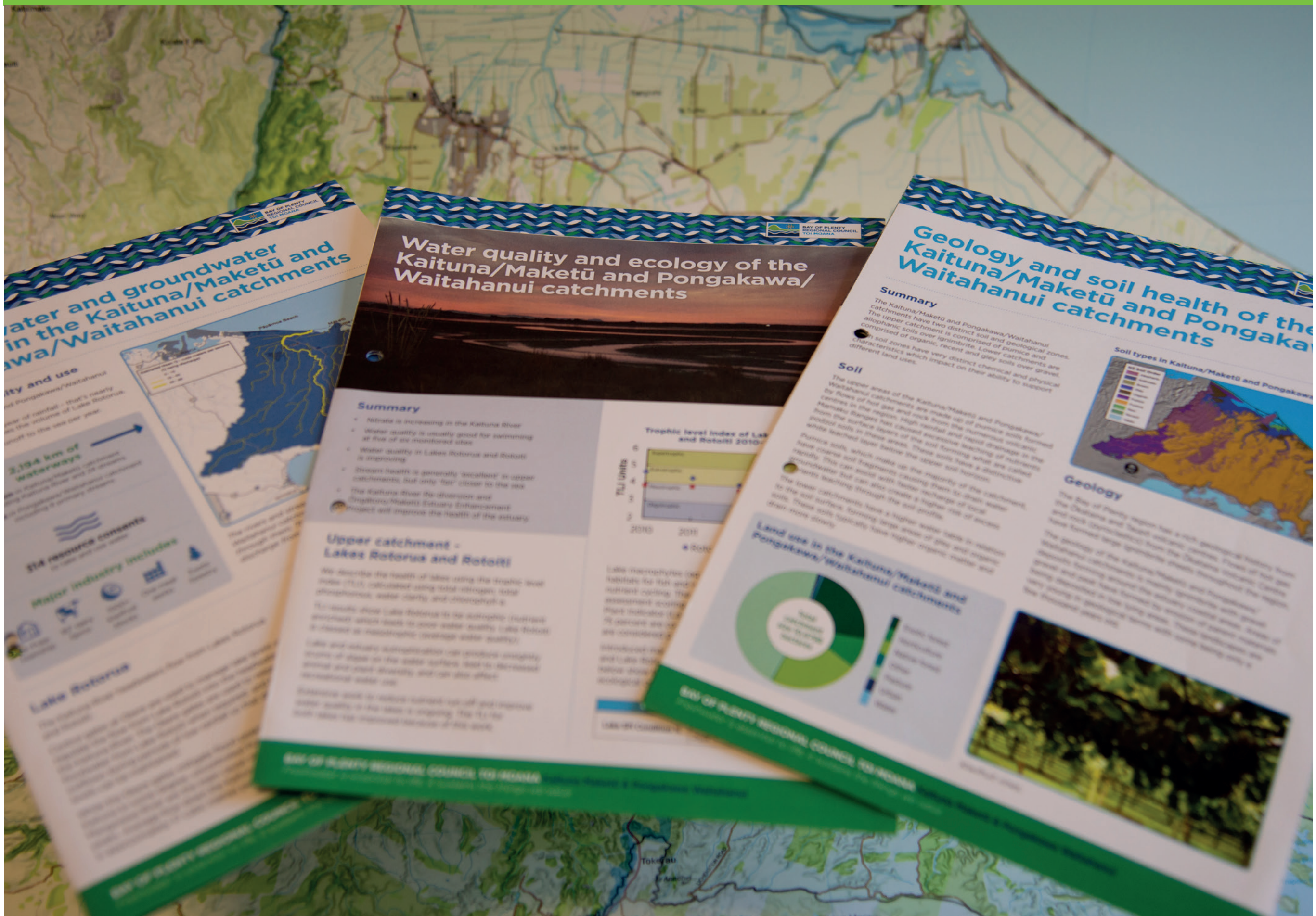
Kaituna-Maketū and Pongakawa-Waitahanui Water Management Area:
Current State and Gap Analysis



Bay of Plenty Regional Council
Environmental Publication 2016/01

5 Quay Street
PO Box 364
Whakatāne 3158
NEW ZEALAND

ISSN: 1175-9372 (Print)
ISSN: 1179-9471 (Online)

BAY OF PLENTY REGIONAL COUNCIL TOI MOANA

Kaituna-Maketū and Pongakawa-Waitahanui Water Management Area: Current State and Gap Analysis

Environmental Publication 2016/01
ISSN: 1175-9372 (Print)
ISSN: 1179-9471 (Online)

March 2015

Bay of Plenty Regional Council
5 Quay Street
PO Box 364
Whakatāne 3158
NEW ZEALAND

Prepared by Alastair Suren (Freshwater Ecologist), Stephen Park (Marine Ecologist), Rochelle Carter (Water Quality Scientist), Raoul Fernandes (Hydrologist), Marcus Bloor (Soil Scientist), Janine Barber (Senior Groundwater Scientist) and Shay Dean (Wetland Ecologist)

Document status

Rev No.	Reviewer	Approved for Issue	
1	Paul Scholes	Rob Donald	8 March 2016
2	Rob Donald		
3	Ned Norton/ Ton Snelder (Land Water People)		
4	Rob Donald		

Acknowledgements

Thanks to Paul Scholes and Rob Donald for review comments, and to Toni Briggs and Vanessa Baker who originally highlighted the need for such a Gap Analysis. This report was reviewed by Ned Norton and Ton Snelder (Land Water People), and we thank them also for their many comments.

Executive summary

1 The National Policy Statement for Freshwater Management 2014 (NPS-FW) directs Council to manage fresh water in an integrated and sustainable way, within water quality and quantity limits. Limits relate to the values and objectives for which a water body, or part of a water body, is being managed.

2 The Bay of Plenty Regional Council (BOPRC) needs to provide information on the current state of waterways in the region, as well as information on the pressures responsible for this current state. It is expected that the Council will work with communities to establish freshwater objectives (i.e. desired states) for water quantity and water quality throughout the region, and set limits on resource use which allow those objectives to be met.

3 BOPRC is implementing the NPS-FW progressively by working in priority catchments (called Water Management Areas) first, of which the Kaituna-Maketū and Pongakawa-Waitahanui WMA (hereafter referred to as the Kaituna WMA) is one. This report provides a summary stocktake of all science work conducted in the Kaituna WMA, firstly to identify our current state of knowledge, and secondly to identify what knowledge gaps are apparent. The report has the following aims:

   (a) to describe the spatial extent of different waterway types throughout the Kaituna WMA when classified according to the River Environment Classification (REC),

   (b) to summarise the current surface water quality and quantity, and ecological monitoring programmes occurring in the Kaituna WMA, and to assess whether these represent the necessary different water body types,

   (c) to summarise the land use and soil health, and groundwater monitoring programmes occurring in the Kaituna WMA,

   (d) to summarise the current state of the wetland and estuary monitoring occurring in the Kaituna WMA,

   (e) to identify gaps in monitoring programmes and strengthen linkages between monitoring programmes in the Kaituna WMA, and

   (f) to make recommendations for future work to be undertaken to help fill the identified knowledge gaps.

   Note that full technical reports on science and information supporting any plan changes that are considered necessary, including what is and is not known about current state and trends, will be prepared at a later date.

   Major science work programmes conducted in the Kaituna WMA, include physically-based monitoring programmes (soil, hydrology and groundwater), water quality monitoring, river ecology monitoring (mainly invertebrates and fish and some limited algal monitoring), and monitoring of wetlands and estuaries. Each of these science programmes was examined and reviewed with the aim of summarising their current condition, identifying gaps, and making recommendations. Information summarising the current condition came from a number of sources including the BOPRC library, the Natural Environment Regional Monitoring Network (NERMN) Programme, consent and compliance monitoring investigations (where easily accessible), and other studies that have been undertaken throughout the Kaituna WMA.

4 This review of current state allowed the identification of knowledge gaps in the different monitoring programmes, which led to a number of recommendations being made. All recommendations were subsequently assigned to one of six themes:

(a) Spatial frameworks

(b) Obtain new data

(c) Improvements to methods and reporting

(d) Identify values

(e) Data for models

(f) Data management

As some of the recommendations in this report are compiled from existing reports, each recommendation has been given a 'Status' to indicate whether the recommendation is 'New', 'Already Underway', or 'Planned and Resourced'. Some recommendations (e.g. periphyton monitoring) were identified in previous reviews and have been allocated resources, and some are currently being implemented. These existing recommendations have been included in this report for completeness.

5 The importance of creating a consistent and relevant spatial framework for implementation of the NPS-FW was identified across all science work programmes. It is considered impractical to describe the current environmental state, identify freshwater objectives, and set and implement numerical limits for water quality and quantity at the WMA level. There is simply too much natural variability between waterways in each WMA for this process to be workable. In recognition of this, the NPS-FW requires councils to create Freshwater Management Units (FMUs) that need to consider the importance of both stream hydrology and catchment conditions – both of which influence water quality and ecology. A key requirement of FMUs is, therefore, to group streams according to overarching environmental factors that constrain ecological and water quality conditions. These groups form part of a spatial classification of waterways, which will be used to identify their current ecological state, while ensuring that such comparisons are not compounded by natural differences between streams caused by climate, flow regime or geology. BOPRC thus needs to investigate which spatial frameworks are most appropriate.

6 All of the science programmes examined identified the need to obtain new data from within the Kaituna WMA. This reflects the fact that the NPS-FM has placed greater requirements that were not previously known or foreseen. Thus, many of the current monitoring programmes were set up to fulfil their own aims and purposes, and made efficient use of the limited resources available for monitoring. This has, however, left unintended consequences with a lack of monitoring from other areas that have now been identified as knowledge gaps, from the perspective of implementing the NPS-FM requirements. For example, water quality and ecological monitoring is under-represented in hill-fed rivers flowing through catchments dominated by exotic plantation forestry, or native vegetation in the Kaituna WMA, and the soil monitoring programme is under-represented in catchments dominated by dairy farming and kiwifruit growing. Other science gaps reflect a lack of information in emerging fields such as the interactions between ground and surface waters. Of all the themes identified in the recommendations, obtaining new data is likely to have the greatest cost implications.

7 The setting of water quality and quantity limits is central to the implementation of the NPS-FW. Limits are defined as "*the maximum amount of resource use available, which allows a freshwater objective to be met*". Limits are thus needed for the amount of water that can be abstracted from a specific waterway without compromising its values, or need to be established as a maximum load of contaminants (e.g., bacteria or nutrients) that a catchment can accommodate without compromising values such as the need to maintain swimmable water, or the need to keep periphyton (slime) to levels below specific bands that are deemed unacceptable to the community. When considering limits, it is likely that computer models will be needed to examine relationships between, for example, land use and nutrient inputs into both surface and groundwater, and between water quantity in groundwater and surface waters. Such models would link key processes associated with the effects of land use intensification, and would provide important feedback to the community and BOPRC as to the physical, chemical and biological implications of various land use scenarios. Scenario testing is particularly important as it allows the social and economic consequences of different objectives to be examined transparently. Model development and testing are critical to such scenario testing, and is thus recommended for many science work programmes.

8 While not specifically a knowledge gap for the Kaituna WMA, the importance of good data management has been highlighted by this review. The lack of a centralised data repository for all water quality and ecological sampling has been identified, along with the difficulty of obtaining data from both the Council's NERMN programme, and from the numerous compliance or consent investigations that have been undertaken. Although centralised databases for some work programmes have been created (e.g. the use of Aquarius for all flow data, and the development of individual databases for invertebrate and fish data), future implementation of work programmes as part of the NPS-FW will greatly benefit from more streamlined database processes that maximise both discoverability and accessibility of data.

9 In conclusion, while this review shows that BOPRC monitors a wide range of parameters in the Kaituna WMA, it is apparent that there are many gaps in the current monitoring programmes. The challenge is how to best fill these gaps given the reality of constrained resources and time. The next step is to prioritise and rank these knowledge gaps so that the needs of the NPS-FW implementation process are met. In undertaking such a ranking process, it is important to consider a number of key issues, including that:

- monitoring needs to examine more than just the current compulsory national attributes,
- monitoring needs to be representative of the range of land uses,
- monitoring design needs to be aware of the often strong links (connectivity) between groundwater and surface water in streams, rivers, lakes and estuaries,
- there is a need for better integration of different science programmes, and
- there is a need to consider the data and information needed to support computer models.

10 By considering these issues as part of the gap analysis and prioritisation process, it is expected that more informed decisions can be made about gaps which need to be addressed as a matter of urgency and those which can be regarded as optional.

Contents

Part 1: Overview

1.1 Purpose of this report

This report provides an overview of the current state of land and freshwater natural resources in the Kaituna-Maketū and Pongakawa Water Management Area (hereafter referred to as the Kaituna WMA) and identifies gaps in our scientific knowledge. This information is needed to support implementation of the National Policy Statement for Freshwater Management 2014 (the NPS-FW).

The report covers the ecological, hydrological, water quality, land and soil, and groundwater characteristics of the Kaituna WMA. While this work was restricted to the science areas listed above, Part 13 of this report outlines other considerations that were beyond the current scope of this report.

The report has the following aims:

(a) to describe the spatial extent of different waterway types throughout the Kaituna WMA when classified, according to the River Environment Classification (REC),

(b) to summarise the current surface water quality and quantity, and ecological monitoring programmes occurring in the Kaituna WMA, and to assess whether these effectively represent all of the different water body types,

(c) to summarise the land use and soil health, and groundwater monitoring programmes occurring in the Kaituna WMA,

(d) to summarise the current state of the wetland and estuary monitoring occurring in the Kaituna WMA,

(e) to identify gaps in monitoring programmes and strengthen linkages between monitoring programmes in the Kaituna WMA,

(f) to make recommendations for future work to be undertaken to help fill the identified knowledge gaps.

Note that full technical reports on science and information supporting any plan changes that are considered necessary, including what is and is not known about current state and trends, will be prepared at a later date.

1.2 The NPS for Freshwater Management

The National Policy Statement for Freshwater Management 2014 (NPS-FW) directs councils to manage fresh water in an integrated and sustainable way, within water quality and quantity limits. Limits relate to the values and objectives for which a water body, or part of a water body, is being managed. Of particular relevance to this report, the NPS-FW includes requirements to:

1 implement a National Objectives Framework for establishing freshwater objectives, which includes:

    (a) consideration of the current state of freshwater management units,

    (b) assigning a current state for specified national attributes and other attributes that Council considers appropriate (for compulsory and other appropriate values),

2 establish environmental flows and levels,

3 establish a monitoring plan to monitor progress towards, and achievement of, freshwater objectives, and

4 establish an accounting system for freshwater quality and quantity, including making required accounting available to the public.

These requirements are to be applied at a Freshwater Management Unit (FMU) scale. At the time this report was prepared BOPRC had already decided to divide the region into 9 Water Management Areas (WMAs), and to implement the NPS-FW in stages across 2-3 WMAs at a time, starting with the Rangitāiki WMA and the Kaituna WMA (see Figure 1). However, BOPRC had not identified FMUs, or values and attributes in addition to the compulsory national attributes set in the NPS-FW. These will all be the subject of separate reports. Hence this current state and gap analysis is an initial collation of what we know and monitor with a particular focus on deficiencies in our monitoring and data and recommendations for addressing these.

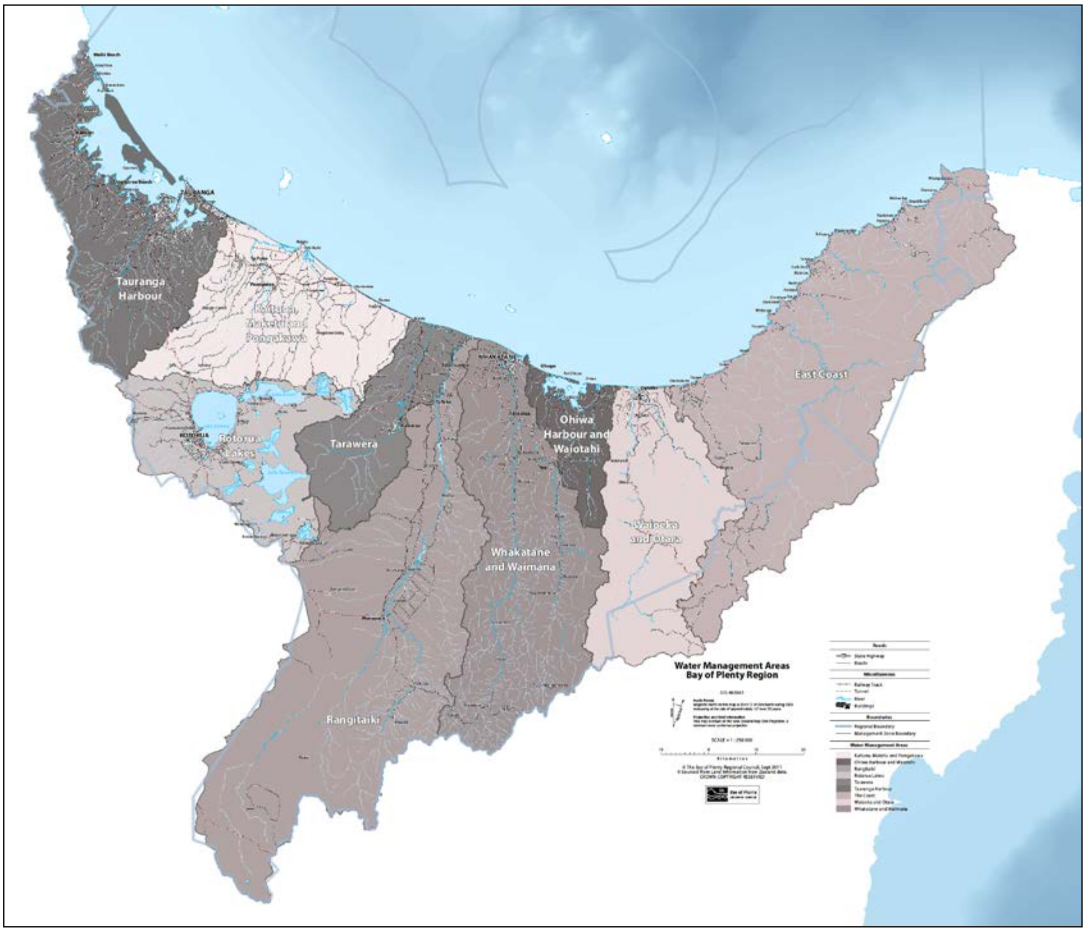


Figure 1 Map of the nine Water Management Areas in the Bay of Plenty region.

The NPS-FW sets national bottom lines for two compulsory values: ecosystem health and human health for recreation. It also currently specifies the following attributes to support the compulsory values and these define the National Objectives Framework (NOF):

- algae (periphyton) – lakes and rivers
- total nitrogen and total phosphorus - lakes
- nitrate (for toxicity) – rivers
- ammonia (toxicity) – lakes and rivers
- dissolved oxygen (below point source discharges) - rivers
- Escherichia coli (E. coli) – lakes and rivers
- Cyanobacteria – Planktonic – lakes and lake fed rivers.

Four discrete state bands (A, B, C, and D) have been identified for each of these attributes, with the bottom of C band representing 'national bottom lines'. Where waterways are below these bottom lines, they will need to be improved to at least the national bottom line over time.

Note that while this report specifically focusses on current state and trend information and monitoring for these compulsory national attributes, some additional parameters are also discussed (e.g. invertebrates). Further work will need to be carried out on identifying appropriate additional attributes to support values within the WMA and identifying current state and gaps for these.

The NPS-FW also requires council to establish environmental flows and levels to give effect to objectives set, and to amend regional plans to provide for the efficient allocation of fresh water to activities within the limits set to give effect to these. This current state report therefore also summarises the state of data we hold relating to surface and groundwater hydrology.

1.3 Review process

This review is based on an extensive literature review of all reports assembled on the Kaituna WMA from the BOPRC library, access to the current (NERMN) monitoring network data, as well as some external data sources. It also makes use of the River Environment Classification (REC) to give a spatial context to the previous studies.

Regional monitoring conducted by BOPRC as part of its NERMN programme is summarised in the report, as well as monitoring conducted by other organisations as part of either consent or compliance monitoring, where this was readily available. Based on these summaries, a number of knowledge gaps have been identified. Consequently, recommendations have been made to fill these knowledge gaps within the Kaituna WMA.

The NERMN programme was recently reviewed by Donald (2014), where a number of high-level recommendations were made. Such recommendations included expanding the number of monitoring sites to include areas currently under-represented in the monitoring programme (e.g., sampling in hill-country streams, streams dominated by non-volcanic geology, or streams draining catchments dominated by exotic or native forest), as well as alterations to sampling methodologies (e.g., increasing water quality sampling to monthly at all sites). Many of these recommendations are also applicable to monitoring within the Kaituna WMA. However, the intent of this report is to refine these more general recommendations of the regionally based NERMN Programme, to more specific recommendations based on the Kaituna WMA and knowledge gaps identified there.

Following the identification of recommendations within each science work stream, a prioritisation and ranking process will be required so that the most important recommendations that address knowledge gaps are implemented. For ease of prioritising, all recommendations were assigned to one of six themes:

(a) Spatial frameworks

(b) Obtain new data

(c) Improvements to methods and reporting

(d) Identify values

(e) Data for models

(f) Data management.

Implementation of selected recommendations will help ensure that any future monitoring work is conducted to fulfil the aims of both the NERMN programme, and Government policy such as the NPS-FW.

It should be noted that this summary has focussed only on chemical, biological and physical measures of waterway attributes as assessed using western scientific methods. It does not include other assessments of stream values associated with cultural values (and in particular those of iwi), recreational, landscape or economic values. All monitoring outlined in this report is based on western science and does not directly consider tangata whenua values and interests. However, we acknowledge that there needs to be opportunities for cultural health monitoring (or other appropriate measures of mauri) and inclusion of this information will greatly broaden our spectrum when helping communities to define the current state of a waterway, and assess its values. Due consideration should thus be given to these other values as part of implementation of the NPS-FW throughout the region.

1.4 Report structure

This report is written in 14 Parts and has been structured in a logical order that follows the hydrological cycle:

- **Part 1** explains the rationale behind the report and its links to the NPS-FW.
- **Part 2** explains the need to develop spatial classification of waterways.
- **Part 3** describes geology, land use and soils.
- **Parts 4 and 5** describe stream hydrology and groundwater.
- **Part 6** describes the water quality of rivers and streams.

- **Parts 7, 8, 9 and 10** describe freshwater ecology (periphyton, cyanobacteria, macroinvertebrates and fish).
- **Part 11** describes wetlands.
- **Part 12** describes estuaries.

The report concludes in **Parts 13 and 14** with other consideration and a summary of the recommendations that are provided throughout the report.

Part 2: Spatial classification

2.1 Introduction

Although BOPRC has decided to implement the NPS-FW in nine WMAs, it is important to emphasise that the actual limit setting process and community discussion on setting appropriate bands for the different compulsory national attributes needs to be made at spatial scales different to that of a WMA. Many of the attributes measured under the NOF vary in response to environmental factors such as climate, source of flow (where water comes from, e.g. lake fed streams or hill fed streams), geology and land use. These factors impose natural constraints on a waterway's inherent character, and therefore on the overall NOF banding of a river. For example, algal biomass is a product of both a stream's nutrient regime, and its flow regime. Thus algal biomass is unlikely to be high in a stream with high nutrients and a high flood frequency, but could conceivably be high in a stream with lower nutrients but a lower flood frequency.

Because of this, it is necessary for BOPRC to group streams according to overarching environmental factors that ultimately constrain ecological and water quality conditions. It is likely that these groups would form part of a spatial classification of waterways throughout the region which will be used to help set limits and identify desired states. These groups are equivalent to the Freshwater Management Units (FMUs) referred to in the NPS-FW. Once FMUs have been created, we can more accurately describe the current state of streams in each FMU.

2.2 Spatial frameworks considered

A number of spatial classifications already exist, including the River Environment Classification (REC), and the Freshwater Environments of New Zealand (FENZ). The REC was developed by NIWA for MfE to provide a spatial framework for regional (or larger) scale environmental monitoring and reporting, environmental assessment and management (Snelder and Biggs 2002). It was developed to discriminate spatial variation in a wide range of stream characteristics, including physical and biological characteristics. It is a multi-scale classification, delineating patterns at a range of scales from approximately hundreds of km^2 to 1 km^2.

In the absence of any formal decision on what spatial framework should be used to create freshwater management units in the Bay of Plenty, we have used the REC to classify all waterways (rivers and streams) in the Kaituna WMA, according to parameters known to influence ecological communities such as climate, source of flow, geology and land cover (Figure 2). From this analysis, we were able to calculate the total length of waterways belonging to different REC classes, as well as the number of small, medium and large streams in the area. In this way a quantitative description of the waterways in the Kaituna WMA could be made to help inform the location of potential gaps in water quality, water quantity, soil or ecological monitoring programmes.

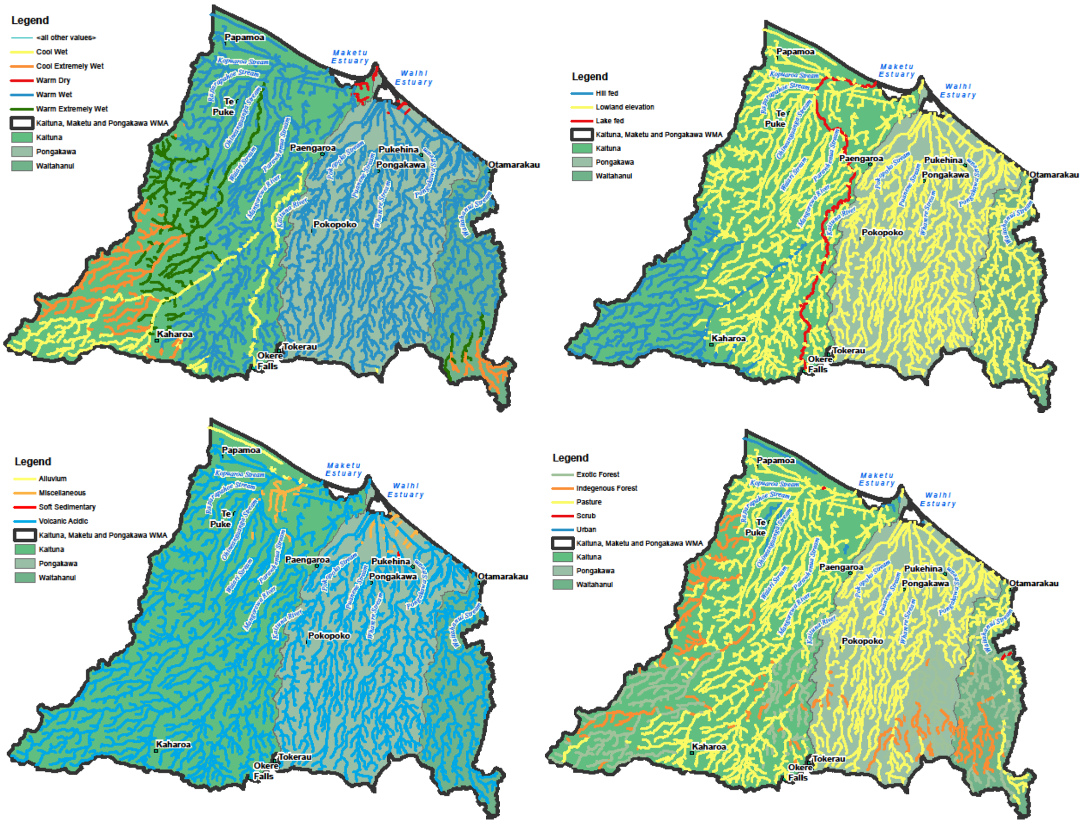


Figure 2 Map of the Kaituna WMA showing the location of waterways in different REC classes.

2.3 River Environment Classification analysis for the Kaituna WMA

The REC analysis showed that a total of 1,710 km of waterways exist within the Kaituna WMA. Most of these (74%) were small first or second-order headwater streams, and large rivers (fifth-order or greater) contributed only 4.4% of total waterway length (Table 1).

The vast majority (76%) of waterways were in the arm-wet climate class, while 8% were in either the warm-extremely wet or cool-extremely wet class. The dominant source of flow consisted of low elevation streams (85%) and hill-fed streams (12%, Table 1). Lake-fed streams only occupied 3% of total stream length, and comprised the length of the Kaituna River from the Ōkere Falls to its outlet into the Maketū Estuary.

Table 1 List of the different REC classes for climate, source of flow, geology, land cover and stream size found within the Kaituna WMA, showing the combined length of waterways in each class, as well as a percentage of waterway length.

Variable	REC class	Stream length (km)	% of WMA stream length
Climate class	Warm-extremely wet	141.6	8.3
	Warm-wet	1302.0	76.1
	Warm-dry	9.7	0.6
	Cool-extremely wet	135.3	7.9
	Cool-wet	121.7	7.1
Source of flow	Hill	203.1	11.9
	Lowland	1458.0	85.3
	Lake	49.2	2.9
Geology	Alluvium	12.3	0.7
	Soft sedimentary	1.1	0.1
	Miscellaneous	28.8	1.7
	Volcanic acidic	1668.1	97.5
Land cover	Exotic forestry	316.4	18.5
	Indigenous forestry	193.8	11.3
	Pastoral	1174.8	68.7
	Scrub	1.6	0.1
	Urban	23.7	1.4
Stream size	Small (order 1+2)	1270.6	74.3
	Medium (order 3+4)	364.0	21.3
	Large (order 5+)	75.7	4.4

The dominant geology consisted of volcanic material, which comprised 98% of stream length. Alluvium and "Miscellaneous" geological material composed 2% and less than 1% of stream length respectively. The miscellaneous category (which covers rock types that occur infrequently throughout the country, and includes Peat (Snelder *et al.,* 2010)) was found in what appears to be artificial drains flowing into the Kaituna Maketū wildlife management area, whilst alluvium was found in a wetland area running parallel to Papamoa Beach.

Just under 70% of waterway length drains catchments classified as "pastoral" land use (representing either horticulture or grazing), while exotic forestry plantations were found in 19% of waterway length. Natural vegetation (native forest, scrub and tussock) was the dominant vegetation in only 11% of waterway length in the Kaituna WMA. Urban land use drained only 1%.

Note that this REC analysis considered only the percentage length of different waterways throughout the Kaituna WMA. An alternative analysis could be based on river flow and volume. For some attributes such as nutrient concentrations, water volume is important as it allows the calculation of catchment nutrient yields to be made. However, such calculations would be constrained by the fact that they would be based purely on modelled flows from each waterway, and could not consider the fact that these are highly temporally variable. Furthermore, reach length would be proportional to catchment area, and it is important to recognise that small streams have much higher segment-length to catchment area ratio than larger rivers. This means that small streams are in more intimate contact with the surrounding land use, and are arguably more sensitive to changes in land use condition than the larger rivers and streams.

The conclusion from this analysis is that the vast majority of waterways in the Kaituna WMA are represented by small streams draining catchments dominated by volcanic geology and supporting predominantly agricultural land use, followed by exotic plantation forestry and indigenous forestry. Monitoring programmes need to ensure that these stream types are monitored according to their occurrence within the Kaituna WMA to be representative of dominant conditions within the Kaituna WMA.

2.4 Gaps and recommendations

Table 2 outlines the gaps identified and provides recommendations to fill the gaps.

Table 2 Identified gaps for spatial considerations and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Spatial framework	Under the NPS-FW, councils are expected to create Freshwater Management Units. These units need to represent streams which are similar to each other, so that appropriate limits for the compulsory national attributes can be accurately determined.	BOPRC needs to consider which spatial framework is appropriate to create water management units. These units could be based on either the REC or FENZ classifications, or an alternative. To assist with decision-making, it may be cost-effective to get input from external experts on this matter.
Spatial framework	Lack of spatial classification for all monitoring programmes.	Develop a consistent spatial classification for different monitoring programmes (e.g. water quality and quantity, land use and soils, and ecology).

Part 3: Geology, land use and soils

3.1 Introduction

Geology, land use and soils are important drivers influencing water quality and quantity. This section describes the geological setting in the Kaituna WMA, the current state in terms of land use and soils, and identifies information gaps for soil health and land use.

3.2 Geology

The Bay of Plenty region has been shaped by a rich history of geological activity, particularly from the Ōkataina and Taupō volcanic centres. The underlying geology of the Kaituna WMA is primarily comprised of ignimbrite. Numerous successive eruptions of tephra (volcanic air fall material) have been the driving force behind the formation of soils in the region (Molloy, 1998). Pyroclastic flows have covered the area forming large ignimbrite deposits across the catchment. Gravel and peat areas in the northern end of the catchment have been created by erosion and alluvial deposition of parent materials to lower lying areas. Smaller areas of rhyolite exist throughout the catchment, which are more closely related to volcanic structures (Figure 3).

On a geological timescale these landscapes are very young, some of which are only a few thousand years old (Molloy, 1998).

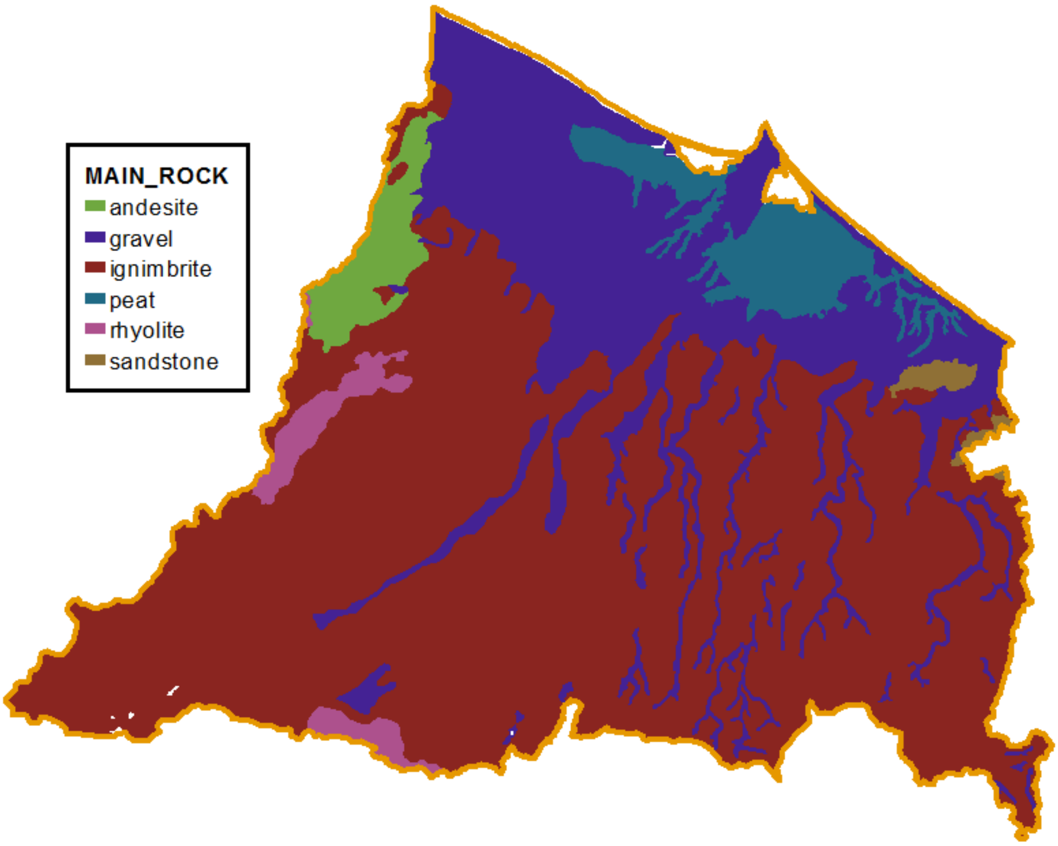


Figure 3 Geology within the Kaituna WMA.

3.3 Soil formation

The interactions among the principal factors of soil formation (parent material, climate, topography, vegetation and time) and soil-forming processes have given the soils of the Bay of Plenty their distinctive characters. Parent materials range from thick layers of volcanic ash mantling the surface, to alluvium derived from greywacke, sandstone, mudstone and volcanic ash, to peat and wind-blown sand.

Volcanic eruptions occurred at different times from sources in the Rotorua and Taupō districts, depositing coarse volcanic material called lapilli and blocks over the Bay of Plenty. Finer material or ash was usually deposited during the final stages of an eruption at greater distances away from the volcanoes

Climate is probably the most important factor influencing present-day land use within the Bay of Plenty. The climate varies from warm and moist in coastal areas to cool and moist in the uplands of Urewera National Park, the Mamaku Plateau and the Kaimai Range.

The region is somewhat sheltered from prevailing winds by the high country of the North Island. Consequently, the Bay of Plenty has a sunny climate with dry spells, but may have prolonged heavy rainfall periods. Annual rainfall ranges from about 1,200 mm at the coast to over 2,000 mm inland at higher elevations, but decreases again in inland basins such as near Murupara.

Rainfall plays an important part in the development of soils. Broadly speaking, the higher the rainfall the stronger the leaching that takes place in the soil and, at annual rainfall over 1,800 mm, podzolisation processes (the leaching of certain minerals from the upper soil horizons) are evident in the subsoil (redder subsoil).

There is also a clearly defined winter rainfall maximum, with approximately 30% of rainfall falling from June to August. Annual rainfall distribution closely follows topography, rising from 1,300 mm or less near the coast to approximately 2,000 mm in the Kaimai and Mamaku Ranges and over 2,200 mm in the Raukumara Ranges (Chappell, 2013). Days with more than 1.0 mm rainfall range from around 103 a year at Whakatāne to around 138 at Waihī (Chappell, 2013).

Vegetation has also played an important role in soil development. Changes in vegetation since the commencement of farming and commercial forestry have had considerable effects on properties such as soil stability.

3.4 Soil mapping

BOPRC has a near complete coverage of soils classification mapping for the region. The dataset is compiled from a range of surveys conducted by various sources, but the scale of each survey can vary. The majority of the region has been surveyed at 1:50,000, which is suitable for catchment analysis. More detailed surveys (1:15,000) have been conducted over discrete areas such as Maketū. These detailed surveys are more suitable for property scale analysis.

Most previous soil mapping work in the Bay of Plenty was carried out by the former Soil Bureau, a division of the Department of Scientific and Industrial Research (DSIR). In later years some other, mainly unpublished work, was carried out by Landcare Research on behalf of BOPRC.

Each soil type has been analysed for ‘typical’ physical and chemical properties during the survey process. Drainage characteristics as well as texture and rooting depth are provided. Within the Kaituna WMA, the majority of soils are pumice or allophanic. Podzolised soils are present in higher rainfall areas and areas formerly under podocarp forests. These areas have good drainage and are resistant to wetting problems (see Figure 4).

Low lying areas to the north of the catchment are characterised by poorly drained gley soils. These soils tend to hold water more frequently which results in distinctive greying of the soil with mottles often appearing (see Figure 4).

There is full mapping coverage for the Kaituna WMA. Data is readily available through the GeoView 2 viewer and through Landcare Research’s publically accessible S-Maps site (http://smap.landcareresearch.co.nz/home).

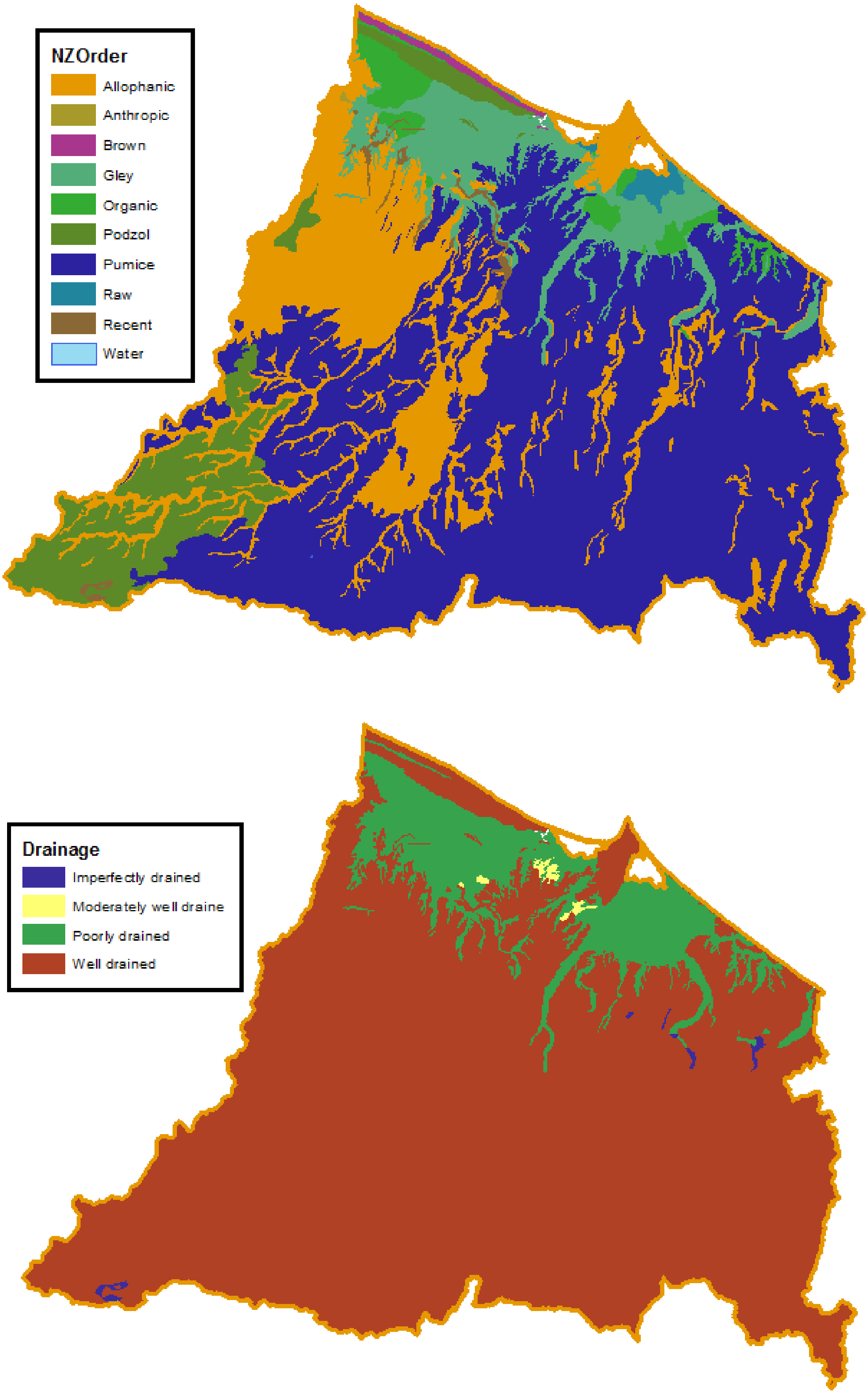


Figure 4 Soil orders and drainage characteristics within the Kaituna WMA.

3.5 Soil monitoring in the Bay of Plenty

3.5.1 Trace elements

Trace element sampling has been monitored during BOPRC's regular regional soil quality/health monitoring programme (Guinto 2009; 2010). This programme has monitored soil conditions at 47 sites (Figure 5). This programme was initiated in 2010 as a result of concerns regarding the potential risk of contaminant accumulation associated with some past and present-day land use practices such as fertiliser application and disease control. For example, cadmium is an unavoidable contaminant in phosphate fertilisers, facial eczema treatment contains high levels of zinc, and copper is used as a fungicide in orchards. Copper is also now commonly used to combat the recently discovered *Pseudomonas* bacterial disease (*Pseudomonas syringae* pv *actinidiae* or Psa) of kiwifruit. Other regional councils (e.g. Tasman, Marlborough and Waikato) have also included trace element sampling as part of their soil quality monitoring programmes.

Previous work on the trace element concentrations of soils in agricultural and horticultural areas of the Bay of Plenty (Solutions in Environmental Management (SEM) 2005) has indicated that copper and arsenic were the elements that most frequently exceeded the selected "trigger levels" or "guideline values" for agriculture and residential land uses. Out of 103 topsoil (0-7.5 cm) samples analysed, an exceedance rate of 15.5% was found for copper and 13% for arsenic.

It recommended that further investigation of agricultural and horticultural lands occur prior to development to more sensitive land uses such as residential. More recent research on kiwifruit orchards in the Bay of Plenty (Benge and Manhire 2011) has shown that, on average, the topsoil (0-15 cm) concentrations of trace metals were below the guideline values. However, concern has been expressed for arsenic, copper and cadmium as their average concentrations were close (50-63%) to their respective guideline values (NZWWA 2003). It was noted that arsenic could be potentially leaching into soils from treated posts, cadmium accumulating from phosphate fertilisers and copper from sprays used in orchards.

Samples for trace element analysis are taken from the existing soil quality monitoring sites and analysed for a range of metals. Archived soil samples have also been used to give data as far back as 1999/2000 for many sites. Data on trace elements have been reported on separately, with the most recent update in 2011.

Figure 5 shows the initial concentrations (1999/2000 sampling) of trace elements in farmed sites relative to initial background levels in indigenous forest sites (2000 sampling). This gives an indication of the degree of trace element contamination already associated with agricultural land uses at the commencement of the regional soil quality monitoring programme. With a few exceptions (e.g. arsenic, mercury), indigenous forest topsoils have lower concentrations of trace elements compared with farmed topsoils.

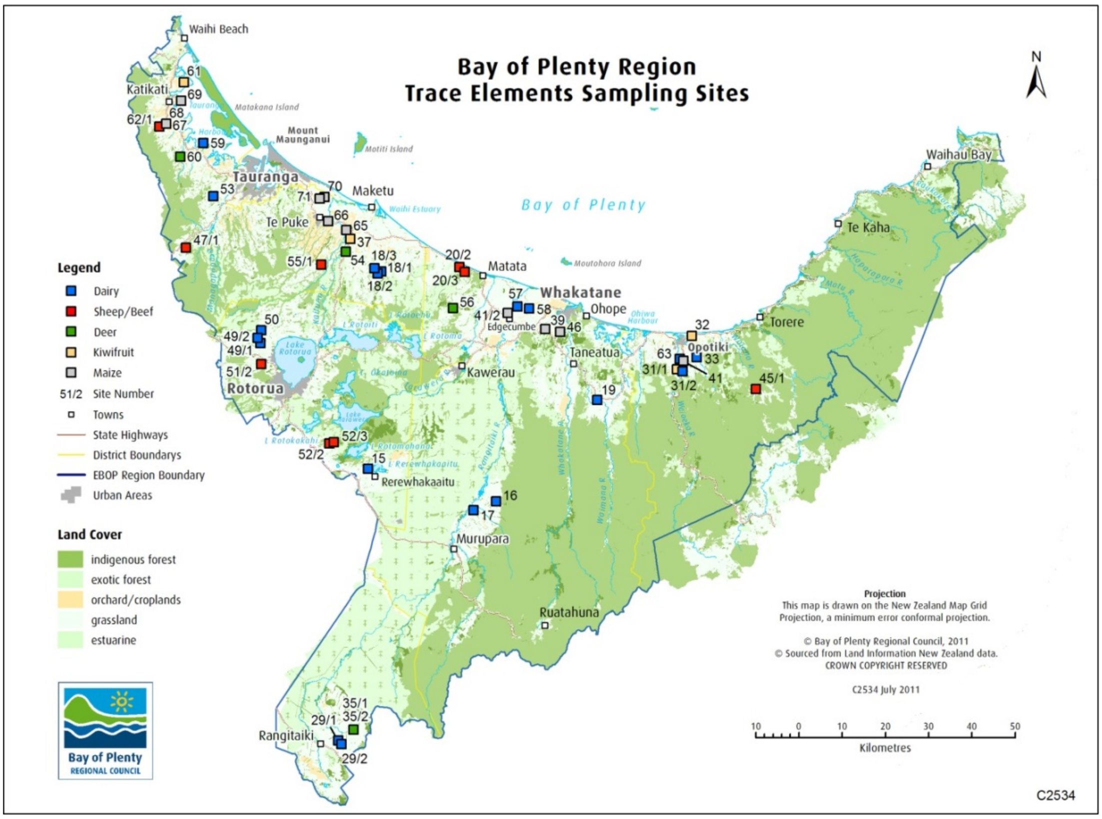


Figure 5 Trace element sampling sites.

For the land uses monitored, many of the topsoil trace element concentrations were below environmental guideline values (Table 3). Observed temporal changes in mean trace element concentrations were not significant. For dairy pasture sites, there were increasing trends in cadmium and zinc concentrations over a 10-year period (1999-2009) but these increases were not statistically significant. In fact, for cadmium, mean concentrations in 2004 (0.76 mg/kg) and 2009 (0.75 mg/kg) were almost identical suggesting that cadmium concentration has not increased since 2004. However, in the 2009 sampling, 26% (5 out of 19 sites) had cadmium levels exceeding the 1 mg/kg guideline value, which is a concern. In kiwifruit orchard sites, copper and zinc concentrations over the 10-year period (2000-2010) appear to be increasing but the increases were not statistically significant due to the small sample size. Nevertheless, this will most likely be a concern particularly for copper which is now a widely used spray to control the Pseudomonas disease (Psa) of kiwifruit vines.

Table 3 Initial mean topsoil (0-10 cm) concentrations of trace elements (mg/kg) under farmed land uses relative to background levels in indigenous forests. Also shown are the NZWWA guideline values.

Element	Indigenous forest 2000 (n =5)	Dairy 1999/2000 (n = 11)	Maize 2000 (n = 6)	Sheep/ beef 2000 (n = 8)	Deer 2000 (n=4)	Kiwifruit 2000 (n = 6)	Guideline value (mg/kg)
Arsenic	6.4	5.3	6.2	7.1	2.8	5.3	20
Cadmium	0.08	0.68	0.23	0.38	0.60	0.65	1
Chromium	3.0	7.7	8.5	3.9	4.2	7.7	600
Copper	15.0	16.4	15.0	9.8	15.2	24.0	100
Lead	8.4	6.6	9.3	5.9	4.5	9.6	300
Mercury	0.14	0.07	0.069	0.08	0.05	0.08	1
Nickel	1.4	5.7	6.8	1.8	2.8	5.5	60
Uranium	0.52	1.43	0.90	0.82	1.05	1.18	23
Zinc	29.6	51.7	47.0	65.2	62.0	72.0	300

Topsoil trace element concentrations were generally higher in agricultural land uses relative to background concentrations in indigenous forest sites reflecting that enrichment is attributable to land management practices that added detectable quantities of trace elements to soils.

Monitoring of trace elements will continue as part of BOPRC's ongoing NERMN soil monitoring programme and then next reporting round is due in mid-2015. This information will be critical in determining the impacts of PSA treatments during the recent 2010 outbreak and to determine whether longer term accumulation is occurring.

3.5.2 Soil health

BOPRC has established a monitoring programme to determine long-term trends in soil health across a range of land uses throughout the region. The programme was set up as part of the MfE 500 Soils Project, of which Bay of Plenty contributed 75 sites. These sites have been maintained as part of the Council's NERMN programme. The status of soil quality in the region has been reported periodically by Landcare Research (Sparling 2001; Sparling and Rijkse 2003; Sparling 2004; Sparling 2005; Sparling 2006a; Sparling 2006b) for all land uses and more recently by Guinto (2009) for dairy pasture and maize cropping sites.

The NERMN soils programme monitors a range of land uses to determine trends in long-term soil health. Land uses monitored include dairy, cropping, dry stocking, forestry, indigenous forests, kiwifruit and deer (see Table 4 and Table 5).

The frequency of monitoring ranges from 10 yearly for forestry sites to three-yearly for cropping sites. The frequency of dairy monitoring is currently five-yearly, however, this is likely to increase given the trends in fertility properties of the soils, as discussed below.

Trace element sampling of soils has more recently been included in the soil quality/health monitoring programme, due to concerns regarding the potential risk of accumulation associated with some past and present-day land use practices, such as fertiliser application and disease control.

Table 4 Number of NERMN monitoring sites within the Kaituna WMA of different land use classes.

Land uses	No of NERMN sites
Dairying	3
Deer	1
Kiwifruit	1
Sheep/beef	1
Cropping	3
Total	**9**

Table 5 Monitoring frequency for trace element analysis by land use within the Kaituna WMA.

	Dairy	Maize	Dry stock	Forestry	Indigenous forest	Kiwifruit
Monitoring frequency	5-yearly	3-yearly	5-yearly	10-yearly	10-yearly	5-yearly

Long-term monitoring data from the NERMN programme has identified that the amount of fertility nutrients (nitrogen and phosphorus) contained within topsoil is increasing to amounts that are classed as being high to excessive, due to the maximum utilisation by plants being exceeded. Excess nutrients in the soil profile increases the risk to receiving waters. Mean Olsen P values on dairy farms have been increasing consistently, and in 2014 were 99.8 mg/kg (see Figure 6). Nitrogen is also increasing steadily in dairy soils, with anaerobically mineralisable nitrogen and total nitrogen reaching the upper limits of optimal farm production (see Figure 7). The upper limit of pasture productivity is where the benefit to pasture growth diminishes and the risk to the environment increases. Not only does excess fertility lead to land managers making an economic loss, it also increases the risk of contamination/eutrophication of nearby water bodies.

Kiwifruit sites as well as sheep/beef and deer sites have shown steady increases in Olsen P measurements. Kiwifruit sites had a mean Olsen P concentration of 106 mg/kg in 2010.

Figures 6 and 7 show the long-term trends in fertility levels of soils in the NERMN programme. The upper desirable levels as described in the LMF guidelines are shown with orange and red lines. Further monitoring is required to obtain more data to provide greater confidence in soil health trends.

Soil health updates have been provided as a snapshot of the region and results have not been provided per site. Therefore, further analysis would be required to delineate this information for the Kaituna WMA.

Published soil health updates are available on the BOPRC website (http://www.boprc.govt.nz/media/99812/2010_22__soil_quality_in_the_bay_of_plenty_2010_update.pdf).

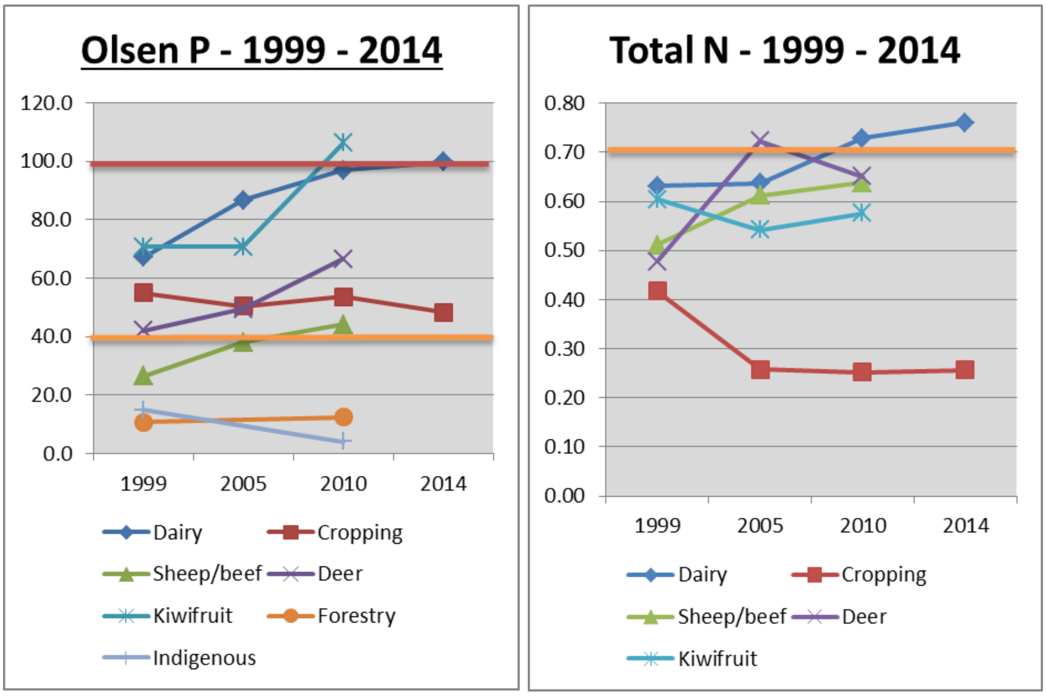


Figure 6 Olsen P and Total N trends across all land use types under the NERMN soils programme. Desirable values as described in the LMF manual are shown in orange and maximum production values (for Olsen P only) are shown in red.

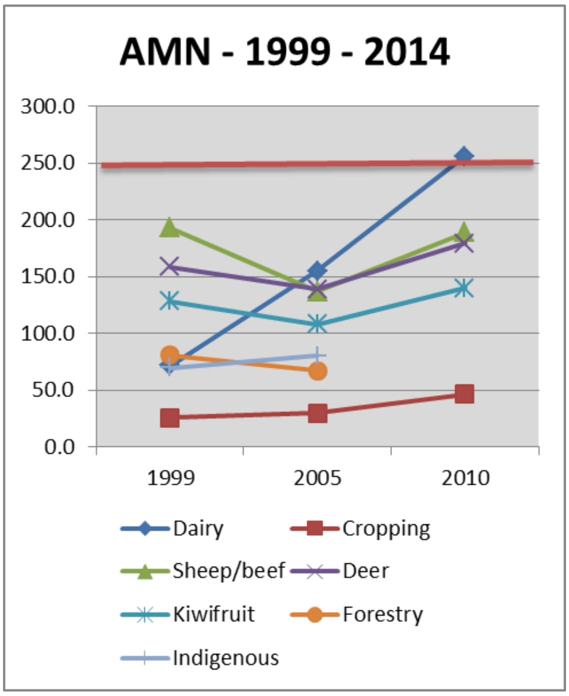


Figure 7 Anaerobically mineralisable nitrogen (AMN) trends across all land use types under the NERMN soils programme. The maximum production value as described in the LMF manual are shown in red.

3.6 Land use

The New Zealand Land Use Map (LUM) was developed in response to New Zealand's obligations under the Kyoto Protocol and shows land use from 1990, 2008 and 2012. This map is focused on carbon accounting, primarily through distinguishing between forested areas and non-forested areas such as productive land. The map is a valuable resource to show land use change between major categories such as forestry to agriculture over a long time frame (22 years).

The Land Cover Database (LCDB version 4 (LCDB4)) shows much more detailed land cover information over a shorter timeframe - from 1996, 2001, 2008, 2012 (16 years). The LCDB4 is a valuable tool to show more subtle changes in land use and is able to provide more detail than the LUM. A comparison of land use categories between the two datasets is outlined in Table 6.

Table 6 Comparison between land use categories of LCDB and LUM.

LCDB4 – 1996-2012	LUM – 1990-2012
Broadleaved indigenous hardwoods	Natural forest
Built-up area (settlement)	Grassland - high producing
Deciduous hardwoods	Grassland - with woody biomass
Estuarine open water	Cropland - perennial
Exotic forest	Grassland - low producing
Forest - harvested	Other
Gorse and/or broom	Wetland - open water
Gravel or rock	Planted forest - pre-1990
Herbaceous freshwater vegetation	Cropland - annual
Herbaceous saline vegetation	Settlements
High producing exotic grassland	Wetland - vegetated non forest
Indigenous forest	
Lake or pond	
Low producing grassland	
Mangrove	
Manuka and/or kanuka	
Matagouri or grey scrub	
Mixed exotic shrubland	
Orchard, vineyard or other perennial crop	
River	
Sand or gravel	
Short-rotation cropland	
Surface mine or dump	
Transport infrastructure	
Urban parkland/open space	

The highest percentage of land within the Kaituna WMA is in high-producing exotic grassland (49,651 ha - 46.5%). Forested areas make up 39.7% of the catchment with 18.7% in indigenous forests. There are also 8,151 ha of orchards/cropping lands within the catchment (Table 7).

Dairy sites are distributed across the catchment within the Kaituna WMA. The high proportion of dairy within the WMA is a significant pressure and the impacts of such land use on soil health and ecological values in the WMA need to be better understood. There is also risk from conversions from forestry to productive pasture in the upper catchment. However, because the majority of forestry land in this area is steep, the risk of such dairy conversions is considered to be relatively low.

Current land use is shown in Figure 8. It is not clear what the change in composition of catchment land use has been over time (1996–2012). This exercise has been proposed as a recommendation for future work.

Table 7 Land cover database analysis of the Kaituna WMA.

LCDB4 – 1996 – 2012	**Area of catchment (ha)**	**% of total catchment**
Broadleaved indigenous hardwoods	2,024	1.9%
Built-up area (settlement)	1,049	1.0%
Deciduous hardwoods	199	0.2%
Estuarine open water	21	0.0%
Exotic forest	19,772	18.5%
Forest - harvested	2,660	2.5%
Gorse and/or broom	95	0.1%
Gravel or rock	4	0.0%
Herbaceous freshwater vegetation	399	0.4%
Herbaceous saline vegetation	85	0.1%
High producing exotic grassland	49,651	46.5%
Indigenous forest	20,013	18.7%
Lake or pond	11	0.0%
Low producing grassland	414	0.4%
Mangrove	0	0.0%
Manuka and/or kanuka	756	0.7%
Matagouri or grey scrub	51	0.0%
Mixed exotic shrubland	117	0.1%
Orchard, vineyard or other perennial crop	8,151	7.6%
River	131	0.1%
Sand or gravel	84	0.1%
Short-rotation cropland	801	0.7%
Surface mine or dump	130	0.1%
Transport infrastructure	19	0.0%
Urban parkland/open space	159	0.1%

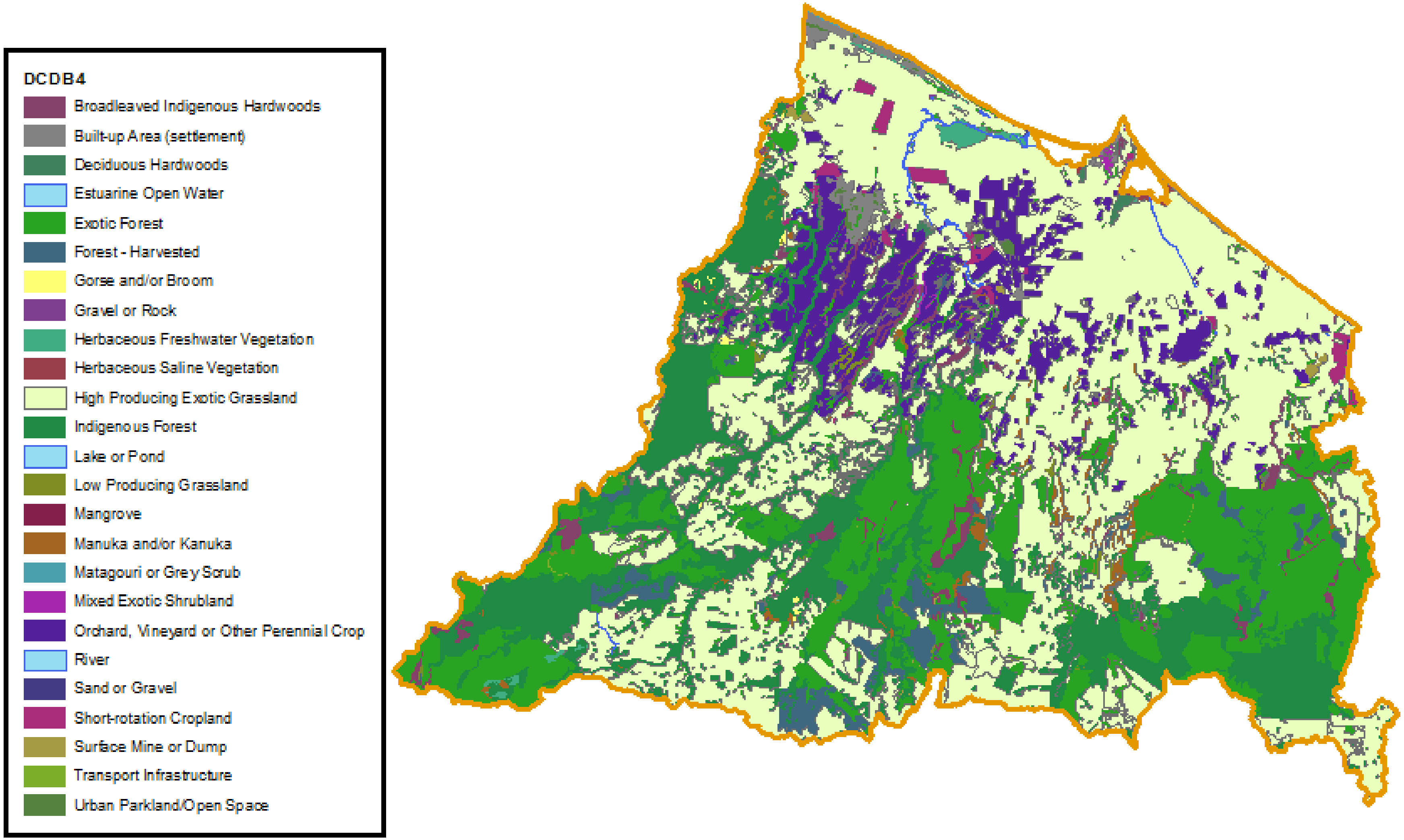


Figure 8 LC DB4 map of the Kaituna WMA (2012).

3.6.1 Catchment Land Use for Environmental Sustainability

The National Institute of Water and Atmospheric Research (NIWA) and Ministry of Agriculture and Forestry (MAF) have developed a GIS based modelling system called Catchment Land Use for Environmental Sustainability (CLUES) that assesses the effects of land use change on water quality and socio-economic indicators. The model allows users to create both land use and farm-specific scenarios and to predict loading of phosphorus and nitrogen in waterways, and displays results in graphical and tabular formats. Some specific training would be required, but the model is available in-house, utilising already available software.

3.6.2 Land Use Capability mapping

The Land Use Capability (LUC) classification is defined as a systematic arrangement of different kinds of land according to those properties that determine its capability for long-term sustained production (Manderson *et al.,* 2007). The LUC system builds on the Land Resource Inventory to categorise land into eight classes according to its long-term capability for production (Manderson *et al.,* 2007). This dataset provides valuable information about the physical quality of the environment and also provides an indication of land uses that would be more suitable for a particular parcel of land.

This dataset makes it possible to analyse how land is currently allocated in terms of current land use and mapped capability (Figure 9). Optimal land allocation can be subjective and is dependent on a number of external factors, such as tenure and land ownership, but broadly speaking is the allocation of the most intensive land uses on the most productive land. Poorly allocated land would be high intensity land uses such as dairying and cropping on land that has low productive capability, due to one or a number of factors. Plantation forestry on highly productive land could also be an example of poorly allocated land.

In reality it is not possible to achieve optimal land allocation, but determining the level to which land uses within a catchment are aligned with the capability of the land is a valuable indicator of the current land use pressures within that catchment.

A more detailed analysis of the catchment should be conducted to determine how current land use is allocated according to the LUC categories. This analysis has been recommended for future work.

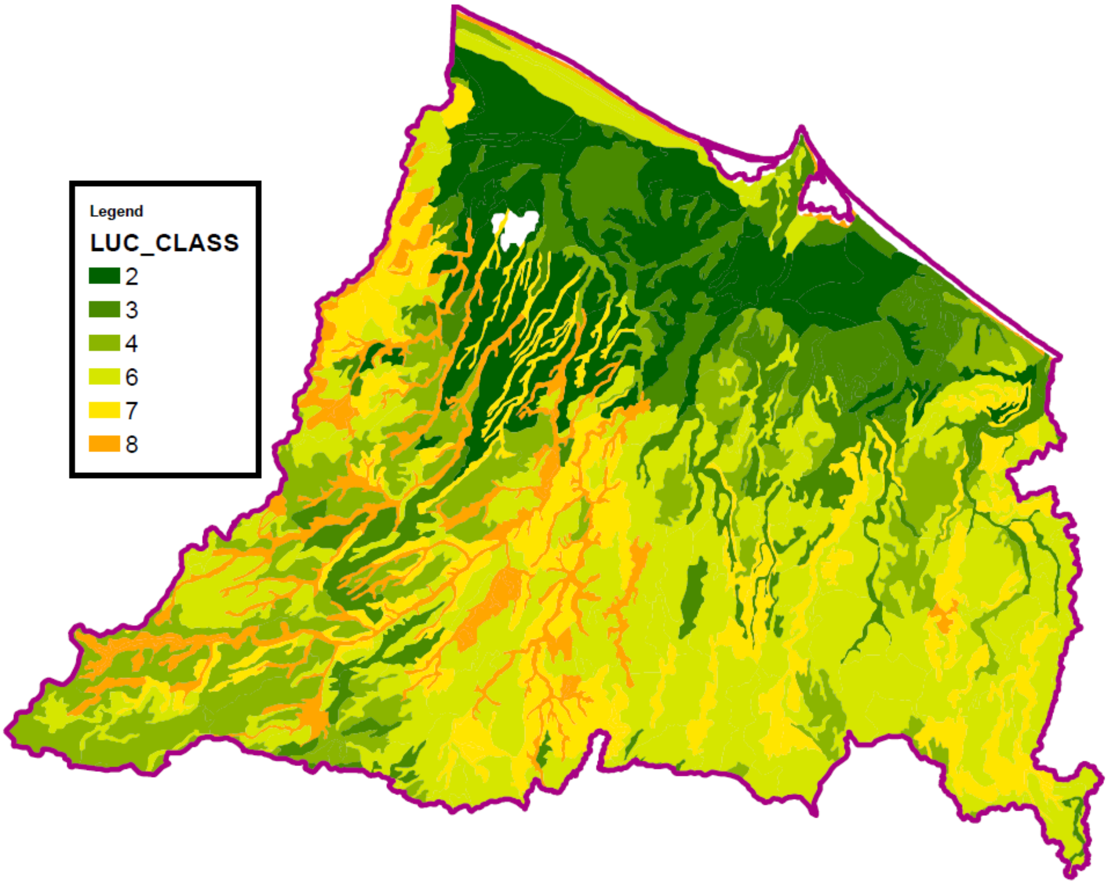


Figure 9 LUC map of Kaituna WMA.

3.6.3 Light Detection and Ranging

Light Detection and Ranging (LiDAR) is a remote sensing technology that provides high resolution topography of a site. It provides the ability to spatially represent slopes with a high level of accuracy. Accurate slope information is critical to cross checking other sources of information that utilise slope as a key determinant, e.g. Land Use Classification. Light Detection and Ranging information is currently available for the entire Kaituna WMA. The accuracy and resolution provided is adequate for use in the current state project. Complete coverage of the region has been obtained in 2006/2007 and again in 2011/2012. These datasets will allow more accurate analysis of erosion and land stability over time. To date this information has not been used to monitor land stability formally.

3.7 Gaps and recommendations

It is critical to understand pressures arising from land use change/intensification both to comprehend the likely causes of existing downstream impacts on ecological values such as receiving waters, and also to pre-empt future problems and manage them accordingly. Without appreciating land use pressures it is difficult to manage and improve ecological values, particularly while still maintaining economic viability and equity of the land (see Figure 10).

Determining the current state of soils is also critical in understanding the impacts of land use change on ecological values. The primary impacts observed on receiving waters in the Bay of Plenty arise from eutrophication processes occurring from increased fertility of nitrogen and phosphorus and from erosion and sedimentation from land to waters.

Many land managers are aiming to achieve optimal production within their operations, which often involves the use of fertilisers and irrigation techniques. Fertilisers can have unintended impacts such as the accumulation of trace elements in the soil and loss of nutrients to receiving environments. The accumulation of trace elements in the soil can impact on the plants growing in the soil and the animals grazing on that land.

Soil stability, particularly in close proximity to waterways is highly important to managing the ecological values of our waters. An initial study of soil stability, including identification of high risk areas, should be undertaken.

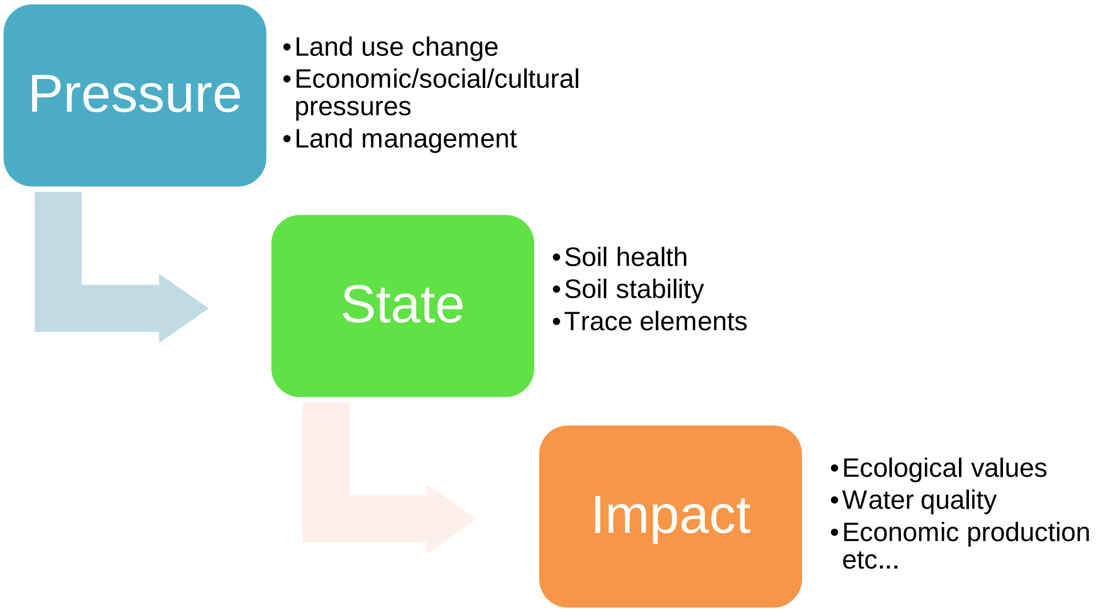


Figure 10 Land management process flow diagram.

BOPRC's NERMN soil health programme is a critical source of information about trends occurring within topsoil which is a direct indicator of the land management practices occurring. As part of the Kaituna WMA limit setting process, it would be a valuable exercise to run a pilot sampling programme to obtain detailed background information on the current condition of the catchment in relation to the soil quality indicators. While it would not be possible to identify trends from a single sampling period it would be possible to determine the status of soil quality indicators within the catchment for particular land uses.

There is a primary gap in knowledge of the interactions between land use - soil health - land management and ecological impacts (see Figure 10). Although BOPRC has data available to begin formally monitoring land use pressures and emerging trends in soil health, obtaining information that provides a clearer picture between land use change, soil health, and resultant effects on aquatic ecosystems is more difficult. A detailed analysis of the Kaituna WMA should be conducted to identify land use change over time and provide more detail around how land use may be impacting on water quality within the catchment.

The link between increasing concentrations of nutrients within the soil profile and impacts on downstream water bodies is currently not clear. Further work is required to link land use pressures and soil health to ecological impacts within receiving waters. This involves complex process and interactions but is critical to better understand the drivers of water quality within these catchments. Setting up localised trials and focussed study sites where programmes of co-ordinated science monitoring is conducted across disciplines would greatly assist in this process.

Identifying broad changes in land use, for example from forestry to pasture, is possible through spatial analysis and using nationally available datasets. There is currently no formal reporting or monitoring of land use change, however, due to the availability of national datasets it is possible to monitor change within specified catchments and report on findings.

Land use intensification and land management practices, particularly subtle changes such as winter support for dairy on dry stock farms, is much more difficult to monitor and often requires input from land holders and other local knowledge. This information is pertinent to identifying land use pressure in the catchments. It is recommended that the efficacy of methods to monitor land use intensification over time be investigated.

A point that is worth noting is that sieving of soil particles greater than 2 mm prior to analysis has been raised as a potential issue in obtaining accurate Olsen P readings on pumice soils (Rajendram *et al.*, 2011). It is worth investigating the potential impacts of this on the results obtained from the NERMN soils programme to date. There may be an ability to use this information to determine whether Olsen P tests have overestimated the amount of phosphorus available to plants. The laboratory used for soil chemical properties has not been changed since the commencement of the monitoring programme; therefore any trends in Olsen P concentrations identified in the NERMN programme are still valid. If any overestimation is found then it should be relatively straight forward to adjust results.

The NERMN soil monitoring programme has been running since 1999 and three to four monitoring periods have been obtained for most land uses monitored. Fertility indicators on dairying sites have been trending upwards and a number of sites are showing levels of fertility that are deemed to be excessive (LMF guidelines, 2009). To get better clarity on this trend it is recommended that monitoring of dairy and kiwifruit sites be increased to every three years from the current five years. Having this improved dataset will show/confirm any emerging trends more accurately and greatly improve our decision-making ability. Soil fertility above certain measures represents an economic loss to the farmer, so any readjustment to more suitable levels could have significant environmental as well as economic implications.

To facilitate the NERMN soil health monitoring programme the location of each site remains confidential between BOPRC and individual landowners. This makes it difficult to provide analysis at any level finer than regional scale. Regardless of this, the low number of sites available within each WMA would make it difficult to draw any conclusive trends emerging from the reduced dataset. The baseline analysis recommended above would fill this gap and allow a baseline in soil state to be determined.

Soil stability is not currently monitored effectively within the region and is critical in understanding sediment loads likely to enter waterways. The Land Monitors Forum provides a methodology to be followed by regional councils to assess soil stability. A number of regional councils currently monitor soil stability as part of their ongoing state of the environment reporting. The monitoring process involves analysing aerial photography and is a desktop exercise. It does however require an analyst with advanced aerial photography analysis skills to conduct the monitoring. It is recommended that a baseline soil stability assessment be conducted over the Kaituna WMA.

Soil fauna populations are poorly understood in the region as an indicator of soil health. The Land Monitoring Forum is running a pilot programme to determine the level of protectiveness required for soil fauna. The presence of soil fauna is closely linked to organic soil carbon, which is a key driver of soil nutrient status and soil moisture. Soil fauna populations in the WMA need to be investigated through obtaining baseline information from various land uses and reference sites. The prevalence of dairying land uses within the WMA increases the importance of a more detailed picture of soil health.

BOPRC’s lysimeter network provides valuable information of moisture flow through the soil profile and if utilised can provide an indication of the expected leaching rates of particular soils when combined with other metrics. To improve knowledge of drainage and potential leaching (N and P) from local soils, the existing soil lysimeter network could be leveraged to determine leaching rates within pumice, allophanic, and recent soils in these catchments. If this data was obtained over a three-year period it would allow modelling to be calibrated more closely to locally occurring soil types.

A key recommendation for land use and soil health moving forward is to align current land use and monitoring and reporting into categories as presented in Figure 11 above. This will provide the organisation and the public with a clearer view on what is being measured and the relationship between land use, soil health and ecological impacts. The recommendations arising from this review are summarised in (Table 8).

Table 8 Table of soil health and land use recommendations for the Kaituna WMA.

Gap theme	Gap	Recommendation
Improvements to methods	No formal methodology/reporting mechanism currently exists to monitor and report on land use pressures. Intensification of land through activities such as dairying support on a predominantly dry stock block needs to be better understood/monitored.	Develop a standard methodology for monitoring and reporting on land use pressures using a range of nationally available datasets including LCDB, LUM, Stats NZ data, NERMN, Agribase etc. The reporting frequency of such reports will be limited to the availability of the underlying data and therefore a return period of less than 4-5 years is unlikely. Investigate combining detailed farm knowledge with land use pressure monitoring. Investigate alternative information sources such as Agribase and Statistics NZ. This information is likely to confirm how rapidly land use pressures have emerged over time and outline the current state of the WMA. Without this information it is not possible to robustly analyse how changes in land use may have impacted on ecological values within the catchment. It will also not be possible to determine the key economic drivers within the catchment and to determine what impact mitigation measures would likely have.

Gap theme	Gap	Recommendation
Data for models	There is a need to identify what role pumice/gravelly soils play on nutrient loss and leaching. Overseer is used extensively to model nutrient loses, but is poorly calibrated to local conditions in the Bay of Plenty.	Conduct a detailed review on the available literature on pumice soils. Rajendram *et al.* have conducted a preliminary study on the impact that laboratory methods can have in overestimating Olsen P in pumice soils. Need to develop a programme to better understand the role of leaching in our most prevalent soils (pumice, allophanic and recent) and investigate utilising/leveraging off our existing lysimeter network and input into the planning for proposed lysimeters to better understand leaching in the region and these catchments. Landcare Research should be consulted to ensure any data obtained is suitable for calibrating Overseer modules. Overseer is used extensively to model predicted leaching rates and therefore without this information it is not possible to provide a high degree confidence in the outputs produced for certain soil types and climatic zones.
Improvements to methods and reporting	Identify NERMN soil health monitoring results for each specific WMA.	Develop a database for existing NERMN data that allows comparisons of individual sites as well as between distinct geographic areas such as WMAs. The number of sites available in any particular area will dictate how robust the data is. A valuable data resource exists as a result of the NERMN soil health monitoring programme. The programme was designed to provide a region wide snapshot as opposed to specific soil types or catchments. See below comments on obtaining baseline information for each WMA.
Data management	Include trace elements as part of the standard NERMN monitoring suite.	Trace elements are currently reported on separately from the soil health programme. They should be included in the regular NERMN monitoring and reported on in the regular soil health updates.

Gap theme	Gap	Recommendation
Improvements to methods and reporting	Dairy and kiwifruit are showing trends in soil health that need to be better understood.	The initial NERMN monitoring programme was designed around monitoring those land uses with the greatest soil disturbance. After multiple monitoring periods it is evident that it is more appropriate to monitor the most intensive land uses more frequently and potentially reduce monitoring of those land uses that were previously more frequently monitored. It is recommended to increase the monitoring period of dairy and kiwifruit to three-yearly.
Data for models	Do not currently have the ability to predict the effects of land change on water quality.	First phase model to allow interactive discussions on land use change scenarios and impacts on water quality with stakeholders. CLUES has been recommended as a suitable model which can be built and run in-house if desired.
Identify values	Cultural pressures on land are not clearly understood at this stage.	Investigate whether cultural pressures can be readily identified and incorporated into land pressures monitoring. This would involve reviewing available information sources and the robustness of any such information. It should be noted that other groups within BOPRC are investigating this work, so it is suggested as a desktop exercise to determine how readily this information could be included with other metrics.
Obtain new data	When reviewing the information available from the NERMN programme it is evident that there are relatively few representative sites per WMA.	The amount of soil health information available per WMA is relatively low. It is recommended that a pilot programme is conducted to take a snapshot of soil health in the WMA. This would indicate the number of sites that are currently exceeding soil health criteria, particularly relating to fertility (nitrogen and phosphorus). The number of sites included in such a programme would need to be statistically robust enough to enable extrapolation across the WMA. If combined with land use monitoring above it will provide a powerful tool for assessing the state of the WMA. Any such monitoring programme should also include additional parameters (water quality etc.) to provide a complete picture.

Gap theme	Gap	Recommendation
Improvement to methods	The link between land use pressure, soil state and water quality is not clearly understood.	The Science Team should work on identifying linkages between land use pressures/soil health and water quality/ecological values. While good information exists within each discipline there have been few linkages drawn. Given that land use change can be slow to occur and any exercise linking pressure and state with Impact would be complex it would be recommended to take a long-term view on any analysis.
Obtain new data	Soil stability characteristics are not known within these WMAs.	Assess soil stability, soil intactness and soil disturbance over time. This analysis will help to determine whether the soil is: • Stable, • unstable but inactive (erosion prone), • recently eroded, or • freshly eroded. This information will provide a framework for assessing land use disturbance due to land use. Phosphorus is a key contributor to eutrophication processes yet the loss of soil sediments to receiving waters is not well understood within the WMA. This information is critical to understanding the loss of productive soil, but also the potential for impacts on ecological values. This information could be combined with baseline soil health data to provide an indication of the state of the catchment.
Obtain new data	Soil microbial/fauna populations.	The Land Monitoring Forum is involved in a pilot programme to identify the level of protectiveness required for soil fauna. Obtaining baseline information for the Kaituna WMA is important in understanding accumulation from trace elements such as copper and cadmium from kiwifruit treatments.
Improvements to methods and reporting	Need to monitor economic production from particular land.	This will allow us to determine the economic productivity of particular land uses and also to predict the likely impacts on the economy when making decisions about nutrients targets. Key reporting metrics would need to be decided.

Part 4: Hydrology

4.1 Introduction

As part of the NERMN programme, BOPRC's Environmental Data Services (EDS) team collects continuous flow information from 12 continuous gauging stations throughout the Kaituna WMA. These sites provide detailed information on a river's flow regime (where rating curves are available) or river's stage (where rating curves are unavailable). Flows are monitored for a number of reasons, including monitoring high flows for flood forecasting, and monitoring low flows to help set minimum flows for water allocation purposes. Because it is expensive and impractical to establish water level recorders in all rivers throughout the region, BOPRC is relying on producing flow correlations between permanently gauged sites and ungauged catchments to build better relationships to flows in ungauged catchments.

The calculation of low flow statistics for ungauged sites is based on a statistical relationship between the gauged sites and the ungauged sites. An additional 23 monitoring sites are thus gauged during the summer to obtain statistics on low flow variables. These low flow sites are used to correlate the flow in the ungauged catchments to a permanently gauged monitoring station in order to provide flow statistics in catchments without a permanent gauging station.

The surface water hydrology science programme has been reviewed by Fernandes (2015), and so only the salient points of relevance to the Kaituna WMA are discussed here. The current state of hydrological monitoring stations throughout the Kaituna WMA is reviewed, and recommendations for future work made. Information on available gauging stations and associated flow statistics can be found in Table 9.

Table 9 Hydrological characteristics of the Kaituna WMA, showing continuous gauging stations and locations of low flow sites.

Kaituna, Pongakawa and Maketū WMA *				
Area: 106,797 ha				
Number of catchments: 23				
Gauging stations				
Kaituna at Clarkes [1] Kaituna at Fords Cut [2] Kaituna at Taaheke (NIWA) Kaituna at Te Matai [1] Mangorewa at Saunders Kopuaroa at SH29 [3]		Waiari at Muttons (NIWA) Raparapahoe at Drop structure [2] Lake Rotoiti Outlet (NIWA) Pongakawa at Old coach Road [4] Waitahanui at Ōtamarākau [5,3] Puanene at SH 2 [6,3]		
Low flow sites: 23				
Catchment	**River/stream**	**Site name**	**Q_5 7day l/s**	**MALF l/s**
Upper Kaituna	Kaituna	Taaheke	10,564	11,913
Kopuaroa	Kopuaroa	Above Waikoura Confluence	36	39
	Kopuaroa	McFarlances Farm (SH 2)	71	82

Catchment	River/stream	Site name	Q_5 7day l/s	MALF l/s
Kopuaroa	Waikoura	U/S Kopuaroa Confluence	34	43
Lower Kaituna	Kaituna	Maungarangi Road	15,325	16,677
	Kaituna	Te Matai	26,043	28,953
	Ohineangaanga	Whitehead Avenue	200	250
Mangorewa	Mangorewa	Saunders	4,087	4,422
	Mangorewa	U/S Kaituna Confluence	5,450	6000
Parawhenuamea	Pakipaki R/B Tributary	Burt Orchard	750	-
Pokopoko	Oeuteheuheu	Allport Road	427	492
	Pokopoko	Allport Road	572	657
	Pokopoko	Old Coach Road	1,596	1,683
Pongakawa	Pongakawa	Old Coach Road	4,126	4,345
Raparapahoe	Raparapahoe	Above Drop Structure	610	720
	Raparapahoe	D/S No. 3 Road	282	335
	Raparapahoe	No. 4 Road bridge	535	611
Waiari	Waiari	Muttons	2,984	3,347
	Waiari R/B Tributary	U/S Waiari Confluence	90	105
Waitahanui	Waitahanui	Ōtamarākau Valley Road	4,438	4,730
Wharere	Puanene	State Highway 2	90	94
	Wharere	SH 2 bridge	287	338
	Wharere	Unnamed tributary	17	20

* Disclaimer: Data is the latest available. In some instances this may be over 10 years old and will need to be upgraded. Data is not to be used for allocation purposes and is intended for use in this report only. No liability is assumed for data within this report.

1 Tidally influenced, flows to be used with caution.
2 Level information.
3 Flow available on line. No data in summaries
4 Disestablished sites.
5 New site, established in 2012
6 Established in 2013

The Kaituna WMA can be into a number of "surface drainage catchments", consisting of the greater catchment (in this case the Kaituna WMA), and the primary, secondary and tertiary catchments. The tertiary catchment is generally at the level of an individual river, whilst the secondary and primary catchments are amalgamations of these into larger spatial areas.

To determine whether any extra hydrological stations are needed in these tertiary catchments, each catchment has been individually assessed based on its geology, catchment area, established relationships between gauged and ungauged catchments, and the number of consents already issued within that catchment.

Analysis of this information was used in order to make recommendations on whether flow monitoring should occur in any of these tertiary catchments. For example, any catchments with a drainage area of 5,000 ha or less can be gauged on a case-by-case basis, and when needed. Catchments with a drainage area between 5,000 and 10,000 ha will need an interim gauging programme. Catchments that are greater than 10,000 ha will need to have a permanent gauging station set up, and regularly gauged. Any catchments without water allocation pressure and with little or no current consented abstraction were also deemed to be of a lower priority to gauge than catchments which are subject to high allocation pressure and have a high number of consents issued.

Table 10 provides a summary of the recommendations for all catchments within the Kaituna WMA and the number of active consents.

Table 10 Summary of recommendations for the Kaituna WMA.

Current flow sites?	Recommendation	Sub-catchments
No	No need for flow monitoring[1]	Hururu, Maketū Estuary Coastal, Newdick's Coastal, Ohineapanea Coastal, Ōtamarākau Coastal, Papamoa, Pukehina Beach Coastal, Pukehina Coastal, Te Puke East.
No	No need for flow monitoring[2]	Lower Kaituna.
No	Establish gauging site	Kaikokopu, Rangiuru South.
No (gauging disestablished)	Re-establish gauging site	Pongakawa.
Yes	Need more gaugings at existing sites	Kopuaroa, Mangorewa, Ohineangaanga, Pokopoko, Raparapahoe, Wharere, Waitahanui, Wharere.
Yes	Need new sites	Mangorewa, Parawhenuamea, Upper Kaituna, Waiari, Waitahanui.

[1] Catchments < 5,000 ha. Can be gauged on a case-by-case basis when needed.
[2] Kaituna River is currently being monitored at Waitangi (Site = Kaituna at Te Matai).

The National Institute of Water and Atmospheric Research has also developed a database of flow statistics for all reaches throughout the Bay of Plenty region (Booker *et al.,* 2014), giving us the ability to look at modelled flow statistics in the Kaituna WMA. Many of these flow statistics reflect ecologically important parts of a river's flow regime that are known to greatly influence algal, invertebrate and fish communities. For example, the frequency, magnitude and duration of both floods and low flows can have profound effects on river ecology. Based on these modelled flow statistics, it would be possible to examine how variable these ecologically relevant flow parameters are throughout the Kaituna WMA, and ensure that we are monitoring sites that cover a range of these parameters.

Parts of BOPRC's responsibilities revolve around setting minimum flow and allocation limits in rivers subject to abstraction. Water is abstracted for a variety of uses, including town supply, irrigation (for both pasture and horticulture such as kiwifruit), dairy shed use, and frost protection.

Under the current Regional Water and Land Plan (RWLP), clear processes and methods exist for minimum flows to be set in waterways. Of particular relevance are Methods 177 and 179. Under Method 179, a default in stream minimum flow has been set to 90% of the Q5 7-day low flow. This means that 10% of the Q5 7- day low flow is available for abstraction. This simple hydrology based method is based on the assumption that the degree of habitat protection within a river is linearly related to the amount of water within a river, and that setting a minimum flow of 90% of that which occurs naturally once every five years over a seven-day period is unlikely to have any adverse ecological effects.

For ecological minimum flows, the 'In Stream Flow Incremental Methodology' (IFIM) is used. This method calculates the weighted usable area of fish habitat for different fish species in each river, and sets the minimum flow based on the protection of a specific level of habitat that is found at the streams Minimum Annual Low Flow (MALF). This is a robust methodology that has been used to set ecologically relevant low flows throughout the Bay of Plenty (Jowett 2012). Currently, BOPRC has undertaken detailed IFIM surveys in 57 rivers throughout the region. Of these, six were in the Kaituna WMA (Table 11). Finalised minimum flows in these six sites have to be recalculated using RHYHABSIM and the new methodology as suggested by Jowett (2012). This revised methodology bases habitat retention relative to a stream's MALF, instead of relative to a stream's median flow (which is what the current RHYHABSIM calculations are based on).

Table 11 List of the six rivers in the Kaituna WMA where detailed IFIM analyses have been undertaken and where minimum flows have been set to protect specific ecological values. Note that the final IFIM minimum flows have yet to be calculated for these sites, based on habitat retention relative to a stream's MALF, instead of relative to a stream's median flow.

River	MALF (L/s)	Q5 7-day low flow (L/s)	Default minimum low flow (L/s)
Mangorewa	6,000	5,450	4,905
Ohinieangaanga	250	200	180
Pongakawa	4,450	4,350	3,915
Raparapahoe number four	600	550	495
Raparapahoe number three	300	250	225
Waitahanui	4,950	4,800	4,320

4.2 Gaps and recommendations

Identified gaps are summarised in Table 12. A significant resourcing challenge is also to obtain a satisfactory coverage of the region with continuous flow monitoring sites (Table 12). Currently, continuous flow recorders operate at 12 sites throughout the Kaituna WMA, and there may be a requirement to increase this number slightly. In lieu of setting up permanent flow sites, a series of spot flow gaugings can be undertaken in a range of other rivers in the area, with the aim of developing good correlations between permanently gauged and ungauged catchments. Analysis of the proposed water allocation surface water catchments has identified a number of these where such spot flow gaugings are recommended.

Given the importance of stream hydrology to ecological communities, and the realisation that it is impossible to monitor flows in all waterways throughout the Kaituna WMA, the importance of hydrological models in providing estimates of ecologically relevant flow statistics cannot be over-emphasised. Of relevance to water allocation and the setting of low flows is the use of the NIWA EFSAP model. This tool is currently undergoing validation at sites where detailed IFIM surveys have been done throughout the region.

Table 12 Identified gaps for hydrological monitoring and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Spatial frameworks	Firm guidance as to what an appropriate spatial framework would be for stream hydrology.	Examined the appropriateness of the proposed catchment-based classification as water management units for hydrology, and contrast this to other spatial frameworks that could be used for water quality and ecology.
Data for models	Inadequate coverage of data within geological provenances for comparison of water resource monitoring data.	Expand the geological portion of the REC to include more classes.
Obtain new data	Lack of monitoring sites within geological provenances.	Target groundwater systems (aquifers) by installation of bore fields, for comprehensive monitoring and data comparison. This includes groundwater – surface water interaction.
Obtain new data	Improve calculated statistical relationships between continuously gauged and ungauged catchments.	Continue flow monitoring within catchments that do not currently have a permanent gauging station.
Obtain new data	Lack of flow monitoring in catchments where this has been identified.	Implementing new flow monitoring sites as needed.
Obtain new data	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater to waterways (springs, base-flow to rivers and wetlands) within the Kaituna WMA and the relative nutrient load contributed from groundwater sources.
Obtain new data	Need for improved understanding of infiltration rates to subsurface storage.	Maintain and monitor existing sites until robust statistical relations have been developed. Install new sites to obtain adequate coverage.
Obtain new data	Lack of isotope and water quality data to understand groundwater residence time (age), source and flow direction.	Isotope monitoring sites to use as a predictive tool for future water quality and quantity.

Gap theme	Gap	Recommendation
Obtain new data	Sites that are currently over-allocated in the Kaituna WMA lack further hydrological analyses to set minimum flows apart from the default method.	Consider undertaking detailed IFIM surveys of sites that are heavily over-allocated, OR use EFSAP to help set more defensible low flow levels and allocation levels for over-allocated waterways.
Improvements to methods	Data quality analysis.	Establish confidence limits and intervals. Maintain gauging programme to ensure that establish regressions are valid. Investigate new methods, including multiple regression; regional prediction curves; and spatial interpolation. Consider synthetic stream flows.
Improvements to methods	Information on structures in surface water bodies.	Develop a GIS layer that shows the location, size of structure, water volume impounded, available minimum flow downstream, establishment of natural Q5, MALF or relevant parameter prior to establishment of structure.
Improvements to methods	Integrated catchment management workgroup –water.	To establish a group of experts to develop and scope work programme that allows groundwater and surface water resources to be managed as a single resource, where hydraulically connected.
Data for models	Proper assessment as to the accuracy of hydrological models developed by NIWA.	Compare empirically derived flow statistics against flow statistics obtained from hydrological models
Data for models	Permitted take model.	Maintain and update existing numerical model for calculation of estimated permitted water use for inclusion to water allocation methods. Ground-truth model on five-yearly cycle for WMA.
Data for models	Groundwater flow model.	Develop and calibrate models for groundwater and surface water for the development of an integrated water resource management model.
Data for models	Surface water models for base and low flow.	Construct and calibrate model for surface water allocation.
Gap theme	**Gap**	**Recommendation**
Data for models	Lack of proper validation of EFSAP model low flows.	Undertake validation of modelled habitat retention obtained through EFSAP to data obtained from a detailed IFIM surveys
Data management	Lack of regular technical reporting.	Five-yearly technical report, annual summary report, up-to-date data on BOPRC website (or LAWA).

Part 5: Groundwater

5.1 Introduction

For the Kaituna WMA, the spatial extent of the groundwater systems have been 'mapped' using EarthVision, a 3D conceptual model of the geology beneath ground surface. Lithological data from BOPRC Wells database and GNS Science geological maps were used to construct the spatial model of our groundwater systems. For the Kaituna WMA seven groundwater systems have been identified. The groundwater systems are not named; therefore the geological unit that the aquifer occurs in has been used to identify the groundwater systems. These are: Tauranga Group sediments, Mamaku Formation, Rotoiti Formation, Whitianga Group, Waiteariki Ignimbrite, Aongatete Ignimbrite. Most of these layers are mapped in the example below of the geological model construct in EarthVision for the Western Bay area (Figure 11).

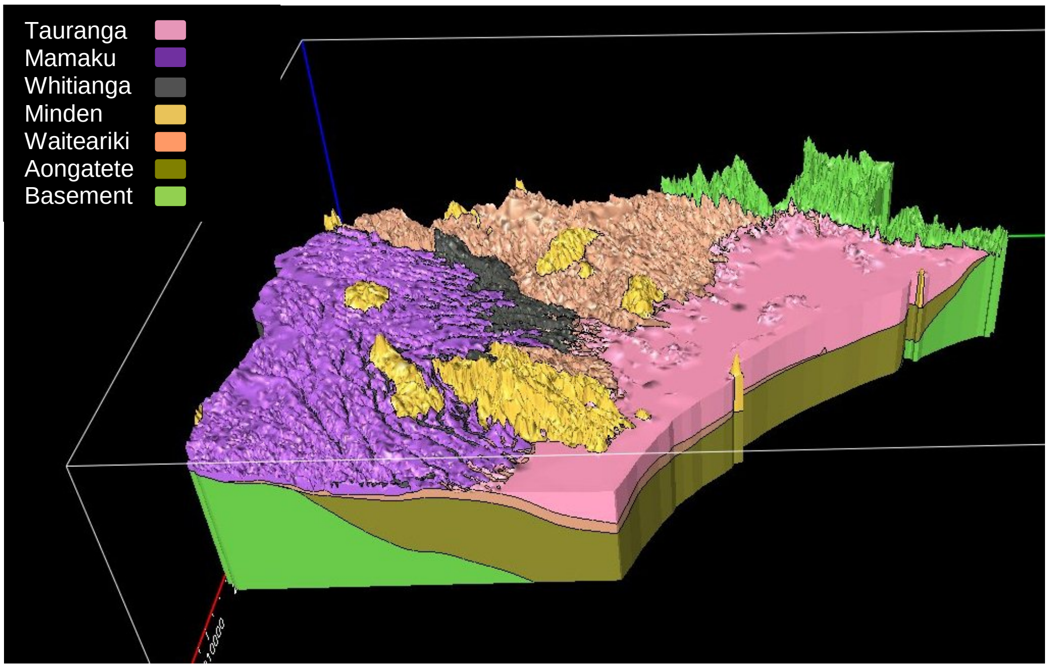


Figure 11 Screenshot of EarthVision 3D model of a portion of the Western Bay area, showing the location and extent of the geological units that contain groundwater systems.

The lithological information and pump test information from groundwater permit applications indicate that the groundwater systems are hydraulically connected to each other and to surface water bodies. This will remain the assertion until future investigations determine otherwise. These types of groundwater systems are known as unconfined or leaky aquifers. The only system that is considered to be confined (not hydraulically connected to other aquifers or surface waters), is the Waiteariki Ignimbrite and Aongatete Ignimbrite systems. However, these systems are considered hydraulically connected to each other.

The evaluation of the groundwater systems of the Kaituna WMA are reported in GNS Science Reports 2008/240 and 2008/134. These reports not only consider the spatial extent of the groundwater systems, but also consider how the systems are replenished, the calculated groundwater flow volume, groundwater quality and allocation. These reports were based on information supplied from the NERMN groundwater monitoring programme and allocation information from the Consents database. The GNS reports recommended improvements to our current monitoring programme and identified information gaps that needed to be addressed. These were incorporated into the review of the NERMN groundwater monitoring programme completed in 2013.

The NERMN groundwater monitoring programme for the Kaituna WMA included nine water level sites and seven water quality sites. However, these sites were not based on representative coverage of the aquifer systems that groundwater was being taken from. The monitoring was based on access to privately-owned bores, most of which were production bores. This meant that the monitoring coverage was not consistent for each aquifer, and the water level data from production bores was skewed due to pumping interference.

In 2013, an assessment of all groundwater monitoring data collected under the NERMN programme was completed and reported in BOPRC Environmental Publication 2013/02. This work assessed the quality of the existing data set and recommendations were made to retain, improve or drop sites from the programme. The report also identified where new sites were required to provide key information.

In 2014, a report was presented to Council setting out the reviewed groundwater monitoring programme and seeking additional funds to implement these changes (BOPRC Environmental Publications 2014/01). One of the recommendations was that further staff resourcing would be required to implement changes to the monitoring programme and information gaps identified in the review. This was addressed by establishing new positions to Environmental Data Services and the new position Environmental Scientist Hydrology. Funds were granted for the improvements to the groundwater monitoring programme. Funding for capital works was sourced from Section 36 Resource Management Act (RMA) charges.

5.2 Overview of current state

The revised groundwater monitoring programme seeks to create a suite of comprehensive monitoring stations at each monitoring site. Benefits of this will include the consolidation of all hydraulic monitoring to one area for correlation of data (in real-time), ease of access, reduced travel time, shared use of equipment, and efficient operational maintenance.

Existing rainfall recorder sites have been investigated to determine whether a rainfall recharge station can be installed to utilise existing access, equipment and data. In the same manner, existing groundwater monitoring sites have been investigated to determine suitability to have a bore field installed to target each groundwater system that lies beneath (Table 13).

Table 13 Proposed groundwater monitoring programme for Kaituna WMA.

Kaituna WMA	Water level and water quality	Salt water intrusion	Rainfall recharge
Retain existing sites as is	4	2	2
Upgrade existing sites	8		
New installations	4		2
Totals	**16**	**2**	**4**

The springs in the Kaituna WMA are the surface expression of groundwater. Groundwater supports the flow of many streams and rivers within the Kaituna WMA. Recommendations on further work to understand this resource are provided in the Hydrology section of this report.

High groundwater use occurs on the Kaituna plains and to some extent the low hills just above the plains. These areas are the focus for the Kaituna WMA groundwater monitoring programme to assess use and impacts.

Recommendations related to monitoring in the Kaituna WMA are shown in Figure 12, whereby:

- The orange dots show the location of completed monitoring stations for salt water intrusion.
- The blue squares show the location of completed rainfall recharge stations.
- The blue dots show the location of completed monitoring bores for water level and water quality.
- The white circles are areas being investigated for the installation of bore fields (to targeted groundwater systems) and to better understand springs.

Drilling and installation of new monitoring bores within the heavily utilised Tauranga Group sediment groundwater system has begun (2014/2015). The remaining deeper systems are to be targeted progressively over the next two to three years.

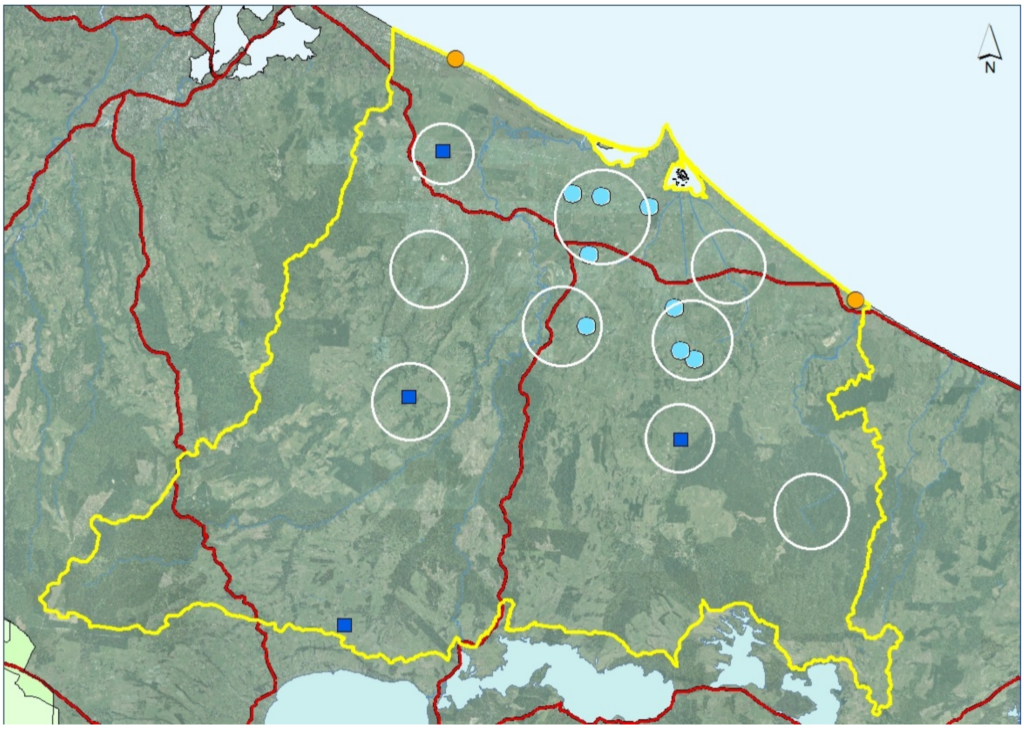


Figure 12 Proposed groundwater monitoring sites for Kaituna WMA (yellow outline) presently being implemented (see text for explanation of coloured site indicators).

The assessment of the NERMN level monitoring data for the Kaituna WMA showed that Bore 2,822 (121 m depth) in the Pongakawa area has a declining water level trend. It is unclear at this time whether the decline is localised or extends over the WMA, due to lack of targeted monitoring bores in crucial locations.

The assessment of the NERMN quality monitoring data for the Kaituna WMA showed that Bores 3,034 (10 m depth); 3,566 (122 m depth); 4,968 (10 m depth) had levels of Nitrate-Nitrogen (NO_3-N) that indicated anthropogenic effects (median concentration above 1.6 g/m3 NO_3-N).

The assessment of the Kaharoa rainfall recharge site (BOPRC Environmental Publication 2010/21) showed that 50% of the mean annual rainfall volume infiltrated to ground storage. During winter up to 70% rainfall infiltrated to ground storage. This compares to summer where as low as 20% rainfall infiltrated to ground storage. The default NES allocation limit for aquifers is up to 35% of the average annual recharge.

5.3 Information on current state

A work programme is planned and underway for the Kaituna WMA to address information gaps and improve data. This programme has 10 elements: seven monitoring, two modelling, and one regulatory. The list below summarises the groundwater monitoring programme being implemented and a brief of each work programme for the Kaituna WMA.

1 Bore fields (level and quality - automated continuous data; aquifer testing).

2 Bore log and core samples (informs model).

3 Rainfall recharge (recharge zones).

4 Salt water intrusion.

5 Isotope.

6 Spring (surface expression of groundwater).

7 Groundwater-surface water interaction (as one resource).

8 Groundwater flow model (MODFLOW & ArcGIS).

9 EarthVision Model update.

10 Resource Management Act consented and permitted takes (allocation).

5.3.1 Bore field (partial information gap being addressed)

Where possible monitoring sites will be consolidated into bore fields. This will be a monitoring station where a number of bores are installed to target depths (aquifers) for regular water level and quality sampling. These stations may also include rainfall recorders, lysimeters, soil moisture probes, and where appropriate, hydrological sites. These comprehensive monitoring sites aim to be automated as much as possible for real-time data assessment and resource management.

Aquifer testing is required to determine hydraulic conductance and connectivity within aquifers, between unconfined, semi-confined aquifers, and also between aquifers and surface water bodies. The current default is to use pump test data from groundwater permit applications.

5.3.2 Bore log and core samples (partial information gap being addressed)

A programme of drilling is planned and being undertaken to establish designated monitoring bores to target aquifers. This will provide adequate coverage for resource management. The lithology is being recorded and samples taken. These samples are examined to determine the geological unit being drilled through. This provides robust data for the conceptual geological models. Each aquifer is being hydraulically tested, samples for water quality analysis taken, and isotope work completed to provide robust data on aquifer properties for the groundwater flow models planned for development.

5.3.3 Rainfall recharge (gap being addressed)

At the time the GNS models were constructed and mass water balances calculated for the Kaituna WMA the only data available for rainfall infiltration rates to storage was located at Kaharoa. It was identified that rainfall and rainfall infiltration rates to storage are crucial to the water balance calculation. Infiltration data can be used to calculate groundwater flows and manage allocation. Three rainfall recharge sites have since been installed and set up with automated continuous monitoring.

Analysis of rainfall infiltration (lysimeter) data has only been completed for the Kaharoa site, as this site has the longest data record. This data was last assessed in 2010. Work is planned to analyse the data sets from both the Kaharoa and Pongakawa Bush Road sites. This data will help inform the groundwater flow model for the Kaituna WMA.

The lysimeter sites are located under pastoral land use (not irrigated). The infiltration to storage beneath other land use has not been considered. This would be relevant for understanding recharge rates under different land uses in the WMA: exotic forest, native forest, horticulture and irrigated sites. This may also provide information on nutrient loss.

5.3.4 Saltwater intrusion (gap being addressed)

The groundwater systems of the Kaituna WMA discharge to the coast. There is a hydraulic connection with salt water. The pressure gradient, within the aquifer to the coast changes when water is taken from the groundwater systems. Saltwater can move inland. The location of the freshwater–saltwater interface has been investigated for the Kaituna WMA. Two continuous automated monitoring sites are established to track the behaviour of the interface over time. If the risk of salt water contamination of fresh groundwater resources increases then further monitoring sites could be required.

5.3.5 Isotope (partial information gap)

The monitoring of isotopes has not been part of the NERMN monitoring programme. Work has been completed for some groundwater systems under the BOPRC drill programme, by District Councils, and GNS Science for research purposes. The value of isotope analysis is that the data can provide crucial information about residence time, flow direction, source of recharge and groundwater flow. It supports work to determine groundwater flow to surface water bodies within the Kaituna WMA, and can provide a unique signature to identify the aquifer.

5.3.6 Spring (gap not yet addressed)

Springs are the surface expression of groundwater. The quantity and quality of spring flows has not been part of the NERMN monitoring programme. Data is required on the volumes of groundwater that leave the system to provide spring flow to surface water bodies. The flow needed to support surface water values can then be accounted for when setting allocation limits for the groundwater systems. To determine these flows and manage allocation of the groundwater resource requires that springs be part of our regular monitoring programme. This data (flow, quality and isotopes) will also support allocation from surface waters in relation to the Q_5, MALF and IMFR.

5.3.7 Groundwater – surface water interaction (gap not yet addressed)

Within the Kaituna WMA are unconfined; semi-confined (leaky) groundwater systems that are hydraulically connected to surface water. Many of the spring-fed rivers and streams within this WMA are sourced from groundwater. Along the length of a stream, from hill country to the coast, water can flow into and out-of the stream system from groundwater; groundwater feeds to surface water systems (springs, streams, rivers and wetlands) in some areas, and surface water feeds the unconfined groundwater systems in other areas.

There are currently no monitoring regimes to measure and understand this interaction. This interaction becomes important when needing to manage water resources and s*et al*location limits for both surface water and groundwater. Water allocation from groundwater systems has the potential to impact on spring flows and affect in-stream flow requirements for a number of streams in the Kaituna WMA.

New NERMN programmes established under the Surface Water Quantity and Quality programmes will be of relevance to the understanding of groundwater-surface water interaction for the purpose of allocation.

5.3.8 Groundwater flow model (gap being addressed)

The proposal for development of a groundwater flow model for the Kaituna WMA has been funded. The aim of the model is to be able to predict groundwater flow and groundwater-surface water interaction under various water allocation scenarios to inform assessment of long-term sustainable management of the water resource. This model construct has been planned for future use in an integrated catchment model.

5.3.9 EarthVision model - update (gap being addressed)

The conceptual models of the geology (groundwater systems) were constructed during 2006-2007 for the Western Bay area. Since this time, improvements to data entry and quality checks, additional bore information, updates to Digital Terrain Mapping, and updates to national geological mapping in New Zealand, has meant that recent valuable information is not included. To address this, a proposal is being prepared for the ongoing update and maintenance of these models so that the information and model remain relevant.

5.3.10 Resource Management Act consented and permitted takes - allocation impact (gap being addressed)

Kaituna WMA has been identified as a priority area for water allocation. Groundwater evaluation reports completed by GNS provided an estimate of groundwater available for allocation. When this was compared to resource consent takes, it was shown that groundwater allocated could be exceeding volumes of recharge, i.e. more groundwater was being taken than could be replenished. This raised concerns about the sustainable management of the groundwater resource.

In the absence of groundwater allocation policy in the Regional Water and Land Plan, the default allocation regime is the Proposed National Environmental standard on ecological flows and water levels. Estimated actual consented use, calculated estimated groundwater flow, and default allocation limit flagged this area as having allocation concerns. Allocation pressure needed to be investigated further and a better understanding of how the groundwater systems responded over time.

Part of the allocation calculation necessarily includes estimates of water use covered by permitted activities under the RMA and WLP. A numerical model has been constructed to provide estimated volumes and field work undertaken to ‘ground-truth’ the model. The results from this model will form part of the overall water use budget and allocation for the Kaituna WMA.

5.4 Gaps and recommendations

Recommendations to improve the data record and knowledge of the Kaituna WMA water resources have been briefly described in Section 10.3. These recommendations have been listed in Table 14, and further set out in the Current State Project Gap Identification and Prioritisation Template spreadsheet attached.

Table 14　Recommended solutions to address gaps in current knowledge.

Gap theme	Gap	Recommendation
Data for models	Inadequate coverage of data within geological provenances for comparison of water resource monitoring data.	Expand the geological portion of the REC to include more classes.
Data for models	Improve conceptual understanding of subsurface geology.	Designated bore fields to target depths. Record lithology and obtain cores for geological unit identification.
Obtain new data	Lack of monitoring sites within geological provenances.	Target groundwater systems (aquifers) by installation of bore fields, for comprehensive monitoring and data comparison. This includes groundwater–surface water interaction.
Obtain new data	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater to waterways (springs, base-flow to rivers and wetlands) within the Kaituna WMA and the relative nutrient load contributed from groundwater sources.
Data for models	Lack of information on hydraulic conductance within aquifers, between unconfined, semi-confined aquifers, and also between aquifers and surface water.	Hydraulic pump testing of the aquifer systems within the Kaituna WMA and surface water bodies.
Obtain new data	Need for improved understanding of infiltration rates to subsurface storage.	Maintain and monitor existing sites until robust statistical relationships have been developed. Install new sites to obtain adequate coverage.
Obtain new data	Risk of saltwater contamination to fresh groundwater resources.	Maintain and monitor existing sites to understand movement of freshwater-saltwater interface with pumping stress over time. Establish new sites if necessary to address risk.
Obtain new data	Lack of isotope and water quality data to understand groundwater residence time (age), source and flow direction.	Isotope monitoring sites to use as a predictive tool for future water quality and quantity.
Improvements to methods	Integrated catchment management workgroup –water.	To establish a group of experts to develop and scope work programme that allows groundwater & surface water resources to be managed as a single resource, where hydraulically connected.

Gap theme	Gap	Recommendation
Improvements to methods	Frequency and interval of monitoring to establish trends for both quality and quantity.	Standardise monitoring timeframes to provide data that can be assessed over time for trend analysis. Increase use of automated continuous monitoring sites for water level data over time. For water quality, increase the frequency and establish regular sampling intervals, to allow for trend analysis over time (seasonal change).
Data for models	Permitted take model.	Maintain and update existing numerical model for calculation of estimated permitted water use for inclusion to water allocation methods. Ground-truth model on fiver-yearly cycle for WMA.
Data for models	Conceptual groundwater model.	Maintain and update existing conceptual groundwater models from Wells database, updated DTM and geological maps.
Data for models	Groundwater flow model.	Develop and calibrate models for groundwater and surface water for the development of an integrated water resource management model.
Data management	Lack of regular technical reporting.	Five-yearly technical report, annual summary report, up-to-date data on BOPRC website (or LAWA).

Part 6: Freshwater quality – rivers and streams

6.1 Introduction

River water quality in this section refers to the physical and chemical properties of flowing freshwater (e.g. temperature, dissolved oxygen, water clarity). The indicator bacteria *E.coli* is also included as an indicator of bacterial contamination in the waterway. Other factors of water quality such as periphyton and cyanobacteria are covered in Parts 7 and 8 in this report.

Water quality is impacted by many natural factors (e.g. climate, geology) and anthropogenic factors (e.g. land use change, point-source discharges). Water quality in a river or stream can impact its ability to support healthy aquatic ecosystems and protect or provide for desired values. For example, increased sediment in a waterway could reduce a river's aesthetic and recreational appeal as it would look brown or dirty. Increased sediment may also make substrate conditions in the river unsuitable for many invertebrate taxa, and for many fish species that require clean gravels for spawning.

BOPRC monitors a number of water quality parameters. These include some that are compulsory national attributes in the NPS-FW and some that are not. All are reported here as it is possible that some of the parameters will be assigned as attributes in the future. Note also that some future attributes may not be monitored at all (e.g. urban contaminants). This report does not assess which attributes would be most appropriate to support the range of values associated with the Kaituna WMA.

6.2 Information reviewed

Currently 11 sites within the Kaituna WMA are sampled as part of the NERMN programme. There are two NERMN modules relevant to this review: river water quality sampling and recreational bathing sampling. The current sites and sampling details are provided in Table 15 for both the river and recreational bathing programmes. The sites are as follows:

- two sites with long-term monthly sampling since 1990,
- one site with quarterly monitoring from 1991-2005, and monthly monitoring since 2006,
- four sites on a rotation sampling programme whereby monthly sampling is undertaken for a year, once in every three years since 1990 (one site), 1995 (one site) or 1999 (two sites),
- two impact sites monitored quarterly since 1990 (one site), or quarterly from 1992-2008, then monthly from 2008 (one site), and
- two sites sampled weekly over summer each year since 2005 (one site) or 2010 (one site).

Table 15 *NERMN River monitoring sites, parameters monitored, sampling frequency and length of data record within the Kaituna WMA. Grey boxes indicate sites in the NERMN Rivers programme, yellow boxes are sites in the NERMN recreational bathing programme.*

NERMN site name	**Site ID**	**Parameters monitored**	**Sampling frequency**	**Data record**	**River flow**
Kaituna at Lake Rotoiti Outlet	BOP110026	Temperature, dissolved oxygen, pH, water clarity, conductivity, NH_4-N, NO_x-N, TN, DRP, TP, turbidity, TSS, colour coefficient, *E.coli*, Faecal Coliforms, *Enterococci*, chlorophyll-a.	Monthly	1990-present	Yes*
Kaituna at Te Matai Rail Bridge	BOP110028		Monthly	1990-present	Yes*
Kaituna at Maungarangi Road Bridge	BOP110027		Quarterly 1991-2005 Monthly since 2006	1991-present	Yes*
Kaituna at AFFCO Intake Pontoons	BOP210050	Temperature, dissolved oxygen, pH, conductivity, NH_4-N, NO_x-N, TN, DRP, TP, turbidity, TSS, colour coefficient, *E.coli*, Faecal Coliforms, *Enterococci*, chlorophyll-a.	Quarterly 1992-2008 Monthly since 2008	1992-present	Yes*
Kaituna D/S of Waiari Stream	BOP210130 BOP110139		Monthly	2005-present	Yes*
Pongakawa at SH 2 Bridge	BOP110030	Temperature, dissolved oxygen, pH, water clarity, conductivity, NH_4-N, NO_x-N, TN, DRP, TP, turbidity, TSS, colour coefficient, *E.coli*, Faecal Coliforms, *Enterococci.*	Monthly on three year rotation	1990-present	Yes#
Pongakawa at Old Coach Road (or Valley Rd Bridge)	BOP110112		Monthly on three year rotation	1999-present	Yes#
Pongakawa at Pumphouse	BOP110118		Monthly on three year rotation	1999-present	Yes#
Waitahanui Stream at SH 2 Bridge	BOP110095		Monthly on three year rotation	1995-present	Yes^
Kaituna River at Trout Pool Road	160112	*E.coli*	Weekly over summer	2005-present	N/A
Pongakawa River at SH 2~	110030	*E.coli*	Weekly over summer	2010-present	N/A

* derived from permanent telemetered rated site at BOP110028.
# manually gauged during water quality sampling.
^ permanent telemetered rated site.
~ This site is also part of the NERMN Rivers programme, thus monthly water quality data is available in addition to the weekly summer E.coli data.

Comparison of NERMN river sampling sites with their corresponding REC class (Table 16) shows that streams in the cool wet climate classification have been over-represented and both cool and warm extremely wet classifications have been under-represented. As a result of the high number of sites on the main stem of the Kaituna River (five out of nine sites in the Kaituna WMA), the lake-fed source-of-flow category has been over-represented and both the lowland and hill classifications have been under-represented. All sampling sites drain from volcanic geology with pastoral land cover over-representing both of these categories. Given that 97.5% of waterways in the Kaituna WMA drain from volcanic geology, there is a slight under-representation of alluvium and miscellaneous categories. Exotic and indigenous forestry, scrub and urban land use are under-represented.

Finally, most of the sampling is from medium or large streams, with small order streams under-represented. Note that the sampling design behind the current NERMN monitoring sites was focused on identifying trends and spatial patterns down large rivers such as the Kaituna (an important river for the public) rather than representing all waterways within this WMA. This analysis simply highlights that the new requirements of the NPS-FW will require more monitoring on waterways that were not considered under the original aims of the NERMN programme.

Table 16 Calculated percentage stream length in different REC classes for climate, source of flow, geology, land cover and stream size within the Kaituna WMA, and number and percentage of NERMN water quality monitoring sites in each class.

Variable	Value	% of WMA stream length	No. WQ Sites	% WQ sites
Climate class	Warm-extremely wet	8.3	0	0.0
	Warm-wet	76.1	7	77.8
	Warm-dry	0.6	0	0.0
	Cool-extremely wet	7.9	0	0.0
	Cool-wet	7.1	2	22.2
Source of flow	Hill	11.9	0	0.0
	Lowland	85.3	4	44.4
	Lake	2.9	5	55.6
Geology	Alluvium	0.7	0	0.0
	Soft sedimentary	0.1	0	0.0
	Miscellaneous	1.7	0	0.0
	Volcanic acidic	97.5	9	100.0
Land cover	Exotic forestry	18.5	0	0.0
	Indigenous forestry	11.3	0	0.0
	Pastoral	68.7	9	100.0
	Scrub	0.1	0	0.0
	Urban	1.4	0	0.0
Stream size	Small (order 1+2)	74.3	0	0.0
	Medium (order 3+4)	21.3	2	22.2
	Large (order 5+)	4.4	7	77.8

In addition to NERMN sampling, there have been numerous surveys on water quality within the Kaituna WMA. The following reports are particularly relevant:

- **Water Quality Survey of the Lower Kaituna Catchment 2007-2008 (Park, 2010).**

  This study of the lower Kaituna catchment downstream of Ōkere Falls sampled seven sites monthly for 12 months and captured the major inflowing tributaries of the lower Kaituna River (Kopuaroa, Raparapahoe, Ohineangaanga, Waiari and Parawhenuamea Streams, and the Mangorewa River). In addition, the study captured samples from eight sights during two rainfall events and analysed for suspended solids, turbidity and nutrients.

- **Lower Kaituna Catchment and Water Quality (Park, 2007).**

  This report presented available water quality data up to the end of 2006 and included four freshwater sites (Kaituna at Ōkere where the Kaituna flows out of Lake Rotoiti, Kaituna at Maungarangi Road near Paengaroa, Kaituna above the AFFCO Rangiuru freezing works and Kaituna at Te Matai), and one estuarine site at Te Tumu where the Kaituna River discharges to the sea. These sites are all part of the current NERMN rivers (freshwater sites) or estuary (estuarine site) programmes.

- **Impact of the Ōhau Channel Diversion on the Ōkere Arm, Kaituna River and Maketū Estuary (McIntosh, 2005).**

  This report detailed the water quality in Lakes Rotorua and Rotoiti, and the Kaituna River as part of the investigation into the impacts of the Ōhau Channel Diversion. The sites in the Lower Kaituna (downstream of the lakes) were at Ōkere Falls, Maungarangi Road near Paengaroa, Kaituna above the AFFCO Rangiuru freezing works and Kaituna at Te Matai, and one estuarine site at Te Tumu where the Kaituna River discharges to the sea. These sites are all part of the current NERMN rivers programme.

- **Distribution of plant nutrients in the Kaituna River (White *et al.,* 1978).**

  This study sampled nutrients at 12 sites along the Kaituna River from Ōkere Falls, to the river mouth, and one site on each of the six main tributaries (Mangorewa, Parawhenuamea, Waiari, Ohineangaanga, Raparapahoe (Atuaroa) and Kopuaroa).

- **Ecological surveys of the Ohineangaanga Stream (Bioresearchers, 1977, 1978, 1979, 1980a, 1980b 1982, 1983, 1985).**

  These surveys sampled water quality and ecology both upstream and downstream of the discharge from the Te Puke Dairy Factory once each year with the objective of determining the impact from the discharge.

- **Ecology of the Kaituna River (Bioresearchers 1975a).**

  This survey sampled water quality and ecology at four sites along the Kaituna River and one site on the Mangorewa River, upstream of its confluence with the Kaituna River.

- **Ecological monitoring surveys of the Bay of Plenty (Bioresearchers, 1974, 1975b, 1975c).**

  These surveys sampled water quality and ecology at four sites along the Kaituna River (as well as sites on the Tarawera, Rangitāiki and Whakatāne Rivers, Te Rahu Canal and Ōhau Channel).

- **Impact Assessments of the AFFCO Rangiuru Abattoir (Bioresearchers, 1986, 1993).**

  These surveys sampled water quality and ecology above and below the discharge from the abattoir at Rangiuru with the objective of determining the impact from the discharge.

The Ministry for the Environment (MfE) commissioned an extensive review of freshwater monitoring protocols and reporting nationally as part of the New Start for Fresh Water programme (NIWA, 2012). The outcomes of the review have been the development of recommended variables and sampling regimes to provide national consistency for state of environment water quality monitoring. The key water quality recommendations from the report were:

- sampling should be monthly, within ± 1 hour of previous sampling events and occur in all flow and weather conditions (where practicable and safe to do so),
- all sites should have corresponding stream flow available that corresponds to sampling events,
- visual clarity should be measured on each sampling occasion, with alternative methods used during high-flow conditions (see NIWA, 2012 for details),
- consistent field protocols be used (preferably nationally agreed protocols), and
- reliable and accurate site metadata to be recorded.

There have also been three reviews of BOPRC monitoring programmes relevant to this report.

- **Review of BOPRC Natural Environment Regional Monitoring Network freshwater quality (Hamill, 2012).**

  This project reviewed freshwater quality NERMN monitoring programmes and evaluated their effectiveness for spatial representativeness, QA/QC protocols and the adequacy of variables/frequency for meeting the Council's functions under the RMA. Key recommendations from the Hamill report included:

  - increase the number of NERMN river sites in hill fed streams draining non-volcanic geology, and low-elevation streams draining non-volcanic geology,
  - monitor all NERMN sites monthly and phase out rotation sampling,
  - include possible reference sites in the network,
  - increase the number of sites with permanent DO loggers, particularly in large U-shaped rivers,
  - monitor periphyton cover and/or biomass at appropriate sites, and store data using a single taxonomic list,
  - include duplicates/blanks as part of QA/QC protocols,
  - laboratory data entered to the best available estimate (i.e. not censored),

- improve the monitoring and reporting of consents and land use intensity to enable easy integration with NERMN monitoring and assist with trend interpretation, and
- re-survey wetland extent, and initiate wetland condition monitoring.

- **Low-flow monitoring Strategic Review (Ellery and Putt, 2012: Internal Report).**

  This reviewed the hydrologic monitoring network in relation to its effectiveness to provide adequate regional representation for the management of low-flows. Many recommended enhancements to the current network were proposed. Relevant recommendations within the Kaituna WMA included:

  - close site on Pongakawa River at Old Coach Road and install water level and flow recording station at Waitahanui at Ōtamarākau. (NOTE: this action has been completed), and
  - install water level and flow recording station in Kaikokopu, Pokopoko or Wharere Catchment.

- **Review of the NERMN Programme 2014 (Donald, 2014).**

  This reviewed the entire NERMN monitoring programme and made recommendations for enhancement. The recommendations align with those reported in Hamill (2012) and NIWA (2012) and included:

  - increase the number of network sites by 10 (including 1-2 reference sites and sites meeting the non-volcanic and hill or low-elevation fed classes),
  - increase sampling to monthly for all sites, and
  - have flow or stage height recorded at each sampling event.

6.3 Current water quality state in the Kaituna WMA

The following summarises the current state of the waterways based on the best available information. To gain an understanding of the current state of waterways within the Kaituna WMA, water quality data for NERMN sites has been assessed against the National Objectives Framework (NOF). The NOF outlines a series of state 'bands' and a minimum acceptable state (national bottom line) for the following attributes in rivers:

• Periphyton • Nitrate • Ammonia • Dissolved Oxygen	To protect ecosystem health
• E.coli • Cyanobacteria	To protect human health for recreation

Figure 13 shows the nitrate bands within the Kaituna WMA. Four out of the seven NERMN sites fall within the ‘A’ band which is deemed unlikely to have toxicity effects on sensitive species (NPS, 2014). The three sites on the Pongakawa River all lie within the ‘B’ band, which may cause some growth effects on up to 5% of species in a waterway (NPS, 2014).

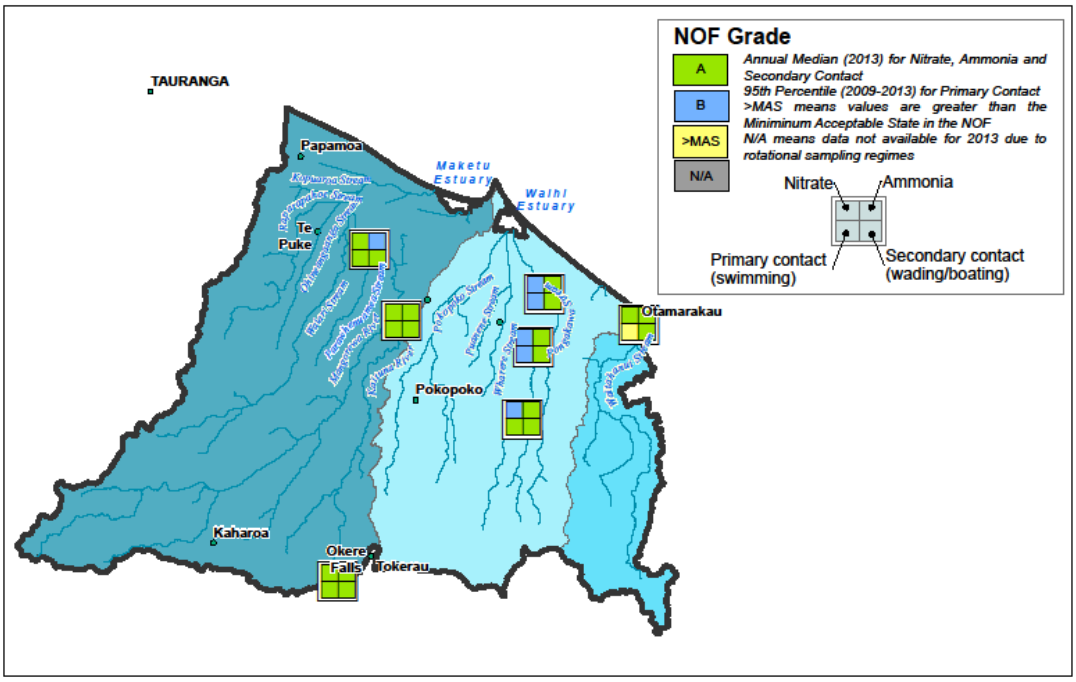


Figure 13 NOF Banding within the Kaituna WMA.

Figure 13 shows that all sites within the Kaituna WMA with the exception of Kaituna at Waitangi fall within the ‘A’ band for Ammonia. The ‘A’ band is designed to protect 99% of species, and the ‘B’ band 95% of species. In the ‘B’ band, ammonia toxicity starts to impact on 5% of the most sensitive species in a waterway (NPS, 2014).

The NOF outlines two levels of protection for human health based on the indicator bacteria *Escherichia coli (E. coli)*. These levels are based on the level of immersion in water, and relate to the risk of exposure to faecal contamination. Primary contact refers to activities that involve full immersion in water, like swimming. Secondary contact refers to activities like wading and boating that involve occasional immersion in water, and the possibility of ingesting water. Figure 13 shows that all three NERMN sites on the Kaituna River are classified ‘A’ band for primary contact (swimming), which is deemed to have a ‘low risk’ of infection from swimming (up to 1% risk; NPS, 2014). The two most downstream sites on the Pongakawa River are classified ‘B’ band, which is deemed to have a ‘moderate risk’ of infection from swimming (up to 5% risk). The bottom end of the ‘B’ band also represents the minimum acceptable state for swimming. The site on the Waitahanui Stream does not meet the minimum acceptable state for primary contact in the NOF.

Figure 13 also shows that all seven NERMN sites in the Kaituna WMA are categorised ‘A’ band for secondary contact recreation (e.g. wading, boating). This is deemed very low risk (<0.1% risk) of infection from contact with water during activities (NOF, 2014).

A similar picture exists when reviewing the summer surveillance of recreational bathing sites (refer Table 17). Kaituna at Trout Pool Road is graded in the 'A' band for both primary and secondary contact. Kaituna at Te Matai is graded 'A' for secondary contact, and 'B' band for primary contact. The Pongakawa River at SH 2 fails to meet the minimum acceptable state for primary contact, however is graded 'A' band for secondary contact. There are currently no monitored recreational bathing sites on the Waitahanui Stream.

Table 17 *NOF Banding for Human Health for primary contact recreation (E.coli 95th percentile 2009-2014) and secondary contact recreation (annual median 2013-2014).*

Site	NOF 1º (swimming)	NOF 2º (wading/boating)
Kaituna River at Trout Pool Road	A	A
Kaituna at Te Matai	B	A
Pongakawa River at SH 2	>MAS	A

Routine periphyton monitoring has not been established in the Bay of Plenty region, and this is a knowledge gap that is currently being addressed. This is important as the NOF nitrate bands are based on toxic effects, and the fact that the A band is achieved at a particular site does not necessarily rule out the possibility that nitrate is an issue for periphyton, and results in unacceptably high periphyton biomass. Additionally, continuous dissolved oxygen is currently only monitored at one site on the Tarawera River (outside the Kaituna WMA).

6.4 Water quality trends

Whilst current state gives an indication of the state of waterways, trends indicate whether or not a particular parameter (e.g. water clarity, *E.coli*) is getting better or worse over time. Table 18 shows the 10 year water quality trends for the key attributes in the NOF (Scholes, 2015).

Table 18 *Trends in water quality parameters. ▲= declining water quality, ▼ improving water quality, NT = No Trend apparent (Scholes, 2015).*

Site	Nitrate	Ammonia	*E.coli*
Kaituna at Lake Outlet	▲	▲	▼
Kaituna at Maungarangi	▲	NT	NT
Kaituna at Waitangi	▲	▼	▼
Pongakawa at Old Coach Road	▲	NT	NT
Pongakawa at SH 2	▲	NT	NT
Pongakawa at Forest	▲	NT	NT
Waitahanui at Otamarakau	▲	NT	NT

There are worsening trends for nitrate at all sites within the Kaituna WMA and this trend has been documented over time (e.g. Taylor and Park, 2001; Park, 2007; Scholes, 2009). However, recent increases in nitrate in the Kaituna River can in part be attributed to improving water quality in Lakes Rotorua and Rotoiti which are primary sources of flow for the Kaituna River. This improvement has resulted in a decrease in phytoplankton growth in these lakes and hence a reduction in nitrate uptake which also results in higher nitrate concentrations in the Kaituna River. In contrast there is an improving trend for *E.coli* bacteria at two sites, and this has been attributed to improvements in discharge quality from the AFFCO Rangiuru meat processing site (Park, 2007).

6.5 Gaps and recommendations

There are many factors, both natural and human induced, that impact on water quality and all need to be considered in the discussion of setting water quality limits. For example, consideration needs to be given (but not restricted to) the following:

- Existing water quality (Policy CA3 in NPS-FW).
- Connection between water bodies (Policy B1 b).
- Sensitivity of, and connectivity with, downstream receiving waters (e.g. estuaries) (Policy A1 a ii and iii in NPS-FW).
- Natural geological conditions and background levels of contaminants.
- Climate (Policy B1 a in NPS-FW).
- Minimum flows and flood frequency.
- Interaction between groundwater and surface water (Policy B1 b in NPS-FW).

In considering these factors and incorporating the information reviewed above, gaps have been identified that range from improving current methodologies, to establishing new monitoring programmes.

6.5.1 Obtain new data

There are a number of knowledge gaps identified that require gathering new data. For example, continuous dissolved oxygen (DO) is currently only monitored within the region at one site on the Tarawera River (outside the Kaituna WMA), and this knowledge gap has been included in Table 19 below. Dissolved oxygen is a measure of how much oxygen is dissolved in the water. Stream ecosystems both produce and use oxygen. Oxygen is provided to streams from the air, and also from aquatic plants as a by-product of photosynthesis. Conversely, oxygen is consumed within a stream by aquatic animals as they respire, and as organic matter (e.g. leaves, twigs) decompose. Additionally, waste that is discharged into a river (e.g. from industry or stormwater) can also contain contaminants that consume oxygen. Oxygen is needed in aquatic ecosystems to support life. Subsequently, the NOF requires that DO be measured downstream of point-source discharges and this is to protect the value of ecosystem health.

There are currently two significant point source discharges within the Kaituna WMA, one at Rangiuru (Affco) and one at Te Puke (Wastewater treatment plant). Dissolved oxygen should be monitored downstream of both of these discharges in accordance with the time periods outlined in the NOF.

Many streams within the Kaituna WMA are fed by groundwater discharging as springs into the waterways (Livingston, 1975). The contribution of groundwater to the flow of the rivers is, as yet, unquantified. Similarly, the impact of this contribution to water quality is also unknown. Work is currently being proposed to address this gap (see Part 5). Similarly, other gaps identified included the hydrologic links and impacts of waterways with wetlands and the drainage network within the WMA.

6.5.2 Spatial frameworks

Part 2 outlined the overall spatial considerations for implementing the NPS-FW. Building on that discussion, a decision needs to be made on the scale at which freshwater will be managed, monitored and accounted for under the NPSFW. For example, with 1,710 km of waterways within the Kaituna WMA, are the same water quality limits going to be set for every waterway within the WMA (i.e. at a WMA level)? Or are limits going to be set at sub-catchment level?

6.5.3 Improvements to methods and reporting

A number of gaps identified are able to be filled by improving methodologies to bring them in line with current best-practice. For example, changing sampling frequency from quarterly or rotational sampling, to monthly sampling each year, enables trends to be detected over time once sufficient data has been collected. Additionally, having flow recorded for each monthly sampling event allows relationships between flow and contaminants to be built up over time, allows trend data to be corrected for flow, and allows computation of catchment load.

6.5.4 Data management

Similarly, with some improvements to data management practices, some gaps could be partially filled. For example, there is a large amount of water quality data in reports prepared as part of consent applications, this information could be better captured in a database (with appropriate quality coding and reference) and would increase the amount of information available for water quality assessments.

6.5.5 Data for models

It is acknowledged here that models can be a useful tool in analysing changes within a catchment (e.g. the change in downstream nutrient levels if nutrient discharge from a sub-catchment is changed) and this is beneficial when trying to set limits to meet desired values. It is thus recommended that opportunities for model development or modification of existing models be considered for the Kaituna WMA.

Table 19 summarises the gaps identified based on the information reviewed above and gives recommendations on how each gap could be addressed. Wherever possible, these recommendations should be addressed alongside recommendations for other environmental components (e.g. invertebrates, fish, hydrology, soils and groundwater) as these components are all connected within the environment.

It should be noted that other gaps are likely to become apparent as implementation of the NPS proceeds and this list will need to be amended accordingly.

Table 19 Identified gaps for water quality sampling and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Improvements to methods	Monthly water quality sampling (± 1 hr) every year.	Increase the frequency of sampling at four existing sites (Pongakawa at SH 2, Pongakawa at Old Coach Road, Pongakawa at Pumphouse, Waitahanui at SH 2) to monthly every year. Support: Donald (2014), Hamill (2012), NIWA (2012).
Improvements to methods	Flow recorded for each sampling event.	Measure flow (or develop a relationship to predict flow) at Pongakawa at Old Coach Road now that existing flow site has been disestablished. Measure flow or record stage height (to read flow off existing rating curve) for all new sampling sites established. Support: Donald (2014), NIWA (2012).
Data management	Information from consents, compliance and land management be integrated (where applicable) with NERMN data or interpretation.	Ecological or monitoring reports for consents be registered individually in Objective (i.e. not just under consent file). Water quality data from these reports be captured in existing spreadsheets/databases (see recommendation below). Information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) be grouped for each WMA and this information able to be queried/extracted as needed for purposes of interpretation of water quality data. Support: Hamill (2012).
Data management	Easy access to water quality from other sources (e.g. historic sampling, data from consents etc.).	Investigate options to capture, store and maintain a portal to house all water quality data (regardless of source), with appropriate reference and quality coding.
Improvements to methods	Uncensored laboratory data.	Enter data to best estimate with appropriate coding to indicate level of accuracy. Support: Hamill (2012).
Improvements to methods	Sample blanks and duplicates as part of QA/QC protocols.	Incorporate this process as part of standard NERMN sampling. Support: Hamill (2012).

Gap theme	Gap	Recommendation
Obtain new data	Lack of DO profiles, especially in U-shaped streams. AND Lack of DO monitoring downstream of point source discharges.	Install DO loggers below AFFCO and Te Puke wastewater discharges. Loggers should remain in place from 1 November to 30 April to permit comparison against NOF bands. Support: Hamill (2012), NIWA (2012).
Obtain new data	Under-representation of hill and low-elevation fed streams. AND Lack of representation of tributaries discharging into main-stem rivers.	Initiate new water quality sampling site on each of the six tributaries flowing into the Kaituna River, and on the Pokopoko Stream. The location of these sites should coincide with sites selected for water level/flow monitoring (see Part 6). Monitor sites initially for one year and review data to determine whether relationships can be derived to long-term NERMN sites. Monitoring may need to continue beyond one year depending on the strength of relationships and the applicability of catchment models. Support: Hamill (2012)*
Obtain new data	Underrepresentation of dominant stream classes in the region (based on REC).	Add 10 new permanent monitoring sites to the NERMN Rivers network to better represent dominant waterways in Bay of Plenty. Support: Hamill (2012), Donald, (2014)
Improvements to Methods	Consistent and regular visual clarity sampling.	Visual clarity be measured on each sampling event irrespective of stream flow. Alternate methods to be used during periods of high flow. Support: NIWA (2012)
Data for models	Cumulative impact on receiving environments.	Consider the desired values in receiving environments (i.e. estuaries), establish assimilative capacity of receiving environment for the chosen variable(s), and then work upstream into the catchment to ensure limits in receiving environment can be met.
Identify values	Values for waterways.	In collaboration with communities, establish agreed values for waterways within the Kaituna WMA. This will enable better direction of additional monitoring to meet the needs of NPS implementation.

Gap theme	Gap	Recommendation
Obtain new data	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater into the waterways within the Kaituna WMA and the relative nutrient load contributed from the groundwater springs.
Spatial frameworks	Definition of spatial scale for limit setting.	Decision needs to be made on the scales that water quality limits will be set on. For example, with 1,710 km of waterways within the Kaituna WMA, are the same water quality limits going to be set for every waterway within the WMA (i.e. at a WMA level)? Or are limits going to be set at a sub-catchment level?
Data for models	Model of water quality within the Kaituna WMA.	Investigate opportunities for model development (or modifying existing models) to support decision-making and estimation of cumulative impact on waterways.
Obtain new data	Impact of drainage canals.	Investigate the impact the drainage network is having on downstream water quality.
Obtain new data	Connection with wetlands and wetland extent.	Re-survey wetland extent, determine connection with waterways, and incorporate WQ monitoring in wetland monitoring programme where there is a hydrologic connection. Support: Hamill (2012).

*This only partially fulfils the recommendations from Hamill (2012) which were to increase sites from hill-fed or low-elevation fed streams in non-volcanic geology. Given that volcanic geology comprises 97.5% of the catchment, there seems little benefit installing sites that fit the category and only represent 2.5% of the catchment. The recommendation in Hamill (2012) applied to the whole Bay of Plenty region, not specifically the Kaituna WMA.

Part 7: Periphyton

7.1 Introduction

Periphyton is the term used to describe the slime that grows attached to rocks, stumps, and other stable substrates in rivers and streams. It is composed mostly of algae, although it can also contain quantities of fungi and bacteria. It is a natural component of rivers, and provides an important food source for invertebrates. It is also an important indicator in changes of water quality as any increases in stream nutrient levels may result in excessive growths of periphyton (called a bloom). Periphyton blooms have detrimental impacts on not only the ecological value of rivers, but also their recreational, aesthetic and cultural values.

Periphyton biomass can influence many in-stream values, such as recreation, aesthetics, and ecology. In recognition of this, MfE has produced interim guideline values for periphyton biomass for the maintenance of aesthetics, benthic biodiversity, and trout habitat and angling (Biggs, 2000). These guidelines use a measure of either cover estimates of diatoms/cyanobacteria or filamentous algae, or measures of chlorophyll-a (the photosynthetic pigments that is found in all algae). For example, maintenance of aesthetics and recreation would be achieved in rivers having less than 60% cover of a thin (<0.3 cm thick) diatom films, or less than 30% cover of filamentous algae (less than 2 cm long). Benthic biodiversity would also be maintained if a maximum of chlorophyll-a concentration of <50 mg m^{-2} is maintained (Biggs, 2000).

More recently, (Matheson et al. 2013) highlighted a number of limitations of the Biggs (2000) guidelines. One was that the MFE guidelines provided separate thresholds for mat forming algae (such as the diatoms and cyanobacteria) and filamentous algae. However, it is possible for combined cover by both types of periphyton to be high, while cover by each type is below the MfE threshold. For example, 30% cover of diatom/cyanobacterial mats combined with 25% cover of filamentous algae (each of which meets the respective MFE guideline) is likely to constitute an unacceptable condition which would negatively impact in stream values. To solve this anomaly, Matheson et al. (2013) recommended the use of a periphyton weighted composite cover (PeriWCC) such that:

PeriWCC = % filamentous cover + (% mat cover/2)

Matheson et al. (2013) also suggested four bands for PeriWCC such that <20% = “excellent”; 20 – 39% = “good"; 40 – 55% = “fair"; >55% = “poor”. They showed that invertebrate metrics such as the MCI, QMCI and percentage of EPT responded in a relatively consistent manner to increases in PeriWCC, and suggested that these four bands could form the basis of provisional general periphyton cover thresholds to protect benthic biodiversity.

Because of its importance in affecting many in stream values, periphyton biomass (expressed as measurements of chlorophyll-a) is a compulsory attribute under the NOF. Although monitoring periphyton biomass using chlorophyll-a is relatively expensive, Snelder et al. (2013) highlight that this is a single and relevant variable representing periphyton abundance which has been used extensively in New Zealand and overseas. Statistical models relating periphyton biomass to other factors such as water chemistry and flow regimes are generally stronger for Chlorophyll-a than for other measures such as percent cover. Finally, Snelder et al. (2013) emphasise that chlorophyll-a is a standard metric for measuring periphyton abundance internationally, so that any advances in our understanding of factors controlling periphyton growth can be more easily applied if this metric is used in New Zealand.

The NOF sets four bands (A to D) for periphyton biomass, with the D band representing conditions that fail to meet the national "bottom line". The NOF chlorophyll bands also include an exceedance frequency, recognising that even streams flowing through unmodified catchments can experience short lived (weeks to months in duration) algal blooms. However, stream ecosystems are highly resilient to short term algal blooms, and ecological health will generally not decrease if these blooms do not persist for more than a short period of time (Suren et al. 2003a)

7.2 Periphyton monitoring in the Bay of Plenty

BOPRC currently does not monitor periphyton cover, either through the annual invertebrate monitoring programme, or the monthly water quality monitoring programme. This lack of monitoring constitutes a major gap in ecological monitoring and highlights that there is no present ability for BOPRC to comment on either the current state of periphyton biomass in the region (or the Kaituna WMA), or to consider the need for nutrient limits to keep periphyton biomass at acceptable levels (Table 20).

There is limited monitoring of blue green algae cover in some rivers throughout the region. This is restricted to weekly or fortnightly monitoring of cover during the summer months only. However, there has been no blue green algal monitoring of any waterways in the Kaituna WMA.

The amount of periphyton in a stream is generally regarded as a function of both nutrient status and stream flow regime. If BOPRC is to set freshwater objectives that include periphyton biomass in streams, and set limits to resource use accordingly, then we need to understand the interactions between nutrients and flow, and periphyton biomass. Such interactions will also be controlled by other factors such as stream shade and substrate stability. Monitoring periphyton in the region also needs consideration of where such monitoring sites should be.

A document is currently being prepared by BOPRC to outline issues such as where samples should be collected, what other parameters should be collected, and the methods behind these.

7.3 Gaps and recommendations

Table 20 Identified gaps for periphyton sampling and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Obtain new data	Knowledge is required of periphyton biomass (both spatial and temporal variability) of selected sites throughout the Kaituna WMA.	Periphyton biomass be monitored at selected sites throughout the Kaituna WMA.
Obtain new data	Lack of detailed information on the extent of problem blooms.	As part of algal monitoring, monitor the cover of dominant algal groups. This will provide information as to the spatial and temporal extent of any algal blooms.
Spatial frameworks	Under the NPS-FW, councils are expected to create their own Freshwater Management Units. These units need to represent streams which are similar to each other, so that appropriate bands for the compulsory national attributes can be accurately determined.	BOPRC needs to consider which spatial framework is used to create own water management units. These units could be based on either the REC or FWENZ classifications, or an alternative. To assist with decision-making, it may be cost-effective to get input from external experts on this matter.
Data for models	Linkages between periphyton, nutrients and flow.	Where possible, any periphyton monitoring should be done at sites where monthly water quality data is collected, and within continuously gauged catchments, or close to such catchments. This will allow BOPRC to: i) test current models of algal/nutrient interactions, ii) Develop new models of interactions between algae and nutrients.

Part 8: Cyanobacteria

8.1 Introduction

Cyanobacteria are a group of single-celled organisms (bacteria) that live naturally in fresh water worldwide. Because they have chlorophyll, they behave like plants and are capable of photosynthesis. Cyanobacteria are often referred to as 'blue-green algae' even though they are not actually algae. Cyanobacteria can be benthic (live attached to the bottom of a stream) or planktonic (not attached to anything and live floating in the water column). Under certain environmental conditions, such as high levels of light and nutrients and warm water temperatures, cyanobacteria can multiply and congregate to form blooms. For planktonic cyanobacteria, blooms usually present as pea-coloured, soupy looking water or scum on the water surface which may also smell "earthy" or "musty".

For benthic cyanobacteria, blooms often show up as light brown or black mats that cover large cobbles and boulders on the river bed. Some species of cyanobacteria produce toxins which may be harmful to humans and other animals that come into contact with the toxins. In lakes, these toxins have been responsible for fish deaths, as fish swim through and accidentally ingest the small planktonic algae. In rivers, dog deaths have occurred when dogs are attracted to the distinctive smell of cyanobacterial mats that have become dislodged from the riverbed, and which have been washed up on the edge of the river. Fortunately, river cyanobacteria are often quickly washed away from rivers during periods of high flow, and so often disappear in autumn with the onset of seasonal rain.

8.2 Cyanobacterial monitoring in the Bay of Plenty

Because of the potential health risks of cyanobacteria blooms, BOPRC monitors planktonic cyanobacteria in the Rotorua Lakes and the Kaituna River (which is fed from both Lake Rotoiti and Lake Rotorua). The lake cyanobacteria monitoring programme was initiated in the Rotorua Lakes in 1997 in response to blooms that exceeded safe levels for drinking and contact recreation (Scholes, 2009). The core monitoring programme consists of collecting weekly samples over summer from 15 sites in four lakes (Ōkaro, Rotoehu, Rotoiti and Rotorua), and from three sites in the Kaituna River.

All cyanobacterial samples are analysed for cell count and biovolume - a combination of the number of cells counted and the overall size of individual cells. All biovolume results are assessed in line with the Interim New Zealand Guidelines for cyanobacteria (MfE/MoH, 2009) to determine the level of health risk. There are three guideline levels:

- **Green** = biovolume below threshold levels, no health warnings in place.
- **Amber** = biovolume between 0.5–9.99 mm^3/L; increase monitoring to weekly.
- **Red** = biovolume > 10 mm^3/L; initiate public health warnings and potentially consider implementing intervention activities such as alum dosing to help lock up excess nutrients.

A summary of all results is sent weekly to BOPRC lakes operations staff, Rotorua Lakes Council, and Te Toi Ora Public Health. During red alert levels, monitoring is sometimes increased to better determine how long blooms last, and also to monitor the effectiveness of any interventions that may be employed.

BOPRC also monitors benthic cyanobacteria (*Phormidium*) in rivers known to experience blooms. This programme was initiated in 2007 in response to a dog death near Edgecumbe, in the lower Rangitāiki River, where a dog ingested some detached *Phormidium* that had become trapped in some floating aquatic plants. The origin of this detached clump of cyanobacteria in the river is unknown, but most likely would have come from some upstream areas of stable rip-rap that occur along the river. The monitoring programme runs over the summer-autumn period (when blooms are most likely), especially when river flow has been stable, and when *Phormidium* can grow without being washed away during flood events. Monitoring includes estimating the percentage cover of *Phormidium* at five points along four transects at each site, with the mean percentage cover calculated from all 20 observations (Scholes, 2014).

Typical rivers where *Phormidium* blooms can occur are wide, cobble-bed rivers with shallow, fast flowing water. Such rivers include areas of the Rangitāiki, Whakatāne, Otara and Waimana Rivers in the central Bay of Plenty region, and the Uretara and Te Rereatukahia Rivers in the Western Bay of Plenty. *Phormidium* favours these conditions as cobbles provide a stable place for them to attach, and fast flowing water means that they can more efficiently take up nutrient such as nitrogen from the water column. However, *Phormidium* mats have also been observed growing in pumice-bed streams during periods of extended low-flow as this highly mobile material is not easily moved under such conditions (Scholes, 2014).

8.3 Current State of planktonic cyanobacteria

The NOF provides numeric values for planktonic cyanobacteria in lakes and lake-fed rivers that are designed to protect the national value of 'Human Health for Recreation'. The numeric values are based on biovolume or cell count (which reflects the differences in monitoring programmes). Scholes (2015) provides complete assessment of the Rotorua Lakes and Kaituna River sites monitored for planktonic cyanobacteria from 2011–2014 (Table 21).

Table 21 NOF banding for planktonic cyanobacteria biovolume (mm^3/L) from 2011-2014 (from Scholes, 2015).

Cyanobacteria biovolume	2011-2014
Kaituna at Te Tumu	A
Kaituna at Trout Pool	A
Kaituna at Waitangi	A
Lake Okaro	D
Lake Rotoiti at Hinehopu	A
Lake Rotoiti at Okawa Bay	C
Lake Rotoiti at Okere Arm	A
Lake Rotoiti at Otaramarae	A
Lake Rotoiti at Te Weta	A

Cyanobacteria biovolume	2011-2014
Lake Rotorua at Hamurana	A
Lake Rotorua at Holdens Bay	A
Lake Rotorua at Ngongotaha	A
Ōhau Channel	A

The majority of lake sites, and all sites in the Kaituna River were classified in the ‘A’ band, which identifies the risk of exposure to cyanobacteria as no different to that under natural conditions (NPS, 2014). The only sites not in ‘A’ band were Lake Ōkaro and Lake Rotoiti at Okawa Bay. The high cyanobacteria biovolume in Lake Ōkaro reflects the high nutrient levels in this small, relatively shallow lake. Under such conditions, high cyanobacterial biovolume is not unexpected. The high cyanobacterial biovolume in the Okere Arm at Lake Rotoiti reflects the occasional short-lived summer blooms where biovolume levels are high enough to put this lake into the "red” alert level. When this occurs, warnings are corrected to highlight the presence of a cyanobacterial bloom to potential water uses. These warnings usually only persists for a few weeks before dropping back to amber or green alert levels.

This highlights the high temporal variability of cyanobacteria communities in the lakes. For example, total biovolume in the Okere Arm on 18 February 2014 was only 0.013 mm^3/L and no cyanobacteria were detected one week later. However, by 4 March, total biovolume increased to 13.8 mm^3/L, placing this area in the "red" alert level. This persisted until 8 April, when it had decreased to amber level, and by 22 April, it had decreased to green.

8.4 Gaps and recommendations

The current lake cyanobacteria monitoring programme has been running since 1993 in some lakes, and continues to this day. This monitoring programme has resulted in temporary health warnings being issued when cyanobacteria biovolume exceeds recommended guideline values. The NOF specifies that a minimum of 12 samples over three years need to be used for assessments against the numeric values, with a recommended 30 samples over three years. The data being collected by the present lake monitoring programme is ideally suited to meet the requirements of the NOF.

Although the NOF stipulates that biovolume values are calculated using a minimum of 12 samples collected over three years, it recommends that 30 samples be collected over three years. It does not, however, provide any information as to how bands are calculated on data which is continually gathered. It is therefore recommended that the 80th percentile of biovolume data be calculated on a three-year rolling average, based on a year running from November-June each year (Table 22).

The NOF also stipulates that planktonic cyanobacteria be monitored in lake-fed rivers. This is currently being done in the Kaituna River as part of the consent conditions (RC63209) for the Ōhau diversion channel. This consent expires in October 2017, and new monitoring conditions as part of any new consent have to be set. Cyanobacterial biovolumes at the three sites below the Trout Pool (i.e., Maungarangi, Waitangi and Te Tumu) are mostly below 0.5 mm^3/L, and therefore in green alert mode. Only two sites (Maungarangi and Trout Pool) have ever recorded biovolumes greater than 10 mm^3/L, both on a single occasion in May 2009.

Given the fact that the vast majority of monitoring of these river sites has only returned green alert modes, it is suggested that this monitoring be discontinued when the consent is renewed. Instead, a more targeted monitoring programme would require the lower sites to be monitored only when the upper site (Trout Pool) exceeds the red alert threshold.

Although benthic *Phormidium* is not included as a NOF attribute, it is recommended that the current relatively ad-hoc monitoring programme for *Phormidium* is more formalised. It is suggested that the planned periphyton monitoring programme also includes a component of monitoring *Phormidium* cover at the selected sites. This would be done as part of visual observation monitoring for periphyton cover of other algal groups such as diatoms, and filamentous green algae. Although sites for the periphyton monitoring have yet to be chosen, it is planned that sites where the current *Phormidium* monitoring is underway could be included as part of the overall periphyton monitoring programme.

Table 22 Identified gaps for cyanobacterial monitoring and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Improvements to methods	Compulsory national attributes do not consider how to calculate banding for ongoing monitoring programmes where > 3 years of data are, or will be collected.	Calculate the 80th percentile of biovolume data on a three-year rolling average, based on a year running from November-June each year.
Improvements to methods	Current cyanobacterial monitoring of Kaituna River as part of Ōhau Channel consent are too broad and unnecessarily complex.	Discontinue future monitoring of lower sites in the Kaituna River when the current consent is renewed. Implement a more targeted monitoring programme to monitored lower sites only when the upper site (Trout Pool) exceeds the red alert threshold.
Obtain new data	Benthic cyanobacterial cover is not a compulsory national attribute.	Given the potential danger of *Phormidium* proliferations to river users, combine *Phormidium* monitoring with routine periphyton monitoring.

Part 9: Stream invertebrates

9.1 Introduction

Traditional physical and chemical measures of water quality are useful to help determine sources of water contamination, but they only indirectly measure the health of the aquatic ecosystem because they don't look directly at biological responses to pollution. The most direct way to understand the health of a river ecosystem is to monitor the animals and plants living in the river. Unlike water chemistry, which may be highly variable from day-to-day depending on the timing of discharges, and river flow patterns, stream invertebrates integrate all chemical, physical, and biological influences in their habitat over their lifecycle, which in some cases can be many years. As a result, the numbers and types of invertebrates in a water body reflect the quality of their surroundings. Stream invertebrates are thus used by all regional councils throughout New Zealand to help them assess the ecological condition of rivers, and to assist in their statutory responsibilities for environmental monitoring.

A central part of using freshwater invertebrates to monitor stream health is the creation of biotic indices. These numbers are used to reduce the inherent complexity of ecological data (i.e., multiple species found at multiple sites), allowing resource managers to tell at a glance how healthy a particular waterway is. The most commonly used biotic index in New Zealand is the Macroinvertebrate Community Index (MCI), and it's quantitative variant (QMCI). Use of these two metrics is further simplified by the creation of four water quality classes based on the value of the MCI/QMCI (Stark and Maxted, 2007). Thus, streams with an MCI greater than 120 are regarded as being in "excellent" condition, while streams with an MCI less than 60 are regarded as being in "poor" condition.

9.2 Invertebrate monitoring in the Bay of Plenty

A freshwater invertebrate monitoring programme has been conducted in the Bay of Plenty since 1992 as part of the NERMN programme. This has included 18 sites in the Kaituna WMA which have been sampled more or less annually every summer since either 2001 (11 sites) or 2002 (seven sites). This monitoring will provide at least some information as to the overall ecological health of the monitored streams in the Kaituna WMA. A number of other studies have also surveyed invertebrate communities at sites throughout the Kaituna WMA as part of compliance investigations or one-off ecological surveys. For example, Bioresearchers (1986, 1993) examined the effects of the AFFCO freezing works discharge at Rangiuru on the ecology of the Kaituna River. Here they examined invertebrate communities and measured water quality parameters at two sites above and two sites below the discharge.

Prior to this, Bioresearchers (1974) surveyed the Kaituna River as part of one-off investigations of the four large waterways draining the Bay of Plenty (Kaituna, Tarawera, Rangitāiki and Whakatāne) for the then Bay of Plenty Catchment Board. A total of three sites were collected from the Kaituna River, with the upper site at Maungarangi Road, some 25 km below the Ōkere Falls, and a lower site upstream of the Kaituna Maketū wildlife management reserve, some 5 km upstream of the river mouth. Bioresearchers also undertook a number of studies examining the ecological effects of dairy effluent on the Ohineangaanga Stream (Bioresearchers 1978, 1980, 1982, 1983, 1985). Here they sampled two sites above the discharge, and three sites at increasing distances downstream. Finally, Hamill (2014) surveyed invertebrate communities in the lower Kaituna River as part of investigations for the Kaituna Maketū diversion scheme.

The Council's NERMN invertebrate monitoring programme has recently been reviewed (Suren 2015) and 32 recommendations made to improve this. Many of these recommendations concerned the use of databases such as the REC and FENZ to assist with providing information on the spatial extent of sampling, as well is providing spatially linked habitat data contained in these databases. Other recommendations related to sample collection and processing procedures, and to data storage. To date, 20 of these recommendations have been implemented. Two recommendations (numbers 30 and 32) are particularly relevant to this Gap Analysis, as they concerned maximising linkages between the current invertebrate monitoring programme and any current or future planning and policy work undertaken by BOPRC. This has obvious implications for implementation of the NPS-FW throughout the region.

9.3 Spatial coverage

Examination of all invertebrate monitoring sites (both NERMN and consent/compliance monitoring) when coded to their appropriate REC classification shows considerable divergence between the types of streams present in the Kaituna WMA and those sampled (Table 23). For example, streams in the warm-wet climate classification have been over-represented in the current surveys, whilst those in the warm-extremely wet, cool-extremely wet and cool-wet classes have been under-represented. The high number of samples collected from the Kaituna River as part of compliance investigations around the AFFCO Rangiuru freezing works means that lake-fed streams had also been over-represented, while hill-fed and lowland-fed streams had been under-represented (Table 23). Streams draining both exotic and indigenous forests have also been under-represented, while streams draining pasture land use are over-represented. Finally, most sampling has concentrated on medium or large waterways (Table 23), with smaller streams being neglected.

The result is an obvious need to sample some of these under represented sites so that more detailed ecological information can be collected with a view to presenting a more balanced picture on the current state of streams throughout the Kaituna WMA. This is important as, for example, the ecological condition of pasture streams is generally somewhat lower than that of streams draining either indigenous or exotic plantation forests. Thus, the over-representation of streams draining pasture catchments may suggest that stream health in the Kaituna WMA is lower than it potentially is.

Table 23 Calculated percentage stream length in different REC classes for climate, source of flow, geology, land cover and stream size within the Kaituna WMA, and from streams where invertebrate samples had been collected. Sites where invertebrate sampling has significantly under-represented a particular REC class are highlighted in orange, while sites which have over-represented a class are highlighted in green.

Variable	Value	% of WMA stream length	Surveyed stream length
Climate class	Warm-extremely wet	8.3	3.3
	Warm-wet	76.1	94
	Cool-extremely wet	7.9	0.8
	Cool-wet	7.1	2.0
Source of flow	Hill	11.9	0.8
	Lowland	85.3	61.8
	Lake	2.9	37.4
Geology	Volcanic acidic	97.5	100
Land cover	Exotic forestry	18.5	4.4
	Indigenous forestry	11.3	1.5
	Pastoral	68.7	94.1
Stream size	Small (order 1+2)	74.3	4.5
	Medium (order 3+4)	21.3	55.9
	Large (order 5+)	4.4	39.6

9.4 Gaps and recommendations

The above spatial analysis clearly shows relatively large gaps in our information behind the ecological health of some REC stream classes throughout the Kaituna WMA (Table 24). It is important to fill these gaps by sampling, for example, more hill-fed streams dominated by exotic or indigenous forests. Note that any extra sites where samples are to be collected do not necessarily have to be included in the current NERMN sampling programme, but instead could be collected as part of a one-off campaign designed to fill gaps in our current state of knowledge. This is similar to the large-scale ecological survey recently conducted at sites throughout the Rangitāiki Catchment. This survey provided valuable information as to the current state of stream health throughout the Rangitāiki, and showed how it was affected by natural factors such as climate and source of flow, as well as by human activities associated with land use change and the construction of hydroelectricity dams.

Although the NPS-FW highlights the need for councils to “maintain or enhance water quality throughout their region", the compulsory national attributes have focused primarily on water quality, with the exception of periphyton biomass. Periphyton was included as an attribute because it has strong effects on a number of waterway values, including ecological, recreational, aesthetic and cultural, and is also potentially responsive to a number of resource uses (e.g. point and diffuse discharges of nutrients and water abstractions). However, the compulsory national attributes do not cover any form of ecological monitoring using invertebrates. This was unexpected, especially given the fact that indices such as the MCI are commonly used by both councils and Central Government to summarise the ecological health of waterways. Despite the current absence of the MCI in the NOF, we consider that invertebrate monitoring, and the use of the MCI, is an appropriate attribute for BOPRC to monitor in terms of meeting the NPS-FW requirements under Policy CA2(c)1B.

A central reason for ecological monitoring is to convey information about the ecological health of a waterway. Although this information can easily be summarised into biotic indices such as the MCI, ideally some form of banding system could also be used so that Council and the community can determine whether the current ecological state is acceptable. In the absence of any banding system for MCI scores under the NOF, the onus will be up to individual councils to develop these bands. Although water quality bands have already been created for the MCI (e.g., Stark and Maxted 2007), it is yet to be determined whether these bands would be applicable to represent desired ecological states of waterways throughout the Kaituna WMA.

Table 24 Identified gaps for ecological sampling and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Obtain new data	Information on ecological health of small waterways, and of waterways draining hill-fed country, and in catchments dominated by exotic and indigenous forest.	Initiate a one-off sampling campaign to provide information on the ecological health of sites where this information is lacking.
Spatial frameworks	Freshwater Management Units need to be made at relevant spatial scales to represent streams which are similar to each other. In this way, BOPRC can accurately convey the current state of waterways in each WMA to community groups with greater clarity.	Decide on what spatial framework will be used to create water management units.
Identify values	Provision of any form of banding system to assign biotic metrics such as the MCI to an acceptable (A) or unacceptable (D) level.	Analysis of ecological data currently held by Council, and collected as part of any future sampling could be used to help develop suggested bands for MCI scores.

Part 10: Fish communities

10.1 Introduction

One of the most important ecological values of rivers and streams for most people would undoubtedly be fish communities. Freshwater fish historically sustained iwi who have developed a very close relationship with the natural life cycle of many of New Zealand's native freshwater species to ensure they could harvest this bountiful supply (McDowall 2015). With the arrival of European settlers, introduced fish such as salmon and trout were liberated throughout the country, and these have now formed the basis of a hugely important recreational resource throughout the country (McDowall 1990).

Despite their importance, many fish (both native and introduced) are being adversely affected by human activities throughout New Zealand. In particular activities associated with agricultural development such as removal of riparian vegetation, channel straightening and ongoing drain maintenance, water abstraction and inputs of nutrients and sediments are having demonstrable effects on fish communities throughout the country. Furthermore, large hydroelectric dams have affected the ability of native fish to successfully complete their life cycle as they have blocked free access to and from the sea. Finally, many native New Zealand fish have been displaced by the larger and more aggressive introduced trout and salmon.

10.2 Fish monitoring in the Bay of Plenty

As with many councils, BOPRC currently does not monitor fish communities as part of their annual SoE work. Any fish work conducted by BOPRC is usually for focused studies conducted as part of council investigations. Other organisations such as NIWA, DOC, and Fish and Game have also conducted numerous fish surveys throughout the region. Finally, a number of consultancies have also surveyed fish communities as part of either consent applications or for compliance monitoring. Most fish data collected from the region has been uploaded into the New Zealand Freshwater Fish Database (FFDB), maintained by NIWA. The FFDB contains over 30,000 records of freshwater fish observations throughout the country, and represents a nationally significant database.

Data from the FFDB has also been used to produce predictive models of fish distribution throughout New Zealand. These predictive models show the probability of occurrence of different fish species in the absence of human activities. They could thus be used to assess the degree to which fish communities have been affected by human activities throughout the catchment by comparing observed and predicted fish distributions.

Data for fish surveys that have been conducted in the Kaituna WMA was obtained from the FFDB. A total of 191 sites where fish surveys had occurred were found. Seven records were from sites surveyed prior to 1980, while the most up-to-date records come from eight sites surveyed in 2010 and 2011. Most samples (90) were collected post 2000, whilst 46 and 48 sites were collected respectively during the 80s and 90s.

The most commonly collected fish were longfin and shortfin eels (found at 46 and 42% of sites respectively), followed by common bully (found at 28% of sites), as well as inanga, smelt and redfin bully (collected at 24% of sites). Introduced fish such as mosquito fish and rainbow trout were found at 14% of the sites sampled.

Fish communities in New Zealand are also strongly regulated by distance inland, as many fish are migratory and need access to and from the sea. Many fish are also relatively poor climbers, and so do not penetrate very far inland. The average distance from a sampling site to the coast in the Kaituna WMA was 19 km, with the closest site being only 300 m to the sea, and the furthest being 54 km inland. Most samples (73) were collected between 10 and 20 km inland.

Examination of the fish survey sites when coded to their appropriate REC classification also shows some difference between the types of streams present in the Kaituna WMA and those sampled (Table 25). Streams in the warm-extremely wet climate classification have been over-represented in the FFDB, whilst those in the cool-extremely wet class have been under-represented. However, most of the sites surveyed in the FFDB were in the warm-wet climate class, and with a similar number to those found naturally in the Kaituna WMA. As with the invertebrate sampling, hill-fed sites have been under-represented while lake-fed sites have been slightly over-represented (Table 25). Streams draining indigenous forest have been under-represented, while streams draining pasture land use are over-represented. Finally, most sampling has concentrated on medium or large waterways (Table 25), with smaller streams being neglected.

Table 25 Calculated percentage stream length in different REC classes for climate, source of flow, geology, land cover and stream size within the Kaituna WMA, and from streams where fish surveys have been conducted. Sites where fish surveys have significantly under-represented a particular REC class are highlighted in orange, while sites which have over-represented a class are highlighted in green.

Variable	Value	% of WMA stream length	Surveyed stream length
Climate class	Warm-extremely wet	8.3	16.7
	Warm-wet	76.1	68.9
	Cool-extremely wet	7.9	1.3
	Cool-wet	7.1	10.8
Source of flow	Hill	11.9	1.9
	Lowland	85.3	83.3
	Lake	2.9	14.8
Geology	Volcanic acidic	97.5	93.4
Land cover	Exotic forestry	18.5	10.8
	Indigenous forestry	11.3	2.5
	Pastoral	68.7	83.5
Stream size	Small (order 1+2)	74.3	24.3
	Medium (order 3+4)	21.3	56.6
	Large (order 5+)	4.4	19.1

10.3 Gaps and recommendations

The above spatial analysis clearly shows relatively large gaps in our information on fish communities in some stream types in the Kaituna WMA (Table 26). As with the invertebrate data, more surveys are required from hill-fed streams draining indigenous forest, as well as from small streams throughout the region.

As mentioned, BOPRC presently does not routinely monitor fish communities. However, given their high value to the community, and the pressures they are faced with, it may be worth considering setting up a fish monitoring programme at selected "sentinel sites" throughout the region, including the Kaituna WMA. Where possible, the sites could be paired with sites which are either sampled for invertebrates, water quality or periphyton (or all three) to maximise the value of the information collected.

Fish are highly dependent upon free access to a particular site, and so their absence from a site does not necessarily indicate that habitat conditions are unsuitable. Part of any site selection process should therefore ensure that any migrating fish do not encounter obstructions that would block their free movement to and from the sea. An integral part of this process would just be to develop a database of all known fish obstruction barriers throughout the Kaituna WMA. Part of this process would be to then prioritise a list of existing fish barriers that could be retrofitted with devices to allow fish passage, or which could be replaced with more fish friendly devices.

The challenge of monitoring fish communities is that their abundance is highly temporally variable, especially for many of the migratory native fish. This high temporal variability reflects many factors, including the previous generations spawning success, growth and survivability of larvae in the marine environment, and the ability of migrating fish to successfully find and colonise usable freshwater habitat.

There is a general consensus amongst New Zealand fisheries scientists that native New Zealand fish do not come back to their natal streams, so the populations found in a particular stream cannot be related back to the spawning success from that stream. This means that there are often large temporal fluctuations in fish density within a site over time. Moreover, it is often difficult to obtain accurate quantitative information on fish within streams. Because of this, it is recommended that any sampling is done to record fish presence-absence, as well as the relative abundance of different species at a site. Records of observed fish distributional data could be compared to predict models of fish distribution to assess whether the spatial extent of fish communities is reducing throughout the Kaituna WMA.

Table 26 Identified gaps for monitoring fish communities and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Obtain new data	Knowledge on fish communities in some REC classes in the Kaituna WMA, especially in small waterways, draining hill-fed country, and in catchments dominated by exotic and indigenous forest.	Initiate a one-off sampling campaign to provide information on fish communities in sites where this information is lacking.
Obtain new data	Lack of any ongoing monitoring programme for fish communities.	Consider implementing monitoring fish communities at selected "sentinel sites" throughout the Kaituna WMA. This could be done at regular intervals (e.g., 2-4 years).
Data for models	Knowledge of whether fish community distribution in the Kaituna WMA is changing over time as a result of land use activities.	Ensure that implementation of any monitoring programme is able to compare observed fish distributions with those predicted in the absence of human activities.
Obtain new data	Knowledge about the location of structures such as culverts, pump stations, and floodgates that may obstruct the free migration of native fish.	Develop and maintain a database of all potential fish areas throughout the Kaituna WMA, which can then be used to set priorities for their removal or remediation.

Part 11: Wetlands

11.1 Introduction

The RMA 1991 definition of a wetland is broad and includes permanently or intermittently wet areas, shallow water, and land water margins that support a natural ecosystem of plants and animals that are adapted to wet conditions (Peters 2012).

Characteristics which distinguish wetlands from other terrestrial and freshwater ecosystems include shallow standing water and/or waterlogged soils, anoxic conditions (the absence of oxygen) in the soil, and dominance of emergent aquatic plants (Sorrel & Gerbeaux 2004, Ausseil *et al.* 2008).

New Zealand has committed to wise use of wetlands as a party to the Ramsar Convention 1976, has identified protection and preservation of wetlands as a matter of national importance under the RMA 1991, and has included wetlands as one of four national priorities for protection of biodiversity on private land (MfE 2007).

The NPS-FW (2014) specifically identifies the need to protect the significant values of wetlands, and attributes for wetlands are currently being developed for inclusion in subsequent versions of the National Objectives Framework (NOF) (MfE 2013, Clarkson *et al.* 2015).

The three key threats impacting on the ecosystem health of wetlands are loss of wetland extent, excessive nutrient and sediment inputs, and hydrological alteration. These three factors act cumulatively to alter wetland processes, and result in altered wetland plant communities and reduced species diversity.

11.2 Wetland Monitoring in the Bay of Plenty

The NERMN regional wetland monitoring programme has been designed to collect information on the condition of wetlands in the region. The methodology (refer Clarkson *et al.* 2014) involves collection of soil and foliage samples (physico-chemistry) and assessment of species composition (percent cover) within 5 x 5 m vegetation plots, as well as field based assessment of 'Wetland Condition Index'.

A regionally representative set of wetlands has been selected for this monitoring programme based on rarity, current extent, distribution, Ecological District, ecological significance ranking, and adjacent land uses (Fitzgerald *et al.* 2013).

There have been 11 wetlands from the Kaituna WMA selected for inclusion in the programme, but so far only two have been sampled. This is in part because the programme was only initiated in 2014/2015, and in part because of difficulties obtaining landowner permission to access monitoring sites.

11.3 Current wetland state in the Kaituna WMA

In the absence of data from the NERMN regional wetland monitoring programme, the best and most comprehensive data sources available for assessing the overall state of wetlands in the Kaituna WMA include:

- Waters of National Importance project (WONI).
- Freshwater Environments of New Zealand (FENZ).
- BOPRC's 'WetlandExtents' geospatial layer modified by Fitzgerald *et al.* 2013.
- BOPRC's 'WetlandVegetationType' geospatial layer.
- Protected Natural Area programme (table 1) and Significant Natural Area reports (e.g. Beadel 2006, Wildlands 2006, 2008).

These sources provide, or could potentially provide, information on:

- Significance levels and WONI rankings.
- Current and historic wetland extent by wetland type.
- Diversity and extent of vegetation types.
- Ecological Integrity Index.
- Scores for naturalness, viability and diversity.

11.3.1 Significance levels (under BOPRC RPS criteria 2008) and WONI rankings

Fitzgerald *et al.* 2013 undertook a desktop analysis of significance levels for wetlands in the Bay of Plenty region, based mainly on dated PNA surveys and DOC reports. This analysis indicates that there is insufficient information to classify a number of the 23 wetlands in Kaituna WMA, but that at least three could be considered nationally significant, and at least nine considered regionally significant.

The Waters of National Importance (WONI) project ranked wetlands in the Bay of Plenty biogeographic unit (which differs from Regional Council boundary) based on complementarity, ecological integrity, and irreplaceability (refer Ausseil *et al.* 2008). According to this ranking, the Kaituna WMA contains three of the Bay of Plenty biogeographic unit's top 10 most significant wetlands.

11.3.2 Current and historic wetland extent

A map of New Zealand's historic (circa 1840) wetland extent was produced by the WONI project, using soil information held by the Land Resource Inventory (Newsome *et al.* 2000), and a 15 m digital elevation model to refine soil polygons (Ausseil *et al.* 2008).

The Landcover Database (LCBD4) mapped four wetland land cover classes based on satellite imagery from 2012. However, LCDB4 has large errors (O'Donnell & Zanders 2006) and is not particularly effective at identifying small wetlands or wetlands within intensively farmed or peri-urban landscapes (Davis *et al.* 2013).

Thus the best available map of ‘current’ wetland extent is provided by the BOPRC ‘WetlandExtents’ layer, which is based primarily on 2004-2007 aerial photography with limited ground-truthing. Clipping the WONI historic and BOPRC ‘WetlandExtents’ layers to the Kaituna WMA boundary indicates that 476 ha of wetland remains in the WMA - only 3.5% of estimated historic extent.

This analysis also indicates that most (56%) of the remaining wetlands in the Kaituna WMA are smaller than 5 ha (Table 27), though it’s worth noting that this WMA does contain the largest wetland in the Bay of Plenty (Kaituna Wildlife Management Reserve) and that funding for 100 ha of wetland re-creation has been allocated in Council’s Long-term Plan 2015-2025.

Table 27 Size class distribution of remaining wetlands in Kaituna WMA.

Size class	# Wetlands
<0.99	7
1-4.99	6
5-19.99	3
20-49.99	4
50-99.99	2
100-149.99	-
150-200	1
TOTAL	**23**

11.3.3 Wetland type extent

Freshwater wetlands can be classified into types (e.g. swamp, marsh, fen, bog) according to water and nutrient regimes and substrate characteristics. Because different wetland types harbour distinctly different species assemblages (Johnson & Gerbeaux 2004), maintaining the full range of wetland species in the Kaituna WMA necessitates the maintenance of the full range of wetland types.

Wetlands in the WONI historic extent map are classified by wetland type based on soil attribute data and a 15 m digital elevation model (Ausseil *et al.* 2008). Additionally, wetlands in BOPRCs ‘WetlandExtents’ layer have been classified by wetland type based on vegetation information in BOPRCs ‘WetlandVegetationType’ layer, aerial imagery (RDAM 2010), Protected Natural Area reports, and individual wetland surveys (refer Fitzgerald *et al.* 2013).

Clipping the historic WONI and modified BOPRC ‘WetlandExtents’ layers to the Kaituna WMA boundary indicates the three main wetland types in the Kaituna WMA are fen (11.9%), swamp (85.8%) and marsh (2.6%) (Table 28). Fen wetlands have been most reduced in extent, followed by swamp and then marsh (noting that both mapping exercises will have missed many small wetlands, including seepages, due to limited resolution of satellite imagery and aerial photography).

Table 28 'Current' and historic extent of wetland types in the Kaituna Catchment.

Wetland type	Area historic (ha)	Area remaining (ha)	Percent remaining
Fen	2,154.0	56.8	2.6%
Marsh	176.6	10.8	6.2%
Swamp	11,286.8	410.6	3.6%
TOTAL		**476**	**3.5%**

11.3.4 Diversity and extent of vegetation types

Diversity of vegetation types within and among wetlands influences habitat heterogeneity, and thus is likely to play an important role in determining overall wetland species diversity in the Kaituna WMA. However, diversity of vegetation types can be impacted by invasion by exotic species and/or take over by species tolerant of excessive nutrients and altered hydrological regimes.

Some data on vegetation types within the catchment wetlands is available through PNA surveys, and surveys undertaken by BOPRC to ground-truth wetlands in the 'WetlandExtents' geospatial layer, but this data is very dated (mid 1990s and 2007 respectively), and doesn't cover all wetlands.

Data on vegetation extent and diversity from these sources has not been summarised for the purposes of this report, but could provide a useful baseline data against which to assess change in extent and diversity of vegetation types should vegetation mapping be repeated in the future.

11.3.5 Ecological Integrity Index

The Ecological Integrity (EI) Index in the Freshwater Environments of New Zealand (FENZ) national database was developed for individual wetlands as part of the WONI project based on GIS based measures for naturalness of catchment cover, artificial impervious cover, nutrient enrichment, introduced fish, woody weeds, and drainage (refer Ausseil *et al.* 2008 for more detail).

Recent analyses by Clarkson *et al.* 2015 found that the EI Index is a good predictor of the field assessed 'Wetland Condition Index' (refer Clarkson *et al.* 2004 and Clarkson *et al.* 2014). This indicates that the EI Index can probably be used in cases where the Wetland Condition Index for individual wetlands is not available (as is the case for all but two wetlands in Kaituna WMA).

Figure 14 below shows the distribution of EI Index for the (13) wetlands in the Kaituna WMA that were assessed for EI by the WONI project. Higher EI scores (closer to 1) predict good condition whereas lower scores (closer to 0) predict poor condition. The average EI Index of sites in Kaituna WMA is 0.32 (cf 0.38 for Bay of Plenty). Both marshes and swamps had relatively low EI scores (Table 29), while the single fen that has been sampled in the WMA had a much higher EI score.

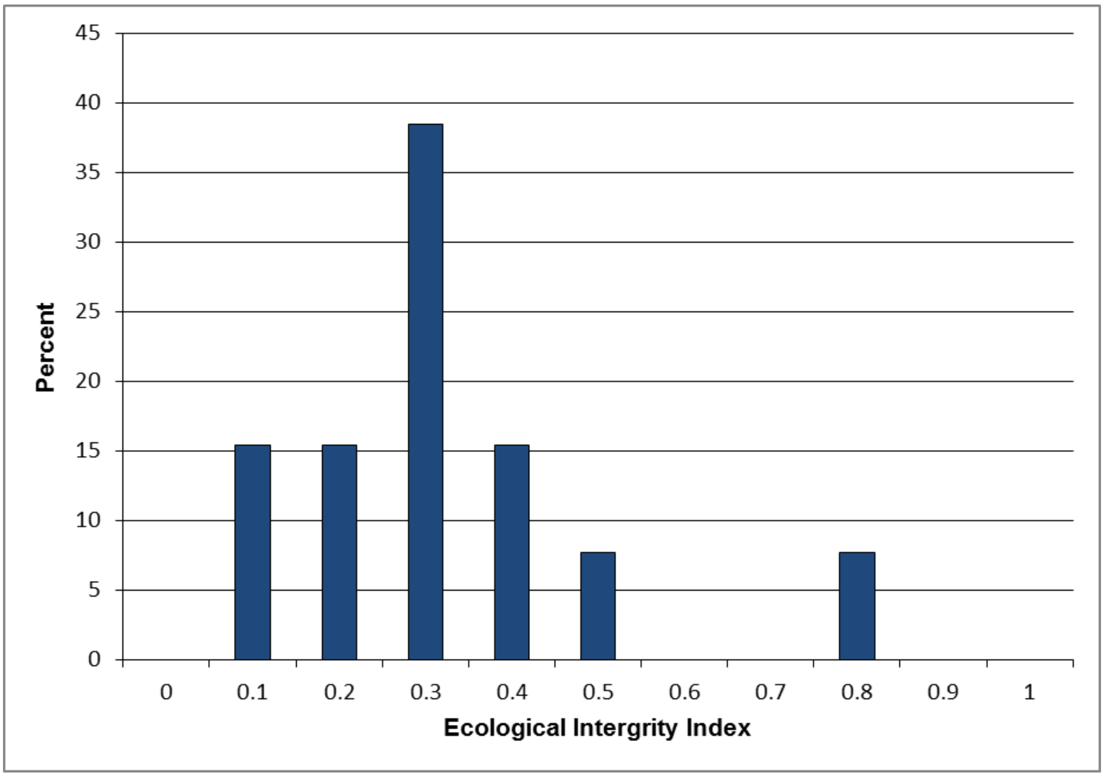


Figure 14 *Histogram of Ecological Integrity Index for 13 wetlands in Kaituna WMA. The EI Index is expressed as a value between 0 and 1, with high values predicting good condition and lower values predicting poor condition.*

Table 29 *Average Ecological Integrity Index for wetland types in the Kaituna WMA. Wetlands types with low EI Index are likely to be subject to greater levels of human disturbance than wetland types with higher scores.*

Wetland type	# WONI sites	Average Ecological Integrity
Fen	1	0.51
Marsh	2	0.3
Swamp	10	0.31

11.3.6 Rankings for naturalness, viability and diversity

Various reports (including those undertaken for the Protected Natural Area programme) have assessed sites in the region against Bay of Plenty Regional Policy Statement Heritage Criteria and have thus given sites a score of high, medium or low for naturalness and viability criteria. No attempt has been made to assess the extent to which these reports cover wetlands in the Kaituna WMA or to summarise the scores given to wetlands in the WMA.

11.4 Gaps and recommendations

Data on the health of wetlands in the Kaituna WMA are currently limited and dated. More specific data may be available from other agencies for individual wetlands but this is not currently in an easily digestible format. Key knowledge gaps, and recommendations for addressing these gaps, have been listed in Table 30. Note that improved direction regarding the monitoring required to meet the needs of NPS implementation will be possible following development of wetland compulsory national attributes.

Table 30 Identified gaps for wetland monitoring programmes and recommended solutions to address gaps in current knowledge.

Gap theme	Gap	Recommendation
Improvements to methods and reporting	Lack of compulsory national attributes for wetlands.	Collaborate with other Regional Councils to support development of compulsory national attributes for wetlands. Better direction of additional monitoring required to meet the needs of NPS implementation will be possible once attributes (and values) have been fully developed.
Identify values	Values for wetlands.	Following availability of for wetlands, establish agreed values for wetlands in collaboration with communities. This will enable better direction of additional monitoring to meet the needs of NPS implementation.
Improvements to methods and reporting	Lack of up-to-date/ comprehensive geospatial layers for wetland size and aerial extent.	Update the geospatial layer for wetland extent using the latest aerial photography (and other available tools), and use new geospatial layer to determine changes in wetland extent, extent of wetland types, and size of wetlands over time.
Obtain new data	Lack of quantitative plot-based data on plant species composition and biomass paired with sampling of soil and foliage physico-chemistry.	Undertake NERMN regional wetland monitoring programme within the WMA as planned but consider increasing sample size for the WMA to provide better catchment level data.
Obtain new data	Lack of field verified classification of sites by wetland type.	Undertake field verification of wetlands types based on soil/water chemistry and hydrology etc., and incorporate into attribute table in geospatial layer of wetland extent.

Gap theme	Gap	Recommendation
Obtain new data	Lack of up-to-date geospatial layers for wetland vegetation types.	Undertake vegetation type mapping for mapped wetlands and consider assessing changes in extent and diversity of vegetation types compared to PNA and other survey reports.
Obtain new data	Lack of data on wetland condition/ecosystem health.	Undertake field based assessment of Wetland Condition Index for mapped wetlands or update Ecological Integrity Index (or other GIS based assessment) for all mapped wetlands using updated/recent GIS data.
Obtain new data	Lack of data on wetland condition and threats for highly significant, irreplaceable and/or vulnerable wetlands.	Undertake comprehensive monitoring of wetland condition (ecology, water quality and/or hydrology) for selected highly significant, irreplaceable and/or vulnerable wetlands.
Data for models	Lack of models for supporting decision-making and estimation of cumulative impact on wetlands.	Investigate opportunities for model development (or supporting model development), in particular models to estimate phosphorus risk for wetlands.
Improvements to methods and reporting	Lack of interpretative data for determining cause of declines in wetland condition.	Manage information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) in a way that will allow this information to be used for interpretation of wetland condition data.
Obtain new data	Lack of data on changes wetland condition/ecosystem health over time.	Consider analysis of Fish & Game Council data on waterfowl survival/production as an indicator of long-term trends in wetland ecosystem health.

Part 12: Estuaries

12.1 Introduction

Estuaries are the transitional environment between rivers and the sea and because of this they have complex hydrology and water quality. Rivers and streams transport various contaminants including sediment and nutrients and these can build up over time in estuaries, often with ecological consequences.

Although the NPS-FW is primarily focussed on freshwater, Policy A1 (a) (iii) identifies the need to consider the connection between freshwater and coastal water. Therefore, when considering setting limits for freshwater it is important that the effects of these limits on estuaries are understood.

Within the Kaituna WMA, there are two major estuaries. The Waihī Estuary is a shallow tidal inlet of approximately 2.4 km^2 and is almost completely exposed at low tide. This estuary is fed by four main streams (the Kaikokopu, Wharere, Pongakawa and Pukehina), which below SH 2 have been extensively straightened and channelised. The Maketū Estuary is of a similar size (2.3 km^2), but is fed almost exclusively from the Kaituna River. Although the river historically flowed into the estuary at its western end (in the vicinity of Ford's Cut), the river was cut through to the sea at Te Tumu in the 1950s.

Although some of the Kaituna River flow was diverted back into the estuary through Fords Cut, there still has been a clear deterioration in estuary condition, reflecting (amongst other things) reduced flushing in the upper (western) parts, increased sedimentation, high nutrient levels, and high algal biomass. A resource consent application to divert more of the Kaituna River back into the estuary was recently granted (see Section 12.3), meaning that more flushing of the currently "stagnant" western part of the estuary will occur.

12.2 Estuary monitoring in the Bay of Plenty

BOPRC currently monitors 19 estuary or marine sites within the Kaituna WMA (Table 31). There are three NERMN modules collecting this information: estuary water quality sampling, recreational bathing sampling and benthic macrofauna monitoring. The extent of seagrass, red algae (*Gracilaria chilensis*) and mangroves throughout both estuaries are also mapped at five-yearly intervals based on the aerial photography flown across the Bay of Plenty. In addition to these aquatic components of the estuary, the extent of saltmarsh and other contiguous freshwater wetlands have been mapped at various times and been evaluated for ecological significance. However, this current review concerns only the aquatic components of the two estuaries, and terrestrial monitoring is not considered further.

A number of consent and compliance monitoring programmes have also been initiated in these estuaries, but these also have not been considered further. An exception to this is for the recent application to re-divert water from the Kaituna River back into the estuary. Given the importance of this work, relevant results have been summarised in Section 12.3.

Table 31 List of NERMN monitoring sites, parameters monitored, sampling frequency and length of data record within the Kaituna WMA.

NERMN site name	Site ID	Parameters monitored	Sampling frequency	Data record
Kaituna River diversion structure	BOP150020	Temperature, dissolved oxygen (surface), salinity, conductivity, pH, NH_4-N, NO_x-N, DRP, TP, turbidity, TSS, *E.coli*, faecal coliforms[a], *Enterococci*[a], chlorophyll-a	Bi-monthly	1990-present
Maketū Estuary boat ramp	BOP150005		Bi-monthly	1990-present
Waihī Estuary at domain	BOP150006 and BOP160016[a]		Quarterly 1991-2005 Monthly since 2006	1990-present
Kaituna River at Te Tumu	BOP110029	Temperature, dissolved oxygen, pH, conductivity, NH_4-N, NO_x-N, TN, DRP, TP, turbidity, TSS, colour coefficient, *E.coli*, faecal coliforms, *Enterococci*, chlorophyll-a	Episodic 1985-1995 Monthly since 2008	1985-present
Pukehina Beach at Pukehina	160170	Enterococci, faecal coliforms	Weekly/biweekly over summer	2009- present
Little Waihī Domain Boat Ramp	160016	Enterococci, faecal coliforms (water samples)	Episodic 1991-2003 Weekly over summer since 2003	1991-present
Maketū Surf Club	160017	Enterococci, Faecal Coliforms (water samples)	Episodic 1991-2003 Weekly over summer since 2003	1991-present
Pāpāmoa Beach Surf Club	160026	Enterococci	Episodic 1991-2000 Weekly over summer since 2000-2014	1991-2014
Maketū Est. Site 1	BOP980001	Benthic macrofauna	Annual	1991-2008
Maketū Est. Site 2	BOP980002	Benthic macrofauna	Annual	1991-2009
Maketū Est. Site 3	BOP980028	Benthic macrofauna	Annual	1991-present

NERMN site name	Site ID	Parameters monitored	Sampling frequency	Data record
Maketū Est. Site 4	BOP980027	Benthic macrofauna	Annual	1991-2009
Maketū Est. Site 5	BOP980501	Benthic macrofauna	Annual	2013-present
Waihī Est. Site 1	BOP900014	Benthic macrofauna	Annual	1991-present
Waihī Est. Site 2	BOP900015	Benthic macrofauna	Annual	1991-1995
Waihī Est. Site 3	BOP900086	Benthic macrofauna	Annual	1991-1998
Papamoa Beach	BOP980022	Benthic macrofauna	Annual	1991-2013
Matata Beach	BOP980009	Benthic macrofauna	Annual	1991-2011

12.3 Kaituna River re-diversion investigations

Extensive investigations were completed as part of the Kaituna River Re-diversion and Ongatoro/Maketū Estuary Enhancement Project. Reports from this project are available on the Council's website at http://www.boprc.govt.nz/kaitunamaketū. The investigations included the development and use of a computer model to describe 3D hydrodynamic and water quality processes in the estuary (DHI, 2011, 2014), and investigation of ecology and dissolved oxygen levels in the estuary (Hamill, 2014).

Relevant information from the investigations follows.

12.4 Comparison to guidelines

12.4.1 Water quality

There are currently no specific guideline values for estuarine or marine water quality, or any nationally consistent indices of estuary health in New Zealand. To provide some context to the water quality information, reference has been made to the ANZECC (2000) guidelines which provide estuarine and marine trigger values for south-east Australia. Until more specific guidelines are developed for New Zealand estuaries, these ANZECC guidelines provide an indication of potential environmental risk (Table 32).

Table 32 Trigger values for stressors for slightly disturbed estuarine ecosystems. (ANZECC, 2000; after Scholes, 2015).

	Chl a *mg/m^3*	**DRP** *mg/m^3*	**TP** *mg/m^3*	**NOxN** *mg/m^3*	**NH_4N** *mg/m^3*	**Turbidity** *NTU*	**DO** **(%)**
Trigger value lowland rivers	-	10	33	444	21	5.6	98-105
Trigger value estuaries	4	5	30	15	15	10*	80-110
Trigger value marine ecosystems	1	25	25	5	15	-	90-110

*Adopted from Murphy and Crawford, 2002.

Additionally, the Microbial Water Quality Guidelines have been developed for New Zealand to protect human health for contact recreation (e.g. swimming). These guidelines provide limits for indicator bacteria (*E.coli* and Enterococci) and are used to assess the level of risk to humans from swimming (Table 33).

Table 33 Microbiological Assessment Category (MAC) definitions (from MfE and MoH, 2003; from Scholes, 2015).

Marine waters	
Green mode	No single sample > 140 Enterococci per 100 mL
Orange alert	Single sample > 140 Enterococci per 100 mL
Red alert	Two consecutive samples > 280 Enterococci per 100 mL

Freshwater	
Green mode	No single sample > 260 Escherichia coli per 100 mL
Orange alert	Single sample > 260 Escherichia coli per 100 mL
Red alert	Single sample > 550 Escherichia coli per 100 mL

12.4.2 Shellfish

There are currently guideline values for shellfish in regards to the level of bacterial contamination that is deemed acceptable for human consumption. Different guidelines exist for the water above shellfish gathering areas, and shellfish flesh. For shellfish flesh, guidelines include levels for faecal coliforms and *E.coli*.

BOPRC tests water quality above shellfish gathering areas for faecal coliform (FC) levels, in accordance with the microbiological water-quality guidelines to indicate the presence of pathogenic bacteria, protozoa and viruses. Furthermore, faecal coliforms have a stronger correlation with health risks associated with eating shellfish than that of enterococci (MfE/MoH, 2003), making them a useful indicator. The guidelines for safe shellfish consumption are as follows:

- The median FC content should not exceed a Most Probable Number (MPN) of 14/100 mL.
- No more than 10% of samples should exceed a MPN of 43/100 mL.

For shellfish flesh, the FC levels should be less than 330 MPN/100g and levels between 230-330 MPN/100g are considered ‘marginal’ (BOPRC, 2011). This standard was based on the Microbiological Reference Criteria for Food (MoH, 1995).

Additionally, limits for E.coli specified by New Zealand Food Safety (2006) for safe food consumption, state that the median *E.coli* level should be below 230 MPN/100 g, and no more than 10% of samples should exceed 700 MPN/100 g (NZFSA, 2006).

12.5 Current State of estuaries in the Kaituna WMA

12.5.1 Waihī Estuary

The Waihī Estuary is the ultimate receiving environment for all waterways within the Pongakawa Catchment. This catchment lies between the Kaituna Catchment in the west, and the Waitahanui Catchment in the east and includes the smaller coastal catchments of Pukehina, Ohinepanea and Ōtamarākau. The catchment is approximately 365 km^2 in size, and extends to the north from Lakes Rotoehu and Rotoiti, to the Waihī Estuary. Tributaries draining into the Waihī Estuary run through catchments ranging from exotic and native forests in the headwaters, to horticulture, sheep, beef and dairy farms and lowland flood-plains (Scholes, 2015).

North of SH 2, the natural drainage of the region has been modified by a series of drains and canals. Four canals drain into the Waihī Estuary (Kaikokopu, Wharere, Pongakawa and Pukehina).

Water quality

Scholes (2015) presented water quality results for all estuaries in the Bay of Plenty region. Relevant sections from Scholes (2015) are summarised below. The estuary has relatively high sediment concentrations (Table 34), notably higher than the Kaituna Estuary (see section 12.5.3). This is to be expected since the estuary is shallower and has smaller mean tidal flow rate than the Kaituna Estuary. This means that factors like wind and wave action, and flood flows often cause sediment in the estuary to be re-suspended (Scholes, 2015).

Table 34 Water quality statistics for Waihī Estuary, 1990-2013 (BOP150006; after Scholes, 2015).

	n	Mean	Median	Min.	Max.	SD	%of samples within guidelines
DO%	132	89.1	86.1	65.4	137.3	11.4	18.9
Temperature (ºC)	136	17.2	16.7	11.9	25.0	3.1	
Cond (mS/m)	133	4933	5230	522	5460	872	
SS (g/m^3)	135	19.5	15.0	1.0	170.0	19.2	
Turbidity (NTU)	108	4.5	2.8	0.4	29.0	5.4	92.6
pH	135	8.0	8.0	6.0	8.6	0.3	
DRP (g/m^3)	134	0.013	0.009	0.001	0.125	0.017	100

	n	Mean	Median	Min.	Max.	SD	%of samples within guidelines
Ammonium (g/m^3)	132	0.022	0.013	0.001	0.154	0.024	100
TOx-N (g/m^3)	115	0.050	0.024	0.001	1.170	0.123	100
TN (g/m^3)	61	0.233	0.194	0.042	1.690	0.216	
TP (g/m^3)	128	0.030	0.021	0.007	0.237	0.029	100
E.coli (cfu/100 ml)	129	31	2	1	1000	117	
Ent (cfu/100 ml)	135	37	3	1	2800	242	
FC (cfu/100 ml)	133	35	6	1	1000	113	
Chl-a (mg/m^3)	115	1.44	1.00	0.05	8.70	1.42	95.7

Water quality monitoring at four popular swimming sites showed that during the 2014/2015 season, 95% of samples from Waihī Estuary complied with the 'Safe' swimming guidelines, the same result as the 2013/2015 season (Figure 15).

Figure 15 *Coastal marine enterococci levels (2013-2014 and 2014-2015 seasons) compared against each of the modes in the Microbial Water Quality guidelines for recreational bathing monitoring sites in the Kaituna WMA. NOTE: Papamoa Beach at the Surf Club was not monitored in 2014/2015.*

Additionally, monitoring of water above three shellfish gathering sites showed that the median faecal coliform value for Waihī Estuary met the guideline value (median FC content not exceeding the MPN of 14/100 mL) in two of the three sites monitored (Figure 16). Only at the Maketū Surf Club site was the median FC level slightly higher than this guideline value. Of interest was the finding that two of the sites (Waihī Estuary and Maketū Surf Club) exceeded the recommended guideline values for having only 10% of samples above the 43 cfu/100 mL guideline limit (Figure 17). The Pukehina Beach Surf Club site reported the lowest median FC levels, as well as reporting no times when samples exceeded the 43 cfu/100 mL guideline value. This probably reflects the fact that this site receives far more sea water than the other two sites.

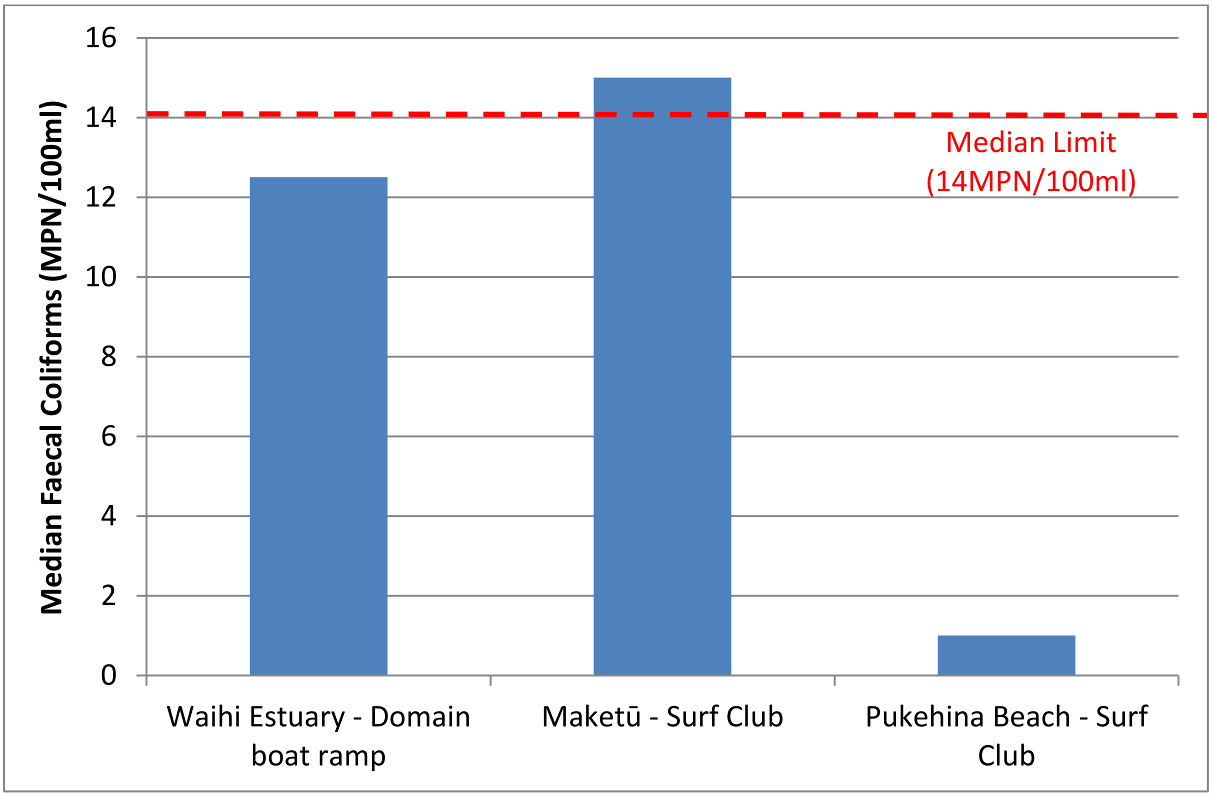


Figure 16 Graph of median faecal coliform value during the 2014-2015 season compared to the Microbial Water Quality guidelines.

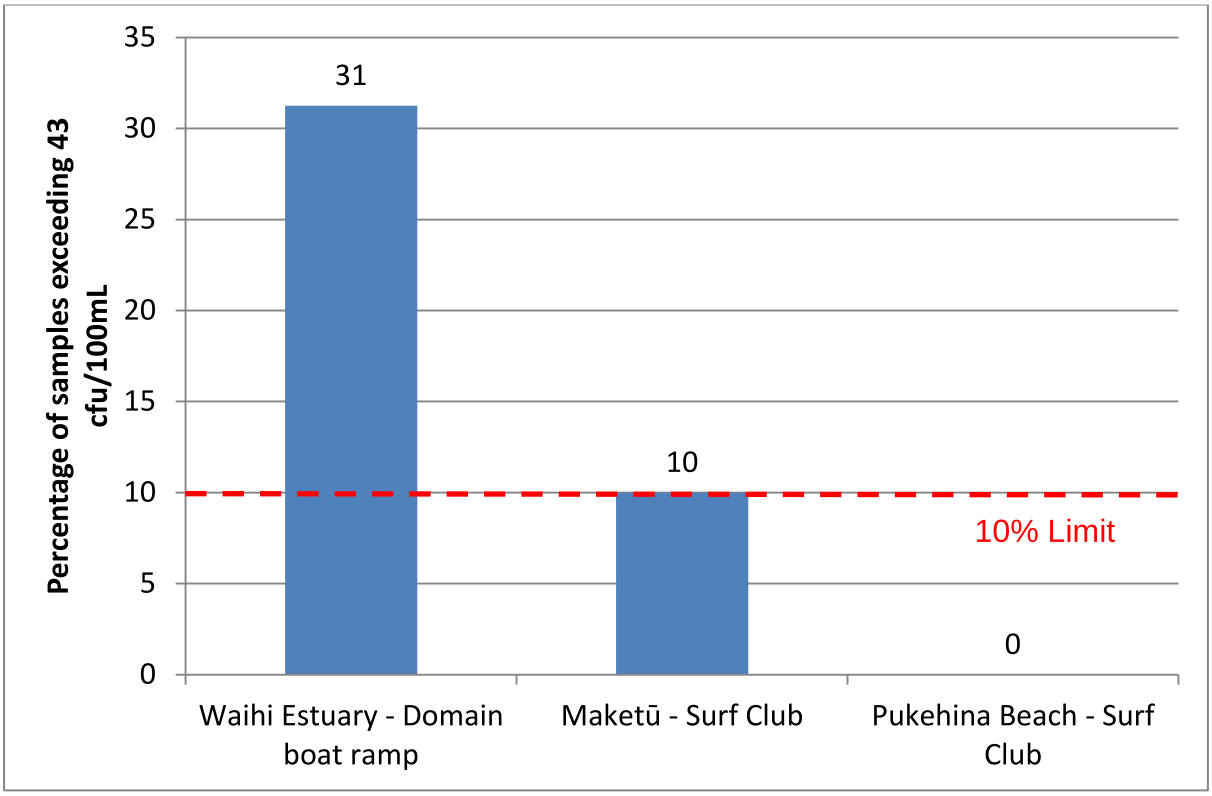


Figure 17 Percentage of samples that exceed Microbial Water Quality guidelines for only 10% of samples having faecal coliform counts above the 43 cfu/100 mL guideline limit.

An investigation into the water quality draining into the estuary was initiated by BOPRC during summer 2014/2015, however only preliminary results are currently available. These results suggest that there are moderately high nutrient inputs from the drains during dry weather, and that bacterial levels are much higher in the smaller streams than larger systems such as the Pongakawa Stream. During rain events there are significantly higher levels of both bacteria and nutrients being carried into the estuary from these drains (as is typical). Given the large extent of the drainage network throughout the area, it is important that water quality conditions in these are better characterised in the future.

Shellfish

Monitoring of the benthic macrofauna of the estuary shows that this is dominated by bivalves and polychaetes (Park, 2012). Monitoring has shown that there has been a decrease in the number of macrofauna at one site (BOP900014) in the Waihī Estuary, however the numbers present are still considered relatively abundant in comparison to other similar sites (Park, 2012). Cockle density and size have varied over time, but no significant trends are apparent (Figure 18; Park, 2012).

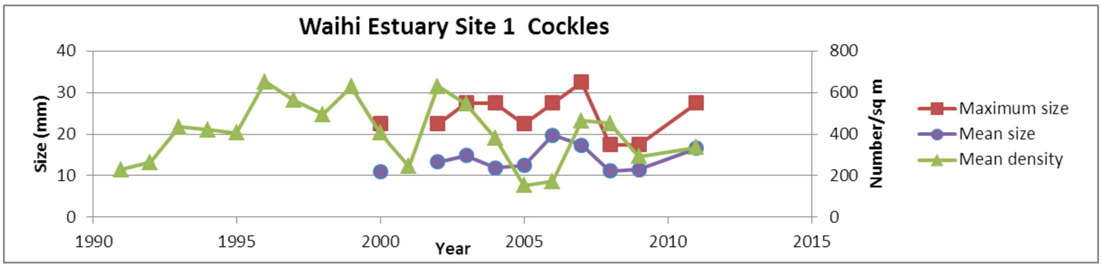


Figure 18 Mean cockle density and size, and maximum size recorded at Waihī Estuary Site 1 (BOP900014) (from Park, 2012).

Monitoring of shellfish flesh (pipi, cockle, oyster and tuatua) for bacterial contamination between 2012-2014 showed that levels of faecal coliform bacteria in pipi were above the MoH safe guideline level in Waihī Estuary on two of the four sampling occasions (Scholes, 2014; Table 35). These results are consistent with the water quality monitoring above shellfish gathering areas which indicated that there are times when it would be considered unsafe to collect and consume shellfish from within Waihī Estuary (Figure 17).

Table 35 Shellfish indicator bacteria results. Samples exceeding the MoH guideline are indicated in red/bold (from Scholes, 2014).

Site		**Date sampled**	**Shellfish type**	***E.coli* (MPN/100g)**	**ENT (MPN/100g)**	**FC (MPN/100g)**
Maketū Estuary	Opposite boat ramp	24/01/13	Pipi	1	1,200	180
Maketū Estuary	Opposite boat ramp	26/02/13	Pipi	2	13	4
Maketū Estuary	Opposite boat ramp	02/04/13	Pipi	8	240	27
Maketū Estuary	Opposite boat ramp	28/11/13	Pipi	2	14	49
Maketū Estuary	Opposite boat ramp	11/12/13	Pipi	2	33	70
Maketū Estuary	Mid-estuary	26/02/13	Cockles	110	170	140
Waihī Estuary	Main Channel	24/01/13	Pipi	1	1	79
Waihī Estuary	Main channel	28/11/13	Pipi	140	59	**540**
Waihī Estuary	Main channel	11/12/13	Pipi		350	**540**
Waihī Estuary	Main channel	29/01/14	Pipi	6	11	180

Macroalgae

The red macroalgae *Gracilaria chilensis* has recently been observed at nuisance levels in the Waihī Estuary. Initial indications suggest that the bloom is not a natural fluctuation as its persistence and frequency are greater than expected. More investigations are being undertaken to monitor this situation and identify whether there are links between this excessive *Gracilaria* growth and high nutrient inflows into the estuary.

12.5.2 Maketū Estuary

The lower Kaituna River Catchment ranges from downstream of Lakes Rotorua and Rotoiti at Ōkere Falls to the coast, where it extends along the coast from Pāpāmoa East to Maketū. The Kaituna River flows north from Ōkere Falls, drops over a steep gradient through a number of gorges (Bioresearchers, 1975a), travels west of Paengaroa and then discharges into the sea at Te Tumu. In the past, the river discharged into the Maketū Estuary, but during a flood in 1907 the river broke out to the coast at Te Tumu (Scholes, 2015). The river migrated back into the Maketū Estuary with the help of Ford's Cut in 1926.

Due to the need for improved flood protection, the river was diverted to discharge at Te Tumu in 1957 (Park, 2010). Some flow was subsequently redirected back into Maketū Estuary in 1996. At the time of writing, there is a proposal to alter the existing diversion structures to allow more water to be diverted into Maketū Estuary (see Section 12.3). Land use in the upper catchment (immediately north of the Rotorua lakes) is predominantly pasture and exotic forestry, with some native forest cover remaining. The mid-section of the catchment is dominated by horticulture or pastoral land use, with large areas of kiwifruit in the catchment. In the lower regions of the catchment, the land is largely used for dairy farming, and extensive drainage schemes operate in this area (Scholes, 2015).

Water quality

Bi-monthly water samples have been collected from the Maketū Estuary (BOP150005) since 1990, and analysed for a range of parameters. Analysis of TOx-N and Total N were commenced only from 1993. This gave approximately 20 years of monitoring data. Comparison of this data with trigger values for estuarine ecosystems (Table 32) shows that chlorophyll-a and turbidity values were lower than the trigger values, whereas NOx-N and NH4 were higher (Table 36). Median total P levels were close to the trigger values (29 mg/m^3 vs 30 mg/m^3).

Table 36 Water quality statistics for Maketū Estuary (after from Scholes, 2015).

	n	Mean	Median	Min.	Max.	SD	% of samples within guidelines
DO%	131	86.6	84.7	43.0	138.3	12.5	26
Temperature (ºC)	136	17.4	16.6	11.7	24.5	3.3	
Cond (mS/m)	133	4903	5070	2060	5450	577	
SS (g/m^3)	135	20.5	16.0	3.7	80.0	14.2	
Turbidity (NTU)	108	5.4	3.9	0.6	38.0	5.3	88.0
pH	135	8.0	8.0	6.9	8.3	0.2	
DRP (g/m^3)	134	0.013	0.011	0.001	0.087	0.011	97.8
Ammonium (g/m^3)	132	0.031	0.020	0.001	0.331	0.041	99.2
TOx-N (g/m^3)	114	0.057	0.033	0.001	0.659	0.084	99.1
TN (g/m^3)	62	0.268	0.249	0.047	0.908	0.136	
TP (g/m^3)	128	0.033	0.029	0.010	0.140	0.017	99.2
E.coli (cfu/100 ml)	128	33	2	1	2000	190	
Ent (cfu/100 ml)	134	30	5	1	2000	178	
FC (cfu/100 ml)	135	41	8	1	2000	189	
Chl-a (mg/m^3)	117	2.01	1.60	0.05	16.90	1.87	93.2

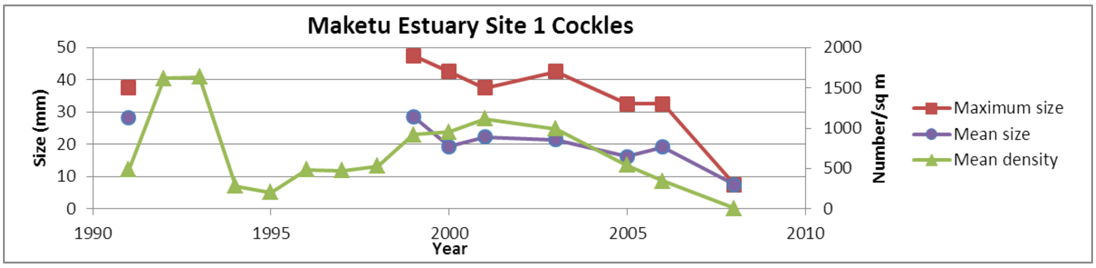
As part of the Kaituna re-diversion consenting studies, Hamill, (2014) conducted an intensive study to better understand diurnal fluctuations in water chemistry of the estuarine water. This work showed large diurnal fluctuations in Dissolved Oxygen (DO) as a result of the large accumulations of *Ulva* sp. and *Gracilaria* sp. For example, Hamill, (2014) recorded DO concentrations of less than 2 mg/L in the mid-estuary and less than 1 mg/L in the upper (western) estuary and Papahikahawai Lagoon. Given that the ANZECC (2000) guideline for DO in marine waters is >80% saturation, or greater than 6 mg/L, the observed very low DO levels in the Maketū Estuary could have excluded many fish species from parts of the estuary during times of the day when DO is at its lowest - usually early morning (Hamill, 2014). DO levels in many parts of the estuary are expected to improve as a result of the Kaituna River Re-diversion and Ongatoro/Maketū Estuary Enhancement project, as more water will be flowing into the estuary from the Kaituna River promoting more flushing of the estuary (Hamill, 2014).

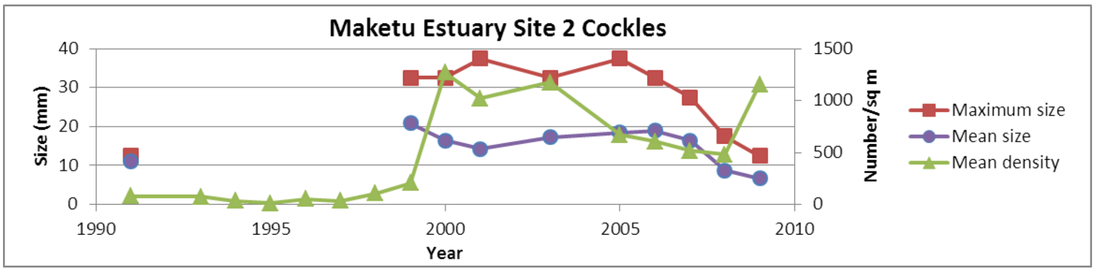
Monitoring at popular swimming sites showed that during the 2014/2015 season, 100% of samples from Maketū Estuary complied with the 'Safe' swimming guidelines, compared to 95% during the 2013/2015 season (Figure 15). These results are comparable to those of Park (2011) where water quality monitoring (one sample in February each year) as part of resource consent conditions showed that all three sites met the guideline values from 2003-2011. Additionally, monitoring of water above shellfish gathering sites showed that the median faecal coliform value for Maketū Estuary exceeded the guideline value (Figure 16), and the percentage of samples above 43 cfu/100 mL was at the 10% guideline limit (Figure 17).

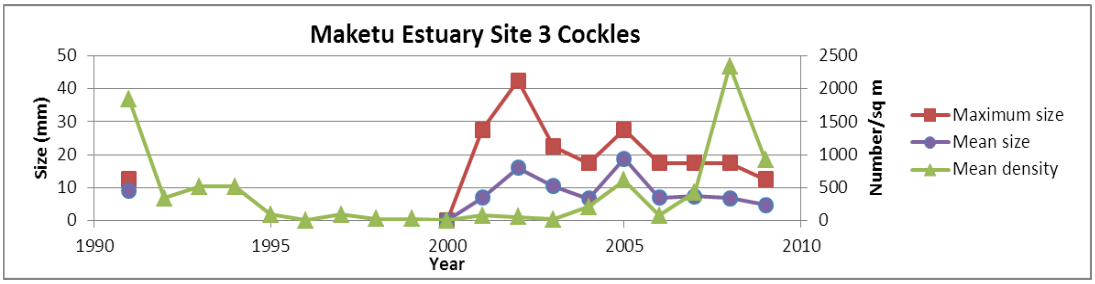
Macrofauna

In a recent survey of 39 sites as part of the Kaituna re-diversion consent, (Hamill, 2014), found that infauna (animals that live in the sediment) are generally sparse or absent in the upper estuary and southern margin of the estuary. Their densities were seen to increase in the mid estuary, with findings of moderate cockle numbers and abundant polychaetes there. In the lower estuary, towards the estuary mouth Hamill, (2014) also found that cockles and wedge shells were abundant. Pipi are commonly found in the lower estuary channel and whilst mussel populations have declined as a result of increased sand into the estuary, there are mussels on the rocks near the estuary entrance (Hamill, 2014). This distribution of infauna and shellfish links closely with the distribution of anoxic sediment in the upper estuary and southern margin of the estuary, and greater densities of *Gracilaria* and sea lettuce (Hamill, 2014).

Long-term monitoring sites for benthic macrofauna have been subject to habitat changes over time as a result of shifting channels and sand influx into the estuary (Park, 2012). These habitat changes have resulted in changes in species diversity and sediment over time (Park, 2012). Cockles appear to be the most wide-spread shellfish in the mid-lower estuary (Hamill, 2014), and thus provide a good indication of any changes over time in this area (Park, 2011). Monitoring data shows that cockle density and size varies considerably at all sites over time (Figure 19), largely as a result of changing habitats (i.e. shallowing at site 1). Because of the habitat dynamics, conclusions cannot be drawn about other factors influencing cockle size or abundance in the mid to lower estuary (Park, 2011). The monitoring sites do not cover the upper or southern estuary areas, hence no quantitative data is available to assess the impacts of the algal blooms as noted by Hamill in his more recent surveys.







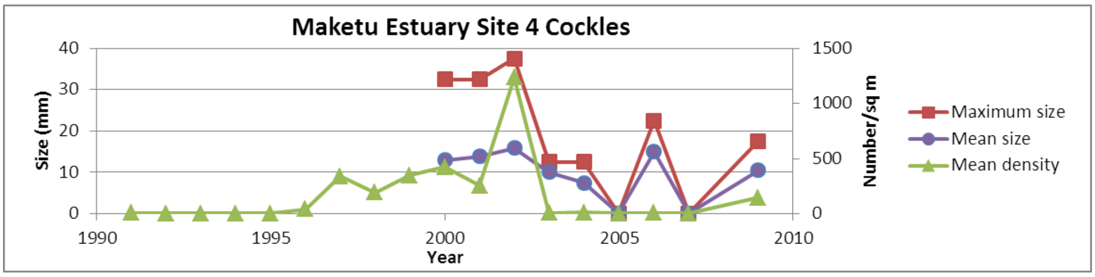


Figure 19 Mean cockle density and size, and maximum size recorded at sites in the Maketū Estuary (from Park, 2012).

Park (2011) concluded that changing habitats were the likely driver for changes in cockle beds, with high-tide sites (sites that are the least affected by sand influx) showing relatively stable (sites 2 and 4), or increasing (sites 3 and 5) cockle densities.

Shellfish

Monitoring of shellfish flesh (including pipi and cockle) for bacterial contamination between 2012-2014 showed that levels of faecal coliform and E.coli met the guideline values in the Maketū Estuary (refer Table 35; Scholes, 2014). Bacteria concentrations in the flesh of shellfish (pipi and cockles) are also measured at up to five sites, annually in February as part of consent monitoring (Park, 2011). This monitoring programme has shown that faecal coliform numbers in cockles and pipi sometimes exceeded the single sample limit, but complied with the median limit. The difference in these findings may just reflect the natural temporal fluctuations of bacterial loadings into the estuary, and emphasises the value of a well-designed and long-term monitoring programme. Note also that the long-term monitoring reported by Park (2011) showed that there had been no significant change in bacterial concentration (both enterococci and faecal coliforms) over time in shellfish.

Algae and seaweed

Hamill (2014) provided detailed information about the current state of algae and seaweed in the Maketū Estuary. He found that the dominant algae species in the estuary were sea lettuce (*Ulva pertusa*) and *Gracillaria* sp. In 2014, around 30% of the estuary had algal coverage of greater than 50% (Hamill, 2014). There is a complex relationship between nutrient levels in the estuary that support algal growth. This includes external nutrients (nutrients provided to the estuary by freshwater inputs) and internal nutrients (nutrients in the sediment). Many management activities are associated with reducing the nutrient levels in streams, which in turn would reduce the external nutrient load into the estuary. However, the internal nutrient load within the estuary may continue to support prolific algal growth (Hamill, 2014). Hamill (2014) suggested that identification of the main nutrient sources within the catchment would thus be an important starting point for reducing the effects of high nutrient levels and the resultant high algal cover.

Fish

The dominant fish species around the estuary margin were introduced mosquito fish (*Gambusia affinis*), common and giant bully (*Gobiomorphus cotidianus* and *G. gobioides*), shortfin eel (*Anguilla australis*) and inanga (*Galaxias maculatus*: (Hamill, 2014). This reflects the need for these fish to complete their life cycle in freshwater, and highlights the importance of maintaining sufficient fish passage through the numerous flood gates and pumping stations found in many of the drains. Other commonly found fish in the main body of the estuary include mullet (*Aldrichetta forsteri*), cockabully (*Grahamina nigripenne*), parore, flounder (*Rhomboslea* sp) and kahawai (*Arripis trutta*: Hamill, 2014). These “marine wanderers” dwell primarily in estuarine environments, or venture into estuaries at times during feeding activities.

12.5.3 Kaituna River Estuary

Water quality is consistently high at the lake fed outlet at the start of the Kaituna River, but this declines markedly as it flows through the lower catchment and as smaller tributary streams and drains enter the river (Scholes 2015). This means that, by the time the Kaituna River discharges at Te Tumu, a small riverine estuary of approximately 0.2 km^2, water quality conditions have been somewhat degraded.

The Kaituna River Estuary has a high average concentration of chlorophyll-a (Table 37) with average concentrations (3.16 mg/m^3) slightly below ANZECC guideline trigger level (4 mg/m^3: Scholes, 2015). These high chlorophyll-a concentrations are largely driven by cyanobacterial blooms in Lake Rotorua. However, as water quality in Lake Rotorua has improved, the chlorophyll-a concentration has decreased since 2011 (Park, 2010, Scholes, 2015).

Table 37 Water quality statistics for Kaituna Estuary (adapted from Scholes, 2015).

	n	Mean	Median	Minimum	Maximum	SD
DO%	98	91.0	90.7	57.8	123.9	10.5
Temperature (ºC)	101	16.1	15.9	10.7	23.5	3.3
Cond (mS/m)	101	1198	776	22	5,050	1,209
SS (g/m^3)	102	8.1	7.0	3.0	31.0	4.5
Turbidity (NTU)	98	3.7	3.1	0.5	14.0	2.3
pH	99	7.4	7.4	6.6	8.2	0.4
DRP (g/m^3)	98	0.024	0.021	0.001	0.426	0.042
Ammonium (g/m^3)	97	0.084	0.066	0.001	1.420	0.146
TOx-N (g/m^3)	99	0.444	0.461	0.024	0.762	0.146
TN (g/m^3)	45	0.765	0.743	0.362	1.250	0.161
TP (g/m^3)	94	0.050	0.041	0.017	0.855	0.085
E.coli (cfu/100 ml)	98	281	68	1	13,000	1,316
Ent (cfu/100 ml)	100	126	39	1	3,600	425
FC (cfu/100 ml)	101	470	140	4	13,000	1,350
Chl-a (mg/m^3)	98	3.16	2.05	0.40	17.00	3.22

12.6 Water quality trends

12.6.1 Waihī Estuary

For the period 1990-2014, there are only three significant and meaningful trends (that is, the rate of change is > 1% per year) in water quality parameters measured in the Waihī Estuary, all for the faecal indicator species (Table 38). These indicator species show an increasing rate of change of approximately 6%, 7.5% and 8% for faecal coliform, E.coli and enterococci respectively. A comparison to trends on the Pongakawa Stream (which flows into Waihī Estuary) showed that there was minimal change in these faecal indicators from 1999-2014, indicating that increases in faecal indicators are likely to be coming from inputs other than the Pongakawa Stream (Scholes, 2015). Scholes (2015) suggested that the observed increases could be a result of the increased dairying intensity in the lower catchment over the last decade, as well as estuarine nutrient recycling dynamics and climatic drivers. Results from the water quality study currently underway may provide some more information on the likely sources in time.

Table 38 Trend statistics for Waihī Estuary (from Scholes, 2015).

		SS	**Turbidity**	**pH**	**E.coli**	**Ent**	**FC**
Site		**(g/m^3)**	**(NTU)**		**(cfu/100 ml)**	**(cfu/100 ml)**	**(cfu/100 ml)**
Waihī Estuary	**Trend**	▫	▫	▫	➚	➚	➚
	%/yr (RSEN)	2.02	-1.08	0	**7.50**	**8.03**	**6.04**
	Slope (10^{-3} units/yr)	243	-24	0	19	36	44

		DRP	**NH_4-N**	**TOx-N**	**TP**	**Chl-a**
Site		**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(mg/m^3)**
Waihī Estuary	**Trend**	▫	▫	▫	▫	▫
	%/yr (RSEN)	<0.01	1.79	-0.7	-0.97	0.01
	Slope (10^{-3} units/yr)	<0.01	0.2	1.7	-0.2	0.1

Trend: ⬀⬂ significant increasing or decreasing trend of parameter over time ($p<0.05$); ➚➘ significant and meaningful trend ($p<0.05$, %/yr >1%); ▫ not significant.

12.6.2 Maketū Estuary

Between 1990 and 2013, there was only one significant and meaningful trend (that is, rate of change is > 1% per year) of measured water quality parameters in the Maketū Estuary (Table 39). Here, suspended sediment increased at a rate of approximately 3% per year. Scholes (2015) highlighted that similar trends were not observed in either the Kaituna Estuary or the Kaituna River, suggesting that the increase is likely to be from processes such as stirring of sediments by wind within the estuary, or by increased sediment inputs from other (unmeasured) inflows.

Table 39 Water quality statistics for Maketū Estuary (from Scholes, 2015).

		SS	Turbidity	pH	E.coli	Ent	FC
Site		**(g/m^3)**	**(NTU)**		**(cfu/100 ml)**	**(cfu/100 ml)**	**(cfu/100 ml)**
Maketū Estuary	**Trend**	➚	▫	▫	▫	▫	▫
	%/yr (RSEN)	**2.96**	-2.05	0.02	5.19	1.69	0.06
	Slope (10^{-3} units/yr)	417	-66.5	1.6	15.4	12.5	0.6

		DRP	NH_4-N	TOx-N	TN	TP	Chl-a
Site		**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(mg/m^3)**
Maketū Estuary	**Trend**	▫	▫	▫	▫	▫	▫
	%/yr (RSEN)	-0.97	1.07	-0.75	0.77	-0.7	-0.25
	Slope (10^{-3} units/yr)	-0.1	0.2	-0.2	2	-0.2	-3.5

Trend: ⬀⬂ significant increasing or decreasing trend of parameter over time ($p<0.05$); ➚➘ significant and meaningful trend ($p<0.05$, %/yr >1%); ▫ not significant.

12.6.3 Kaituna (River) Estuary

Trend analysis for the Kaituna Estuary shows significant and meaningful trends for six of the measured water quality parameters (Table 40). Three parameters (turbidity, ammonium and chlorophyll-a) decrease over time and three (enterococci, dissolved reactive phosphorus and oxidised nitrogen) increase. The decreasing trends for turbidity and chlorophyll-a could in part be explained by the reduction in cyanobacterial blooms in the Rotorua Lakes and the Kaituna River (Scholes, 2015). The decreasing ammonium trend is also seen further upstream in the Kaituna River at Te Matai, and Scholes (2015) suggested this could be due to improvements in the discharge from the AFFCO freezing works, as this discharge is a known contributor of ammonium to the river.

The significant increase in DRP in the estuary trend (Table 40) is in contrast to DRP trends in the Kaituna River at Waitangi, which has not changed significantly. Scholes (2015) suggests that this different pattern in DRP levels could be a result of decreased productivity in the estuary (as shown by decreasing chlorophyll-a trends) meaning that there is less uptake of DRP by plants in the estuary.

Increasing trends in oxidised nitrogen are observed in other riverine estuaries in the region (Scholes, 2015) and are likely a reflection of the increasing agricultural intensity in the catchments.

Scholes (2015) noted that the increasing trend in enterococci may be due to point-source discharges within the catchment, although levels of enterococci in the Kaituna Estuary are similar to those in other riverine estuaries.

Table 40 Trend statistics for Kaituna Estuary (from Scholes, 2015).

		SS	Turbidity	pH	E.coli	Ent	FC
Site		**(g/m^3)**	**(NTU)**		**(cfu/100 ml)**	**(cfu/100 ml)**	**(cfu/100 ml)**
Kaituna Estuary	**Trend**	□	↘	□	□	↗	□
	%/yr (RSEN)	-0.74	**-2.27**	0.05	-0.86	**2.0**	-0.5
	Slope (10^{-3} units/yr)	-51.6	**-67.5**	3.6	-16.1	**33**	-10.9

		DRP	NH_4-N	TOx-N	TN*	TP	Chl-a
Site		**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(g/m^3)**	**(mg/m^3)**
Kaituna Estuary	**Trend**	↗	↘	↗	□	□	↘
	%/yr (RSEN)	**1.91**	**-3.50**	**1.92**	-1.51	0.25	**-2.67**
	Slope (10^{-3} units/yr)	**0.4**	**-2.3**	**8.7**	11.4	0.1	**54**

Trend: ⬀⬂ significant increasing or decreasing trend of parameter over time ($p<0.05$); ↗↘ significant and meaningful trend ($p<0.05$, %/yr >1%); □ not significant.

12.7 Gaps and recommendations

Whilst existing monitoring and research provides an indication of the health of estuaries within the Kaituna WMA, there are a number of knowledge gaps still existing (Table 41).

Table 41 Identified gaps for estuarine monitoring programmes and recommended solutions to address gaps in current knowledge.

Gap theme	Gap	Recommendation
Data for models	Cumulative impact on receiving environments.	Consider the desired values in receiving environments (i.e. estuaries), and establish assimilative capacity of the receiving environment for the chosen variable(s) (e.g., algal biomass). Undertake studies upstream into the catchment to ensure that limits in the final receiving environment can be met.
Obtain new data	Impact of drainage canals.	Investigate the impact the drainage network is having on downstream water quality. NOTE: drainage network may come under Appendix 3 of NPS, if so this recommendation may not be required.

Gap theme	Gap	Recommendation
Obtain new data	Connection with wetlands and wetland extent.	Re-survey wetland extent, determine connection with waterways, and incorporate WQ monitoring in wetland monitoring programme where there is a hydrologic connection. Support: Hamill (2012).
Obtain new data	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater into the waterways within the Kaituna WMA and the relative nutrient load contributed from the groundwater springs.
Obtain new data	Sediment and nutrient recycling within the estuaries.	Investigate the dynamics within the estuary to better understand the recycling of internal sediment and nutrients within the estuaries.

Part 13: Other considerations

13.1 Introduction

While this review shows that BOPRC monitors a wide range of parameters in the Kaituna WMA, it is apparent that there are many gaps in the current monitoring programmes, with respect to informing the resource management questions now required under the newly released NPS-FW. The requirements under the NPS-FW have now placed a much greater demand on monitoring programmes than have occurred in the past. The challenge is how to best fill these gaps given the reality of constrained resources and time.

The next step is to prioritise and rank these knowledge gaps so that the needs of the NPS-FW implementation process are met. In undertaking such a ranking process, it is important to consider a number of key issues, including that:

- monitoring needs to examine more than just compulsory national attributes,
- monitoring needs to be representative of the range of land uses,
- a high degree of longitudinal connectivity (links) exists between waterways and their ultimate receiving environments such as lakes or estuaries,
- there is a need for better integration of different science programmes, and
- there is a need to consider the data and information needed to support computer models.

By considering these issues as part of the gap analysis and prioritisation process, it is expected that more informed decisions can be made about gaps which need to be addressed as a matter of urgency and those which can be regarded as lower priority.

13.2 Other attributes

Under the National Objectives Framework in the NPS-FW (Section CA) Council is required to identify any attributes (in addition to compulsory attributes in NPS-FW Appendix 2) that are considered appropriate for each value that Council identifies for each freshwater management unit (including compulsory national values and other values). Many of the compulsory national attributes are focused on water quality and algal biomass (as chlorophyll). These parameters are likely to be affected by changes in land use activities such as the intensification of farming and urban development.

It is important to recognise that monitoring needs to cover more than just the compulsory national attributes. Indeed, Policy CA2 of the NPS-FW specifically requires councils to identify other relevant attributes for their situation. This is important, as streams could arguably meet the current NPS bottom lines for the two compulsory standards of “human health for recreation” and “ecological health”, and yet show a marked decline in overall ecological condition. This is because other important parameters that affect ecological communities in streams, such as sediment, and habitat condition, are not included in the NOF. Sediment, in particular is a highly relevant contaminant in streams draining catchments dominated by pasture and exotic forest, and is well known to cause significant adverse ecological effects (e.g., Ryan 1991, Clapcott et al. 2011). In some cases sedimentation may also be a major contaminant in streams draining urban areas.

In-stream habitat condition such as substrate, flow, and riparian vegetation may also change dramatically as a result of land use activities and effect ecological health. For example, increased sedimentation may make substrate conditions in streams unsuitable for many invertebrate taxa, and for many fish species that require clean gravels to spawn upon. Removal of riparian vegetation will also affect invertebrates by increasing the amount of sunlight reaching a stream, which may result in higher water temperatures, or higher algal biomass. Riparian vegetation is also important to many native fish, which spawn amongst native grasses or leaf litter during periods of high flow.

Identification and selection of an appropriate suite of attributes to support values will follow confirmation of values, later in the NPS-FW implementation process.

13.3 Land use representativeness

Monitoring frameworks should include appropriate representation of different catchment land uses so that the effects of these can be identified. Although it is important to monitor streams flowing through the most developed catchments (where the most pressure is likely to occur), it is also important to monitor the same compulsory national attributes in less modified streams where these attributes are likely to be in the A band. This is important, as it allows limits to be considered for stream types where the community wishes to maintain a high level of quality and ecological health (Policy CA2 b in NPS-FW). It also allows the results of monitoring streams draining more modified catchments to be put into perspective. Because of this, it is important to also monitor streams draining catchments dominated by exotic and native forest.

Monitoring streams flowing through exotic forest is important so that BOPRC can assess the long-term effects of forestry on stream ecosystems. This is especially important considering the potential effects on forestry activities in relation to sediment inputs (Harding et al. 2000), as well as potential effects on water yield as a result of increased interception and transpiration (Fahey and Watson 1991). Any reductions in water yield as a result of afforestation has potential implications for the setting of low flows in the lower areas of the catchments.

Monitoring streams flowing through catchments dominated by native forest is also important as it allows natural changes in water quality, ecology and flow to be documented over time in the absence of significant human activity. In this way we are able to determine whether climate could be responsible for any degradation (or improvement) identified in streams flowing through more developed catchments.

13.4 Links to receiving environments

Rivers and streams usually discharge into lakes, estuaries or harbours, or to the open coast. These receiving environments represent the ultimate destination for contaminants that are transported via rivers and streams. They often act like sinks, and contaminants can build up in them over time, often with ecological consequences.

Although the NPS-FW is primarily focussed on freshwater, Policy A1 (a) (iii) requires Council to have regard to the connections between freshwater bodies and coastal water. When considering limit setting in rivers, it is imperative that the cumulative impacts on the receiving environment are actively considered and accommodated into the freshwater management approach to be implemented under the NPS-FW.

For a number of reasons, monitoring programmes (and reporting) are generally segregated by water body (e.g. lakes, rivers, estuaries etc.). The NPS-FW identifies the need for this integrated approach to managing freshwater in whole catchments, including the interactions between freshwater ecosystems, land and the coastal environment. Within the Kaituna WMA, two clearly defined receiving environments are the Waihī and Maketū estuaries.

13.5 Better integration of science programmes

A wide range of scientific investigation programmes have been conducted within the Kaituna WMA. Traditionally, much of the science conducted by BOPRC has been focused on the individual disciplines (e.g. water quality, ecology etc.), with monitoring designed to maximise the scientific information of relevance to each. For example, there is a relatively large disassociation between water quality monitoring sites and invertebrate monitoring sites. This reflects the practicalities of monitoring river systems. Ecological monitoring is limited to 'wadeable' streams and is more concerned with investigating headwater catchments where the effects of land-use changes to ecology are more pronounced. Whereas water quality monitoring can only practically monitor a few key locations in a catchment, As such water quality monitoring sites occur in key locations which cover key catchment attributes or all of the catchment in some cases.

Many of the recommendations made in this review have highlighted the need to collect data at new sites within the Kaituna WMA. These recommendations have been made across most of the science disciplines. There is an opportunity to obtain better coordination between the different science programmes to ensure that BOPRC is monitoring as many parameters within a catchment as possible. It is therefore recommended that a number of "Sentinel sites" be established throughout the Kaituna WMA where detailed and coordinated monitoring is undertaken of groundwater, surface water (including quantity and quality), soil attributes (including nutrients), and ecology (periphyton, invertebrates and fish). These could be established at a few locations of differing land uses, so that links between land-use intensification, effects on water quality and quantity, soil attributes, and the resultant ecological responses can be unravelled over time.

It is envisioned that long-term data gleaned from the use of such Sentinel sites will allow BOPRC to both better communicate its science to the community, and to fulfil its obligations under both the RMA and the NPS-FW.

13.6 Modelling needs

One of the key challenges under the NPS-FW is for BOPRC to maintain or improve water quality in the face of a community desire to continue land-use development associated with agriculture (dairy or beef farming, horticulture, or cropping), forestry activities, and urbanisation. Many of the recommendations made in this report centre around the need to collect more data so that relationships between pressures associated with land-use development and the resultant water quality/ecology can be quantified and better understood. However, it is impractical and unrealistic to assume that BOPRC can measure everything. There is, therefore, an undeniable imperative that a large component of the NPS implementation work will involve the need to model interactions between land use activities and water quality.

Extensive use of models has two major benefits. Firstly, measurements and knowledge obtained from some locations can be applied to other locations For example, reliable estimation of nutrient losses from farmland is fundamental in understanding relationships between economic productivity from farming and any potential environmental effects associated with nutrient losses and possible associated periphyton blooms. The likelihood of such blooms is, however, driven by many factors other than just nutrients, including hydrology, substrate size, and shade. Any ecological models predicting the effects of increased nutrients on periphyton biomass will thus also need a strong hydrological component, as well as the ability to model predicted substrate size and shade.

The second benefit of a strong modelling component is that models allow “what if” assessments of future scenarios to be made: i.e. they are predictive tools. This is a highly important attribute, as it will allow BOPRC staff the ability to model different land use scenarios and how these may affect defined management objectives, and instream values. Such scenario testing is envisioned to be an important part of any community consultation to show the community what potential effects are of different development scenarios.

Other important interactions to consider is the need to understand linkages between surface and groundwater, as streams which are predominantly surface water fed are likely to respond very differently to the effects of land use intensification than streams which are predominantly groundwater fed. In addition, groundwater resources may or may not be affected by land use activities. Thus, groundwater resources in unconfined aquifers which are hydraulically linked to soil water are likely to be affected by increases in nutrients associated with land-use intensification, whereas groundwater resources in deeper, confined aquifers may not be affected to the same degree.

The importance of models showing the interaction between land use and nutrients has been highlighted by both the Land and Water Forum and MFE. This importance is also reflected in the large number of models that are currently available in New Zealand that link land use and water quality. For example, Cichota and Snow (2009) identified 17 different models used to estimate nutrient loss from pasture farms in New Zealand. These models differed greatly in their spatial and temporal resolution, and in the number of different processes each model considered. Simple models were typically associated with large spatial and temporal scales, and were used to calculate average annual losses of nutrients from a farm or catchment.

Because these models were based on large-scale processes, they were built on relatively simple systems, as the variability of many processes decreases at large spatial scales. More complex models are used at smaller spatial scales in order to better understand processes operating within, for example, a single paddock. Cichota and Snow (2009) highlight that different models are appropriate for different purposes, and so it is important to know what each model can and cannot do, and select the most appropriate model for the user's needs. Thus, models designed to accurately predict nutrient losses at small scales such as a single paddock may be of interest to researchers, whereas models designed to predict nutrient losses at the catchment scale may be more useful to organisations such as BOPRC for their NPS implementation work.

Although Cichota and Snow identified 17 models to estimate nutrient losses, it must be emphasised that understanding nutrient losses from a farm to a stream is only half the story. As discussed, any effects of nutrient enrichment on streams can be mediated by the interaction with groundwater, and so it is important to understand and model groundwater and surface water interactions throughout the catchment. It is also important to understand and model stream flow throughout the region, particularly as not all waterways in a region can be gauged. Finally, ecological models also need to consider interactions between a stream's nutrient and flow regime, and the resultant periphyton biomass that will form. This is important as periphyton biomass is the only NOF attribute that has direct relevance to ecosystem health.

It is important to also recognise the fact that nutrient inputs are only one stressor arising as a result of land use intensification. Increased demand for water is often a consequence of land use intensification, and within the Bay of Plenty, there is a high demand for water from a wide range of agricultural sectors including dairy, cropping, and horticulture. The NPS-FW requires Council to set environmental flows and levels at the amount of water in a freshwater unit which is required to meet freshwater objectives. For this reason, more robust methods such as IFIM and RHYHABSIM are recommended to help inform decision making on environmental flows (and allocation) in waterways to protect ecological health.

This was the rationale behind the development of EFSAP (Booker et al. 2014), which uses generalised habitat suitability curves to model habitat retention for a range of fish species relative to mean annual low flow in all waterways. A central theme of EFSAP is also to estimate the reliability of supply in different waterways given a minimum flow derived on a pre-defined habitat protection level for a target fish species. Thus, as the minimum flow increases, so does the level habitat protection for the target fish. This is, however, countered by a reduction in reliability, and in the quantity of water available for out-of-stream users. Conversely, making more water available for out-of-stream users means there is a decrease in habitat availability for fish species, but an increase in reliability of supply. A key feature of EFSAP is to graphically model different outcomes that demonstrate trade-offs between minimum flow, reliability of supply, and habitat protection for different abstraction scenarios. EFSAP therefore relies on models of fish habitat at different flows, as well as models of flows throughout the region. Within the Bay of Plenty, Booker (2014) found that the TOPNET model most accurately predicted low flows throughout the region.

The effects of water abstraction are not just limited to decreasing potential habitat availability for fish and invertebrates, or decreasing recreational values such as kayaking and fishing within rivers. Reduced flows can also influence water quality in terms of increased temperature, reduce dissolved oxygen, and increases in concentrations (by reduced dilution) of potential toxicants such as nitrate and ammonia. The effects of low flows on water quality have been modelled using WAIORA (Jowett et al. 2004): a decision-support system designed to provide guidance on whether a water abstraction or discharge could have adverse impacts on environmental parameters such as dissolved oxygen, total ammonia, and water temperature. WAIORA uses measurements of stream geometry and numerical models to estimate how these parameters change with flow, and compares the predicted changes to environmental guidelines to determine if an adverse effect is likely to occur as a result of abstraction. It can also model what mitigation scenarios may ameliorate any adverse impacts.

Other stressors arising from land-use intensification include sedimentation. Sedimentation can have a huge adverse effect on the ecological values of waterways (e.g., Ryan 1991; Clapcott et al. 2011). As with nutrients, a number of models have been developed to predict sediment losses from catchments with different slopes, vegetation cover, and soil types. For example, SedNet calculates mean annual sediment budgets for regional scale river networks to identify patterns of material fluxes. It also predicts the sediment supply from surface and hillslope erosion, gully erosion and erosion from banks. This enables users to target management actions to improve water quality, and assists in planning catchment management actions by identifying major areas within catchments where sedimentation sources are likely to be high.

13.7 Use of models to implement the NPS

It is clear that a wide diversity of different models exist within New Zealand, each designed for different tasks. The challenge faced by BOPRC is to firstly decide which of the many models are appropriate, and secondly, their ability to be linked (i.e., their interoperability). As part of a study investigating model interoperability, Elliot et al. (2014) identified over 40 models dealing with nutrients, flow and groundwater. Summaries of these are available on the Framework for Interoperable Freshwater Models (FIFM) webpage: https://teamwork.niwa.co.nz/display/IFIM/Compilation+of+models+and+their+attributes

It is important to note that this inventory is still relatively limited and does not include water allocation models such as EFSAP, CHES, or water quality models such as WAIORA. We have examined the initial Elliot et al. list for models with high relevance to the planned work that BOPRC intends to do, and combined this with other models of relevance to the requirements of the NPS. A total of 16 models was consequently identified (Table 42). Note that this list is only indicative and likely to change depending on future examination and rationalisation of BOPRC’s modelling needs. Also to note is the absence of any specifically named models that describe interactions between algal biomass (a NOF attribute), and stream flow, or nutrient levels. Although statistical relationships between these parameters have been developed (Biggs 2000, Snelder et al. 2014), no stand-alone model currently exists that allows a time series representation of algal biomass at different spatial scales to be created.

Table 42 List of 16 relevant models potentially of interest to BOPRC as part of its implementation of the NPS. Some of this list comes from work by Elliot et al. (2014, see: https://teamwork.niwa.co.nz/display/IFM/Compilation+of+models+and+their+attributes), whilst other models were listed through consultation with BOPRC staff.

Number	Model	Description	Addresses	Purpose
1	ARC HydroGroundwater (ARC_HG)	A geodatabase design for representing multidimensional groundwater data including data from aquifer maps and well databases, data from geologic maps, 3D representations of borehole and hydrostratigraphy, temporal information, and data from simulation models.	Groundwater	Uses the ARC-GIS platform to archive, manage, and visualise groundwater information, and to create water level, water quality and flow direction maps, create, archive and visualise MODFLOW models, and create and visualise both 2D and 3D geologic models.
2	CLUES	CLUES is a catchment model developed to address implications of land use scenarios on stream water quality and some socio-economic indicators.	N and P yields	CLUES predicts the impacts of land use changes on river quality and socio-economic indicators, e.g. GDP, or employment. It also identifies sensitive and at risk catchments, such as those sensitive to the effects of dairy land use.
3	CHES (Cumulative Hydrological Effects Simulator)	Estimates the net changes to the flow regime throughout a catchment due to multiple water use schemes. It also quantifies the consequences for both the overall availability and reliability of the water resource and the residual flows that determine the in-stream environmental effects.	Hydrology - effects of allocation	CHES predicts how water flows in a catchment will change with multiple water uses (e.g. direct abstractions or storage reservoirs) and what the consequences will be to in-stream ecosystems and reliability of water-take.
4	EFSAP (Environmental Flow Simulation Allocation Platform)	Estimates how physical habitat for fish and the reliability of water supplies for out of channel users changes when different limits on water allocation are set.	Hydrology - effects of allocation	To describe the consequences of water resource planning scenarios (i.e., different options for managing water resources) on in stream and out of channel values across all parts of a catchment or region.

Number	Model	Description	Addresses	Purpose
5	FEFLOW	A professional software package for modelling fluid flow and multi-species reactive contaminants and heat transport in the vadose and groundwater zones.	Groundwater	FEFLOW is a general purpose groundwater flow and transport model. It may also be linked to surface water models.
6	HEM (Hillslope Erosion Model)	Estimates sediment yield and erosion from hill-slopes during storm events.	Sediment	
7	LeapFrog3D	3D geological modelling software.	Groundwater	Allows a 3D visual representation of groundwater resources.
8	Mike11	River modelling software. The core is a model for hydraulics including dynamic wave routing, but there are add-ons for rainfall-runoff (to generate inflows), contaminant dispersion, and sediment transport.	Sediment	Simulation of hydrology, hydraulics, water quality and sediment transport in rivers.
9	MODFLOW	A 3D finite-difference model for simulating saturated groundwater flow. Companion modules also track particle path lines, simulate contaminant transport, and allow simulation of chemical reactions.	Generic WQ contaminants to groundwater	A general purpose groundwater flow and transport model.
10	NZEEM (NZ Empirical Erosion Model)	Predicts mean annual soil loss from annual rainfall, type of terrain and level of woody vegetative cover. The model can be used to identify vulnerable land for soil conservation prioritisation, and to minimise erosion and flood damage. Can also be used to estimate the effects of land use cover change on erosion.	Sediment	Provides a quantitative spatial picture of where sediment in rivers is sourced and can be applied to the prioritisation of: farm plans, regional soil conservation and soil conservation for reducing sediment yield.
11	Overseer	Model for farm-scale nutrient budgeting and loss estimation.	N and P yields	Estimation of nutrient and GHG budgets for pastoral farms and arable/horticultural paddocks.

Number	Model	Description	Addresses	Purpose
12	RHYHABSIM	RHYHABSIM is a habitat-hydraulic model designed to predict the amount of microhabitat available in a stream or river for fish or macro-invertebrates at different flows.	Hydrology (and temperature)	To provide integrated solutions to common hydrometric and hydraulic computations in flow assessment, such as calculation of flow, stage/discharge rating curves, water surface profile analysis, incremental flow analysis (IFIM), including flushing flows, sediment deposition, flow fluctuations and water temperature modelling.
13	SedNet	1. Constructs mean annual sediment budgets for regional scale river networks to identify patterns of material fluxes. 2. Assists effective targeting of catchment and river management actions at regional scales to improve water quality and riverine habitat.	Sediment	Predicts the sediment supply from surface and hillslope erosion, gully erosion and erosion from banks. This enables users to effectively target management actions to improve water quality, and assists in planning of catchment management actions by identifying the relative importance of processes supplying sediment and nutrients to the river network, and hotspot areas of each source.
14	TopNet	A semi-distributed hydrological model for simulating catchment water balance and river flow.	Hydrology	Research purposes: climate change and land use change effects on hydrological cycle. Application purposes: Simulation of catchment water balances and river flow, and flood forecasting.
15	WAIORA	WAIORA is a decision-support system designed to provide guidance on whether a water abstraction or discharge could have adverse impacts on parameters such as dissolved oxygen, ammonia, temperature and habitat for aquatic life.	Temperature, DO and habitat	Uses measurements of stream geometry and numerical models to estimate how they change with flow, and compares predicted changes to environmental guidelines to determine if adverse effects are likely occur, and what mitigation scenarios could ameliorate any adverse impacts.

Number	Model	Description	Addresses	Purpose
16	WATYIELD	Decision support tool to estimate water yield. Developed in the ICM (Integrated Catchment Modelling) project. The model is intended for use in situations where there is a limited amount of data on the climate, soils, and vegetation of the catchment, and is similar to the approach widely used for computing crop water requirements.	Hydrology	To evaluate the effect of land use change on water yields.

One of the major challenges faced by BOPRC is to decide which of the many models as listed in Table 42 are most appropriate to help them meet their obligations under the NPS. Furthermore, many models have different inter-relationships with each other. Some models are closely linked, while others operate in relative isolation from other models (Figure 20). This raises considerable challenges to organisations such as BOPRC in deciding what models to use when trying to set limits in catchments in order to maintain specific bands for the different compulsory national attributes.

To illustrate the potential complexity by way of a hypothetical example, consultation with the community may have highlighted the fact that they wish to maintain chlorophyll biomass of a particular stream in the B-band. Chlorophyll biomass is a function of flow regime, nutrients, substrate type and shade. All of these controlling factors can be affected by land use activities. Converting a stream from plantation forestry to farming will result in large changes to the stream's hydrological regime, reflecting differences in interception and transpiration rates between plantation forests and pasture. During any conversion phase, high quantities of sediment may also be released, which may or may not affect the habitat suitability for periphyton.

Converting stream catchment land use to dairy farming is also likely to increase nutrient inputs, with potential effects on periphyton biomass. Removing a forest canopy cover and opening the stream to full sunlight is also likely to increase periphyton biomass. Finally, conversion to dairy farming may result in an increased demand for water abstraction, which would lead to low flows. These low flows may affect stream ecology through the loss of physical habitat, or may result in increased temperatures, or reduced oxygen. If BOPRC wishes to maintain algal biomass within a particular NOF band, or maintain the stream and its current ecological condition, then they are likely to have to consider setting both upper nutrient limits, as well as minimum flow requirements. Both of these questions have considerable modelling requirements, requiring models of flow, land use nutrient interactions, and any potential effects of abstraction to all be considered in an integrated way (Figure 20).

There is no doubt that many of these modelling requirements currently exist as stand-alone features. The real challenge exists in trying to bring these disparate models together into a more coordinated system. As part of their review of model interoperability, Elliott *et al.* (2014) also highlighted the fact that many end users such as BOPRC are likely to have difficulty in understanding the range of different models that are available and used within New Zealand, and how these models related to each other. To help with this, they created a new model (called ModelVis) that allows users to search for models with particular attributes, shows how a particular model may interrelate with other models, and shows where end-users can find additional information about a selected model. This is available at: https://teamwork.niwa.co.nz/display/IFM/Relationships+between+models+the+ModelVis+tool).

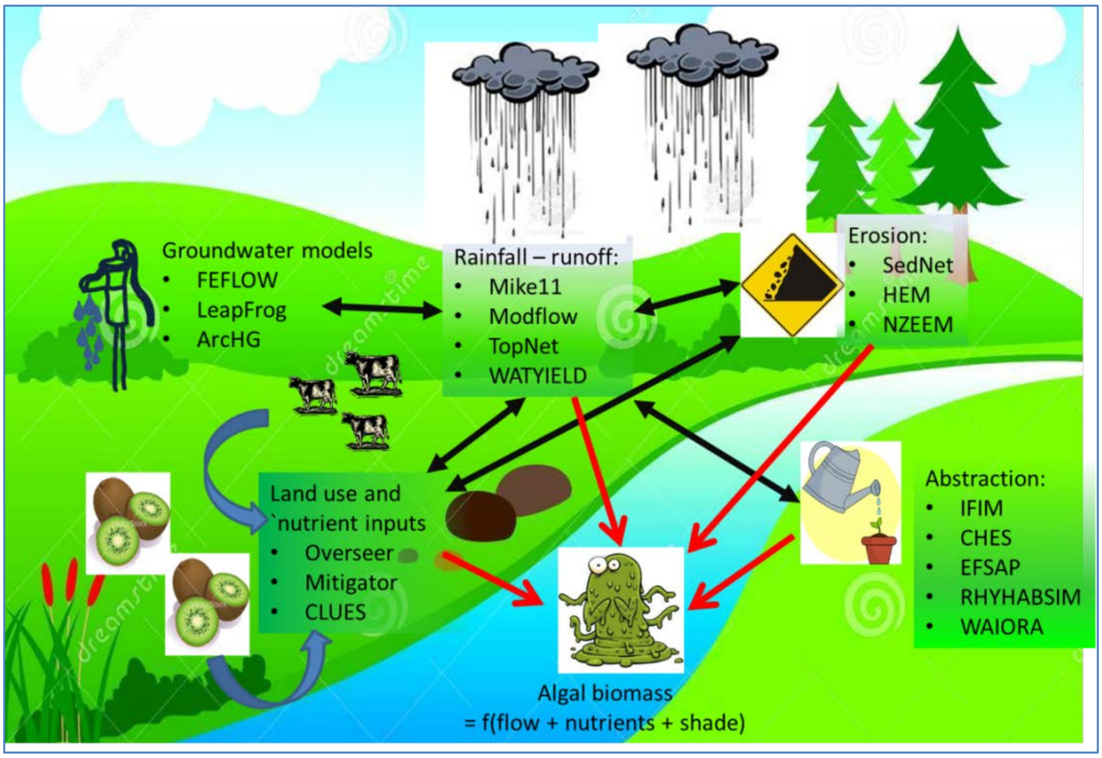


Figure 20 *Schematic relationships between the different models potentially of use to BOPRC. Interactions between models are shown as black arrows. Note that in order to achieve a specific national bottom line (in this case algal biomass), then input from three independent models is likely to be needed (red arrows).*

Finally, Elliott *et al.* investigated what software infrastructure could be used to link different models together, and made some useful recommendations as to what they considered the best platform for this task. Such platforms can be used to allow end-users to effectively link different models together rather than running them individually.

To conclude, there is a definite need for appropriate models to be used by BOPRC, but also challenges ahead in deciding which of the many models should be used. Many specific recommendations for modelling requirements have been made under the appropriate sections for each science discipline, and so a general recommendation made here would be to undertake a workshop with selected individuals to help choose and prioritise which of the many models can be used. Part of this prioritisation process should refer to the ModelVis tool developed by Elliott *et al.* (2014).

Part 14: Summary of recommendations

Table 43 summarises all of the recommendations presented in this report. The recommendations are grouped under the following themes:

(a) Spatial frameworks

(b) Obtain new data

(c) Improvements to methods and reporting

(d) Identify values

(e) Data for models

(f) Data management

For recommendations for specific science work programmes (e.g. soils, invertebrates) refer to the appropriate section of this report.

As some of the recommendations in this report are compiled from existing reports, each recommendation has been given a 'status' to indicate whether the recommendation is 'new', 'already underway', or 'planned and resourced'.

Some recommendations (e.g. periphyton monitoring) were identified in previous reviews and have been allocated resources, others are currently being implemented. These existing recommendations have been included in this report for completeness.

The 'status' assigned to each recommendation was used to support prioritisation of the gaps identified. A series of meetings was subsequently held between relevant BOPRC staff to establish a priority list of work to be done as part of the gap filling process. All subsequent information generated as part of this gap filling process will eventually feed into work being conducted within the Kaituna WMA, and will be presented as a series of community workshops to highlight the current state of the physical, chemical and ecological condition of waterways within the WMA. Note that this prioritisation process did not, in the first instance, consider the prioritisation of work dealing with either wetlands or estuaries. This was partially because the NPS-FW had not yet created specific attributes for either wetlands or estuaries. In the absence of such guidance, it was decided to concentrate primarily on the prioritisation of work dealing with the physical processes of soils, hydrology and groundwater, and on water quality and ecological processes of running waters. It is anticipated that more work will concentrate on wetlands and estuaries as the work requirements for surface waters are slowly completed.

Table 43 Summary of gaps and recommendations made for each Science Work Programme, arranged according to identified themes. Work which was prioritised and resourced for implementation has been highlighted (green). It is anticipated that studies in other areas will commence once the priority work has been completed.

Science work programme	Gap	Recommendations	Status
I. Spatial framework			
Hydrology Water quality periphyton ecology	Under the NPS-FW, councils are expected to create Freshwater Management Units. These units need to represent streams which are similar to each other, so that appropriate limits for the compulsory national attributes can be accurately determined.	BOPRC needs to consider which spatial framework is appropriate to create water management units. These units could be based on either the REC or FENZ classifications, or an alternative. To assist with decision-making, it may be cost-effective to get input from external experts on this matter.	New
Hydrology	Firm guidance as to what an appropriate spatial framework would be for stream hydrology.	Examined the appropriateness of the proposed catchment-based classification as water management units for hydrology, and contrast this to other spatial frameworks that could be used for water quality and ecology.	New
All	Lack of spatial classification for all monitoring programmes.	Develop a consistent spatial classification for different monitoring programmes (e.g. water quality and quantity, land use and soils, and ecology).	New
Water quality	Definition of spatial scale for limit setting.	Decision be made on the scales that water quality limits will be set on. For example, with 1,710 km of waterways within the Kaituna WMA, are the same water quality limits going to be set for every waterway within the WMA (i.e. at a WMA level)? Or are limits going to be set at sub-catchment level?	New

Science work programme	Gap	Recommendations	Status
Invertebrates	Freshwater Management Units need to be made at relevant spatial scales to represent streams which are similar to each other. In this way, BOPRC can accurately convey the current state of water ways in each WMA to community groups with greater clarity.	Decide on what spatial framework will be used to create water management units.	New
II. Obtain new data			
Soils	When reviewing the information available from the NERMN programme it is evident that there are relatively few representative sites per WMA.	The amount of soil health information available per WMA is relatively low. It is recommended that a pilot programme is conducted to take a snapshot of soil health in the WMA. This would indicate the number of sites that are currently exceeding soil health criteria, particularly relating to fertility (nitrogen and phosphorus). The number of sites included in such a programme would need to be statistically robust enough to enable extrapolation across the WMA. If combined with land use monitoring above it will provide a powerful tool for assessing the state of the WMA. Any such monitoring programme should also include additional parameters (water quality etc.) to provide a complete picture.	New
Soils	Soil stability characteristics are not known within these WMAs.	Assess soil stability, soil intactness and soil disturbance over time. This analysis will help to determine whether the soil is: stable/unstable but inactive (erosion prone), recently eroded or freshly eroded. This information will provide a framework for assessing land use disturbance due to land use. Phosphorus is a key contributor to eutrophication processes yet the loss of soil sediments to receiving waters is not well understood within the WMA. This information is critical to understanding the loss of productive soil, but also the potential for impacts on ecological values. This information could be combined with baseline soil health data to provide an indication of the state of the catchment.	New

Science work programme	Gap	Recommendations	Status
Soils	Soil microbial/fauna populations.	The Land Monitoring Forum is involved in a pilot programme to identify the level of protectiveness required for soil fauna. Obtaining baseline information for the Kaituna WMA is important in understand accumulation from trace elements such as copper and cadmium from kiwifruit treatments.	New
Hydrology/groundwater	Lack of monitoring sites within geological provenances.	Target groundwater systems (aquifers) by installation of bore fields, for comprehensive monitoring and data comparison. This includes groundwater – surface water interaction.	Resourced
Hydrology	Improve calculated statistical relationships between continuously gauged and ungauged catchments.	Continue flow monitoring within catchments that do not currently have a permanent gauging station.	New
Hydrology	Lack of flow monitoring in catchments where this has been identified.	Implementing new flow monitoring sites as needed.	New
Hydrology/groundwater/ water quality/estuaries	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater to waterways (springs, base-flow to rivers and wetlands) within the Kaituna WMA and the relative nutrient load contributed from groundwater sources.	New
Hydrology/groundwater	Need for improved understanding of infiltration rates to subsurface storage.	Maintain and monitor existing sites until robust statistical relations have been developed. Install new sites to obtain adequate coverage.	Additional
Hydrology/groundwater	Lack of isotope and water quality data to understand groundwater residence time (age), source and flow direction.	Isotope monitoring sites to use as a predictive tool for future water quality and quantity.	New
Hydrology	Sites that are currently over-allocated in the Kaituna WMA lack further hydrological analyses to set minimum flows apart from the default method.	Consider undertaking detailed IFIM surveys of sites that are heavily over-allocated, OR use EFSAP to help set more defensible low flow levels and allocation levels for over-allocated waterways.	New

Science work programme	Gap	Recommendations	Status
Groundwater	Risk of salt water contamination to fresh groundwater resources.	Maintain and monitor existing sites to understand movement of freshwater – saltwater interface with pumping stress over time. Establish new sites if necessary to address risk.	Additional
Water quality	Lack of DO profiles, especially in U-shaped streams. AND Lack of DO monitoring downstream of point source discharges.	Install DO logger on Kaituna River below AFFCO discharge. Logger should remain in place from 1 November to 30 April to permit comparison against NOF bands. Support: Hamill (2012), NIWA (2012).	Outstanding
Water quality	Under-representation of hill and low-elevation fed streams. AND Lack of representation of tributaries discharging into main-stem rivers.	Initiate new water quality sampling site on each of the six tributaries flowing into the Kaituna River, and on the Pokopoko Stream. The location of these sites should coincide with sites selected for water level/flow monitoring (see Part 6). Monitor sites initially for one year and review data to determine whether relationships can be derived to long-term NERMN sites. Monitoring may need to continue beyond one year depending on the strength of relationships and the applicability of catchment models. Support: Hamill (2012)*.	New
Water quality	Underrepresentation of dominant stream classes in the region (based on REC).	Add 10 new permanent monitoring sites to the NERMN Rivers network to better represent dominant waterways in BOP. Support: Hamill (2012), Donald, (2014).	Partially implemented and funded
Water quality/estuary	Impact of drainage canals.	Investigate the impact the drainage network is having on downstream water quality. NOTE: drainage network may come under Appendix 3 of NPS, if so this recommendation may not be required.	New
Water quality	Connection with wetlands and wetland extent.	Re-survey wetland extent, determine connection with waterways, and incorporate WQ monitoring in wetland monitoring programme where there is a hydrologic connection. Support: Hamill (2012).	Planned and resourced

Science work programme	Gap	Recommendations	Status
Periphyton	Knowledge is required of periphyton biomass (both spatial and temporal variability) of selected sites throughout the Kaituna WMA.	Periphyton biomass be monitored at selected sites throughout the Kaituna WMA.	Planned and resourced
Periphyton	Lack of detailed information on the extent of problem Phormidium blooms.	As part of algal monitoring, monitor the cover of dominant algal groups, including Phormidium. This will provide information as to the spatial and temporal extent of any algal blooms.	Planned and resourced
Cyanobacteria	Benthic cyanobacterial cover is not currently a compulsory national attribute.	Given the potential danger of Phormidium proliferations to river users, combine Phormidium monitoring with routine periphyton monitoring.	New
Invertebrates	Information on ecological health of small waterways, and of waterways draining Hill fed country, and in catchments dominated by exotic and indigenous forest.	Initiate a one-off sampling campaign to provide information on the ecological health of sites where this information is lacking.	New
Fish	Knowledge on fish communities in some REC classes in the Kaituna WMA, especially in small waterways, draining Hill fed country, and in catchments dominated by exotic and indigenous forest.	Initiate a one-off sampling campaign to provide information on fish communities in sites where this information is lacking.	New
Fish	Lack of any ongoing monitoring programme for fish communities.	Consider implementing monitoring fish communities at selected “sentinel sites” throughout the Kaituna WMA. This could be done at regular intervals (e.g., 2-4 years).	New
Fish	Knowledge about the location of structures such as culverts, pump stations, and floodgates that may obstruct the migration of native fish.	Develop and maintain a database of all potential fish areas throughout the Kaituna WMA, which can then be used to set priorities for their removal or remediation.	Underway (resources already allocated)

Science work programme	Gap	Recommendations	Status
Wetlands	Lack of quantitative plot based data on plant species composition and biomass paired with sampling of soil and foliage physico-chemistry.	Undertake NERMN regional wetland monitoring programme within the WMA as planned but consider increasing sample size for the WMA to provide better catchment level data	New
Wetlands	Lack of up-to-date geospatial layers for wetland vegetation types	Undertake vegetation type mapping for mapped wetlands and consider assessing changes in extent and diversity of vegetation types compared to PNA and other survey reports.	New
Wetlands	Lack of data on wetland condition / ecosystem health	Undertake field based assessment of Wetland Condition Index for mapped wetlands or update Ecological Integrity Index (or other GIS based assessment) for all mapped wetlands using updated/recent GIS data.	New
Wetlands	Lack of data on wetland condition and threats for highly significant, irreplaceable and/or vulnerable wetlands	Undertake comprehensive monitoring of wetland condition (ecology, water quality and/or hydrology) for selected highly significant, irreplaceable and/or vulnerable wetlands.	New
Wetlands	Lack of data on changes wetland condition/ecosystem health over time	Consider analysis of Fish & Game Council data on waterfowl survival/production as an indicator of long-term trends in wetland ecosystem health.	New
Wetlands	Lack of field verified classification of sites by wetland type	Undertake field verification of wetlands types based on soil/water chemistry and hydrology etc. and incorporate into attribute table in geospatial layer of wetland extent.	New
Estuaries	Connection with wetlands and wetland extent	Re-survey wetland extent, determine connection with waterways, and incorporate WQ monitoring in wetland monitoring programme where there is a hydrologic connection. Support: Hamill (2012).	Planned and resourced

Science work programme	Gap	Recommendations	Status
Estuaries	Sediment and nutrient recycling within the estuaries	Investigate the dynamics within the estuary to better understand the recycling of internal sediment and nutrients within the estuaries.	New
III. Improvements to methods and reporting			
Soils	The link between land use pressure, soil state and water quality is not clearly understood.	The science team should work on identifying linkages between land use pressures/soil health and water quality/ecological values. While good information exists within each discipline there have been few linkages drawn. Given that land use change can be slow to occur and any exercise linking pressure and state with Impact would be complex it would be recommended to take a long-term view on any analysis.	New
Soils	No formal methodology/reporting mechanism currently exists to monitor and report on land use pressures. Intensification of land through activities such as dairying support on a predominantly dry stock block needs to be better understood/monitored.	Develop a standard methodology for monitoring and reporting on land use pressures using a range of nationally available datasets including LCDB, LUM, Stats NZ data, NERMN, Agribase etc…The reporting frequency of such reports will be limited to the availability of the underlying data and therefore a return period of less than 4-5 years is unlikely. Investigate combining detailed farm knowledge with land use pressure monitoring. Investigate alternative information sources such as Agribase and Statistics NZ. This information is likely to confirm how rapidly land use pressures have emerged over time and outline the current state of the WMA. Without this information it is not possible to robustly analyse how changes in land use may have impacted on ecological values within the catchment. It will also not be possible to determine the key economic drivers within the catchment and to determine what impact mitigation measures would likely have.	New
Soils	Identify NERMN soil health monitoring results for each specific WMA.	Develop a database for existing NERMN data that allows comparisons of individual sites as well as between distinct geographic areas such as WMAs. The number of sites available in any particular area will dictate how robust the data is. A valuable data resource exists as a result of the NERMN soil health monitoring programme. The programme was designed to provide a region wide snapshot as opposed to specific soil types or catchments. See below comments on obtaining baseline information for each WMA.	Planned and resourced

Science work programme	Gap	Recommendations	Status
Soils	Dairy and kiwifruit are showing trends in soil health that need to be better understood.	The initial NERMN monitoring programme was designed around monitoring those land uses with the greatest soil disturbance. After multiple monitoring periods it is evident that it is more appropriate to monitor the most intensive land uses more frequently and potentially reduce monitoring of those land uses that were previously more frequently monitored. It is recommended to increase the monitoring period of dairy and kiwifruit to three-yearly.	Planned and resourced
Soils	Need to monitor economic production from particular land.	This will allow us to determine the economic productivity of particular land uses and also to predict the likely impacts on the economy when making decisions about nutrients targets. Key reporting metrics would need to be decided.	New
Hydrology	Data quality analysis.	Establish confidence limits and intervals. Maintain gauging programme to ensure that established regressions are valid. Investigate new methods, including multiple regression, regional prediction curves, and spatial interpolation. Consider synthetic stream flows.	New
Hydrology	Information on structures in surface water bodies.	Develop a GIS layer that shows the location, size of structure, water volume impounded, available minimum flow downstream, establishment of natural Q5, MALF or relevant parameter prior to establishment of structure.	New
Hydrology/groundwater	Integrated catchment management workgroup-water.	To establish a group of experts to develop and scope work programme that allows groundwater and surface water resources to be managed as a single resource, where hydraulically connected.	New
Groundwater	Frequency and interval of monitoring to establish trends for both quality and quantity.	Standardise monitoring timeframes to provide data that can be assessed over time for trend analysis. Increase use of automated continuous monitoring sites for water level data over time. For water quality increase the frequency and establish regular sampling intervals, to allow for trend analysis over time (seasonal change).	Additional
Water quality	Monthly water quality sampling (± 1 hr) every year.	Increase the frequency of sampling at four existing sites (Pongakawa at SH 2, Pongakawa at Old Coach Road, Pongakawa at Pumphouse, Waitahanui at SH 2) to monthly every year. Support: Donald (2014), Hamill (2012), NIWA (2012)	Planned and resourced

Science work programme	Gap	Recommendations	Status
Water quality	Flow recorded for each sampling event.	Measure flow (or develop a relationship to predict flow) at Pongakawa at Old Coach Road now that existing flow site has been disestablished. Measure flow or record stage height (to read flow off existing rating curve) for all new sampling sites established. Support: Donald (2014), NIWA (2012).	Planned and resourced
Water quality	Uncensored laboratory data.	Enter data to best estimate with appropriate coding to indicate level of accuracy. Support: Hamill (2012).	Underway (resources already allocated)
Water quality	Sample blanks and duplicates as part of QA/QC protocols.	Incorporate this process as part of standard NERMN sampling. Support: Hamill (2012).	Underway (resources already allocated)
Water quality	Consistent and regular visual clarity sampling.	Visual clarity be measured on each sampling event irrespective of stream flow. Alternate methods to be used during periods of high flow. Support: NIWA (2012).	Underway (resources already allocated)
Cyanobacteria	Compulsory national attributes do not consider how to calculate banding for ongoing monitoring programmes where > 3 years of data are, or will be collected.	Calculate the 80th percentile of biovolume data on a three-year rolling average, based on a year running from November-June each year.	New
Cyanobacteria	Current cyanobacterial monitoring of Kaituna River as part of Ōhau Channel consent are too broad and unnecessarily complex.	Discontinue future monitoring of lower sites in the Kaituna River when the current consent is renewed. Implement a more targeted monitoring programme to monitored lower sites only when the upper site (Trout Pool) exceeds the red alert threshold.	Underway (resources already allocated)
Wetlands	Lack of up-to-date/ comprehensive geospatial layers for wetland size and areal extent.	Update the geospatial layer for wetland extent using the latest aerial photography (and other available tools), and use new geospatial layer to determine changes in wetland extent, extent of wetland types, and size of wetlands over time.	New

Science work programme	Gap	Recommendations	Status
Wetlands	Lack of compulsory national attributes for wetlands.	Collaborate with other Regional Councils to support development of compulsory national attributes for wetlands. Better direction of additional monitoring required to meet the needs of NPS implementation will be possible once attributes (and values) have been fully developed.	New
Wetlands	Lack of interpretative data for determining cause of declines in wetland condition.	Manage information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) in a way that will allow this information to be used for interpretation of wetland condition data.	New
IV. Identify values			
Soils	Cultural pressures on land are not clearly understood at this stage.	Investigate whether cultural pressures can be readily identified and incorporated into land pressures monitoring. This would involve reviewing available information sources and the robustness of any such information. It should be noted that other groups within BOPRC are investigating this work, so it is suggested as a desktop exercise to determine how readily this information could be included with other metrics.	Underway (resources already allocated)
Water quality	Values for waterways.	In collaboration with communities, establish agreed values for waterways within the Kaituna WMA. This will enable better direction of additional monitoring to meet the needs of NPS implementation.	Planned and resourced
Invertebrates	Provision of any form of banding system to assign biotic metrics such as the MCI to an acceptable (A) or unacceptable (D) level.	Analysis of ecological data currently held by Council, and collected as part of any future sampling could be used to help develop suggested bands for MCI scores.	New
Wetlands	Values for wetlands.	Following availability of compulsory national attributes for wetlands, establish agreed values for wetlands in collaboration with communities. This will enable better direction of additional monitoring to meet the needs of NPS implementation.	New

Science work programme	Gap	Recommendations	Status
V. Data for models			
Soils	There is a need to identify what role pumice/gravelly soils play on nutrient loss and leaching. Overseer is used extensively to model nutrient loses, but is poorly calibrated to local conditions in the Bay of Plenty.	Conduct a detailed review on the available literature on pumice soils. Rajendram *et al.* have conducted a preliminary study on the impact that laboratory methods can have in overestimating Olsen P in pumice soils. Need to develop a programme to better understand the role of leaching in our most prevalent soils (pumice, allophanic and recent) and investigate utilising/leveraging off our existing lysimeter network and input into the planning for proposed lysimeters to better understand leaching in the region and these catchments. Landcare Research should be consulted to ensure any data obtained is suitable for calibrating Overseer modules. Overseer is used extensively to model predicted leaching rates and therefore without this information it is not possible to provide a high degree confidence in the outputs produced for certain soil types and climatic zones.	New
Soils	Do not currently have the ability to predict the effects of land change on water quality.	First phase model to allow interactive discussions on land use change scenarios and impacts on water quality with stakeholders. CLUES has been recommended as a suitable model which can be built and run in-house if desired.	New
Hydrology	Inadequate coverage of data within geological provenances for comparison of water resource monitoring data.	Expand the geological portion of the REC to include more classes.	New
Hydrology	Proper assessment as to the accuracy of hydrological models developed by NIWA.	Compare empirically derived flow statistics against flow statistics obtained from hydrological models.	New
Hydrology	Permitted take model.	Maintain and update existing numerical model for calculation of estimated permitted water use for inclusion to water allocation methods. Ground-truth model on five-yearly cycle for WMA.	Additional
Hydrology	Surface water models for base and low flow.	Construct and calibrate model for surface water allocation.	New
Hydrology	Lack of proper validation of EFSAP model low flows.	Undertake validation of modelled habitat retention obtained through EFSAP to data obtained from a detailed IFIM surveys.	New

Science work programme	Gap	Recommendations	Status
Groundwater	Inadequate coverage of data within geological provenances for comparison of water resource monitoring data.	Expand the geological portion of the REC to include more classes.	New
Groundwater	Improve conceptual understanding of subsurface geology.	Designated bore fields to target depths. Record lithology and obtain cores for geological unit identification.	New
Groundwater	Lack of information on hydraulic conductance within aquifers, between unconfined, semi-confined aquifers, and also between aquifers and surface water.	Hydraulic pump testing of the aquifer systems within the Kaituna WMA and surface water bodies.	New
Groundwater	Permitted take model.	Maintain and update existing numerical model for calculation of estimated permitted water use for inclusion to water allocation methods. Ground-truth model on five-yearly cycle for WMA.	New
Groundwater	Conceptual groundwater model.	Maintain and update existing conceptual groundwater models from Wells database, updated DTM and geological maps.	Additional
Hydrology/groundwater	Groundwater flow model.	Develop and calibrate models for groundwater and surface water for the development of an integrated water resource management model.	New
Water quality	Cumulative impact on receiving environments.	Consider the desired values in receiving environments (i.e. estuaries), establish assimilative capacity of receiving environment for the chosen variable(s), and then work upstream into the catchment to ensure limits in receiving environment can be met.	New
Water quality	Model of water quality within the Kaituna WMA.	Investigate opportunities for model development (or modifying existing models) to support decision-making and estimation of cumulative impact on waterways.	New

Science work programme	Gap	Recommendations	Status
Periphyton	Linkages between periphyton, nutrients and flow.	Where possible, any periphyton monitoring should be done at sites where monthly water quality data is collected, and within continuously gauged catchments, or close to such catchments. This will allow BOPRC to: i) test current models of algal/nutrient interactions, ii) Develop new models of interactions between algae and nutrients.	New
Fish	Knowledge of whether fish community distribution in the Kaituna WMA is changing over time as a result of land use activities.	Ensure that implementation of any monitoring programme is able to compare observed fish distributions with those predicted in the absence of human activities.	New
Wetlands	Lack of models for to supporting decision-making and estimation of cumulative impact on wetlands.	Investigate opportunities for model development (or supporting model development), in particular models to estimate phosphorus risk for wetlands.	New
Estuaries	Cumulative impact on receiving environments.	Consider the desired values in receiving environments (i.e. estuaries), and establish assimilative capacity of the receiving environment for the chosen variable(s) (e.g., algal biomass). Undertake studies upstream into the catchment to ensure that limits in the final receiving environment can be met.	New
VI. Data management			
Soils	Include trace elements as part of the standard NERMN monitoring suite.	Trace elements are currently reported on separately from the soil health programme. They should be included in the regular NERMN monitoring and reported on in the regular soil health updates.	New
Groundwater/hydrology	Lack of regular technical reporting.	Five-yearly technical report, annual summary report, up-to-date data on BOPRC website (or LAWA).	New

Science work programme	Gap	Recommendations	Status
Water quality	Information from consents, compliance and land management be integrated (where applicable) with NERMN data or interpretation.	Ecological or monitoring reports for consents be registered individually in Objective (i.e. not just under consent file). Water quality data from these reports be captured in existing spreadsheets/databases (see recommendation below). Information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) be grouped for each WMA and this information able to be queried/extracted as needed for purposes of interpretation of water quality data. Support: Hamill (2012).	Outstanding
Water quality	Easy access to water quality from other sources (e.g. historic sampling, data from consents etc.).	Investigate options to capture, store and maintain a portal to house all water quality data (regardless of source), with appropriate reference and quality coding.	New

Part 15: References

ANZECC (Australia and New Zealand Environmental Conservation Council) (2000): Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Wellington and Canberra: Australia and New Zealand Environmental Conservation Council.

Ausseil A-G, Gerbeaux P, Chadderton W, Stephens T, Brown D, Leathwick J 2008. Wetland ecosystems of national importance for biodiversity. Landcare Research Contract Report LC0708/158 for Chief Scientist, Department of Conservation.

Barber, J and Harvey, D. 2013. NERMN groundwater monitoring report. BOPRC Environmental Publication 2013/02.

Bay of Plenty Regional Council 2008. Bay of Plenty Regional Policy Statement incorporating Change No. 1. Whakatāne, Bay of Plenty Regional Council.

Bay of Plenty Regional Council. 2011. Regional Coastal Environment Plan. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Beadel 2006, Otanewainuku Ecological District. Survey report for the Protected Natural Areas Programme. New Zealand Protected Natural Areas Programme No. 37. Department of Conservation, Bay of Plenty Conservancy 2006.

Benge, J. and Manhire, J. 2011. Toxicity of soil from conventional and organic Hayward kiwifruit orchards in the Bay of Plenty. Final Report for Zespri International Ltd (Project EC1144). The AgriBusiness Group, Lincoln University and University of Otago, March 2011.

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

Bioresearchers 1976. Ecology of Maketū Estuary. Prepared for Bay of Plenty Catchment Commission and Regional Water Board.

Bioresearchers Ltd. 1974. Ecological monitoring survey, Bay of Plenty. Report prepared for the Bay of Plenty Catchment Commission and Regional Water Board.

Bioresearchers Ltd. 1975a. Ecology of the Kaituna River. Report prepared for the Bay of Plenty Catchment Commission and Regional Water Board.

Bioresearchers Ltd. 1975b. Ecological monitoring survey of the lower reaches of the major Bay of Plenty rivers, the Ōhau Channel and parts of the Tauranga Harbour. Report prepared for the Bay of Plenty Catchment Commission and Regional Water Board.

Bioresearchers Ltd. 1975c. Ecological monitoring survey of the lower reaches of the major Bay of Plenty rivers, the Ōhau Channel and parts of the Tauranga Harbour. Report prepared for the Bay of Plenty Catchment Commission and Regional Water Board.

Bioresearchers Ltd. 1977. Ecology of a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1978. Ecology of a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1979. Ecology of a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1980a. A survey of the water quality and fish habitat in a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1980b. Ecology of a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1982. A survey of the water quality and fish habitat in a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1983. A survey of the water quality and fish habitat in a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1985. Ecology of a section of the Ohineangaanga Stream. Report prepared for the Bay of Plenty Coop Dairy Association (Te Puke) Ltd.

Bioresearchers Ltd. 1986. AFFCO Rangiuru abattoir effluent impact assessment. Report prepared for the Auckland Farmers Freezing Co-operative Limited.

Bioresearchers Ltd. 1993. An assessment of the impact of abattoir effluent (AFFCO Rangiuru) on the water quality and ecology of the Kaituna River. Report prepared for the Auckland Farmers Freezing Co-operative New Zealand Limited.

Booker, D.J. 2014. Hydrological estimates for the Bay of Plenty. NIWA Client Report, CHC2014-069 43p. NIWA Christchurch.

Chappell, P.R. 2013. The climate and weather of Bay of Plenty, 3rd Edition. National Institute of Water and Atmospheric Research. NIWA Science and Technology Series number 62.

Cichota, R.; Snow, V.O. 2009. Estimating nutrient loss to waterways - an overview of models of relevance to New Zealand pastoral farms. New Zealand Journal of Agricultural Research. 52: 239-260.

Clapcott, J.E.; Young, R.G.; Harding, J.S.; Matthaei, C.D.; Quinn, J.M.; Death, R.G. 2011. Sediment assessment methods. Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values., p 105. Cawthron Institute, Nelson.

Clarkson BR, Overton JM, Ausseil A-G, & Robertson, HA 2015. Towards quantitative limits to maintain the ecological integrity of freshwater wetlands: Interim report. Landcare Research Contract Report LC1933. Prepared for Department of Conservation.

Clarkson BR, Fitzgerald NB, & Overton JM 2014. A Methodology for monitoring Bay of Plenty wetlands. Landcare Research Contract Report LC1779. Prepared for Bay of Plenty Regional Council.

Clarkson BR, Sorrel BK, Reeves PN, Champion PD, Partridge TR, Clarkson BD 2003 (revised in 2004). Handbook for monitoring wetland condition. Ministry for the Environment.

Davis M, Brown D, Robertson H & Chadderton L. 2013 How well does LCDB2 map wetlands in the Wellington region. Department of Conservation Research and Development Series 341.

DHI, 2014. Kaituna River Re-diversion and Ongatoro/Maketū Estuary Enhancement Project Numerical Modelling. Prepared for the Bay of Plenty Regional Council. DHI, Wellington.

Donald, R. 2014. Review of the NERMN Programme 2014. Bay of Plenty Regional Council, Whakatāne. Bay of Plenty Regional Council Environmental Publication 2014/01. 54p.

Ellery, G., and Putt, C. 2012. Low flow monitoring strategic Review (Internal Report). Bay of Plenty Regional Council, Whakatāne.

Elliott, S.; Turek, G.; Rutledge, D.; Ritchie, A.; Herzig, A.; Snow, V.O. 2014. Framework for interoperable freshwater models: testing and recommendations. Prepared for the Ministry of business, innovation and employment., NIWA Client Report, p 59. NIWA Hamilton, Hamilton.

Fahey, B.D.; Watson, A.J. 1991. Hydrological impacts of converting tussock grassland to pine plantation, Otago, New Zealand. Journal of Hydrology (New Zealand) 30: 1-15.

Fitzgerald NB, Clarkson BR, Price RJ 2013. A priority framework for monitoring Bay of Plenty wetlands. Landcare Research Contract Report LC 1334. Prepared for Bay of Plenty Regional Council.

Freeman, J. 2010, Groundwater recharge at the Kaharoa rainfall recharge site – Rotorua. BOPRC Environmental Publication 2010/21.

Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment.

Guinto, D 2009: Soil Quality in the Bay of Plenty: 2009 Update. Environment Publication 2009/14. Environment Bay of Plenty.

Guinto, D 2010: Soil Quality in the Bay of Plenty: 2010 Update. Environment Publication 2010. Environment Bay of Plenty.

Hamill, K.D., and Aussiel. O. 2012. Review of BOPRC Natural Environment Regional Monitoring Network freshwater quality. Opus International. Consultants, Whakatāne.

Hamilll, K. Kaituna River Re-diversion project: Ongatoro/Maketū Estuary condition and potential ecological effects. Prepared for the Bay of Plenty Regional Council. River Lake Ltd, Whakatāne.

Harding, J.S.; Quinn, J.M.; Hickey, C.W. 2000. Effects of mining and production forestry. In: Collier, K.J., Winterbourn, M.J. (Editor), New Zealand stream invertebrates: ecology and implications for management, pp 230-259. New Zealand Limnological Society, Christchurch.

Johnson P, Gerbeaux P 2004. Wetland types in New Zealand. Wellington, Department of Conservation.

Land Monitoring Forum. 2009. Land and Soil Monitoring: A guide for SoE and regional council reporting. Published by the Land Monitoring Forum, New Zealand.

Livingston, M.A. 1975. Flow report for the Mangorewa River at Saunder's Farm, Site No. 14628 for period 670801 to 780601. Water and Soil Division, Hamilton Science Centre, Hamilton.

Manderson, A., Palmer, A., MacKay, A., Wilde, H., and Rijkse, W. 2007. Introductory Guide to Farm Soil Mapping. AgResearch Ltd, Palmerston North, New Zealand.

Matheson, F.; Quinn, J.M.; Hickey, C.W. 2013. Review of the New Zealand in stream plant and nutrient guidelines and development of an extended decision-making framework: Phases 1 and 2 final report., NIWA Client Report, p 127. NIWA Hamilton, Hamilton.

McDowall, R.M. 1990. New Zealand Freshwater Fish - a natural histroy and guide. Heinemann Reed, Auckland.

McDowall, R.M. 2011. Ikawai. Freshwater fishes in Maori culture and economy. Canterbury University Press, Christchurch.

McIntosh, J. 2005. Impact of the Ōhau Channel Diversion on the Kiere Arm, Kaituna River and Maketū Estuary. Environment Bay of Plenty Regional Council, Whakatāne.

Ministry for the Environment & Department of Conservation 2007. Protecting our Places: Introducing the national priorities for protecting rare and threatened native biodiversity on private land. Ministry for the Environment Publication ME799. Wellington.

Ministry for the Environment 2013. Proposed amendments to the National Policy Statement for Freshwater Management 2011: a discussion document. Wellington, Ministry for the Environment.

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

Ministry for the Environment and Ministry of Health (2003): Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment Publication number: ME 474.

Ministry for the Environment and Ministry of Health (2003): Microbiological Water Quality.

Ministry of Health. 1995. Microbial Reference Criteria for Food. Ministry of Health, Wellington, New Zealand.

Molly, L. 1998. Soils in the New Zealand Landscape - the Living Mantle, 2nd Edition. New Zealand Society of Soil Science.

Murphy, R. and C. Crawford, 2002: Water Quality Indicators and Health Assessment in Tasmanian Estuaries.

National Environmental Standards on Ecological Flows and Water Level – Proposed: Discussion Document, March 2008, Ministry for the Environment.

National Institute of Water and Atmospheric Research. 2012. Freshwater Monitoring Protocols and Quality Assurance (QA) National Environmental Monitoring and Reporting (NEMaR) Variable Step 2. National Institute of Water and Atmospheric Research, Hamilton.

National Policy Statement for Freshwater management (2014). Issued by notice of gazette on 4 July 2014. New Zealand Government, Wellington.

New Zealand Food Safety Authority (2006): NZFSA Animal Products (Specifications for Bivalve Molluscan Shellfish) Notice 2006.

New Zealand Water and Wastes Association (NZWWA). 2003. Guidelines for the safe application of biosolids to land in New Zealand. NZWWA, Wellington.

Newsome P, Wilde H.G, Willoughby EJ 2000. Land Resource Information System spatial data layers. Landcare Research, Palmerston North, New Zealand.

O'Donnell, CFJ, & Zanders D 2006.Mapping the freshwater habitats of New Zealand: a trial integration and interpretation of GIS databases. Department of Conservation, Christchurch, New Zealand (unpublished report).

Park, S. 2007. Lower Kaituna Catchment and Water Quality. Bay of Plenty Regional Council, Whakatāne.

Park, S. 2010. Water quality survey of the Lower Kaituna catchment 2007-2008. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Park, S. 2011. Consent 04 0277 Compliance Monitoring Report 2003-2011 – Kaituna River Partial Re-diversion to Maketū Estuary. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Park, S. 2012. Coastal and Estuarine Benthic Macrofauna Monitoring Report 2010. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Park, S. 2014. Extent of wetland vegetation in Maketū Estuary – 1939 to 2011. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Peters M 2012. Introduction. Chapter 1 in Peters, M & Clarkson, B (eds): Wetland Restoration: A Handbook for New Zealand Freshwater Systems, Manaaki Whenua Press, Christchurch, New Zealand.

Rajendram, G., Hawke, M., MacCormick, A., Matheson, L., Butler, L., Devey, K., Stafford, A. 2011: What do high Olsen P values mean on Pumice-Gravel soils in the Rotorua district

In: Adding to the Knowledge Base for the Nutrient Manager (Eds. L D Currie and C L Christensen). Occasional Report No. 24. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 8p.

Ryan, P.A. 1991. Environmental effects of sediment on New Zealand streams: a review. New Zealand Journal of Marine and Freshwater Research 25: 207-221.

Scholes, P. 2014. Recreational Waters Surveillance Report 2013/2014. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Scholes, P. 2015. Freshwater in the Bay of Plenty, a comparison against the National Objectives Framework. Bay of Plenty Regional Council, Whakatāne (in prep.).

Scholes, P. 2015. NERMN Estuary Water Quality Report 2014. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Scholes, P. 2015. NERMN Estuary Water Quality Report 2014. Bay of Plenty Regional Council, Whakatāne, New Zealand.

Snelder, T.; Biggs, B.J.F.; Kilroy, C.; Booker, D. 2013. National objective framework for periphyton., p 39. NIWA Christchurch, Christchurch.

Snelder, T.; Biggs, B.J.F.; Weatherhead, M.A. 2010. New Zealand River Environment Classification User Guide. p 144. Ministry for the Environment, Wellington.

Solutions in Environmental Management (SEM) New Zealand. 2005. Background levels of agrichemical residues in Bay of Plenty soils: a preliminary technical investigation.

Presented to Environment Bay of Plenty, Whakatāne. SEM NZ Ltd., Mount Maunganui.

Sorrell B, Gerbeaux P 2004. Wetland Ecosystems. Chapter 28 in Harding J, Mosley P, Pearson C, Sorrell B (eds): Freshwaters of New Zealand. New Zealand Hydrological Society, New Zealand Limnological Society, Caxton Press, Christchurch, New Zealand.

Sparling, G. 2001. Summary of sites, soil types, soil orders, land use, and laboratory analyses for soil quality characteristics of all sites sampled under the 500 Soils Project in Bay of Plenty 1998-2001 (June 2001). Manaaki Whenua Landcare Research, Hamilton.

Sparling, G. 2004. Soil quality in the Bay of Plenty Region in 2004: changes since 1998-2000. Landcare Research Contract Report 0405/002 (August 2004). Manaaki Whenua Landcare Research, Hamilton.

Sparling, G. 2005. Soil quality in the Bay of Plenty Region in 2004-2005: changes since 1998- 2000. Landcare Research Contract Report LCR0405/134 (June 2005). Manaaki Whenua Landcare Research, Hamilton.

Sparling, G. 2006a. Soil quality in the Bay of Plenty Region 2006: comparison with previous samplings in 1998-2000 revised. Landcare Research Contract Report 0506/153 (November 2006). Manaaki Whenua Landcare Research, Hamilton.

Sparling, G. 2006b. An overview of soil quality in the Bay of Plenty 1998-2006: comparison with data from other regions. Landcare Research Contract Report LC0607/054 (December 2006). Manaaki Whenua Landcare Research, Hamilton.

Sparling, G. and Rijkse, W. 2003. Implementing soil quality indicators for land: arable sites in the Bay of Plenty, 2003. Landcare Research Contract Report LC0304/019 (September 2003). Manaaki Whenua Landcare Research, Hamilton.

Stark, J.D.; Maxted, J.R. 2007. A user guide for the macro invertebrate community index. Cawthorn Report Number 1166, p 58. Prepared for the Ministry for the Environment.

Suren, A.M. 2014. An ecological assessment of waterways throughout the Rangitāiki Catchment. Environmental Report 2014/11, p 123. Bay of Plenty Regional Council, Whakatāne.

Suren, A.M.; Biggs, B.J.F.; Duncan, M.J.; Bergey, L. 2003. Benthic community dynamics during summer low-flows in two rivers with contrasting enrichment 2. Invertebrates. New Zealand Journal of Marine and Freshwater Research 37: 71-83.

Suren, A.M.; Biggs, B.J.F.; Kilroy, C.; Bergey, L. 2003. Benthic community dynamics during summer low-flows in two rivers of contrasting enrichment 1. Periphyton. New Zealand Journal of Marine and Freshwater Research 37: 53-69.

Taylor, J.R., and Park, S.G. 2001. Natural Environment Regional Environment Report: Bay of Plenty Rivers' Water Quality (1989-2000). Environment Bay of Plenty (now Bay of Plenty Regional Council), Whakatāne.

White, E., Don, B., Downes, M.T., and Kemp, L. 1978. Distrtibution of plant nutrients in the Kaituna River. New Zealand Journal of Marine and Freshwater Research, 12 (1): 23-27.

White, P *et.al.* 2009, Groundwater resource investigations of the Paengaroa-Matatā area stage 1 – conceptual geological and hydrological models and preliminary allocation assessment, GNS Science Consultancy Report 2008/134.

White, P et.al. 2009, Groundwater resource investigations of the Western Bay of Plenty are stage 1 – conceptual geological and hydrological models and preliminary allocation assessment. GNS Science Consultancy Report 2008/240.

Wildland Consultants Ltd 2006 Significant indigenous vegetation and significant habitats of indigenous fauna in the coastal environment of the Bay of Plenty Region.

Wildland Consultants Ltd 2008 Natural Areas in Tauranga Ecological District. Report No. 1914. Prepared for Environment Bay of Plenty.