-rohe

4.3.1 Landuse classification

Regionally, indigenous forest was the dominant land use classification for third-order streams and higher, yet the majority of NERMN water quality sites were in the pastureland use classification (Table 15). Both indigenous forest and pasture intensive were under-represented by the water quality network in the region. There were only two water quality monitoring sites classed as 'urban' (Table 15). While urban land use is a low proportion of the region for third-order streams and higher (0.7%), it has significant impacts on stream ecosystem health and overrepresentation may be appropriate.

Table 15 Representativeness of the water quality monitoring network in the four land use classes in the region. Table shows the total segment length of waterways in each land use class, as well as the number of sites currently being monitored in the network. Representativeness was calculated as the ratio of the % of sites in each class being sampled to the % of waterway length. Over-represented sites = Orange shading; Under-represented sites = Red shading; Representative sites = Green shading. Where a particular waterway class has the largest contribution of total waterway length, the representativeness value is highlighted in bold text; where this is less than 10% of waterway length, the class is shaded grey. ns = classes where no sites are being sampled

Land use classification	Total segment length (km)	Number of sites	Representativeness
Exotic Forest (EF)	1024	6	0.60
Indigenous forest (IF)	2547	17	0.69
Pasture (P)	1091	23	2.17
Pasture Intensive (PI)	657	4	0.63
Urban (U)	36	2	5.73

4.3.2 Biophysical classification

The biophysical classifications are relatively evenly distributed for the region, with V-LG having the most river length (>2nd order streams) at 39%. The NERMN water quality sites were well represented for V-HG, overrepresented for V-LG, and underrepresented for NV with only 17% of sampling effort despite covering 31% of stream length (Table 16).

Table 16 Representativeness of the water quality monitoring network in three biophysical classes in the region. Conventions as per Table 15.

Bio-physical classification	Total segment length (km)	Number of sites	Representativeness
NV	1639	9	0.57
V-HG	1662	14	0.87
V-LG	2066	29	1.45

4.3.3 Biophysical x land use

As discussed above, the biophysical and land use classifications are important for explaining the variability of water quality in rivers. Four classes were representative (V-HG- EF, V-HG-IF V-LG-IF, and V-LG -PI), while four were overrepresented (Table 17). Sites were under-representative in seven classes, including four where there are no monitoring sites. This indicates that our ability to draw conclusions about the state of these land use classes in the associated biophysical class across the region is limited.

Table 17 Representativeness of water quality monitoring sites in the biophysical x land use classification. Conventions as per Table 15.

	Total segment length (km)					Number of sites					Representativeness				
	EF	IF	P	PI	U	EF	IF	P	PI	U	EF	IF	P	PI	U
NV	48	**1336**	229	16	9	0	0	7	1	0	ns	**0.54**	0.45	ns	11.68
V-HG	243	**1008**	291	112	2	2	2	8	4	0	0.85	**0.82**	1.41	ns	ns
V-LG	**733**	203	571	528	25	4	4	2	18	4	**0.56**	1.02	3.25	0.78	4.09

4.4 FMU representativeness

4.4.1 FMU classification

Representativeness of the river water quality NERMN for each FMU is detailed in Table 18. River segment lengths also include the headwater of streams that lie outside the region that otherwise flow through the Bay of Plenty. Only three FMUs, Kaituna, Tarawera and Waitahanui had a representative number of river water quality monitoring sites in comparison to the total river length in that FMU. Four FMUs, which have the four longest river lengths of the FMUS were under-represented (Table 18). Two of these (East Coast and Rangitāiki) had a relatively high number of sites (Five and seven, respectively), yet the number of waterways (or stream length) in these FMUs was at least double any other FMU except for Whakatāne. Tauranga Moana was the most overrepresented FMU, which is likely a result of a greater number of small streams in this FMU than in others. All FMUs have at least one NERMN river water quality site, the low total river length in Waiōtahe and Ōhiwa Harbour FMUs result in them being overrepresented with only one site.

Table 18 Representativeness of the number of River water quality NERMN sites in each draft FMU. Conventions as per Table 15.

FMU_DRAFT	Total river segment length (km)	Number of River water quality NERMN sites	Representativeness
East Coast	1075	5	0.48
Kaituna	281	3	1.10
Ōhiwa Harbour	60	1	1.72
Rangitāiki	1263	7	0.57
Rotorua Te Arawa Lakes	360	5	1.43
Tarawera	270	2	0.76
Tauranga Moana	454	18	4.09
Waihī-Pongakawa	162	3	1.91
Waioeka-Otara	506	2	0.41
Waiōtahe	57	1	1.80
Waitahanui	116	1	0.89
Whakatāne	763	4	0.54

4.4.2 Landuse classification

Because we are assessing representativeness of the NERMN water quality sites for third order streams or higher, these results of the land use percentages were different to those presented in the section on invertebrate monitoring. Pasture or pasture intensive was the dominant land use for four FMUs (Table 19) (Kaituna, Ōhiwa Harbour, Waihī-Pongakawa, Waitahanui). Indigenous forest was the dominant land use for four FMUs (East Coast, Waioeka-Otara, Waiōtahe and Whakatāne). Only two FMUs (Rangitāiki and Tarawera) had EF as the dominant land use. Urban land use cover was very low for all FMUs, but as discussed above, we consider it important to include due to its major effects on stream ecosystem health.

Table 19 Percentage land use in each FMU for river segments stream order three and above. Dominant land use is indicated by bold text.

Draft FMU	%_EF	%_IF	%_P	%_PI	%_U
East Coast	3.9	**88.4**	7.4	0.4	0.0
Kaituna	11.1	5.3	**53.6**	28.4	1.6
Ōhiwa Harbour	3.9	13.2	32.8	**50.1**	0.0
Rangitāiki	**51.4**	26.3	11.1	11.2	0.0
Rotorua Te Arawa Lakes	17.1	16.7	34.7	27.4	4.1
Tarawera	**50.8**	18.7	9.3	20.1	1.0
Tauranga-Moana	2.7	37.8	**46.0**	10.5	3.0
Waihī-Pongakawa	10.2	7.0	30.0	**52.8**	0.0
Waioeka-Otara	1.5	**84.0**	10.0	4.5	0.0
Waiōtahe	7.2	**84.4**	0.0	8.4	0.0
Waitahanui	18.5	11.4	**50.0**	20.0	0.0
Whakatāne	6.0	**83.0**	2.9	8.0	0.2

The number of monitoring sites in the dominant land use was either representative or over-represented in all FMUs (Table 20). Only one water quality site was monitored in the Waitahanui FMU, which was in the dominant land use (P). However, streams draining exotic forestry there were under-represented. EF was also under-represented in three other FMUs with more than 10% of the rivers flowing through this class: Kaituna, Rotorua Te Arawa Lakes, and Waihī-Pongakawa (Table 20). IF was under-represented in five FMUs where more than 10% of rivers flowing through this class, three of which had no monitoring sites in this land use (Ōhiwa Harbour, Rotorua Te Arawa Lakes, and Waitahanui). Tarawera, Waioeka-Otara and Whakatāne have no monitoring sites in pasture or pasture intensive land use when these combined land uses were the second most dominant in that FMU.

Our results show that urban land use would be ‘representative’ with no sites due to the land use being <10% for each FMU. Tauranga Moana, however, has two sites in urban land use, making it over representative. Urban land use is often at the bottom of a catchment, and while water quality monitoring is also generally at the bottom of catchments, they are often above these urban areas to avoid possible tidal influences. The threshold for being classed as urban land use is 15%, which is lower than that of the other land use such as pasture, which occurs when a catchment has > 25% of its catchment in this land use class. This lower threshold for a catchment to be classified as urban is in acknowledgment of the effects urban land use has at low percentages. Monitoring water quality in urban land use is potentially a gap in our current monitoring network.

Table 20 Representativeness of the number of river water quality NERMN sites in each land use classification for each draft FMU. Conventions as per Table 15.

	Total River segment length (km)					Number of River water quality NERMN sites					Representativeness				
FMU_DRAFT	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**	**EF**	**IF**	**P**	**PI**	**U**
East Coast	38	**822**	209	7	—	0	4	1	0	—	0.00	**1.05**	1.03	0.00	—
Kaituna	31	15	**150**	80	4	0	0	3	0	0	0.00	0.00	**1.87**	0.00	0.00
Ōhiwa Harbour	2	8	20	**30**	—	0	0	0	1	—	0.00	0.00	0.00	**2.00**	—
Rangitāiki	**649**	332	140	141	—	4	1	1	1	—	**1.11**	0.54	1.29	1.28	—
Rotorua Te Arawa Lakes	59	59	**121**	95	14	0	1	4	0	0	0.00	1.18	2.31	0.00	0.00
Tarawera	**138**	50	25	55	3	2	0	0	0	0	**1.96**	0.00	0.00	0.00	0.00
Tauranga Moana	12	171	**209**	48	13	0	4	12	0	2	0.00	0.59	**1.45**	0.00	3.74
Waihī-Pongakawa	16	11	49	**85**	—	0	0	1	2	—	0.00	0.00	1.11	**1.26**	—
Waioeka-Otara	6	**384**	89	27	—	0	2	0	0	—	0.00	**1.32**	0.00	0.00	—
Waiōtahe	4	**48**	—	5	—	0	1	—	0	—	0.00	**1.18**	—	0.00	—
Waitahanui	21	13	**58**	23	—	0	0	1	0	—	0.00	0.00	**2.00**	0.00	—
Whakatāne	46	**633**	22	61	1	0	4	0	0	0	0.00	**1.21**	0.00	0.00	0.00

4.4.3 Biophysical classification

As with the land use data, the dominant biophysical classification (based on third order streams and higher) in each of the 12 FMU's was identified (Table 21). Non-volcanic was the dominant biophysical unit for the three most eastern FMUs (East Coast, Waioeka-Otara, and Waiōtahe). The dominant biophysical unit for Ōhiwa Harbour, Tarawera, Waitahanui and Whakatāne was V-HG and the remaining five FMUs having V-LG as the dominant class.

Table 21 Percentage of biophysical units in each FMU for river segments stream order three and above. Dominant biophysical unit indicated as bold text.

Draft FMU	% Non Volcanic	% V-HG	% V-LG
East Coast	**99.1**	0.7	0.2
Kaituna	1.8	15.3	**82.9**
Ōhiwa Harbour	0.0	**71.7**	28.3
Rangitāiki	5.0	24.3	**70.8**
Rotorua Te Arawa Lakes	0.4	21.9	**77.8**
Tarawera	0.9	**69.5**	29.6
Tauranga	2.3	22.5	**75.1**
Waihī-Pongakawa	1.6	11.1	**87.3**
Waioeka-Otara	**90.5**	6.0	3.5
Waiōtahe	**90.1**	8.9	1.1
Waitahanui	0.0	**81.6**	18.4
Whakatāne	7.8	**86.8**	5.4

All of the dominant biophysical classes for each FMU are adequately represented by our monitoring sites, being representative or over-representative (Table 22). Except for Ōhiwa Harbour, where 72% of stream length runs through V-HG but the one monitoring site in this FMU is in the V-LG class. The NV class was adequately represented for East Coast, Waioeka-Otara and Waiōtahe FMUs where it was also the dominant biophysical class. The NV class composed < 10% of waterway length in the Tauranga Moana FMU but has one monitoring site, resulting in it being over-represented (Table 22).

Table 22 Representativeness of the number of river water quality NERMN sites in each biophysical classification for each draft FMU. Conventions as per Table 15.

	Total River segment length (km)			Number of River NERMN water quality sites			Representativeness		
FMU_DRAFT	**NV**	**V-HG**	**V-LG**	**NV**	**V-HG**	**V-LG**	**NV**	**V-HG**	**V-LG**
East Coast	**1035**	37	3	5	0	0	**1.04**	0.00	0.00
Kaituna	5	43	**232**	0	0	3	0.00	0.00	**1.21**
Ōhiwa Harbour	—	43	17	—	0	1	—	**0.00**	3.54
Rangitāiki	63	306	**894**	0	1	6	0.00	0.59	**1.21**
Rotorua Te Arawa Lakes	1	78	**281**	0	0	5	0.00	0.00	**1.28**
Tarawera	2	**189**	79	0	2	0	0.00	**1.43**	0.0
Tauranga Moana	11	102	**341**	1	6	11	2.38	1.48	**0.81**
Waihī-Pongakawa	3	18	**141**	0	0	3	0.00	0.00	**1.15**
Waioeka-Otara	**407**	84	14	2	0	0	**1.24**	0.00	0.00
Waiōtahe	**52**	5	1	1	0	0	**1.11**	0.00	0.00
Waitahanui	—	**95**	21	—	1	0	—	**1.23**	0.00
Whakatāne	60	**663**	41	0	4	0	0.00	**1.15**	0.00

4.4.4 Stream order classification

In all FMUs, the majority of stream length comprised medium sized streams, although six FMUs had more than 20% of their waterway length made up of large streams (East Coast, Kaituna, Rangitāiki, Tarawera, Waioeka-Otara, Whakatāne). Three FMUs, each having only one NERMN river water quality site, (Ōhiwa, Waiōtahe and Waitahanui) were representative of the medium stream size class, with the water quality monitoring site in the dominant stream size (or only stream size). Monitoring sites in the Tauranga Moana FMU were representative of medium streams with 16 sites and over-representative of large streams with two sites, although, large streams only accounted for 5% of stream length in the FMU (Table 23).

The remaining FMUs were over-represented for large streams and under-represented in medium size streams. This was not surprising, given that water quality sampling is traditionally focussed at the base of catchments, as discussed above. However, given that the majority of waterway length was in the medium sized streams, there may be implications for our ability to properly assess water quality conditions in these medium-sized catchments.

Table 23 Representativeness of the number of River water quality NERMN sites in stream order classifications for each draft FMU. Medium = 3rd – 4th order, Large = 5th order or more. Conventions as per Table 15.

	Total River segment length (km)		Number of River water quality NERMN sites		Representativeness	
FMU_DRAFT	**Medium**	**Large**	**Medium**	**Large**	**Medium**	**Large**
East Coast	**828**	247	1	4	**0.26**	3.48
Kaituna	**217**	63	0	3	**0.00**	4.42
Ōhiwa Harbour	**60**	—	1	—	**1.00**	—
Rangitāiki	**991**	271	1	6	**0.18**	3.99
Rotorua Te Arawa Lakes	**307**	53	0	5	**0.00**	6.75
Tarawera	**211**	59	0	2	**0.00**	4.56
Tauranga Moana	**430**	24	16	2	**0.94**	2.08
Waihī-Pongakawa	**149**	13	1	2	**0.36**	8.58
Waioeka-Otara	**385**	121	0	2	**0.00**	4.18
Waiōtahe	**57**	—	1	—	**1.00**	—
Waitahanui	**108**	8	1	0	**1.08**	0.00
Whakatāne	**538**	225	0	4	**0.00**	3.39

4.4.5 Hydrological classification

Generally, the monthly water quality sampling regime for our NERMN river water quality sites appeared to be representative with the associated flow duration curve (FDC) at each site. This finding may be somewhat counterintuitive to the general understanding that regular monthly monitoring is likely to miss higher flows, and as a result, under-estimate a large proportion of catchment loadings. However, it is important to understand what is meant by 'high flows'. Table 24 shows that we are representative of the upper quartile of flows: indeed, further analysis showed that we were also largely representative of this upper quartile when further split into 5 percentile groupings (i.e., the 75th, 80th, 85th 90th and 95th percentile flows). Although we may be sampling the 95th percentile flows, there is still a large difference between these, and the maximum flow observed at all sites. For example, at the Kopurererua at SH29 site the 95th percentile flow is 3.77 m^3/s, while the maximum recorded flow is 36.15 m^3/s. Thus, although these 'high flows' are occurring for <5% of the time, they would still account for a large proportion of nutrient and sediment loads (Hoare, 1982; Abell *et al.,* 2013). As such, in terms of being representative of the general state of the rivers, the monthly sampling regime adequately captures the state across the FDC, however, it is not truly representative of catchment loads, as we are indeed missing these rare, high flow events.

Table 24 Representativeness of the number of river water quality NERMN samples in each hydrological flow quartile for the associated site. Q1 = 0-25th percentile (lowest flows), Q2 = 25th-50th percentile, Q3 = 50th-75th percentile, Q4 = 75th-100th percentile (highest flows). Conventions as per Table 15.

	Number of samples in each quartile				Representativeness			
FMU - Water Quality Site	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
East Coast - Motu Waitangirua	118	93	93	81	1.23	0.97	0.97	0.84
East Coast - Motu Houpoto	104	117	105	80	1.02	1.15	1.03	0.79
Kaituna - Kaituna Te Matai	33	19	26	36	1.16	0.67	0.91	1.26
Kaituna - Kaituna at Maungarangi	11	9	5	13	1.16	0.95	0.53	1.37
Ōhiwa Harbour – Nukuhou at Glenholme	19	12	24	18	1.04	0.66	1.32	0.99
Rangitāiki - Rangitāiki at SH5	23	25	22	24	0.98	1.06	0.94	1.02
Rangitāiki – Whirinaki at Galatea (NIWA)	106	120	98	88	1.03	1.17	0.95	0.85
Rangitāiki – Rangitāiki at Te Teko (NIWA)	62	107	159	127	0.55	0.94	1.40	1.12
Rangitāiki - Rangitāiki at Murupara (NIWA)	91	90	116	105	0.91	0.90	1.15	1.04
Rotorua Te Arawa Lakes – Ngongotahā at SH36	104	118	117	67	1.02	1.16	1.15	0.66
Tarawera – Tarawera at Awakaponga	81	101	107	90	0.85	1.07	1.13	0.95
Tauranga Moana – Kopurererua at SH29	80	48	60	46	1.37	0.82	1.03	0.79
Waihī-Pongakawa – Pongakawa at Old Coach Road	36	19	28	40	1.17	0.62	0.91	1.30
Waioeka-Otara – Otara at Browns Bridge	39	46	39	32	1.00	1.18	1.00	0.82
Waiōtahe – no appropriate sites								
Waitahanui – Waitahanui at Ōtamarākau marae	17	23	23	25	0.77	1.05	1.05	1.14
Whakatāne – Tauranga at Tāneatua Bridge	6	8	5	2	1.14	1.52	0.95	0.38

4.4.6 Temporal representation

The NERMN river water quality sites are sampled at regular monthly intervals and are expected to be representative of any seasonal variations over the year. The 54 sites have been established at different times ranging from 1989 to 2013. Having long-term datasets is hugely beneficial in terms of monitoring change and being representative of how the catchment reacts to land use changes. The benefits of maintaining these sites should be considered as a part of any decisions in any future network design.

4.5 General discussion and summary/Matapakitanga

The assessment of site representativeness for river water quality monitoring was based on assessing the current NERMN locations in >2nd order streams at 52 sites throughout the region. This assessment included NIWA operated sites but excluded 'impact' monitoring sites (which are located at some consented discharges) and one NERMN water quality location on a 2nd order stream. All of the NERMN water quality sites in the analysis were restricted to third-order streams or higher, as many smaller first and second order streams in the region can be ephemeral and have small catchment sizes. Representativeness was assessed for four classifications separately (land use, biophysical, stream size, hydrology) and one combined classification of biophysical x land use (at a regional scale only). The way in which the monitoring sites have been grouped into the associated classifications is based on the REC and BOPRC 2017 Landuse layer (Carter *et al., in prep*), which determines the dominant land use and / or biophysical unit upstream of the reach in which the monitoring site is located. It therefore aligns with the common concept of water quality monitoring where the monitoring site is generally located to capture cumulative inputs from the whole catchment upstream of it. The results of this analysis have identified some obvious gaps in our river water quality NEMRN and also highlighted some discussion points of how we determine representativeness.

4.5.1 Gaps

The regional analysis of representativeness highlighted a lack of representation across some land use and biophysical units, such as IF catchments and waterways in NV geology types and EF catchment and waterways in V-LG geology types. The higher numbers of some of our monitoring sites in certain areas are generally reflective of the potential for water quality issues. For example, a large proportion of our sites were located in in reaches with pasture (17 sites) and pasture intensive (23 sites) as the dominant upstream land use. Although major land use classes are generally represented by our river water quality NERMN within each FMU, a major gap in our monitoring was the lack of monitoring in 'urban' land use classes. While the percentage of urban land use in both the region (0.7%) and within each FMU is generally low (a maximum of 4.1% in Rotorua/Te Arawa Lakes), the impacts of urban development at even low percentages are significant and so it is important to capture these impacts. Many of our urban areas are located in low lying coastal parts of the region which results in issues of avoiding tidal influence for river monitoring. There are, however, opportunities throughout the region, specifically Rotorua and Tauranga, where we could be monitoring reaches that have high urban influence.

A number of land use and biophysical classifications are under-represented within different FMUs, while fewer are over-represented. This indicates that redistributing the sites would not necessarily resolve our under-representation and the number of sites would need to increase to enable us to be representative across all the classifications in each FMU. This will have obvious resourcing implications, with the need for monthly monitoring, and flow measurements at all new sites. Assessment of representativeness in each FMU showed that the water quality network was either representative, or over-representative in all dominant landuses.

This finding suggests that the current water quality network is monitoring the dominant land use in each FMU.

Despite the current network being mostly representative of the dominant land use in each FMU, it was also clear that secondary land use classes, that represented 18% or more of total waterway length, were often under-represented, or not even sampled in the current programme. For example, streams draining IF were not sampled in the Waitahanui or Tarawera FMUs, and streams draining catchments dominated by pasture or pasture intensive were not sampled in the Tarawera, Waioeka-Otara, and Whakatāne FMUs. Under s3.8 (4) of the NPS-FM, councils are meant to sample sites that are representative of the FMU or *relevant part of the FMU*. While not sampling IF sites in some FMUs may not be regarded as a major issue from the point of view in detecting effects of land use, the fact that pasture or pasture intensive streams in three FMUs were not sampled highlights the challenges with meeting these requirements. Furthermore, although it is important to monitor sites in land use classes that are undergoing development, sampling in 'reference' condition waterways is also very important in helping tease out climatic influences in any observed trends in water quality. A lack of sampling in some land use classes may also be resolved by using sites in other FMUs to infer the conditions in areas that are under-represented, or not sampled (discussed further below).

4.5.2 Extrapolating state across the region

Regionally, streams draining catchments dominated by IF were under-represented by the current network. This is partially a result of these sites generally being in upper catchments, and water quality sampling being focussed at the base of catchments. It is also reflective of the fact that there is less anthropogenic pressure in this land use class. As highlighted in the invertebrate discussion, there is the question of whether this under-representation is justified, given the low risk of potential land use impacts. However, the use of these sites as 'reference' condition waterways is vital, as it helps tease out the effects of natural climatic influences. Given that we have 17 monitoring sites regionally under the IF land use classification which are distributed relatively evenly across the biophysical units (although not proportionate to the length of each biophysical unit in IF), it is likely that we could infer conditions in other IF sites throughout the region where we are not monitoring. For example, although Tarawera and Kaituna FMUs have no monitoring sites in the IF classification, IF monitoring in other FMUs with the same biophysical classification may be indicative of the state of these waterways. It may also suggest that the under representation of the East Coast, Waioeka-Otara and Whakatāne FMUs are not overly concerning when considering that they have >80% reach length as IF. Furthermore, the under representation of Tauranga Moana's dominant land use (IF) could be justified given that there are four sites in that classification and because of the expected higher predictability under this land use. Based on this, we consider the coverage to be adequate.

A similar argument could be made for the NV classification as for the IF land use. The NV biophysical unit is largely constrained towards the east of the region, where land use pressures are lower and land use is largely IF. While we are underrepresented in the NV biophysical classification, the majority of this biophysical unit is under the IF land use classification. Therefore, the condition of waterways within this biophysical classification could likely be inferred from the current monitoring sites.

The potential to extrapolate conditions within the IF land use is possible because of the lower number of factors and / or pressures to consider when looking in the upper catchments, where IF dominates. Once extending further down the catchment, an increasing number of factors and anthropogenic influences often occur. Inferring conditions from other 'like' areas therefore becomes more difficult as neither the dominant land use and/or biophysical unit would explain as much of the variation observed in water quality. Attempting to extrapolate the water quality condition to other similar, but un-monitored sites was also discussed in the Invertebrate section and raises the similar issue of sufficient site replication to maintain minimum sample size to accurately infer conditions in the same biophysical unit and / or land use. Water quality in a given waterway is a combination of upstream influences. Teasing apart a dominant influence or a standardised mix of influences (such as land use) to be able to relate to other areas would be a difficult and resource heavy task. In order to consider extrapolation in non-IF areas, a detailed exercise of investigating influences would need to be undertaken most likely on a case-by-case basis.

4.5.3 Objectives of NERMN monitoring

State of the environment monitoring (our NERMN monitoring) was originally established to provide broad information as to the state of our region and provide information to central government to inform the national state of our rivers. This information informs our policies and plans and monitors their suitability and effectiveness. Hamill and Ausseil (2012) reviewed the NERMN river water quality programme and identified the type of data analysis required to inform state of the environment reporting, catchment management and policy development and monitoring processes. The three main types of data analysis they identified were, assessing state, determining trends, and determining loads. It is therefore important to assess the NERMN programmes representativeness in relation to these three data analysis objectives.

Over time, the use (or desired use) of this network has expanded to understanding impacts of land use and discharges, as well as needing to calculate loads to receiving environments, of which the original design of the NERMN programme does not necessarily cater for. As described above, our current monitoring programme is representative of flow and temporal variation in terms of understanding the state (and trends) of our rivers water quality. However, it is not representative of the larger storm events that contribute significant contaminant loading to receiving environments. To be representative of the loads being transported downstream, targeted high flow event sampling is required which regular monthly monitoring does not achieve. This highlights why the objectives of the NERMN programme are important to define, as while our network might be representative for one, it may not be for another. Work is currently being undertaken by BOPRC to identify sensitive receiving environments in the region. It may be that in future, selected rivers in these sensitive areas are identified for more intensive work in understanding contaminant loads at rare, high flow events that may be missed by regular sampling.

The majority of sites are located in the fifth order streams or higher, largely located at the base of catchments. There are many valid reasons for this, such as the need to capture cumulative pressures throughout a catchment, site accessibility, and efficiency of resourcing, but it also results in a monitoring network that is over-represented in the large stream size class and under-represented in the medium stream size classification for most FMUs. Whether this focus on large-order rivers at the base of catchments is representative for understanding the state and trends for the region could be looked at in a few ways. On the one hand, monitoring the base of the catchment can provide data on the 'worst case scenario', where all the different inputs and cumulative impacts are captured. On the other hand, any adverse water quality impacts in upstream tributaries could be under-estimated (or not detected), due to increased dilution in the larger rivers. As many of our FMUs are lacking monitoring sites in the upper parts of the catchments (i.e., medium sized tributaries), it suggests that the current water quality network is not representative of the state and trends of our rivers at this level. However, a large proportion of currently un-monitored medium sized streams are in IF land use, so results of water quality monitoring in these stream types could be extrapolated from the current monitoring network of sites draining catchments dominated by IF.

When considering the objective of determining loads, monitoring in the larger rivers, at the base of catchments, is the appropriate approach and spatially is representative of the inputs to receiving environments. Although, as discussed above, the current temporal approach is not representative for determining loads to receiving environments.

Part 5:
Dissolved Oxygen Monitoring/ Te aroturukitanga hāora whakarewa

The NPS-FM includes an attribute for dissolved oxygen (DO) in rivers downstream of point source discharges (Table 7 in the NPS-FM) and requires continuous measurement of DO from 1 November to 30 April. Carter and Scholes (2015) identified the region's major point source discharges into rivers. Some of these discharges come from wastewater treatment plants (WWTP), while others come from industrial complexes such as the AFFCO meat processing plant, the Fonterra Dairy at Edgecumbe, or the Tasman/Asaleo mills discharges into the Tarawera River. Continuous DO has been monitored at some of these sites (Table 25) as required by the NPS-FM. Additional point source discharges have also been identified, but these were located outside the priority Water Management Areas (WMA) at the time, and some have potential issues with tidal influence. No monitoring of DO below these other discharge locations has currently been done. However, the Trustpower discharge into the Rangitāiki River is at the Matahīna Dam as part of this hydro-electric power scheme (HEPS). Given that the penstocks for this dam take relatively shallow, oxygenated water from Lake Matahīna, this discharge is highly unlikely to reduce DO in this river. Mahon (2021) also assessed all consented point source discharges into rivers, which thus far has identified over 240 potential discharges. However, further work is required to exclude insignificant or short-term discharges and various other classifications. The current network of DO monitoring downstream of point source discharges thus captures the major discharges in the region.

Table 25 Identified point source DO monitoring locations.

River	FMU	Discharge from	First monitoring period
Waiari River	Kaituna	Western Bay DC WWTP	2015/16
Rangitāiki River	Rangitāiki	Whakatāne DC WWTP	2016/17
Kaituna River	Kaituna	AFFCO	2015/16
Rangitāiki River	Rangitāiki	Fonterra	2016/17
Tarawera at Awakaponga	Tarawera	Tasman pulp and paper mill	2009/10
Whakatāne River	Whakatāne	WDC WWTP ponds	Not started
Rangitāiki River	Rangitāiki	Trust Power	Not started
Whakatāne River	Whakatāne	Whakatāne Board Mills	Not started
Omehue Canal	Tarawera	WDC Edgecumbe WWTP ponds	Not started

Note that BOPRC is not currently monitoring DO in other areas, as implied in Table 17 of the NPS-FM, where DO is to be monitored to help protect "ecosystem health". It is likely that any such monitoring will, in the first instance, be restricted to the current NERMN water quality monitoring sites, however, this does not preclude monitoring this attribute at other as yet unidentified sites.

Part 6:
River periphyton monitoring/ Te aroturukitanga rauropi piri awa

6.1 Background/Kupu Whakamārama

6.1.1 Origins of the Periphyton Monitoring Network

The BOPRC Periphyton Monitoring Programme was initiated in October 2015 with the intention of, understanding the current state of periphyton biomass in waterways; helping set target attribute states for periphyton biomass based on established NOF bands; monitoring biomass change over time at sites of interest, and generating data that can be used to link in-stream nutrients and flow dynamics with biomass.

An initial site selection process took place prior to establishment of the programme to ensure accurate representation across the region (Suren and Carter, 2015). This process consisted of the following steps:

1. Identification and mapping of areas where periphyton biomass could potentially accrue.
   - Periphyton biomass accumulation is limited to areas with a stable substrate, which excludes many soft-bottom streams of volcanic origin that are distributed throughout the region. The REC layer was used to identify all reaches that had a substrate size class of less than three, (i.e., fine sand, pumice, and mud), which were excluded from the analysis.
   - Periphyton growth also requires sunlight, so stream reaches with greater than 80% shade, as identified in the FWENZ database (Leathwick *et al.,* 2010), were also removed from the analysis.
2. Allocation of controlling physical and hydro-chemical variable to each REC reach.
   - All remaining reaches were allocated a water quality class based on predicted CLUES dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) concentrations included in the REC layer. DIN and DRP are identified as the two key nutrient drivers of periphyton biomass (Biggs & Kilroy, 2000).
   - Elevated flows reduce periphyton biomass through scouring and flushing processes, therefore each reach was attributed a flood frequency class (measured by floods three times the median flow (FRE3)) which have been shown to remove periphyton biomass (Clausen and Biggs 1997). The number of FRE3 events was determined using modelled flow data (Booker and Woods 2013), which is also included in the REC layer.
   - Each reach in the REC layer was intersected to their relevant biophysical classification, which is described in detail in the general methodology section (see also Snelder *et al.,* 2015).
   - The resultant nutrient class, flood frequency, and biophysical classification were combined to create a bespoke 'periphyton class' for each REC reach, that showed theoretical NZReaches where periphyton biomass was predicted to occur.

3 Consideration of logistical constraints.

- Reaches greater than seventh order were removed from the dataset due to difficulty sampling in deep water. First order reaches were also removed due to many of these streams being ephemeral.
- Each reach that intersected a road was identified as a potential site.

4 Random selection based on the criteria above.

- The resultant periphyton classes took the format of [Biophysical Unit] [Nutrient] [Flushing Frequency], e.g., Volcanic+Eutrophic+Low
- Field validation was used to help choose appropriate sites from those randomly selected, as stream access was often not possible.
- Whakatāne at Pekatahi Bridge is the only exception to this process as it is a 7^{th} order river but has a shallow wadeable run on the true left side, downstream of the bridge. This site is known to have significant periphyton accumulation on occasions and was therefore included in network.
- 30 sites were selected through this process in October 2015, however this number dropped to 26 sites by 2020 for the following reasons identified in Table 26.

Table 26 Sites that were originally selected for the Periphyton Monitoring Network but have been subsequently removed.

Site Name	Reason Removed	Date Removed
Otangimoana at Forestry Road	Slip preventing access to site.	2016
Otangimoana at Matea Road	Logistics associated with access.	2019
Mangamate at Troutbeck Road	River realignment work at site.	2015
Waikokopu at Galatea Road	Health and Safety risk	2018

6.1.2 Definition of representativeness

For the purpose of this analysis, we defined a representative network as one that has a representative number of sites within each sub-category per FMU, or over the entire region, relative to the proportion of river reach length that make up each FMU or the entire region.

6.2 Methods/Huarahi

The current analysis used similar methods to those used for establishing the original network. In summary, the REC was used to identify and remove reaches that had unsuitable substrate, shade, or were too large to sample. The remaining reaches were intersected with the draft FMU layer, and attributed water quality, flood frequency, and the three biophysical classes.

Each reach was also intersected with the FWENZ layer to provide a dominant land use class. The dataset was exported and manipulated in ‘R’ (2021) using the ‘dplyr’ package (Wickham *et al.* 2021) to summarise the length of REC reaches that correspond to each applicable FMU, periphyton class, and land use category.

The same process was carried out for the 26 current periphyton monitoring sites.

Summarised data from the REC and current sites were combined, and the ratio of the current site proportion to REC reach length within the unit of interest, provided an index of representativeness.

6.3 Results and discussion/Ngā Otinga me Matapakitanga

6.3.1 Region wide distribution per FMU

The Rangitāiki, East Coast, and Whakatāne FMU's contained the greatest length of reaches that were suitable for periphyton growth, with 22%, 20% and 14% of waterway length respectively. This reflected in part their hard greywacke, sandstone, mudstone geology. The Waiōtahe, Waitahanui, Waihī-Pongakawa, and Ōhiwa Harbour FMUs all contained the smallest of length of reaches suitable for periphyton growth in the region (approximately 1%).

The Rangitāiki (1.25) and Waioeka-Otara (1.13) FMUs were both adequately represented based on proportion of suitable reaches, while the East Coast FMU was under-represented (0.52) by the current periphyton monitoring network. However, this analysis does not take into account land pressure, population, or forecast land use change, therefore although the East Coast FMU is under-represented, this is potentially appropriate given the current (and expected future) low human pressure in this FMU.

The Whakatāne and Tauranga Moana FMUs were both over-represented, although only slightly (Table 27). However, the Waiōtahe Catchment was heavily over-represented (9.76), reflecting the large number of sites here (4) relative to the very small length of NZSegments where periphyton could potentially grow. However, it must be remembered that the original site selection was based on regional representation of the most at risk sites, combined with a matrix of flood frequency and nutrient status, and finally overlain by site access and site suitability It may be possible to redistribute some of these over-represented sites to provide better representation in the East Coast FMU, or perhaps establish new sites in the Rotorua Te Arawa Lakes FMU (8% of reach length), assuming of course that suitable sites can be found.

Table 27 The distribution of reaches suitable for periphyton growth throughout the region and the number of current monitoring sites, categorised by FMU. The ideal number of sites shows a near 'perfect' distribution based on the length of reaches within each FMU and the total regional length, and representativeness provides an index of how representative our current site distribution is for each FMU. Conventions as per Table 15.

FMU	Length of NZSegments (km)	Proportion of Region	Number of Sites	Ideal number of sites	Representativeness
Rangitāiki	1146	0.22	8	6	1.25
East Coast	1037	0.20	3	5	0.52
Whakatāne	707	0.14	6	4	1.52
Tauranga Moana	563	0.11	5	3	1.59
Waioeka-Otara	477	0.09	3	2	1.13
Rotorua Te Arawa Lakes	433	0.08	0	2	0.00
Tarawera	295	0.06	0	2	0.00
Kaituna	283	0.05	0	2	0.00
Waiōtahe	74	0.01	4	0	9.76

FMU	Length of NZSegments (km)	Proportion of Region	Number of Sites	Ideal number of sites	Representativeness
Waitahanui	73	0.01	0	0	0.00
Waihī-Pongakawa	70	0.01	0	0	0.00
Ōhiwa Harbour	46	0.01	0	0	0.00

6.3.2 Site distribution across periphyton categories

The 26 current periphyton monitoring sites were split between five of the top six periphyton categories that make up the region by reach length. Three of these classes, Non-volcanic+Eutrophic+High (1.40), Non-volcanic+Eutrophic+Medium (1.74), and volcanic+Eutrophic+High (4.37) were over-represented at a regional scale. The volcanic+Eutrophic+High class occurred around the western Tauranga Harbour area and has among the highest periphyton biomasses in the region, particularly in times of sustained low flow, which potentially explains why this category is over-represented.

The volcanic+Eutrophic+Medium category was within the bracket of ideal representation (0.7-1.3: Table 28). In contrast, the volcanic +Eutrophic+Low class was under-represented, with only three sites for 20% of the regional reach length (Table 28). This category is likely to be among the highest risk classes for periphyton biomass accumulation given the suitable substrate, elevated nutrient status, and reduced flood frequency, and could potentially benefit from more monitoring sites. However, it must be remembered that these classes were based on modelled data for, amongst other things, substrate size, and these models may not be particularly accurate in the Bay of Plenty. Indeed, field observations of many of the sites that were initially selected based on the procedure outlined earlier showed that they were in fact dominated by smaller substrates, where periphyton would not grow, despite the FENZ models predicting them to have coarse substrates.

Other potential biophysical + nutrient status + flood frequency classes had less than 0.10 proportional share of the regional river length; therefore, it was deemed appropriate to have no monitoring sites in these (Table 28).

Table 28 The distribution of NZSegments per periphyton catgory and the number of current monitoring sites. The ideal number of sites shows a near 'perfect' distribution based on the length of reaches belonging to each periphyton category in the region, and representativeness provides an index of how representative our current site distribution is relative to each. Conventions as per Table 15.

Periphyton Category	Length of NZSegments (km)	Proportion of Region	Number of Sites	Ideal Number of Sites	Representativeness
Volcanic+ Eutrophic+ Medium	2331.4	0.45	9	11	0.77
Volcanic+ Eutrophic+ Low	1017.7	0.20	3	5	0.59
Non-volcanic+ Eutrophic+ High	712.6	0.14	5	4	1.40
Non-volcanic+ Eutrophic+ Medium	576.2	0.11	5	3	1.74
Non-volcanic+ Mesotrophic+ High	303.8	0.06	0	2	
Volcanic+ Eutrophic + High	183.1	0.04	4	1	4.37
Non-volcanic+ Mesotrophic + Medium	35.9	0.01	0	0	
Volcanic+ Mesotrophic + Low	15.6	0.00	0	0	

Periphyton Category	Length of NZSegments (km)	Proportion of Region	Number of Sites	Ideal Number of Sites	Representativeness
Non-volcanic+ Eutrophic + Low	15.3	0.00	0	0	
Volcanic+ Mesotrophic + High	5.2	0.00	0	0	
Volcanic+ Oligo + Low	1.8	0.00	0	0	
Volcanic+ Oligo + Medium	1.4	0.00	0	0	
Non-volcanic+ Oligo + Medium	1.3	0.00	0	0	
Non-volcanic+ Oligo + High	0.8	0.00	0	0	
Volcanic+ Oligo + High	0.7	0.00	0	0	
Volcanic+ Mesotrophic + Medium	0.5	0.00	0	0	

6.3.3 Site distribution across landuse classes

Ninety six percent (25) of periphyton monitoring sites were located in areas dominated by IF which comprised 48% of the total reach length. This reflected field-based observations of many so-called “hard-bottomed” streams in Pasture catchments actually being dominated by smaller substrates that were unsuitable for periphyton sampling, and by logistical constraints of being able to sample mainly shallow, wadeable rivers. Suitable sites were thus more commonly found more in ‘accessible’ sites in areas of IF than lower in the catchment were pasture dominated. The representative index of IF streams was about double (2.02) relative to the regional composition (Table 29). The one other monitoring sites located in EF land use (One site; 4%) which was underrepresented, with a representative index value of 0.21.

Table 29 The distribution of regional NZ segments according to dominant different land use categories. The ideal number of sites shows a near ‘perfect’ distribution based on the length of reaches belonging to each land use category in the region, and representativeness provides an index of how representative our current site distribution is relative to each. Conventions as per Table 15.

Land use Category	Length of NZSegments (km)	Proportion of Region	Number of Sites	Ideal Number of Sites	Representativeness
IF	2547	0.48	25	12	2.02
P	1091	0.20	0	5	0.00
EF	1024	0.19	1	5	0.21
PI	657	0.12	0	3	0.00
U	36	0.01	0	0	0.00

6.3.4 Site distribution across FMUs and periphyton categories

The Rangitāiki and Whakatāne FMUs had appropriate representation for the bespoke periphyton category composition of the region (Table 30). Furthermore, the East Coast, Rangitāiki, Waiōtahe, and Whakatāne FMUs had appropriate representation for their dominant periphyton category (Table 30).

In contrast, the Kaituna, Ōhiwa Harbour, Rotorua Te Arawa, Tarawera, Waihī-Pongakawa, and Waitahanui FMUs had no current monitoring sites, and were therefore under-represented in all present categories. This is predominantly due to the small proportional stream lengths in these areas, with each of these FMU's making up less than 10% of the regional coverage, and therefore being appropriately represented with no monitoring sites.

The East Coast, Tauranga Moana, Waioeka-Otara, and Waiōtahe FMU's were over or under-represented for some periphyton categories (Table 30). Furthermore, Tauranga Moana had the greatest representation index for VA_Hard Eutrophic High (5.13), followed by the East Coast Non_VA_Hard Eutrophic Medium.

Table 30 *The total length of NZSegment reaches, number of current sampling sites, and calculated representativeness index per periphyton category and FMU combination. Categories with less than 0.10 proportional share of the total FMU reach length have been removed. Conventions as per Table 15.*

FMU	>10% of Regional Reach Length	Kilometres of NZSegments						Number of Sampling Sites						Representativeness					
		Non_volcanic Eutrophic High	Non_volcanic_Eutrophic Medium	Non_volcanic_ Mesotrophic High	Volcanic_ Eutrophic High	Volcanic_ Eutrophic Low	Volcanic_ Eutrophic Medium	Non_volcanic_ Eutrophic High	Non_volcanic_ Eutrophic Medium	Non_volcanic_ Mesotrophic High	Volcanic_ Eutrophic High	Volcanic_ Eutrophic Low	volcanic_ Eutrophic Medium	Non_volcanic_ Eutrophic High	Non_volcanic_ Eutrophic Medium	Non_volcanic_ Mesotrophic High	Volcanic_ Eutrophic High	Volcanic_ Eutrophic Low	Volcanic_ Eutrophic Medium
East Coast	Yes	452.0	228.9	302.9				1	2	0				**0.76**	3.02	0.00			
Kaituna	No					47.2	234.2					0	0					0.00	**0.00**
Ōhiwa Harbour	No				13.8		32.3				0		0				0.00		**0.00**
Rangitāiki	Yes					660.3	423.2					3	2					**1.04**	1.08
Rotorua Te Arawa Lakes	No					169.5	251.5					0	0					0.00	**0.00**
Tarawera	No				30.7		241.9				0		0				0.00		**0.00**
Tauranga Moana	Yes				87.9	57.9	412.6				4	0	1				5.13	0.00	**0.27**
Waihī-Pongakawa	No						70.0						0						**0.00**
Waioeka-Otara	No	249.9	196.4					3	0					**1.91**	0.00				
Waiōtahe	No	10.7	56.4					1	3					1.72	**0.98**				
Waitahanui	No						73.3						0						**0.00**
Whakatāne	Yes						567.7						6						**1.25**

6.3.5 Site distribution across FMU's and landuse classes

The Whakatāne FMU was the only FMU that had adequate representation of land use, with six sites situated in indigenous forest which made up 90% of the river reach length (Table 31). Four FMUs; East Coast, Waioeka-Otara, Waiōtahe, and Whakatāne, were all within the band of adequate representation for their dominant land use categories, but all aside from Whakatāne were underrepresented for other land use categories (Table 31).

As for periphyton categories, the Kaituna, Ōhiwa Harbour, Rotorua Te Arawa Lakes, Tarawera, Waihī-Pongakawa, and Waitahanui FMUs contained no monitoring sites and were therefore underrepresented for each land use category shown. However, each of these FMUs made up less than 10% of the regional reach length and could be assumed to be adequately represented by no monitoring sites. In addition, many of the waterways in these areas were in fact dominated by small substrates that would not be suitable for periphyton monitoring, and which would also be unsuitable habitat for periphyton to develop.

The East Coast P land use class made up 9% of the total FMU reach length, and contained one monitoring site, and was therefore overrepresented with a representative index of 3.77 (Table 31). Over-representation was also observed in the Rangitāiki FMU in streams draining IF, with five monitoring sites in a stream class that contributed only 31% of the total reach length in this FMU. A similar over-representation was also observed in the Tauranga Moana FMU in streams draining IF, with an index of 1.41 for the four monitoring sites (Table 31).

Possible improvements to the current periphyton monitoring programme could include shifting one East Coast FMU site from the P land use to the IF land use category, distributing the five Rangitāiki FMU sites to include EF and P reaches, and shifting one or two Tauranga Moana IF sites to the P classification. However, all this assumes that suitable sites with large, stable substrates can be found in these other areas, and this can often be determined only by field assessments to validate modelled outputs.

Table 31 The total length of NZSegment reaches, number of current sampling sites, and calculated representativeness index per land use category and FMU combination. Categories with less than 0.10 proportional share of the total FMU reach length have been removed. Conventions as per Table 15.

FMU	>10% of Regional Reach Length	Kilometres of NZSegments			Number of Sampling Sites			Representativeness		
		EF	IF	P	EF	IF	P	EF	IF	P
East Coast	Yes		862.3	91.6		2	1		**0.80**	3.77
Kaituna	No	70.9	43.3	168.7	0	0	0	0.00	0.00	**0.00**
Ōhiwa Harbour	No	11.3	9.3	25.6	0	0	0	0.00	0.00	**0.00**
Rangitāiki	Yes	518.5	360.5	246.1	0	5	0	**0.00**	3.18	0.00
Rotorua Te Arawa Lakes	No	77.2	94.4	251.9	0	0	0	0.00	0.00	**0.00**
Tarawera	No	176.5	62.5	50.0	0	0	0	**0.00**	0.00	0.00
Tauranga Moana	Yes		319.0	221.6		4	1		**1.41**	0.51
Waihī-Pongakawa	No	8.5	14.7	46.8	0	0	0	0.00	0.00	**0.00**
Waioeka-Otara	No		408.9	49.2		3	0		**1.17**	0.00
Waiōtahe	No	10.3	55.1	8.1	1	3	0	1.78	**1.00**	0.00
Waitahanui	No	15.7	17.7	39.9	0	0	0	0.00	0.00	**0.00**
Whakatāne	Yes		643.4			6			**1.10**	

6.4 Conclusions and recommendations/Whakakapinga me Ngā Tūtohutanga

This analysis has shown that there are many different categories that can be used to define regional representativeness. In this case, we compared proposed FMU boundaries, a bespoke periphyton category that combines biophysical class, nutrient status, and flood frequency, as well as a separate land use category, to show regional and FMU representativeness.

6.4.1 Periphyton categories

Regional representation

The classification based on periphyton categories was arguably a more robust approach to a representative network than one based on FMUs or land use, because this classification system combined the key factors known to control periphyton growth.

The most obvious gap in the distribution of reaches pertaining to each periphyton category across the region was the underrepresentation of the Volcanic+Eutrophic+Low category, which makes up 20% of the regions' applicable reaches by length. This category theoretically has the highest risk of all categories due for periphyton blooms, reflecting the combination of the (theoretically) hard substrate, volcanic geology, high nutrients, and low flood frequency. These reaches were located on the western side of the Rangitāiki catchment through to Tauranga-Moana FMU. However, despite the models predicting many of the streams in this area to have coarse substrates, field observations made as part of the final site selection process showed that many of these so-called "hard-bottomed" sites were instead dominated by smaller substrates. As such, these sites were dropped from the site selection process, as they were unsuitable for both periphyton monitoring, and would be unsuitable habitat for periphyton blooms to develop.

The Non-volcanic + Mesotrophic + High category was also under-represented, with the most accessible reaches situated in the East Coast FMU, inland from Te Kaha. However, given the fact that these waterways are located in largely undeveloped land where human pressures are low, the benefits of including more sites in this area is questioned.

FMU representation

Representation of periphyton categories within each FMU varies, with good representation across all categories in the Rangitāiki and Whakatāne FMU, moderate representation in the East Coast and Waiōtahe FMUs, and over-representation for some categories in Tauranga Moana and Waioeka-Otara. Furthermore, there were no monitoring sites in the other six FMUs, although these made up less than the arbitrary 10% threshold.

Easy improvements to representativeness could be achieved in the Tauranga Moana by reducing the number of sites within the Volcanic + Eutrophic + High category, and identifying sites within the under-represented dominant category, volcanic + Eutrophic + Medium, and the less prevalent volcanic + Eutrophic + Low category. These latter two categories theoretically have a greater risk of excess periphyton biomass accumulation due to reduced flushing potential, which suggests that our current understanding of periphyton accumulation in this FMU may be biased towards sites with lower accumulation.

Other simple improvements could occur in the East Coast FMU by moving one site from the Non-volcanic + Eutrophic + Medium category to the Non-volcanic + Mesotrophic + High category, although the latter is more difficult to access (see above). Finally, the Waioeka-Otara FMU could be improved by moving one site from the Non-volcanic + Eutrophic + High category to Non-volcanic + Eutrophic + Medium. A number of these reaches are predicted to occur in similar terrain to our current monitoring sites, which might imply that the differences are not worth the cost of disrupting a long-term dataset.

6.4.2 Landuse categories

Regional representation

There were four dominant land use categories in the regional subset of applicable reaches, Indigenous Forest (IF), Pasture (P), Pasture Intensive (PI), and Exotic Forest (EF). The current distribution of monitoring sites over-represents IF at the expense of the others, possibly due to the tendency for periphyton sites to be placed in the middle-upper catchment where stream orders are lower and surveys are easier to carry out, which is typically where the IF land use category is found.

It is understandable that the existing periphyton monitoring network is not equally representative of land use classes given the steps taken to establish the network (refer to background section). However, if land use was deemed the most important category with which to stratify the periphyton network in the future, and assuming no additional sites could be added to the network, approximately five sites could shift from the IF land use class to each of P and EF, and an additional three could shift from IF to PI, to ensure a balanced regional network. This would result in a reduction by more than half of the monitoring sites within IF land use, however.

FMU representation

Only the Whakatāne FMU has appropriate representation across all land use classes. However, the East Coast, Waioeka-Otara, and Waiōtahe FMUs represented their dominant land use class appropriately. The Rangitāiki and Tauranga Moana FMUs both over-represented the IF category within their FMU's, which could be mitigated by identifying and converting sites to the P category (Tauranga Moana), or the P and EF category (Rangitāiki).

6.4.3 FMU's as a proportion of regional length

This report assumes a unit should have an arbitrary threshold of 10% of the regional reach length to justify the presence of monitoring sites. With this in mind, the periphyton monitoring programme could be limited to the following FMU's: Rangitāiki, East Coast, Whakatāne, and Tauranga Moana, all of which are currently monitored to some extent. The 26 current monitoring sites could be distributed more appropriately if representation of the length of river reaches within each FMU is the primary objective of the periphyton monitoring programme. This would see a reduction of sites within the Tauranga Moana and Whakatāne FMU's and an increase in sites within the East Coast FMU. The Waioeka-Otara and Waiōtahe FMU's fall outside of the threshold so their sites could be redistributed.

An alternative approach may be to set this threshold at 4%, i.e., the percent contribution of one monitoring site relative the pool of 26 (shown in the ideal number of sites column). This would double the number of monitored FMUs through inclusion of: Waioeka-Otara, Rotorua Te Arawa Lakes, Tarawera, and Kaituna. This distribution would see a reduction in the number of monitoring sites in all monitored FMU's, and the creation of sites within the Rotorua Te Arawa Lakes, Tarawera, and Kaituna FMU's.

Regardless of the approach, the Waiōtahe FMU stands out as being abnormally overrepresented and could be redistributed to establish representative balance in other FMU's. However, any action needs to consider the value of long-term datasets and whether the achieved increase in representativeness warrants time-series disruption.

Part 7:
Lake water quality monitoring/ Aroturukitanga o te kounga wai roto

7.1 Background/Kupu Whakamārama

The lake water quality monitoring programme began in the Rotorua Te Arawa Lakes between 1990 and 1994 in response to community concerns over degrading water quality and algal blooms in some of the lakes (Hamill & Aussiel, 2012), and a need to set clear water quality targets that could be assessed through a monitoring programme. This programme has evolved to its current state where 16 sites are sampled monthly across 13 lakes: the 12 Rotorua Te Arawa lakes, and Lake Matahīna. Sites are typically situated at the deepest point within a lake which is assumed to be representative of ambient conditions at other locations. However, there are exceptions to this rule; Lake Rotorua is sampled in two locations, Site 2 (south of Mokoia Island) and Site 5 (north of Mokoia Island), and Lake Rotoiti is sampled in three locations, Okawa Bay, Site 3 and Site 4. Multiple sites are usually selected due to lake size or morphology which make it difficult to infer overall conditions from a single point. Lake Rotokakahi is also sampled at the lake outlet (Te Wairoa Stream) due to problems access the lake on a routine basis.

The lake monitoring programme has been developed to provide water quality information, to determine a lake's changing chemical balance and ecological status. This in turn provides information on how to manage lake quality effectively (Scholes and Hamill 2015). Specific components include: physico-chemical water quality monitoring used to generate the TLI, algal monitoring, and macrophyte monitoring, which is managed using the Lake Submerged Plant Indicators (LakeSPI index – see below)

A previous report by Hamill and Aussiel (2012) described the distribution of lakes within BOPRC's lake monitoring programme as representing 'a significant number of the larger and most used lakes in the region' but noted that this was not a truly comprehensive coverage of other lakes in the region. In particular, they highlighted a lack of monitoring sites on Lake Rotokawau, lakes in the Rangitāiki Catchment (Lake Pouarua, and the 2 hydro lakes – Aniwaniwa and Matahīna), lakes within the Tarawera catchment (e.g., Lake Pūpūwharau, Lake Rotoitipaku, and Lake Rotoroa), and coastal lagoons. These authors stated that "some attention may need to be given to assessing the state of these other lakes as part of the process for implementing the National Policy Statement for Fresh Water" (Hamill and Aussiel 2012). However, as discussed below, some of these lakes (e.g. Lake Aniwaniwa) are part of Hydroelectric Power Schemes (HEPS), and not really representative of lakes, while others (e.g. Lake Rotoitipaku) were regarded as being too small or too highly modified to be considered a lake. Other lakes (e.g., Lake Rotoroa), were now used as treatment ponds as part of industrial activities, and so monitoring these was not considered appropriate in the context of the NPSFM.

7.2 Definitions/Ngā Tautuhinga

Definition of representativeness

There are two main questions of representativeness regarding lake water quality and ecological sampling. The first is whether our current monitoring programme covers a representative subset of lakes across the region and within each FMU. The second question is whether each monitoring site, or combination of monitoring sites, is representative of the spatial variability that occurs within each lake.

Definition of a lake

The distinction between a pond, wetland, lagoon, and lake is not clearly defined. The RMA (1991) definition of a lake is "a body of fresh water which is entirely or nearly surrounded by land" is not particularly helpful, as it gives no indication as to how small a "lake" can be, or how large a "wetland" can be. The Conservation Act (1987) defines a lake as "a body of fresh water whose bed has an area of 8 ha or more and which is entirely or nearly surrounded by land". However, this definition is in reference to the requirement for esplanade reserves or strips, which does not perfectly match the objectives of this analysis. Johnson and Gerbeaux (2004) provided another definition of a lake as a waterbody body having a major dimension of 0.5 km or more: anything less is considered to be a wetland. Given the absence of a clear definition of "lake" in the RMA, we have decided to use a mixture of the 8 ha and major dimension > 0.5 km as a filter to remove any smaller wetlands from the following analysis. This meant disregarding named lakes such as Lake Rotoitipaku, as this only had an area of 4.5 ha, or a major dimension of only 340 m.

7.3 Methods/Huarahi

7.3.1 Representativeness of lake monitoring sites throughout the region

This analysis uses the Waters of National Importance (WONI) as a reference layer, which was developed as part of the Freshwater Ecosystems of New Zealand (FENZ) database project (Leathwick *et al.,* 2010). This layer contains 3820 lakes with an area greater than 1 ha. Each lake has been pre classified according to a primary classification framework which combines six environmental variables into seven discrete lake classes (Table 32). Other physical variables are also included, such as the known or estimated maximum depth, solar radiation, average summer wind, fetch, estimated residence time, and geomorphic type. All lakes within the WONI layer were clipped to the Bay of Plenty regional boundary, resulting in 102 identified lakes greater than 1 ha. This dataset was intersected with the draft FMU layer to attribute an FMU class to each WONI lake. Finally, based on our definition of a lake, we omitted all lakes < 8 ha from the dataset, and checked that the major dimension of any other remaining lakes was > 0.5 km. This resulted in 32 lakes within the region that meet our definition of lake. Four of these lakes had a WONI Primary Class of "W", implying "wetland".

Closer examination of these showed that the two lakes in the Kaituna FMU could indeed best be regarded as wetlands, as they appeared shallow and at least one was fringed with known wetland vegetation. However, Te Matahī Lagoon, in the southeast of Lake Rotomā was originally classified as "W", whereas two more lagoons to the north-east of Lake Rotomā (Whakarewa Lagoon and Te Onewhero Lagoon) were classified as "B" (Warm, moderately shallow, small). Field observations of all three lagoons (A. Suren pers. obs.) showed little obvious differences between these waterbodies, so they were all classified as "B". Similarly, Lake Pouarua (at the headwaters of the Rangitāiki) was also reclassified as "B", as its area (40.3 ha) was well in excess of the 8 ha we used in our definition. These two lakes were thus reallocated their appropriate Primary Classification Class from a "W" to a "B". This meant that there were 30 defined lakes in the region.

The 13 lakes that form the BOPRC lake monitoring programme were copied from the WONI dataset into a separate dataset called 'current monitoring'. The same intersection process was used to allocate all current lake monitoring sites to an FMU.

The subset WONI database was extracted and manipulated using the 'dplyr' package in the 'R' statistical language. Summary tables were produced to show the number of WONI lakes > 8ha: per FMU, per primary class, and per geomorphic type. An additional two tables were produced where each FMU was further split per category to show the composition and representativeness of WONI lakes within each draft FMU (i.e., FMU-primary class; FMU-geomorphic type).

Table 32 Primary classification of lakes within the WONI layer.

Class	Definition
A	Warm, shallow, moderate sized
B	Warm, moderately shallow, small
C	Warm, shallow, very small
D	Mild, deep, large
E	Mild, moderate depth and size
F	Mild, shallow, small

7.3.2 Representativeness of lake monitoring sites within each lake

The lake water quality monitoring programmes are designed to be representative of the conditions experienced throughout each monitored lake. This ensures that water quality results can be used to report on the condition of the lake as a whole and used to inform appropriate management actions throughout the wider contributing catchment. The process of allocating monitoring sites within a lake has typically been based on 'practitioner wisdom' informed by local knowledge and historic ad-hoc samples. This usually results in a single site per lake in the deepest basin, however large or morphologically complex lakes may have multiple sites to ensure that spatial variability is accounted for.

Ideally the process of site allocation should be informed by detailed knowledge of the spatial variability of water quality variables within a lake prior to site establishment, ensuring that new sites are representative of the average conditions of the lake. However, this is rarely ever achieved due to the cost and logistics associated with measuring water quality variables at multiple sites across a lake, and at fine enough timescales to understand how spatial and temporal variation interact.

Remote sensing is one method that could help improve this knowledge gap, with limited pre-investment. This technology uses spectral reflectance from satellite imagery as a proxy for lake water quality parameters and has been previously used to estimate in-lake concentrations of: chlorophyll-a, suspended sediment and dissolved organic matter.

Lehmann *et. al.* (in press) used remote sensing methods to summarise five years of estimated chlorophyll-a concentrations within 13 lakes in the Rotorua Te Arawa Lakes FMU (12 monitored lakes and Rotokawau). These authors used the Multispectral Instrument (MSI) on Sentinel-2 satellites, and the C2RCC algorithm to calculate chlorophyll-a concentrations on a pixel-by-pixel basis, across each lake.

They used this information to comment on the spatial variability of chlorophyll-a within each lake, and to infer how representative BOPRC's lake monitoring sites are of the targeted median lake concentration. This study is currently going through the process of peer-review, however limited findings are discussed in the results section below.

7.4 Results and discussion/Ngā Otinga me Matapakitanga

7.4.1 Representativeness of lake sites by FMU

The Rotorua Te Arawa Lakes FMU contains 17 (57%) of the 30 identified WONI lakes over 8 ha that are present within the Bay of Plenty region. This was followed by the Tarawera FMU with six lakes (20%), and the Rangitāiki and Tauranga Moana FMUs with four and three lakes, respectively (9%). Only two lakes were identified in the Kaituna WMA (Table 34). In comparison, 12 of the 13 BOPRC's lake monitoring sites (92%) are situated in the Rotorua Te Arawa Lakes FMU making this over-represented (1.84). The Rangitāiki FMU was the only other FMU to have a lake monitoring site (Lake Matahīna), which equates to adequate representation (0.72), while the Tarawera, Tauranga Moana and Kaituna FMU's are underrepresented (Table 33), as no lakes are monitored here.

Table 33 Representativeness of lake water quality monitoring in the four draft FMUs where lakes >8 ha are located. Conventions as per Table 15.

FMU	Number of WONI Lakes >8 ha	Proportion of Region	Lakes Monitored	Proportion of	Ideal Number of Lakes	Representativeness
Rangitāiki	4	0.139	1	0.08	1	0.57
Rotorua Te Arawa Lakes	17	0.57	12	0.92	8	1.62
Tarawera	6	0.208	0	0.00	3	0.00
Tauranga Moana	3	0.10	0	0.00	1	0.00

7.4.2 Representativeness of lake sites by geomorphic type

Not surprisingly, volcanic lakes made up the greatest proportion of WONI lakes within the region (53%), followed by riverine lakes (13%), and dams and shoreline lakes (17% each: Table 34). The vast majority of BOPRC's lake monitoring sites (92%) are located on volcanic lakes which are over-represented relative to other categories (1.73). Dam lakes are the only other geomorphic type monitored (8%) with a single location on Lake Matahīna but falls below the threshold for adequate representation (0.46). Riverine and shoreline lakes are not represented at all in the current lake monitoring programme (Table 34).

Table 34 Representativeness of lake Water Quality monitoring by WONI Geomorphic class in the region. Conventions as per Table 15.

Geomorphic Type	Number of WONI Lakes >8ha	Proportion of Region	Lakes Monitored	Proportion of	Ideal Number of Lakes	Representativeness
Dam	5	0.16	1	0.08	2	0.46
Riverine	6	0.13	0	0.00	1	**0.00**
Shoreline	5	0.17	0	0.00	2	**0.00**
Volcanic	16	0.53	12	0.92	8	1.73

Examination of the representativeness of lake monitoring in each of the four geomorphic classes in each FMU showed that only the Rotorua Te Arawa Lakes FMU was representative of the major lake type (Volcanic: Table 35). Three shoreline lakes (Te Onewhero Lagoon, Whakarewa Lagoon and Te Matahī Lagoon) also exist on the eastern side of Lake Rotomā in this FMU but are not currently monitored. However, these lakes are very much smaller in comparison to the 12 other Te Arawa lakes in this FMU, and are unlikely to have high recreational use, so their current omission is likely to reflect this.

Only the Rangitāiki FMU had an over-representation of lakes (1.50 for dams) but was under-represented for riverine and shoreline lakes (Lake Pourau and Thornton Lagoon, respectively: Table 35). The over-representation of the Dam lakes simply reflects the small number of lakes in this FMU and means that any monitored sites were likely to be over-represented relative to their wider distribution. The Tarawera FMU contained two each of shoreline, riverine, and volcanic lakes, neither of which are being monitored (Table 35). The Tauranga Moana FMU contained three dam lakes (Lake McLaren, and two unnamed storage dams), and the Kaituna FMU contained two riverine lakes, neither of which are monitored. However, these lakes are generally small, and unlikely to have high recreational use.

Table 35 Representativeness of the four geomorphic lake types in each of the draft FMUs. Bold values = dominant geomorphic lake type in each FMU. Conventions as per Table 15.

	Number of WONI lakes				Number being monitored				Representativeness			
	Dam	Riverine	Shoreline	Volcanic	Dam	Riverine	Shoreline	Volcanic	Dam	Riverine	Shoreline	Volcanic
Rangitāiki	2	2			1	0	0		**2.00**	0.00	0.00	
Rotorua Te Arawa Lakes			3	14			0	12			0.00	**1.21**
Tarawera		2	2	2			0	0		**0.00**	**0.00**	**0.00**
Tauranga Moana	3				0				**0.00**			

7.4.3 Representativeness of lake sites by WONI Primary Classification

The largest proportion of lakes within the region was the "warm, moderate shallow lakes" (WONI category B) and the "warm, shallow lakes" (WONI category A), both of which made up 30% of lakes (Table 36). Less common lakes included mild, deep, larger lakes (category D; 20%), mild, moderate depth and size (category E; 17%), and mild, shallow, small (category F; 3%). Of these, categories A (0.51) and B (0.00) were under-represented, and D (2.31) and E (1.85) and F (2.31) were over-represented (Table 36).

Table 36 Representativeness of the current lake water quality monitoring programme throughout the region according to the WONI Primary Classification. Conventions as per Table 15.

Primary Classification	Number of WONI Lakes >8 ha	Proportion of Region	Lakes Monitored	Proportion of monitored lakes	Ideal Number of Lakes	Representativeness
A	9	0.30	2	0.15	4	0.51
B	9	0.30	0	0.00	3	0.00
D	6	0.20	6	0.46	3	2.31
E	5	0.17	4	0.31	2	1.85
F	1	0.03	1	0.08	1	2.31

An assessment of the representativeness of the different Primary Lake categories in each FMU showed that no lake monitoring was done in any lakes in two FMUs (Tauranga-Moana, and the Tarawera (Table 37). The Tauranga-Moana FMU contained three lakes in category B (warm, moderately shallow, small), all in the Wairoa Catchment. These are part of the Ruahihi HEPS. Lake McLaren is the only named example, however, both of the other unnamed lakes are associated with the same power scheme but located further up the catchment.

The Tarawera FMU contains 6 WONI lakes within the A primary classification category, none of which are monitored. Named examples of this category include: Lakes Pūpūwharau, Rotoroa, and Tamurenui. Some of these (e.g., Lake Rotoroa) have been so modified that they are now part of the pulp and paper infrastructure in Kawerau, and act as aeration ponds.

The Rotorua Te Arawa Lakes FMU was the closest FMU to having good representation of primary classification categories, where categories A, D, E, and F were only slightly over-represented (1.33 each: Table 37). Category B was under-represented within this FMU, which includes the three lagoons beside Lake Rotomā (Te Matahī Lagoon, Onewhero Lagoon, and Whakarewarewa Lagoon), and Lake Rotokawau. Lake Rotokawau has been subject to a comprehensive study by Pearson *et al.* (2011). These authors collected water quality samples, sediment samples, and carried out conductivity, temperature, depth (CTD) casts of the water column. Their findings indicated that the lake had not undergone mixing at the time of the study (mid-winter) which made it unique among other lakes within the Rotorua Te Arawa Lakes Complex. The authors suggested that this may be due to its morphology, i.e., a small surface area with a maximum depth of 74 m, combined with the sheltered nature of the catchment. Pearson *et al.* recommended that Lake Rotokawau was incorporated into BOPRC's routine lake monitoring programme, so that any improvement or degradation in water quality can be detected and the mixing frequency of the lake determined. This, however, has not occurred to date.

The Rangitāiki FMU was over-representative for its main primary classification category (E), which was composed of the two hydro-electric power scheme (HEPS) lakes (Lake Aniwaniwa above the Aniwhenua Dam, and Lake Matahīna, above the Matahīna Dam). The category A lake (warm, shallow, moderate sized) was the Thornton Lagoon, located at the mouth of the Rangitāiki River. Lake Pouarua, in the upper (southern) part of the Rangitāiki was the category B lake (warm, moderately shallow, small), formed from fluvial processes. Although this was originally defined in the WONI database as a wetland "W", its large size (40.27 ha) meant that it was reclassified as a Lake according to our definitions of a lake.

Table 37 Representativeness of the current lake water quality monitoring programme according to the WONI Primary Classification, within each of the four FMUs that contained lakes. Conventions as per Table 15.

	Number of WONI lakes (32)					Number being monitored (13)					Representativeness				
FMU	**A**	**B**	**D**	**E**	**F**	**A**	**B**	**D**	**E**	**F**	**A**	**B**	**D**	**E**	**F**
Rangitāiki	1	1		2		0	0		1		0.00	0.00		**2.00**	
Rotorua Te Arawa Lakes	2	5	6	3	1	2	0	6	3	1	1.41	0.00	**1.41**	1.41	1.41
Tarawera	6					0					**0.00**				
Tauranga Moana		3					0					**0.00**			

7.4.4 Within-lake spatial representation

Lehmann *et al*. (in press) found that there was high variability in chlorophyll-a concentrations across each of the main Te Arawa Rotorua lakes, although chlorophyll-a patterns were predictable over time, and concentrations increased with distance from the shore, particularly in larger lakes such as Rotorua, Rotoiti, Tarawera, Rotoehu, and Rotomā. - In smaller lakes such as Ōkaro, Rerewhakaaitu, and Ōkāreka, pixels were distributed more irregularly and there were less defined spatial patterns than in deep lakes. A comparison of the overall distribution of chlorophyll-a concentrations showed that BOPRC's monitoring sites on Lakes Ōkaro, Rerewhakaaitu, and Tarawera were located in areas that most often represented the median chlorophyll-a concentrations of each lake (Table 38). Monitoring sites on Lakes Ōkāreka, Rotoehu, Rotomā, Rotomāhana, and Tikitapu were most often representative of upper quartile chlorophyll-a concentrations, while Ōkataina and Rotoiti (east) were representative of the lower quartile chlorophyll-a concentrations. Lake Rotoiti (west) and Lake Rotorua (north and south) sites were too variable to categorise.

Although these results are only applicable to chlorophyll-a distribution, they demonstrate how spatially variable lakes within the Rotorua Te Arawa Lakes FMU can be, and how difficult it can be to position monitoring sites without information such as that derived from satellite imagery. Consideration could be put into adjustment of sites that are over or under representative of chlorophyll-a concentrations. However, these decisions need to be compared to the benefits of maintaining long term datasets in these systems and take into consideration that the spatial variability of the other water quality parameters of interest (e.g., N and P, and secchi depth) are not likely to be equal, and that a perfectly representative site may not exist at all within each lake.

Table 38. Percentage of the lake area (in number of pixels) where estimated chlorophyll-a was typically within 10% of the median, upper, or lower quartiles. Asterisks represent the location of BOPRC's monitoring site, if a conclusive category can be obtained. This has been clarified in the conclusion column. Modified from Lehmann et al. (in press). Note that an over-representation of chlorophyll monitoring could be as bad as an under-representation, as chlorophyll-a values may be significantly over-estimated in relation to the median.

Lake (and site)	Lower quartile	Median	Upper Quartile	Conclusion
Ōkareka	24	6	16*	Over-representative
Ōkaro	19	22*	4	Representative
Ōkataina	19*	8	16	Under-representative
Rerewhakaaitu	15	5*	9	Representative
Rotoehu	25	6	13*	Over-representative
Rotoiti (east)	20*	7	15	Under-representative
Rotoiti (west)	21	8	20	Too Variable
Rotomā	16	8	14*	Over-representative
Rotomāhana	16	7	13*	Over-representative
Rotorua (north)	20	8	15	Too Variable
Rotorua (south)	14	8	12	Too Variable
Tarawera	25	7*	19	Representative
Tikitapu	22	9	16*	Over-representative

7.5 Conclusions and recommendations/Ngā whakakapinga me ngā tūtohutanga

This analysis has shown that BOPRC's current lake water quality monitoring programme represents lakes within the Rotorua Te Arawa Lakes and Rangitāiki FMU's reasonably well but contains no sites in the Tauranga Moana or Tarawera FMU's. Absence of lake monitoring in these two FMUs most likely reflects the nature of these lakes, and their subsequent recreational and ecological values. For example, the three lakes within the Tauranga Moana FMU are artificially created and associated with Ruahihi power scheme. Lake McLaren is the most well-known of these lakes and is a popular recreational destination for activities such as kayaking, fishing, and swimming. Lake McLaren was formed below the confluence of the Opuiaki River and the Mangapapa River. The bulk of the inflowing water from these rivers then travels down the Ruahihi canal and into the Wairoa River at the Ruahihi HEPS. From September to May, there are controlled releases of water down the McLaren Falls into the Wairoa River. The water in this lake thus has a very low residence time, so the lake would in fact behave more like a river. Because of this low residence time, it is highly unlikely that water quality problems such as cyanobacterial blooms, and lake stratification which are often observed in the Rotorua Lakes would exist in either Lake McLaren, or in the other two HEP Lakes in the Tauranga Moana FMU.

Two other HEP Lakes are found in the Rangitāiki FMU, of which only one (Lake Matahīna) is regularly monitored through the current water quality monitoring program. Scholes (2019) reviewed the water quality and ecological conditions in both Lake Matahīna and Lake Aniwaniwa. Based on this review, he concluded that Lake Matahīna has typically identifiable lake characteristics (strong summer stratification resulting in low hypolimnetic oxygen levels, high phytoplankton biomass that causes seasonality in dissolved reactive phosphorus), whereas Lake Aniwaniwa can be better characterised as a run-of-the-river system, with a low residence time, low phytoplankton biomass, and dominance of aquatic macrophytes in shallow areas. For this reason, BOPRC only monitors water quality at Lake Matahīna. Thus, although the current lake water quality monitoring programme may be under-representative of these HEP lakes, most of them have hydro-dynamic and ecological features more typical of rivers. As such, it could be argued that, despite being identified as “lakes” in the WONI layer, it is not really appropriate to monitor them as part of the lake monitoring programme.

No lake monitoring has been undertaken in the Tarawera FMU, where warm, moderately shallow lakes (WONI A primary classification) are found. As with the HEPS lakes, the lack of lake monitoring in these FMUs most likely reflects the nature of these lakes, and their perceived values. Lake Rotoroa (identified as two separate lakes in the WONI database) has been so modified that it is part of the pulp and paper infrastructure in Kawerau and acts as aeration ponds. Similarly, Lake Pupuwharau is located in a relatively inaccessible area in Kawerau, is privately owned by an iwi trust, and unlikely to have particularly high recreational usage. Other lakes in the Tarawera FMU include the coastal Matatā Lagoon, and Lake Tamurenui, located near the Onepū wetlands near Braemar Rd. These lakes are gazetted as Government Purpose Reserves and are managed as Wildlife Management Reserves by the Department of Conservation and/or Fish and Game. Furthermore, unlike the Rotorua Te Arawa Lakes where public concern back in the late 1980s and early 1990s was the impetus for the commencement of the water quality monitoring programme, there does not seem to be the same level of public concern about lake water quality in these smaller lakes in the Tarawera FMU.

Our analysis showed that BOPRC’s monitoring programme is focussed predominantly on Volcanic lakes, with the exception of one Dam Lake (Lake Matahīna). The focus on volcanic lakes reflects their dominance in the region (53%), so this is not surprising. It also needs to be remembered that the lake water quality monitoring programme arose out of concern about the apparent degradation of water quality in the highly valued Rotorua Te Arawa lakes, and a desire to improve their condition. It could be argued that the other lake types may not be facing the same pressures as the larger Te Arawa Rotorua Lakes, or do not have the same level of public concern about their condition, either because they are too inaccessible (e.g., Lake Pourua, at the head of the Rangitāiki, or Lake Pūpūwharau in Kawerau), or are Wildlife Management Reserves. Four other un-monitored lakes include three HEP lakes in the Tauranga-Moana FMU, and Lake Aniwaniwa in the Rangitāiki FMU. These have very short residence times, so do not support phytoplankton blooms, and would be very unlikely to undergo stratification. As such these four HEP lakes would in fact be more similar to rivers, and so it would not be appropriate to include them in a lake water quality monitoring programme. Therefore, even though the other lake types compose about 43% of the identified WONI lakes and are, in theory, underrepresented by the current water quality programme, the reality is that many of these other lakes are either inaccessible, managed for different reasons, or are in fact more riverine than lacustrine. Their under-representation is therefore based more on the methodology we have used to assess representativeness, rather than a lack of monitoring lakes where there are pressures.

Analysis from Lehmann *et al.* (in press) shows that each of the 12 monitored lakes within the Rotorua Te Arawa Lakes FMU have spatially variable concentrations of chlorophyll-a. In larger lakes, the spatial distribution is more predictable, typically increasing with distance from shore, however smaller lakes can be more unpredictable. Assessment of existing monitoring sites suggest that sites on Lakes Tarawera, Rerewhaakaitu, and Ōkaro are situated in areas that approximately represent the median chlorophyll-a concentration across each lake. Lakes Ōkāreka, Rotoehu, Rotomā, Rotomāhana, and Tikitapu likely overrepresent the overall median chlorophyll-a concentration, and Lake Ōkataina and the Rotoiti (east) site underrepresent median chlorophyll-a concentrations.

Although remote sensing provides a useful method to assess spatial variability of some water quality variables and can be used to define optimal sampling sites in unmonitored lakes, care should be taken when considering adjusting the location of existing sites due to disruption of valuable continuous datasets. An additional consideration is that the currently analysis only shows the spatial variability of chlorophyll-a, and it is unlikely that all water quality parameters will show the exact same pattern. Therefore, there may not be a perfectly representative site that caters for all variables.

Part 8:
Lake macrophyte monitoring/ Aroturukitanga rauropi ika roto

8.1 Background/Kupu Whakamārama

Since 2005, NIWA has been contracted by BOPRC to assess the ecological condition of the 12 Te Arawa Rotorua lakes using the LakeSPI (Submerged Plant Indicators) methodology. LakeSPI provides a quick and cost-effective bio-assessment tool for monitoring and reporting on the ecological condition of lakes using submerged macrophytes as an ecosystem indicator of "lake health" (Burton 2019). It allows lake managers to assess and report on the ecological status of lakes at an individual, regional or national level; monitor changes in a lake or group of lakes over time and prioritise lake management initiatives accordingly (e.g., protection, monitoring, weed surveillance). LakeSPI is recommended by the Ministry for the Environment as one of the few indicators for State of the Environment (SOE) reporting and is also a compulsory attribute in the NPS-FM (2020).

Key features of aquatic vegetation structure and composition are used to generate three LakeSPI indices:

- 'Native Condition Index (NCI)' – This captures the native character of vegetation in a lake based on diversity and extent of indigenous plant communities. A higher NCI score means healthier, deeper, diverse beds.
- 'Invasive Impact Index (III)' – This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species. A higher III score means more impact from exotic species, which is often undesirable.
- 'LakeSPI Index' – This is a synthesis of components from both the NCI and III of a lake to provide an overall indication of lake condition. The higher the LakeSPI score, the better the condition.

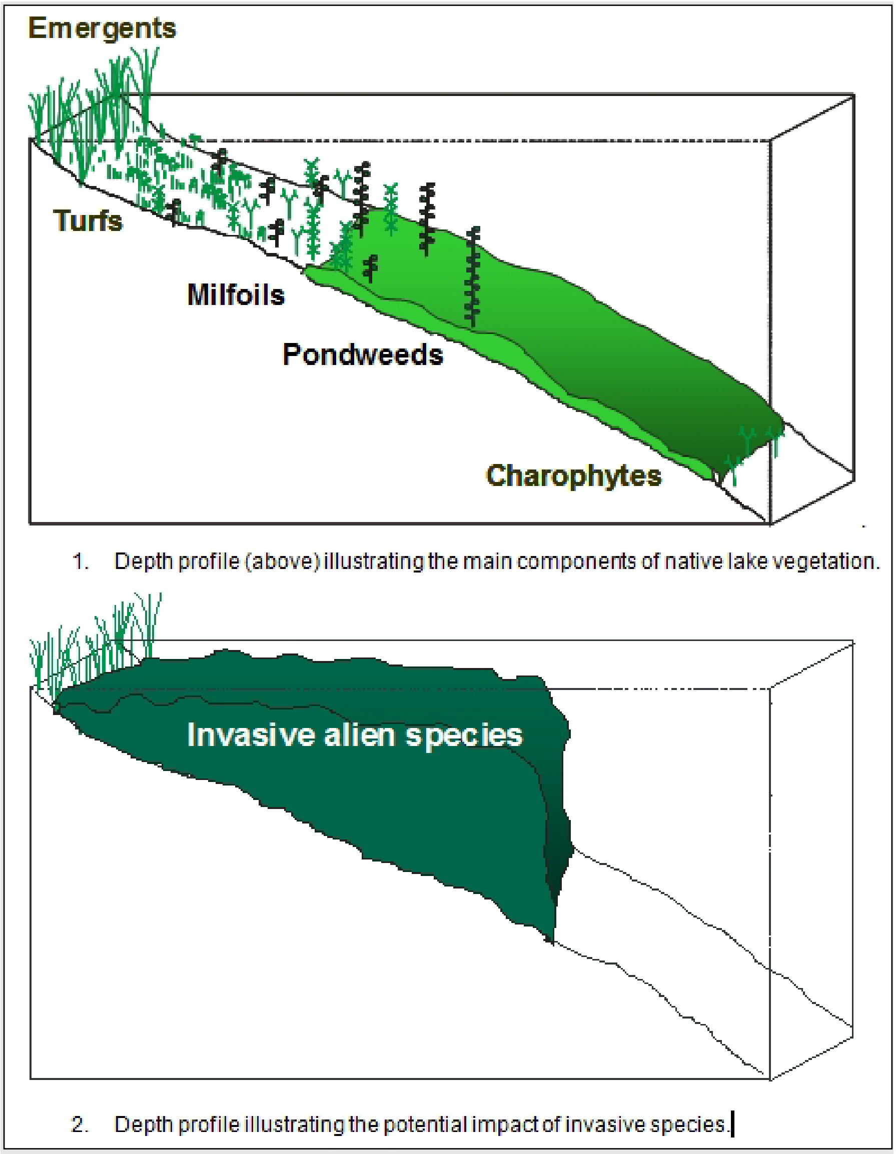
Key assumptions of the LakeSPI method are that native plant species and high plant diversity represents healthier lakes or better lake condition, while invasive plants are ranked for undesirability based on their displacement potential and degree of measured ecological impact (Clayton & Edwards 2006b).

Because lakes have differing physical characteristics that can influence the extent and type of submerged vegetation, each of the LakeSPI indices are expressed in this report as a percentage of a lake's maximum scoring potential. Scoring potential reflects the maximum depth of the lake to normalise the results from very different types of lakes. A lake scoring full points for all LakeSPI indicator criteria would result in a LakeSPI Index of 100%, a Native Condition Index of 100% and an Invasive Impact Index of 0%.

The Rotorua Te Arawa lakes have been significantly affected by changes both in water quality and through the introduction of invasive aquatic plants. Historic land use activities have resulted in a progressive deterioration in water clarity, reducing the depth to which submerged aquatic plants grew. Furthermore, a range of invasive plant species have become established in the Te Arawa Rotorua Lakes, thus affecting overall LakeSPI scores, by displacing a complex community of often low-statured plants with a uniform community of dense, tall alien vegetation (Figure 4).

For example, *Elodea canadensis* was likely to have established in Lake Rotorua during the 1930s, as the Ngongotahā trout hatchery had ‘oxygen weed’ in their hatchery ponds then, which were flushed annually into the Ngongotahā Stream. Another invasive plant, *Lagarosiphon*, had appeared in Lake Rotorua in the early 1950s, and by the late 1950s major weed problems were apparent in both Lake Rotorua and Rotoiti. *Lagarosiphon* has subsequently spread rapidly through most of the Rotorua Te Arawa Lakes, with Lake Rerewhakaaitu estimated to have been invaded in the mid-1980s.

The spread of significant invasive weed species into the remaining Rotorua Te Arawa Lakes is a gradual and on-going process, and there is a strong correlation with boat traffic and lake accessibility, with early weed introduction mainly at boat ramps (Johnstone *et al.,* 1985).



1. Depth profile (above) illustrating the main components of native lake vegetation.
2. Depth profile illustrating the potential impact of invasive species.

Figure 4 *Depth profiles within a lake showing how a complex community of native vegetation displaying discrete depth zones can be replaced by a uniform monoculture of introduced alien species. (Figure from Burton 2016).*

8.2 Representativeness of LakeSPI sampling

Lake SPI surveys are routinely conducted in the 12 Te Arawa Rotorua lakes. LakeSPI monitoring was first conducted between September 2003 and March 2005 (Clayton *et al.,* 2005), and since this time, lakes have been surveyed biennially in March-April each year to maintain a consistent record, except for in 2020, where no lakes were surveyed due to the national Covid-19 lockdown. All lakes were, however, surveyed in 2021, thus minimising a data gap. In addition to these 12 Rotorua Te Arawa lakes, 3 other lakes (Matahīna, Aniwhenua, Pupuwharau) in the Bay of Plenty Region have also been surveyed on an ad hoc basis, although no consistent monitoring has been done in these lakes.

At each lake, macrophyte surveys are undertaken in five established baseline transect lines running from the shore to the deepest limit of the photic zone, where plants can grow. While these transects were not selected randomly within the lakes, they were selected on the basis of having profiles most suited for macrophyte development and were thus restricted to relatively gently sloping sites with sandy or muddy substrates. Steep sided locations with a boulder or bedrock lakebed were not selected. The restriction of sites to those where macrophytes can grow was similar to the "bespoke" method used to select sites for the periphyton monitoring, based on modelled variables pertaining to biophysical class, nutrient status, and flood frequency. All Lake SPI transects are re-located with reference to site maps, GPS references and shoreline photos during each survey, so that changes to LakeSPI condition can assessed over time.

Because each lake is surveyed only at sites where aquatic plants can grow, the LakeSPI methodology is not considered to be fully representative of overall macrophyte development throughout individual lakes, but instead is focussed on surveying areas where plant growth is maximised. In this regards it is similar to the site selection process as outlined for the periphyton monitoring programme, which a priori selected a subset of streams throughout the region conducive to periphyton development.

The fact that LakeSPI monitoring is routinely conducted in each of the 12 Te Arawa Rotorua lakes means that our assessment of representativeness of the LakeSPI programme would be very similar to that of the water quality programme. The only difference between the water quality monitoring programme and the LakeSPI programme is that LakeSPI assessments are not routinely undertaken in Lake Matahīna. This means that from a FMU perspective, the LakeSPI programme is over-representative in the Rotorua FMU, and under-representative in the Rangitāiki FMU. Furthermore, it is absent from the Tarawera and Tauranga-Moana FMUs. The lack of LakeSPI monitoring in the three HEPS lakes in the Tauranga-Moana FMU is consistent with these lakes being functionally more similar to rivers, while the lack of LakeSPI monitoring in the Tarawera FMU is consistent with the fact that these lakes are either inaccessible, managed as wildlife reserves for gamebirds by Fish and Game, or are part of aeration pond infrastructure for the pulp and paper plants in Kawerau.

Although routine LakeSPI monitoring is not occurring in Lake Matahīna, it is questionable as to whether it should be. Firstly, macrophyte development in this lake is severely limited by the lakes' bathymetry, where many of the sides are very steep and dominated by bedrock. This means that there are only relatively few places in the lake where macrophytes could flourish. Furthermore, the LakeSPI assessment that was done here in 2014 showed that invasive plants dominated the lake here, with an invasive impact score of 96.3, and a Native Condition Index of only 2.7. The dominant plant community here was composed of hornwort (*Ceratophyllum demersum*), *Egeria densa*, Canadian pondweed (*Elodea canadensis*), and curly pondweed (*Potamogeton crispus*). These plants are found throughout the catchment (and especially in Lake Aniwaniwa), making their control extremely difficult or impossible.

Given the already highly degraded LakeSPI scores in this lake, the relatively small area of lake where plants can grow, and the fact that little real management options are available to improve LakeSPI scores, the usefulness of continued monitoring here is questionable. If LakeSPI surveys were not undertaken here, this would mean that no LakeSPI assessments were done in the Rangitāiki.

If LakeSPI assessments were to be done in this FMU, an obvious choice for an initial assessment would be in Lake Pouarua, at the headwaters of the catchment. No LakeSPI assessments have been conducted there to date, so its condition is unknown. It may thus be valuable to undertake at least a one-off LakeSPI assessment here to determine its condition. Based on the results, it may be justifiable to add this lake to the routine LakeSPI monitoring programme. However, at this stage it is suggested that the current LakeSPI programme is indeed providing adequate information about the ecological status of macrophyte communities in all the major lakes where macrophyte development may occur.

Part 9:
Lake cyanobacterial monitoring

9.1 Background/Kupu Whakamārama

Bay of Plenty Regional Council's planktonic cyanobacteria monitoring programme has been established since 1997 following severe blooms in Lakes Rotorua, Rotoiti, Ōkaro, and Rotoehu, which have persisted on a near-annual basis since that date (Dare, 2020). Sites are targeted towards areas where the public are likely to have the greatest exposure to cyano-toxins through vectors of immersion, consumption, or inhalation.

Twelve sites are currently monitored across four lakes; Rotorua, Rotoiti, Ōkaro, and Rotoehu, with an additional site on the upper Kaituna River, at the Trout Pool downstream of the Okere Falls. This later site was included as part of the consent condition monitoring requirements for the Ōhau Diversion Channel. All sites are easily accessible by car for sampling purposes, are located in areas known to experience historic cyanobacteria blooms and are assumed to be important areas for community recreation.

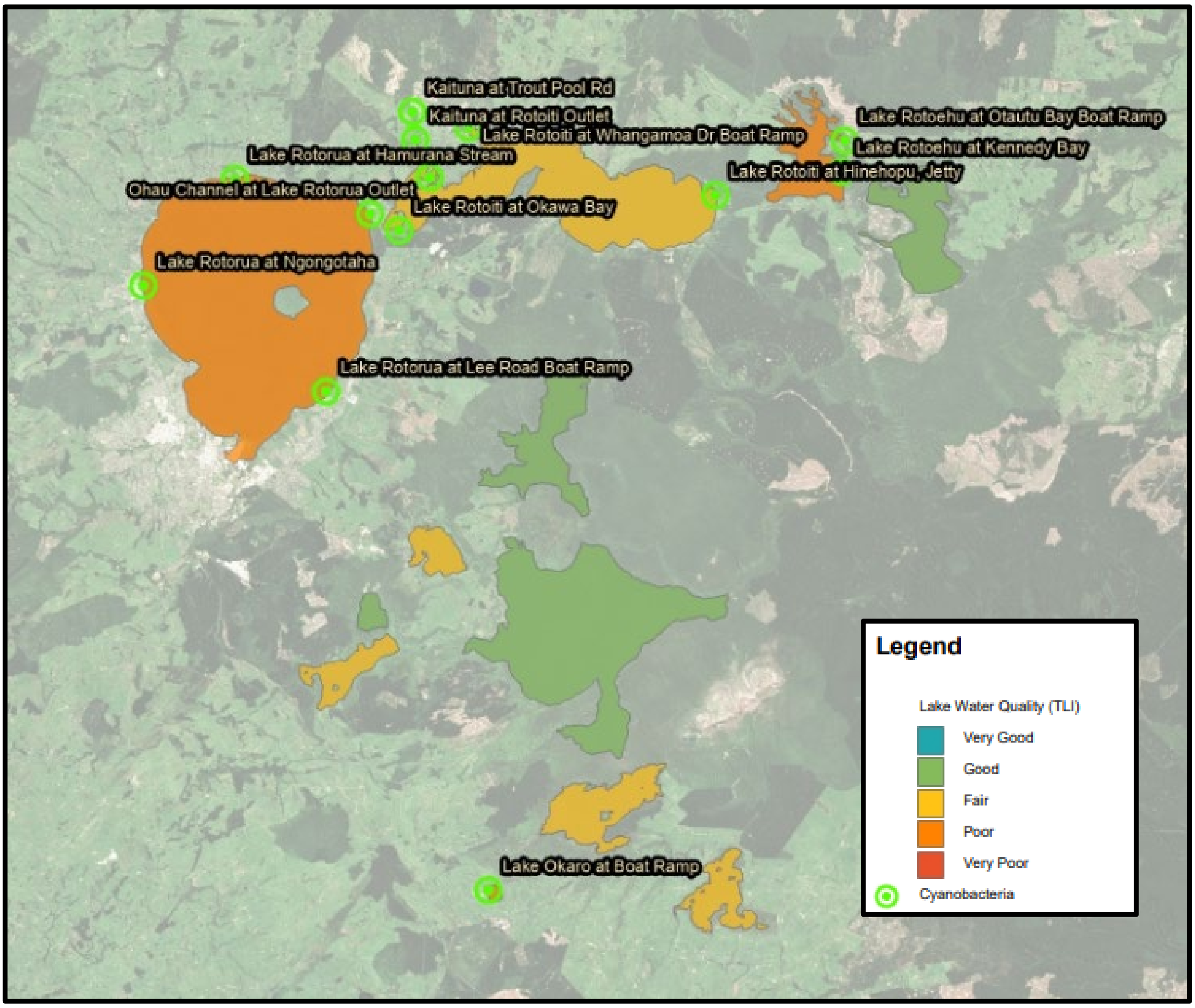


Figure 5 Map showing the location of the 13 cyanobacteria sites monitored by BOPRC, as well as the long-term Trophic Lake Index (TLI) of each lake monitored for water quality.

One lake that is not included in the list of routinely monitored sites is Lake Tarawera which, although oligotrophic, has experienced cyanobacterial blooms near the Wairua Arm. This lake is well used by the general public, particularly on public holidays, but has been excluded from routine sampling due to access difficulties. Sampling of this lake is carried out on an ad-hoc basis, typically initiated by reports of cyanobacterial activity from the public or business using the lake, or more recently, from observations of high-resolution satellite imagery.

9.2 Definition of representativeness

In order to assess whether the planktonic cyanobacteria monitoring programme is representative, we first need to define what full representation of lake sampling entails. In this case it is assumed that full representation means that there is at least one monitoring site in each area that is at risk of cyanobacteria blooms, and that is used by the community for recreational purposes. The public should be able to refer to the most appropriate monitoring site to obtain information on the current status of cyanobacteria at the location they choose to interact with.

Research has shown that cyanotoxins can bioaccumulate in the flesh and livers of important food resources such as trout or eels (Wood *et al.,* 2004), however, these need to be consumed in much larger quantities than typical recreational consumption rates to pose a direct health risk. With this in mind, we subsequently limited our definition of recreational purposes to those activities that involve direct immersion in water, i.e., swimming, which is also consistent with the NPS-FM. It should also be noted that this analysis is based around human contact only and does not address water takes used for domestic drinking water.

9.2.1 Freshwater recreational survey layer

Bay of Plenty Regional Council has established its bathing monitoring and cyanobacteria monitoring programmes based on ‘local knowledge’ of where people most commonly swim, however this is by no means a complete census of swimming spots within the region. Without this knowledge, it is difficult to assess if bathing and cyanobacteria monitoring programmes are representative of where people interact with the water.

The most comprehensive list of public recreation sites that BOPRC possesses was collated by the Policy team during the summer of 2020. This list contains over 150 identified recreational sites in the form of a GIS layer, henceforth referred to as the Freshwater Recreational Survey Layer (FRSL)[10]. Information collated in the FRSL covers a variety of recreation types, including swimming, kayaking, rafting, boating, and food gathering (from a water quality during collection perspective, not food safety), but it does not include any assessment or analysis of usage/popularity, or cultural significance. Data points and associated metadata were sourced from various sources, including websites; internal reports; statutory documents; community workshops; and internal staff surveys. There were a small number of instances where the FRSL did not cover sites that form part of BOPRC’s current bathing water quality or cyanobacteria monitoring programmes. These sites are recognised recreational sites and were therefore added to the FRSL.

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[10] See Internal Student report: Objective ID A3467512

9.3 Methods/Huarahi

Planktonic cyanobacteria blooms are predominantly a risk in lentic (still water) environments, so all riverine sites were excluded from the analysis, with the exception of sites located around the Okere falls, between the Okere Control Gates and the Kaituna at Trout Pool Road site.

The FRSL was assumed to be a census of all freshwater recreational sites within the Bay of Plenty Region and was used to compare the distribution of current monitoring sites. To do this, the FRSL was intersected with the draft FMU layer to define a specific FMU for each site. The dataset was exported and manipulated in 'R' (2021) using the 'dplyr' package (Wickham *et al.,* 2021) to summarise the number and proportion of total FRSL sites that correspond to each applicable FMU. The same process was carried out for all 13 current cyanobacteria monitoring sites, and the two tables were combined so they could be compared. The ratio of the current site proportion to FRSL proportion per FMU was used as an index of representativeness.

There was also consideration of current monitoring sites that were close enough to FRSL sites that the results would be representative of ambient conditions. To address this, a three-kilometre buffer was drawn around each monitoring point, and all FRSL sites contained within this were considered to be adequately represented by the monitoring point. There were a limited number of exceptions to this rule, such as when headlands or embayments separated the current monitoring site from the FRSL site. These were assessed on a case-by-case basis and the representative link was removed if needed (Table 40).

A final analysis was carried out on the Rotorua Lakes where the results calculated above were split by each lake and compared with the trophic status represented by TLI (Table 41).

9.4 Results and discussion/Ngā Otinga me Matapakitanga

Current cyanobacteria monitoring sites are well represented in the Rotorua Te Arawa Lakes FMU (Table 39), which contains 94% of the identified FRSL sites. The Kaituna FMU was deemed overrepresented, however this was due to the small number of FRSL sites identified to the analysis cut-off point (Kaituna at Trout Pool). The Kaituna at Trout Pool site was put in place to identify export of cyanobacteria laden water from Lake Rotoiti, and to satisfy consent conditions associated with the Lake Ohau Diversion Channel.

The Rangitāiki and Tauranga Moana FMUs had no monitoring sites but contained less than 10% of the identified FRSL sites and could therefore be categorised as being adequately represented. A single FRSL sites was identified in Lake McLaren in the Tauranga-Moana FMU, but this is not known as a popular swimming spot, and little is known about its trophic status.

Table 39 Comparison of current monitoring sites and Freshwater Recreational Survey Layer (FRSL) sites per FMU. Conventions as per Table 15.

Draft FMU	Current Sites	Current Proportion	`FRSL Sites	FRSL Proportion	Representativeness
Kaituna	1	0.08	1	0.03	2.69
Rotorua Te Arawa Lakes	12	0.92	33	0.86	0.98
Tauranga Moana	0	0.00	1	0.03	0.00

Of the thirty identified FRSL sites in the Rotorua Te Arawa FMU, 54.5% (18 sites) were within 3 km of an existing cyanobacteria site (Table 40). The Kaituna FMU had 100% coverage, but this only represented one FRSL site identified for (safe) swimming in a small stretch of river from the Okere gates to the Kaituna at Trout Pool monitoring site.

Table 40 FRSL sites within a 3 km buffer of current monitoring sites split by FMU.

	FMU	Current Sites	FRSL Sites <3 km of Current	Total FRSL Sites	Current Coverage (%)
LAKE	Rotorua Te Arawa Lakes	12	18	33	54.5
LAKE	Tauranga Moana	0	0	1	0.0
RIVER	Kaituna	1	1	1	100.0

When broken down into individual lakes, the Rotorua Te Arawa Lakes analysis showed that 100% of the identified FRSL sites were within three kilometres of cyanobacteria monitoring site at the two lakes with the highest trophic level, and hence the highest risk of bloom formation (Lakes Ōkaro and Rotoehu: Table 41). Lakes Rotorua and Rotoiti had more FRSL between them than all other lakes and were both 83.3% covered by current monitoring sites (Table 41). Lake Tarawera stood out from the remaining lakes, with four identified FRSL sites but no cyanobacteria monitoring. This is mitigated somewhat by ad-hoc sampling that occurs on Lake Tarawera when BOPRC is informed of a bloom, either from the public or via satellite imagery.

Table 41 FRSL sites within the Rotorua Te Arawa Lakes FMU which are located within a 3 km buffer of current monitoring sites.

Lake	TLI	Current Sites	FRSL Sites <3 km of Current	Total FRSL Sites	Current Coverage (%)
Lake Ōkaro	4.5	1	1	1	100.0
Lake Rotoehu	4.4	2	2	2	100.0
Lake Rotorua	4.1	4	10	12	83.3
Lake Rotoiti	3.7	5	5	6	83.3
Lake Ōkāreka	3.0	0	0	2	0.0
Lake Tikitapu	2.8	0	0	1	0.0
Lake Tarawera	2.7	0	0	4	0.0
Lake Okataina	2.6	0	0	1	0.0
Lake Rotomā	2.2	0	0	1	0.0

9.5 Conclusions and recommendations/Ngā whakakapinga me ngā tūtohutanga

Bay of Plenty Regional Council's cyanobacteria monitoring programme shows good representation for the areas of highest risk to cyanobacteria blooms which are largely situated around the Rotorua Te Arawa Lakes. It's no coincidence that the four most eutrophic lakes are monitored for cyanobacteria concentrations above others, and further analysis shows that within these lakes, a minimum of 83% of identified FRSL sites are well represented by nearby monitoring sites.

These lakes are only monitored during the highest risk period for cyanobacteria growth, which lasts from November to June, which also coincides with a period of high recreational use from the community. However, blooms can occur outside this period, such as a large bloom observed in October 2020 in Lake Rotorua (Figure 6). The prevalence of these out-of-season blooms may increase with climate change. Currently BOPRC relies on public information about these out-of-season blooms, which is followed up by sampling. Although this can cause delays in the issue of public health warnings, this risk is somewhat ameliorated by the comparatively low level of contact activity on the lakes during winter. This risk is also further mitigated by the recent investment in daily commercial satellite imagery via Planet.com. This enables cyanobacterial blooms to be detected without field visits, assuming that weather conditions are suitable for satellite imagery. However, a better solution may be to simply maintain a scaled-down version of the monitoring programme over the off season.

Less eutrophic lakes are not well represented due to the lower risk of blooms occurring. This is validated by observations from high resolution satellite imagery, and a lack of feedback from the public. However, that doesn't mean that blooms do not occur there, or will not occur there in the future, and future sampling design may have to be revisited if conditions change.

The current monitoring programme does not represent the single FRSL site identified in each of the Rangitāiki or Tauranga Moana FMU for the same reasons as for less eutrophic lakes, and because the number of people interacting with the water is much lower than other areas. It is recommended that neither Lake Aniwaniwa or Lake McLaren are not routinely monitored unless conditions change and the risk to the public increases.

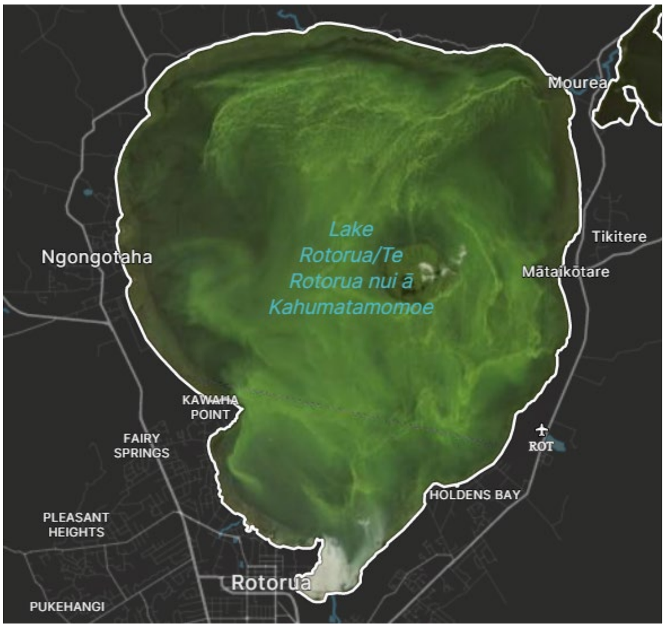


Figure 6 *The October 2020 cyanobacteria bloom in Lake Rotorua. This image comes from high resolution, commercial satellite imagery via Planet.com.*

Part 10:
Bathing water monitoring

10.1 Background/Kupu Whakamārama

Bay of Plenty Regional Council's bathing monitoring programme consists of 31 river bathing sites and 13 lake bathing sites in freshwater (estuarine and coastal sites are also included in the monitoring programme but not assessed here). These sites have been established through historical knowledge of where people swim and the risk of contamination. Sites are monitored for *Escherichia coli* concentrations on a weekly basis from late October to the end of March. *E. coli* is used as an indicator of pathogens and pathogenic micro-organisms that commonly manifest as gastroenteritis (MfE, 2003).

Results are assessed against the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MWQG) (MfE, 2003) with individual samples being graded as being in 'green/surveillance', 'orange/alert', or 'red/action' bands. Results are provided to the district health board, Toi Te Ora, who assess the results and decide if a health warning is to be issued. Health warnings are typically issued for sites that express exceedances of the red/action band threshold (550cfu) for reasons other than heavy rainfall. Each year, results are also reported against the NPS-FM (2020).

10.2 Definition of representativeness

For the purpose of this analysis, we define a location as being represented if the community can refer to the results of another nearby site to obtain information that is representative of ambient conditions. This is difficult to achieve using comparisons of land use and topography alone due to the importance of local sources of variability. Therefore, this analysis assumes that for sites to be representative of each other they must be on the same body of water and close enough to prevent environmental processes from significantly changing the ambient conditions. It is also assumed that the FRSL layer provides a census of all swimming sites within the region.

10.3 Methods/Huarahi

The FRSL was used as the best representation of a census of swimming sites within the region. This contains information regarding the following recreational activities: swimming, fishing, kayaking, food gathering, boating, and rafting. However, for the purposes of this report we limit analysis to FRSL sites that are used for swimming as this is the highest risk primary contact activity.

The FRSL layer was intersected with the draft FMU layer to ensure that each FRSL point was attributed to an FMU. The dataset was exported and manipulated in R (2021) using the 'dplyr' package to summarise the number and proportion of total FRSL sites that correspond to each applicable FMU.

The same process was carried out for the 31 current riverine bathing water quality monitoring sites, and 13 lake bathing water quality monitoring sites. Summarised data from the FRSL and current sites were combined and the ratio of the current site proportion to FRSL proportion, providing an index of representativeness.

Existing bathing monitoring sites that were within three kilometres of FRSL sites were assumed to be representative of ambient conditions at FRSL sites. Similar to the cyanobacteria analysis, sites on unconnected branches of the river, separated by headlands, or embayments were not included as being within the zone of representativeness.

E. coli samples were also collected at NERMN river and lake water quality monitoring sites. These sites are only sampled on a monthly basis so are not considered as appropriate for detecting short-term changes in *E. coli* concentrations as weekly samples that are collected at bathing monitoring sites. However, in the absence of any better information monthly *E. coli* measurements provide some indication of the level of contamination and variability seen in certain areas.

10.4 Results and discussion/Ngā Otinga me Matapakitanga

Table 42 provides a summary of FRSL sites that have been identified for each FMU, split into relevant recreational activities. This shows that around 45% of FRSL sites were identified for the purposes of swimming, followed by fishing (18%), boating (17%).

Table 42 A summary of FRSL data for each identified recreational activity, across each FMU.

Type	FMU	Swim	Fish	Kayak	Food	Boating	Rafting	TOTAL
LAKE	Rangitāiki	0	5	0	1	4	0	**10**
LAKE	Rotorua Te Arawa Lakes	33	18	2	0	30	0	**83**
LAKE	Tauranga Moana	1	1	1	0	0	0	**3**
RIVER	East Coast	5	4	2	0	2	2	**15**
RIVER	Kaituna	12	2	8	1	1	5	**29**
RIVER	Rangitāiki	10	3	5	1	2	4	**25**
RIVER	Rotorua Te Arawa Lakes	8	3	0	0	0	0	**11**
RIVER	Tarawera	4	1	0	0	0	0	**5**
RIVER	Tauranga Moana	22	5	8	0	1	0	**36**
RIVER	Waihī-Pongakawa	2	0	0	1	0	0	**3**
RIVER	Waioeka-Otara	5	1	3	0	0	4	**13**
RIVER	Waiōtahe	1	0	0	0	0	0	**1**
RIVER	Whakatāne	8	1	0	0	2	0	**11**
TOTAL		**111**	**44**	**29**	**4**	**42**	**15**	

10.4.1 Representativeness of riverine bathing sites by FMU

River based FRSL sites were split between the Tauranga Moana FMU (24%), Kaituna (19%), and Rangitāiki (17%), with the remainder shared between the other FMUs.

Analysis of current river bathing water quality sites against identified FRSL swimming sites shows that the Kaituna (0.41) and Tarawera (0.62) FMUs are under-represented relative to the distribution of identified sites in the FRSL (Table 43). In contrast, Rotorua Te Arawa Lakes (2.48) and Waioeka-Otara (1.49) were over-represented. All other FMUs were within the 0.7-1.3 bracket of 'ideal representativeness', with the exception of the Waiōtahe FMU which contained no monitoring sites but comprised just over 1% of the total regional reach lengths so was considered adequately represented relative to its regional contribution.

Table 43 Comparison of current riverine bathing water quality monitoring sites and identified FRSL sites, per FMU. Conventions as per Table 15.

FMU	Current Sites	Current Proportion	FRSL Sites	FRSL Proportion	Representativeness
East Coast	2	0.06	5	0.06	0.99
Kaituna	2	0.06	12	0.16	0.41
Rangitāiki	4	0.13	10	0.13	0.99
Rotorua Te Arawa Lakes	8	0.26	8	0.10	2.48
Tarawera	1	0.03	4	0.05	0.62
Tauranga Moana	7	0.23	22	0.29	0.79
Waihī-Pongakawa	1	0.03	2	0.03	1.24
Waioeka-Otara	3	0.10	5	0.06	1.49
Waiōtahe	0	0.00	1	0.01	0.00
Whakatāne	3	0.10	8	0.10	0.93

10.4.2 Representativeness of lake bathing sites by FMU

All lake bathing water quality sites were situated within the Rotorua Te Arawa Lakes FMU, which contained 97% of the identified FRSL sites, and the representativeness index revealed a good representation (1.03) (Table 44). Lake FRSL sites were also identified in Tauranga Moana FMU, located at Lake McLaren. The single FRSL site in Tauranga Moana FMU makes up less than 10% of the total FRSL sites for lakes, thus justifying a lack of monitoring sites.

Table 44 Comparison of current lake bathing water quality monitoring sites and identified FRSL sites, per FMU. Conventions as per Table 15.

FMU	Current Sites	Current Proportion	FRSL Sites	FRSL Proportion	Representativeness
Rotorua Te Arawa Lakes	13	1.00	33	0.97	1.03
Tauranga Moana	0	0.00	1	0.03	0.00

10.4.3 Representativeness of bathing sites by proximity

Thirty nine of the 77 riverine FRSL sites (51%) were located within three kilometres of a bathing water quality site (Table 45). Rotorua Te Arawa Lakes was the only FMU to have complete coverage of FRSL sites by bathing sites, however, three FMUs had 100% coverage when monthly river water quality sites were taken into account (Rotorua Te Arawa Lakes, Waihī-Pongakawa, and East Coast). In comparison, Rangitāiki (60%), Waioeka-Otara (60%), Tauranga Moana (54.5%), and Waihī-Pongakawa (50%) had between 50 and 60% coverage, and Tarawera (25%), Kaituna (25%), and Waiōtahe (0%) had the lowest coverage. Site coverage was improved by 50% (from 25% to 75%) for the Tarawera and Waihī-Pongakawa FMU's when monthly river water quality sites were included. Only the Kaituna and Waiōtahe catchments have less than 50% coverage when all monitoring was taken into account.

Twenty six of the 34 identified lake FRSL sites (76%) were situated within three kilometres of a representative river or lake bathing water quality site (Table 45). Rotorua Te Arawa Lakes FMU was the only FMU to have less than 100% coverage, with gaps present in the centre of Lake Rotoiti around Ngarehu/Motuoha Point (four FRSL sites), in the South-West corner of Lake Rotorua around the Utuhina Stream inflow (Three FRSL sites), at Hot Water Beach on Lake Tarawera (One FRSL site), and Lake Ōkataina (One FRSL site). The single FRSL site identified at Lake McLaren in the Tauranga Moana FMU, was within 3 km of the McLaren Falls bathing monitoring site. However, care should be taken when assuming the falls site is representative of the lake due to the significant bird population in the lake, and the bypassing of the bulk of the lake inflows through the Ruahihi Power Station.

Table 45 FRSL sites that are located within a 3 km buffer of current bathing water quality (Bwater quality) or any site with microbiological monitoring.

Type	FMU	Sites <3 km of Bwater quality	Sites <3 km Any Site	Total Sites Identified	% Bathing Coverage	% Any Coverage
LAKE	Tauranga Moana	1	1	1	100.0	100.0
LAKE	Rotorua Te Arawa Lakes	25	31	33	75.6	93.9
RIVER	Rotorua Te Arawa Lakes	8	8	8	100.0	100.0
RIVER	Rangitāiki	6	6	10	60.0	60.0
RIVER	Waioeka-Otara	3	3	5	60.0	60.0
RIVER	Tauranga Moana	12	14	22	54.5	63.6
RIVER	Waihī-Pongakawa	1	2	2	50.0	100.0
RIVER	East Coast	2	5	5	40.0	100.0
RIVER	Whakatāne	3	5	8	37.5	62.5
RIVER	Tarawera	1	3	4	25.0	75.0
RIVER	Kaituna	3	4	12	25.0	33.3
RIVER	Waiōtahe	0	0	1	0.0	0.0

10.5 Conclusions and recommendations/Ngā whakakapinga me ngā tūtohutanga

The lake water quality bathing programme has appropriate coverage for the distribution of lake bathing sites within the region, which predominantly occur within the Rotorua Te Arawa Lakes FMU. One other lake was identified in the Tauranga Moana FMU but the overall distribution of FRSL sites throughout the region suggests representativeness with no monitoring sites.

Overall, 75.6% of lake sites within the Rotorua Te Arawa Lakes FMU were within 3 km of a bathing monitoring site, which increased to 93.9% when additional monthly monitoring was considered. The Tauranga Moana FRSL site, situated at Lake McLaren, was also within 3 km of the McLaren Falls bathing site, however caution should be assumed when relating these results as the lake is likely to have elevated levels of avian faecal contamination.

The Kaituna and Tarawera FMUs are under-represented by riverine current bathing sites and should be considered for establishment of new monitoring sites. This is mitigated slightly for the Tarawera River by the addition of river water quality sites, but these additional sites are only monitored monthly so and short-term variation will be missed, increasing the risk to the community. Surplus riverine bathing water quality sites could be relocated to these FMU's from the Rotorua Te Arawa Lakes or Waioeka-Otara FMU's which are both currently over-represented.

This and the cyanobacteria analysis, assumes the FRSL includes all bathing sites within the region that are frequented by the community. We know that this is unlikely to be true in its current state, however it would be beneficial to expand the list by incorporating new sites as identified by the community.

Part 11: Groundwater monitoring

11.1 Introduction/ Kupu Whakataki

The objectives of groundwater monitoring can be multiple, in which the information needs of managing the groundwater resource are examined. These might include:

- What are the current attribute state bands, and what are their trends, (and over what timeframes?),
- Provide data for protection of groundwater systems from over-allocation,
- Control of saline water intrusion or up-coning in aquifers,
- Protection of aquifers from contamination by diffuse sources of pollution,
- Meet obligations under NPS-FM, and
- Assess contribution of groundwater on surface waters.

Freshwater monitoring units (FMUs) are the spatial scale in the NPS-FM. The definition of FMUs is intentionally flexible so councils can determine the spatial scale best suited to managing fresh water in the specific circumstances of their region. Unlike surface water, groundwater moves relatively slowly through the rock matrix which can mean changes to the level and quality respond on a slower time scale than surface waters. Hence, representation of groundwater is better achieved at a hydrogeological level, such as using the HGU framework (Fernandes, 2021). Management includes setting values, objectives, limits, and undertaking freshwater accounting and monitoring.

The Natural Environmental Regional Monitoring Network (NERMN) for groundwater has been in operation for over 20 years. Groundwater monitoring has been largely developed on an ad hoc basis with monitoring bores largely utilising existing production bores. Targeted bore installation has been undertaken for over a decade and has slowly built up a dedicating groundwater monitoring network.

The present monitoring network comprises 73 bores; 16 measure water level, 50 measure water level and water quality, seven measure water quality, two springs, six also measure salinity intrusion (Figure 7). A new programme investigating springs across the region, augmenting some previous investigation centred predominantly around the Rotorua area, has also been undertaken. While data collected from this investigation may inform aspects of recharge and catchment areas for springs, as well as contributions and aspects or water quality in surface waters; the programme is investigative it hence it is not appropriate to assess representation at this time.

Groundwater level is monitored continuously for 49 bores, with most other bores levels measured quarterly. Accurate groundwater level representation can be compromised in some bores that are used for commercial purposes (e.g., irrigation), especially for quarterly sampling (10 bores) as a result of pump operation prior to the time of sampling.

Bores tested for water quality are analysed at BOPRC and Hill Laboratories, and the GNS Science Wairakei Analytical Laboratory for 17 water quality indicators (i.e., major ions, nutrients, metals). This allows for characterisation of the quality of Bay of Plenty groundwater resources at the national scale and permits differentiation of natural chemical signatures and changes from those caused by human activity.

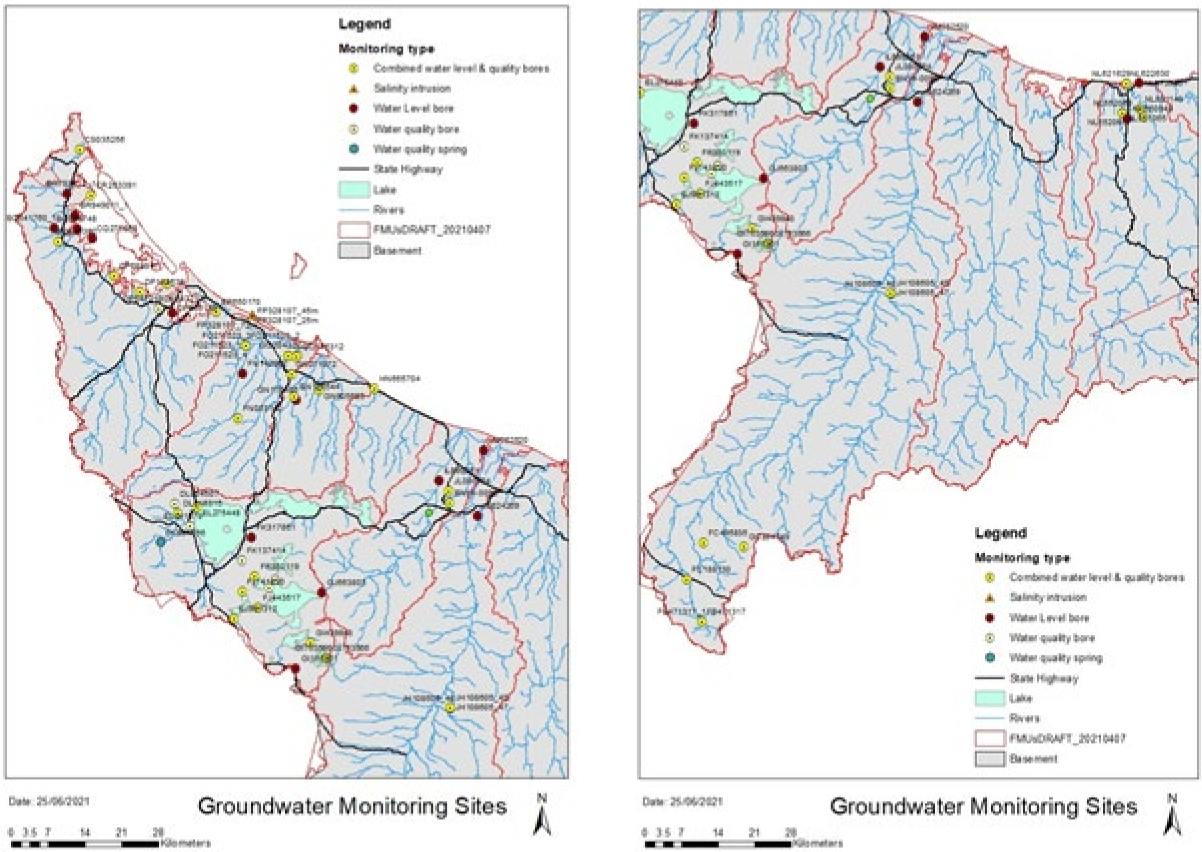


Figure 7 NERMN Bore locations and monitoring type

11.2 Representation at Hydrogeologic Unit and Freshwater Management Spatial Scale

The number of bores used for monitoring in each HGU and by FMU (Table 46) shows that representation of HGUs ranges from good to poor. Of the 57 groundwater bores monitored for water quality the most are in the Rotorua FMU (14 bores), closely followed by Tauranga Moana FMU (12 bores) with most of these being in the shallow superficial sediments and Tauranga Group sediments. Less represented are the Pongakawa and Waitahanui FMUs, with no monitoring occurring in Whakatāne, Ōhiwa, Waiōtahe and East Coast FMUs.

43.8% of monitoring bores are in coastal or upland sedimentary basin HGUs. The shallower coastal ‘lowland sedimentary basin’ HGU has the highest number of monitoring bores with 23 bores, four of these being in the Kaituna FMU, two in the Rangitāiki, nine in the Waioeka-Otara, three of which also monitor saline intrusion. The Upland sedimentary HGU are well represented with the Rotorua HGU having six bores, three in Galatea and one at the top of the Rangitāiki. Waioho and Whakatāne sedimentary basins are not represented. Descriptions of each of the HGU and areal extent are given in Table 47, while maps of individual HGUs and associated bores are shown in Appendix 1.

The Upper Volcanic C HGU is poorly represented with only one bore in a fragmented extent of the HGU south of Rotorua. Greater representation in the Pongakawa and Waitahanui FMUs would be a priority given the high agricultural land use in this area and current allocation pressures. In contrast, Upper Volcanic B is monitored by several bores and land use is mostly forestry.

Bores in the Lower Kaituna and Pongakawa FMUs give the Mamaku HGU reasonable representation at the lower end of the HGU, with two bores south of Rotorua and a water quality bore to the west of Rotorua giving some representation to near the top of the HGU. Kāingaroa Formation to the south predominantly in the Rangitāiki FMU is not represented.

The Upper Volcanic A HGU is made up of undifferentiated Volcanics and rhyolites, found mostly in Rotorua FMU, around Lake Tarawera. It has the smallest extent of any of the HGUs and therefore has a fair representation by a single bore currently.

The Pokai, Chimp and Pokopoko (PCP) are ignimbrite ash formations that have been grouped together. Lying north of Rotorua, through the Kaituna, west Pongakawa, and southern Tauranga FMUs, this HGU is represented by three bores in the Kaituna, west Pongakawa FMUs. One bore also is in the northern extent of this formation in the Tauranga FMU. No representation occurs in the Rotorua FMU or southern Tauranga.

Three bores monitor the Matahīna HGU, one bore in the top of the formation (Rangitāiki FMU) and two nearer the coast on the Rangitāiki Plains (Tarawera FMU). The formation is extensive in the eastern Rotorua FMU, and partially to the west, but has no representation there. Further representation is required given the extent of the unit but should be driven by use.

The Whakamaru HGU deeper rhyolites and undifferentiated volcanics are found through Upper Rangitāiki and Rotorua FMUs. Four bores are located in the Upper Rangitāiki, and three in south-east of the Rotorua FMU. There is a lack of representation in the southern extent of the Rangitāiki and western Rotorua.

Deeper sedimentary lithology of the Pleistocene Sedimentary HGU is prominent near coastal margins from Kaituna to Waioeka-Otara FMUs. Only two bores are located in the western extent of this HGU, in the Kaituna and Pongakawa catchments. Areas to the east are not represented and may need to be considered depending on current and potential use.

The extensive Lower Volcanic B is similar in areal extent to the Whakamaru HGU but extends further to the coast and is present to the north in the Tauranga FMU. The HGU has poor representation with only one bore in the lower Tarawera, but this is largely due to its depth. In contrast Lower Volcanic A is well represented with 8 bores on the coastal region of the Tauranga FMU and one in lower Kaituna. Smaller areas of this HGU to the east are not currently monitored.

The basement HGU is largely made up of greywacke through many areas of the Bay of Plenty, although other material such as the Waipapa (composite) terrane, the Torlesse (composite) terrane, the Coromandel Group, Whitianga Group, or even younger units may also be present. Bores in the northern area of the Tauranga FMU represent this HGU or Aongatete Formation and other Volcanics. Two of these bores measure water quality, and all five have measure level data.

Table 46 *Monitor bore numbers by Hydrogeological Unit (HGU) and by Freshwater Management Unit (FMU), as of June 2021. Bores are a mixture of combined water quality and water level, water level only and water quality only monitor bores. Number in parenthesises are water level only, dark grey shaded areas HGU is not present in FMU, light grey has very minor presence. HGU relative representation is rated green =good, yellow= fair, orange = poor.*

	FMU								
HGU	**Kaituna**	**Waihī-Pongakawa**	**Rangitāiki**	**Rotorua Te Arawa**	**Tarawera**	**Tauranga Moana**	**Waioeka and Otara**	**Waitahanui**	**Total Bores**
Lowland sedimentary basin	6	1	2 (2)			4	9 (2)	1	**23 (4)**
Upland Sedimentary Basin			3	6 (2)					**9 (2)**
Upper Volcanic C				1					**1**
Upper Volcanic B				3	1 (1)				**4 (1)**
Mamaku	1 (1)	2		3					**6 (1)**
Upper Volcanic A				1					**1**
PCP/ Pleistocene Sedimentary		1 (1)							**1 (1)**
PCP/Lower Volcanic A						1 (1)			**1 (1)**
PCP	2								**2**
Matahīna			3 (1)						**3 (1)**
Whakamaru	?		4	3					**6**
Pleistocene Sedimentary	1								**1**
Lower Volcanic B			1						**1**
Lower Volcanic A	1					8 (2)			**9 (2)**
Basement						5 (3)			**5 (3)**
Total Bores	**11 (1)**	**4 (1)**	**13 (3)**	**16 (2)**	**1 (1)**	**18 (6)**	**9 (2)**	**1**	**73**

Table 47 Description of hydrogeological unit (HGU) extent and area where bores are located relative to Freshwater Management Unit (FMU).

HGU	Extent & FMU Location Description	FMU Bore Location Description	Area (km^2)	Bore Nos.
Lowland sedimentary basin	Coastal Sedimentary HGUs comprised of unconfined or semiconfined sedimentary aquifers, located in the low-lying plains. Extensive in Rangitāiki and Tarawera, Kaituna, Pongakawa and Tauranga. Smaller extent to the east.	One bore in Tauranga north, five in Kaituna, one in Waitahanui, nine in Waioeka-Otara (Three salinity).	1208.4	23 (4)
Upland Sedimentary Basin	Predominantly unconfined sedimentary aquifers, comprises five separate HGU with relatively small areal extent.	Rotorua is well represented with five bores, as is Galatea (Rangitāiki) with three bores.	524.8	9 (2)
Upper Volcanic C	Ignimbrite sheet flows of Oruanui Formation and Mangaone Subgroup are south of the Rotoiti Formation, a non-welded ignimbrite, which extends from Lake Rotoiti to the coast.	Only one monitor bore located at top of Rotorua FMU.	1049.6	1
Upper Volcanic B	Made up of the post-caldera rhyolites, undifferentiated pyroclastics, and younger Okataina rhyolites. Found mostly betwe boundary of Rotorua and Tarawera, and west of Lake Rotorua	Three bores located in Rotorua, one bore in Tarawera	422.9	4 (1)
Mamaku/Kāingaroa	Kāingaroa Formation outcrops in the Rangitāiki and Rotorua FMUs, and Mamaku ignimbrite sheets forms a fan north, northwest and southwest of Rotorua, capping the Mamaku–Kaimai Plateau extending to the coast in Kaituna and Pongakawa	Three bores are located in the Rotorua FMU, one in Kaituna and teo in Pongakawa	2339.2	6 (1)
Upper Volcanic A	Made up of undifferentiated Volcanics and rhyolites, found mostly in the Rotorua FMU around Lake Tarawera.	One bore is located in Rotorua FMU	347.1	1
PCP/ Pleistocene Sedimentary	Pokai, Chimp and Pokopoko (PCP) have been grouped together. They are lie in the north of Rotorua, Kaituna, west Pongakawa, and southern Tauranga FMUs, with some lesser extent in north Tauranga	One water level bore sits in the northern Tauranga, with two bores located in Kaituna and one in Pongakawa FMUs.	1724.9	1 (1)
PCP/Lower Volcanic A				1 (1)
PCP				2

HGU	Extent & FMU Location Description	FMU Bore Location Description	Area (km^2)	Bore Nos.
Matahīna	Ignimbrite with four members, distributed around Rotorua and central BoP (Rangitāiki, Tarawera, Waitahanui)	Upper Rangitāiki represented by one bore, and two bores in the lower Tarawera.	2181.0	3 (1)
Whakamaru	Deeper rhyolites and undifferentiated Volcanics found through upper Rangitāiki and Rotorua FMUs	Upper Rangitāiki represented by four bores, and south-east Rotorua represented by three.	3096.7	7
Pleistocene Sedimentary	Deeper sedimentary lithology dominant near coastal margins from Kaituna to Waioeka-Otara FMUs	Kaituna Pongakawa area represented by one bore, other areas to the east not represented	1456.3	1
Lower Volcanic B	Deeper rhyolites and undifferentiated Volcanics prevalent through central Bay of Plenty and coastal north Tauranga	Represented by one bore in lower Tarawera	4363.5	1
Lower Volcanic A	Deeper ignimbrites are spatially dominant in the Tauranga, Kaituna and northern Rotorua FMUs	Spread of bores dominant along the coastal margin at the bottom of the FMU	4811.5	9 (2)
Basement	Regionally extensive	5 bores located in north Tauranga, 2 also in Lower Volcanic A	NA	5 (3)
Total				**73**

11.3 Salinity Intrusion

Saltwater intrusion occurs when saline (salty) water is drawn into a freshwater aquifer. Saltwater intrusion can affect one bore, or multiple bores in an aquifer, contaminating the aquifer making the water unpotable and reducing irrigation potential. While there are natural mechanisms for saltwater intrusion, over pumping of aquifers particularly near the coast is the area of highest risk in the Bay of Plenty.

Detection of saltwater intrusion is usually undertaken by measuring chloride and electrical conductivity of groundwater as proxy for increasing salinity. Bay of Plenty Regional Council has several bores purposely located to detect potential saline increases. In the east three bores are located in the Waioeka-Otara FMU, three in the Tauranga FMU at Pāpāmoa, and one at Ōmokoroa.

There is a lack of representation in the Kaituna, Pongakawa and Rangitāiki/Tarawera FMUs. A project is underway to investigate filling this gap. Investigation will also help develop a risk profile which could inform consent requirements for monitoring for saline intrusion potential and requiring restrictions under certain conditions (e.g., bores containing groundwater with chloride concentration greater than 150 mg/L, specific conductivity greater than 1000 µS/cm may not be allowed to take water in summer season).

11.4 Drinking water

Human health is closely coupled to groundwater through drinking water supply and animal drinking water. Contamination of unconfined and confined aquifers may occur through unsecured bores resulting in contamination of deeper aquifers. Drinking Water Standards for New Zealand have requirements to protect against this contamination.

NZS 4411 broadly sets out the minimum national environmental performance requirements for bores that draw water from any groundwater source. Advice from ministries in response to the Havelock North Inquiry's findings, include the inadequacy of the existing regulatory regime and land-use controls in protecting sources of human drinking-water, so may recommend alternative legislative or regulatory approaches to achieve the desired improvements. This advice will also cover the role of drinking-water suppliers, who have responsibility for contributing to 'first barrier protection' under section 69U of the Health Act[1]. The Ministry for the Environment will be exploring opportunities to improve water quality in drinking-water catchments, which may include controlling increases in the intensity of land use, as part of its wider work programme to restore New Zealand's waterways.

Source protection of groundwater supplies have been examined for major drinking water suppliers (Aqualinc Research Ltd, 2018), but this has not extended to surface water catchments except in the cases of drinking water supplied from surface waters. The Drinking Water National Environmental Standard (NES) Inquiry recommended extending the scope of the regulations, so they apply to land-use activities that pose a risk to drinking water sources, including activities governed by district plans; and requiring regional councils to inform drinking water suppliers and local health authorities of any consent applications with a potential to pose a risk to drinking water sources.

Draft attributes for groundwater are centred around protection of groundwater for drinking water supply and take. While the first line of defence is bore security as per Drinking Water regulations, the draft attributes consider measuring *E.coli* and nitrate-nitrogen to protect drinking water zones (registered drinking water supplies or supply bores), hydrogeological units (HGU) or freshwater management units (FMU), from activities that potentially could introduce contaminants to groundwater used for drinking water.

Sources in shallow, unconfined aquifers less than 10 m below ground level cannot achieve secure status as defined in the Drinking-water Standards for New Zealand (Ministry of Health, 2018), and hence may not be considered in terms of catchment protection. Bore water is considered secure as a drinking water source when it can be demonstrated that contamination by pathogenic organisms in compliance with bore water security criteria 1:

- water younger than one year not being detectable in the aquifer; or
- the lack of significant variability in determinands that are linked to surface effects.

Currently there is no targeted monitoring by Regional Council in terms of potable supplies, although territorial authorities do monitor their supplies as per the Drinking Water Standards. Data on supplies is available along with risk analyses to supplies in some cases. These data would only be an immediate reference to registered potable supplies. BOPRC is looking at undertaking a groundwater vulnerability assessment, which would look at the risk to groundwater based on key physical attributes. Such an assessment will aid in delineating drinking water zones.

Toi Te Ora Public Health currently have records of 20 registered drinking water supply bores in the Bay of Plenty located in confined aquifers and 19 in unconfined (Figure 8). It is unclear how the confining status has been defined. NERMN water quality monitoring bores are located within 2 km of these groundwater supplies. These are: two bores in the Waioeka-Otara FMU (Hedley Bore 1 & 2); two bores in the Rangitāiki FMU (Johnson Road North & South); one on Pongakawa FMU (ESZ 8); one in Waitahanui (WSZ 5); and three in Tauranga FMU (WSZ 5, Athenree Quarry Bores North & South). Although nine of 39 groundwater bores have nearby NERMN monitoring it is unclear if the same aquifer is monitored.

There is potential for NERMN bores near these drinking water supply bores to provide some security criteria 1 drinking water standards data. Water quality data is available, and this could provide some representation in terms of variability, but this would be dependent on which aquifer is monitored. Also, age related data may also be available for some drinking water sources. Other NERMN bores may provide information on the supply catchment groundwater, but this has not been generally an objective of the NERMN. Water quality data is available, and this could provide some representation in terms of variability, but this would be dependent on which aquifer is monitored. Other NERMN bores may provide information on the supply catchment groundwater, but this has not been generally an objective of the NERMN.

Draft groundwater attributes pertaining to drinking water supply of nitrate-nitrogen and *E.coli* may only be recognised in specialised drinking water supply zone or individual bore hole or site. Regionally nitrate-nitrogen is also recognised as the anthropogenically derived attribute to potentially impact drinking water and ecological values of surface waters. Bands have been derived to provide some flexibility in setting objectives for groundwaters to be able to meet community aspirations from commercial land uses to potable water supplies.

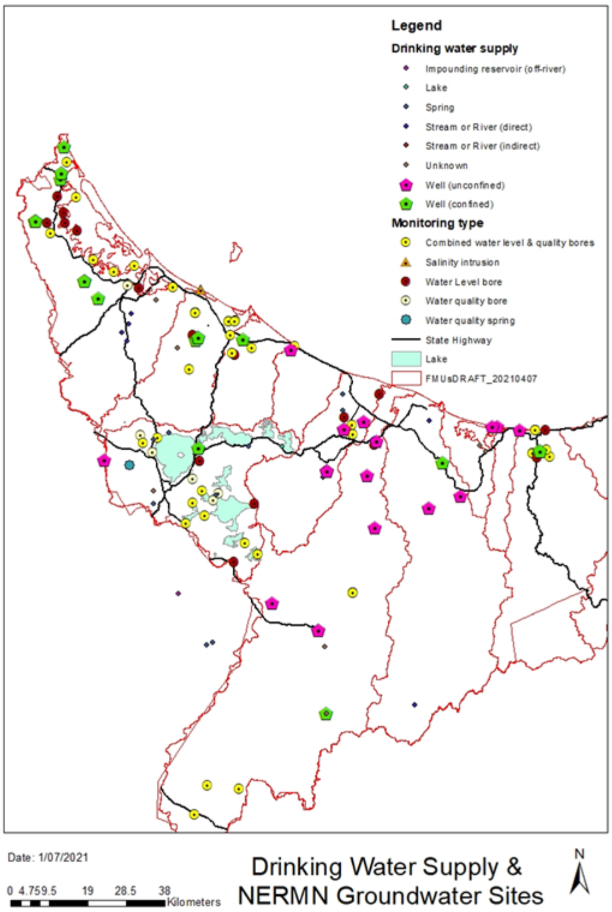


Figure 8 *Toi Te Ora Public Health registered drinking water supplies for populations over 25 (as of April 2021), and NERM groundwater monitoring sites, Bay of Plenty.*

[1] https://www.health.govt.nz/system/files/documents/pages/cabinet-paper-government-response-to-hni-redacted.pdf

11.5 Conclusion and recommendations/Ngā whakakapinga me ngā tūtohutanga

Groundwater quality is represented disproportionally across the region and by HGU and FMU. This is part due to access to the resource, legacy monitoring programmes and as a consequence of the geological conditions.

The eastern BoP (East Coast FMU) is not represented but has only a small groundwater footprint due to the relatively small area of sedimentary material there. Extraction pressures and increased contamination may occur with expanding Kiwifruit industry around the East Coast, so monitoring may be required looking at allocation pressures preferentially over water quality. Other aquifers with shallow groundwater flow systems, that is the lower coastal and upper sedimentary HGUs, are fairly well represented, with the exception of the Pongakawa and Tauranga FMUs. Whakatāne and Ōhiwa upland sedimentary are also not represented.

Most of the lower coastal and upper sedimentary HGUs are under cultivated land with the exception of urban areas. As shallow aquifers are the most vulnerable and responsive to changes in land use activities, a higher level of representation may be required, depending on monitoring objectives.

Upper Volcanic HGUs A, B and C along with Matahīna and Pokai, Chimp and Pokopoko (PCP) ignimbrites and pyroclastic deposits can be unconfined inland and confined to semi-confined towards the coast. These shallower pyroclastic units, ignimbrites sheets and rhyolites underlying sedimentary units and present near the surface of many areas of the central and western of the Bay of Plenty. The hydraulically connected geologic formation, part of a formation, or a group of formations which have distinct groundwater flow and storage have mixed representation from fair to poor. Increased representation across all of these units requires investigation.

Mid Pleistocene sediments are poorly represented. They are generally found 150m below ground level along the coast and are situated below what is predominantly agricultural land use. Similarly, the Lower Volcanic B HGU is poorly represented, in contrast to the well represented Lower Volcanic A HGU. Future representation of these Lower Volcanic HGU units would benefit from a better understanding of where existing bores are targeting these deeper depths. A similar approach might be taken for basement units, but at present there is only a limited extent of these bores due to their greater depth and unknown water bearing capacity.

If nitrate-nitrogen is to be adequately detected, then monitoring of groundwater will need to target under-represented areas. This may not require a specialised BOPRC network but could utilise consented bores.

Bores associated with the detection of saline intrusion are limited to the Tauranga and Waioeka-Otara FMUs and these are being investigated further. The priority is for the Kaituna area.

Of the 39 recognised drinking water bores used for potable supplies, nine are near current BOPRC groundwater monitoring sites. Drinking Water Standards have requirements for monitoring including the proposed draft attributes of nitrate-nitrogen and *E. coli* for potable groundwater supplies. As these attributes are likely to be recognised in drinking water supply zones no other monitoring may be required and representation will be assessed through consenting or territorial authority monitoring. Data collected by the BOPRC groundwater monitoring network could supplement and enhance knowledge around drinking water supplies. A risk assessment to drinking water supplies bores on a regional scale is to be undertaken.

References/Ngā Tohutoro

Abell, J. M., Hamilton, D. P., & Rutherford, J. C. (2013). Quantifying temporal and spatial variations in sediment, nitrogen and phosphorus transport in stream inflows to a large eutrophic lake. Environmental Science: Processes & Impacts 15(6) 1137-1152.

Aqualinc Research Ltd, (2018), Water Source Protection Zones: Delineation methodology and potential impacts of national implementation, Report prepared for the Ministry for the Environment.

Biggs, B., & Kilroy, C. (2000). Stream Periphyton Monitoring Manual. NIWA.

Booker, D., and R. Woods. (2013). Comparing and combining physically-based and empirically-based approaches for estimating the hydrology of ungauged catchments. Journal of Hydrology 508:227-239.

Carter, R., Suren, A. and Scholes, P. (2017). Water Quality and Ecological Attributes for rivers and lakes in the Bay of Plenty. Environmental Publication 2017/06. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Carter, R., A. Suren, J. Dare, P. Scholes, and J. Dodd. (2018). Freshwater in the Bay of Plenty. Comparison against the recommended water quality guidelines. Environmental Publication 2018/10. Bay of Plenty Regional Council, Whakatāne. 88p.

Carter, R. & Scholes, P. 2015 (*unpublished*). Monitoring locations for measuring DO below point sources. Internal memorandum to Rob Donald, dated 13 October 2015. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Carter, R., Donald, R., McBride, C, Franklin, P., Zygadlo, M, Suren, A., Scholes, P., Clapcott, J., Norton, N. (*in prep*). Estimated Current State for river attributes in the Bay of Plenty. Environmental Publication, Bay of Plenty Regional Council, Whakatāne, New Zealand

Clapcott, J. E., R. G. Young, J. S. Harding, C. D. Matthaei, J. M. Quinn, and R. G. Death. (2011). Sediment assessment methods. Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values. Cawthron Institute, Nelson

Clapcott, J.E., (2015). National Rapid Habitat Assessment Protocol Development for Streams and Rivers. Cawthron Institute Report 2649, Cawthron Institute, Nelson, New Zealand.

Clausen, B., and B. J. F. Biggs. (1997). Relationships between benthic biota and hydrological indices in New Zealand streams. Freshwater Biology **38**:327-342.

Dare, J. (2020). Recreational Waters Surveillance Report 2019/20 Bathing Season.

Fernandes, R. (2021). Hydrogeolgical units for the Bay of Plenty: A system for modelling groundwater flow using numerical models. Bay of Plenty Environmental Publication 2021/04.

Gadd, J., R B Williamson, G N Mills, C W Hickey, M Cameron, N Vigar, L Buckthought and J Milne. (2019). Developing Auckland-specific ecosystem health attributes for copper and zinc: summary of work to date and identification of future tasks. Prepared by the National Institute of Water and Atmospheric Research, NIWA and Diffuse Sources Ltd for Auckland Council. Auckland Council discussion paper, DP2019/004

Hamill K. and O. Ausseil (2012): Review of BOPRC Natural Environmental Regional Monitoring Network – freshwater quality. Opus International Consultants

Hoare, R. A. (1982). Nitrogen and phosphorus in the Ngongotahā Stream. New Zealand journal of marine and freshwater research, 16(3-4), 339-349.

James, A. (2008). Ecology of the New Zealand Lamprey (*Geotria australis*). A literature review. 9 Te Tai Hauauru - Whanganui Conservancy Fauna Series (2008)/1. Department of Conservation, Wanganui Conservancy, New Zealand. 28 p.

Joy, M. K., and R. G. Death. (2004). Application of the index of biotic integrity methodology to New Zealand freshwater fish communities. Environmental Management 34:415-428.

Joy, M. K., B. David, and M. Lake. (2013). New Zealand freshwater fish sampling protocols. Part 1. Wadeable rivers and streams., The Ecology Group - Institute of Natural Resources, Massey University, Palmerston North.

Hamill, K., & Ausseil, O. (2012). Review of BOPRC Natural Environment Regional Monitoring Network—Freshwater Quality (No. 2-34137.00). Opus International Consultants.Leathwick, J., D. W. West, P. Gerbeaux, D. Kelly, H. Robertson, D. J. Brown, W. L. Chadderton, and A.-G. Ausseil. (2010). Freshwater ecosystems of New Zealand (FENZ) Geo database. Version 1 - August (2010). User guide. Department of conservation, Wellington.

Lehmann, M. K., Schütt, E. M., Hieronymi, M., Dare, J., Krasemann, H. (2020) Analysis of spatiotemporal variability in satellite-derived chlorophyll a to aid the selection of representative sites for lake water quality monitoring. (Submitted to International Journal of Applied Earth Observations and Geoinformation).

Mahon, L. 2021 (*unpublished*). Prioritising discharge consents for continuous dissolved oxygen monitoring as per NPS-FM (2020). Internal Memorandum to Rochelle Carter, dated 19 March 2021. Bay of Plenty Regional Council, Whakatāne, New Zealand.

MfE. (2003). Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (ME 474). Ministry for the Environment.

Ministry of Health. (2018). Drinking-water Standards for New Zealand (2005) (revised (2018)). Wellington: Ministry of Health.

Pearson, L., Hamilton, D., & Hendy, C. (2011). *Lake Rotokawau: Water quality and sediment study* (CBER Report No. 127; p. 20). University of Waikato.

Snelder T. & Scarsbrook M. (2005). Spatial patterns in state and trends of environmental quality in New Zealand rivers: an analysis for State of Environment reporting. p. 82. Ministry for the environment, Wellington.

Snelder, T., C. Fraser, and A. Suren. (2016). Defining freshwater Management units for the Bay of plenty region: a recommended approach. LWP project (2016) – 001, LandWaterPeople, Lyttleton.

Snelder, T., K. Dey, and A. Suren. (2019). Analysis of habitat factors influencing invertebrate communities in streams of the Bay of Plenty Region. LandWaterPeople Client Report (2018)-14, Lyttelton. 50p.

Stark J.D., Boothroyd I.K.G., Harding J.S., Maxted J.R. & Scarsbrook M.R. (2001) Protocols for sampling macroinvertebrates in wadeable streams., New Zealand Macroinvertebrate Working Group Report No. 1. 57p.

Stoddard, J., Larsen, D., Hawkins, C., Johnson, R., Norris R. (2006) Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological applications 16(4):1267-76

Suren, A. M. (2013). Review of Bay of Plenty NERMN Stream Bio-monitoring Programme. Environmental Publication (2013)/04. Bay of Plenty Regional Council, Whakatāne. 66p

Suren, A.M., Carter, R (2016). Development of a periphyton monitoring programme within the Bay of Plenty. Environmental Publication (2016)/08. Bay of Plenty Regional Council, Whakatāne. 48p

Suren, A. M. (2016). Development of a Fish Index of Biotic Integrity for the Bay of Plenty. Environmental Publication (2016)/11. Bay of Plenty Regional Council, Whakatāne. 23p

Suren, A. M., and S. Elliot. (2004). Effects of urbanisation on streams. Page 764 *in* J. S. Harding, M. P. Mosley, C. P. Pearson, and B. K. Sorrell, editors. Freshwaters of New Zealand. New Zealand hydrological Society Inc and New Zealand Limnological Society Inc., Christchurch.

Suren, A. M., D. Van Nistelrooy, and V. Fergusson. (2017). State and trends in river health (1992 – (2014)) in the Bay of Plenty: results from 22 years of the NERMN stream and biomonitoring programs. Environmental publication (2017)/01, Bay of Plenty Regional Council, Whakatāne.

R Core Team. (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing

Ruddick, K.G. *et al.,* (2019). A Review of Protocols for Fiducial Reference Measurements of Water-Leaving Radiance for Validation of Satellite Remote-Sensing Data over Water. *Remote Sens.* (2019), *11*(19), 2198; https://doi.org/10.3390/rs11192198

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. I. Morgan. (2005). The urban stream's syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society **24**:706-723.

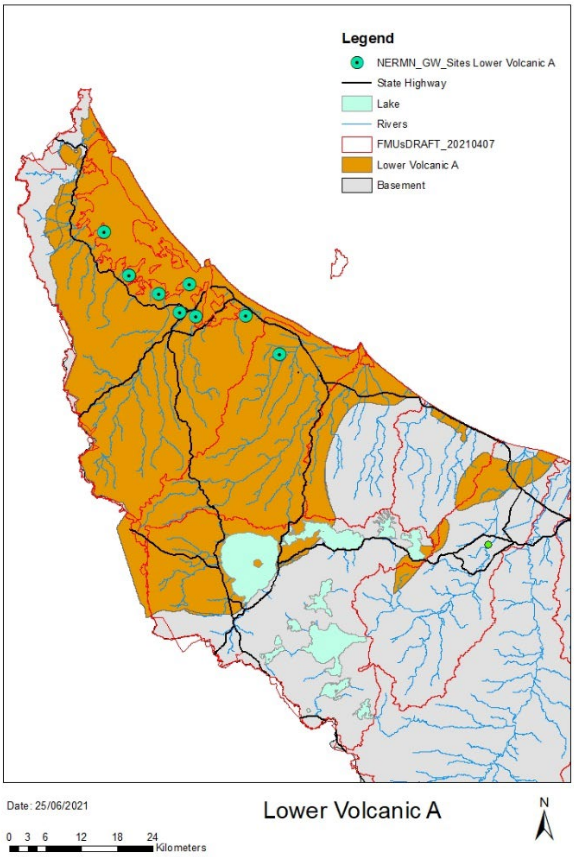
Wickham, H., François. R, Henry, L and Müller, K. 2021. dplyr: A Grammar of Data Manipulation. R package version 1.0.6. https://CRAN.R-project.org/package=dplyr

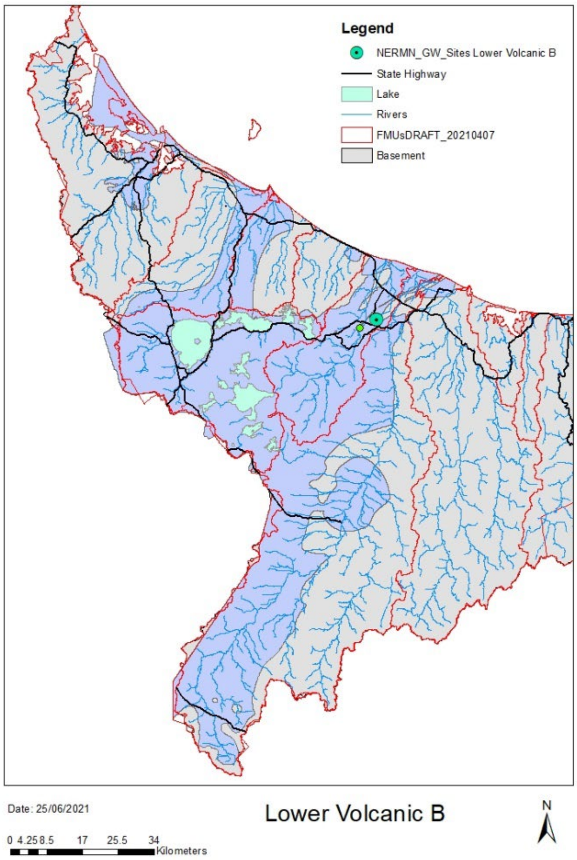
Wood, S., Briggs, L., Sprosen, J., Bloxham, M., Ruck, J., Wear, B (2004) Microcystins in Lakes Rotoiti and Rotoehu. A report on microcystin levels in water, trout and freshwater mussels in Lakes Rotoiti and Rotoehu during (2003)/4. 68p.

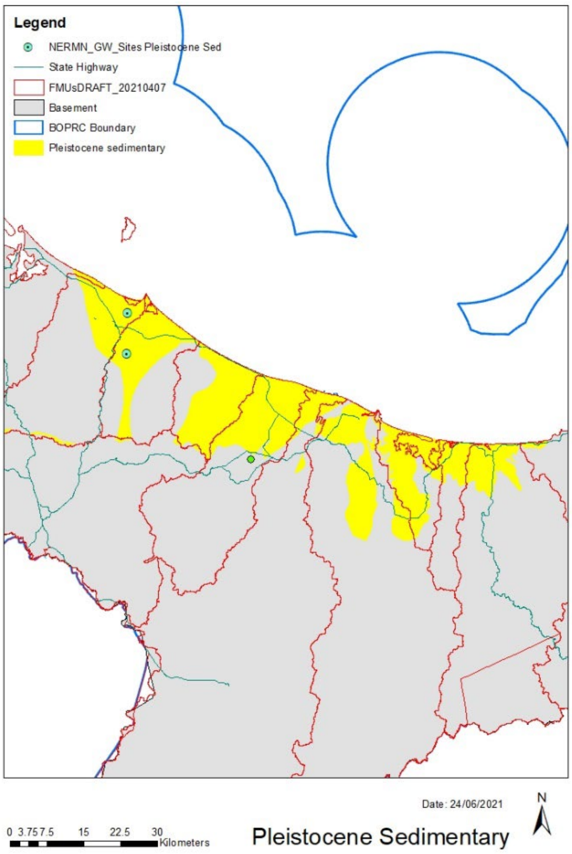
Yates, A.G., Bailey, R.C. (2010). Selecting objectively defined reference sites for stream bioassessment programs. *Environmental Monitoring and Assessment* **170,**129–140. https://doi.org/10.1007/s10661-009-1221-1

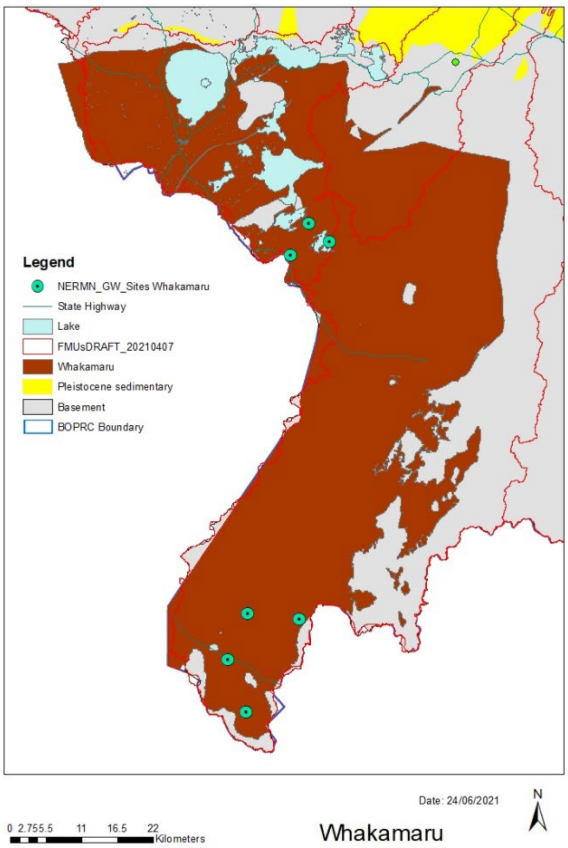
Appendices/Ngā Āpitihanga

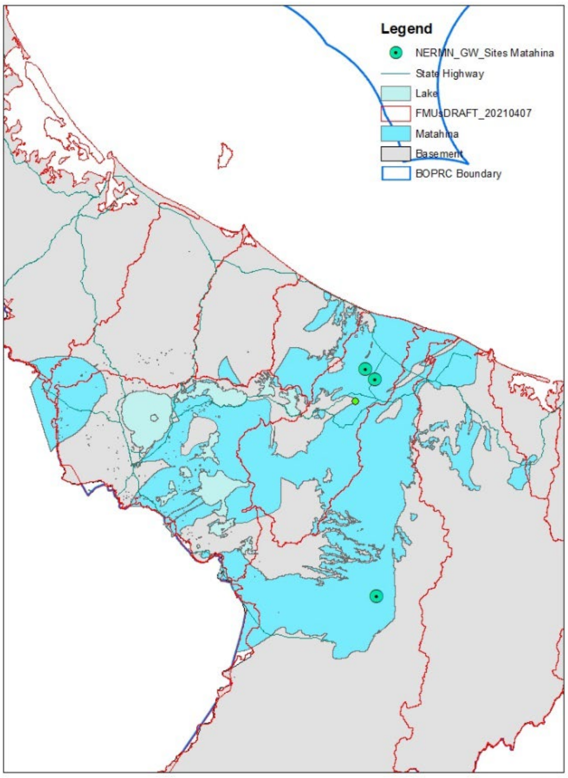
Appendix 1/Āpitihanga 1: Bore locations relative to Hydrogeological Unit (HGU) and FMU


Legend
NERMN_GW_Sites Lower Volcanic A
State Highway
Lake
Rivers
FMUsDRAFT_20210407
Lower Volcanic A
Basement
Date: 25/06/2021
Lower Volcanic A
0 3 6 12 18 24
Kilometers
N


Legend
NERMN_GW_Sites Lower Volcanic B
State Highway
Lake
Rivers
FMUsDRAFT_20210407
Basement
Date: 25/06/2021
Lower Volcanic B
0 4.25 8.5 17 25.5 34
Kilometers
N


Legend
NERMN_GW_Sites Pleistocene Sed
State Highway
FMUsDRAFT_20210407
Basement
BOPRC Boundary
Pleistocene sedimentary
Date: 24/06/2021
Pleistocene Sedimentary
0 3.75 7.5 15 22.5 30
Kilometers
N

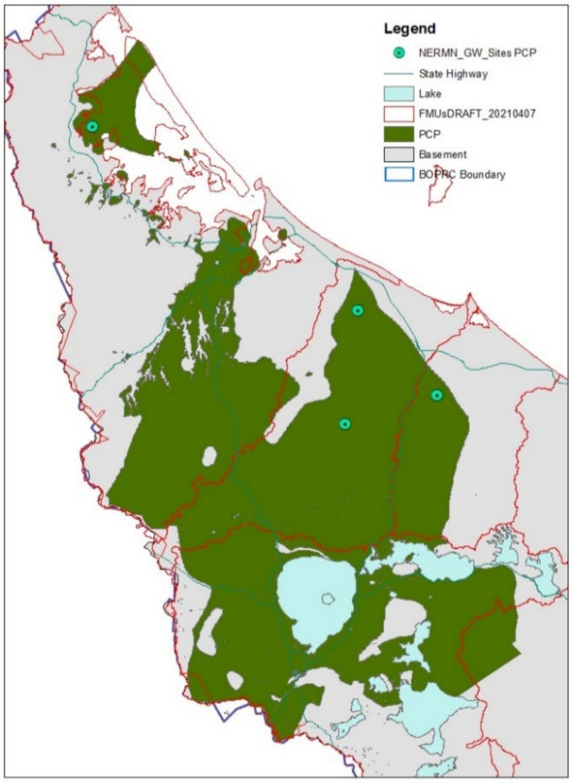

Legend
NERMN_GW_Sites Whakamaru
State Highway
Lake
FMUsDRAFT_20210407
Whakamaru
Pleistocene sedimentary
Basement
BOPRC Boundary
Date: 24/06/2021
Whakamaru
0 2.75 5.5 11 16.5 22
Kilometers
N



Date: 24/06/2021

Matahina

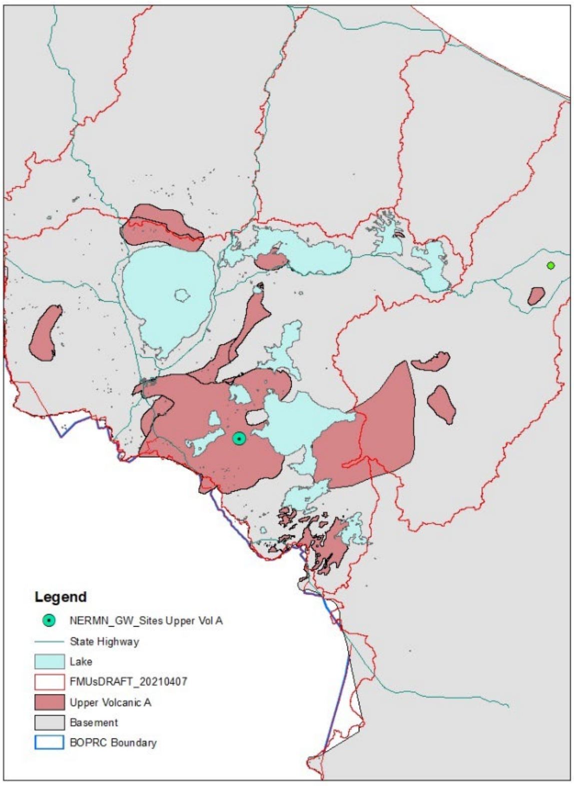
0 3.25 6.5 13 19.5 26 Kilometers



Date: 24/06/2021

Pokai, Chimp, Pokopoko (PCP)

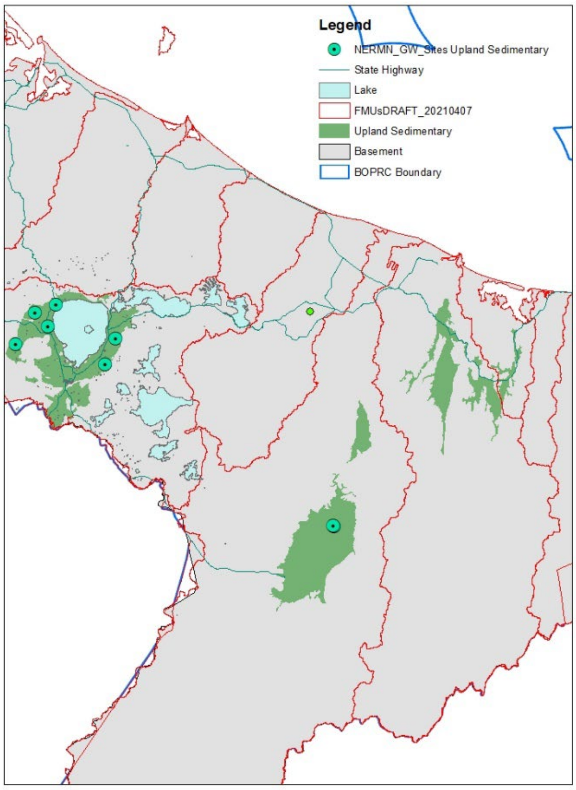
0 2 4 8 12 16 Kilometers



Date: 24/06/2021

Upper Volcanic A

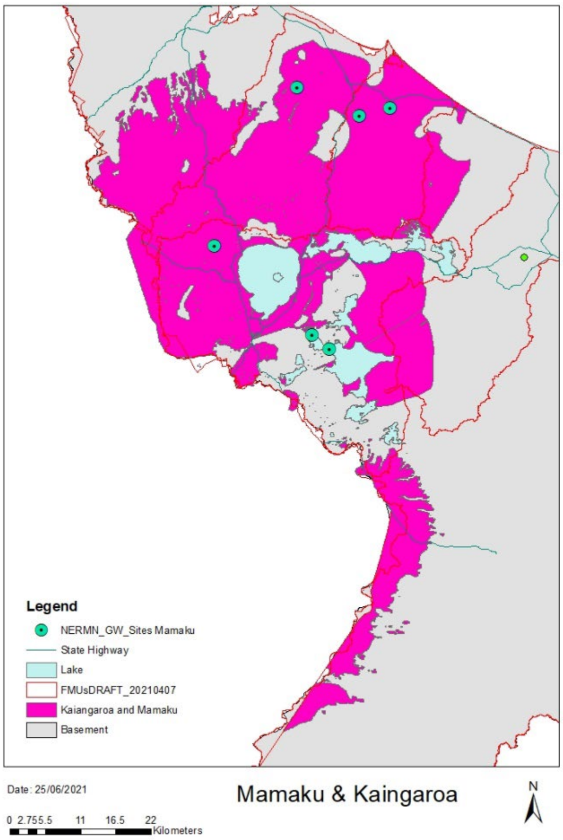
0 1.75 3.5 7 10.5 14 Kilometers

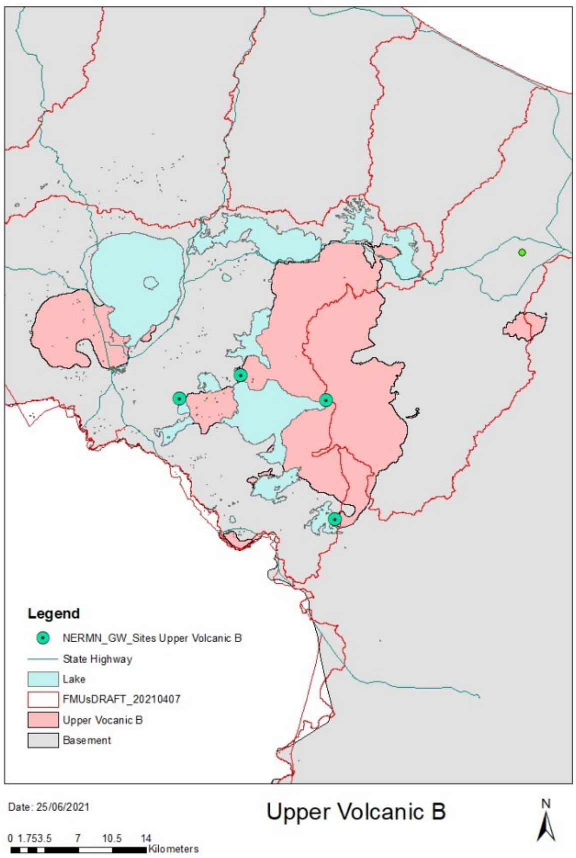


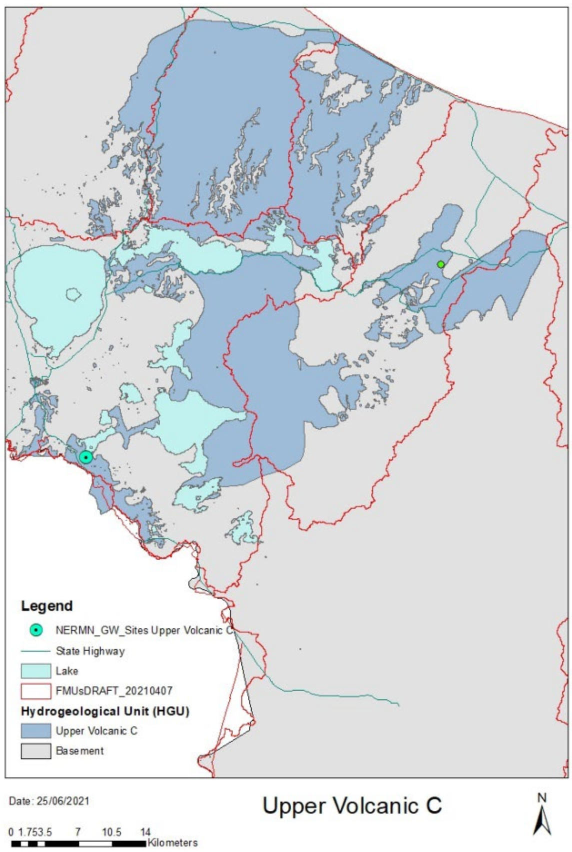
Date: 24/06/2021

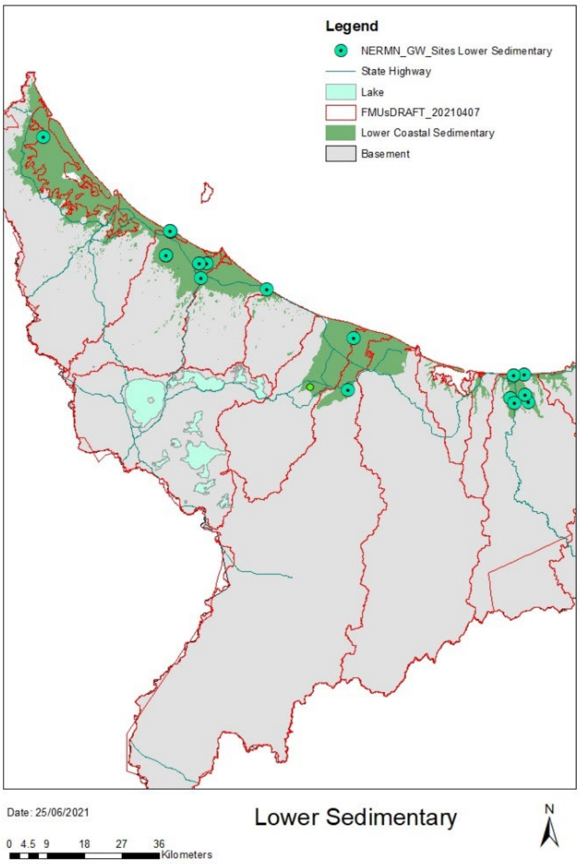
Upland Sedimentary

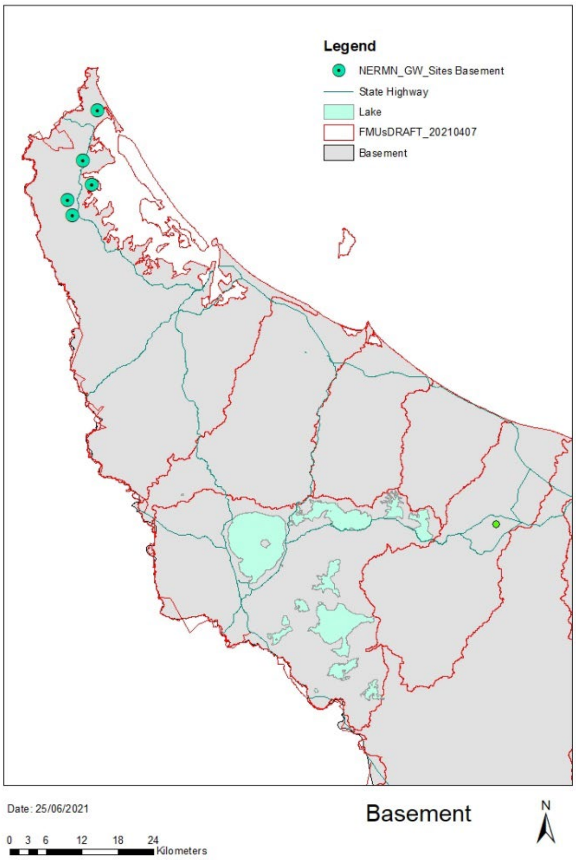
0 3 6 12 18 24 Kilometers


Legend
NERMN_GW_Sites Mamaku
State Highway
Lake
FMUsDRAFT_20210407
Kaiangaroa and Mamaku
Basement
Date: 25/06/2021
Mamaku & Kaingaroa
N
0 2.755.5 11 16.5 22
Kilometers


Legend
NERMN_GW_Sites Upper Volcanic B
State Highway
Lake
FMUsDRAFT_20210407
Upper Vocanic B
Basement
Date: 25/06/2021
Upper Volcanic B
N
0 1.753.5 7 10.5 14
Kilometers


Legend
NERMN_GW_Sites Upper Volcanic C
State Highway
Lake
FMUsDRAFT_20210407
Hydrogeological Unit (HGU)
Upper Volcanic C
Basement
Date: 25/06/2021
Upper Volcanic C
N
0 1.753.5 7 10.5 14
Kilometers


Legend
NERMN_GW_Sites Lower Sedimentary
State Highway
Lake
FMUsDRAFT_20210407
Lower Coastal Sedimentary
Basement
Date: 25/06/2021
Lower Sedimentary
N
0 4.5 9 18 27 36
Kilometers


Legend
NERMN_GW_Sites Basement
State Highway
Lake
FMUsDRAFT_20210407
Basement
Date: 25/06/2021
Basement
N
0 3 6 12 18 24
Kilometers