Defining Freshwater Management Units for Northland: A Recommended Approach

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Executive Summary

The National Policy Statement for Freshwater Management 2014 (NPS-FM) directs regional councils to develop regional plans for managing freshwater quality and quantity. Plans must contain freshwater objectives, policies and limits.

The quality and quantity of water in water bodies, the values they support and the appropriate balance between water resource use and other values varies spatially. This means that it is generally inappropriate to set freshwater (i.e. numeric) objectives that apply to all water bodies in a region. The NPS-FM requires that regional councils subdivide their regions into Freshwater Management Units (FMUs). The NPS-FM defines a FMU as a water body, multiple water bodies, or any part of a water body determined by a regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management purposes.

Implicit in this definition is the idea that FMUs are to be established based on how water bodies, or parts of water bodies, are valued. There is therefore interdependence between establishing FMUs and determining the values (objectives) for which they are to be managed.

Northland Regional Council (NRC) is currently developing its second generation regional plan, in part to give effect to the NPS-FM. The new plan will address water management at the regional scale (a region-wide plan) by establishing default objectives, policies and limits and a basis of accounting for resource use and monitoring. Default plan provisions establish a generalised management framework that applies to the entire region, but which can be revised and refined over time to address catchment-specific water quality or quantity issues. NRC therefore needs to define FMUs to provide a spatial framework for the plan.

The definition of FMUs is integral to the plan development. Therefore, it is important that the process of defining FMU boundaries is transparent and alternative options can be considered by decision-makers. This report considers alternative approaches to defining FMUs for the Northland region and recommends an approach. Some iterative refinement of the FMUs proposed in this report may be necessary as part of the development of the new regional plan.

This report proposes FMUs for the Northland region that would establish a default regional spatial framework for managing river water quality and quantity in the new regional water plan. The same principles that have been applied to rivers in this report could be used to define FMUs for lake water quality and quantity management. The FMUs proposed in this report form a framework of spatial units and are not a simple subdivision of the region. There are several reasons that a framework of spatial units is necessary for a region-wide plan including:

- To provide for different plan development processes (e.g. community consultation versus developing specific management polices),
- The need to manage different issues (e.g. water quality versus water quantity), and
- The need to provide a basis for different management functions (e.g. setting objectives versus accounting for resource use and consenting water takes).

The FMUs were developed in three steps. The first step was to *classify* the region's rivers for water quality and quantity management. The region's rivers were represented as individual segments of a digital river network and each segment was classified on the basis of physiographic drivers of water quality and quantity. These classifications broadly discriminate variation in the characteristics of the water bodies that are relevant to management including their values and capacity for resource use.

The proposed *water quality management classification* is comprised of two classes: hills and lowlands. Individual segments were classified as hill class if the average slope of the upstream catchment was greater than 10 degrees and lowland if the average slope was less than 10 degrees. The proposed *water quantity management classification* comprises four classes: large rivers, coastal rivers, small rivers and rivers with a warm extremely wet climate. Individual segments were classified as large if the mean flows exceeded $20 m^3/s$, and coastal if they were small (mean flow < 0.75 m3/s) and close to the coast (< 10km). The warm extremely wet climate class is defined by the national River Environment Classification and the remainder of the segments in the region were classified small rivers.

To illustrate the FMUs and their implications, this study has suggested credible objectives for all classes of both management classifications. Selecting objectives is ultimately a political decision and therefore the objectives in this report should be regarded as examples.

The second step involves assigning land areas to *management zones*. Management zones need to be defined so that management actions and limits that apply to them provide for the achievement of the most restrictive downstream objective. For example, in some circumstances land may drain to a river segment that is relatively resistant to the effects of nutrient concentrations. However, further downstream may be a main-stem river or lake that is more sensitive. In this case, management actions must be consistent with this more stringent objective. Management zones clarify these important concepts (i.e. that policies and limits apply to use and development within contributing catchments and that policies and limits applying at any location must be consistent with the most restrictive downstream objectives).

The third step recognises that administration and accounting for contaminant discharges and water takes must occur within individual catchments. A minimum set of individual catchments are defined by the points in the drainage network where there is a change in the management zone. These points represent a framework of *administrative units* each of which defines a sub-catchment or catchment. This results in a large number of administrative units but this will not result in a complicated plan because administrative units are of relevance to plan implementation whereas plan provisions apply only to the management classes (water quality and quantity objectives) and associated management zones (controls on use and development). Quantitative limits (e.g., contaminant mass loads and volumetric allocation rates) can be determined for each individual administrative unit provided that they are defined on a scalable basis such as proportion of a flow statistic that reflects stream size such as the Mean Annual Low Flow (MALF) for water quantity limits and an area basis for contaminant loads (e.g. kg/ha/yr).

Some water bodies have specific values or management issues that are not discriminated by the management classifications but which may need to be provided for in the new regional plan. These water bodies can be associated with special FMUs that over-ride the objectives set for the management classes. Examples of water bodies requiring separate management objectives may be sites of significance (e.g. swimming spots, or sites of special cultural or ecological significance). Water bodies requiring special objectives and the catchments upstream of these water bodies would be special FMUs for which specific plan provisions (objectives and policies) would apply.

Alternative approaches to defining FMUs could be developed based on sea-draining catchments or *ad hoc* subdivision of these catchments. However, the proposed approach has a number of benefits over these two alternatives, including:

1. The use of classifications provides appropriate resolution of variation in the characteristics of relevance to management. Large sea-draining catchments generally comprise considerable variation in these characteristics and therefore do not provide sufficient resolution,
2. The approach is transparent because it is based on specific criteria,
3. The logic that objectives apply to the water bodies and that the limits and actions apply to the catchments is inherent in the approach,
4. That limits need to be set and actions taken to achieve the most constraining downstream objective is built into the approach,
5. The process is easily repeatable allowing the criteria to be varied and for the definition of FMUs to be integral to the plan development process,
6. The level of detail of the plan provisions can be as coarse or fine (simple or complex) as required based on the level of classification detail used,
7. Aspects of the plan's implementation (e.g., consenting and accounting for resource use) can be undertaken at appropriately fine levels of spatial resolution defined by the administrative points,
8. The framework provides an efficient and justifiable basis for water quality monitoring and reporting at the regional level based on having a representative number of monitoring sites in each management class, and
9. The framework is spatially clear and certain about where limits need to be met and where accounting should occur (administrative points).

The proposed approach is based on simple two and four class classifications for water quality and quantity respectively. The course level of classification and subsequent discrimination of characteristics is consistent with the requirements of a broad regional approach to management that requires trading off detail (precision) with coverage and simplicity. It is also anticipated that some special FMUs will be needed to manage specific values and issues, for example swimming spots and sedimentation issues in some harbours and estuaries.

The framework of FMUs that are presented here is to provide a basis for "default" plan provisions. Default plan provisions are a backstop set of provisions that apply region-wide in the absence of more specific provisions. This regional and coarse scaled approach is most likely to be acceptable if it is clear that more specific policies can be developed for catchments that have particular issues. More specific provisions may ultimately be developed by more focussed, perhaps catchment specific, processes and these may supersede the default provisions defined in the region-wide plan, for example by defining more aspirational objectives or more enabling resource use rules where these can be justified.

1 Introduction

1.1 National Policy Statement for Freshwater Management

The National Policy Statement for Freshwater Management 2014 (NPS-FM) directs regional councils to develop regional plans for managing freshwater quality and quantity. Plans must contain freshwater objectives, policies and limits.

The NPS-FM requires councils to identify community values that are associated with freshwater (for example environmental values such as recreation, and economic use values, namely contaminant assimilation and water supply) and to collect water quality and quantity information to assess the current state of water bodies within their regions. With reference to the current state and taking into account the community's values, councils are required to develop freshwater objectives that express numerically (where practicable) the desired environmental state of water bodies.[1] Under the NPS-FM, freshwater objectives must strike a balance between enabling water resource use and sustaining other values of water. However, they must also provide for overall maintenance or enhancement of regional water quality.[2] In addition the NPS-FM requires councils to set objectives that are above specified minima or 'national bottom lines'.[3] Councils must develop policies, which may include limits and other management actions, to achieve the freshwater objectives.[4] Where objectives are not currently being achieved the NPS-FM directs regional councils to determine how and over what timeframes, those goals are to be achieved.[5]

1.2 Freshwater Management Units

The quality and quantity of water in water bodies, the values they support and the appropriate balance between water resource use and other values varies spatially. This means that it is generally inappropriate to set freshwater objectives that apply to an entire region. The NPS-FM addresses this with the concept of the Freshwater Management Unit (FMU). A FMU refers to a water body, multiple water bodies, or any part of a water body designated to be managed for a particular value(s)[6] (purpose) and for freshwater accounting and management purposes. A plan that addresses water management at the regional scale (a region-wide plan) requires a spatial framework of FMUs that subdivides the region at an appropriate spatial scale for managing water quality and quantity.

FMUs are a significant component of a regional plan because they provide a framework for applying different plan provisions[7] and management functions including;

1. Setting freshwater objectives,
2. Defining management actions, including water quality and quantity limits, to achieve the objectives,
3. Accounting for resource use (within limits), and

[1] See Policy CA2, NPS-FM
[2] See Objective A2 and Policy A1, NPS-FM
[3] See policies CA2 and CA3 , NPS-FM
[4] See policies A1 and B1, NPS-FM
[5] See policies A2 and B6, NPS-FM
[6] The NPS-FM defines a FMU to be the water body, multiple water bodies or any part of a water body determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management purposes.
[7] Plan provisions refers to objectives, polices, methods and rules that are defined in the regional plan.

4. Monitoring progress towards, and the achievement of, freshwater objectives.

There is interdependence between defining FMUs and determining the plan provisions that apply to them. Therefore, the development of FMUs is integral to the plan development process and cannot be divorced from other normative[8] decisions that are required such as determining the level of protection for various water quality and quantity dependent values (i.e. setting freshwater objectives) and appropriate management actions. Moreover, it is important that the process for determining FMU boundaries is transparent (i.e. it should not be "hidden") and alternative options can be considered by resource managers and decision-makers. In other words, the development of FMUs is integral to the decision making associated with formulating regional water plan and the methodology should be transparent and the decision maker should be able to consider and weigh up alternative options.

The scale of FMUs is a key consideration. Large FMUs may not provide sufficient resolution of values, community aspirations for water quality maintenance and enhancement, and current state and subsequently may not provide plan provisions of sufficient precision. By contrast, many independently defined and small FMUs may produce overly detailed plan provisions that may be difficult to justify and result in inefficient water resource management.

1.3 Northland Regional Water Plan

Northland Regional Council (NRC) is currently in the process of developing its second generation regional plan, in part to meet the council's obligations under the NPS-FM. The new plan will establish a default regional framework for managing water quality and quantity. Over time, the plan may be revised and refined to include catchment-specific provisions for areas in the region that are subject to significant water quality or quantity related issues.

A key requirement for NRC's new regional plan is a framework of FMUs that differentiates the region's water bodies in a manner that resolves differences in how (1) they are valued by the community, (2) their capacity for use[9], and (3) how they need to be managed. The framework must also be adaptable to future amendments to the NPS-FM.

This project has attempted to provide a logical basis for defining FMUs for the Northland region-wide water plan. This report considers alternative approaches to defining FMUs for the Northland region and recommends a preferred approach. Some iterative refinement of the FMUs proposed in this report is expected to be necessary.

An important assumption of this report is that the framework of FMUs that are presented is to provide a basis for "default" plan provisions. Default plan provisions are a backstop set of provisions that apply region-wide in the absence of more specific provisions. More specific provisions may ultimately be developed by more focussed, perhaps catchment specific, processes. More specific provisions may over-ride the default provisions, for example by defining more aspirational objectives or more enabling resource use rules where these can be justified.

To illustrate the implications of the proposed FMU framework this report has used data describing the current state of river water quality and the current level of water allocation in

[8] Decisions that concern the prescriptive aspects of the plan such as the definition of objectives and rules and that are ultimately made by a political process.

[9] The amount of resource use that can be made by people while sustaining all competing values at some agreed level. In the context of water quality, the capacity for use is the capacity of the water body to dilute and/or assimilate contaminants derived from human uses, while sustaining all other values at desired levels. In the context of water quantity, the capacity for use is the rate at which water can be removed from the water body (or be diverted or dammed) while sustaining all other values at the desired level.

the Northland region. The report has also suggested some example plan provisions including objectives and limits that are associated with the framework.

The proposed criteria for defining FMUs and the suggested objectives and rules are options that can be easily altered. It is likely that differences in any or all criteria used in this report would result in a different balance between the economic, social, cultural and environmental outcomes. While the choices used in this report are technically viable options, it is important to acknowledge that decisions concerning the definition of FMUs and objectives are not purely technical and are ultimately socio-political in nature. It is therefore important that the choices for defining FMUs and objectives and their implications are considered by the community and decision-makers.

1.4 Structure of this report

The study that is the subject of this report commenced with a two day workshop that was held at NRC in February 2015 to explore FMU options for Northland. Some of the potential options that were put forward at that workshop have been further developed in this report, which is structured as follows:

- Section 2 provides an overview of the nature of FMUs, looks at alternative approaches to defining them and sets out a recommended approach for establishing FMU's for Northland's rivers,
- Section 3 illustrates the recommended approach with respect to managing river water quality,
- Section 4 illustrates the recommended approach with respect to managing river quantity, and
- Section 5 discusses the findings and recommendations.

An understanding of patterns in water quality state is an important component of determining the efficacy of a proposed framework of FMUs. Therefore, Appendix A of this report provides an analysis of river water quality data pertaining to long term state of environment monitoring sites in the Northland region.

2 Alternative approaches to defining FMUs

2.1 Overview

Most regional councils have either developed region-wide water plans or are in the process of doing so. Some councils have operational second generation plans that were developed prior to the release of the NPS-FM but nevertheless these plans address many of its requirements of including numeric objectives and limits. In addition, some councils are well advanced with developing their second generation plans that will need to be consistent with the requirements of the NPS-FM, including defining FMUs.

For example, Horizons (Manawatu-Wanganui) Regional Council defined 44 water management zones and 117 subzones in the Manawatu-Wanganui region's One Plan. These zones are catchment or sub-catchment based and encompass the water bodies within the zone and the surrounding catchment land area. Water quality and quantity related values for the water bodies in the zone have been identified and objectives defined. Because the Horizons water management zones/subzones are catchment-based, specific load-based limits have been defined for each zone. To assess compliance with the objectives and limits, a monitoring site is required at the downstream end of each zone. It is anticipated that some management functions will occur at the subzone level (e.g. surface water allocation), while other management functions will occur at the zone level (e.g. water quality monitoring).

Environment Canterbury has defined management units at various scales. At the regional level a subdivision of the region along socio-political and also catchment boundaries into eight Water Management Zones[10] is used as a basis for collaborative management. At a lower level of spatial subdivision, the operative Land and Water Plan has defined default objectives for all water bodies in the region based on a bio-physical classification of rivers and lakes. For rivers the classes are based on a modified River Environment Classification framework. Individual Zone plans are regional plans that are specific to each of the eight management zones. These plans are based on sub-catchments that are defined by "nodes". These are points of significance that are tied to particular actions and resource use limits such as contaminant load and water quantity limits.

Taranaki Regional Council has defined four freshwater management units in its draft second generation regional plan based on common water related values, physical and hydrological characteristics, and associated catchments.

For the purposes of collaborative planning processes, the Greater Wellington Regional Council has defined six "whaitua" that encompass the catchments of the region's rivers. It is anticipated each whaitua will be sub-divided into sub-catchments that reflect differences in values and objectives.

2.2 Catchments and scale

The purpose of FMUs is to provide a basis for setting water quality and quantity objectives and associated limits, and managing and accounting for water resource use. It is fundamental to the approach taken in this report that FMUs are based on catchments because the nature of water bodies[11] including their values, physical and ecological functioning, and their state (i.e. their condition) is largely determined by the character of their upstream drainages (e.g. climate, topography, land use) and the nature of the resource use that occurs within them (e.g. land use and management, water takes, and point source discharges). It is noted that the NPS-FM definition of FMUs does not explicitly mention catchments but it is assumed that it is the intent of the NPS-FM that FMUs involve catchments.[12]

Catchments can be defined at different scales, for example, an entire land area that drains to a river mouth at the coast (referred to in this report as a sea-draining catchment) or a smaller scale subdivision of tributary streams.

A sea-draining catchment would be an appropriate scale for managing sedimentation rates or nutrient enrichment in estuaries and harbours. However, subdivision of large sea-draining catchments may be appropriate if, for example, there is variation in water quality or the values within the catchment. The scale at which FMUs need to be defined ultimately depends on the size that achieves reasonable homogeneity with respect to several characteristics of the water

[10] http://ecan.govt.nz/get-involved/canterburywater/Pages/canterbury-water-zone-map.aspx

[11] In this report a water body is defined as a physiographical feature such as a stream, river, lake or wetland or any part thereof. Furthermore, a catchment is defined as the upstream drainage of a water body. It is unclear from the NPS-FM definition of a FMU whether a water body is defined as per this report or if it is includes the catchment. However, in this report an FMU is assumed to include the catchment because objectives set for water bodies must primarily be achieved by managing resource use in their catchments.

[12] Policy C1 of the NPS-FM directs regional councils to "manage fresh water and land use and development in catchments in an integral and sustainable way, so as to avoid, remedy or mitigate adverse effects, including cumulative effects."

bodies they contain, including; (1) their values, (2) their capacity for use, and (3) management requirements resulting from their bio-physical functioning[13]. Where there are multiple water related values, and/or differences in other relevant water quantity or quality characteristics, this may require that catchments of differing sizes are defined and that smaller catchments are 'nested' within larger catchments.

Sub-catchments can be defined at any scale from fine-scale first order (i.e. headwater) catchments to coarse-scale drainages of significant tributaries and entire sea-draining catchments. The size of a sub-catchment generally determines the degree of similarity (i.e. homogeneity) of the values and other characteristics they contain. Water bodies in small sub-catchments such as headwater areas, are relatively similar, whereas large sea draining catchments may contain a more diverse range of values and other characteristics. Defining a regional framework of FMUs therefore involves subdividing catchments such that the values and other characteristics they contain are sufficiently homogeneous that a set of plan provisions can be justifiably applied. For a region-wide plan (i.e. a plan that applies to the entire region) it is important that the framework of FMUs divides the region into catchments that are applicable and justifiable, but that the level of detail and complexity is kept to a minimum (i.e. the scale is as coarse as possible).

2.3 FMUs based on sea-draining catchments

One way that FMUs could be defined is by treating each individual sea-draining catchment in the region as a unit. In the Northland region there are more than 1600 sea draining catchments (Figure 1). While the sea-draining catchments are appropriate units for managing land impacts on the coastal environment (where there are water quality impairment issues), the freshwater bodies that are contained within these catchments are generally variable (i.e. are not homogeneous).

Treating each sea-draining catchment as a unit leads to two practical problems. First, the large catchments are generally not homogeneous units with respect to values, capacity for use or management requirements. As water in a catchment drains from its upper reaches in the hills to its mouth at the coast, its quality and quantity is affected by changes in geology, soils, land cover, use and development. Often the upper areas of catchments are characterised by steep land dominated by natural and exotic woody vegetation. Water bodies in these areas have physical characteristics (e.g. rocky and eroding stream beds) and water quality state that reflect these characteristics. By contrast, lowland areas of catchments are often characterised by flat land that is used for intensive agriculture or urban development. The water bodies in lowland areas generally exhibit different physical characteristics (e.g. soft muddy stream beds) and their state may be strongly influenced by the economic use of their resources.

Variation in the current water quality state within catchments is illustrated in Figure 1, which shows the available water quality[14] data for 35 long term monitoring sites in Northland. These sites are distributed over 20 sea draining catchments. Figure 2 shows that state (i.e. water quality) is very variable in catchments with more than one site (e.g. catchment 4161 and 4385, see Figure 2). Note that these catchment numbers are derived from a national definition of

[13] For example, differences in the flow regimes and morphology of streams and rivers within large sea-draining catchments may be sufficiently large that different nutrient concentration criteria is appropriate.

[14] This report includes an analysis of water quality and macro-invertebrate data collected at 35 long term state of environment monitoring sites distributed across the Northland region (Figure 1). A detailed description of the analysis of these data is contained in Appendix A1 of this report. The outputs of these analyse (for example, site median values of water quality variables) are used in later sections of this report and it is assumed the reader will refer to Appendix A1 to understand how these data were derived.

catchments that are included in the Freshwater Environments of New Zealand (FENZ) database. In other words, water quality state in single large sea-draining catchments is likely to be insufficiently homogeneous for a single set of plan provisions to be justifiably applied for the purposes of managing some freshwater values.

Some sea-draining catchments may be sufficiently homogeneous that a single set of plan provisions can be consistently and justifiably applied. However, variation in the character of a catchment and its water bodies may be too contrasting for some sea-draining catchments to be considered an appropriate unit for management. In this case the sea-draining catchment needs to be sub-divided and different plan provisions applied to the various sub-catchments.

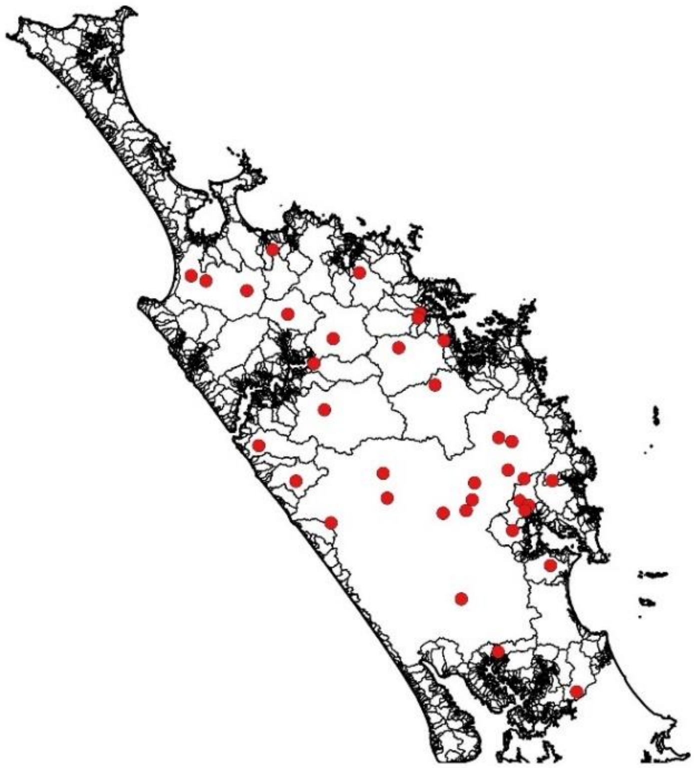

Figure 1. The sea-draining catchments in the Northland region. The red dots indicate long-term water quality monitoring sites on rivers or streams.

The second problem is that developing freshwater objectives and management actions for each unique sea-draining catchment is inefficient because many catchments (or parts of catchments) are sufficiently similar that they can be considered part of a homogeneous group to which a single set of plan provisions can be justifiably applied.

A framework based on sea-draining catchments can be simplified by grouping similar catchments. For example, small coastal catchments could be grouped, perhaps by location within the region or some other physiographic basis such as size. However, some types of limits need to be defined and resource use would need to be accounted for on the basis of individual catchments because these are only be meaningful within individual catchments or sub-catchments. Therefore, at the level of plan implementation (e.g. resource consenting and accounting functions) grouped catchments would need to be disaggregated to individual catchments.

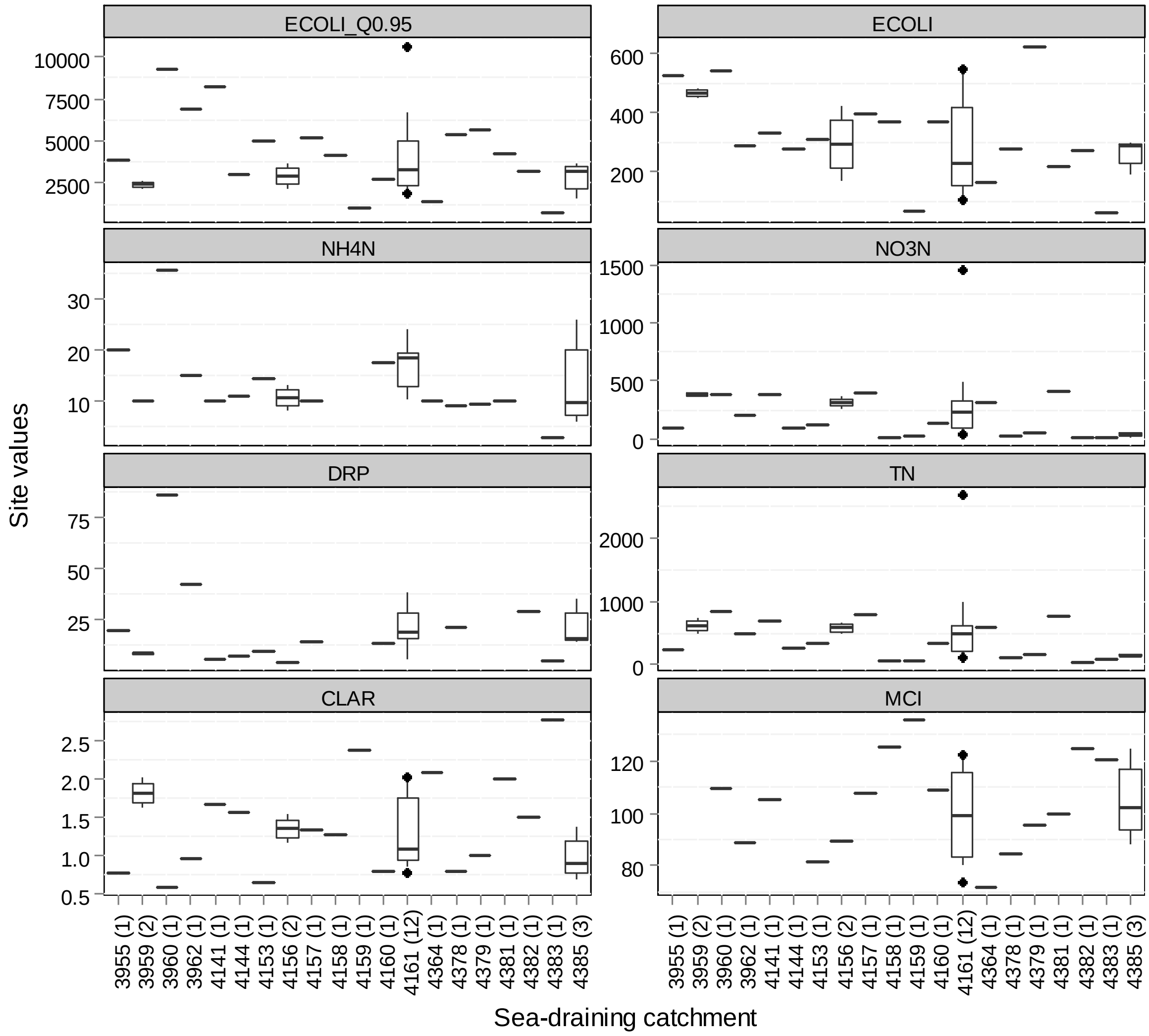

Figure 2. Distributions of site median values for water clarity (CLAR), macroinvertebrate community index (MCI), dissolved reactive phosphorus (DRP), ammoniacal nitrogen (NH4N, Nitrate nitrogen (NO3N), total nitrogen (TN), dissolved reactive phosphorus (DRP), total phosphorus (TP), Escherichia coli (ECOLI) and 95th percentile values for Escherichia coli (ECOLI Q0.95) of water quality variables for 35 water quality monitoring sites. The data are grouped according to the sea-draining catchment in which the site is located, which are identified by numbers between 3955 and 4385. These catchment numbers are derived from a national definition of catchments that are included in the Freshwater Environments of New Zealand (FENZ) database. The number of sites in each catchment is shown in brackets. The individual site values were derived from data for the 5 year period ending 2013 (see Appendix A1 for details). The central horizontal line indicates the median and the bottom and top of the box indicate the 25th and 75th percentile values. The whiskers extend to the 10th and 90th percentiles. Where the number of sites exceeded 10, the black points indicate the 5th and 95th percentiles. Where the sea-draining catchments are represented by only one site, the median values are plotted as single lines.

2.4 FMUs based on *ad hoc* subdivision of sea-draining catchments

Sea-draining catchments that are too large (i.e. are insufficiently homogeneous) for a single set of plan provisions to be justifiably applied can be subdivided in an *ad hoc* manner (i.e. a subdivision that is made for an individual catchment but which was not made on the basis of a specific criteria). Specific locations can be chosen to define sub-catchments based on pragmatic criteria such as water quality monitoring locations or flow recorders of sites of special significance. This has been the approach taken by some regions for defining FMUs in single large catchments. For example, contaminant load limits for the Hurunui River catchment in Canterbury were set at a site for which long term monitoring data was available. Plan provisions generally applied upstream of that point although the relative contributions from different parts of the catchment and some of the associated provisions varied by major sub-catchment.

Using an *ad hoc* basis to subdivide a single catchment may be pragmatic and acceptable. However, this approach is not an ideal way to define FMUs for an entire region (i.e. for a region-wide plan), particularly in regions with many catchments like Northland. In this circumstance there would potentially need to be many *ad hoc* decision made. It may become difficult to justify these decisions as inconsistency would be evident. In these circumstances a more formulaic approach to subdivision of catchments is needed.

2.5 FMUs based on river classification

Classification of water bodies provides a basis for discriminating variation so that appropriate objectives can be set for different groups (or classes) of water body. A national system for classifying rivers called the River Environment Classification (REC) was developed by the Ministry for the Environment as a tool for various aspects of water management (Snelder and Biggs, 2002). The REC has been used extensively since 2002 as a basis for various aspects of water management including state of environment reporting, catchment contaminant modelling (e.g. CLUES) and a basis for classifying rivers for different management purposes in regional plans. In particular, the REC has been used as a basis for defining objectives in regional plans (e.g., Canterbury NRRP, Southland Regional Water Plan, Horizons One Plan).

REC classes provide a basis for grouping similar water bodies, which are defined by individual segments of the river network. All segments belonging to a class are considered sufficiently similar that the same objective can justifiably apply to them and objectives can vary appropriately between classes. However, the REC classes are not a basis for defining management actions or limits because these apply to land areas draining to the water bodies. In addition, REC classes do not provide a basis for administrative functions such as accounting for resource use because these must be based on individual catchments. However, the REC and its underlying representation of the drainage network provides a starting point for the development of a system of FMUs that is developed in the next section.

2.6 FMUs based on the drainage network

The alternative to the *ad hoc* subdivision of catchments to define FMUs is an approach that is based on specific criteria. The benefit of a criteria-based approach is that the basis for FMUs is transparent and alterable (by changing the criteria) and can be applied generally to an entire region.

The criteria-based approach to the definition of FMUs is built on a detailed (fine-scaled) subdivision of the region’s drainage network and associated sub-catchments. The benefit of the drainage network is that the catchment upstream of any point can be defined. Each point in the network has its own unique sub-catchment defined by all the upstream land draining to that point. Because a drainage network allows subdivision of the region’s catchments to be carried out at any scale, the optimal scale (or alternative scales) of sub-division can be explored.

This project has used three key steps to construct a framework of FMUs based on the drainage network:

1. Define the management classification,
2. Define the management zones, and
3. Define the administrative points.

The first step is the definition of a 'management classification' of the water bodies[15]. This classification involves grouping water bodies into classes that are relatively homogeneous with respect to their characteristics including; (1) their values, (2) their capacity for resource use[16].

The approach taken in this report to defining the management classes (i.e. groups of stream and river segments) is on the basis of physiographic factors. The details of the physiographic factors are set out in subsequent sections but include, for example, the catchment slope, size (as defined by average flow rate) and distance from the coast. These factors are a relevant basis for defining classes because they broadly 'control' physical and biological processes that determine the quality and quantity of water bodies, their values and aspects of their bio-physical functioning.

The management classifications are the basis for defining freshwater objectives for all the water bodies in the region. Individual classes are likely to extend across multiple sea-draining catchments and individual catchments are likely to comprise more than one class.

The second step defines the management zones. Management zones recognise that the management actions (i.e. policies and rules) to achieve objectives apply to land areas (and associated land use and development) that drain to water bodies (and not to the water body itself). Therefore all land areas that drain to water bodies belonging to a particular management class become a management zone. Like the management classes, management zones are not restricted to a single sea-draining catchment and recur in a patchwork across a region. In addition individual sea-draining catchments may comprise different management zones. Management zones need to be defined so that management actions and limits that apply to them provide for the achievement of the most restrictive downstream objective. For example, in some circumstances land may drain to a river segment that is relatively resistant to the effects of nutrient concentrations. However, further downstream, perhaps several kilometres away, the destination of water may be a lake or main-stem river that is more sensitive to nutrient concentrations. In this case the limits set for point and diffuse source discharges in contributing catchments need to ensure that this more stringent objective is achieved. Management zones clarify these important concepts and

[15] In this report the smallest water body is a segment of the drainage network, which is defined as a channel section between its upstream and downstream tributaries. The same approach would be taken for lakes by defining individual lakes as water bodies and classifying them.

[16] The term 'capacity for use' refers to the amount of resource use that can be made while sustaining all competing values at some agreed level. Because value judgements are required to determine the acceptable level for supporting values, so too the capacity for resource use depends on these value judgements. Capacity for use varies widely between water bodies; some water bodies that support very sensitive and significant in-stream values may have zero capacity for use, while other water bodies may have significant capacity for use. In the context of water quality, the capacity for use is the capacity of the water body to dilute and/or assimilate contaminants derived from resource use, while sustaining all other values at desired levels. In the context of water quantity, the capacity for use is the rate at which water can be removed from the water body (or be diverted or dammed) while sustaining all other values at the desired level.

clearly define land and associated development that needs to be managed to achieve a particular objective.

The third step defines the administrative points. Administrative points recognise that controls on contaminant discharges and water takes must occur and be accounted for within individual catchments and sub-catchments. Therefore a subdivision of the region into individual catchments and sub-catchments should occur at least at points in the drainage network where there is a change in the management zone. Administrative points are locations at which contaminant load limits and volumetric allocation limits can be defined in absolute terms and resource use accounting should occur. Contaminant load limits and volumetric allocation limits can be determined in absolute terms for each individual administrative point provided that they are defined for the management zones on a scalable basis. Scalable limits can be based on a proportion of a flow statistic that reflects stream size such as the Mean Annual Low Flow (MALF) for water quantity and an aerial basis for contaminant loads (e.g. kg/ha/yr).

Administrative points are important only in terms of plan implementation. There may be a large number of administrative points but this will not result in a complicated plan because freshwater objectives and water quality and quantity limits are set for a limited number of management classes and associated management zones.

There are several advantages with a region-wide framework of FMUs that are defined based on the drainage network. First, classifying the region's water bodies based on physiographic factors allows spatially discrete but similar water bodies (e.g. located in different sea-draining catchments) to be managed under a common set of plan provisions. The same approach would apply to lakes where lakes belonging to a particular class would be subject to a specific set of plan provisions, which would differ for another class.

A second advantage of the drainage network approach is that the resolution (or level of detail) of the framework can be altered by varying the number of classes of the management classification. Greater resolution can be achieved by the defining more management classes. Higher resolution would enable higher precision in terms of objectives (desired environmental outcomes) and more nuanced policies and limits but would increase the effort and data needed to justify them and the complexity and detail of the plan's final provisions. There is also likely to be tension between the level of detail that is technically and scientifically justifiable (and achievable) and other considerations such as catering for the desire of stakeholders for spatially nuanced policies and limits. It is important to note that this is a key challenge to manage in designing the framework of FMUs for Northland. For example, in Northland there is good quality long term water quality data from 35 state of environment monitoring sites (see Appendix A1). A classification of the rivers into two classes allows for good representation of each class with a minimum of 15 sites in each class. However, increasing this to more classes would mean reducing the representation of each class and potentially induce statistical bias in an assessments based on the classes.

A third advantage is associated with efficiency in the use of available data. If a classification provides good discrimination of variation in characteristics of interest (i.e. values, current state and management requirement), it is reasonable to infer that other locations in the class have similar character. Thus, a classification system makes optimal use of limited data and provides a justifiable basis for monitoring on the basis of a small set of representative sites.

The following section describes in more detail a proposed transparent and efficient framework of FMUs based on the drainage network.

2.7 A recommended approach for Northland

The remainder of this report presents a recommended approach to defining a framework of FMUs for Northland's rivers to be included in NRC's second generation regional plan. The approach is a starting point for discussion and a final decision on a preferred approach should ultimately be made as part of the regional plan decision making process. The principles and methods described here for rivers are applicable to lakes.

The REC system for classifying rivers has been used as the basis for describing the river network in this study. The REC is based on a digital drainage network that was derived from a digital elevation model (DEM) with a spatial resolution of 50 m (Snelder and Biggs 2002). Computer analysis of the DEM identified drainage paths, network segments and the associated sub-catchment boundaries. The REC represents the rivers of the Northland region with approximately 27,000 unique river segments, with a mean segment length of 740 m, defined by upstream and downstream confluences with tributaries (the 'water bodies'). A key feature of the REC is a system of labels for the segments and their associated sub-catchments that allows rapid analysis of upstream–downstream connectivity and accumulation of catchment characteristics (e.g. land areas having different geological or land cover categories) in the downstream direction.

3 Water quality FMUs

This section proposes a network based approach for defining a default regional framework of FMUs for management of river water quality in Northland. This framework is an example and could easily be altered by changing the criteria for determining river classifications. It would be preferable, for the sake of plan simplicity, to have the same FMUs for water quality and quantity. This was considered but characteristics that are relevant to the management of water quality and quantity (i.e. values, current state and aspects of bio-physical functioning) are sufficiently different that it was considered that separate quality and quantity FMUs were required.

3.1 Water quality management classification

A proposed 'water quality management classification' is a coarse subdivision of the region's water bodies for management purposes. It is assumed that first and foremost objectives and policies would aim to maintain the current state of water quality and that this requirement effectively sets the capacity for use of water bodies in each class. Any objective to improve the current state of a class would apply generally to all locations in the class and be linked to values that are generally held for the management class. Note that Section 3.6 of this report also suggests that some 'special water quality management classes' are also defined to manage for values that are not captured by the general classification.

An analysis of Northland's 'general' river water quality (i.e. water quality as defined by a mix of physical, chemical, and biological parameters) revealed broad variation associated with variation in catchment topography (Appendix A1). Steep hill catchments are associated with relatively higher water quality than lowland (low gradient) catchments. However, attempts to discriminate finer scaled patterns in the variation in general water quality in Northland were not particularly successful. This is because variation in water quality in the region is complex (see Appendix A1 for details). The individual water quality variables tend to vary independently (i.e. they have low correlation to each other). In addition there is large variation in the strength of the relationships between the individual variables and catchment characteristics such as topography, geology, land cover, and climate.

Therefore, this report proposes that a general water quality management classification is based on the topography of the upstream catchment. Topography strongly controls many water quality parameters and is associated with other explanatory variables such as land use (i.e. lowland areas tend to be more intensively farmed and urbanised than hill country areas) and river size and hydrological regime, which affects contaminant dilution, transport and assimilation.

Classifications of rivers for water quality management in other regions have been based largely on the topography level of the REC. For example, the Canterbury Land and Water Plan classifies the region's drainage network based on the REC topography classes: primarily Mountain, Hill and Lowland. Taranaki Regional Council's second generation (draft) regional plan, classifies the region's rivers for different management purposes based largely on topographic variation. The Horizons One Plan also broadly subdivides the region on the basis of REC topography classes.

A classification of Northland's rivers for managing water quality has been defined based on the topographic variable average catchment slope. This is similar to the REC Source-of-Flow classification but is more suited to the Northland region. An average catchment slope threshold of 10 degrees was used to subdivide the region's river network into two classes (*Figure 3*). This threshold maximises the discrimination of variation in regional variation in water quality for a two class classification based on catchment slope (Appendix A1.6). This threshold produces are reasonably even subdivision of the region's rivers into equal sized classes and strongly discriminates variation in most of the measured water quality variables (*Figure 4*). NRC's water quality and biological monitoring network was also reasonably representative of the variation in land cover in each class, which is strongly associated with water quality variation (Appendix A1.6).

Points in the drainage network with upstream catchments having average slopes greater than 10 degrees are labelled "Hill". This class is characterised by catchments with a high proportion by area occupied by native forest, scrub or exotic forests. As a consequence the Hill class is expected to have generally higher water quality than rivers in lowland area and be valued for associated high ecological and aesthetic values. Pressure from resource use (e.g. land use impacts of water quality and water quantity) is expected to be less than in lowland areas. Points in the network with upstream catchments having an average slopes less than 10 degrees are labelled "Lowland". This class is characterised by a dominance of agricultural land use. Points in the network with these lowland catchments are expected to be in a poorer state than the Hill class (i.e. lower water quality, higher pressure on water quantity).

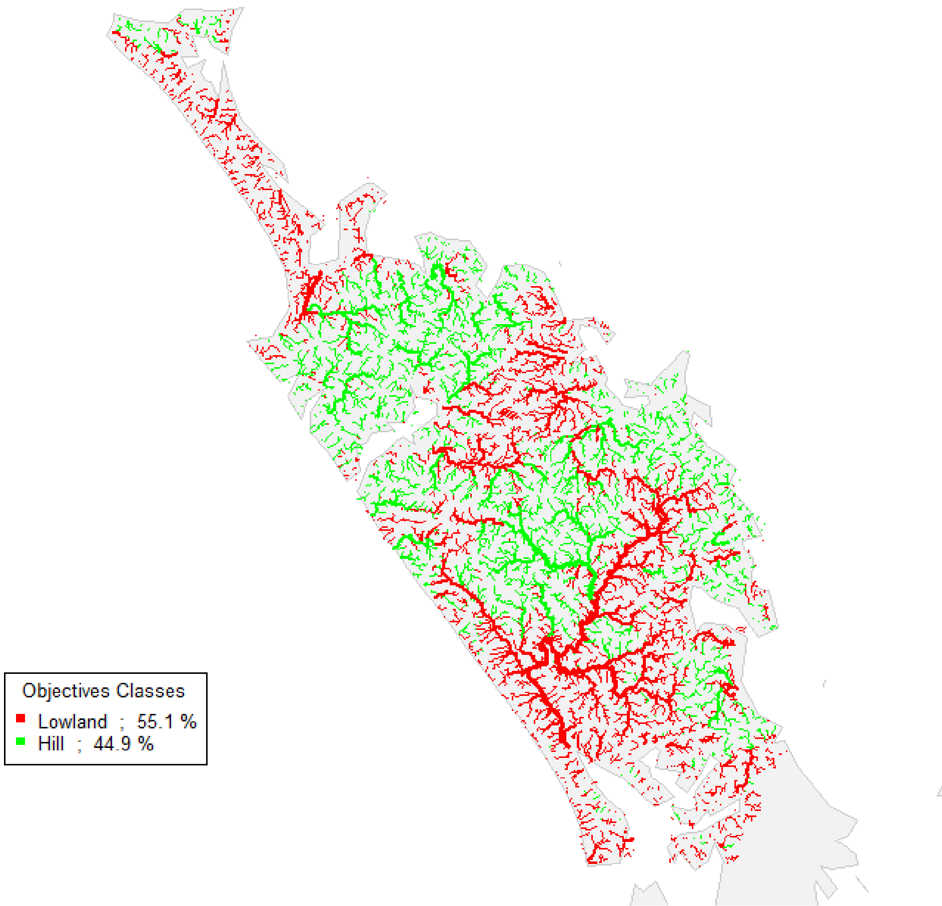

Figure 3. Water quality management classification of the Northland drainage network based on the average slope of the upstream catchment. The slope threshold differentiating the two classes was 10^{o}.

3.2 Potential water quality objectives

This section sets out potential water quality objectives for aquatic ecosystem health and secondary contact recreation for each water quality management class. The NPS-FM has mandated that "ecosystem health" and "human health for secondary contact recreation" are compulsory water quality and quantity related values that must be provided for in all water bodies. However, regional councils have the discretion to manage rivers for other water quality related uses and values, such as primary contact recreation (swimming) and mahinga kai (aquatic food sources).

The NPS-FM has defined "attributes" as the foundation of the numeric "freshwater" objectives. Attributes are defined in the NPS-FM to mean "a measurable characteristic of freshwater, including physical, chemical and biological properties, which supports particular values." The NPS-FM attributes enable communities to choose the level of protection for values by defining numeric attribute states or "bands" (A, B or C bands) and also defines a minimum acceptable states ("bottom lines" or the boundary between C and D bands) for these attributes. A regional plan process must set freshwater objectives for FMUs with reference to at least the NPS-FM attributes.

The NPS-FM attributes that are relevant to rivers include: *Escherichia coli (E.coli)* concentrations (an indicator of the presence of pathogens or human health risk) to provide for human health for recreation secondary contact, ammoniacal nitrogen (NH_4N) and nitrate nitrogen (NO_3N), concentrations to manage toxicity, and periphyton concentrations[17] to manage trophic state.

Attribute states for *E.coli*, NH_4N and NO_3N are based on median and 95th percentile concentrations (see *Table 1*). Objectives for periphyton are expressed in term of biomass measured as Chlorophyll a per square metre of river bed. This analysis used nutrient concentration guideline values (nitrate plus nitrite nitrogen (NNN) and dissolved reactive phosphorus (DRP) that have been used in past Northland State of Environment reports (Ballinger *et al.,* 2014) and which were sourced from ANZECC (2000). These are broadly consistent with nutrient criteria to prevent nuisance periphyton abundance suggested by Matheson *et al.* (2012) and the concentration criteria used to manage periphyton by the Horizons One Plan. It has been assumed that compliance with these criteria would achieve the NPS-FM C state (i.e. to be above the national bottom line) for the periphyton attribute. In the analysis of state that follows, a site was only assigned to the D band if the site median concentrations of **both** NNN and DRP were higher than those shown in *Table 1*. Nutrient concentration criteria for NPS-FM periphyton states A and B are not currently available and the current state with respect to periphyton is not established regionally. Therefore objectives for periphyton that that are associated with the NPS-FM A and B states cannot be defined at this stage.

Additional potential objectives that have been assessed include primary contact recreation (swimming), ecological health based on the macro-invertebrate community index (MCI)[18] and water clarity. Bands for primary contact recreation are provided as optional objectives in the NPS-FM and are based on the 95th percentile *E.coli* concentrations.

Bands for MCI scores were defined based on Stark and Maxted (2007). For the discussion that follows the MCI objective is based on the median of annual values for the last five years and the national hard bottom version of the MCI. More detailed and specific criteria provided by Stark (2014) are possibly appropriate and could be evaluated. An objective for clarity is suggested based on the MFE (1998) guideline of 1.6m. For the discussion that follows this clarity objective is based on median of all samples but more detailed criteria (e.g. based only of lower flows and/or summer sampling occasions) are possibly appropriate and could be evaluated.

[17] Periphyton is slime and algae found on the bed of streams and rivers. Healthy river ecosystems are characterised by low levels of periphyton, but when thick growths occur they usually adversely affect ecosystem health and other values. Periphyton abundance at a site is determined by nutrient concentrations (nitrogen and phosphorus) and is measured in terms of maximum allowable chlorophyll a concentrations (Chl a mg/m^2). The concentrations of nutrients that will achieve a specified maximum periphyton abundance are spatially variable because differences in flow regimes (primarily flood frequency) strongly influence the period available for periphyton abundance to increase.

[18] The MCI is based on the tolerance or sensitivity to organic pollution and nutrient enrichment of different type of benthic macro-invertebrates (small animals without backbones that live on or just below the stream-bed). For example, mayflies, stoneflies and caddis flies are sensitive to pollution, and are only abundant in clean and healthy streams, whereas worms and snails are more tolerant and can be found in polluted streams. MCI values typically range between 50 at extremely polluted or sandy/muddy sites and 150 at sites with high water quality.

Table 1. Potential river water quality objectives. The TN and DRP criteria for periphyton are from Ballinger et al., (2014), which were sourced from ANZECC (2000). The asterisk indicates attributes that are compulsory under the NPS-FM. Note that periphyton TN and DRP criteria for the A and B states are not available.

Attribute	Units	Compliance Statistic	Criteria for bands			
			A (Excellent)	B (good)	C (Poor)	D (Unacceptable)
Human health risk (secondary contact recreation)*	cfu / 100 ml	Median	x ≤ 260	260≤ x ≤540	540 ≤ x ≤ 1000	x ≤ 1000
Human health risk (primary contact recreation)	cfu / 100 ml	95th	x ≤ 260	260 ≤ x ≤ 540	540 ≤ x ≤ 1000	x ≤ 1000
NO_3N toxicity*	mg/m³	Median	x<1000	1000> x < 2400	2400 > x < 6900	>6900
		95th	x<1500,	1500 > x < 3500	3500 > x < 9800	>9800
NH_4N toxicity*	mg/m³	Median	x<30	30 > x < 240	240 > x < 1300	>1300
		95th	x<50	50 > x < 400	400 > x < 2200	>2200
MCI		Median	x >119	100 > x < 119	80 > x <100	x < 80
Clarity	m	Median	Not available[19]	Not available	>1.6	X < 1.6
Periphyton* (as measured by NNN[20])	mg/m³	Median	Not available	Not available	x < 444	X > 444
Periphyton* (as measured by DRP)	mg/m³	Median	Not available	Not available	x < 10	X > 10

3.3 Assessment of current state of river water quality

The current state of rivers and streams in Northland is illustrated in *Figure 4* as the distribution of site median values for the water quality variables and MCI and 95th percentile values for *E.coli*. The distributions are shown for the two classes in the proposed water quality management classification (Hill and Lowland). The plot (*Figure 4*) indicates the classification discriminates variation in the current state more efficiently than do sea-draining catchments (see *Figure 2*). *Figure 4* indicates that in general concentrations of contaminants are lower in

[19] Criteria for clarity and periphyton A and B states are not available.

[20] It has been assumed that if NNN and DRP fall within different bands, the periphyton objective is met for the higher band (i.e. the C band) as per Matheson *et al.* (2012).

the Hill class compared to the Lowland class and that MCI and water clarity are generally higher in Hill class compared to the Lowland class.

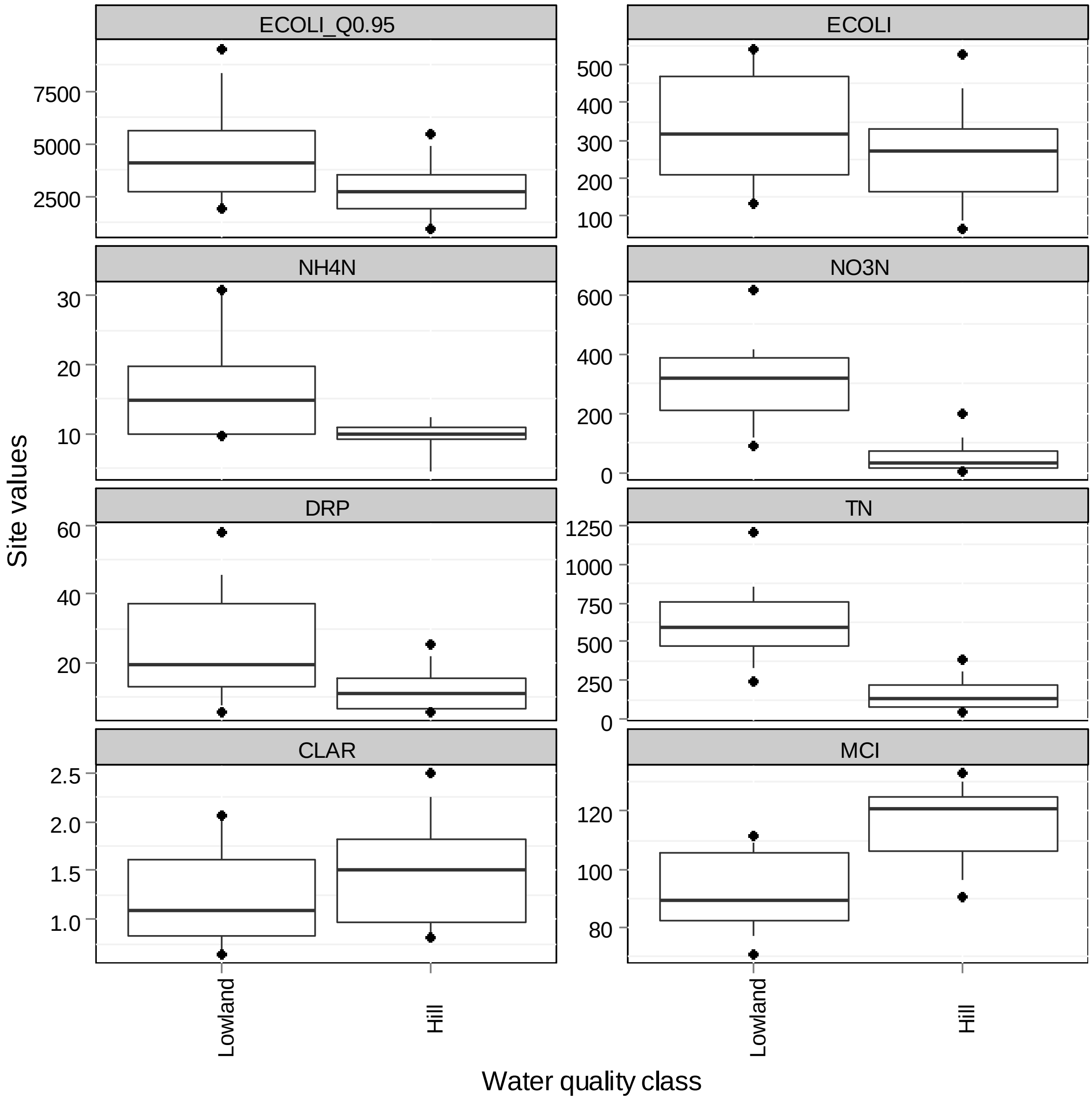

Figure 4. Distributions of site median values for water clarity (CLAR), macroinvertebrate community index (MCI), dissolved reactive phosphorus (DRP), ammoniacal nitrogen (NH4N, Nitrate nitrogen (NO3N), total nitrogen (TN), dissolved reactive phosphorus (DRP), total phosphorus (TP), Escherichia coli (ECOLI) and 95th percentile values for Escherichia coli (ECOLI Q0.95) of water quality variables for 35 water quality monitoring sites. The data are grouped by the two proposed water quality management classes; Lowland and Hill. There were 15 and 20 sites in the Hill and Lowland classes respectively. The individual site values were derived from data for the 5 year period ending 2013 (See Appendix A for details). The central horizontal line indicates the median and the bottom and top of the box indicate the 25th and 75th percentile values. The whiskers extend to the 10th and 90th percentiles. Where the number of sites exceeded 10, the black points indicate the 5th and 95th percentiles.

An assessment of the current state of the two water quality management classes relative to potential objectives is shown in *Table 2*. The table groups the sites by water quality management class and uses the proportion of water quality monitoring sites in each band to assess the state of the class "overall".

The assessment indicates that the periphyton bottom line is not met at two (i.e. 10%) of Lowland water quality monitoring sites but is met in all Hill class sites[21]. It is important to reiterate that this report has used NO_3N and DRP concentrations as a surrogate for actual periphyton data, and therefore the findings should be treated with caution. Moreover, many of Northland's rivers do not support conspicuous periphyton.

All sites in both classes are above the bottom line for human health - secondary contact recreation. The Lowland class is in a marginally poorer state for secondary contact recreation (65% in B or C compared to 54% for Hill). All sites in the Lowland class are in the D state for primary contact recreation (note this is not a compulsory NPS-FM national bottom line). In addition, all but one site in the Hill class are in the D state for primary contact recreation.

All sites are above the bottom line for the two toxicants; NH_4N and NO_3N. For NH_4N sites are predominantly (89%) in the A band in in the Hill class and predominantly in the B band (72%) in Lowland class. For NO_3N sites are entirely (100%) in the A band in the Hill class and predominantly in the A band (95%) in the Lowland class.

Median site MCI scores were consistently lower in the Lowland class with one site in the D band and more than 50% of sites in the C band. By contrast, no sites in the Hill class were in the D band and 65% of sites were in the B band or better. It is important to note that there are technical concerns about the appropriateness of using the MCI for Northland's soft bottomed rivers and streams (Stark, 2014).

There was a high rate of failure of the clarity guideline in both classes and this was marginally higher rate in the Lowland (75%) than Hill (65%) class.

[21] Note that streams with soft (mud or sand) beds will not grow conspicuous periphyton and the objective does not therefore apply to these types of environment. This analysis has not attempted to discriminate soft bed streams because their occurrence cannot be accurately predicted at the regional level. The supporting documentation for the NOF periphyton attribute (Snelder et al. 2013) estimated that approximately one third of Northland streams would support conspicuous periphyton. High periphyton biomass is observed at water quality monitoring and other sites in Northland even in rivers in the Lowland class. Therefore, for this analysis is has been assumed that a reasonable default is to manage nutrient concentrations to meet periphtyon in all streams in the region.

Table 2. Current state of the two water quality classes based on assessment of the proportion (%) of monitoring sites (31) falling into NPS-FM bands for the secondary contact recreation, primary contact recreation, NH_4N and NO_3N toxicity. For periphyton the sites were only assessed against the derived D band NNN[22] and DRP criteria. The sites were assessed against a nominal water clarity criteria of 1.6m. The asterisk indicates attributes that are compulsory under the NPS-FM.

Objective	**State band**	**Water quality management class**	
		Lowland river class	**Hill river class**
Periphyton*	D	10%	0%
MCI	A	0%	58%
	B	31%	25%
	C	56%	17%
	D	12%	0%
Ecoli (Secondary contact recreation)*	A	35%	47%
	B	55%	47%
	C	10%	7%
NH_4N toxicity*	A	28%	89%
	B	72%	11%
NO_3N toxicity*	A	95%	100%
	B	0%	0%
	C	5%	0%
Clarity	D	75%	67%
E.coli (Primary contact recreation)	C	0%	7%
	D	100%	93%

The analysis indicates that current water quality is higher in the Hill class than the Lowland class. This is consistent with the differences in land use in the catchments of water bodies belonging to these classes. The minimum requirement of the NPS-FM is to maintain current state. Therefore, it is likely that justifiable default objectives will be more environmentally protective in the Hill than the Lowland class. More aspirational objectives for some locations (e.g., seeking water quality improvements in the Lowland class) are mandated by policies in the Northland Regional Policy Statement. These could be allowed for but for the discussion that follows it is assumed that the Hill class objectives are more protective than the Lowland class and that consequently policies, including limits, are more restrictive (less enabling of resource use) in the Hill management zone.

[22] Nitrate plus nitrite nitrogen, which has been represented by NO_3N in this assessment as the nitrite nitrogen component is generally small.

3.4 Water quality management zones

As discussed earlier, management zones are areas of land (sub-catchments) that drain to river classes. The management zones for the entire Northland region, associated with the two water quality management classes are shown in *Figure 5*. A smaller scale view of the management zones is shown in *Figure 6*. There are some small and isolated patches of land belonging to the hill zone that are surrounded by large contiguous areas in the lowland zone. Some of these areas are possibly too small for the practical application of policies and these could be merged with the surrounding lowland zone.

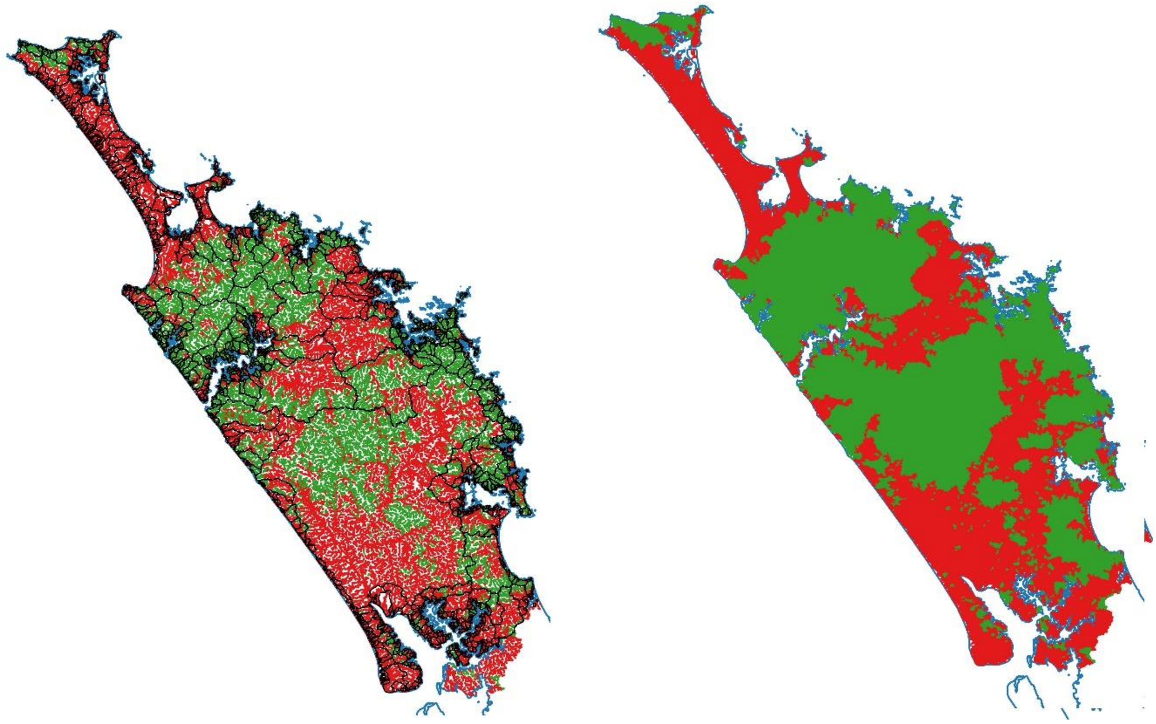

Figure 5. The proposed water quality management classification of the Northland Region based on lowland and hill subdivision (left) and the management zonation of the region on the right.

In general, rivers in the Hill class flow into rivers in the Lowland class. However, this is not always the case because Lowland tributaries can sometimes join main-stem rivers belonging to the Hill class (*Figure 6*). This is because the river classes are based on the average slope of their contributing catchments. *Figure 6* illustrates this, where on the left hand map it can be seen that some Lowland (red) tributaries flow into main stem rivers in the Hill (green) class. The management zone for land areas is shown on the map on the right. The zone at any point on this map reflects the most restrictive downstream objectives class (i.e. if there is a Hill water body downstream the zone will be the more restrictive Hill zone. In these cases the policies and limits applying to the Lowland tributaries need to be consistent with water quality objectives for the Hill tributaries they flow into.

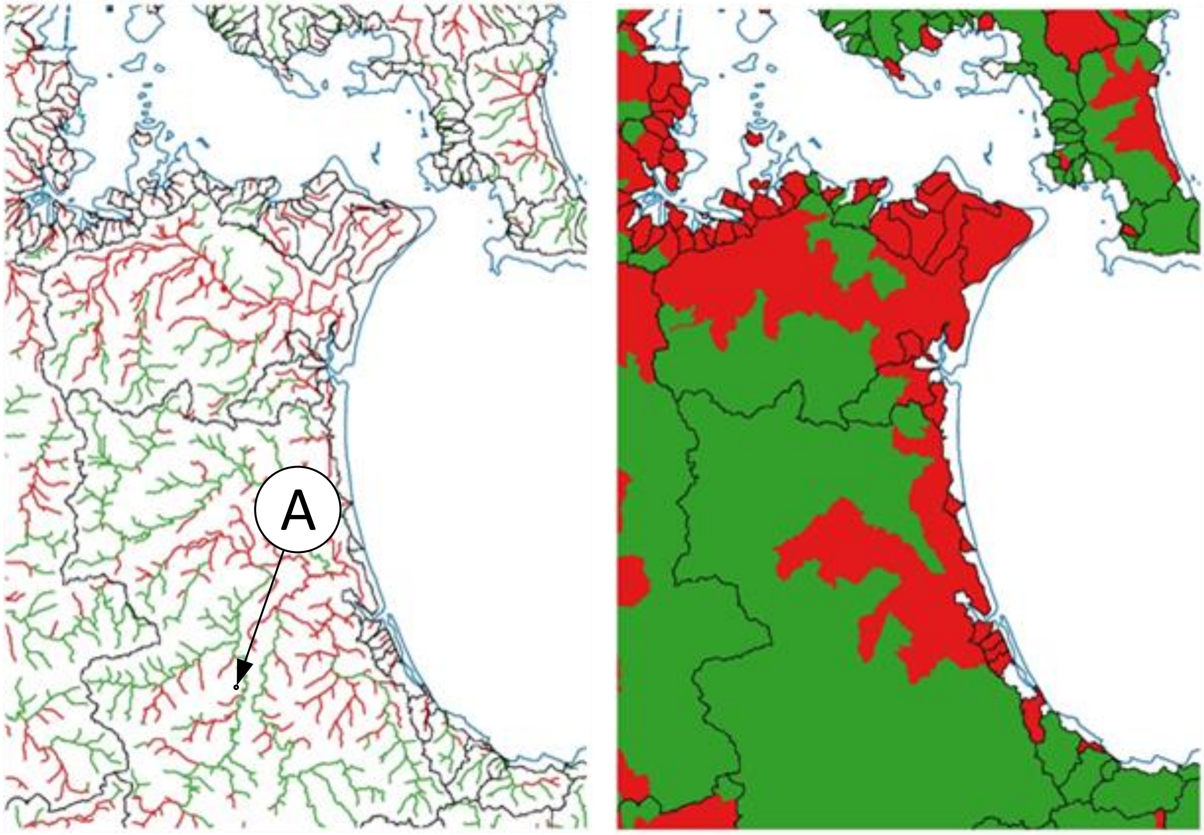

Figure 6. Zoomed view of the relationship between the water quality management classification of network (left) and the management zones (Right). The arrow marked A indicates segments belonging to the Lowland (red) class flowing into segments belonging to the more restrictive Hill (green) class. The management zoning for any location reflects the most restrictive class to which any location discharges. Therefore, catchments of Lowland class rivers flowing into Hill class (see Point A, left map) belong to the Hill management zone (right map).

The Hill and Lowland management zones are likely to be associated with differing policies, including limits. For example, the relatively good state of the Hill zone may be reflected in relatively few management actions but limits will be more restrictive to maintain current state. The lowland zone may be associated with more management actions because the suggest objectives are not always being achieved, but limits will be more enabling of resource use (i.e. discharges of contaminants) than the hill zone.

3.5 Water quality administrative points

The points where the management zones change are locations in the network where management actions and limits change. These points are therefore a minimum set of locations where contaminant load limits might need to apply and resource use accounting would need to occur, especially in any assessment process related to consents. These points therefore define a minimum set of administrative points for the region and are indicated by the black dots in *Figure 7*.

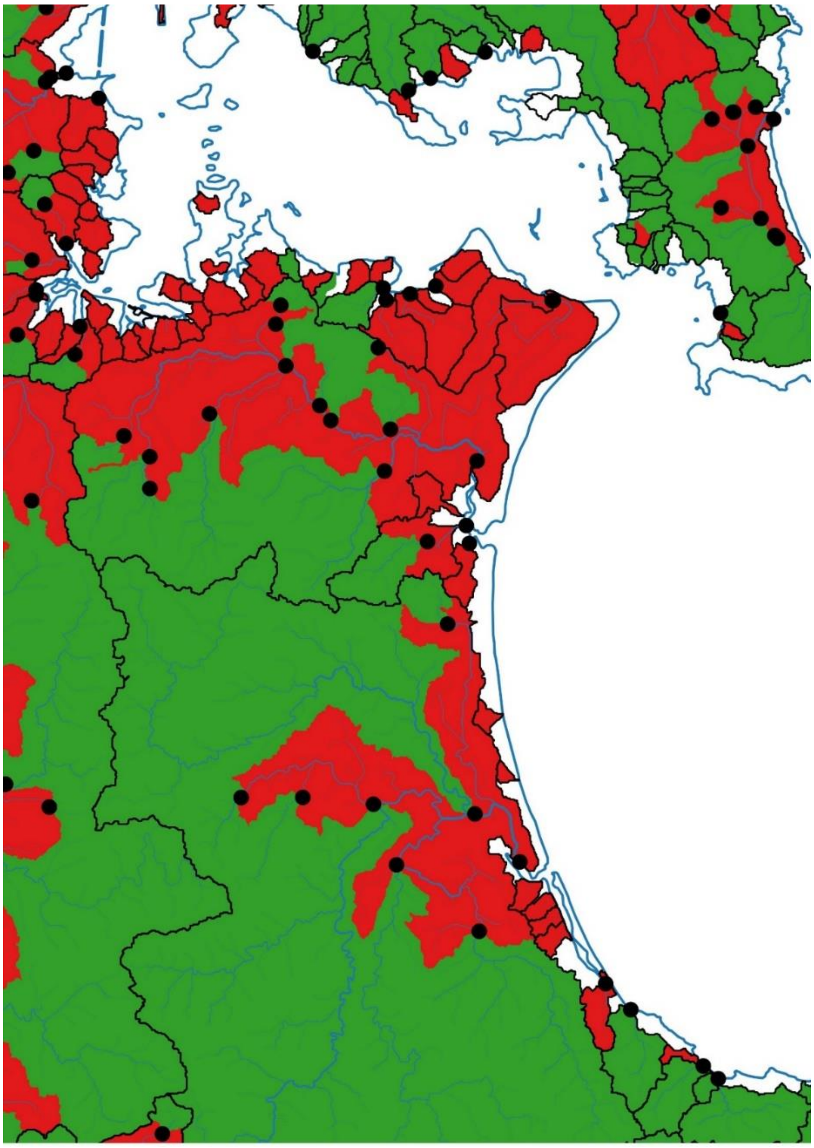

Figure 7. Zoomed in view of the management zones for Northland. The blue lines represent the drainage network and the black lines are the boundaries of the sea-draining catchments. The green zones represent areas that drain to segments in the Hill class of the water quality classification and the red zones represent areas that drain to segments belonging to only the lowland class. The black dots represent points at which the management zone changes from the hill zone to the lowland zone and are relevant administrative units where limits need to apply and resource use accounting needs to occur.

3.6 Special FMUs

It is recognised that some water bodies have specific values or water quality issues that are not discriminated by the water quality management classification but which may need to be provided for by region-wide plan. These water bodies are likely to require separate objectives and associated management actions. Examples of water bodies requiring separate management objectives may be sites of significance (e.g. swimming spots, or sites of special cultural or ecological significance). Water bodies requiring special objectives can be identified in the region-wide plan and specific objectives related to their particular values can be defined. The catchments upstream of these water bodies would be special management zones for which specific limits and policies would apply to achieve the objective. The combination of the waterbody and the upstream catchment are collectively ‘special FMUs’.

An example of a water body with special values is the Whangarei Falls on the Hatea River and the associated catchment (Figure 8). The Whangarei Falls was identified as a swimming site by Booth *et al.* (2013). Objectives for human health for primary contact (i.e. swimming) are stricter than the proposed default *E.coli* objectives, which are for secondary contact. The Whangarei Falls site and the associated upstream catchment would be a part of a special FMU. This FMU would have an appropriate numeric *E.coli* objective (*Table 1*) and more restrictive set of limits and policies would be applied to achieve the objective.

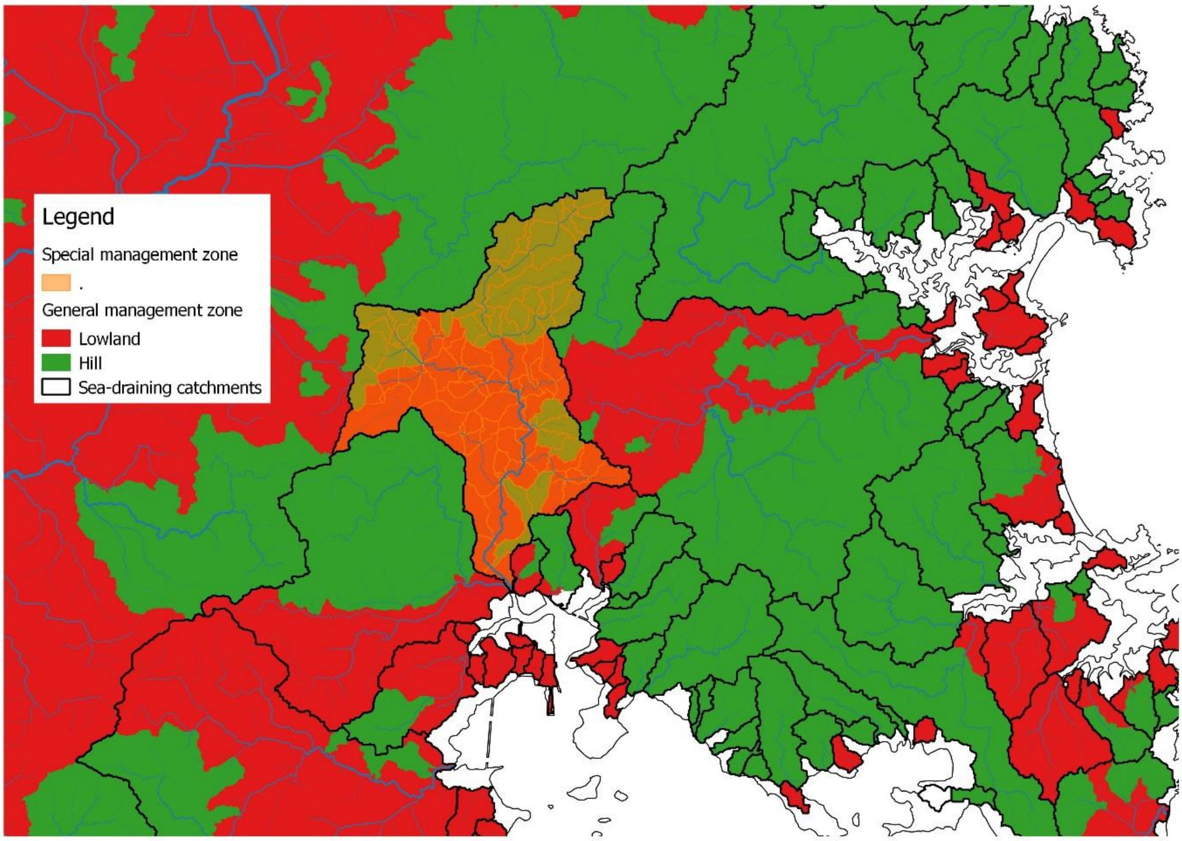

Figure 8. Example of a water body with special values defined by the Whangarei Falls swimming site and the upstream catchment (the management zone).

Specific objectives and special FMUs are likely to be needed across the region to manage several values and issues. Notably, Booth et al (2014) identified 44 swimming sites that would need to be treated as a special water quality management class for primary contact recreation. Collectively these sites and their associated catchments (management zones) could define a special FMU for which specific objectives and policies related to managing water quality for swimming could apply. However, it is important to note that these sites and catchments would also be managed by provisions established by the general FMUs for other values, e.g. water clarity, nitrate and ammonia toxicity, and eutrophication.

Another example where special FMUs may be needed is for managing some specific coastal environments. Special provisions for management of sediment and pathogens derived from catchments upstream of special coastal environments may be considered necessary if the provisions applying to the general management class are not considered to be sufficiently protective of their values. A special FMU for this purpose would be defined by identifying the relevant coastal water bodies and their upstream catchment areas. Note that is this case the management zones would be defined by either a single sea draining catchments or multiple sea-draining catchments where the special coastal water bodies had contributions from multiple catchments such as Whangarei Harbour.

3.7 How the FMUs might be applied for water quality

The analysis carried out by this study indicates that there are important differences in the current state of the two river water quality classes. In broad terms, the Hill class has better water quality than the Lowland class and there are no exceedances of the compulsory NPS-FM bottom lines. Clarity and *E.coli* are the most obvious attributes of water quality that might be judged to be below expectations in this class. However, water clarity is not currently an NPS-FM attribute and further consideration of the appropriate objectives for clarity (and or sediment) need to be included in the plan development process.

It is also noted that almost all sites in both classes are in the D band for *E.coli* primary contact recreation (i.e. not safe for swimming) but that this is not a compulsory national bottom line. Few sites are exhibiting degrading trends in water quality and there is not currently large scale land use intensification occurring that would put pressure on water quality.

Water quality in the Lowland class generally meets the NPS-FM bottom lines but there is evidence that nutrient concentrations are an issue with respect to the periphyton attribute, although it is important to note that the majority of Northland's rivers do not support periphyton because of their turbid nature and fine bed substrates (soft bottoms).

It might be concluded from this that objectives in the Hill class need to generally maintain water quality. Objectives for the Lowland class might need to focus on improving water quality, particularly *E.coli* and possibly nutrients in rivers that support periphyton, and other aspects associated with ecological health (e.g., to improve MCI values). This is consistent with the direction in the Proposed Regional Policy Statement for Northland (2013).

Furthermore, it might be concluded that sediment and faecal contaminant management is needed across the whole region as clarity is broadly poor and *E.coli* concentrations are high. It is also noted that sediment and *E.coli* are issues in the coastal environment of Northland and that the NPS-FM and the Proposed Regional Policy Statement for Northland (2013) requires the regional plan to address this. The relevant polices for achieving improvements could be a mixture of regulatory and non-regulatory measures. Although there is not significant current pressure on water quality, the NPS-FM requires the plan to establish clear limits. These limits could be linked to policies that ensure future significant land use changes or other developments that impact water quality are adequately controlled.

Assuming the above conclusions, or similar, were adopted and ratified by the regional plan process, the default water quality objectives for the Hill water quality management class would be more restrictive than the Lowland class. Each class would be subject to specific and different regional plan policies and limits that would apply to the respective Hill and Lowland management zones. Note that the objectives would apply to the water quality management classes but the policies and, potentially load limits, apply to the management zones (i.e. the catchments). Monitoring would be carried out at a network of sites that was judged to be sufficiently representative of each class of water management classification. This might comprise the existing river water quality monitoring network, which has a reasonable number of sites in both classes and an established period of record. Assessing the achievement of objectives, based on the monitoring data, would be carried out in a similar manner to the present study with the aggregate results for the class being used to evaluate the class at the regional scale. Where particular sites indicate there are water quality issues the default objectives and policies may need to be over-ridden by more specific catchment level plans. Localised catchment plans could be added to the region-wide plan over time as the need arises.

The general provisions set for the Hill and Lowland FMUs could be complemented by more specific provisions that would be defined for special FMUs in the region-wide plan or could be added later by localised catchment plans. A relevant example of this might be for the regional objectives for *E.coli* for the Hill and Lowland FMUs to be set for secondary contact recreation but for these to be over ridden by objectives for primary contact for water bodies that are identified as swimming locations. Special FMUs and associated provisions could be defined (e.g., for *E.coli* concentrations in the case of swimming spots) with all other objectives and policies being defined by Hill and Lowland FMUs.

The points at which any specific contaminant load limits need to be met and accounting for resource use needs to occur are the administrative points at which the management zone changes or the coast. Administrative points (*Figure 7*) would be relevant in assessments related to consents or any investigation associated with objectives that are not being achieved. There are a large number of administrative points but these are important only in terms of implementation and do not result in a complicated plan.

If water quality limits were defined in terms of contaminant loads, limits for all administrative points could be defined a scalable (area) basis (i.e. kg/ha/yr) and the absolute loads could then be assessed as part of administration rather than needing to be defined in the plan. It is noted that the NPS-FM does not specify the limits need to be defined in terms of loads but in some regions this has been the approach taken (e.g. Canterbury and Horizons). Management based on contaminant load limits was considered necessary in these regions due to significant existing and increasing pressure on water quality. Load based contaminant limits may not be considered necessary for the Northland region-wide plan, but the framework suggested here would provide a basis for management of loads should that be considered necessary.

4 Water quantity FMUs

4.1 Overview of water quantity management objectives

The proposed approach to defining FMUs for water quantity management follows the same process to that set out above for water quality. However, the definition of objectives for water quantity management involves some different considerations to water quality.

The first important difference between water quantity and quality is that many activities that take water require consents whereas the major pressure on water quality is diffuse discharges associated with the use of land, which are typically not regulated (i.e. subject to resource consents). Managing water quantity is therefore associated with consents to a greater extent than managing water quality. Significant water take activities have consents and are subject to conditions (e.g. the allowable rate or volume of the take and minimum flows). There are also permitted uses of water allowed under the current Northland water plan, including water takes for stock drinking and reasonable domestic use[23]. The amounts of water taken under

[23] Under the current plan, water takes for stock drinking and reasonable domestic use are permitted, as are takes of less than 30m^3 per day and 10m^3 per day in summer and winter respectively.

these permitted uses are able to be broadly estimated and combined with consented water. This means that estimates of the potential current state, with respect to flow, can be made at all locations in a catchment. This estimate does not represent the actual state because it is based on the potential take and it does not consider whether the allowable take (consented plus permitted) takes are actually occurring. The current total allocation is an important indicator of state with respect to water quantity and this can be assessed by summing all takes located upstream of any particular point in the river network.

Water quantity objectives are analogous to water quality objectives but there are no accepted national guidelines or NPS-FM attributes associated with water quantity. However, the trade-offs between environmental values and water resource use can be specifically evaluated and used to inform decisions about water quantity objectives. Broadly, surface water quantity (i.e. river flow) is managed through the application of two resource use limits; minimum flows and a total allocation (see Snelder *et al.* 2013 for details). The minimum flows and total allocation are imposed to achieve objectives that reflect both environmental protection and resource use objectives. These objectives can be thought of as defining a maximum level of habitat[24] loss, a maximum and a minimum level of reliability. Moreover, habitat and reliability of supply can be considered attributes with respect to instream values and consumptive water takes, respectively.

The details of how the water quantity objectives and their associated limits are defined are complicated and are discussed in detail by Franklin *et al.* (2013). Some key principles that are important to the definition of water quantity management objectives include:

1. The relationship between habitat and flow.
2. The critical value.
3. The reliability of takes.
4. The flow regime and the allocation rate.

The state of hydraulic parameters (width, depth and velocity) determine the suitability of the stream or river to an instream value (e.g. aquatic species such as fish). Flow management decisions are most commonly concerned with maintaining ecosystem values and focus on ecosystem components that have the highest flow requirements, which are generally fish species. Therefore it is the suitability of the hydraulic habitat (width, depth and velocity) for fish that is most often the basis for water quantity management objectives.

Generally the suitability of hydraulic habitat for fish is highest at some intermediate flow and decreases as flow either increase (e.g. velocities become too high) or decrease (e.g. depth, width and velocity become too low). The shapes of these relationships vary for different fish species. Abstractions reduce flows in rivers and decrease the available hydraulic habitat during natural periods of low flow (generally during summer). Setting a minimum flow is therefore concerned with choosing a point at which any further reduction in the natural suitability of the river due to abstraction is unacceptable.

The rate of reduction in hydraulic habitat suitability caused by flow modification varies by fish species. For example, at a site, suitability for large fishes, such as trout, generally reduces

[24] The habitat referred to here is the aspect of habitat that is directly related to the flow rate and comprises river width, velocity and depth. These are referred to as hydraulic habitat. Objectives for habitat can be defined in terms of instantaneous minima and also maximum durations of stable minimum flows to limit “flat-lining” (i.e. where river flow is held for an extended period at a steady low flow).

more quickly than for smaller fishes that tolerate shallower and slower moving water. The choice of fish species (or more generally the "instream value") for setting the minimum flow is therefore important as the level of protection differs between species at any specific flow.

There is generally a mix of fish species in a river. Flow setting processes tend to define a "critical value", which is a species that is a) considered important or significant for some reason at a location and b) is sensitive to flow reductions. The assumption is that if the minimum flow is set to maintain the hydraulic habitat for the critical value at a specific level (i.e. the objective) then other less critical values such as other fish species, invertebrates and aquatic plants will also be maintained to at least this level.

When a river's flow reduces to the specified minimum, water takes must be restricted so that flow is not artificially reduced below the minimum flow. A distribution of river flows, as shown by a flow duration curve (FDC), indicates the frequency that flows are below any specified minimum flow. The position of the minimum flow on the FDC is a measure of the reliability of the river as a water supply for abstractors. Setting a minimum flow is therefore concerned with assessing the trade-off between maintaining a minimum amount of habitat with the reliability of the water supply for the abstractor.

In theory, reductions in the abstraction of water need to commence when the river's natural flow equals the minimum flow plus the allocation rate. This flow is referred to as the 'management flow' and its frequency is also shown on a FDC. The frequency of the management flow is a second measure of reliability of supply, which indicates the proportion of time that the allocation must be restricted (or conversely, the proportion of time that the full allocation is not available for abstraction). The setting of the allocation limit therefore is a trade-off between the total take (i.e. how much water is allocated) and the reliability. The exact values of the two measures of reliability depends on the distribution of flows, which is often referred to as the flow regime and is broadly indicated by the shape of the FDC.

A large regional study of alternative water quantity objectives for the Northland region was undertaken by Franklin *et al.* (2013). This study provides detailed information on the trade-offs between habitat and reliability of supply and a basis for setting objectives and associated minimum flows and allocation limits that would achieve these. The study defined minimum flows and allocation limits in terms of the Mean Annual 7-day Low Flow (MALF).

The MALF[25] is often used for setting water quality limits because it is a measure of water availability during periods of relative scarcity. Scaling flow by MALF standardises the allocation and minimum flow by the size of the river. This allows rivers to be grouped irrespective of the size of the natural river flow (which is broadly a function of catchment area) and for generalised limits to be derived. Expressing hydraulic habitat at any given flow as a proportion of the habitat available at MALF has a similar benefit.

Flows less than MALF generally occur on average once in every two years. Thus, setting minimum flows to produce habitat that is somewhat less than that available at MALF should mean that habitat for aquatic species such as fish is maintained at levels that are not too reduced from the natural flow regime. The underlying assumption is that rivers and their instream values are robust to some degree of reduction in flow and/or that some limited level of impact is an acceptable trade-off for the utility gained from use of the water.

[25] MALF is frequently used as an index for setting total allocations. For example, the proposed National Environmental Standard for Flows and Levels (NES; MFE 2008) suggests default allocation limits of 30% and 50% of MALF for small and large streams respectively (and where the threshold for stream size is defined by a mean flow of 5 m^3/s).

The present study has used the results of the study by Franklin *et al.* (2013) to suggest possible water quantity management objectives and associated limits. The classification of Northland's rivers for water quantity management purposes that was suggested by Franklin *et al.* (2013) has also been adopted and modified by this study to provide a for water quantity management classification.

4.2 Water quantity management classification

Franklin *et al.* (2013) grouped Northland's rivers into three classes based on river size and climate: Large rivers (mean flow >20 m^3/s), Warm Extremely Wet rivers (based on the REC Climate class WX) and all other "Small" rivers. Franklin *et al.* (2013) showed that these three classes have broad differences in their flow regimes and the response of hydraulic habitat and reliability of supply to changes in flow. The Large class was more reliable and has less reduction in habitat for the same (relative) minimum flow and allocation than the Small class. The WX class had the lowest utility as a water resource, largely because these rivers are situated in steep locations for which hydraulic habitat tends to reduce quickly with reduction of flow.

Franklin (2015) suggested a further class is added called "Coastal" rivers, which comprises small rivers (mean flow < 0.75 m^3/s) and close to the coast (< 10km). This class was identified by a study on the risk of deleterious effects of water abstraction on stream habitat in the Northland region by Franklin (2011). Franklin (2011) identified that loss of hydraulic habitat with reduction in flow occurs at a high rate in small streams and several sensitive species (to loss of habitat with flow) have their highest probability of occurrence close to the coast. Subsequent analysis of the results of Franklin *et al.* (2013) by Franklin (2015) did not indicate that the Coastal class is significantly different to the Small class in terms of loss of habitat with flow or utility as water resources. However, Franklin (2015) suggested that the Coastal class adds additional discrimination of the values of interest (coastal river with high fish diversity). A map of this proposed water quantity management classification is shown in Figure 9.

4.1 Example water quantity objectives and limits

This section provides example water quantity objectives and associated limits for the four classes based on previous work by Franklin *et al.* (2013) and updates by Franklin (2015). Franklin *et al.* (2013) used the Environmental Flow Strategic Assessment Platform (EFSAP) tool to derive objectives for hydraulic habitat retention and reliability of supply and the associated minimum flow and allocation limits for the proposed management classes. Note that the coastal class was not explicitly considered by Franklin et al (2013) and but was assessed by Franklin (2015).

The Longfin eel species has been adopted as the critical species for the Large, Small and Warm Extremely Wet (WX) river classes because of its conservation and cultural status. The Longfin eel is a widely distributed species with relatively high flow requirements compared to other native species, although lower than trout (see Table 3-2, Franklin et al., 2013). Banded Kokopu has been used for the Coastal class based on its sensitivity to flow reductions in small streams and prevalence in coastal Northland streams. It is assumed that the objective for habitat in the Small, Warm Wet and Coastal river classes are a median reduction (over all segments in the class) of less than 10% of the habitat for the critical species compared to available habitat at MALF.

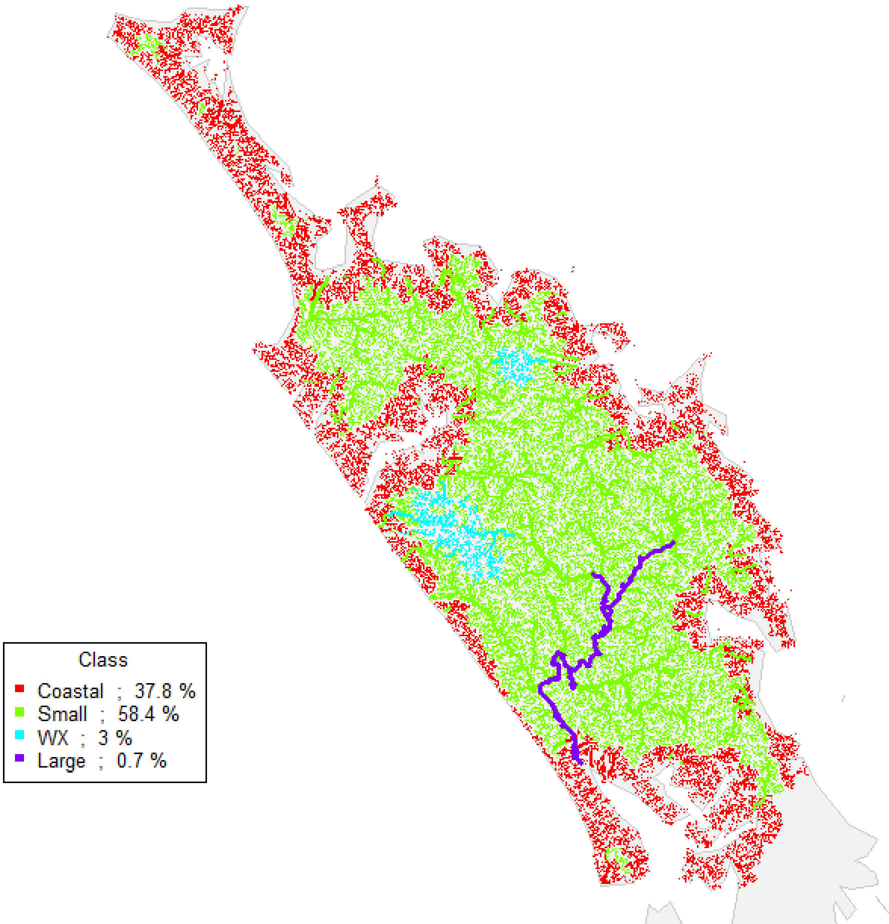

Figure 9. Proposed water quantity management classes.

The limits (i.e. the minimum flows and allocations) that will ensure the example objectives are met in the four water quantity management classes are provided by Franklin (2015) and are summarised in Table 3. Two sets of example objectives and associated limits are shown in Table 3 for each class, which represent different levels of protection. The two objectives are based on achieving the stated outcome in at least 50% or 75% of the segments in the respective classes. Franklin (2015) provided a basis for setting more or less environmentally conservative limits by indicating the limits that would achieve the objectives in at least 10%, 50%, 75% or 90% of the segments. Any other percentile could be assessed from the results of Franklin's (2015) analysis. It is also noted that the analysis undertaken by this study is for the purpose of demonstrating the approach to defining FMUs. Different objectives, including different critical species could be derived and it is probably appropriate to consider these further based on the analysis provided by the Franklin (2015).

Franklin (2015) predicted habitat to increase with reduction in flow in the large river class for flows as low as 30% of MALF. This is a common result in Large rivers and reflects their inherently greater resource use capacity. Therefore, the example objectives for the Large river class is no reduction in habitat (for either 50% or 75% of segments in the class) of the habitat for the critical species that is available at MALF. It is noted that the objective of no reduction of habitat in 75% to the Large river class cannot be achieved at the same time as meeting the reliability objectives. For the other river classes the example habitat objectives are to restrict the reduction in habitat to 10% for Coastal and Small rivers and 20% for the Warm Wet rivers respectively. The example objectives for reliability are uniform for all classes and are set not less than 95% at the minimum flow and at least 90% at the management flow. These are reasonably conservative water quantity objectives.

Table 3. Example objectives for habitat retention and reliability of supply for the four water quantity management classes and the limits (minimum flows and allocations) that will ensure these objectives are achieved. The limits have been derived from analysis using EFSAP by Franklin (2015) and reflect the largest allocation and (then) highest minimum flow that satisfies both objectives. The NA values indicate that the objectives cannot be satisfied.

Water quantity management class	Objectives			Limits	
	Habitat reduction (% habitat available at MALF)	**Reliability at minimum flow (% time).**	**Reliability at management flow (% time)**	**Minimum flow (proportion of MALF)**	**Allocation rates (proportion of MALF)**
Coastal Rivers	Habitat reduction < 10% for Banded Kokopu @ 50% segments	95%@ 50% segments	90%@ 50% segments	0.9	0.6
	Ditto @ 75% segments	95%@ 75% segments	90%@ 75% segments	0.7	0.1
Large Rivers	Habitat reduction = 0% for Longfin eel. @ 50% segments	95%@ 50% segments	90%@ 50% segments	0.3	0.9
	Habitat reduction = 0% for Longfin eel. @ 75% segments	95%@ 75% segments	90%@ 75% segments	NA	NA
Small Rivers	Habitat reduction < 10% for Longfin eel @ 50% segments	95%@ 50% segments	90%@ 50% segments	0.90	0.5
	Habitat reduction < 10% for Longfin eel @ 75% segments	95%@ 75% segments	90%@ 75% segments	0.7	0.2
WX Rivers	Habitat reduction < 20% for Longfin eel @ 50% segments	95%@ 50% segments	90%@ 50% segments	0.9	0.1
	Habitat reduction < 20% for Longfin eel @ 75% segments	95%@ 75% segments	90%@ 75% segments	NA	NA

4.2 Current state

An analysis of water quantity state has been carried out by comparing current levels of allocation in each of the water quantity management classes to the allocation limits proposed in the previous section (Table 3). Minimum flows were not included in this analysis but is an aspect that needs to be assessed.

Surface water take data including the location and the daily mean rate of surface water takes and an assessed reduction in streamflow attributable to ground water takes were obtained from NRC for this analysis. A total of 359 takes (including 37 points at which stream flow reductions caused by ground water takes) occur in a distributed manner over the region's drainage network (*Figure 10*). Note that more than one individual take occurs in some segments but the water takes are aggregated by segment on the map shown in *Figure 10*.

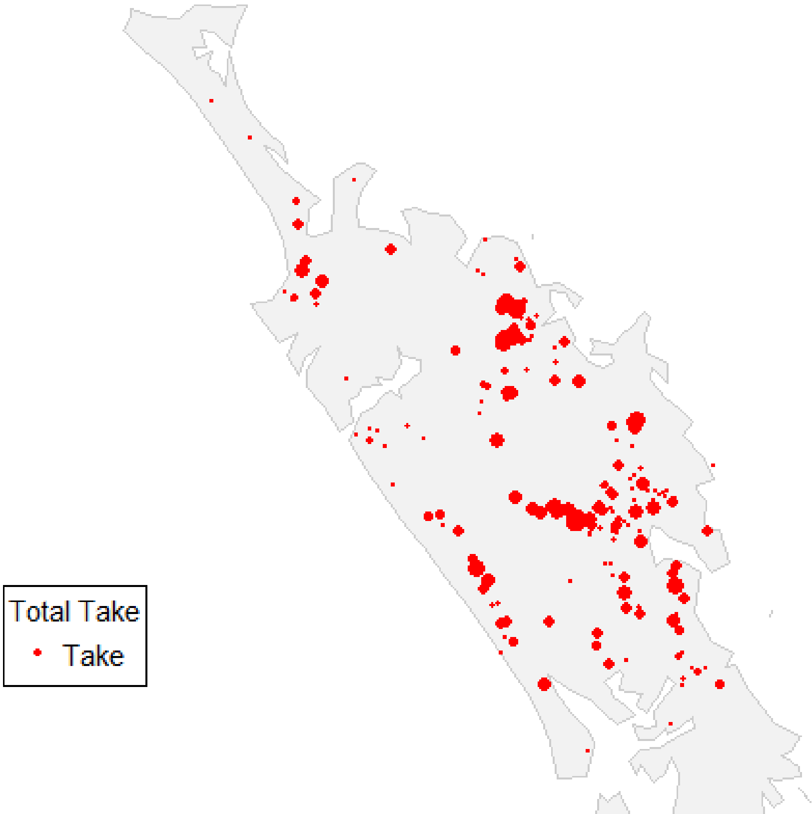

Figure 10. Location of consented surface water takes and estimated streamflow reduction due to groundwater takes in the Northland Region. The take points shown as red dots have been scaled by the relative size of the take based on a log scale. Therefore large dots indicate takes that are much larger than small dots.

The effect of a take at a point in the drainage network is to reduce flows in all downstream segments. Therefore a more appropriate way to express the takes for an assessment of current state is as a map of the drainage network with each segment being coded to represent the total take at that point, including the take occurring in that network segment and in all upstream segments. The accumulated surface water mean daily take is shown on *Figure 11*. In this analysis the total take is divided by the MALF estimated by Booker *et al.* (2012) so that they can be compared to the proposed limits shown in Table 3. *Figure 11* indicates that allocation is low or zero in the majority of segments in the region but that it can be high (i.e. > MALF) in some locations.

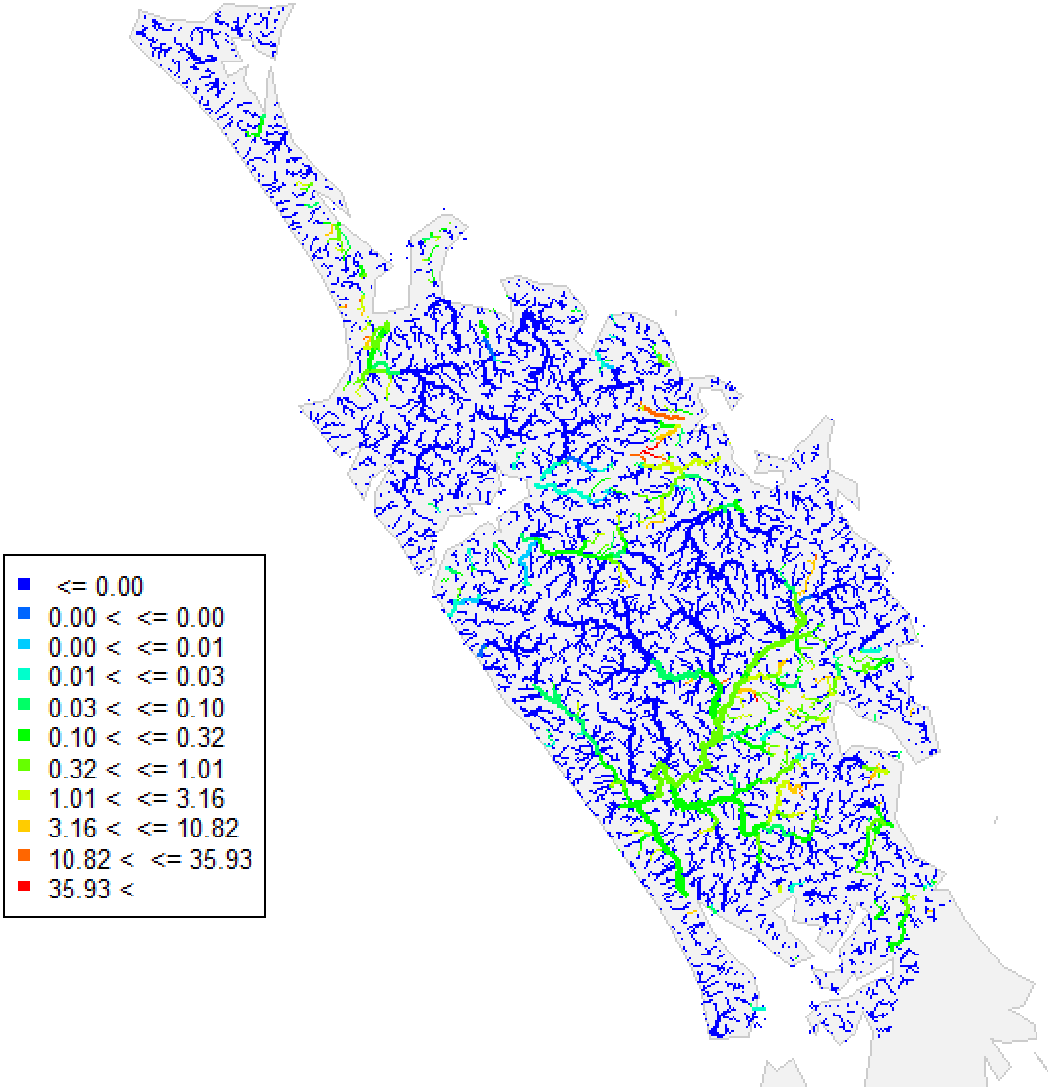

Figure 11. Map of the drainage network with each segment coded to represent the total allocation at that point, including the take occurring in that segment and in all upstream segments. The water takes are divided by MALF estimates derived from Snelder and Booker (2013).

An analysis of the current water quantity state (based on total allocation) for the for water quantity management classes is shown in Table 4. The table shows the proportion of segments in each class that have total allocation exceeding the limits shown in Table 3.

Table 4. Water quantity state in the four water quantity objectives classes. The table shows the percentage of segments for which the total upstream allocation exceeds the limits shown in Table 3 based on the example objectives (applying to 50% of segments) and associated allocation limits (Table 3).

Total upstream allocation	**Coastal**	**Large**	**Small**	**Warm Extremely Wet**
Over-allocated	1.5%	0%	3.2%	0%

The water bodies (i.e. segments) for which total allocation exceeds the limits (i.e. that are "over-allocated") are mapped in *Figure 12*. The over-allocated catchments are defined as the catchment areas upstream of these water bodies (*Figure 13*). The map indicates that approximately 19% of the catchment area in the region is over-allocated. Areas include parts of the Awanui River catchment in the Far North, the Waitangi and Kerikeri catchments in the Bay of Islands, parts of the Whangarei Harbour catchment, including the Otaika River and lower Hatea River sub-catchments, and the Ruakaka River catchment for example. The benefit of a network, rather than sea-draining catchment approach can be seen in *Figure 13*. The map indicates that small tributaries in some locations are over-allocated, whereas the larger sea-draining catchments they are part of are not over-allocated. If a sea-draining catchment approach was taken, this localised over-allocation would not be incorporated. Another benefit of the drainage network approach is that the degree of over-allocation is shown at a high level of detail. For example, although the entire Waitangi River is assessed as over-allocated, some parts of this catchment are significantly more over-allocated than the catchment as a whole. The map shown on *Figure 11* indicates that the degree of over-allocation is highest in the mid catchment area of the Waitangi River catchment.

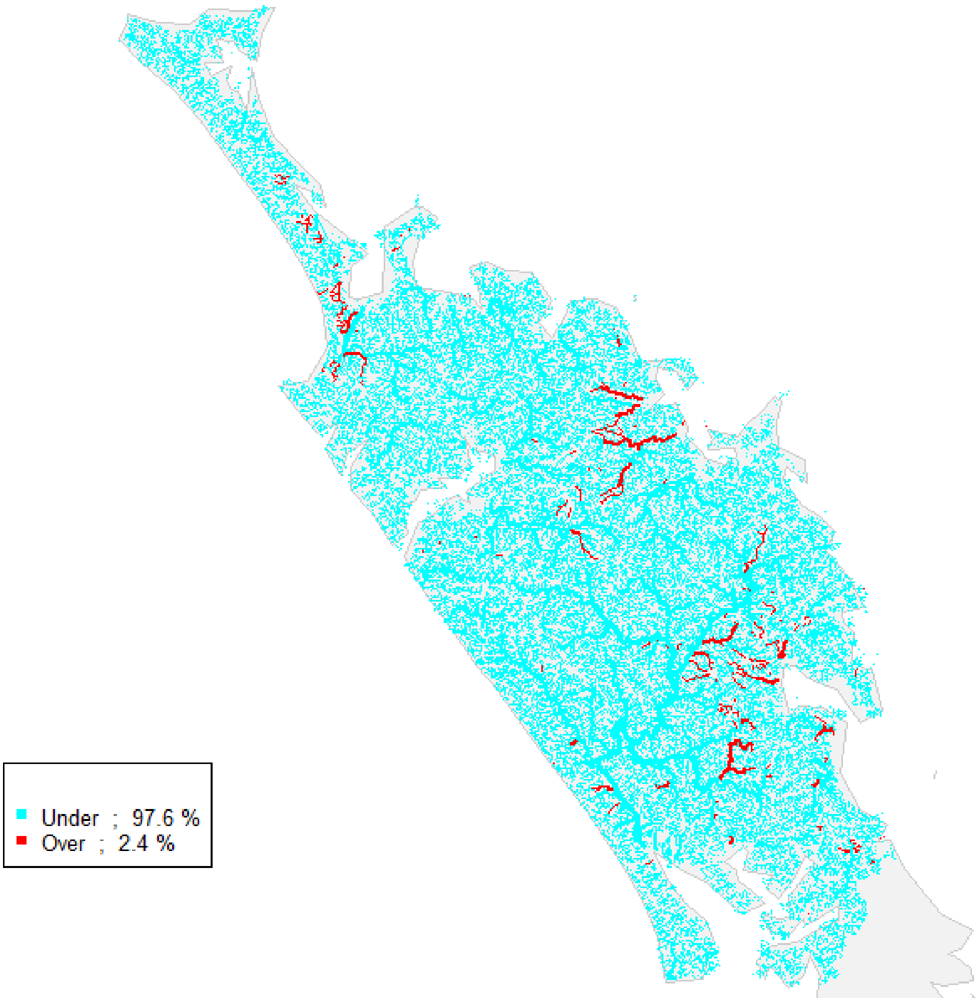

Figure 12. Map showing water bodies (i.e. network segments) that are over-allocated (i.e. for which the total allocation exceeds that defined in Table 3). The red coded segments have total allocation exceeding the limits derived to meet the objectives (see Table 3).

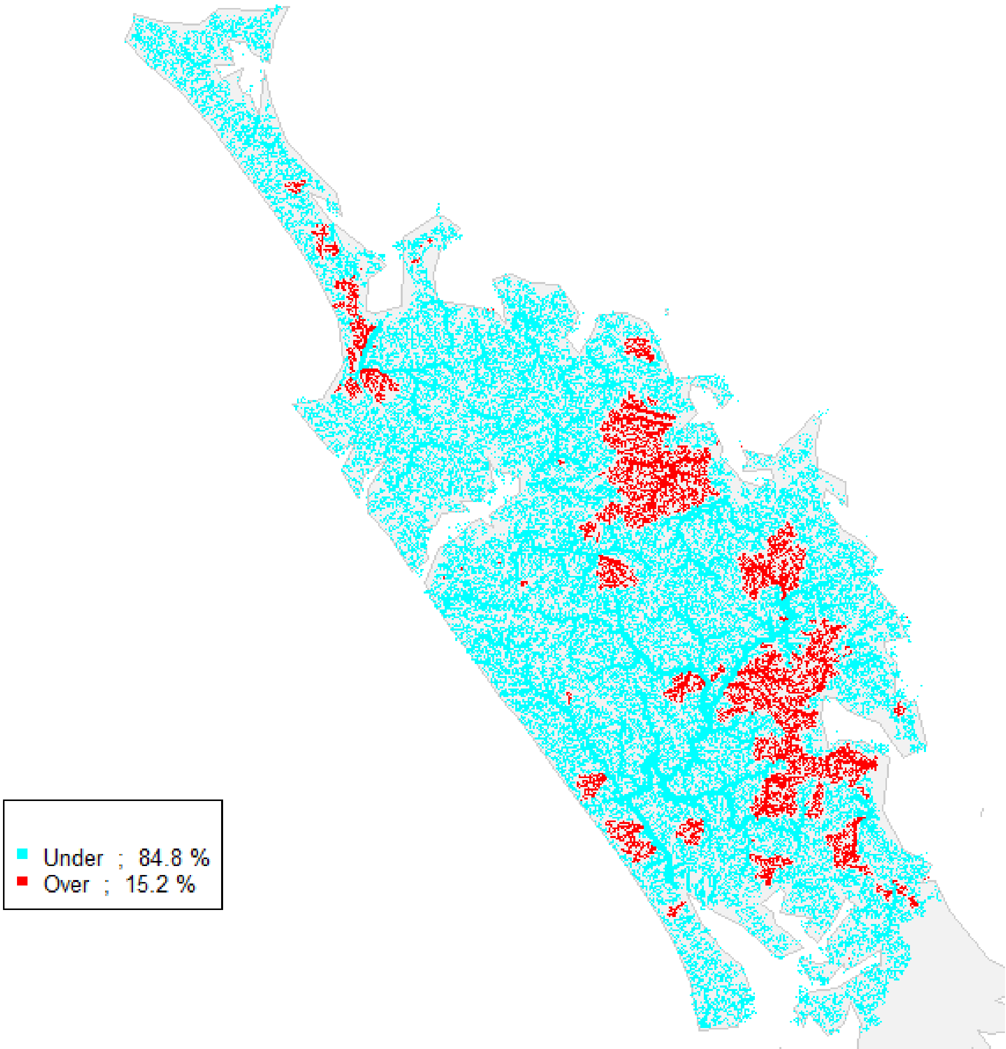

Figure 13. Over-allocated catchments (based on the objectives shown in Table 3) and the over-allocated segments shown in Figure 12.

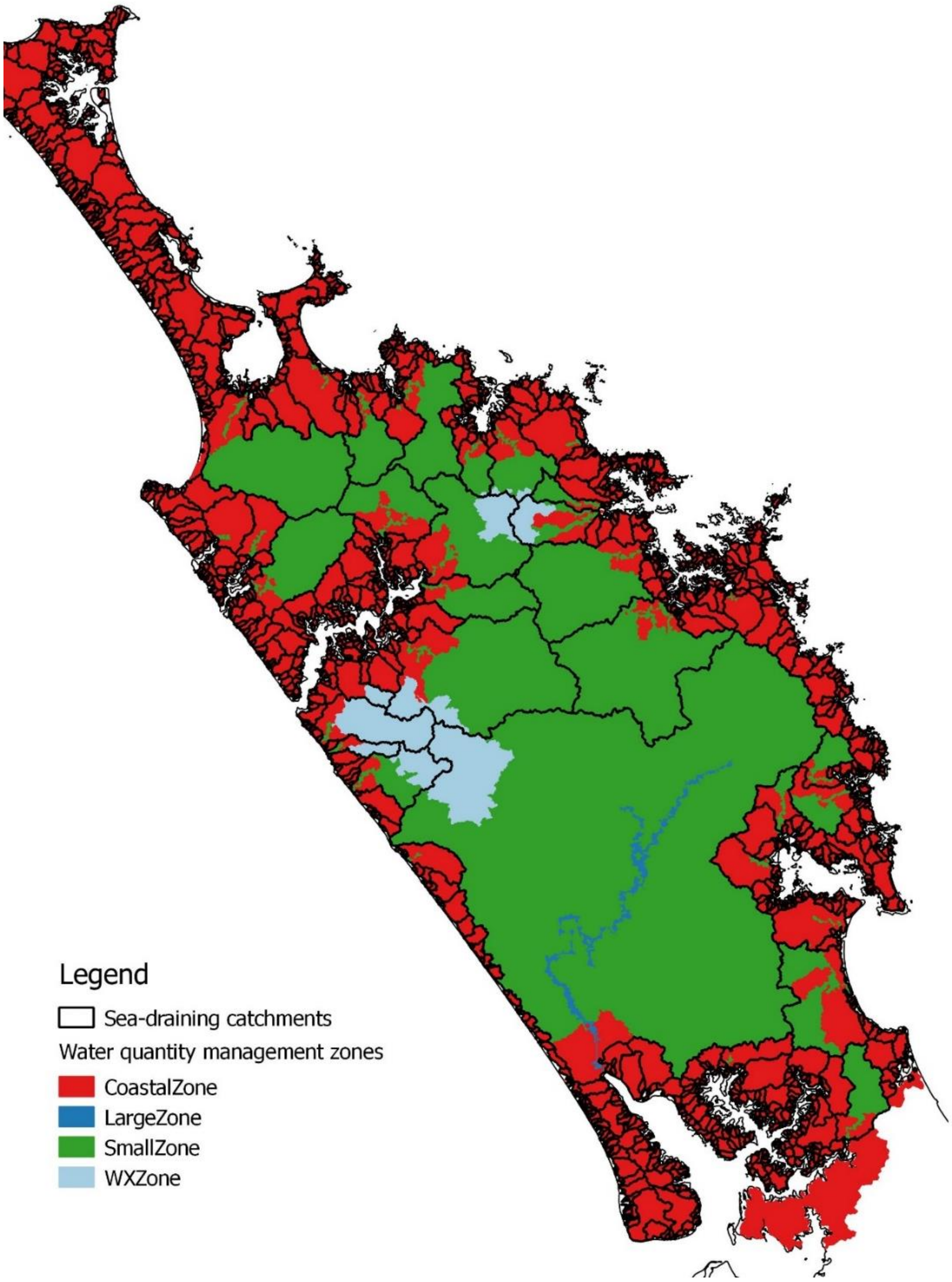

Figure 14. Water quantity management zones.

4.3 Water quantity administrative points

The points on the network where the management zones change are locations where the water quantity objectives and limits change. These points are therefore a minimum set of locations where volumetric allocation limits need to apply and resource use accounting would need to occur[26]. The evaluation of the relevant limits and current allocation is especially relevant in any assessment process related to a consent that is located in the catchment

[26] The NPS-FM defines a "freshwater quantity accounting system" to mean "a system that, for each freshwater management unit, records, aggregates and keeps regularly updated, information on the measured, modelled or estimated:

a) Total freshwater take;
b) Proportion of freshwater taken by each major category of use; and
c) Where limits have been set, proportion of the limit that has been taken.

upstream of an administrative point. These points define a minimum set of administrative points for the management of water quantity in the region and are indicated by the black dots in Figure 15.

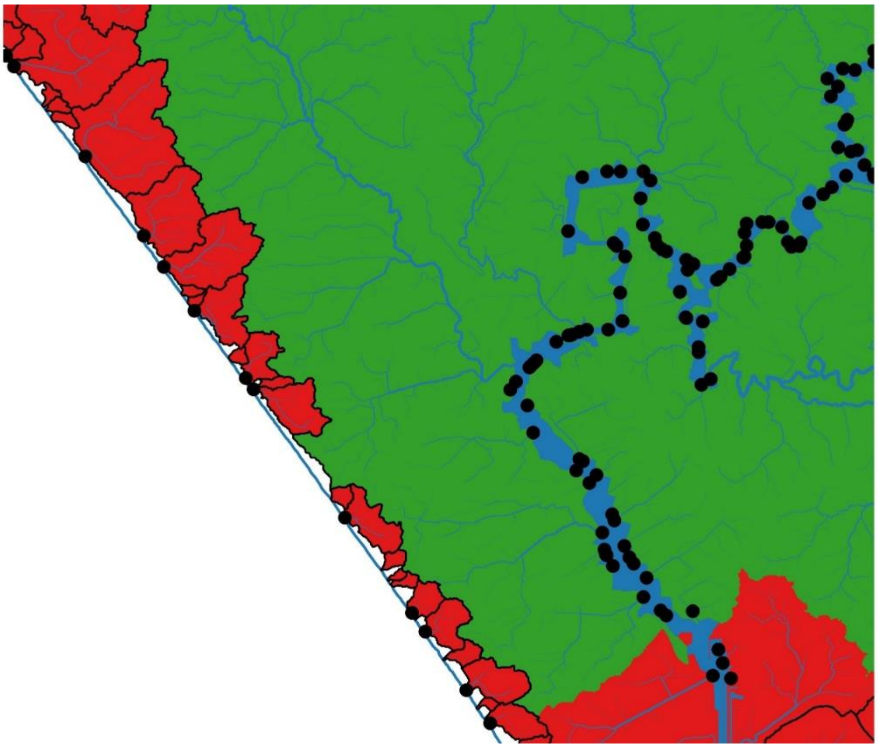

Figure 15. Zoomed in view of the proposed water quantity management zones. The blue lines represent the drainage network and the black lines are the boundaries of the sea-draining catchments. The green zones represent areas that drain to segments in the Small class of the water quantity classification and the red zones represent areas that drain to segments belonging to the Coastal class. The Wairoa main stem belongs to the Large water quantity class. The black dots represent administrative points (where the management zone changes) and where the limits can be defined in volumetric terms (i.e. as flow rates) and resource use accounting should occur.

4.4 How the FMUs might be applied for water quantity

The analysis carried out by this study indicates that some water bodies are over-allocated, relative to the proposed limits. Water bodies that are over-allocated are **potentially** not meeting their environmental or reliability objectives. However it is important to note that whether or not objectives are actually being compromised in these water bodies largely depends on the extent to which the consented allocation is being exercised (and over what time periods the takes occur), the minimum flows and whether restrictions are enforced and observed.

The plan needs to address over-allocation but the response needs to be informed by the extent to which the objectives are being compromised and this probably requires further investigation. For this reason, it is not suggested that highly allocated catchments within these water quantity management classes warrant a standalone FMU status. Rather, a potential default policy could be to allow no further allocation from over-allocated catchments *unless* it can be shown that objectives could continue to be met. The default policy for under allocated water bodies could be to allow further allocation, subject to the objectives and default limits set by the plan (e.g., Table 3).

The relevant locations for defining volumetric limits and accounting for allocation are the administrative points (Figure 15). The default limits set by the plan (e.g., Table 3) are expressed as proportion of MALF and can be converted to volumetric limits or rates at the administrative points by estimating MALF at these locations. MALF can be estimated in a variety of ways including from regionalisations or more detailed analysis of nearby hydrological gauging station data. The administrative points that do not lie within over-allocated catchments could be considered locations for which water is available subject to existing upstream and downstream allocation and the limits set out in Table 3. Resource use could be enabled at these points by consenting based on the limits set out in Table 3. The administrative points that are nested within a larger over-allocated catchment (shown in Figure 13*)* could be considered as locations where further water is unavailable or is only available if it can be shown the objectives can be met (i.e. based on a more rigorous assessment).

The plan could use a tiered system of discretion in consenting water takes to enable resource use in an efficient manner where risks are low but to increase the rigour involved when limits are being reached. Essentially the consenting process needs to demonstrate that a new take will not prevent the objectives from being achieved. Limits derived using generalised model approaches such EFSAP and shown in Table 3 are broadly accurate but are subject to larger uncertainties at the site scale than more detailed analyses.

Assessments of new takes in situations where the current and proposed allocation is "small" relative to limits could be considered as low risk. In these situations limits such as those shown in Table 3, which are based on the EFSAP tool, could be used. Applications for water takes in situations where the current and new takes are large, relative to limits, however would need to be supported by more detailed analyses. Detailed assessments are commonly used to support water quantity management decisions are based on site scale hydraulic habitat models such as RYHABSIM coupled with analysis of relevant hydrological data. These assessments provide the most accurate analysis of the effect of a proposed take relative to objectives but they are expensive and time consuming and may not be justified for small takes.

5 Discussion

This project has developed FMUs to provide a basis for default objectives and policies for the new region-wide Northland water plan. A key finding of this project is that for region-wide plans at least, appropriate FMUs need to be a framework of spatial units rather than a simple single subdivision of the region. There are several reasons that a framework of spatial units is likely to be necessary. These include the need for plans to manage different issues (e.g. water quality versus water quantity) and to provide a basis for different management functions (e.g. setting objectives versus accounting for resource use and consenting water takes).

A key point is that the scale of an FMU must be commensurate with the purpose (i.e. objective) for which a water body, multiple water bodies, or a part of a water body needs to be managed. For example, entire sea-draining catchments are an appropriate scale for managing the cumulative effects of diffuse and point source discharges on coastal water bodies (estuaries and harbours). However, there may be important variation in the values and current state of freshwater bodies within the catchment. This means that many sea-draining catchments need to be subdivided into smaller units to provide sufficient resolution of these differences within the catchment.

The proposed FMUs for the Northland region-wide plan are comprised of three components: (1) the water body, multiple water bodies or any part of a water body that is designated to be managed for a particular purpose (objective), this is termed the “river classification” in this report, and (2) the associated land area (catchment or sub-catchment) that drains to a river class, termed the “management zone”, and (3) the points in the network where the management zone changes, which are administrative points. It is important to note that an administrate point can be determined for any point on a river but that is suggested a minimum set are defined as described here.

It is proposed that water quality and quantity FMUs are based on simple two and four-class classifications respectively. These FMUs broadly discriminate variation in the characteristics of the water bodies that are relevant to management including their values, current state and capacity for resource use. The FMUs also identify the associated land areas that drain to the classes. Management zones are defined so that management actions and limits that apply to them provide for the achievement of the most restrictive downstream objective.

Some water bodies have specific values or management issues that are not discriminated by the management classifications but which may need to be provided for by region-wide plan. These water bodies can be associated with special FMUs that over-ride the objectives set for the management classes. Examples of water bodies requiring separate management objectives may be sites of significance (e.g. swimming spots, or sites of special cultural or ecological significance). Water bodies requiring special objectives and the catchments upstream of these water bodies would be special FMUs for which specific plan provisions (objectives and policies) would apply.

The resolution of the proposed approach could be increased by increasing the number of classes in the management classifications. However, the differences between classes in values, current state and other characteristics of relevance will become less distinct as the number of classes increases. It will therefore be difficult to justify variation in the objectives, policies and limits if there is a large number of classes.

The coarse level of classification and subsequent discrimination of characteristics is consistent with the requirements of a broad regional approach to management that requires trading off detail (precision) with coverage and simplicity. This regional and coarse scaled approach is most likely to be acceptable if it is clear that more detailed assessments of state can be carried out in specific catchments that may be perceived to have issues. In these cases more precise, spatially variable and nuanced objectives and policies may supersede the default provisions defined in the region-wide plan.

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References

ANZECC (2000). Australian and New Zealand guidelines for fresh and marine water quality." Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra. 103 p.

Ballinger, J.; Nicholson, C.; Jean-Charles Perquin, J-C.; Simpson, E. (2014). River water quality and ecology in Northland: State and trends 2007-2011. Northland Regional Council Report.

Booker, D.J., Woods, R.A. Franklin, P., (2012) Hydrological estimates for Northland. NIWA Client report prepared for Northland Regional Council, June 2012, pp47.

Booth, K., Ballinger, J., Glover, N., Greer, L., Jones, D., Lewis, G., Mussle, R., Paraone, T., (2013). River Swimming in Northland: Application of the River Values Assessment System (RiVAS and RiVAS+) LEaP Research Paper No. 22. 49p.

Franklin (2015). Addendum to Franklin et al. (2013).

Franklin, P., Booker, D., Diettrich J. (2013) Options for default minimum flows and allocation limits in Northland. NIWA Client Report No. HAM2013-036. 86 p.

Franklin P.A. (2011) Identifying the degree of hydrological alteration for ecological flow assessment in Northland Streams. NIWA Client Report No. HAM2010-127. 19 p.

Matheson, F.; Quinn, J.; Hickey, C. (2012). 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 HAM2012-081 prepared for the Ministry of Science & Innovation Envirolink Fund.

MFE 2008. Proposed National Environmental Standard on ecological flows and water levels: Discussion document. Wellington, New Zealand Ministry for the Environment. Wellington.

Snelder, T.H.; Biggs. B.J.F. (2002). Multi-scale river environment classification for water resources management. Journal of the American Water Resources Association. 38(5): 1225-1240.

Snelder, T. H., Rouse, H. L., Franklin, P. A., Booker, D. J., Norton, N. Diettrich, J. (2013): The role of science in setting water resource use limits: a case study from New Zealand, Hydrological Sciences Journal, DOI:10.1080/02626667.2013.793799.

Snelder, T., Fraser, C., Hodson, R., Ward, N., Rissman, C. & Hicks, A. (2014). Regional scale stratification of Southland's water quality – guidance for water and land management. Southland Regional Council.

Snelder, T. H., & J Booker, D. (2012). Natural flow regime classifications are sensitive to definition procedures. River Research and Applications. 29(7), 822-838.

Stark JD, Maxted JR 2007a. A biotic index for New Zealand's soft-bottomed streams. New Zealand Journal of Marine and Freshwater Research 41(1): 43-61.

Stark JD 2014. Macroinvertebrate biotic indices for the Northland region. Prepared for Northland Regional Council. Stark Environmental Report No. 2014-08. 33p.

Unwin, M., Snelder, T., Booker, D., Ballantine, D., Lessard, J. (2010). Predicting water quality in New Zealand rivers from catchment-scale physical, hydrological and land use descriptors using random forest models. Ministry for the Environment.

A1 Analysis of river water quality

A1.1 Data acquisition

As of the end of 2013, NRC had carried out state-of-environment monitoring at 31 river sites for periods of between 6 and 18 years. A variety of physical, chemical and biological indicators of water quality are measured at these sites. In addition, water quality and biological monitoring had been carried out by NIWA since 1989 at the 4 river sites in the Northland region as part of the National River Water Quality Network (NRWQN).

River water-quality monitoring data have been acquired from regional councils and NIWA for national studies by Ballantine *et al.* (2010) and Unwin and Larned (2013). These studies had assembled all available data from Northland since the beginning of systematic river water quality monitoring until the end of 2012 into a customised MS-Access database. Since 2014, regional council river water quality monitoring data for the period 2004 to 2013 (inclusive) have been federated into the Land Air Water Aotearoa (LAWA) database. The LAWA data was used to update the MS-Access database so that it contained all Northland monitoring sites up to the end of 2013.

When data was imported into the MS-Access database some data grooming was undertaken to ensure they were as correct and consistent as possible. Time-series plots and other diagnostics were used to identify and correct errors. Common errors included mislabelled site-names, georeferencing errors, and data transcription errors and incorrect units (e.g., mg/L instead of µg/L). Data flags were included to identify censored data (see Unwin and Larned (2013) for details).

In addition to water quality data, sites were associated with meta data such as: site name, location and identifier, NZMS260 grid reference, NZReach number (as defined in the River Environment Classification (REC) geodatabase).

Measured or modelled flow measurements need to be paired with each river water quality measurement because many water quality variables are subject to either dilution (decreasing concentration with increasing flow, e.g., conductivity) or concentration (increasing concentration with increasing flow, e.g., total phosphorus). Flow data is therefore required to flow-adjust concentrations before trend analysis, (i.e. to remove the effects of variation in stream flow). For most sites and sampling occasions, the available water quality data was paired with observed flows at a close flow monitoring station. For some sites and samples, synthetic flows were provided using a national hydrological model (TopNet).

A1.2 Water quality variables

River water quality in the Northland region is routinely monitored using eight variables, which correspond to physical, chemical and microbiological conditions (Table 1). In this report, the term “river water quality” is used to refer to some or all of these eight variables. No distinction is made between data collected at NRC’s sites and the NRWQN sites. All sites are referred to as the “river monitoring network” (Figure 1). Data corresponding to the physical, chemical and microbiological variables came from monthly or quarterly samples with the exception of the macro-invertebrate data which collected annually.

Table 5. River water quality variables included in this study.

Variable type	Variable	Abbreviation	Units
Physical	Clarity	CLAR	m
Chemical	Ammoniacal nitrogen	NH4N	mg/m^3
	Nitrate nitrogen	NO3N	mg/m^3
	Total nitrogen	TN	mg/m^3
	Dissolved reactive phosphorus	DRP	mg/m^3
	Total phosphorus	TP	mg/m^3
Biological	Macro-invertebrate index	MCI	
Microbiological	*Escherichia coli*	ECOLI	n/100 mL

Visual water clarity (CLAR) is a measure of light attenuation due to absorption and scattering by dissolved and particulate material in the water column. Clarity affects primary production, plant distributions, animal behaviour, aesthetic quality and recreational values. It is also correlated with suspended solids, which can impede feeding in fish and cause riverbed sedimentation.

The five nutrient species (NO3N, NH4N, DRP, TN and TP) influence the growth of benthic river algae (periphyton), aquatic plants (macrophytes), and phytoplankton. Nutrient enrichment from point and non-point source discharges is strongly associated with intensive land use. Nutrient enrichment can promote excessive, 'nuisance' growth of periphyton and macrophytes that can, in turn, degrade river habitat, increase daily fluctuations in dissolved oxygen and pH, impede flows, block water intakes, and cause water colour and odour problems. At high concentrations, two species (NO3N, NH4N) are toxic to aquatic organisms.

The concentration of the bacterium *Escherichia coli* (ECOLI) is used as an indicator of human or animal faecal contamination and the risk of infectious human disease from waterborne pathogens in contact-recreation and drinking water.

Benthic macro-invertebrates are small animals without backbones that live on or just below the stream-bed. The Macro-invertebrate index (MCI) is based on the tolerance or sensitivity to organic pollution and nutrient enrichment of different type of benthic macro-invertebrates. For example, mayflies, stoneflies and caddis flies are sensitive to pollution, and are only abundant in clean and healthy streams, whereas worms and snails are more tolerant and can be found in polluted streams. MCI values typically range between 50 at extremely polluted or sandy/muddy sites and 150 at sites with high water quality.

A1.3 Assessment of water quality state at the monitoring sites

The current water quality state at each river site was characterised by the median of the measured values over the period of record from 2009 to 2013 (inclusive). These median was calculated using the Hazen method (MFE).The period of five years represented a reasonable trade-off between sample size and resistance to the effects of trends. Monthly sampling, which has been the norm during the 5 year period, will yield at least 30 samples (allowing for some missing data). Three filtering rules to ensure that site median values were reliable: 1) less than 50% of the values for a variable were censored; 2) values for at least 90% of monthly or quarterly sampling dates were available, including censored values; 3) the 30 values were distributed over four of the five years period from 2009 to 2013. Site by variable combinations that did not comply with these rules were excluded from the analysis.

The current state of the invertebrate communities at each biological monitoring sites was characterised by the median, over the period of record from 2009 to 2013 (inclusive), of the annual national hard bottom MCI scores (Stark and Maxted, 2007). There were differences in the number of years of record and four sites had only one year of data in which case this MCI score was used to represent the state of the site.

A1.4 Grading of sites

The NPS-FM identifies attributes for rivers that are intended to assist regional councils in defining freshwater objectives. A key step required by the NPS-FM is to assess current state relative to these attributes. Therefore sites belonging to the water quality network were graded by comparing their observed state to targets that were generally those set by NOF.

The NPS-FM attributes include two forms of nitrogen that are toxic at high concentrations, NO3N and NH4N. The NPS-FM attributes for NO3N are based on the annual median and the annual 95th percentile concentrations, both of which were derived for all sites. For NH4N the NPS-FM attributes are based on the annual median and the annual maximum, which in this analysis was substituted with the 95th percentile. For NH4N the assessments are based on equivalent concentrations at pH 8 and temperature of 20ºC. For this analysis the relevant conversion was not made as it is very unlikely to alter the grading results. The attribute state grading for each site was based whichever was the lowest band that the median and the annual 95th percentile concentrations fell within.

Nitrogen and phosphorus are nutrients that affect instream plant growth (periphyton and macrophytes). The NPS-FM specifies an attribute based on periphyton, which requires nutrient management to prevent excessive growth but does not specify either attributes for nitrogen or phosphorus concentrations. The reason for omitting nutrient attributes is that periphyton and macrophyte growth is controlled by numerous, spatially variable factors such as flood frequency and riparian shading, in addition to nutrients. Justifiable nutrient concentration criteria are therefore spatially variable and realistically cannot be set at a national level. In addition, justifiable nutrient criteria need to account for the effects of other variables that are affected by resource use and management such as shading (riparian management) and flows (potentially abstractions and dams). Nutrient criteria are therefore highly context specific.

This study used nutrient concentration guideline values (nitrate plus nitrite nitrogen (NNN) and dissolved reactive phosphorus (DRP) that have been used in past Northland State of Environment reports (Ballinger *et al*., 2014), which were derived from ANZECC (2000). These are broadly consistent with nutrient criteria to prevent nuisance periphyton abundance suggested by Matheson *et al.* (2012) and the concentration criteria used to manage periphyton by the Horizons One Plan. The guideline for nitrogen is based on nitrate plus nitrite nitrogen (NNN). This has been represented by NO3N in this assessment as the nitrite nitrogen component is generally small. In the analysis of state that follows, a site was assumed to comply with the guidelines if at least one of the site median concentrations was compliant with the guideline values shown in Table 1. It is noted that this is a conservative assessment because sites with soft bottoms (i.e. sand or silt) do not support conspicuous periphyton biomass.

The NPS-FM *E.coli* attribute is related to objectives for the management of human health associated with secondary contact recreation and is based on median annual concentrations with a bottom-line of 1000 cfu /100 ml (as a median) (Table 6). The NPS-FM also provides bands for primary contact recreation (i.e. swimming) as guidance for communities that may want to set this as an objective. These are the same numeric criteria as for secondary contact (Table 6) but are compared to the 95th percentile concentrations. All sites have been assessed against the NPS-FM attribute for the compulsory national value (human health for recreation – secondary contact) and also against the not compulsory swimming objective. The locations at which the swimming objective applies may be altered as part of the consultative process associated with the regional plan.

Table 6. Attribute state for the E.coli attribute. Where the objective is secondary contact recreation, the criteria are compared to the median concentration. Where the objective is primary contact the criteria are compared to the 95th percentile concentrations.

Attribute Band	*E.coli* concentration (cfu /100 ml)
A	≤260
B	>260 and ≤540
C	>540 and ≤1000
D	>1000

The NPS-FM does not include attributes for visual clarity in rivers or measures of the macroinvertebrate community. The MfE (1994) guideline of 1.6m was used and compared to the median of the observations. Thus sites deemed to fail the clarity criteria have a visual clarity less than 1.6m on more than 50% of sampling occasions. This is a nominal criteria and needs further consideration as part of the regional plan process. Bands for MCI scores were defined based on Stark and Maxted (2007) and are shown in *Table 1*.

The results of the assessment are shown on Figure 16. The figure indicates that there are no sites in the water quality network that are below the bottom line for NO3N or NH4N toxicity. All but one site was graded in the A band for NO3N and the sites were evenly distributed in the A and B bands for NH4N. The majority of sites were graded in the A or B band for secondary contact recreation (median ECOLI) and only three sites in the C band with no sites below the national bottom line. However, when sites were graded for primary contact (95th percentile ECOLI), all but one site was graded D. Thus, if freshwater objectives were for contact recreation, most of the region would not be meeting this objective.

The assessment of periphyton indicated that two of the 35 sites have concentrations of both nutrients at levels that mean the sites could potentially exceed the national bottom line (Figure 16). Levels of DRP exceeded the guideline value of 10 mg/m^3 at 18 sites whereas NO_3N exceeded the guideline at only two sites. It is noted that many of the region’s rivers are dominated by soft beds, particularly those in lowland locations, and therefore the nutrient concentrations in many locations may not produce conspicuous periphyton biomass.

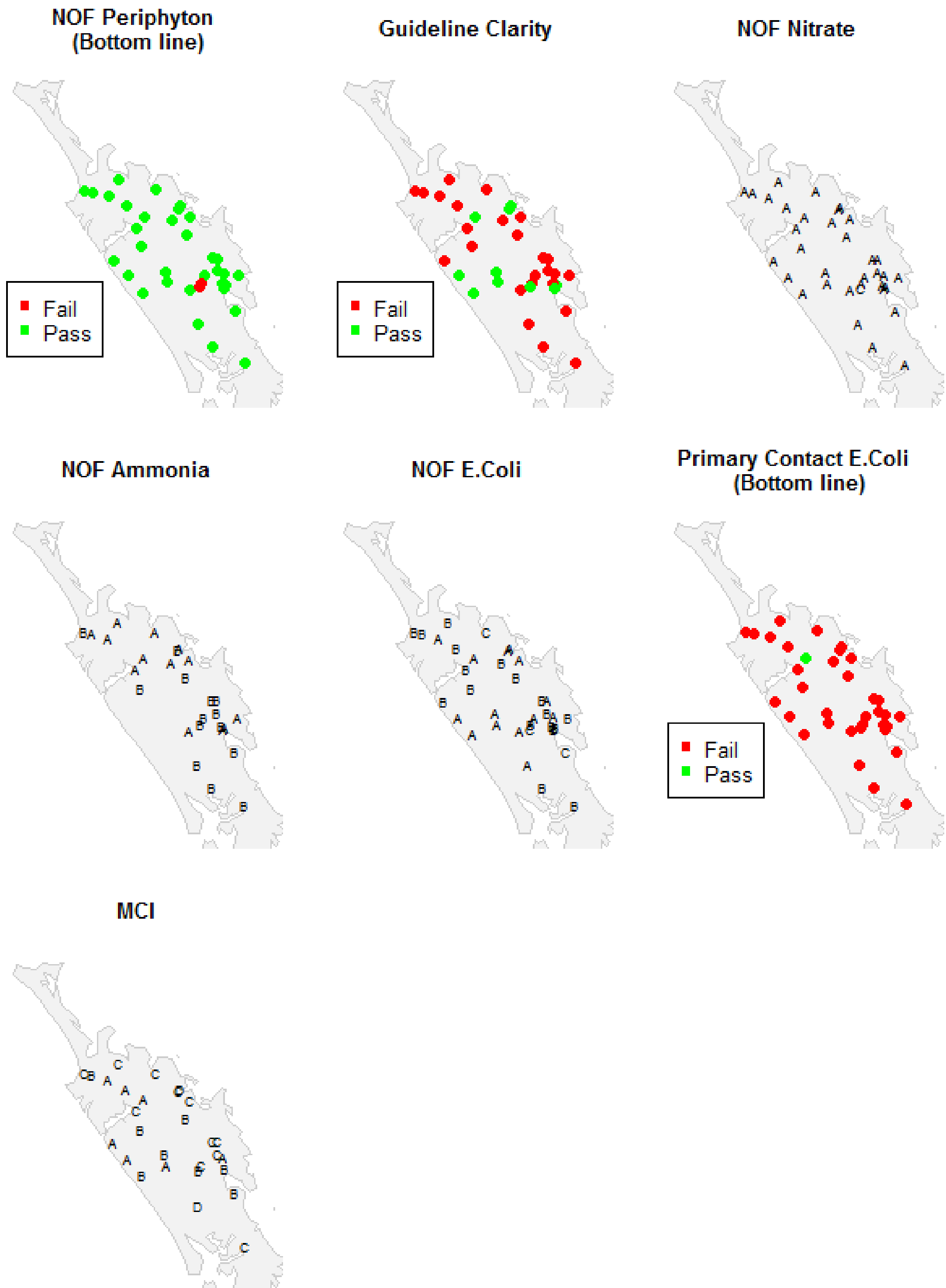

Figure 16. Grading of the NRC water quality network sites.

A1.5 Regional patterns of contaminants

The NPS-FM requirement to assess current state in FMUs presents a challenge because there is a limited number of water quality monitoring sites in Northland. If FMUs are defined that encompass catchments that do not have monitoring sites then the state of these FMUs must be interpolated from the observed state at monitoring sites with similar river and catchment characteristics. It has generally been found that the water quality data obtained from monitoring sites (e.g. median concentrations) are strongly related to the characteristics of the site's catchment (e.g., rainfall, slope, geological characteristics and land cover) upstream of the site (see Unwin *et al.* 2010). This allows water quality to be inferred for FMUs without monitoring data from data collected at monitoring sites. Water quality variables are often found to be highly correlated (i.e. the concentrations of nutrient species and E.coli are consistently low and clarity and MCI scores are high and vice versa).

Establishing these patterns in water quality are important for regional management processes. Establishing patterns between water quality variables provides a basis for making generalisations about where there are (or are not) water quality issues. Spatial patterns provide a basis for defining relevant spatial units for management (i.e. as part of defining FMUs). Two sets of analyses were undertaken to (1) reveal relationships between the water quality variables and (2) to reveal the relationship between individual variables and the characteristics of the upstream catchment (i.e. spatial patterns).

A PCA[27] was used to examine the relationships between the water quality variables at the regional scale. PCA analyses were performed on (i) the median values of the eight observed water quality variables at the 35 SoE sites. PCA is sensitive to the relative scaling and distributions of the original variables and it was therefore performed on the correlation matrix, which effectively re-scales the variables to have the same mean and standard deviation.

The first, and second components of the PCA explained 49%, 24% (respectively) of the total variation in the water quality data. A biplot of the PCA indicates that the water quality variables varied relatively independently (i.e. there was not a single axis of variation that was strongly associated with increasing concentrations of all contaminants) (Figure 17). The relatively high variation explained on the first axis indicates that many variables are correlated with this axis (e.g. DRP, TP and Clarity were reasonably strongly related to this axis). However, the biplot indicated that the two nitrogen species TN and NO3N were approximately orthogonal to these other variables (i.e. these variables are not strongly correlated with the other variables). This indicates that there is strong localisation of the individual contaminants of concern (i.e. some are high where others are low and vice versa) and that it is difficult to make generalised state about water quality at the regional level. It is noted that this is contrary to results from other regions that often indicate strong correlation among all water quality variables such that there is less localisation (e.g. Snelder et al 2014).

[27] PCA is a mathematical procedure that converts a set of observations of several variables into a set of values of linearly uncorrelated variables called 'principal components'. The components are defined so that the first principal component accounts for as much of the variability in the data as possible, and each succeeding component in turn has the highest variance possible under the constraint that it be orthogonal to (i.e. uncorrelated with) the preceding components.

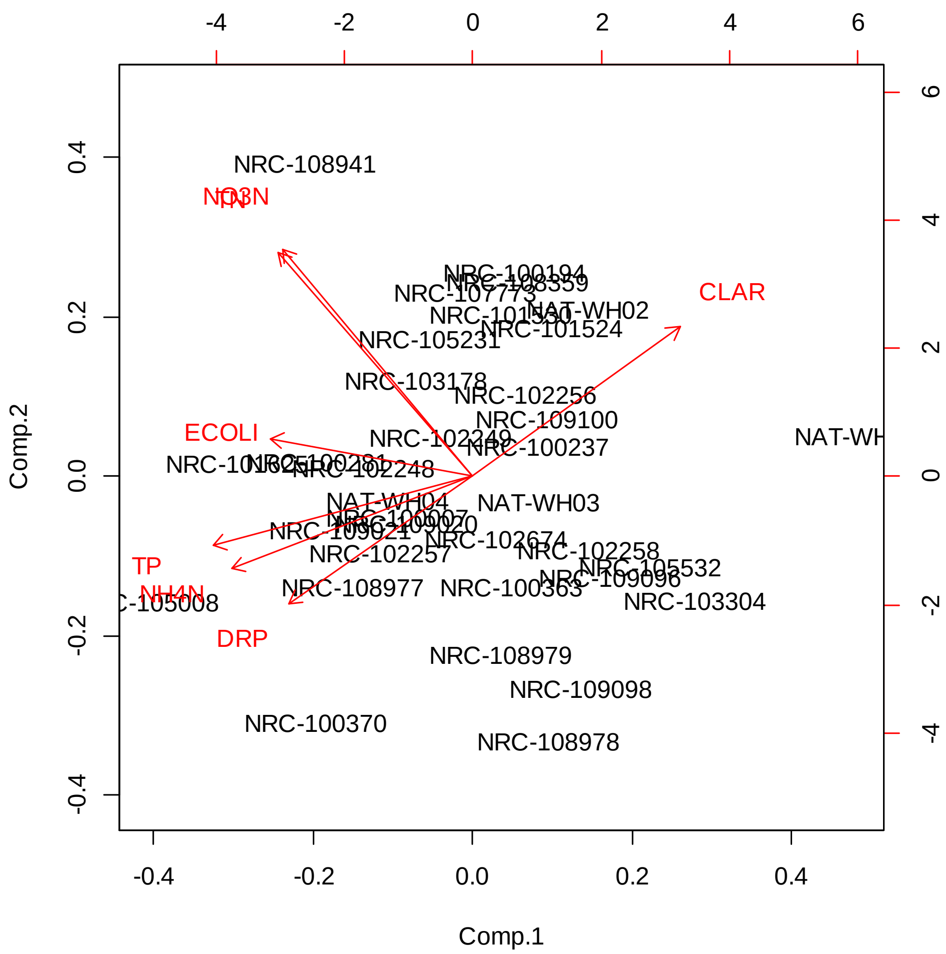

Figure 17. PCA performed on the site median values of the water quality variables. The first two components of the PCA are represent by the two axes and together explained 73% of the total variation in the variables.

For the spatial analysis, variables that represented the characteristics of the upstream catchment were obtained from a digital drainage network database that associated with the River Environment Classification (REC; Snelder & Biggs, 2002). Seven variables were selected to represent catchment characteristics that previous studies have shown to be associated with spatial variation in water quality (e.g. Unwin et al 2010). The average slope of the catchment upstream of a segment was represented by the variable usAveSlope. The proportion of the catchment occupied by the Indigenous Forest and Heavy Pasture land cover categories as defined by the Land Cover Database (LCDB3, MFE 201?) were represented by the variables usIndigForest, and usPastoral. The geology of the upstream catchment was represented by the variables: usHard, usParticleSize, and usPhos which describe the mean induration or hardness, particle size and phosphorous concentration of the catchment regolith (Leathwick et al 2011). The area of the upstream catchment was represented by usArea, which was log (base 10) transformed prior to analysis to make its distribution more normal.

The catchment characteristics had differing levels of correlation with each other (Table 7). Notably the land cover variables usPastoral and usIndigForest were strongly related to each other and to usAveSlope.

Table 7. Correlation (r^2) between the catchment characteristics of the water quality network sites used as explanatory variables in the spatial analysis of water quality.

Variable	usAveSlope	usHard	usPhos	usParticleSize	usIndigForest	usPastoral
usHard	0.25					
usPhos	-0.09	0.75				
usParticleSize	0.04	0.86	0.92			
usIndigForest	0.68	0.43	0.26	0.37		
usPastoral	-0.76	-0.19	0	-0.02	-0.55	
log10(usArea)	-0.03	0.2	0.22	0.35	0.2	0.17

Multiple linear regression models were fitted to the median values of the water quality variables using the catchment characteristics as explanatory variables. The site median values were log (base 10) transformed prior to the analysis to their distributions more normal. Standard forwards and backwards stepwise linear regression was used to identify the minimal adequate model from among the explanatory variables (Venables and Ripley, 2002). Model fit was evaluated using the coefficient of determination (r^2) and the contribution of the explanatory variables to the models was interpreted by examining the correlation between the response variables and the predictor variables.

The water quality variables had variable levels of correlation with the catchment characteristics and the catchment characteristics exhibiting the strongest correlations varied by water quality variable (Table 8). Model performance (r^2 values) was highest for the CLAR and TN models and was poor for the DRP, ECOLI and the 95th percentile ECOLI (Table 9). The models included between one and five predictor variables. The analysis indicates that there is a relatively high level of consistency between CLAR and TN and catchment characteristics. CLAR was most strongly correlated with the geological predictors usHard and usParticle size. CLAR was only weakly negatively correlated with usPastoral (Table 8) and this was not a significant predictor in the model (Table 9). TN was strongly correlated with usAveSlope, usIndigForest and usPastoral (Table 8). Only the first two of these variables were included in the model (Table 9) but this reflects their correlation (Table 8) and should not be interpreted as causative. In general the TN model indicates that TN concentrations are higher in catchments with lower slopes and the predictor correlations (Table 8) indicates these are dominated by pastoral land cover at the expense of indigenous forest. DRP was most strongly correlated with catchments with high pastoral land cover but all but one predictor (usIndigForest) were included in the model (Table 9). The low r^2 value and the large number of predictor variables mean that the observed pattern in DRP is complex. The strongest correlations between ECOLI and the predictors were with usIndigForest, with the negative coefficients indication that ECOLI is lower in catchments with higher indigenous forest. However, the two ECOLI models had the lowest r^2 values of all the models indicating that there is a low level of consistency between ECOLI and the catchment characteristics.

Table 8. Correlations between the water quality variables and all the predictor variables.

Variable	usAveSlope	usHard	usParticleSize	usIndigForest	usPastoral	log10(usArea)
CLAR	0.16	0.75	0.55	0.43	-0.25	0.09
TN	-0.77	-0.26	-0.16	-0.67	0.7	-0.02
TP	-0.29	-0.76	-0.53	-0.47	0.47	-0.15
NO3N	-0.81	-0.25	-0.19	-0.69	0.68	-0.01
NH4N	-0.54	-0.6	-0.28	-0.57	0.53	0.02
DRP	-0.24	-0.34	0	-0.13	0.44	-0.1
ECOLI	-0.25	-0.32	-0.27	-0.39	0.3	-0.28
ECOLIQ95	-0.39	-0.34	-0.19	-0.5	0.4	-0.21

Table 9. Water quality model performance and model coefficients. NA values indicate the predictor was not included in the model.

Variable	r^2	usAveSlope	usHard	usParticleSize	usIndigForest	usPastoral	log10(usArea)
CLAR	0.64	-0.02	0.54	-0.11	0.28	NA	NA
TN	0.61	-0.08	NA	NA	-0.5	NA	NA
DRP	0.47	0.075	-1.01	0.26	NA	0.94	-0.13
ECOLI	0.14	NA	NA	NA	NA	0.33	-0.11
TP	0.77	0.05	-0.98	0.18	NA	0.70	-0.08
NO3N	0.67	-0.119	NA	NA	-0.68	NA	NA
NH4N	0.57	NA	-0.36	NA	NA	0.47	NA
ECOLI_Q95	0.23	NA	NA	NA	-0.57	NA	NA

These analyses indicate that there are not strong relationships between the water quality variables and individually many of these are not strongly associated with catchment characteristics. It is, therefore, difficult to make regional generalisations about water quality patterns. Different aspects of water quality (e.g. clarity versus nutrients) vary independently of each other and the drivers of water quality appear to be different for each variable. The catchment characteristic that most consistently explains spatial patterns is catchment slope (usAveSlope; Table 9). This characteristic was also reasonably highly correlated with patterns in land cover (Table 7).

The relatively poor performance of the water quality models and the independent variation of the individual water quality variables indicates that it will not be possible to produce water quality classifications (based on catchment characteristics) that provide a high level of discrimination of water quality patterns and that also perform highly (i.e. that has low misclassification or that explains a large proportion of the total water quality variation). This supports the use of a very simple two-class subdivision, based on catchment slope, to provide a very broad classification for water quality management.

A1.6 Management classification based on catchment slope

If a simple two-class water quality management classification based on catchment slope is used two relevant questions are; (1) what is the appropriate threshold to define the class boundary? and (2) are the existing monitoring sites reasonably representative of the two classes?

An analysis of alternative criteria for the boundary between the two catchment slope-based classes was undertaken to answer the first question. In this analysis the threshold for the two classes was varied from 5 degrees to 15 degrees in increments of one degree. For each increment the water quality monitoring sites were allocated to the 'lowland' and 'hill' class depending on whether their average catchment slopes were less than or greater than the threshold respectively. The upper and lower limits of the thresholds used in the analysis were determined by the value of average catchment slope at which there were no monitoring sites in one of the classes.

The explanatory power of the classification was evaluated for each increment of catchment slope using analysis of variance (ANOVA). An ANOVA was performed on the site median values for each of the six water quality variables, the 95th percentile for *E.coli* (ECOLI_Q0.95) and the site median value of MCI. The site median values were $\log_{10}$ transformed for the variables ECOLI_Q0.95, NO3N, DRP, TN, CLAR to make the distributions approximately normal. When the ANOVA was significant ($p < 0.05$), the coefficient of determination (i.e. r^2) was used as an indicator of the performance of the classification at the associated slope threshold.

A plot of the ANOVA values for each variable as a function of catchment slope indicated that the explanatory power of the classification generally had the maximum at a threshold of 10 degrees (Figure 18). The mean of the r^2 values over all the variables had a maximum value at 10 degrees.

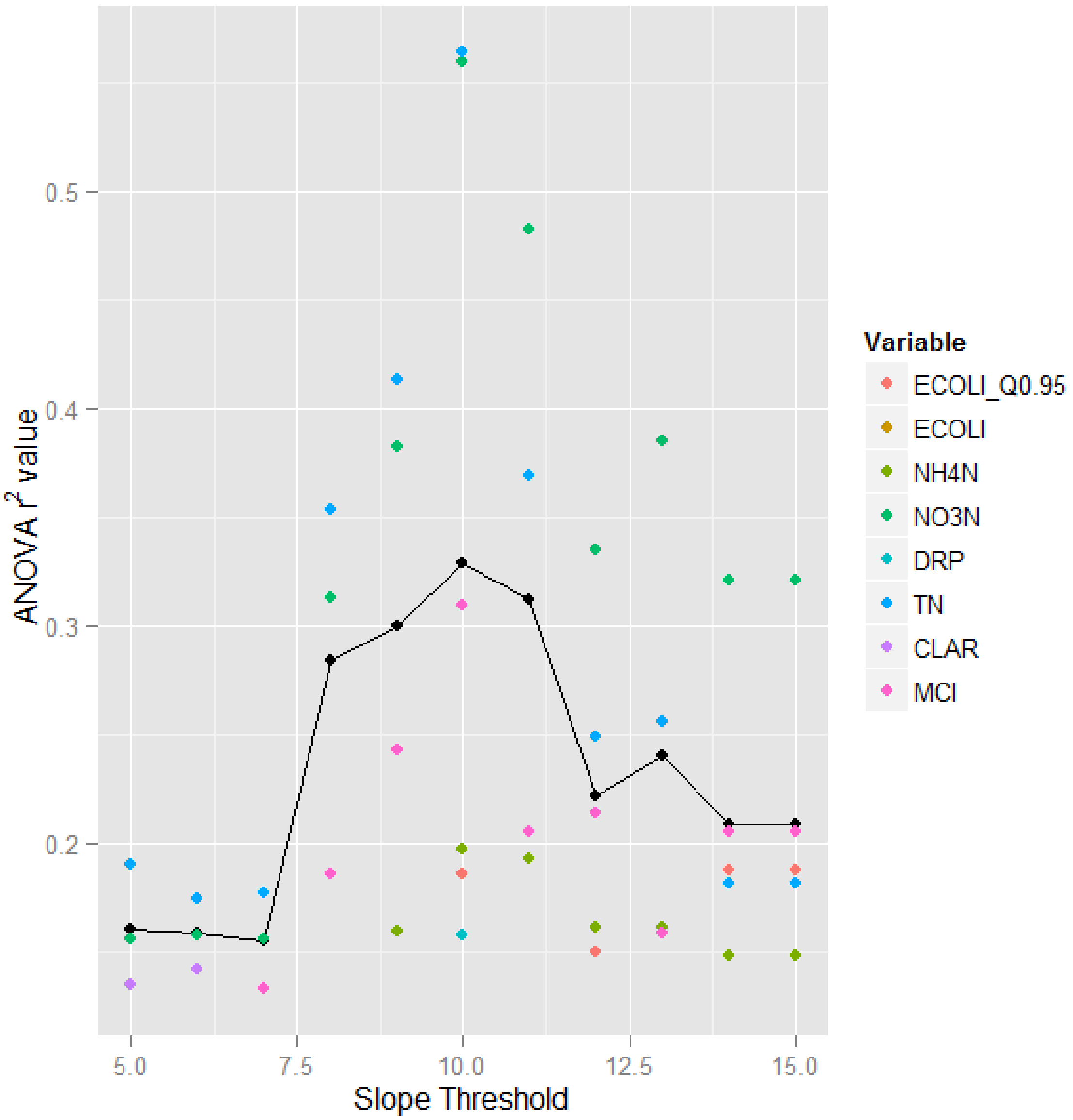

Figure 18. ANOVA r^2 values for each variable as a function of catchment slope. The coloured points show the r^2 value of each variable where the ANOVA was significant ($p < 0.05$). The black line represents the mean value of r^2over all variables.

An analysis was performed to assess the representativeness of the NRC river monitoring network and the water quality assessment based on the proposed water quality management classification presented here. A definitive test of representativeness is not possible due to the variety of environmental variables that affect water quality. For this analysis representativeness was defined to be the extent to which the sites represented the variation in major land cover types within each class. Land cover is a relevant factor due to its close association with land use, which is an important and manageable driver of water quality. The site network, and therefore the analysis presented here was assumed to perfectly represent the class if the proportion of river segments in different REC land cover categories in each class were the same as the proportion of sites in the same categories. The proportion of river segments is by count, results are very similar if weighted by length of each segment.

The representativeness analysis indicated that the NRC monitoring network configuration was reasonably representative of the relative abundance of rivers in each management class by REC land cover category (Table 10). There were minor differences in the representativeness assessment for water quality and invertebrates due to small differences in the configurations of the two monitoring networks. The pastoral category made up the bulk of the REC segments in both management classes and the relative proportions of water quality and invertebrate monitoring sites were very consistent with these. The proportions of REC segments and monitoring sites were also well balanced on both management classes. The proportion of monitoring sites in the Urban category were over-represented compared to their actual number of REC segments in this category and Indigenous Forest sites were under represented by water quality and invertebrate sites, particularly in the Lowland class. The magnitude of the under and over representation of the less prevalent class is associated with the small number of monitoring sites (i.e. one site represents 3% of the total monitoring network). On balance, the analysis suggests that that NRC monitoring network, and therefore the water quality assessment, is reasonably representative of the region from a land cover perspective.

Table 10. Results of analysis of representativeness of the proposed water quality management classification and water quality assessment. The values indicate the proportion (%) of river segments defined by the REC for Northland in each management class belonging to each REC land cover category and the equivalent for water quality and MCI monitoring sites. Note that the columns do not sum perfectly to 100% because some minor land cover categories (Miscellaneous and Wetland) were omitted.

REC Land cover category*	REC		Water quality sites		Invertebrate sites	
	Lowland	Hill	Lowland	Hill	Lowland	Hill
EF	8	12	5	13	5	12
IF	5	35	0	27	0	25
P	83	46	90	47	89	44
S	3	6	0	7	0	6
U	1	0	5	7	5	12

* REC land cover categories EF = exotic forest, IF = indigenous forest, P = pastoral, S = scrub, U = urban.

A1.7 Water quality trends

An analysis of trends in the seven water quality variables was undertaken for two time periods; the 10 the 20 years periods ending at the end of 2013. Trends for MCI scores were assessed only for the 10 year period. There were differing numbers of sites by variable for both periods due to variation in the dates that monitoring commenced at each site and due to some filtering rules that were imposed to ensure the reported trends were robust. Trend analysis is only robust for a specified time period over which the dataset being analysed if it has few missing values. For the water quality data, trends were assessed trends using monthly data, provided a two filtering rules were met: 1) 90% of the sampling dates in each of 90% of the years in a trend period had to have observations and, 2) the number of censored values in a trend period had to be < 15% of the total number of observations. For MCI, the 90% rule applied to annual sampling and these data do not have censored values.

The water quality trends at all sites and variable combinations were formally assessed using the non-parametric Seasonal Kendall Sen Slope Estimator (SKSE) (Sen, 1968). The SKSE is used to quantify the magnitude and direction of trends in data that are subject to appreciable seasonality such as water quality data. Regional councils commonly use the Time Trends software (http://www.niwa.co.nz/our-science/freshwater/tools/analysis) to estimate SKSE values.

The SKSE calculations were accompanied by a Seasonal Kendall test (Helsel & Frans, 2006) of the null hypothesis that there is no monotonic trend. If the associated P-value is 'small' (i.e. $P<0.05$), the null hypothesis can be rejected (i.e. the observed trend or any larger trend, either upwards or downwards, is most unlikely to have arisen by chance).

Flow state at the time that water quality measurement are made can have a significant effect on the observed values because many water quality variables are subject to either dilution (decreasing concentration with increasing flow, e.g. conductivity) or wash-off (increasing concentration with increasing flow, e.g. total phosphorus). Data can be flow adjusted before trend analysis to remove the effects of variation in river flow on water quality variable concentrations. Because changes in river flow are tied to natural changes in precipitation and evapotranspiration, flow adjustment of water quality variable concentrations allows trends caused by other, largely anthropogenic, changes to be more directly assessed.

The flow adjustment procedure was performed by first fitting a second order generalised additive model (GAM) to the $\log_{10}$(variable value) versus $\log_{10}$(flow) relationship for each variable and site. The strength and form of these relationships varied considerably. In general, nutrient concentrations were positively related to flow (linear regression coefficients). The use of a second order GAM ensured that curvilinear relationships between variable values and flow (in log-log space) were able to be represented.

The GAMs were used to adjust variable values in response to flow as outlined by Smith *et al.* (1996): adjusted value = raw value – value predicted by the regression model + mean value. Flow adjustments were made for all river monitoring sites irrespective of the strengths of the water quality-flow relationships at each site. The rationale for this approach was that if flow significantly explains variation in concentration, however weak this relationship may be, the trends are potentially influenced by flow state at the time of sampling unless this relationship is accounted for.

Trends in MCI were not estimated with a seasonal test because the macroinvertebrates used in MCI scores are sampled annually, which precludes accounting for seasonal variation. Instead, trends in MCI scores were estimated with the Kendal Sen Slope Estimator (KSSE) (Sen 1968).

The majority of significant trends (i.e. sites for which $p<0.05$) indicated improving water quality for both time periods. The most significant exceptions were degrading trends in TN for the 10-year period at five sites. There were a large number of insignificant trends, for ECOLI and MCI in particular. This indicates that the water quality variables have large variation ('noise') and that therefore that a definite trend cannot be detected.

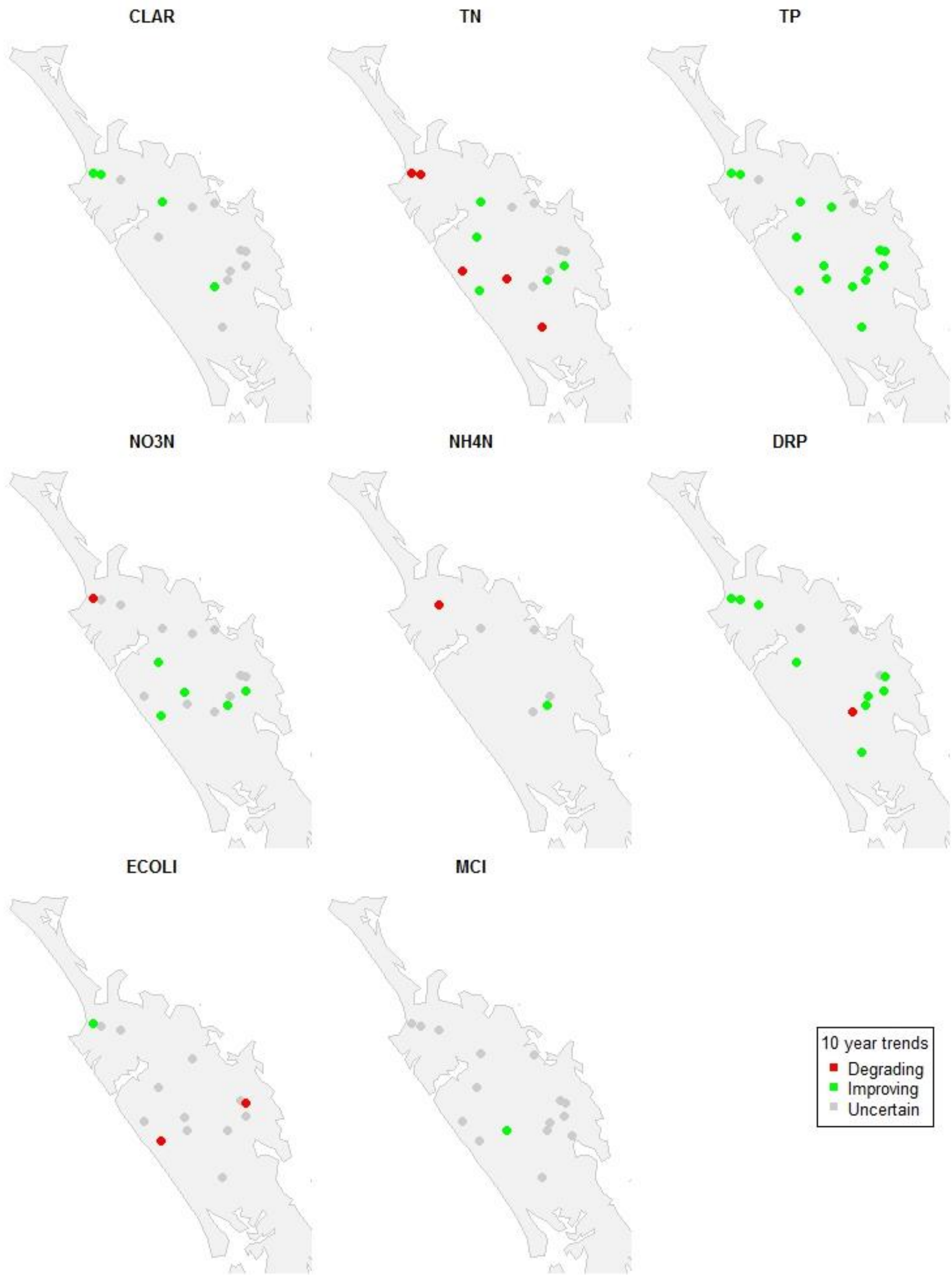

Figure 19. Maps showing the 10-year trends at monitoring sites. Where the trend tests were significant (i.e. the Kendal test p-value < 0.05) the direction of the trend is indicated as improving or degrading. Where the test was not significant the trend is indicated as "uncertain" meaning the test can be regarded as inconclusive concerning the direction of the trend. There are varying numbers of sites by variable because the data met the filtering rules to varying degrees by variable.

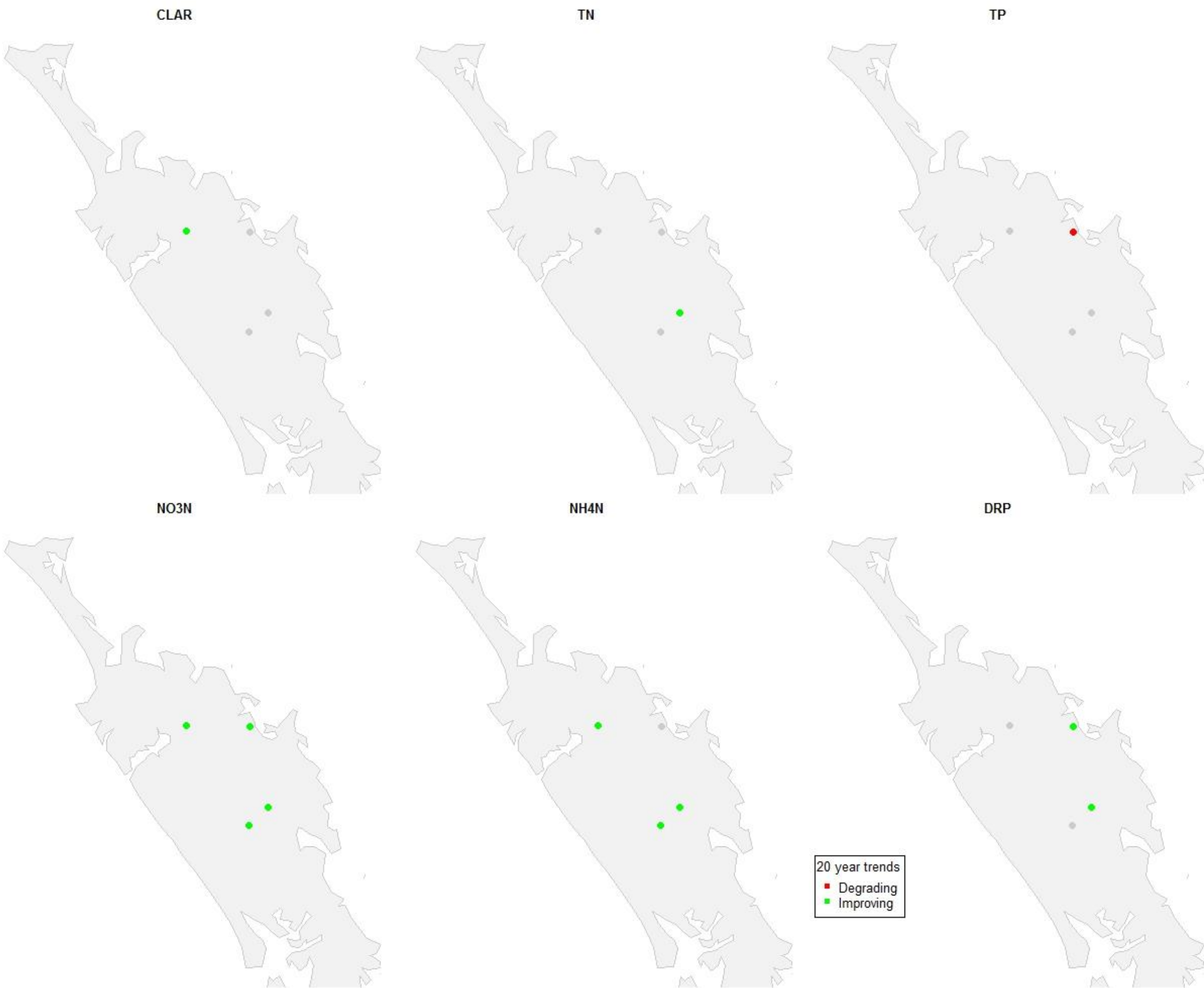

Figure 20. Maps showing the 20-year trends at monitoring sites. Where the trend tests were significant (i.e. the Kendal test p-value < 0.05) the direction of the trend is indicated as improving or degrading. Where the test was not significant the trend is indicated as "uncertain" meaning the test can be regarded as inconclusive concerning the direction of the trend. Note that 20 year trends for E.coli and MCI because monitoring did not extend this far back. There are varying numbers of sites by variable because the data met the filtering rules to varying degrees by variable.