Defining a biophysical framework for Freshwater Management Units of the Ruamāhanga Whaitua

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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 vary spatially. This means that it is generally inappropriate to set specific (i.e. numeric) freshwater objectives that apply broadly 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 the NPS-FM definition is the idea that water bodies, or parts of water bodies, should be delineated and managed based on how they are valued. Therefore, defining a spatial framework of water bodies (i.e. FMUs), is integral to setting objectives, policies and methods. Consequently, it is important that the process of defining FMU boundaries is transparent and alternative options can be considered by decision-makers. Some iterative refinement of the FMUs is likely to be necessary as part of the development of plan provisions.

This report offers a transparent and justifiable bio-physical starting point for defining FMUs for rivers within the Ruamāhanga Whaitua. This report does not consider FMUs for lakes, wetland or aquifers but the approach taken by this study could be expanded to FMUs for these domains. The framework uses a modified version of the national River Environment Classification (REC) system to classify the Whaitua's rivers based on bio-physical characteristics that are relevant to managing water quality and quantity. In this document the bio-physically defined units are referred to as example FMUs but it is assumed that these may be modified, as the Whaitua planning process proceeds, following additional considerations such as specific values, human rather than bio-physical factors and/or additional bio-physical factors of particular water bodies, objectives and policies.

This report proposes that FMUs are not simply a subdivision of geographic region of interest into sub-catchments. Rather, it is proposed that FMUs are a framework of related spatial units that serve different purposes. There are several reasons that this framework of spatial units is necessary including:

- To acknowledge and provide for the "source to sea" spatial structure of rivers, which is a key driver of variation in characteristics, values and objectives within a catchment.
- To acknowledge and provide for the appropriate management of all upstream locations (i.e. catchments) to achieve objectives in receiving water bodies.
- To provide for different plan development processes (e.g. community consultation versus developing specific management polices),
- To manage different issues (e.g. water quality versus water quantity, and surface and groundwater), and

- To provide a basis for different management functions (e.g. setting objectives versus accounting for resource use and consenting water takes).

The study offers example FMUs for management of water quality and quantity in the Ruamāhanga Whaitua, which were developed in three steps. The first step was to classify the Whaitua's rivers for water quality and quantity management, thus producing what is hereafter referred to as a "*management classification*". The Whaitua's rivers were represented as individual segments of a digital river network and each segment was classified on the basis of physiographic "factors" that drive variation in water quality and quantity comprising catchment climate, slope, geology and river size (as defined by average flow rate). The management classes are not restricted to a single location or sub-catchment and recur in a patchwork across the Whaitua. The *management classification* broadly discriminates variation in the characteristics of the water bodies that are relevant to management, including their values and capacity for resource use. The Ruamāhanga Whaitua committee had previously recognised that these physiographic factors are key drivers of variation in characteristics of rivers in the Whaitua and had suggested a preliminary set of FMUs on this basis. This report provides a process for more justifiably and transparently defining the management classification, and has confirmed its robustness and provided examples of how objectives could vary by class. Selecting objectives is ultimately a political decision and therefore the objectives in this report should be regarded as examples.

The second step defines *management zones*. *Management zones* recognise that many of 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 only 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 zone*s are not restricted to a single catchment and recur in a patchwork across a region. In addition, individual locations may belong to more than one *management zone*.

FMUs are defined by a pragmatic layering and merging of *management zones* in an order that is dependent on the policies and limits set for each of the management zones. The layering and merging of the zones recognises that locations that lie in multiple management zones will need to have policies and limits that achieve the *most restrictive downstream objectives*. This means that some management zones may be redundant and can be merged with other zones. It may be appropriate that there is a single set of policies and limits for this merged entity (an FMU) that are designed to achieve the most restrictive objectives, which will therefore also achieve the less restrictive objectives of all other water bodies in the FMU.

Because the layering of management zones is dependent on objectives, policies and limits, the final definition of FMUs is integral to the planning process. However, to provide examples of the approach in its entirety in this report, credible example objectives have been defined for each management class and an ordering of the resulting restrictiveness of policies and limits has been assumed. This has produced example FMUs for water quality and quantity management but it is anticipated that these will need adjustment as the plan process proceeds. The process for defining the FMUs uses the *management classification* and associated *management zones* as building blocks. These building blocks can be combined in a variety of ways thereby allowing for adjustments to be made to the spatial framework (i.e. the FMUs) as plan development proceeds.

The third step recognises that administration and accounting for contaminant discharges and water takes must occur within individual sub-catchments. A minimum set of individual sub-catchments are defined by the points in the drainage network where there is a change in the

FMU. These points represent a framework of *administrative points*, each of which defines a sub-catchment or catchment. This results in a large number of administrative points but this does not complicate the plan because administrative units are of relevance to 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 point 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).

It is noted that administrative points are not monitoring locations; for either water quality or quantity. Monitoring of both water quality and quantity (e.g. monitoring flows) would be carried out at representative sites (such as is currently provided by the water quality and flow monitoring networks) and the data collected at these sites would be used to inform on the achievement of objectives in management classes as a whole or to provide proxy measurements (e.g. flows) at specific administrative points.

Some water bodies have specific values or management issues that are not discriminated by the biophysical management classification described above but which may need to be provided for in the new regional plan. It is suggested that these water bodies can be handled by defining special FMUs that over-ride the objectives set for the management classes. Examples of water bodies requiring special management objectives may be sites of significance such as estuaries, swimming spots, or sites of special cultural or ecological significance. Another example of water bodies with special issues are those where significant infrastructure has ‘permanently’ modified the system such as large dams. 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. Some special FMUs may only be identified as a result of consultation with community groups and could thus be added progressively to the framework as plan development proceeds.

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

1. The use of physiographic classifications provides for variation in the characteristics of interest to be resolved at a level of detail that is appropriate to management. Large sea-draining catchments generally contain considerable variation in these characteristics and therefore do not provide sufficient resolution,

2. The approach is transparent because it is based on specific physiographic factors (e.g. topography) and their associated categorisation (e.g. hill and lowland),

3. The logic that objectives apply to the water bodies and that the limits and actions apply to the catchments draining to those water bodies is inherent in the approach,

4. The need for limits to be set and actions taken to achieve the most constraining downstream objective is built into the approach,

5. The process is flexible and easily repeatable so that FMUs can be modified and their definition is integral to the plan development process.

6. The level of classification detail (i.e. coarse or fine) can be altered by varying the physiographic factors (and their categories) to suit the desired level of detail and spatial specificity of the plan provisions,

7. The layering and merging of management zones can be altered to accommodate changes in the order of restrictiveness of policies and limits that may arise in the development of plan provisions,

8. 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,

9. 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

10. The framework is spatially clear and certain (i.e. mapped) about where limits need to be met and where accounting should occur (administrative points).

The approach offered in this report is based on six and ten class classifications for water quality and quantity respectively as the starting point for defining FMUs. The relatively coarse level of classification and subsequent discrimination of characteristics is consistent with the trading off detail (specificity) with coverage and simplicity. It is also anticipated that some special FMUs will need to be developed to manage specific water quality issues, for example specific swimming spots in certain rivers, and water quality issues in lakes and estuaries. Thus, it is anticipated that a final FMU framework will ultimately require deciding how much complexity is appropriate beyond the six and ten class units that are offered by this study.

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, cultural and social 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 include objectives in regional plans 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 vary spatially. This means that it is generally inappropriate to set specific (i.e. numeric) freshwater objectives that apply broadly to all water bodies in a catchment or 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] and for freshwater accounting and management purposes. A regional plan that addresses the management of water bodies in a catchment or region requires a spatial framework of FMUs that subdivides water bodies and their catchments into groups for which differing management regimes will apply.

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. Because the development of FMUs is integral to the development of the regional water plan, the methodology should be transparent and the decision-maker(s) 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; consequently, large FMUs may not provide plan provisions of sufficient specificity. 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 Ruamahanaga Whaitua Process

Greater Wellington Regional Council (GWRC) has divided the Wellington Region into five Whaitua, or sub-regions, as part of its community led collaborative planning process. The planning process will address a number of land and water management issues, and carry out GWRC's obligations under the National Policy Statement for Freshwater Management (NPS-FM). The Ruamāhanga Whaitua was the first Whaitua to commence in the Wellington Region, with the Ruamāhanga Whaitua Committee being established in December 2013.

The Ruamāhanga Whaitua Committee is a partnership between the Regional Council, iwi, territorial authorities and the community, and will make recommendations to the Council through a Whaitua Implementation Programme (WIP) report. The WIP will contain strategies and actions which will form a programme of work to implement the NPS-FM in the Ruamāhanga Whaitua. It will include recommendations for both statutory and non-statutory actions and methods.

Proposed regulatory provisions in the WIP will be incorporated into the Regional Plan through a plan change process. Non-regulatory programmes will also be developed further and implemented in conjunction with partners.

1.4 Structure of this report

This report is structured as follows:

- Section 2 provides an overview of the nature of FMUs, considers alternative approaches to defining FMUs and sets out a recommended approach for establishing FMU's for the rivers of the Ruamāhanga Whaitua,
- Section 3 offers a bio-physical classification and spatial framework as a starting point for defining FMUs for managing river water quality,
- Section 4 offers a bio-physical classification and spatial framework as a starting point for defining FMUs for managing river water quantity, and

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

- Section 5 discusses the findings and recommendations.

2 Alternative approaches to defining FMUs

2.1 Overview

Most regional councils have either developed regional 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 which address many NPS-FM requirements including numeric objectives and limits. All regional councils have had to account for regional differences in the values and characteristics of water bodies and generally have plan objectives and policies that recognise this variation to at least some extent. Some councils are well advanced with developing their second generation plans in response to the requirements of the NPS-FM, including defining FMUs. However, councils have approached this in various ways. The following is a brief summary of how five other councils in New Zealand have defined their FMUs.

Horizons (Manawatu-Wanganui) Regional Council has defined 44 water management zones and 117 subzones in the Manawatu-Wanganui region's One Plan. These zones are based on catchments or sub-catchments 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 each zone have been identified and objectives defined. Because the Horizons water management zones/subzones are catchment-based, they enabled specific load-based nutrient limits to be defined for managing water quality in 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 quantity 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, eight Water Management Zones[9] have been developed along socio-political and catchment boundaries, and these zones are used as a basis for collaborative management. At a lower level of spatial subdivision, the operative Land and Water Regional Plan (LWRP) has defined default objectives for all water bodies in the region based on bio-physical classifications of ten river classes and six lake classes. For rivers, the classes are based on the national system called the River Environment Classification (REC), which was developed by the Ministry for the Environment as a tool for various aspects of water management (Snelder and Biggs, 2002). Individual Zone plans are sub-regional sections of the Land and Water Plan that are specific to each of the eight Water Management Zones. These sub-regional plan sections are based on catchments and sub-catchments (for surface water) as well as recognising the physiographically defined river and lake classes of the parent LWRP. Water quantity limits (e.g., minimum flows and allocations), and nutrient load limits have been defined at catchment or sub-catchment scale. In some areas groundwater zones are also defined for the purpose of groundwater allocation and these may extend over just a part of, or more than one, surface water catchment.

Taranaki Regional Council has defined freshwater management units in its draft second generation regional plan based on a geo-physical subdivision of the region into four sub-regions. These sub-regions discriminate variation in the values, and physical and

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

hydrological characteristics of the water bodies they contain. The sub-regions contain whole catchments and the sub-region boundaries therefore align with catchment boundaries. The Taranaki FMUs broadly differentiate the streams and catchments draining Mount Taranaki (the “ring plain”), the northern and southern coastal terraces and eastern hill-country. In addition, one FMU differentiates three non-contiguous “Outstanding” rivers and their catchments.

Finally, Northland Regional Council (NRC) and Bay of Plenty Regional Council (BoPRC) have considered how to define FMUs for their geographically complex regions. Both regions comprise many (i.e. > 100) “sea-draining” catchments that exhibit considerable variation in natural factors such as topography, geology and land use. Data describing the characteristics of these water bodies is limited. For example, long term water quality is monitored at only 35 sites in Northland and 50 sites in the Bay of Plenty. In addition, some sea-draining catchments are too heterogeneous with respect to values and capacity for resource use[10] for a single set of plan provisions to be justifiably applied, and many catchments and sub-catchments are very similar to each other with respect to values and capacity for resource use.

The approach taken by NRC and BoPRC has been to define FMUs based on grouping water bodies into bio-physical classes that are relatively homogeneous with respect to their values and capacity for resource use. These classes will be the basis for plan objectives and it is anticipated that the detail of the classification (i.e. the number of classes) will allow objectives and subsequent policies to be drafted at an appropriate level of specificity. A benefit of this approach is that available data are used to represent the state of water quality in the FMUs and the current monitoring sites could be used to monitor their progress toward objectives in the future.

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 for 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 implicit in other parts of the NPS-FM that FMUs must involve consideration of catchments.[12]

[10] 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.

[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 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 integrated and sustainable way, so as to avoid, remedy or mitigate adverse effects, including cumulative effects.”

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 might 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 (e.g. if the catchment includes a lake or parts of the same river system support significantly different values). The scale at which FMUs need to be defined ultimately depends on achieving reasonable (and practical) homogeneity (i.e. degree of similarity) with respect to several characteristics of the water 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 its homogeneity with respect to values and other characteristics. Water bodies in small sub-catchments such as headwater areas are likely to be 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, and that the level of detail and complexity is minimised (i.e. the scale is as coarse as possible).

2.3 Use of river classification in regional water plans

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. The River Environment Classification (REC; Snelder and Biggs; 2002) is a national classification of rivers that 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 LWRP, 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 particular class are considered sufficiently similar that the same objective can justifiably apply to them. Furthermore, objectives can also vary appropriately between different REC classes, reflecting their different physical, chemical and ecological processes. However, REC classes are not an adequate basis for defining management actions or limits because many of these will need to apply to land areas draining to the water bodies, not only to the waterbodies themselves. 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

[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 are appropriate.

provides a starting point for the development of a system of FMUs that is described in the next section.

2.4 FMUs based on bio-physical classification of the drainage network

An approach to the definition of FMUs that builds upon the concepts of the previous sections starts with a physiographic classification that resolves important differences in relatively unchanging and natural aspects of the environment (including topography, geology and river size, which are termed physiographic *factors* in this report) that are relevant to the management of water quality and quantity. The approach subdivides the factors into specific categories, for example, 'hill' and 'lowland' topography can be discriminated by differences in average catchment slopes. The classification is applied to a detailed (fine-scaled) subdivision of the region's drainage network and associated sub-catchments. The benefit of such a category-based approach is that the basis for FMUs is transparent and alterable (by changing the factors and/or their categorisation) and can be applied generally to an entire region.

The benefit of using a drainage network as a basis for defining FMUs is that the catchment upstream of any specific point along a water body can be defined. Each point in the drainage 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 also 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 zone*s, and
3. Define the *administrative points*.

The first step is the definition of a ***management classification*** of the water bodies. This classification involves grouping water bodies into classes that are relatively homogeneous with respect to their biophysical characteristics including; (1) their environmental and ecological characteristics, (2) the capacity of both the water bodies and their catchments for resource use.

The approach taken in this report to defining a suitable *management classification* (i.e. groups of stream and river segments) is based on physiographic factors. The Ruamāhanga Whaitua committee had previously recognised that the physiographic factors are key drivers of variation in characteristics of rivers in the Whaitua and had suggested a preliminary set of FMUs on this basis. 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 classification approach allows the use of these physiographic factors to be formalised. The details of the physiographic factors are set out in subsequent sections but include, for example, the catchment slope, geology and size (as defined by average flow rate).

The *management classification* forms the basis for defining freshwater objectives for all the water bodies in the region. The *management classification* contains a number of individual *management classes*, many of which are likely to extend across multiple sea-draining catchments. Individual catchments are also likely to comprise more than one *management class*.

The second step defines ***management zones***. *Management zones* recognise that many of 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 only 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 zone*s are not restricted to a single catchment and recur in a patchwork across a region. In addition, individual catchments may comprise more than one *management zone*.

FMUs are defined by a pragmatic layering and merging of *management zones*. The layering and merging of the zones recognises that locations that lie in multiple management zones will need to have policies and limits that achieve the *most restrictive downstream objectives*. This means that some management zones may be redundant and can be merged with other zones. For example, in some circumstances land may drain to a river segment that is relatively insensitive to the effects of nutrient concentrations. However, further downstream, perhaps several kilometres away, the destination of water may be a water body that is more sensitive to elevated nutrients. In this case, limits set for point and diffuse source discharges in all upstream catchments need to ensure that the more restrictive management objective is achieved. In this situation, it may be appropriate to merge all management zones upstream of the water body with the most restrictive management objectives. Furthermore, it may be appropriate that there is a single set of policies and limits for this merged entity (an FMU) because these will be designed to achieve the most restrictive objectives and will therefore also achieve the less restrictive objectives of all other water bodies in the FMU.

Because this study precedes the development of objectives, policies and limits, it is not yet possible to identify the most restrictive objectives for any location. Therefore, this study is not able to define the final FMUs but provides the *management zones* them as building blocks, so that the layering and merging process can be carried out as part of the policy development. However, to illustrate the approach in its entirety, a set of credible *FMUs* are derived here as examples. It is anticipated that these example FMUs will be altered as the Whaitua process proceeds.

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 FMU. *Administrative points* are locations at which nutrient load limits for example (for water quality objectives) and volumetric allocation limits (for water quantity objectives) can be defined in absolute terms, and where 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 *FMUs* 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 areal basis for nutrient loads (e.g. kg/ha/year).

Administrative points are important only in terms of plan implementation. There may be a large number of *administrative points* but this need not result in a complicated plan or a large amount of environmental monitoring 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 of FMUs that are defined based on the drainage network. First, classifying water bodies based on bio-physical factors allows spatially discrete but similar water bodies (e.g. different sea-draining catchments or different parts of the same catchment for which values and objectives are similar) 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 defining more *management classes*. Higher resolution enables more specific objectives 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 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. In addition, the management classification must allow for good representation of each class by the monitoring network. For a fixed number of environmental monitoring sites, increasing the number of classes will lead to a reduction in the representation of each class and can potentially induce statistical bias in assessments based on the classes.

A third advantage of using a classification of the drainage network as a basis of developing FMUs 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 same 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.

2.5 A suggested approach for the Ruamāhanga Whaitua

The remainder of this report presents a suggested approach to defining a framework of FMUs for the rivers of the Ruamāhanga Whaitua that is based on a bio-physical classification of the drainage network. In this document these bio-physically defined units are referred to as 'example FMUs' but it is assumed that these may be modified following additional considerations including specific values, human rather than bio-physical factors or additional bio-physical factors of particular water bodies. The approach is a starting point for discussion and a final decision on a preferred approach should ultimately be made as part of the Whaitua Implementation Plan (WIP) decision making process.

The Ruamāhanga Whaitua committee held a workshop in 2014 to explore the concept of FMUs and developed a preliminary definition of FMUs for the region. The approach taken by the committee was to define differences in river characteristics and values and to broadly delineate these based on catchment topography, geology and climate (Figure 1). The approach taken in this report acknowledges the Whaitua committee's recognition that a logical starting point for defining FMUs is to subdivide the Whaitua based on these key catchment characteristics.

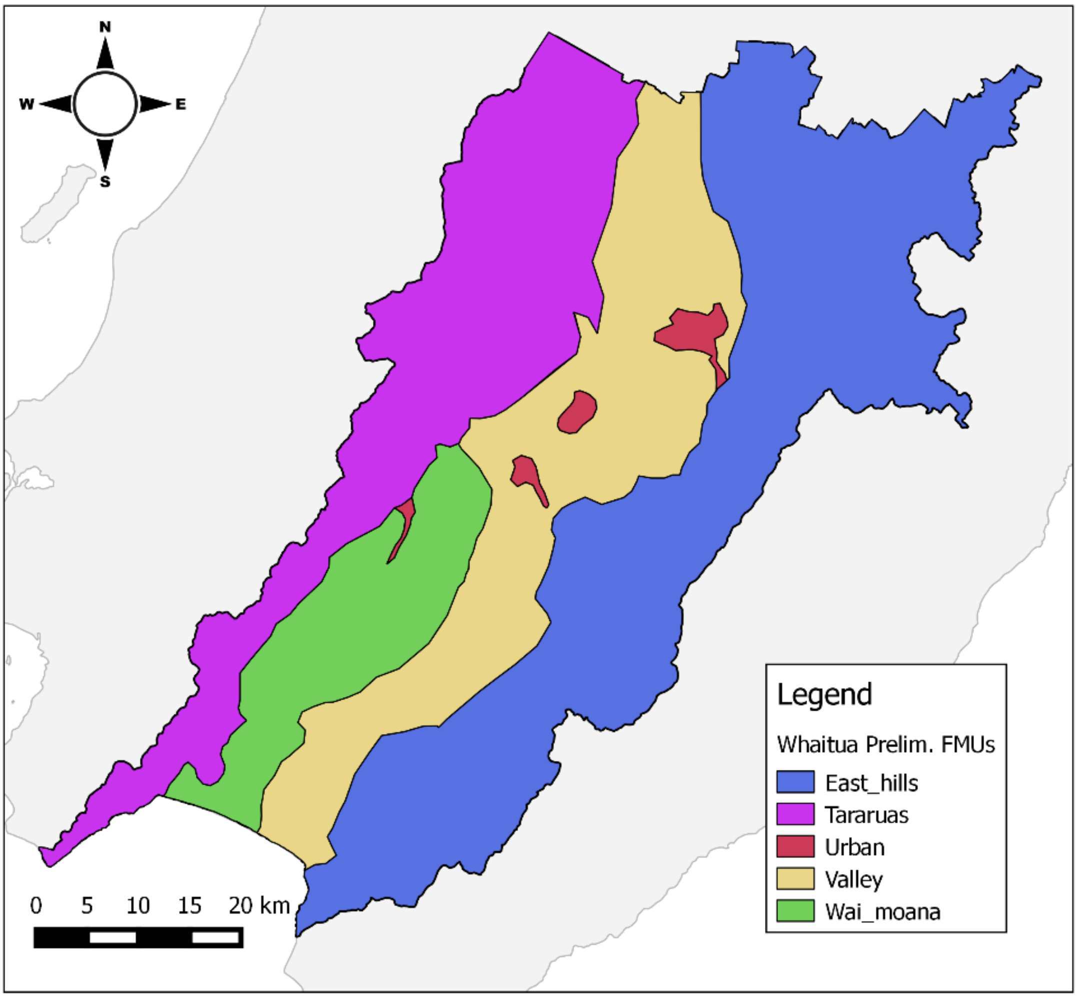

Figure 1: Preliminary FMUs defined by the Whaitua committee in a 2014 workshop.

The approach to defining FMUs for the Ruamāhanga Whaitua presented here is built using the REC as the basis for describing the river network and associated catchments and sub-catchments. 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 Ruamahanaga Whaitua Zone with approximately 7,600 unique river segments, with a mean segment length of 750m, 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 offers a network based approach for defining a default regional framework of FMUs for management of river water quality in the Ruamāhanga Whaitua. This framework should be considered as a starting point that can be altered by changing the criteria for determining river classifications.

3.1 Proposed water quality management classification

The proposed[14] 'water quality *management classification*' is a coarse subdivision of the Ruamāhanga Whaitua's water bodies for management purposes. This water quality *management classification* takes into account variation of physiographic factors previously recognised by the Ruamāhanga Whaitua committee (i.e. catchment topography, climate and geology, Figure 1), observed current water quality, and also expert knowledge of the likely mechanisms that lead to the variability in observed water quality across the Whaitua.

An analysis of the Ruamāhanga's river water quality (i.e. water quality as defined by a mix of physical, chemical, and biological parameters) revealed broad patterns associated with variation in catchment topography, climate and geology (Appendix A). The strongest relationship was with topography, with steep hill catchments being associated with relatively higher water quality than lowland (low gradient) catchments. Weaker relationships were found for the other catchment properties, with wet (high rainfall) catchments generally associated with better water quality compared to dry (low rainfall) catchments, and catchments with soft sedimentary geology generally having poorer water quality than catchments with hard sedimentary geology. While all three of these variables are highly correlated, in combination they provide greater discrimination of the water quality variables than with any one categorisation alone.

Appendix A provides a description of a variety of combinations of catchment factors that were tested to generate alternative water quality classifications, as well as a comparison with the Whaitua Committee's preliminary FMU map (Figure 1). In general, we found that adding more factors led to a higher level of ability to explain the observed patterns in water quality in the catchment; however, in selecting an optimal classification, simplicity, and incorporation of local and expert knowledge are also important considerations. With this in mind, the final classification adopted in this report is based on a combination of slope, rainfall and geology factors, as well as a separate class for the Ruamāhanga River's main stem (defined from the coast up to the confluence with the Waingawa River). This results in six water quality management classes (Figure 2). The proposed classification shows strong similarities with that developed by the Whaitua Committee (Figure 1), notably the eastern and western hills are in separate classes and the valley floor is identified as a distinct class. Most other differences are associated with a finer scale subdivision of the Whaitua, as well as the areas of special consideration (such as the Wairarapa Moana and the urban areas within the region) which have not been specifically identified in the classification shown in Figure 2. However, Section 3.6 addresses how areas of special interest like these could be incorporated.

[14] This report has defined 'proposed management classifications' and associated management zones. We use 'proposed' to indicate that at this stage they appear to be a credible and robust starting point for formulating management provisions for the Whaitua (objectives and policies). We do not mean 'proposed' in the planning sense, in which is means a fully developed, but not yet ratified, regional plan.

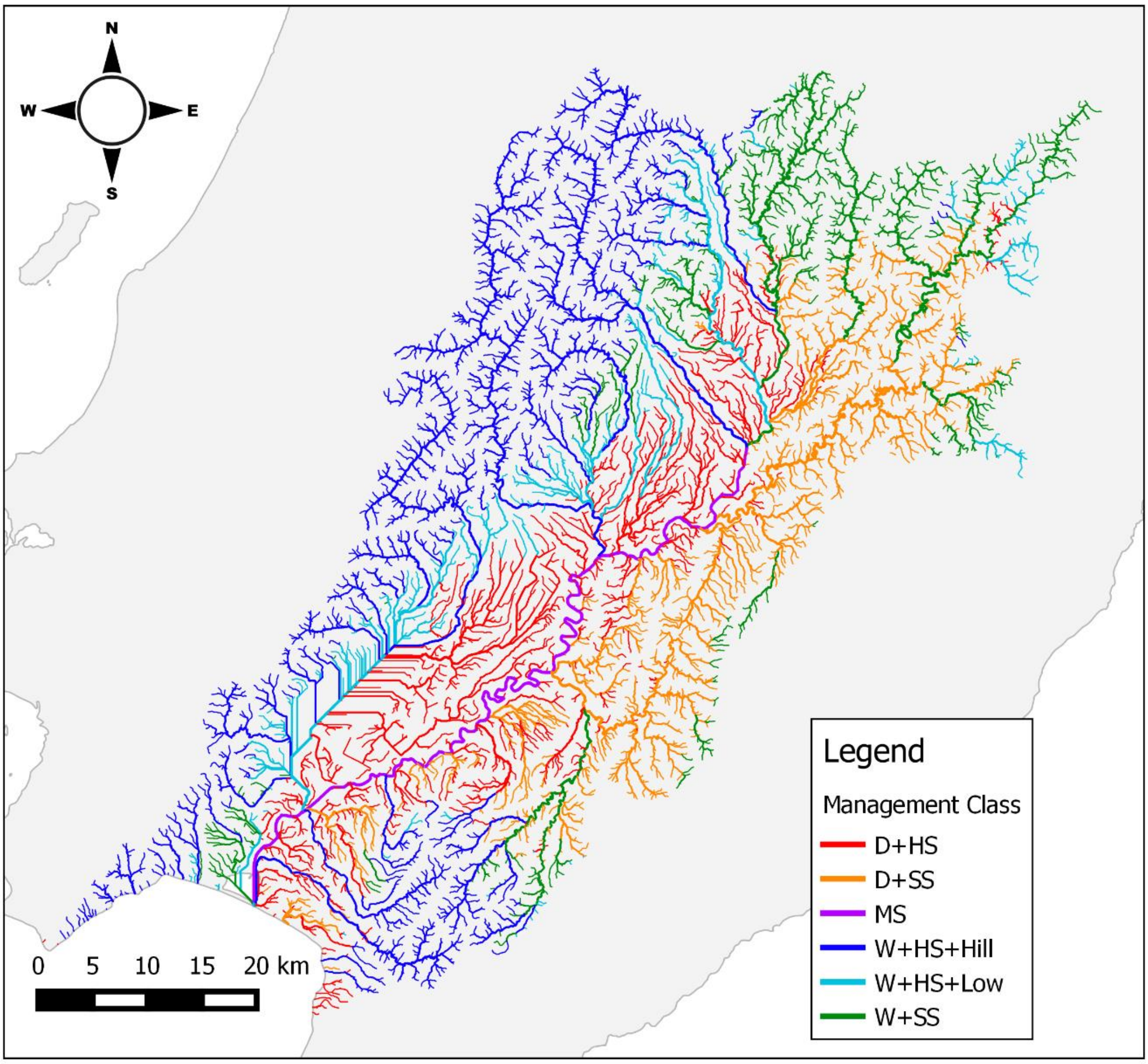

Figure 2: Water quality management classification of the Ruamāhanga Whaitua's drainage network based on geology, slope and rainfall of the upstream catchment. . D = Dry (low rainfall climate), W = Wet (high rainfall climate), Hill = Hilly catchment topography defined by slopes > 17 degrees, Low = Lowland catchment topography defined by slopes < 17 degrees, HS = hard sedimentary catchment geology, SS = soft sedimentary catchment geology, MS = main stem of the Ruamāhanga River.

3.2 Example water quality objectives

This section assesses example water quality objectives for aquatic ecosystem health and secondary contact recreation for each water quality *management class*. It is stressed that the objectives used here, including use of non-NOF attributes and state bands for all attributes, are examples only and are not exhaustive. Although these objectives are credible, they are used purely to demonstrate the approach. The derivation of objectives will be a subject of the future planning process and will involve more comprehensive technical work once objectives have been clarified.

For the purpose of explaining the application of the FMU framework, it was assumed that objectives for a specific *management class* would apply generally to all locations within that class, and would be linked to values that are generally held for that *management class*. It was also assumed that objectives and policies would aim to at least maintain the current state of water quality (as per requirements of the NPS-FM[15]). Furthermore, in cases where the current state was below a minimum acceptable level, it was assumed that objectives and policies would be aimed at improvement. In the discussion that follows, it is assumed that objectives, management regimes and policies applying to a specific *management class* would apply to all locations within that class, and can be linked to values that are generally held for that *management class*. However, the WIP development process may result in more specific (local) objectives, particularly where these can be justified by data or specific values.

The NPS-FM has mandated "ecosystem health" and "human health for secondary contact recreation" as compulsory water quality and quantity related values that must be provided for in all water bodies. However, regional councils have the discretion to also 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 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 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, although councils may choose to also include additional attributes suitable for their region.

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_4-N) and nitrate nitrogen (NO_3-N) concentrations to manage toxicity, and periphyton biomass (expressed as chlorophyll-a concentration) to manage trophic state.

Attribute states for *E.coli*, NH_4-N and NO_3-N 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.

Three additional example objectives were also selected for analysis in this report: 1) primary contact recreation (swimming); 2) water clarity; 3) ecological health based on the Macroinvertebrate Community Index (MCI: see Stark 1985) and its quantitative variant (QMCI). 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 visual clarity are based on the MFE (1994) guideline of clarity of > 1.6 m to be suitable for swimming. For the discussion that follows, this visual clarity objective was subsequently based on the median of all water quality samples collected, but we acknowledge that more detailed criteria (e.g. clarity values collected only during low flows and/or summer sampling occasions) are possibly more appropriate, and could be evaluated.

For the third objective (relating to ecological health), we used four "water quality" bands suggested by Stark and Maxted (2007) for both the MCI and QMCI scores. Thus, the A band referred to streams in "Excellent" condition, and the D band referred to streams in "Poor" condition. All example water quality objectives are summarised in Table 1.

[15] Objective A2 and Policy A1, NPS-FM

Table 1: Band options for example water quality objectives. The asterisk indicates attributes that are compulsory under the NPS-FM.

Attribute	**Units**	**Statistic**	**Criteria for bands**			
			A (Excellent)	**B (good)**	**C (Poor)**	**D (Unacceptable)**
Human health – secondary contact*	E.coli/100ml	Median	x ≤ 260	260≤ x ≤540	540 ≤ x ≤ 1000	x ≤ 1000
Human health – primary contact	E.coli/100ml	95^{th}	x ≤ 260	260 ≤ x ≤ 540	540 ≤ x ≤ 1000	x ≤ 1000
NO_3N toxicity*	mg/m^3	Median	x<1000	1000< x < 2400	2400 < x < 6900	>6900
	mg/m^3	95^{th}	x<1500,	1500 < x < 3500	3500 < x < 9800	>9800
NH_4N toxicity*	mg/m^3	Median	x<30	30 < x < 240	240 < x < 1300	>1300
	mg/m^3	95^{th}	x<50	50 < x < 400	400 < x < 2200	>2200
Periphyton cover*	$chl\text{-}a/m^2$	92^{nd}	x<50	50 < x < 120	120 < x <200	>200
MCI	Not applicable	Median	x >119	100 < x < 119	80 < x <100	x < 80
QMCI	Not applicable	Median	x >4	4 < x < 5	5 < x < 6	x < 6
Visual clarity	m	Median			>1.6	X < 1.6

3.3 Assessment of current state of river water quality

We evaluated the current state of river water quality and ecological health at 24 sites (shown in Figure 3), using data provided by the council's long-term monthly river State of the Environment (RSoE) monitoring programme (labelled RS* in Figure 3), as well as one site monitored as part of a targeted study on the Enaki Stream (ES1) and three sites that are monitored by NIWA as part of the National Water Quality Network (labelled WN* in Figure 3). A total of 24 sites were used for the water quality variables, of which the 20 SoE sites also included annual macroinvertebrate monitoring and all but two SoE sites (RS36 and RS39) also had annual periphyton monitoring (Figure 3). Table 2 provides a summary of the number of sites within each of the *management classes*.

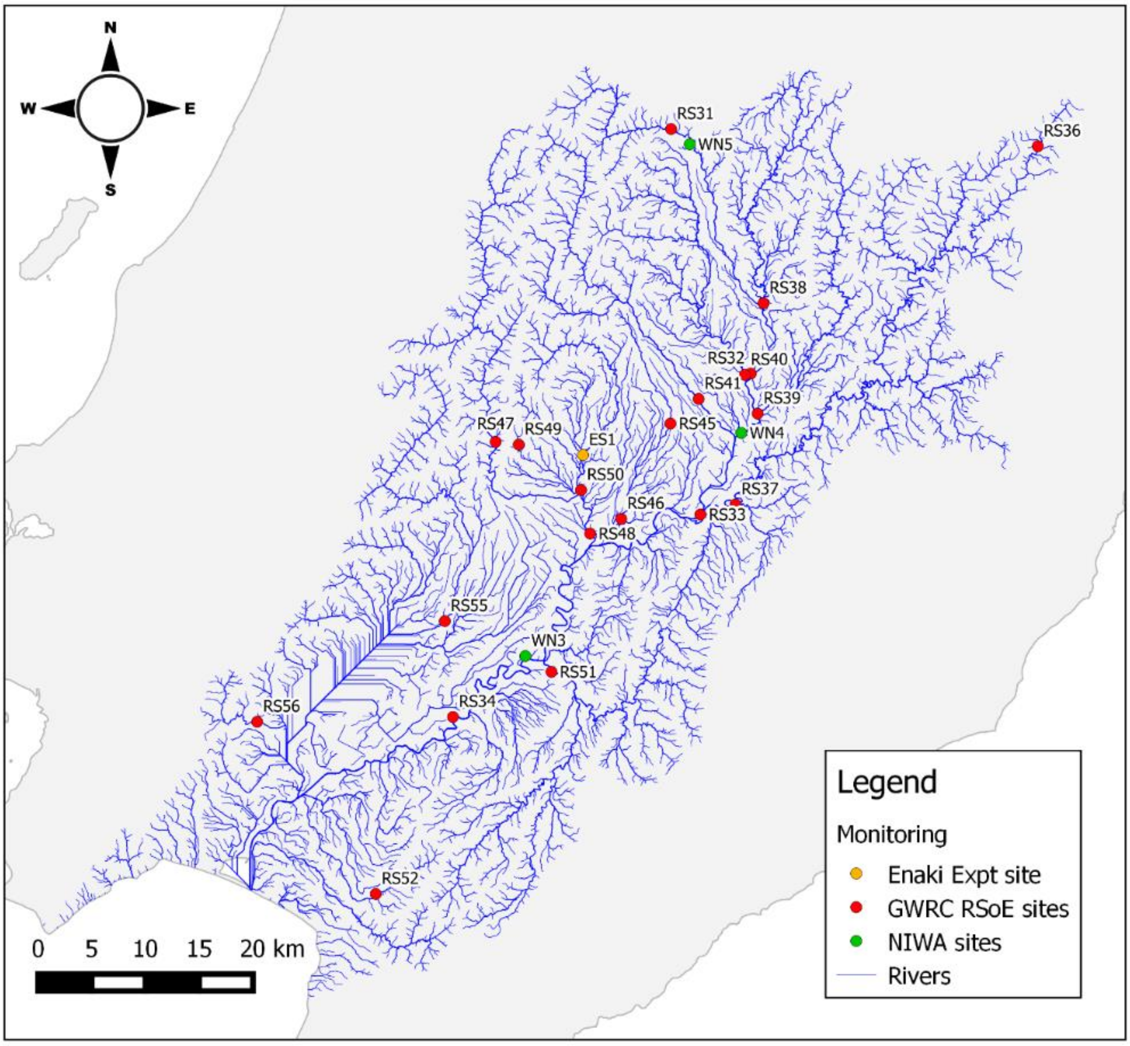

Figure 3: Location of water quality and invertebrate monitoring sites.

Table 2: Distribution of water quality and invertebrate monitoring sites within the proposed management classes. See Figure 2 for explanation of the water quality management classes.

Water quality management class	Number of Water quality sites	Number of invertebrate sites	Number of Periphyton Sites
D+HS	2	2	2
D+SS	3	3	2
MS	3	2	2
W+HS+Hill	9	8	8
W+HS+Low	3	2	2
W+SS	4	3	2

In this report, we evaluated current water quality state based on statistics derived from data pertaining to the ten-year period Sept 2006 – Sept 2015. The current state of rivers and streams in the Ruamāhanga is illustrated in Figure 4 as the distribution of site median values for the water quality variables, Periphyton, QMCI, MCI and 95th percentile values for *E.coli*. MCI and QMCI scores are based on the hard bottomed scores provided by GWRC staff. The distributions are shown for the six classes of the water quality *management classification*. Figure 4 indicates that, in general, concentrations of nutrients are lowest in waterways in the W+HS+Hill management class, and highest in the D+HS class. MCI and water clarity were generally highest in the W+HS+Hill class, and lowest in the Dry climate classes.

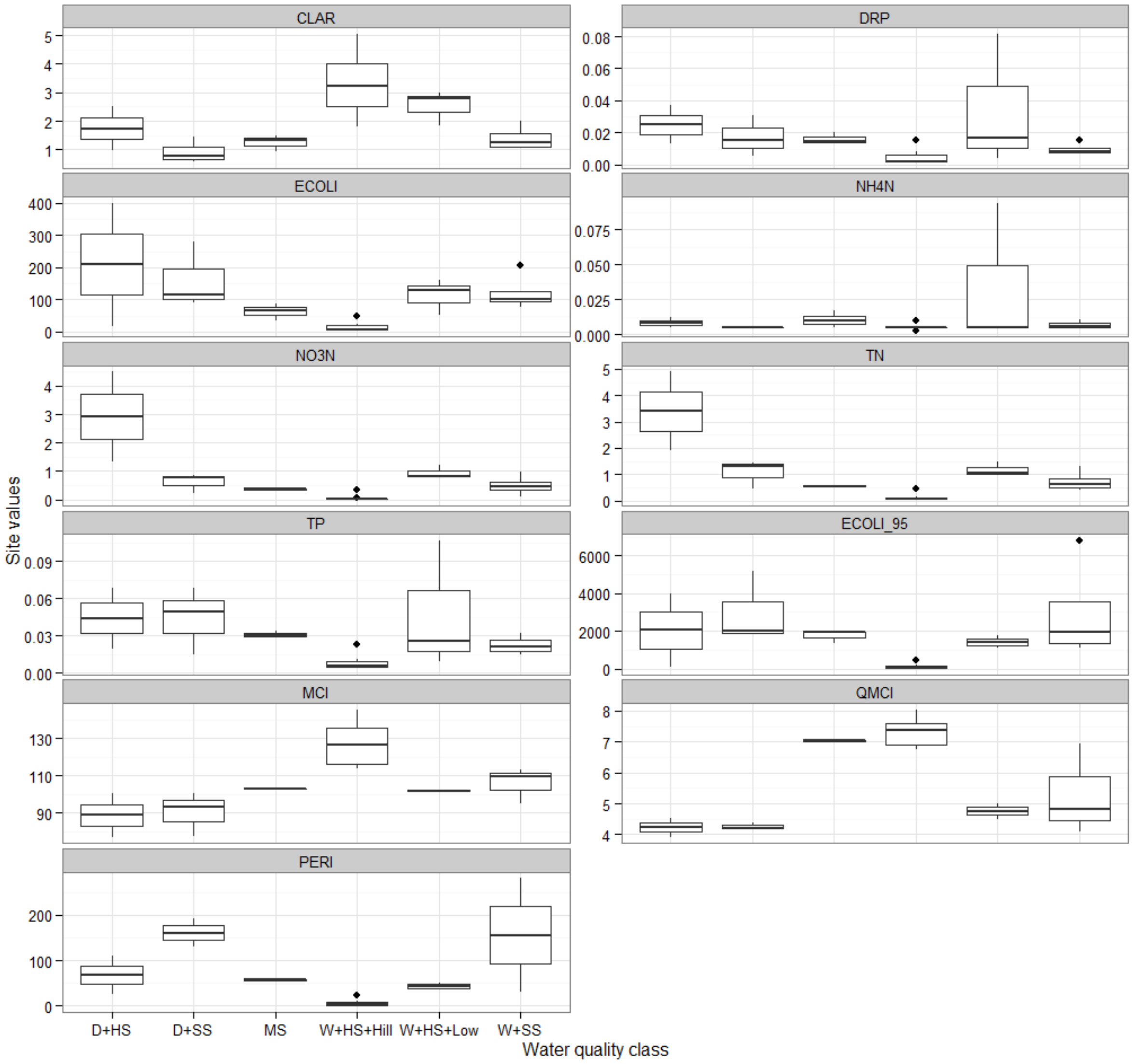

Figure 4: Box and whisker plot showing the distributions of site water quality for 11 variables measured at council's long-term monitoring sites. The variables include; clarity (CLAR), macroinvertebrate community index (MCI), Quantitative macroinvertebrate community index (QMCI), Periphyton cover (PERI), 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 24 water quality monitoring sites, 20 invertebrate sites (MCI and QMCI) and 18 periphyton sites. The data are grouped by the six proposed water quality management classes: D+HS (Dry+Hard Sedimentary), D+SS (Dry + Soft Sedimentary), MS (Main Stem), W+HS+Hill (Wet + Hard Sedimentary + Hill), W+HS+Low (Wet + Hard Sedimentary +Low) and W+SS (Wet + Soft Sedimentary). The individual water quality site values were derived from data for the 10 year period ending Sept 2015. The central horizontal line indicates the median, and the bottom and top of the box indicate the 25th and 75th percentile values. The 'whiskers' (vertical lines) extend to the 10th and 90th percentiles. Where the number of outlier sites exceeded 10, the black points indicate the 5th and 95th percentiles.

An assessment of the current state of the six water quality *management classes* relative to example objectives (listed in Table 1) is shown inTable 3. 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". Note, for NH_4-N and NO_3-N each site is assigned the lower class for either the median or 95th percentile criteria described in Table 1. As periphyton cover is only monitored annually, we have assumed that this sample reflects annual maximum biomass (as measured using percent cover), and hence each annual sample is equivalent to the annual 92nd percentile value that is required by the NOF based on monthly samples (i.e. the biomass exceeded by 1 in 12 samples). We have therefore compared the ten-year median of the annual periphyton observations against the periphyton objective in Table 1.

Table 3: Current state of the six proposed water quality management classes compared to several example objectives. The selected objective could be state band A, B or C, recognising that D band fails NPS-FM bottom lines, but must maintain overall water quality. Data are percentages of sites in each management class that achieve each of the state bands. The asterisk indicates attributes that are compulsory under the NPS-FM.

Objective	**State band**	**Proposed water quality management class**					
		D+HS	**D+SS**	**MS**	**W+HS+Hill**	**W+HS+Low**	**W+SS**
No. of Sites		2	3	2	8	2	3
MCI	A	0%	0%	0%	62%	0%	0%
	B	50%	33%	100%	38%	100%	67%
	C	0%	33%	0%	0%	0%	33%
	D	50%	33%	0%	0%	0%	0%
QMCI	A	0%	0%	100%	100%	0%	33%
	B	0%	0%	0%	0%	50%	0%
	C	50%	100%	0%	0%	50%	67%
	D	50%	0%	0%	0%	0%	0%
No. of Sites		2	2	2	8	2	2
Periphyton*	A	50%	0%	100%	100%	50%	50%
	B	50%	100%	0%	0%	0%	0%
	C	0%	0%	0%	0%	50%	50%
	D	0%	0%	0%	0%	0%	0%
No. of Sites		2	3	3	9	3	4
Clarity	Pass	50%	0%	0%	100%	100%	25%
	Fail	50%	100%	100%	0%	0%	75%
E.coli (Prim. con. recr.)	Pass	50%	0%	0%	100%	0%	0%
	Fail	50%	100%	100%	0%	100%	100%
Ecoli (Sec. con. recr.)*	A	50%	67%	100%	100%	100%	100%
	B	50%	33%	0%	0%	0%	0%
	C	0%	0%	0%	0%	0%	0%
	D	0%	0%	0%	0%	0%	0%
NH_4-N toxicity*	A	50%	67%	33%	100%	67%	75%
	B	50%	33%	67%	0%	33%	25%
	C	0%	0%	0%	0%	0%	0%
	D	0%	0%	0%	0%	0%	0%
NO_3-N toxicity*	A	0%	33%	100%	100%	0%	100%
	B	0%	67%	0%	0%	100%	0%
	C	100%	0%	0%	0%	0%	0%
	D	0%	0%	0%	0%	0%	0%

The assessment indicates that the periphyton bottom line is met at all of the monitoring sites. All sites in all classes are above the bottom line for human health - secondary contact recreation. The Dry classes are in a marginally poorer state for secondary contact recreation (3 sites in total in B compared to 0 for the other classes). Most sites in all classes fail to meet primary contact recreation standard, with the exception of W+HS+Hill sites which all meet the objectives (note this is not a compulsory NPS-FM national bottom line).

All sites are above the bottom line for the two toxicants: NH_4-N and NO_3-N. For NH_4-N, sites are exclusively in the A band for the W+HS+Hill sites, predominantly in the A band in the D+SS, W+HS+Low and W+SS classes and predominantly in the B band for D+HS and MS sites. For NO_3-N sites are entirely (100%) in the A band in the MS and W+HS+HIll classes, predominantly and entirely in the A band in the D+SS and W+HS+Low classes and entirely in the C band in the D+HS class.

Median site MCI scores were predominantly in the A band in the W+HS+Hill class, predominantly or entirely in the B band for MS, W+HS+Low and W+SS classes, and between the B and D classes for the Dry classes (50% of sites in the D-band for the D+HS class and 33% of sites for the D+SS class).

Both Wet+Hard sedimentary classes met the MfE water clarity guidelines; in contrast, the Soft sedimentary classes performed worse, and all sites within D+SS and MS classes failed to meet the guidelines.

In addition to examining the current state of water quality and ecological health, we also evaluated the data for trends. A full explanation of the methods used to assess trends is provided in Appendix B, along with supplementary figures. Table 4 provides a summary of the trend analysis by water quality *management class*. Trends that were not statistically significant are described as uncertain.

For the majority of water quality variables and periphyton, improvements are associated with decreases in measured concentrations (with the exception of clarity, for which improvements are associated with increases in measured values), while for ecological metrics, improvements are associated with increases in MCI or QMCI scores. Overall, there were very few sites within each of the classes to evaluate trends, and as such it is difficult to make meaningful generalisations and comparisons of the trend distributions between the other classes.

Table 4: Summary of trends for the period 2006-2015 for QMCI, MCI and periphyton data and July 2006-Sept 2015 for water quality variables for the six proposed water quality classes. The number of sites for each variable is lower than the total number of monitoring sites because several sites had insufficient information to calculate trends. Trends that were statistically significant and non-zero are described as either degrading or improving.

Objective	Trend	Proposed water quality management class					
		D+HS	D+SS	MS	W+HS+Hill	W+HS+Low	W+SS
Clarity	No. of sites	1	2	3	8	2	4
	Improving	100%			50%	50%	
	Degrading						
	Uncertain		100%	100%	50%	50%	100%
DRP	No. of sites	2	1	3	3	2	3
	Improving	50%		33%	33%	50%	
	Degrading		100%				33%
	Uncertain	50%		67%	67%	50%	67%
E. coli	No. of sites	1	3	3	9	3	4
	Improving				11%	33%	
	Degrading				11%		
	Uncertain	100%	100%	100%	78%	67%	100%
NH4N	No. of sites	0	0	1	1	1	1
	Improving						
	Degrading						
	Uncertain			100%	100%	100%	100%
NO3N	No. of sites	2	3	3	9	3	4
	Improving		33%			33%	
	Degrading				11%		25%
	Uncertain	100%	67%	100%	89%	67%	75%
TN	No. of sites	2	2	3	2	3	4
	Improving		50%			67%	
	Degrading						
	Uncertain	100%	50%	100%	100%	33%	100%
TP	No. of sites	1	3	3	4	3	4
	Improving	100%		33%	25%	33	25%
	Degrading						
	Uncertain		100%	67%	75%	67%	75%
MCI	No. of sites	2	3	2	8	2	3
	Improving						
	Degrading	50%			12%		
	Uncertain	50%	100%	100%	88%	100%	100%
QMCI	No. of sites	2	3	2	8	2	3
	Improving						
	Degrading				25%		67%
	Uncertain	100%	100%	100%	75%	100%	33%
Peri	No. of sites	2	2	2	8	2	2
	Improving	50%			12		
	Degrading						
	Uncertain	50%	100%	100%	88%	100%	100%

It is difficult to rank the different classes in terms of overall water quality, as there is some variability between rankings according to the water quality variable of interest and the analysis of trends does not strongly indicate consistent patterns in direction for particular classes. In general, the highest water quality is in the W+HS+Hill class, and the lowest water quality was in the Dry classes. To develop a more objective ranking of the water quality across the six classes, we took the proportion of sites within each band (Table 3), and applied weights of 1, 2, 3 and 4 for each of the A, B, C and D bands respectively (or 1 for pass and 4 for fail). Summing across all variables provides a total water quality score, where a lower number indicates higher water quality. The scores and rankings derived based on this method for each of the six water quality management classes are shown in Table 5.

Table 5: Summary of overall water quality based on scores and associated rankings for each of the proposed water quality classes and rankings for the percentage of degrading and improving trends within each management class. Low rankings indicate high water quality, minimal degrading trends and maximal improving trends.

Management Class	WQ Score	WQ Ranking	Rank degrading trends	Rank improving trends
D+HS	19.0	5	2	2
D+SS	20.3	6	4	6
MS	15.7	2	1	5
W+HS+Hill	8.4	1	5	4
W+HS+Low	15.8	3	3	1
W+SS	17.2	4	6	3

The W+HS+Hill class currently has the highest water quality. However, it has one of the largest percentage of sites with degrading trends and lowest percentage of sites with improving trends (Table 5). The Ruamāhanga River main stem (MS) has relatively high water quality and predominantly improving trends (where these were certain). The poorest overall water quality is associated with the D+SS and D+HS classes followed by the W+SS class.

The minimum requirement of the NPS-FM is to maintain the overall quality of fresh water. Policies will, therefore, need to address degrading trends in some classes to ensure that current state is at least maintained. The NPS-FM requires freshwater objectives to be set at better than current state for water bodies that are currently in the D-band (i.e., below national bottom lines) (e.g., the Dry classes). Improvement of current state may also be considered an appropriate aspiration in other classes (i.e., seeking water quality improvements). Based on the results in Table 3 and Table 4, and a default objective to maintain current state, it is likely that justifiable objectives will be more environmentally protective (i.e., nutrient, *E. coli* or periphyton values will be lower) in the W+HS+Hill class than the MS, W+HS+Low and W+SS classes, which in turn will be more protective than the D+SS and D+HS classes. Under these circumstances, policies and in particular limits, may need to be more restrictive (less enabling of resource use) in the catchments of the W+HS+Hill class, followed by the catchments of MS, W+HS+Low and W+SS classes then the D+SS and D+HS classes. The aggregation of all catchments draining to each class is a *management zone* and the definition of these zones requires consideration of the relative levels of restrictiveness of the policies and limits to achieve the downstream objectives. We stress that this set of objectives is an example that we have suggested in order to show how water quality management zones can be derived. A final set of management zones could be derived using the same methods as used here once objectives and policies are determined by the Whaitua process.

3.4 Water quality management zones

The *management zone* for any given *management class* is defined as the land area that drains to that *management class.* Hence, the *management zone* delineates the land area that must be managed in order to achieve the objectives of the given *management class*. The management zones for the proposed water quality management classes are shown in Figure 5. Any given location within the Ruamāhanga Whaitua may be within one or more management zones, depending on how many different management classes are downstream of that location. These management zone maps form building blocks for defining the FMU framework.

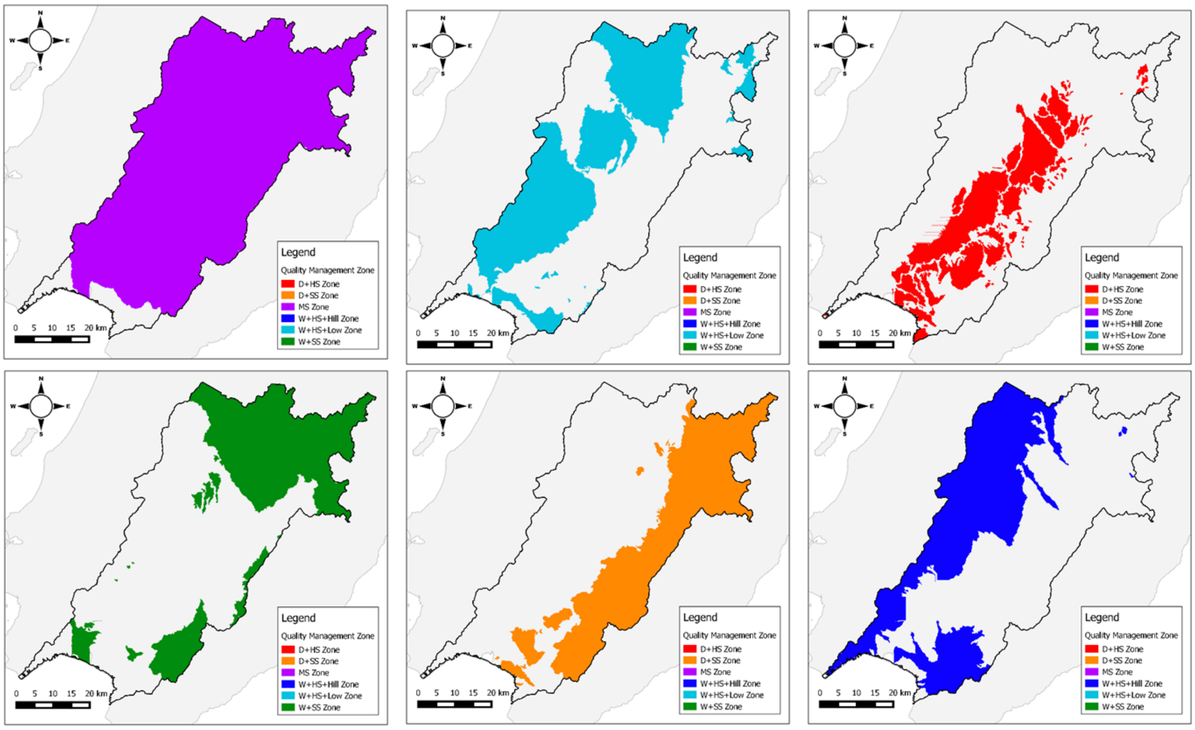

Figure 5: Management zones for each of the proposed water quality management classes.

This study is not able to define the final layering of the management zones because this is dependent on objectives and associated policies and limits. However, we provide a credible example of *FMUs* for the Whaitua based on the assessment of water quality provided above. It is anticipated that this set of example FMUs will be altered as the Whaitua process proceeds.

In this example, we have assumed that the *management zones* of *management classes* with the best water quality scores (Table 5) will be associated with the most restrictive policies and limits (because they will be likely to have more protective objectives), and therefore take precedence to those classes with lower water quality. This structure of *management zones* preserves the potential to define more restrictive policies and limits in the parts of the catchment that currently have better water quality and is illustrated in Figure 6.

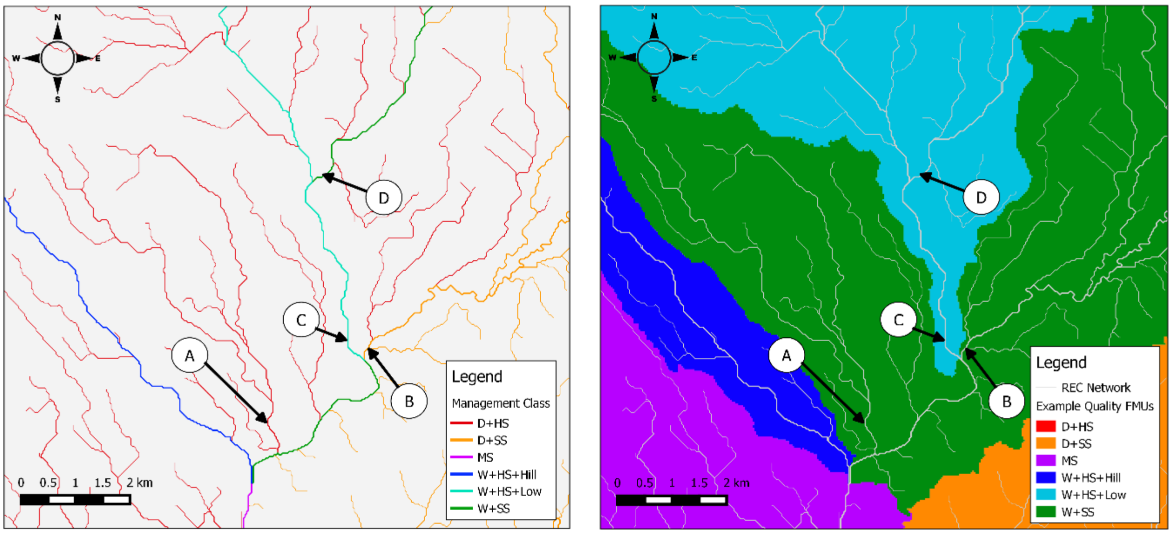

Figure 6: Zoomed view of the relationship between the proposed water quality management classification (left) and the FMUs (right). The arrow marked A indicates segments belonging to the D+HS (red) class flowing into segments belonging to the more restrictive W+SS (green) class; the arrow marked B indicates segments belonging to the D+SS (orange) class flowing into segments belonging to the more restrictive W+SS (green) class; the arrow marked C indicates segments belonging to the W+HS+Low (light blue) class flowing into segments belonging to the less restrictive W+SS (green) class; the arrow marked D indicates segments belonging to the W+SS class flowing into segments belonging to the more restrictive W+HS+Low (light blue) class. The FMU for any location reflects the most restrictive class downstream of that location. Therefore, catchments of D+HS or D+SS class rivers flowing into W+SS class (see Points A and B, left map) belong to the W+SS FMU (right map), catchments of W+SS class rivers flowing into W+HS+Low class (see Point D, left map) belong to the W+HS+Low FMU (right map), and catchments of W+HS+Low rivers flowing into W+SS class (see Point C, left map) belong to the W+HS+Low FMU (right map).

When assigning precedence to the order of *management zones,* we assigned the lowest precedence to the Main Stem class (MS). This assumes that objectives for the MS class would be achieved by actions taken to achieve objectives in management classes upstream of the MS class. This may not be the case and all FMUs upstream of the MS class will need to consider and be consistent with any management regime associated with the MS management zone. If during plan development it becomes apparent that more restrictive policies and limits are required to meet objectives in downstream areas, the layering and merging of the management zones would be altered. This could allow for zones to be either merged or might require more restrictive policies to be applied in the upper catchments for the purpose of achieving downstream objectives (e.g. objectives in the MS management class). Therefore, the example *FMUs* offered here may need adjustment as the plan process proceeds. However, assuming the proposed management classification proves appropriate, the *management zones* defined in this study (Figure 7) provide the building blocks to define FMUs for the Whaitua. Furthermore, the building blocks can be assembled to reflect the objectives, policies and limits that are developed through the plan process; hence the approach preserves flexibility to make adjustments.

The resulting example FMUs (Figure 7) have small, isolated patches of land in belonging to a zone that are surrounded by large contiguous areas that belong to another zone. Some of these areas may be too small for the practical application of policies, and these could be merged with the surrounding zone. An objective method of merging these small isolated patches is to combine segments that are below a nominated stream size (e.g., using a threshold based on stream order, which is a measure of its size) with the *FMU* assigned to the next downstream segment. Figure 8 demonstrates the difference in the *management zones* when this method is used with a stream order threshold of 1 (all river network reaches included) and a minimum stream order of 3.

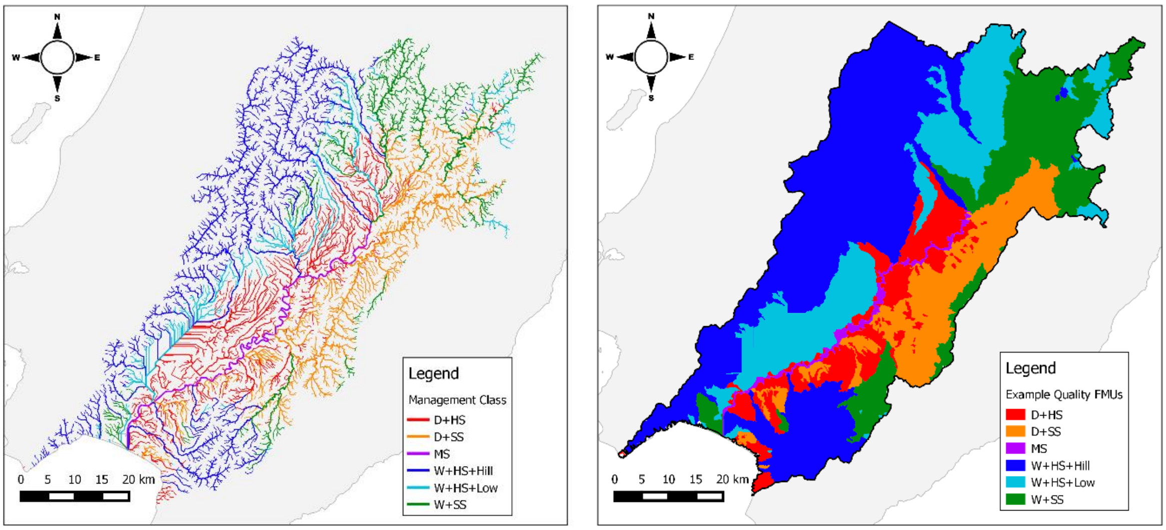

Figure 7: The proposed water quality management classes and example FMUs for the Ruamāhanga Whaitua. The management classes are shown on the left, and the associated FMUs are shown on the right.

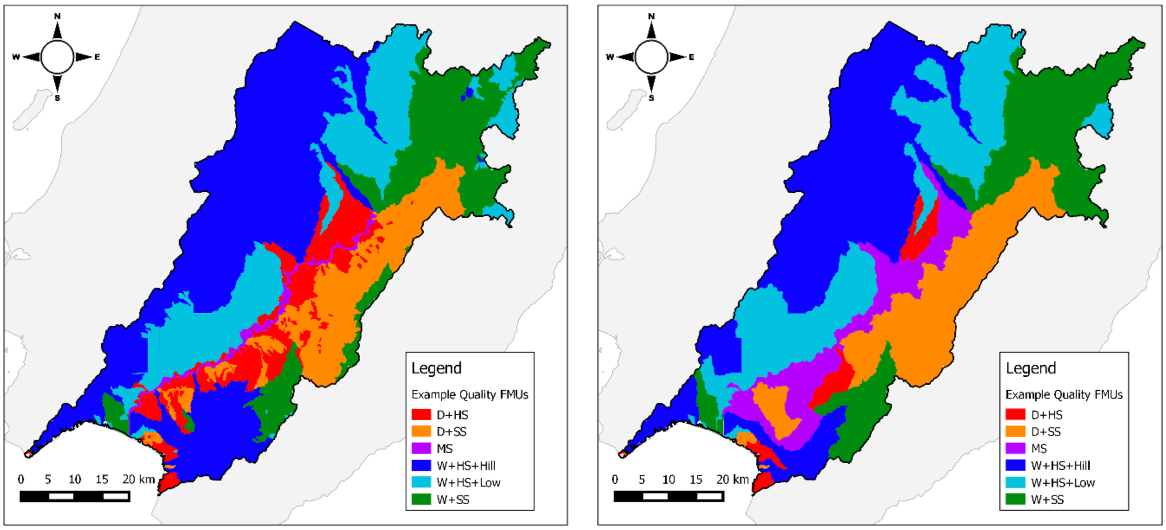

Figure 8: Reduction in the spatial detail of management zones based on merging FMUs using stream order. The example water quality FMUs based on including all river segments (left). In the right hand plots rivers less than or equal to the minimum order threshold of 3 have been merged with their downstream FMU, thereby decreasing the number of individual areas belonging to each FMU.

The six *management zones* are likely to be associated with differing policies, including limits. For example, the relatively good state of the W+HS+Hill zone may be reflected in relatively few management actions but limits will be more restrictive to maintain current state.

Consideration of development pressure and trends is likely to influence the actions and limits in this zone. The Dry zones may be associated with more management actions because the suggested objectives are not always being achieved and trends indicate that some aspects of water quality are degrading, but limits are likely to be less restrictive (i.e. more enabling of discharges of contaminants) than the other zones.

3.5 Water quality administrative points

The points where the *FMUs* change are locations in the network where management actions and limits also change. These points (along with the river coastal outlets) are therefore a minimum set of locations where contaminant load limits apply, and where resource use accounting needs 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 9*.

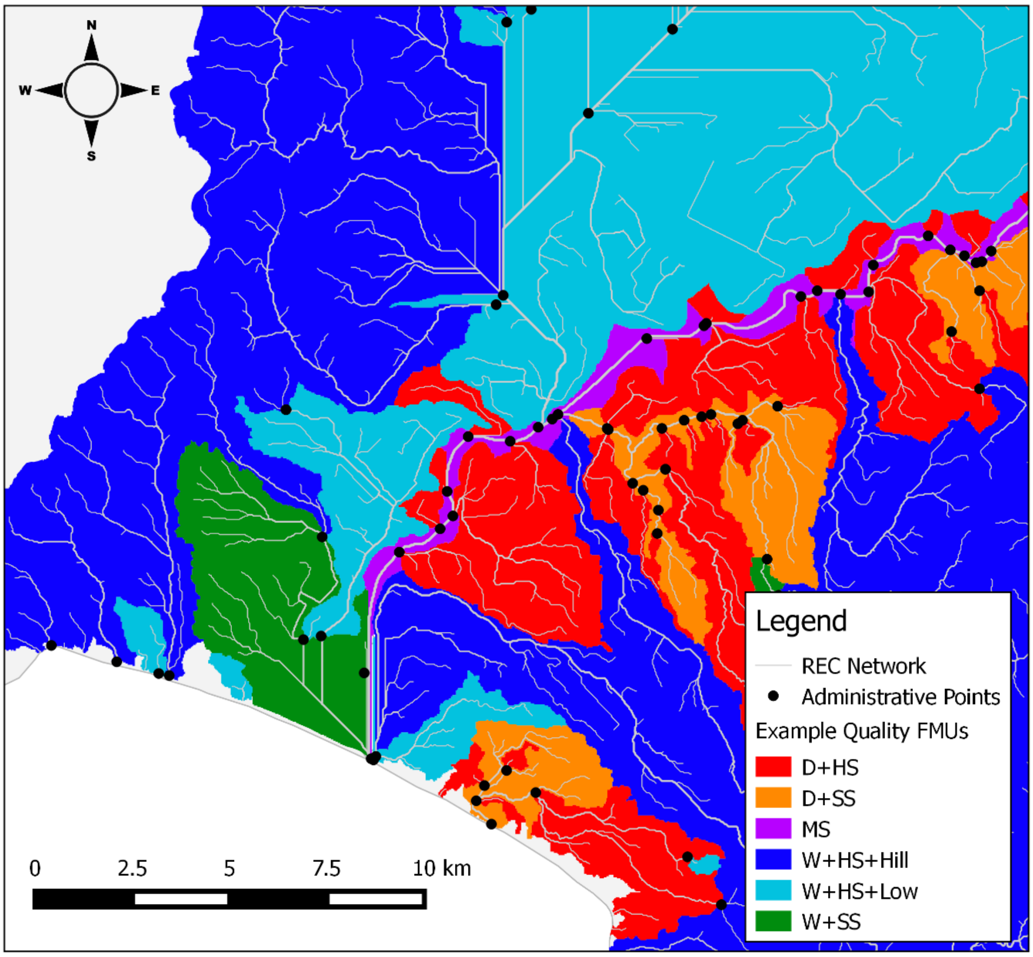

Figure 9: Zoomed in view of the example water quality FMUs. The grey lines represent the drainage network. The black dots represent points at which the FMU changes and are relevant administrative points where limits need to apply and resource use accounting needs to occur. The classes in this figure are based on classes defined with all rivers from order one and up.

Decreasing the resolution of the FMUs (e.g. Figure 8) will also decrease the number of *administrative points*. A minimum possible number of *administrative points* for the Ruamāhanga Whaitua is 25, which is the total number of sea draining catchments within the region. Table 6 demonstrates how the number of *administrative points* reduces as the stream order threshold increases.

Table 6: Variation in number of administrative points with increasing coarseness of the definition of the FMUs. Rivers less than or equal to the minimum order threshold are merged with their downstream FMU, thereby decreasing the number of individual areas belonging to each management zone and administrative points.

Minimum order threshold	Number of administrative points
All segments	439
1	182
2	105
3	62
4	43
5	32

3.6 Special Management Zones

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 associated with specific objectives and management actions. These water bodies are likely to require separate objectives and associated management actions and/or limits. Water bodies requiring separate management objectives are likely to be sites of particular significance e.g. swimming spots, or sites of special cultural or ecological significance.

Water bodies requiring special objectives can be identified and treated as a special class and the catchments upstream of these water bodies would be a *special management zone.*

A potential example of a *special management zone* is Lake Wairarapa and its catchment (Figure 10). Objectives for the lake will be specific to that water body and actions to achieve those will occur in the lake's catchment. A special management zone can be added to the other management zone building blocks and incorporated into the FMU definition following the layering process described earlier.

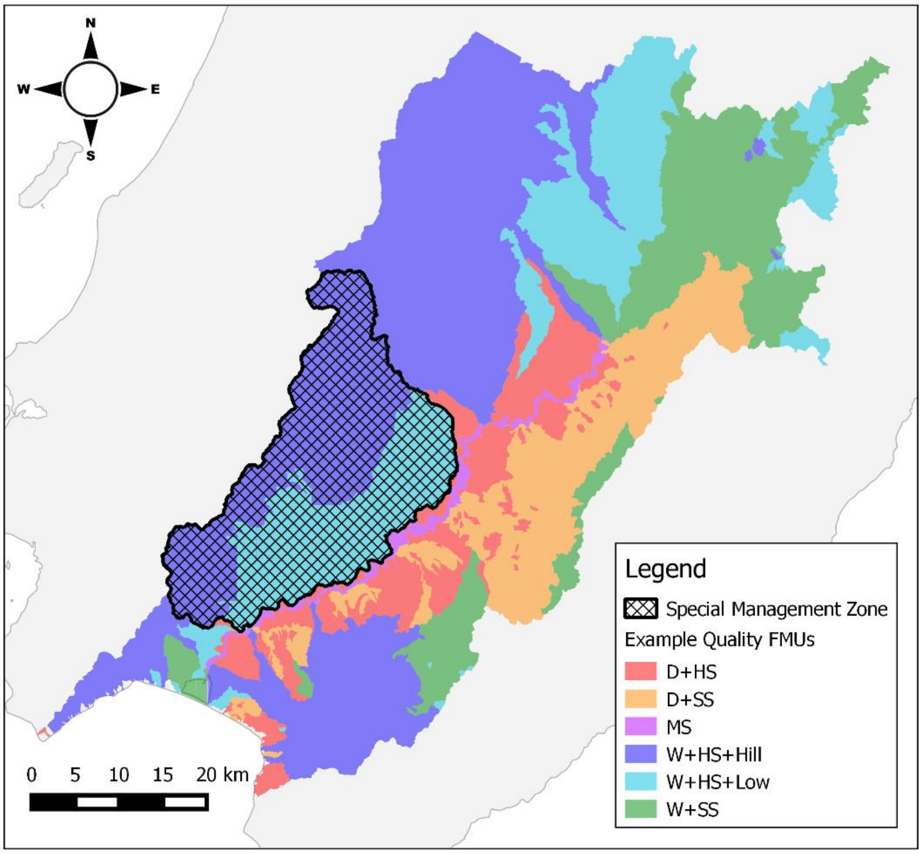

Figure 10: Example of a water body with special water management issues that may require a special management zone.The figure shows Lake Wairarapa and its upstream catchment (the management zone). The objectives set for Lake Wairarapa may not be achieved by policies and limits that are relevant to the objectives set for the management class that the upstream water bodies belong to. A special management zone that comprises the entire catchment of Lake Wairarapa would enable policies and limits that are relevant to the lake's objectives to over-ride those set for the rivers that feed it, should they be more restrictive.

3.7 Next steps – water quality FMUs

The analysis carried out by this study indicates that there are important differences in the current state of the six proposed water quality management classes. These differences, plus differences in values and community aspirations, including development, will need to be considered in order to define objectives and management regimes for each management class and its management zone. The structure of the final FMUs will depend on which management classes require the most restrictive policies and limits. The FMUs defined in this study can be easily modified once the relevant objectives and management regimes are defined by using the *management classes* and associated *management zones* as building blocks.

Monitoring would be carried out at a network of sites judged to include sufficient representation of each class of the water management classification. This might comprise the existing river water quality monitoring network, which has a reasonable number of sites in all six 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 Whaitua scale.

Where particular sites indicate there are water quality issues (i.e., where objectives are not being met), or there are locally specific values, the objectives and/or policies that apply to a particular class may need to be over-ridden by more specific catchment level provisions. Hence the approach could be used to define regionally consistent provisions or could be modified by more specific provisions that apply to a specific site.

The points at which any resource use limits need to be met and accounting for resource use needs to occur are the administrative points at which the FMU 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 need not necessarily result in a complicated plan.

If water quality limits were defined in terms of contaminant loads, limits for all *administrative points* could be defined on a scalable (area) basis (i.e., average kg/ha/yr) and the absolute loads could then be assessed as part of plan implementation and administration rather than needing to be defined in the plan. It is noted that the NPS-FM does not specify that 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. It remains to be determined whether load based contaminant limits are necessary and how they could work for the Ruamāhanga Whaitua, but the framework suggested here would provide a basis for management of loads should that be considered necessary.

Finally, it is emphasized that the approach to defining FMUs using the bio-physically based approach offered in this report represents an initial step of a Whaitua planning process. This process and in particular the consideration of values, objectives, limits and other plan provisions may identify reasons to review and refine the example FMUs offered in this report. The approach used here is flexible and able to accommodate change if this is found to be appropriate.

4 Water quantity FMUs

4.1 Overview of water quantity management objectives

The suggested approach to defining FMUs for water quantity management follows the same process to that set out above for water quality. For plan simplicity, it would be preferable 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 are required.

An important difference between water quantity and quality is that many water takes require consents, whereas the major pressure on water quality is diffuse discharges associated with the use of land, which has historically typically not been subject to individual resource consents. Significant water take activities have consents that are subject to conditions (e.g. the allowable rate or volume of the take, and minimum flows). There are also permitted uses of water for stock drinking and reasonable domestic use.

The second difference between quality and quantity objectives is that there are no NPS-FM attributes directly 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 NPS-FM, details are described by Snelder *et al.* 2013). 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[16] loss, and both a maximum and a minimum level of reliability of supply. Moreover, habitat and reliability of supply can be considered as specific attributes[17] with respect to instream values and consumptive water takes, respectively.

The details of how water quantity objectives and their associated limits are defined are complicated; 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 instream value (e.g. a specific fish species, recreational use or landscape characteristic) and need to maintain it at a suitable level.
3. The reliability of takes.
4. The flow regime and the allocation rate.

Hydraulic habitat suitability involves measures of a river's width, depth and velocity, all of which determine the suitability of the stream or river to a specific instream value (e.g. aquatic species such as fish). Flow management decisions have been, to date, most commonly concerned with maintaining ecosystem values and focus on ecosystem components that have the highest flow requirements, which are generally fish. 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. It is noted that other instream values can have higher flow requirements than fish, such as some recreation activities (e.g. kayaking) or maintenance of natural character, and these have also been considered in specific limit setting process in parts of the country.

Generally, the suitability of hydraulic habitat for fish is highest at some intermediate flow and decreases as flow either increases (e.g. velocities or depth become too high) or decrease (e.g. depth, width and velocity become too low). The shapes of these relationships vary for different fish species. Because abstractions reduce flows in rivers, they will also 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 on a specific habitat-flow curve at which any further reduction in hydraulic habitat due to abstraction is unacceptable. River flows naturally decrease during summer, and fish species can generally tolerate these natural low flows. The selected level of habitat availability to be maintained is therefore usually based on some percentage of hydraulic habitat available at natural low flows e.g. Mean Annual Low Flow (MALF).

[16] 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 hydraulic 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).

[17] In the NPS-FM attributes are measurable quantities that are used to define freshwater (i.e. numeric) objectives. Hydraulic habitat and reliability are similarly measurable quantities that can be used to define objectives but they are not currently included as attributes in the NPS-FM.

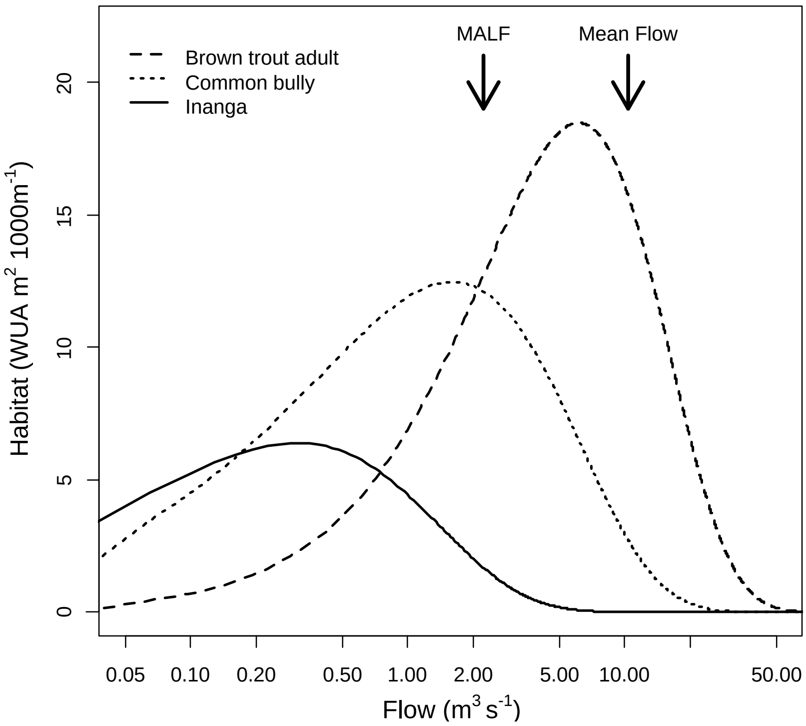

Figure 11: Change in hydraulic habitat with change in flow. The plot shows how Weighted Usable Area (WUA) changes with flow for three common fish species at a site. The Mean Annual Low Flow (MALF) and mean flow at the site are shown. The plot shows that reduction in habitat with flow varies by species and therefore decisions about minimum flows are sensitive to the adopted critical instream value. Figure adapted from Snelder et al. (2013).

The rate of reduction in hydraulic habitat suitability caused by flow modification varies between different fish species. For example, habitat suitability for large fishes such as trout generally decreases with flow reductions more quickly than it does for smaller fishes that can tolerate shallower and slower moving water (Figure 11). The choice of fish species (or more generally the “instream value”) for setting the minimum flow is therefore important, as the amount of available habitat, and therefore the level of habitat protection relative to MALF will differ between species at any specific flow.

There are often many different fish species in a river. Flow setting processes therefore tend to define a “critical instream value”, which is a species that is a) considered important or significant for some reason at a particular location and b) is the most sensitive to flow reductions. The assumption is that if the minimum flow is set to maintain the hydraulic habitat for the critical instream value at a specific level (i.e. the objective) then other less sensitive values such as different fish species that can tolerate lower flows 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. The distribution of river flows can be shown by a flow duration curve (FDC), which indicates the frequency that flows are equal to or greater than any particular flow (e.g., Figure 12). The position of the minimum flow on the FDC is a measure of the reliability of the river as a water supply for abstractors (the red lines in Figure 12). 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.

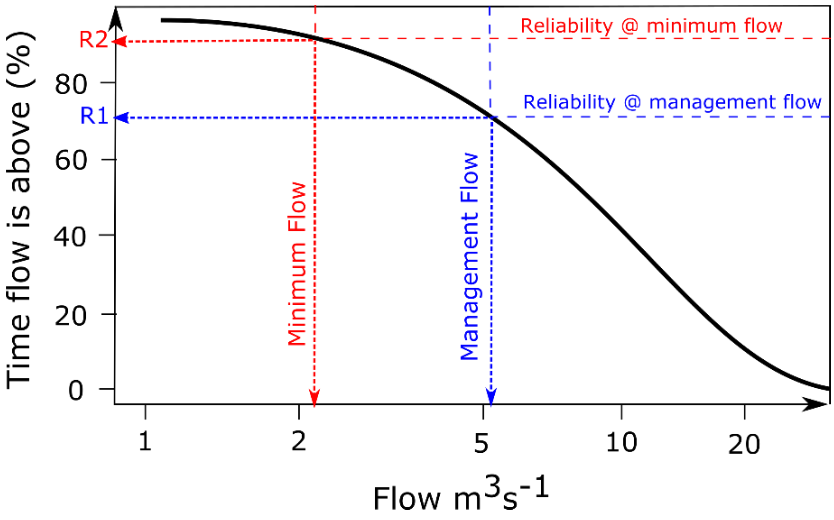

Figure 12: Example FDC. The minimum flow and management flows and their reliabilities (% of time these flows are exceeded) are indicated as positions on the FDC.

In theory, reductions in takes (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 can also be shown on a FDC (the blue lines in Figure 12). 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 in total to all users) and the reliability of supply for each individual user that is deemed acceptable. The exact values of the two measures of reliability depend on the distribution of flows, which is often referred to as the flow regime and is broadly indicated by the shape of the FDC.

In this study, we have defined minimum flows and allocation limits in terms of the Mean Annual 7-day Low Flow (MALF). The MALF[18] is often used for setting water quality limits because it is a measure of water availability during periods of relative scarcity. Another measure to use is the Q_5 7-day low flow, which is the average 7 day low flow period that occurs once every 5 years. 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 a little less than that available at MALF means that habitat for aquatic species such as fish is maintained at levels that are not too reduced from natural low flows occurring in most years. 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.

The present study uses model simulations to explore the impact of different minimum flow and allocation limits on supply reliability and environmental outcomes for all river segments

[18] 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).

within the region; the modelling is described in detail in section 4.3. We used the model simulations to explore classifications that group together river segments that have relatively similar responses to the same limits in order to define spatially distinct water quantity *management classes*.

4.2 Proposed water quantity management classification

This section presents a proposed water quantity *management classification*. We firstly considered the water quality management classification as a starting point and examined how well this classification regime could discriminate variation in habitat (for a range of relevant fish species) and reliability (R1 and R2; Figure 12) using the same ANOVA approach described earlier. We also considered the addition of an additional factor to describe the size of the river as "Large" (mean flow >$5 m^3 s^{-1}$) or "Small" (mean flow >$5 m^3 s^{-1}$). This additional factor was included because changes in habitat are sensitive to flow magnitudes, and because it is likely that large and small rivers might be managed for different fish species. Using a flow magnitude of $5 m^3 s^{-1}$ to further classify rivers is consistent with the approach used in the proposed National Environmental Standard (NES) for Flows and Levels (MFE 2008).

The addition of the river size factor did not produce a significant improvement in the r^2 values for R1 and R2. However, on average, r^2 values increased from 0.4 to 0.61 for the habitat variables. We therefore added the additional large and small flow classes to the water quality management classes, producing 10 water quantity *management classes* (Figure 13) (note that there are no "small" rivers in the MS class, and no "large" rivers in the D+HS class).

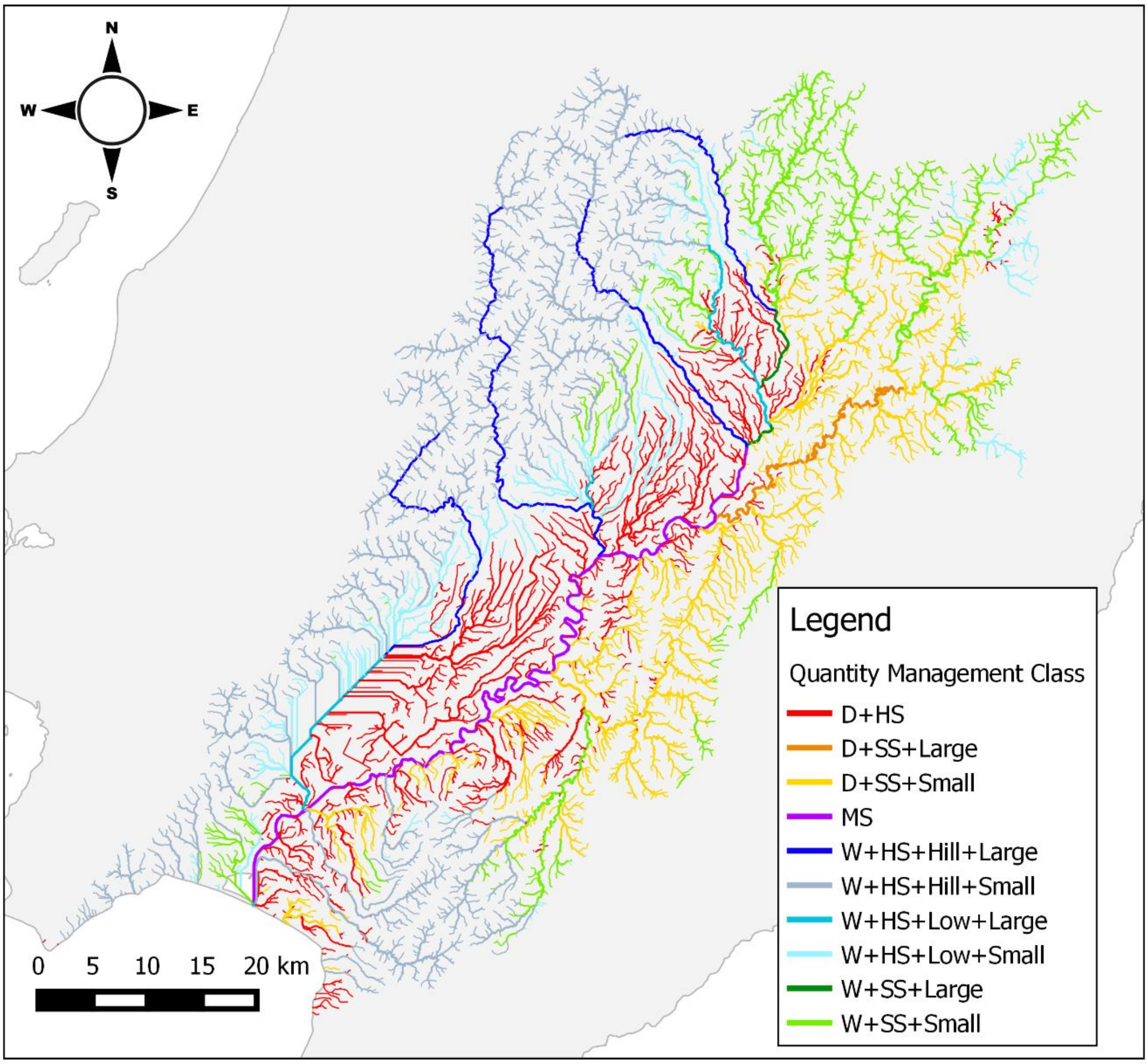

Figure 13: Proposed water quantity management classes.

4.3 Example water quantity objectives and limits

This section provides an example of water quantity objectives and associated limits for the ten water quantity *management classes*. It is stressed that the objectives used here, including the critical values, habitat retention and reliability criteria, are examples only for the purpose of demonstrating the approach. It is noted in particular that the following analysis assesses flow requirement for a shortlist of four fish species. Analysis of flow requirements for a wider range of species is possible. Flow requirements for values such as landscape and cultural values may have higher flow requirements and were not considered by this study. Assessments of flow requirements may also need to consider the effect of flow on water quality, which in some circumstances may be more restrictive than the effect on hydraulic conditions. The derivation of objectives and associated limits will be a subject of the future planning process and will need more comprehensive technical work once environmental values and objectives have been clarified.

Limits to meet example objectives for each of the ten water quantity management classes were determined using model predictions from the Limits Simulator (LIMSIM) tool (Snelder et al., 2014). The LIMSIM tool has been developed to assess the consequences of different limits (water allocation and minimum flows) on habitat reduction for selected fish species and reliability of supply for out-of-stream users. The LIMSIM tool is based on a number of individual "components", including:

1. The digital river network (REC) that provides a spatial framework;
2. Regional hydrology models of MALF estimates;
3. Regionalised flow duration curve tables extracted from EFSAP[19] (Booker and Snelder, 2012)
4. Generalised fish habitat – flow relationships (based on known habitat suitability curves) that provide hydraulic habitat estimates for a variety of target fish species at different flows (Jowett et al., 2008).

Details about the performance of LIMSIM in replicating observed hydrological characteristics (flow duration curves, mean flow, MALF) for six long-term, relatively natural, daily flow gauging stations within the Ruamāhanga Whaitua are provided in Appendix C. Overall, we find that the models perform well, maintaining the relative responses between the different locations and with deviations within the expected model error.

LIMSIM is used to evaluate the effect of different management scenarios (minimum flows and allocations) on specific outcomes - defined by habitat reduction for target fish and reliability of supply. LIMSIM assessments are produced for all segments of the REC river network with specific inputs defining various scenarios for limits (e.g., setting a minimum flow of 80% MALF and a total allocation of 90% of MALF) and selected "critical values" (e.g. the need to maintain 90% of trout habitat at MALF). LIMSIM calculates resultant outputs, showing habitat reduction for selected fish species and reliability of supply for these scenarios.

Results of a large number of LIMSIM model runs that assessed the implications of a wide range of potential limit "scenarios" were used in this study for two purposes. First, the individual LIMSIM outputs were examined to assess the extent to which there were similar outcomes to a set of specific limits within each of the six water quantity *management classes*, and what differences there were between classes. Second, the outputs were used along with nominated example objectives for hydraulic habitat retention and reliability of supply to determine the minimum flow and allocation limits required to meet these objectives for each of the proposed *management classes*.

Following discussions with GWRC staff and based on records from Whaitua meetings, a number of fish species were identified as being significant within the Ruamhanga Whaitua including: inanga, tuna (long and shortfin), kanakana (lamprey), flounder, brown mudfish, trout, koura, kakahi, torrentfish, Cran's bully and upland bully). Of these species, it was possible to model 8 using the LIMSIM model (due to the availability of generalised models for these species): We further refined this list by removing species that had very similar responses to other species, leaving a short list of four: long fin eel, Inanga, adult brown trout, and spawning brown trout.

We examined the reliability of supply measures, looking at both the reliability at minimum flow (R2; Figure 12) and the reliability at management flow (R1; Figure 12). We defined the reliability as the proportion of the time (%) that the flow is at or above the specified flow.

[19] The Environmental Flow Strategic Assessment Platform tool.

The variability in habitat (for the four shortlisted species) and reliability outcomes across the ten proposed water quantity *management classes* is demonstrated in Figure 14. These density plots are based on LIMSIM outputs for a management scenario with a minimum flow of 80% of MALF and a total allocation of 50% of MALF.

In general, the habitat outcomes are similar for all small river classes (see Figure 14). This similarity in habitat outcomes indicates that reduction in hydraulic habitat with flow reduction is higher for all four species in smaller streams than larger rivers, and supports the proposed use of stream size as a classification variable. The results indicate that changes in habitat with flow reduction in the MS class are distinctive with generally smaller (or even positive) change in habitat compared to the other classes (Figure 14). This indicates that the main stem river could potentially sustain relatively larger abstractions than rivers in the other "Large" classes. Conversely, the D+SS+Large class consistently has larger changes in habitat compared to the other large classes; if the additional water quality classification were not included and the classification were only based on river size, minimum flows might be unnecessarily restrictive (over protective for habitat) in the MS class, while potentially being under-protective for the remaining "large" river classes, and in particular for the D+SS+Large class.

The reliability measures (R1 and R2; Figure 14) show a relatively consistent response across the classes, with the exception of the D+HS class, for which many river segments have relatively low reliability (red lines, Figure 14). In general, the distributions of the small classes included a longer tails (greater numbers of low reliability sites) than for the large classes (Figure 14). Although the changes in habitat were more strongly influenced by the river size, reliability at minimum flow appears to be more strongly related to the Wet/Dry classification; this provides further support for the inclusion of the climate factor in the water quantity *management classification*. These differences reflect the inherent differences in hydrological regimes that result from climatic variation across the Whaitua.

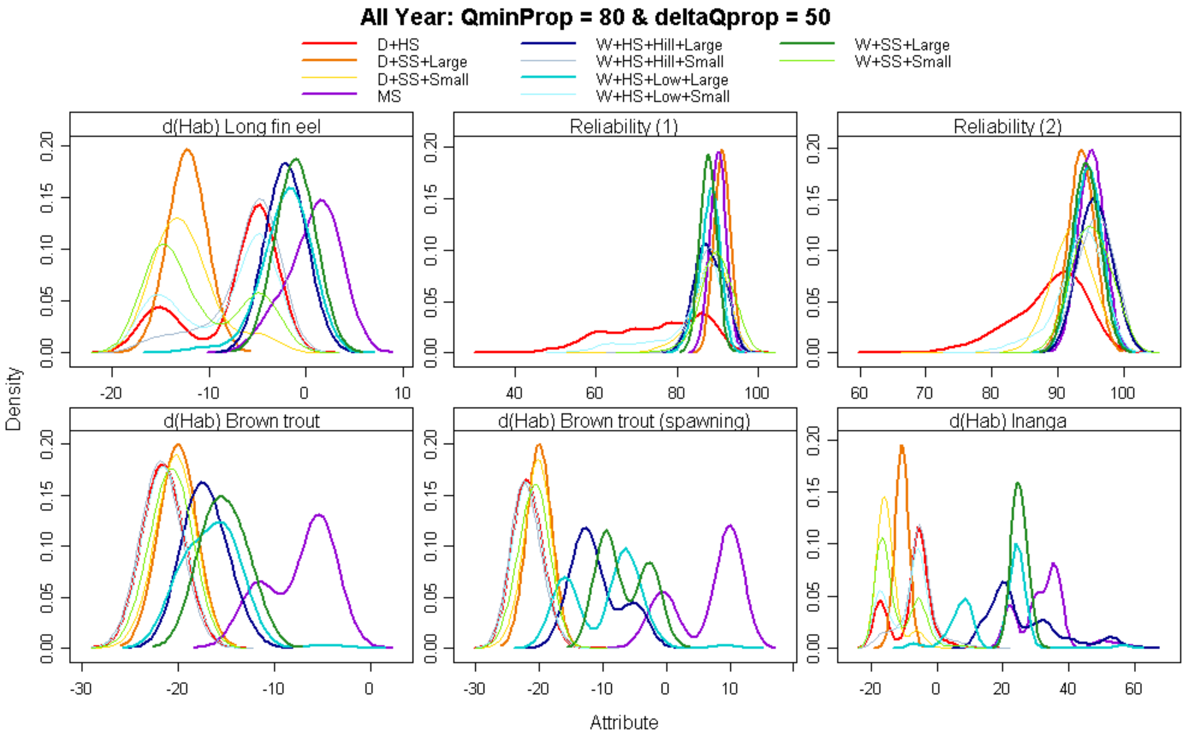

Figure 14: Density plots showing variation in reliability of supply at both the management flow (R1) and minimum flow (R2) and changes to predicted instream habitat (d(Hab)) of long fin eel, adult brown trout, spawning brown trout and Inanga. The density plots are shown for the ten proposed management classes for a management scenario with a minimum flow of 80% of MALF and a total allocation of 50% of MALF. The y-axis (labelled Density) shows the relative likelihood of any individual segment to be equal a given outcome (the x-axis).

Changes in trout habitat were the most sensitive and restrictive across all classes. Maintaining trout habitat, however, may not represent suitable objectives for all streams in the Whaitua. To provide an example of how objectives and management regimes would vary in accordance with values, we adopted Trout as the critical fish species and the “large” class rivers and long fin eel as the critical species in all “small” class rivers. For the example classification included below, the objective for habitat reduction was no more than 10% of the habitat compared to that available at MALF for at least 50% of segments within each *management class*. The example objectives for reliability are a total reliability of no less than 85% for R2 and 80% for R1 for at least 50% of segments within a particular *management class*.

It is stressed that these objectives are all examples and that objectives will need to be defined by the Whaitua process before the structure of FMUs can be finalised. We note that the reliability measures selected are most likely lower than would optimally be targeted, but in our selection one of our aims was that for each of the classes that there would be some combination of allocation and minimum flow that would be able to simultaneously achieve all three of these objectives. The reliability at minimum flow (R2) in the D+HS class decreases rapidly with reduction of the minimum flow, hence more lenient criteria were selected to ensure habitat and reliability measures would be met in our example for the D+HS class. In the future some thought may need to be given to having differing objectives and criteria for the different classes.

The existing LIMSIM outputs could be used to evaluate limits associated with alternative objectives including different levels of habitat retention, different critical species and different levels of reliability of supply. For example, more environmentally conservative limits could be explored by requiring the objectives to be met at 90% or 75% of segments (as compared to 50% as used in our example). It is also important to note, however, that altering objectives may lead to relative differences in the limits between classes, which will in turn affect the assignment of the *management zones*.

The density plots above demonstrate how outcomes vary under a specific management scenario (minimum flow of 80% of MALF and a total allocation of 50% of MALF). By considering a range of possible limits (i.e. minimum flows and total allocations) defined by differing proportions of MALF, a more complete range of potential outcomes can be generated and this can help explore options. An alternative way of exploring the outcomes predicted from LIMSIM is to use decision space diagrams (Snelder et al., 2013). Decision space diagrams summarise the percentage of segments within a *management class* that meet the specified objectives for any given attribute across a range of limits (Figure 15). Decision space diagrams provide a way to identify the limits (i.e. minimum flows and total allocations) for any given attribute that will provide acceptable outcomes for a given water quantity *management class*.

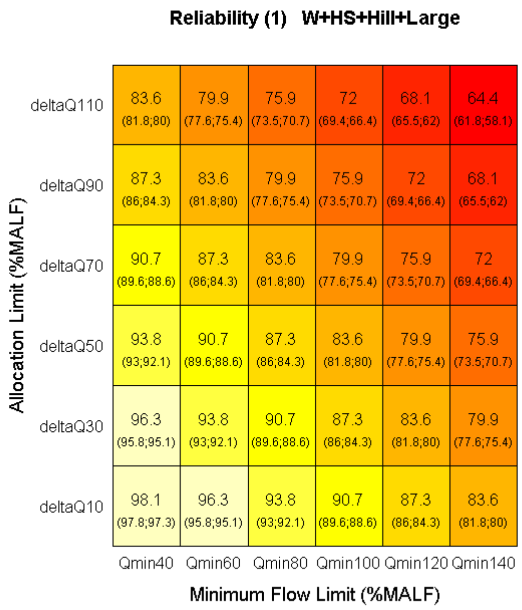

Figure 15: Example decision space diagram showing change in reliability at management flow (R1) in the W+HS+Hill+Large management class. Numbers in the cells are the median change in % reliability across all segments within the management class for each set of limits (minimum flows and allocation). Values in the brackets are the 25th and 10th percentiles of the % reliability (i.e. 75% and 90% of sites achieve values greater than those listed).

However, when setting limits, acceptable outcomes must be achieved across *all* attributes (i.e. R1, R2 and d(Hab)). By overlapping the regions of acceptability for multiple attributes it is possible to generate a combined decision space diagram in order to identify a set of limits that achieves all the objectives. An example of a combined decision space diagram is shown in Figure 16.

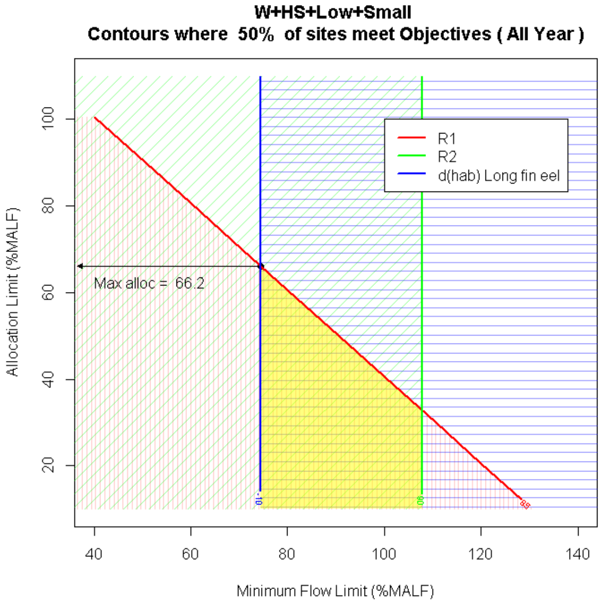

Figure 16: Combined decision space diagram for W+HS+Low+Small class. Solid lines are contours that achieve the minimum acceptable outcomes for each of: reliability at management flow (R1), reliability at minimum flow (R2) and change in long fin eel habitat (d(Hab) Long fin eel). The area within the decision space diagram with acceptable outcomes for each attribute is indicated by hashing: reliability and management flow (R1) – red vertical lines; reliability at minimum flow (R2) – green diagonal lines; and change in trout habitat – blue horizontal lines. The region of the decision space diagram where all objectives are met is indicated in yellow. The maximum possible allocation limit that meets all objectives at 50% of sites within the class is 66.2% of MALF and is demonstrated by an arrow.

Example objectives and associated limits are summarised in Table 7. We used combined decision space diagrams for each water quantity *management class* to identify the limits that achieve the example objectives for 50% of segments. Even within this more constrained set of options for limits, value judgements are required to define a final choice of limits; in this example we have optimised for resource use, by maximising the abstraction limit (as demonstrated in Figure 16).

Table 7: Example objectives for habitat retention for trout and reliability of supply for the ten water quantity management classes and the limits (minimum flows and allocations) that will achieve these objectives. The limits have been derived from the LIMSIM analysis and reflect the largest allocation and (then) highest minimum flow that satisfies all objectives for 50% of segments in each class.

Water Quantity management class	**Critical value**	**Habitat reduction (% at MALF)**	**Reliability at minimum flow (% time)**	**Reliability at management flow (% time)**	**Allocation limit (% of MALF)**	**Minimum flow (% of MALF)**
D+HS	Long Fin Eel	-10	90	85	35.4	64.6
D+SS+Large	Trout	-10	90	85	110	110
D+SS+Small	Long Fin Eel	-10	90	85	94.7	84.6
MS	Trout	-10	90	85	97.7	76.2
W+HS+Hill+Large	Trout	-10	90	85	53.8	88.6
W+HS+Hill+Small	Long Fin Eel	-10	90	85	74.4	72.8
W+HS+Low+Large	Trout	-10	90	85	68	87
W+HS+Low+Small	Long Fin Eel	-10	90	85	66.2	74.4
W+SS+Large	Trout	-10	90	85	60.9	87.9
W+SS+Small	Long Fin Eel	-10	90	85	85.1	85.1

Appendix D provides a series of decision space diagrams that demonstrate the range of outcomes for a wide number of combinations of allocation and minimum flows across all four critical values. Outcomes are provided in terms of the 50%, 25% and 10% percentiles of the distributions as shown (equivalent to 50%, 75% and 90% of segments achieving the listed objectives). Based on these decision space diagrams it is possible for new combined decision space diagrams to be developed if required for alternative combinations of objectives (defined by both a target outcome and a minimum % of sites required to meet this outcome).

4.4 Water quantity Management Zones

We have followed the methodology described in section 3.4 to define the water quantity management zones associated with the ten proposed water quantity management classes demonstrated in Figure 13. Maps of the ten *water quantity management zones* (areas that drain to each of the water quantity management classes) are shown in Figure 17. Any given location within the Ruamahanga Whaitua may be within one or more management zones, depending on how many different management classes are downstream of that location. These water quantity management zone maps form building blocks for defining the FMU framework.

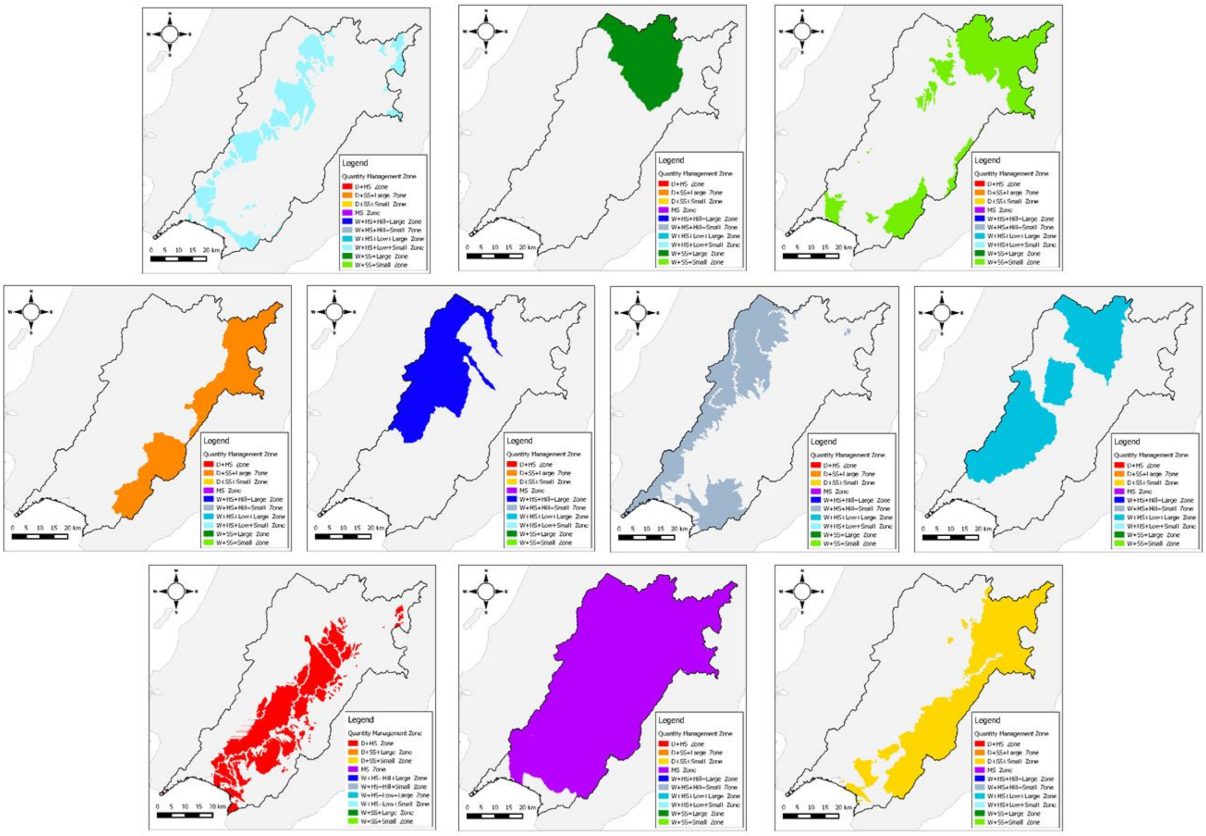

Figure 17: Water quantity management zones.

This study is not able to define the final layering of the management zones because this is dependent on objectives and associated policies and limits. However, we provide a credible example of water quantity *FMUs* for the Whaitua based on the assessment of water quantity provided above. It is anticipated that this set of example FMUs will be altered as the Whaitua process proceeds.

In this example, we have assumed that the *management classes* will have allocation limits as demonstrated in Table 7, based on our example management class objectives. Based on this assumption, the classes can be ordered from the most restrictive (i.e. least resource enabling) to the least restrictive in the following order: D+HS, W+HS+Hill+Large, W+SS+Large, W+HS+Low+Small, W+HS+Low+Large, W+HS+Hill+Small, W+SS+Small, D+SS+Small, MS, D+SS+Large. Using this ordering, we have layered the water quantity management zones to define the example water quantity *FMUs* following the approach used for the water quality *FMUs,* where any given segment is assigned to a zone based on its most restrictive downstream class (Figure 18).

It is important to note that if the Whaitua ultimately selects different objectives from those assessed here (i.e., those in Table 7) different allocation limits and a different relative ordering of the *management classes* will result. This in turn could lead to differences in the way that the water *management zone* building blocks are stacked (and mapped). For this reason the definition (and mapping) of water *management zones* may need adjustment as the plan process evolves. However, the *management zones* proposed here provide a logical starting point and the approach preserves flexibility to make adjustments.

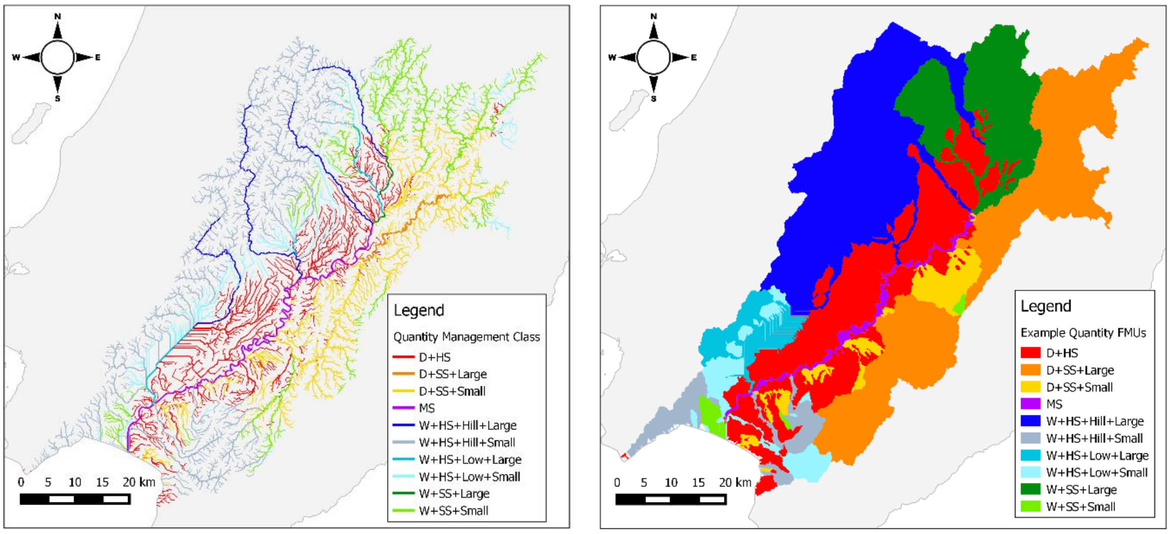

Figure 18: The proposed water quantity management classification (left) and example FMUs (right).

As for the water quality *FMUs*, small and isolated patches of land belonging to a *FMU* may be impractical, and these could be merged with the surrounding *FMU*. We removed small isolated patches by merging segments that were below a defined threshold based on stream order (a measure of the river size) with the *FMU* assigned to the next downstream segment, irrespective of their own *FMU* assignment. Figure 19 demonstrates the difference in the *FMUs* for stream order of 0 (all river network reaches included) and a minimum stream order of 3.

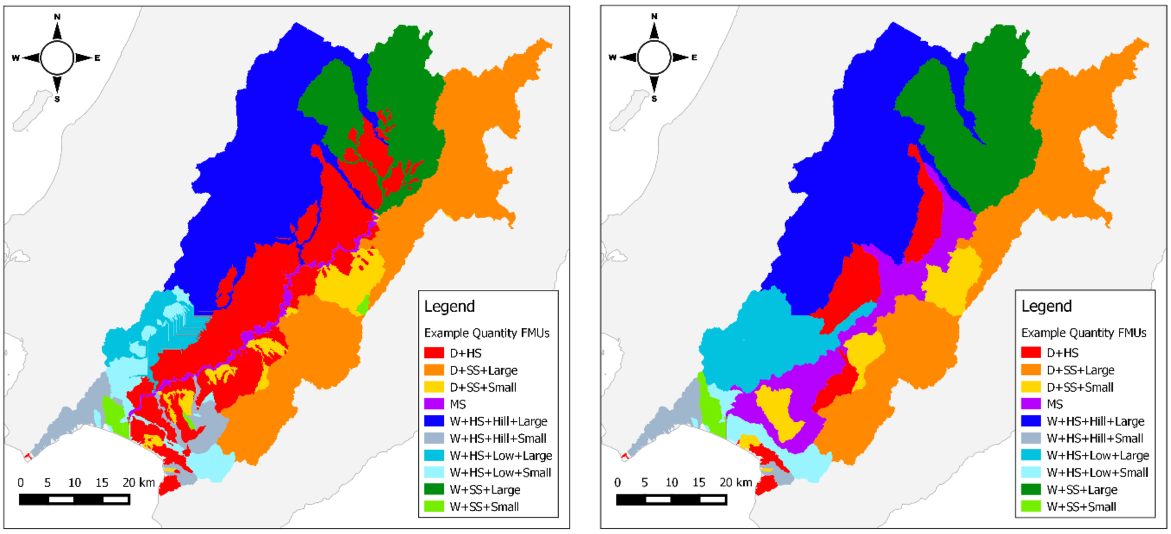

Figure 19: The proposed water quality FMUs for the Ruamahunga Whaitua. In the right hand plot rivers less than or equal to the minimum order threshold of 3 have been merged with their downstream FMU, thereby decreasing the number of individual areas belonging to each FMU.

4.5 Water quantity administrative points

The water quantity *administrative points* have been derived following the same methodology used to derive the water quality *administrative points* and are demonstrated in Figure 20.

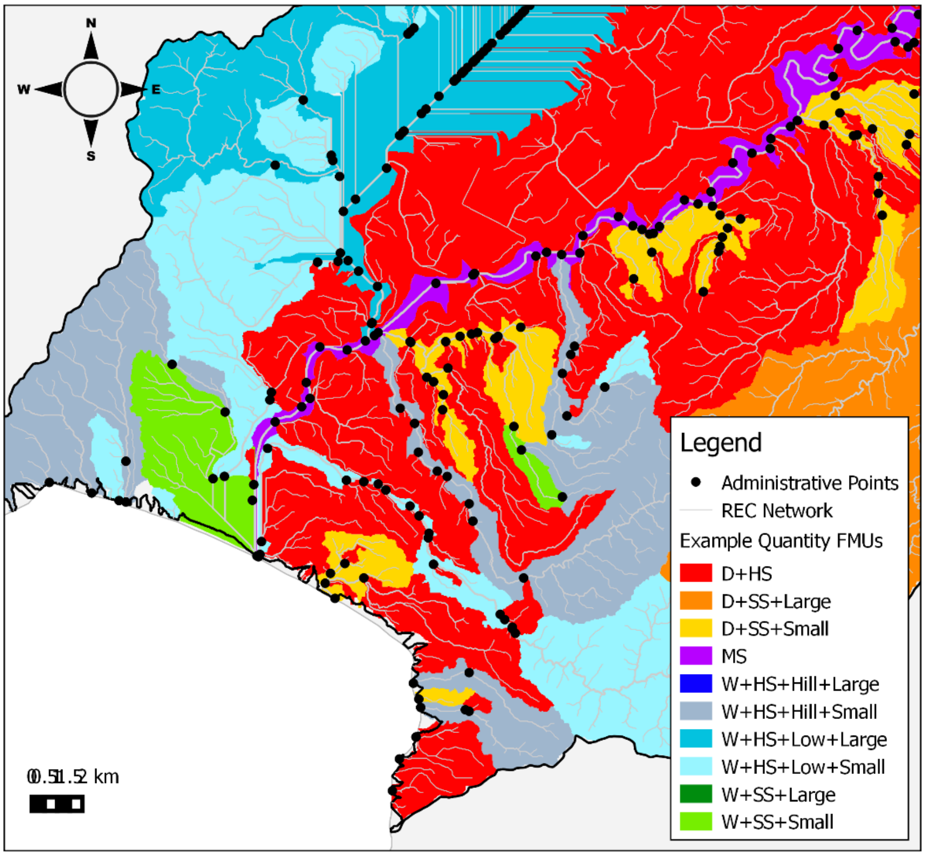

Figure 20: Zoomed in view of the example water quantity FMUs. The grey lines represent the drainage network. The black dots represent points at which the FMU changes and are relevant administrative points where limits need to apply and resource use accounting needs to occur. The classes in this figure are based on classes defined with all rivers from order one and up.

We similarly explored how the number of *administrative points* varies with varying minimum stream order thresholds. Table 8 demonstrates how the number of water quantity *administrative points* reduces as the minimum order threshold increases.

Table 8: Variation in number of administrative points with increasing coarseness of water quantity management zones. Rivers less than or equal to the minimum order threshold are excluded.

Minimum order threshold	Number of administrative points
All segments	478
1	197
2	80
3	46
4	36
5	30

4.6 Next steps – water quantity FMUs

4.6.1 Developing plan provisions

Having defined example objectives and associated options for limits for each water quantity *management zone*, the next step that should be undertaken is to compare these options for allocation limits against the current estimated allocation, which comprises the consented allocation and estimated permitted uses. The total amounts of water allocated are able to be estimated (from consent data and permitted use estimates) for all locations in the river network and these accumulate in the downstream direction. This means that estimates of the potential abstraction, with respect to the allocation limit, can be made at all *administrative points*. This estimate does not represent the actual abstraction because it does not consider whether the allowable total abstraction (consented plus permitted) is actually occurring. However, the current total allocation compared to the allocation limit is an important indicator of locations that are potentially over-allocated.

The relevant locations for defining volumetric limits and accounting for allocation are the *administrative points*. If the limits set by the plan (e.g. Table 7) are expressed as proportion of MALF, they can be converted to volumetric limits or rates at the *administrative points* by multiplying by the estimated MALF at these locations. MALF can be estimated in a variety of ways including from regionalisation 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 7.

Because the LIMSIM tool is based on generalised models, the derived limits (e.g., the options in Table 7) are broadly accurate but are subject to larger uncertainties at the site scale than would be more detailed site specific analyses. However, we consider the LIMSIM tool reliably demonstrates the relative differences between the classes (Appendix C) and therefore justifies the general approach to defining the FMUs. We also note that an independent test of the generalised habitat models used by LIMSIM that was conducted by Hay (2010) indicated that they provided good matches to site specific hydraulic habitat models in the Ruamāhanga catchment.

Specific management regimes (minimum flows and total allocations) could be derived for either sites or water quantity management classes based on detailed site specific analyses rather than the LIMSIM tool used here. Detailed assessments are commonly used to support water quantity management decisions when greater certainty is required and are commonly based on site scale hydraulic habitat models such as RYHABSIM[20], coupled with analysis of relevant hydrological data. These assessments provide the most accurate analysis of the effect of a proposed take relative to aquatic habitat objectives but they are expensive and time consuming and are probably not justified for small takes in situations of low risk. Furthermore, RYHABSIM analysis only addresses ecological flow requirements. Flows needed to support other values (e.g., landscape and cultural values) or to keep river-mouths or flood drainage cuts open, require other assessment methods.

The inherent uncertainties associated with the use of LIMSIM could be acknowledged in the plan by using a tiered system for consenting water takes. Higher levels of discretion and lower levels of assessment effort could be allowed to enable resource use in an efficient manner where risks are low (i.e. where current allocation is well within the limits) but rigour could be increased in situations where current allocation is approaching the assessed limits. Essentially the consenting process needs to demonstrate that a new take will not prevent the objectives from being achieved. 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 7, which are based on the LIMSIM tool, could be used. Applications for water takes in situations where the current and new takes are

[20] River Hydraulics and Habitat Simulation computer program: http://www.jowettconsulting.co.nz/home/rhyhabsim

“large”, relative to the limits, however would need to be supported by more detailed analyses.

4.7 Accounting for groundwater takes and groundwater effects on surface water quality

We also note that our analysis is based on surface water only. Takes from groundwater and discharges from land into groundwater will affect surface water quantity and quality and therefore need to be accounted for in the management of the resource. The details of the joint management of the groundwater and surface water resources of the Whaitua need further consideration that is outside the scope of this study.

To account for groundwater takes on surface water outcomes, we propose that the *management zones* component of the water quantity FMUs be overlaid with mapped representations of the regional aquifers. A scheme should be developed to estimate the degree of hydraulic connection between the aquifers and their adjacent water bodies. The scheme should be developed to express a groundwater take as an equivalent surface water take (for example to be expressed as an equivalent stream depletion) so that the groundwater allocation can be included in the total estimated allocation at the relevant administrative points.

5 Discussion

This project has developed an approach to defining FMUs that provides a biophysical basis for implementation of the NPS-FM. A key finding of this project is that when considering the Whaitua as a whole, appropriate FMUs need to be a framework of spatial units (i.e., comprising management classes, zones and administrative points) rather than a simple single subdivision of the Whaitua into sub-catchments. 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 defining policies and accounting for resource use and consenting water takes).

The suggested approach to defining FMUs for the Ruamāhanga Whaitua comprises three components: (1) the water bodies that are designated to be managed for a particular purpose (objective), termed the “*management classification*” in this report, (2) the associated land area (catchment or sub-catchment) that drains to a management class, termed the “*management zone*”, and (3) the points in the network where the *management zone* changes, which are termed *administrative points*. It is important to note that an administrative point can be determined for any point on a river but it is suggested some minimum set of points should be defined as described here. FMUs are then defined by layering and merging *management zones* in an order that allows the definition of policies and limits that achieve the most restrictive downstream objectives. The details of this layering and merging of management zones must be undertaken as part of the policy development process with the overall aim being the production of a simple and clear set of justifiable plan provisions.

It is suggested that water quality and quantity FMUs could be based, at least in the first instance, on the described six and ten-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. These FMUs also identify the associated land areas that drain to the classes (i.e., the *management* *zones*). FMUs are defined by layering and merging the *management zone building* blocks so that the merged entities define FMUs for which a set of management actions and limits can be defined that achieve the most restrictive downstream objectives.

Some water bodies have specific values or management issues that are not discriminated by the *management classification*s but which may need to be provided for. These water bodies can be associated with *special management zones* that have the potential to over-ride the objectives set for the *management classes*. Examples of water bodies requiring separate management objectives may be sites of significance such as specific estuaries, swimming spots, or sites of special cultural or ecological significance. Another example of water bodies with special issues are those in which significant infrastructure has 'permanently' modified the system such as large dams. Water bodies requiring special objectives and the catchments upstream of these water bodies would be special management zones for which specific plan provisions (objectives and policies) would apply. It is noted that special management zones will add to the complexity of the plan (by creating exceptions to the policies that apply to the general FMUs). It is recommended that specific criteria are derived to avoid a proliferation of special management zones that will undermine the clarity and relative simplicity that is afforded by the general FMUs.

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

1. The use of physiographic classifications provides for variation in the characteristics of interest to be resolved at a level of detail that is appropriate to management. Large sea-draining catchments generally contain considerable variation in these characteristics and therefore do not provide sufficient resolution,

2. The approach is transparent because it is based on specific physiographic factors (e.g. topography) and their associated categories (e.g. hill and lowland),

3. The logic that objectives apply to the water bodies and that the limits and actions apply to the catchments draining to those water bodies is inherent in the approach,

4. The need for limits to be set and actions taken to achieve the most restrictive downstream objective is built into the approach,

5. The process is flexible and easily repeatable so that FMUs can be modified and their definition is integral to the plan development process.

6. The level of classification detail (i.e. coarse or fine) can be altered by varying the physiographic factors (and their categories) to suit the desired level of detail and spatial specificity of the plan provisions,

7. The layering and merging of management zones can be altered to accommodate changes in the order of restrictiveness of policies and limits that may arise in the development of plan provisions,

8. 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,

9. 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

10. The framework is spatially clear and certain (i.e. mapped) about where limits need to be met and where accounting should occur (administrative points).

It is emphasised that the FMUs and associated objectives and limits set out in this report are only examples that provide options for consideration and can be altered through the plan development process. In particular, it is recognised that example FMUs represent a coarse differentiation of the region's rivers with respect to their values, current state and other characteristics of relevance. This 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 (specificity) with coverage and simplicity. The resolution of the suggested approach can be increased by increasing the number of classes in the *management classification*s and accordingly increasing plan complexity. However, the differences between classes will become less distinct as the number of classes increases and it will therefore become difficult to justify variation in the objectives, policies and limits if there is a large number of classes.

The regional and coarse scaled approach offered in this report is most likely to be acceptable if it is clear that it is a starting point and it is acknowledged there may be areas that have issues that warrant more detailed assessments, and that there will be opportunity to refine or develop provisions that apply to local issues as part of the WIP process. In these cases, more specific and nuanced objectives and policies may be developed that apply to the general FMUs but for specific locations.

6 Acknowledgements

We would like to thank the Ruamāhanga Whaitua committee for initial consideration of the bio-physical classification of the Whaitua. We also thank Natasha Tomic, Alastair Smaill, Mike Thompson and Alton Perrie for their time in providing data, advice and feedback.

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Appendix A Classification testing

This appendix provides a description of the work that explored alternative management classifications for the Ruamāhanga. When selecting a classification we are faced with striking a balance between complexity (i.e. number of classes) and ability to discriminate important differences in a range of water quality and quantity characteristics. We explored this trade-off by characterising water quality using the median values of a range of water quality variables as measured by GWRC (21 sites) and NIWA (3 sites). We characterised water quantity responses based on regionalised natural state flow duration curves and MALF for all REC segments within the catchment that were extracted from the Environmental Flow Strategic Assessment Platform tool(EFSAP). Specifically, the variable used was the position of MALF on the flow duration curve, which is a measure of the inherent reliability as a water supply of a particular river location.

A1 Management classification based on catchment slope

If a simple two-class water quality management classification based on catchment slope is used an important question is: what is the appropriate threshold to define the class boundary?

An analysis of alternative criteria for the boundary between the two catchment slope-based classes was undertaken to answer this question. In this analysis the threshold for the two classes was varied from 5 degrees to 25 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 the average catchment slopes for each site 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 water clarity (CLAR), total nitrogen (TN), nitrate-nitrogen (NO3N), total phosphorous (TP), dissolved reactive phosphorous (DRP), *E. coli* (ECOLI), ammoniacal nitrogen (NH4N); the 95th percentile for I (ECOLI_Q0.95), macroinvertebrate community index (MCI), quantitative macroinvertebrate community index (QMCI), Periphyton (PERI); and the location of the mean annual low flow (MALF) on the flow duration curve (FDC) (for all REC segments within the catchment). The water quality variables were log10 transformed 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 20 degrees for the water quality variables, and 17 degree for the water quantity variable (Figure 21).

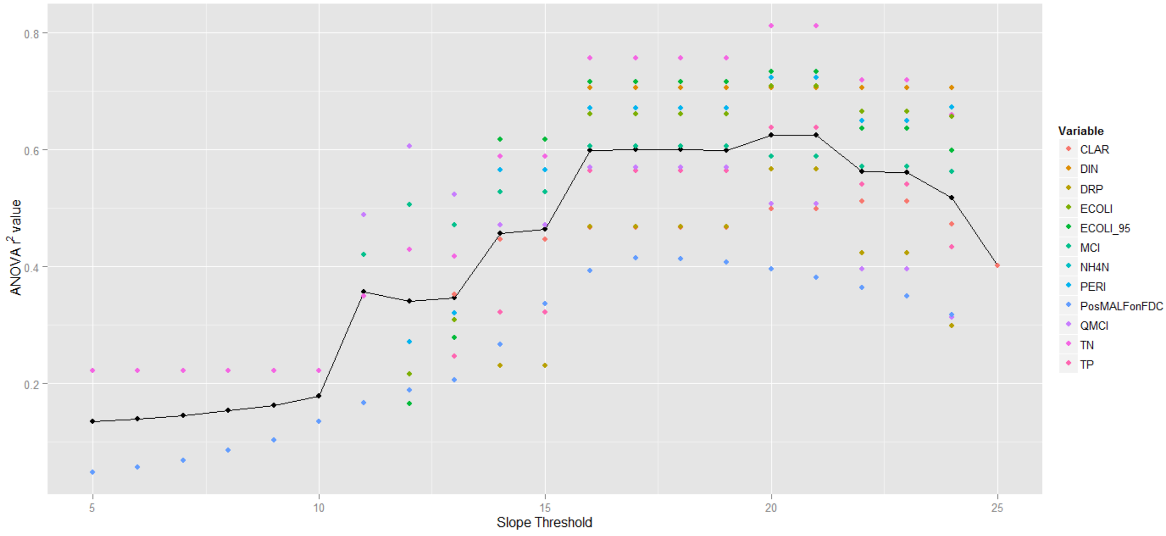

Figure 21: ANOVA r^2 values for each variable as a function of catchment slope. The coloured points show the r^2 value of each variable where the ANOVA was significant ($p < 0.05$). The black line represents the mean value of r^2 over all variables.

We explored the distribution of the 24 monitoring sites between the two classes at each of the slope thresholds and compared this against the distribution of the two classes across all REC reaches within the Ruamahanaga Whaitua area. From approximately a 13 degree slope threshold, the proportion of monitoring sites within the low class is very close to the proportion of that class across the whole Whaitua area (Figure 22). However, the monitoring sites poorly represent lowland catchments slope areas.

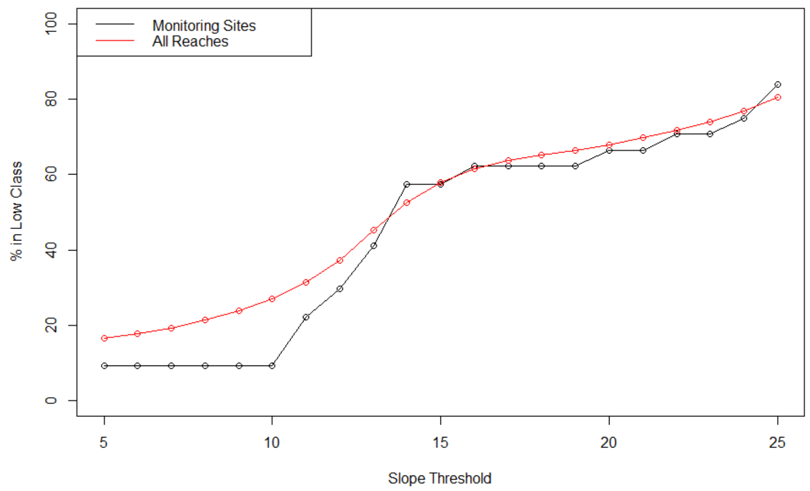

Figure 22: Distribution of monitoring sites compared to All REC reaches within the "Low" slope class as a function of the slope threshold

A2 Exploring management classifications

We explored the ability of 16 alternative classifications to explain regional variation in the test data (i.e. water quality and quantity variables) using analysis of variance (ANOVA). These classifications were based on various combinations of the following 4 categorical factorss:

- T: Temperature class (First letter of the REC climate variable (W=warm, C=cool)
- R: Rain class (Second letter of the REC climate variable, (Classes: “W” – wet, “D” – dry). Note that we merged X (extremely wet) into W.
- G: Geology (GEOLOGY from REC, (Classes: “SS” – soft sedimentary, “HS” – hard sedimentary). Note we simplified by making Al (alluvium) and M (miscellaneous) classes = HS.
- S “Slope”
    - S1: Slope with a 17 degree threshold (Classes: “Low” and “Hill”)
    - S2: Simplified REC Source of Flow (Classes: “L” - lowland and “H” - hill). Note we merged M into H and Lk into L.

The 16th classification used was the set of FMUs defined by the Whaitua committee in a previous workshop on FMUs, as demonstrated in Figure 1Figure 2.

We considered two alternatives for the definition of the slope class. Firstly we used slope with a 17 degree threshold (based on the analysis provided in the previous section). The second classification used a simplified version of REC “Source of Flow” classification. This classification is widely used among regional councils for the categorisation of rivers. The REC “Source of Flow” classification is really a classification of elevation, not slope. It has the advantage that it can be taken as a “given” and no subjective threshold must be defined, as for the Slope categorisation. Below are two plots showing the difference in the spatial distribution between these two classifications (Figure 23). There is very little difference in the spatial distribution. The main differences are in small areas that might be steep, but are otherwise in low-elevation areas.

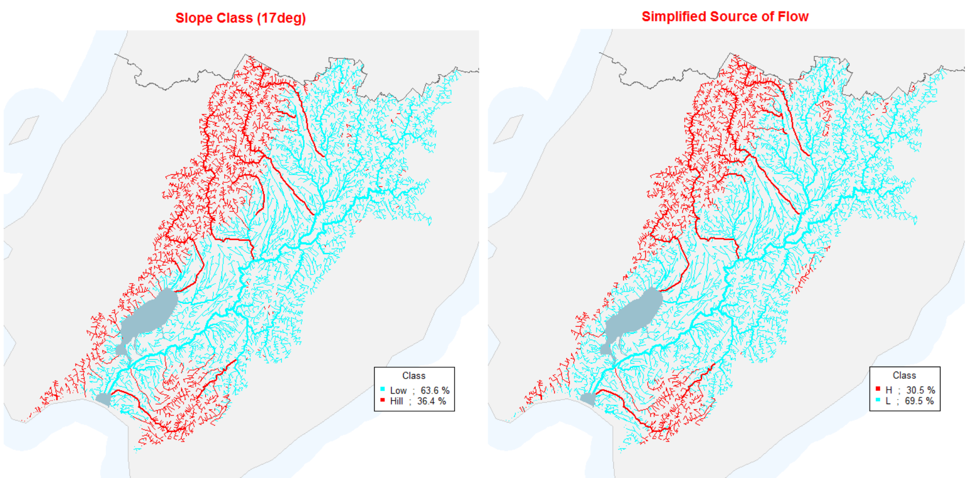

Figure 23: Comparison of spatial distribution of alternative slope classifications

The distributions of the other three variables are shown in Figure 24 below. We note that T (temperature) and R (rainfall) are highly correlated, and all four classifications demonstrate a strong east/west separation.

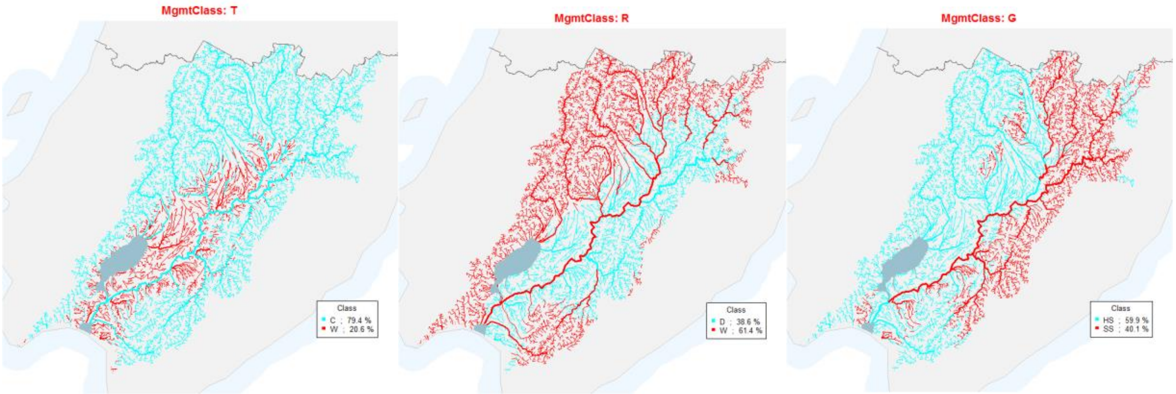

Figure 24: Spatial distribution of Temperature (T), Rainfall (R) and Simplified Geology (G) classifications

An ANOVA was performed on the same variables used to explore the slope classification (11 water quality variables and 1 water quantity variable). 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. The results of the ANOVA tests are shown below, in two tables; the first (Table 9) using slope classification (S1; threshold at 17 degrees), and the second (Table 10) showing the REC "Source of Flow" classification S2. The top part of the table is the r^2 values, where NA values indicate the relationship was not significant. The next section of table rows provides a summary of the mean of the non-NA r^2 values for each classification. In the bottom rows, the number of large classes defined by the classification regime (defined as >5% of the REC reaches) is shown, along with the percentage of all REC reaches that fall within these numbered large classes. It is assumed that classes <5% would be amalgamated with the larger classes. The distributions of the r^2 values for the difference variables across the classes are also shown graphically in Figure 25 and Figure 26.

Table 9: Summary of r^2 values for the 16 alternative management classifications (using S1 for the slope class). NA values indicate no significant relationship for the given variable. The number of large classes is the number of classes with more than 5% of the total REC network. The percentage of large classes is the total percentage of the REC network that is covered by the large classes.

	T	R	G	S	T+R	T+G	T+S	R+G	R+S	G+S	T+R+G	T+R+S	T+G+S	R+G+S	T+R+G+S	Whaitua
CLAR	NA	0.24	0.50	0.47	0.30	0.57	0.47	0.61	0.52	0.60	0.61	0.58	0.62	0.66	0.66	NA
NH4N	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NO3N	0.20	0.23	NA	0.71	0.27	0.39	0.78	0.40	0.74	0.77	0.40	0.78	0.80	0.80	0.80	0.50
TN	0.22	0.28	NA	0.76	0.32	0.45	0.83	0.46	0.80	0.80	0.46	0.84	0.84	0.85	0.85	0.45
TP	NA	0.18	NA	0.56	NA	0.28	0.57	NA	0.58	0.57	NA	0.58	0.57	0.59	0.59	NA
DRP	NA	NA	NA	0.47	NA	NA	0.49	NA	0.47	0.51	NA	0.49	0.51	0.51	0.51	NA
ECOLI	NA	NA	0.32	0.66	NA	0.41	0.66	0.42	0.67	0.67	0.42	0.67	0.67	0.68	0.68	0.39
ECOLI_95	NA	NA	0.40	0.72	NA	0.43	0.75	0.43	0.72	0.74	0.43	0.76	0.76	0.76	0.76	NA
PERI	NA	NA	0.33	0.67	NA	0.44	0.67	0.45	0.68	0.69	0.45	0.69	0.69	0.70	0.70	NA
MCI	NA	0.46	NA	0.61	0.46	0.47	0.65	0.55	0.73	0.61	0.55	0.73	0.66	0.73	0.73	NA
QMCI	NA	0.49	NA	0.57	0.49	0.47	0.61	0.57	0.72	0.57	0.57	0.72	0.63	0.72	0.72	NA
PosMALFonFDC	0.08	0.42	0.20	0.41	0.45	0.37	0.42	0.50	0.54	0.43	0.53	0.55	0.44	0.56	0.56	0.35
Average R2 (no FDC)	0.21	0.31	0.39	0.62	0.37	0.44	0.65	0.49	0.66	0.65	0.49	0.68	0.67	0.70	0.70	0.45
Average R2	0.17	0.33	0.35	0.60	0.38	0.43	0.63	0.49	0.65	0.63	0.49	0.67	0.65	0.69	0.69	0.42
No. sig relationships	3.00	7.00	5.00	11.00	6.00	10.00	11.00	9.00	11.00	11.00	9.00	11.00	11.00	11.00	11.00	4.00
No. lg classes	2	2	2	2	3	3	3	4	3	3	4	4	4	5	5	4
Perc Lg Classes	100	100	100	100	96	96	100	100	99	99	90	96	94	98	88	100

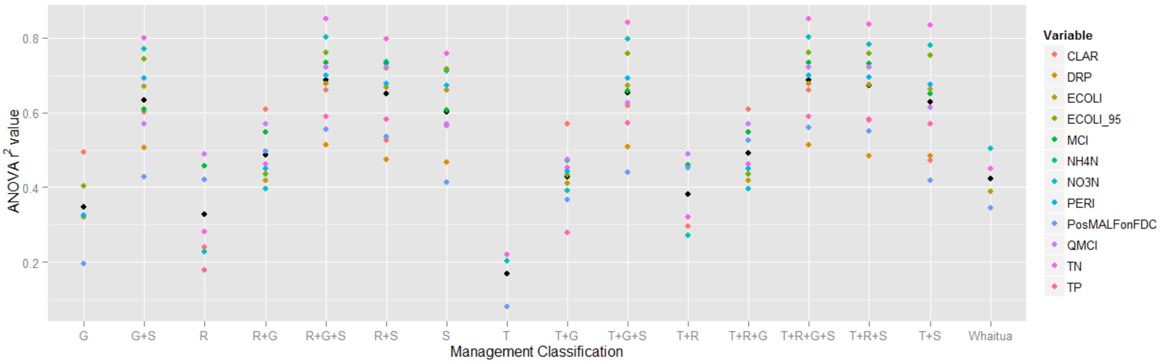

Figure 25: ANOVA r^2 values for each variable for each of the 16 management classes (using S1). The coloured points show the r^2 value of each variable where the ANOVA was significant ($p < 0.05$). The black dots represent the mean value of r^2 over all variables.

Table 10: Summary of r^2 values for the 16 alternative management classifications (using S2 i.e. REC "Source of Flow" classification) for the slope class). NA values indicate no significant relationship for the given variable. The number of large classes is the number of classes with more than 5% of the total REC network. The percentage of large classes is the total percentage of the REC network that is covered by the large classes.

	T	R	G	S	T+R	T+G	T+S	R+G	R+S	G+S	T+R+G	T+R+S	T+G+S	R+G+S	T+R+G+S	Whaitua
CLAR	NA	0.24	0.50	0.43	0.30	0.57	0.43	0.61	0.51	0.60	0.61	0.56	0.62	0.66	0.66	NA
NH4N	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DIN	0.20	0.23	NA	0.56	0.27	0.39	0.65	0.40	0.61	0.57	0.40	0.65	0.65	0.65	0.65	0.50
TN	0.22	0.28	NA	0.58	0.32	0.45	0.68	0.46	0.66	0.59	0.46	0.70	0.69	0.70	0.70	0.45
TP	NA	0.18	NA	0.53	NA	0.28	0.54	NA	0.56	0.53	NA	0.56	0.54	0.56	0.56	NA
DRP	NA	NA	NA	0.49	NA	NA	0.51	NA	0.50	0.51	NA	0.51	0.52	0.52	0.52	NA
ECOLI	NA	NA	0.32	0.50	NA	0.41	0.50	0.42	0.52	0.55	0.42	0.53	0.56	0.56	0.56	0.39
ECOLI_95	NA	NA	0.40	0.64	NA	0.43	0.66	0.43	0.64	0.69	0.43	0.67	0.70	0.70	0.70	NA
PERI	NA	NA	0.33	0.62	NA	0.44	0.62	0.45	0.64	0.66	0.45	0.65	0.67	0.68	0.68	NA
MCI	NA	0.46	NA	0.44	0.46	0.47	0.51	0.55	0.63	0.45	0.55	0.63	0.56	0.64	0.64	NA
QMCI	NA	0.49	NA	0.45	0.49	0.47	0.52	0.57	0.66	0.46	0.57	0.66	0.57	0.67	0.67	NA
PosMALFonFDC	0.08	0.42	0.20	0.33	0.45	0.37	0.34	0.50	0.51	0.39	0.53	0.52	0.43	0.55	0.56	0.35
Average R2 (no FDC)	0.21	0.31	0.39	0.52	0.37	0.44	0.56	0.49	0.59	0.56	0.49	0.61	0.61	0.63	0.63	0.45
Average R2	0.17	0.33	0.35	0.51	0.38	0.43	0.54	0.49	0.58	0.55	0.49	0.60	0.59	0.63	0.63	0.42
No. sig relationships	3.00	7.00	5.00	11.00	6.00	10.00	11.00	9.00	11.00	11.00	9.00	11.00	11.00	11.00	11.00	4.00
No. lg classes	2	2	2	2	3	3	3	4	3	3	4	4	4	5	5	4
Perc Lg Classes	100	100	100	100	96	96	100	100	100	98	90	96	94	98	88	100

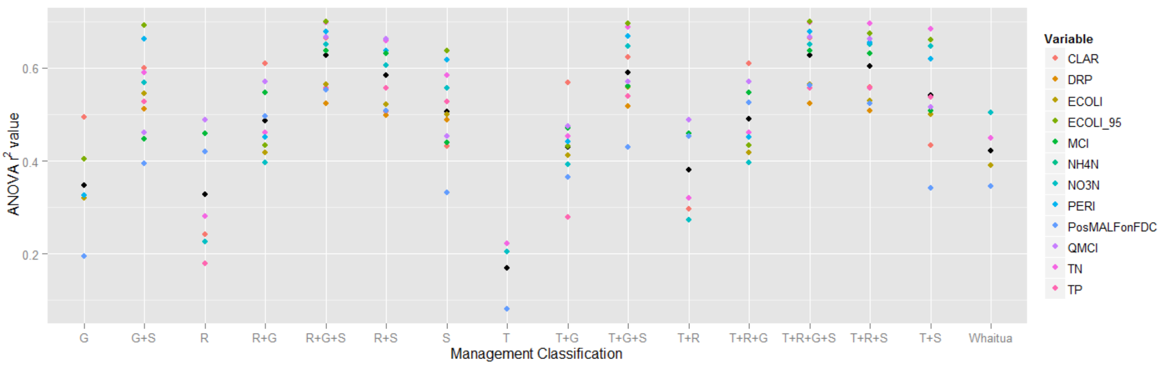

Figure 26: ANOVA r^2 values for each variable for each of the 16 management classes (using S2). The coloured points show the r^2 value of each variable where the ANOVA was significant ($p < 0.05$). The black dots represent the mean value of r^2 over all variables.

Based on the results from Table 9 and Table 10, we suggest that any classification with an r^2 of less than 0.5 would not be acceptable. We also suggest that the classification with all 4 categories was over classified, with at least one classifier being redundant. Balancing r^2 with the number of large classes, the most promising classification appears to be G+S. However, we also note that the Whaitua committee have also identified differences in climate between the east and west as playing an important role in defining the observed variability in the rivers of the Ruamāhanga catchment. As such, we have selected the R+G+S1 classification – this offers a higher r^2 value than the G+S classification, but at the cost of two additional classes.

Appendix B Water quality trends

An analysis of trends in the seven water quality variables, two invertebrate variables and Periphyton was undertaken over an approximately 10 year period ending at the end of September 2015. The water quality variables included data from July 2006 to September 2015; the earlier date being used as this was a time of a change of testing procedures for many of the water quality variables which led to a reduction in the detection limits. For QMCI, MCI and Periphyton, data is only sampled annually, and hence the 2006-2015 data were used in the trend analysis.

There were differing numbers of sites for individual variables due to variation in the dates that monitoring commenced at each site, and due to some filtering rules (described below) that were imposed to ensure the reported trends were robust. Trend analysis is only robust for a specified time period over which the dataset is being analysed if it has few missing values. For the water quality data, trends were assessed using monthly data, provided 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, QMCI and Periphyton, 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 measurements 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) could 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, QMCI and Periphyton were not estimated with a seasonal test because the data used in the scores are sampled annually, which precludes accounting for seasonal variation. Instead, trends in MCI, QMCI and Periphyton scores were estimated with the Kendal Sen Slope Estimator (KSSE) (Sen 1968). The individual MCI, QMCI and periphyton values were not flow adjusted because these variables are not affected by instantaneous flow state in the same way that the water quality variables are.

Most significant trends (i.e. sites for which $p<0.05$) indicated improving water quality. The most significant exceptions were degrading trends for Clarity (all significant trends were degrading) and *E.coli*, which had a greater number of significantly degrading trends than increasing trends. There were many insignificant trends, for MCI, QMCI and periphyton. This indicates that the water quality variables have large variation (‘noise’) and therefore that a definite trend cannot be detected. Most of the NH4N sites were excluded as they had more than 15% of observations below the detection limit.

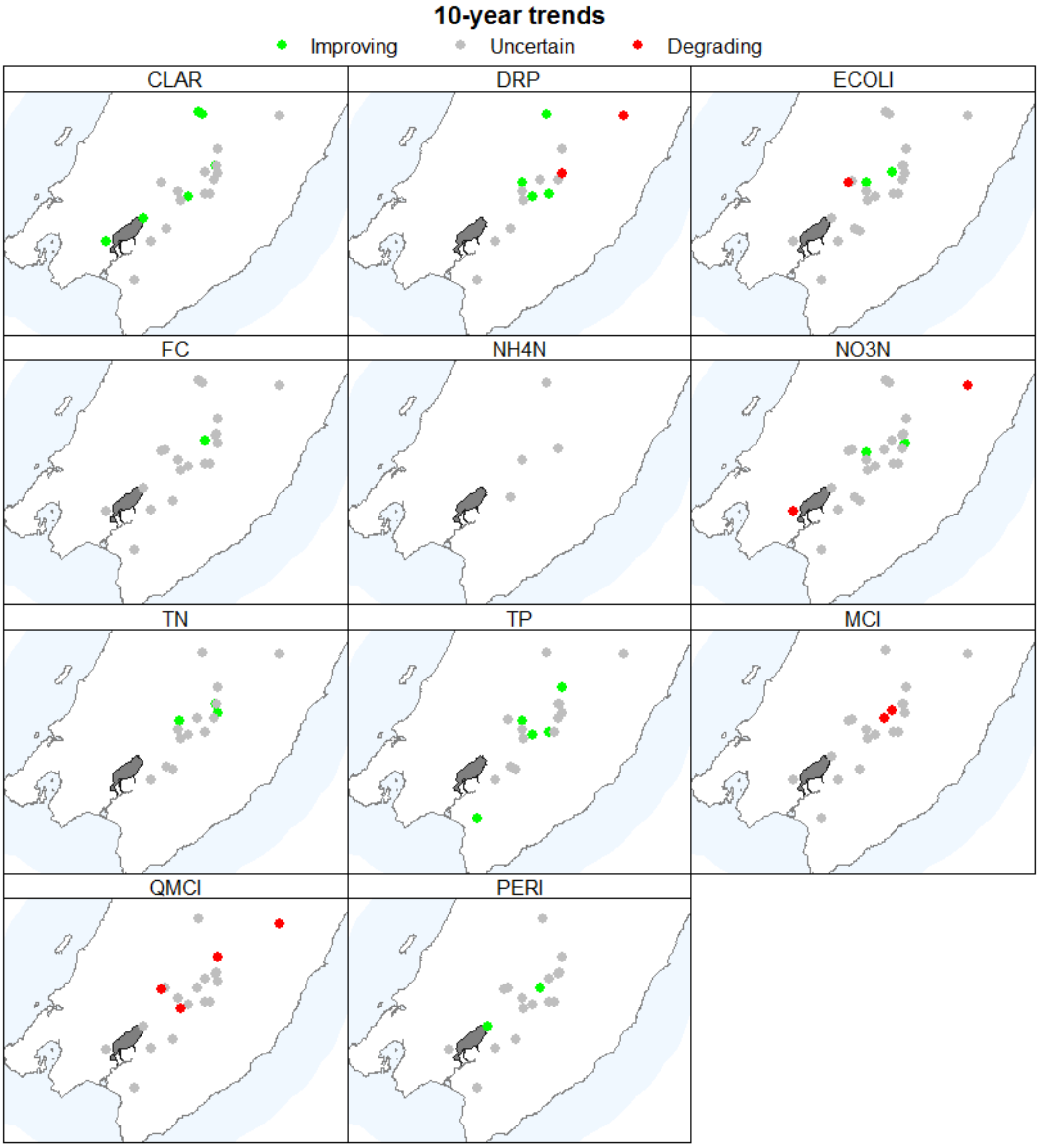

Figure 27: Maps showing the 10-year trends at monitoring sites. Where the trend tests were significant (i.e. the Kendal test p-value < 0.05) the direction of the trend is indicated as improving or degrading. Where the test was not significant the trend is indicated as "uncertain" meaning the test can 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.

Appendix C LIMSIM hydrological model component testing

We tested the performance of the hydrological model components within LIMSIM against eight long-term, relatively natural, daily gauging records within the Ruamāhanga Whaitua. Details of the stations used within these tests are provided in the table below:

Table 11: Details of the gauging stations in the Ruamāhanga Whaitua used to test the performance of the LIMSIM hydrological model components.

Gauge	NZReach	Easting	Northing	Start Date	End Date
Kopuaranga at Palmers Bridge	9002572	1825333	5477907	1/06/1985	1/06/2015
Mangatarere River at Gorge	9005786	1811469	5465421	1/06/1999	16/02/2016
Ruamāhanga River at Mt Bruce	9000870	1819318	5485239	1/06/1976	1/06/2015
Tauherenikau at Gorge	9008990	1798066	5451001	1/06/1976	1/06/2015
Waingawa River at Kaituna	9004463	1812555	5470757	1/06/1976	1/06/2015
Waiohine River at Gorge	9007610	1801812	5456651	1/06/1979	16/02/2016
Waipoua River at Mikimiki Bridge	9003286	1820657	5475132	1/06/2007	1/06/2015
Whangaehu River at Waihi	9002949	1834120	5476086	1/06/1967	29/08/2014

For each gauging station we extracted the MALF, mean flow and Flow Duration Curve centiles. We did this for the maximum data length for each station. Figure 28 below demonstrates the observed and predicted flow duration curves for each of the sites. In general, we find that the shape and magnitude of the FDC is well predicted, particularly for the lower centile values (some deviations are observed for flood flows).

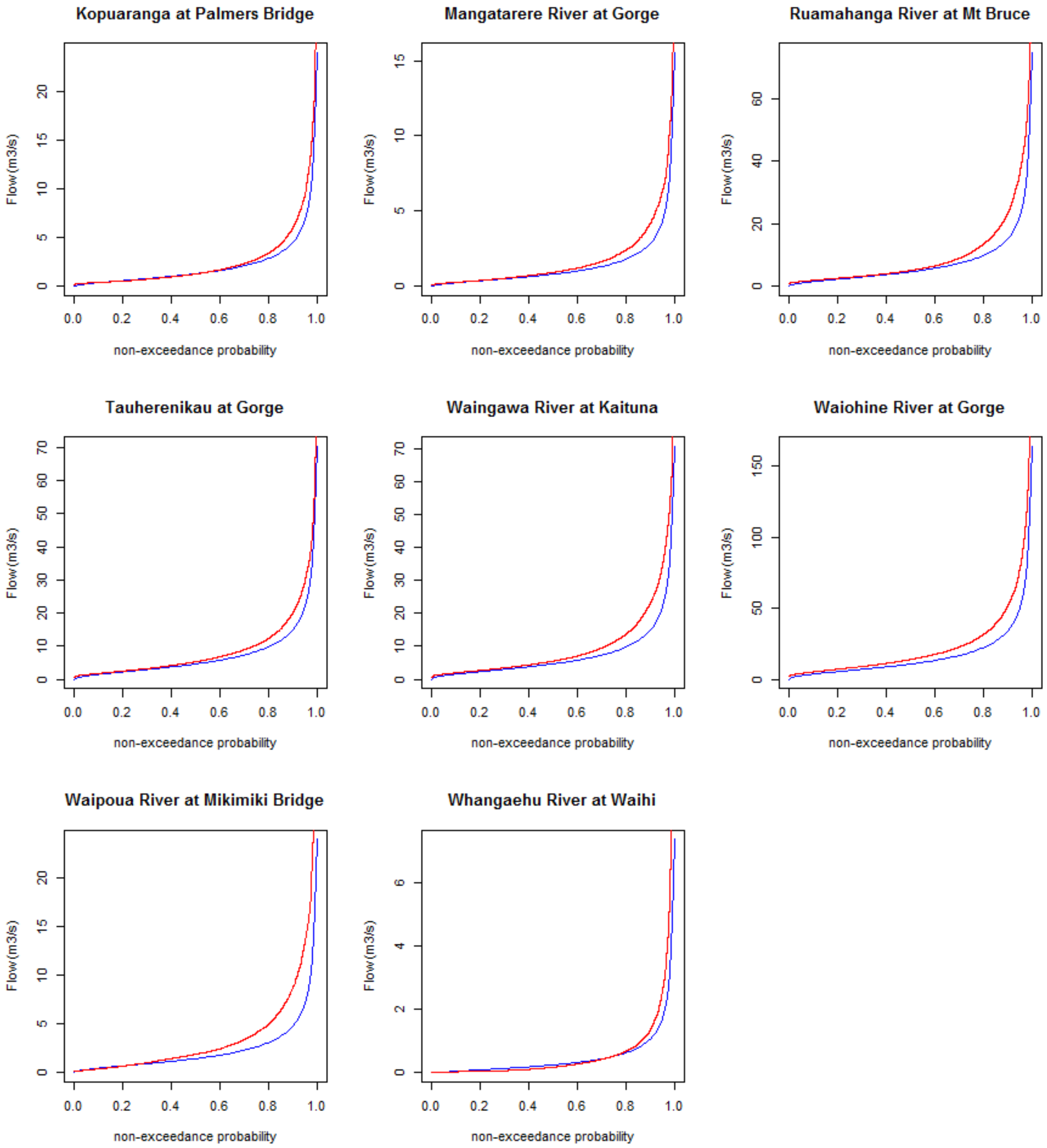

Figure 28: Comparison of observed and predicted duration curves for six gauging stations. Red line shows the observed FDC and blue line shows the predicted FDC (Booker and Snelder, 2012).

Figure 29 below shows the observed versus predicted MALF and mean flow values, respectively. Although there are some under-predictions for the larger rivers, in general the model performs well and reflects the relative differences in flows between locations. The absolute errors are within the range expected for the generalised models.

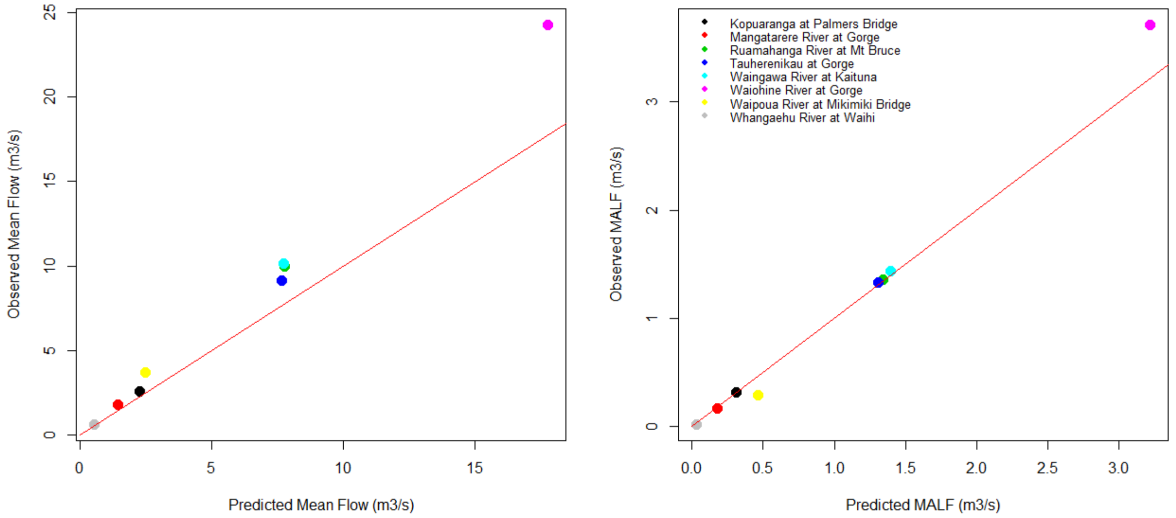

Figure 29: Comparison of predicted versus observed mean flow (left) and MALF (right). Red line indicates the 1:1 line (perfect model performance).

Appendix D LIMSIM outputs

This appendix provides a summary of the EFSAP outputs as decision space diagrams. Each figure is for a separate critical value based on the whole year. Each figure includes ten decision space diagrams – one for each of the water management classes.

Numbers in the cells are the median change in habitat across all reaches within the management class for each management scenario. Values in the brackets are the 25th and 10th percentiles of the % change in habitat (i.e. 75% and 90% of sites achieve values greater than those listed).

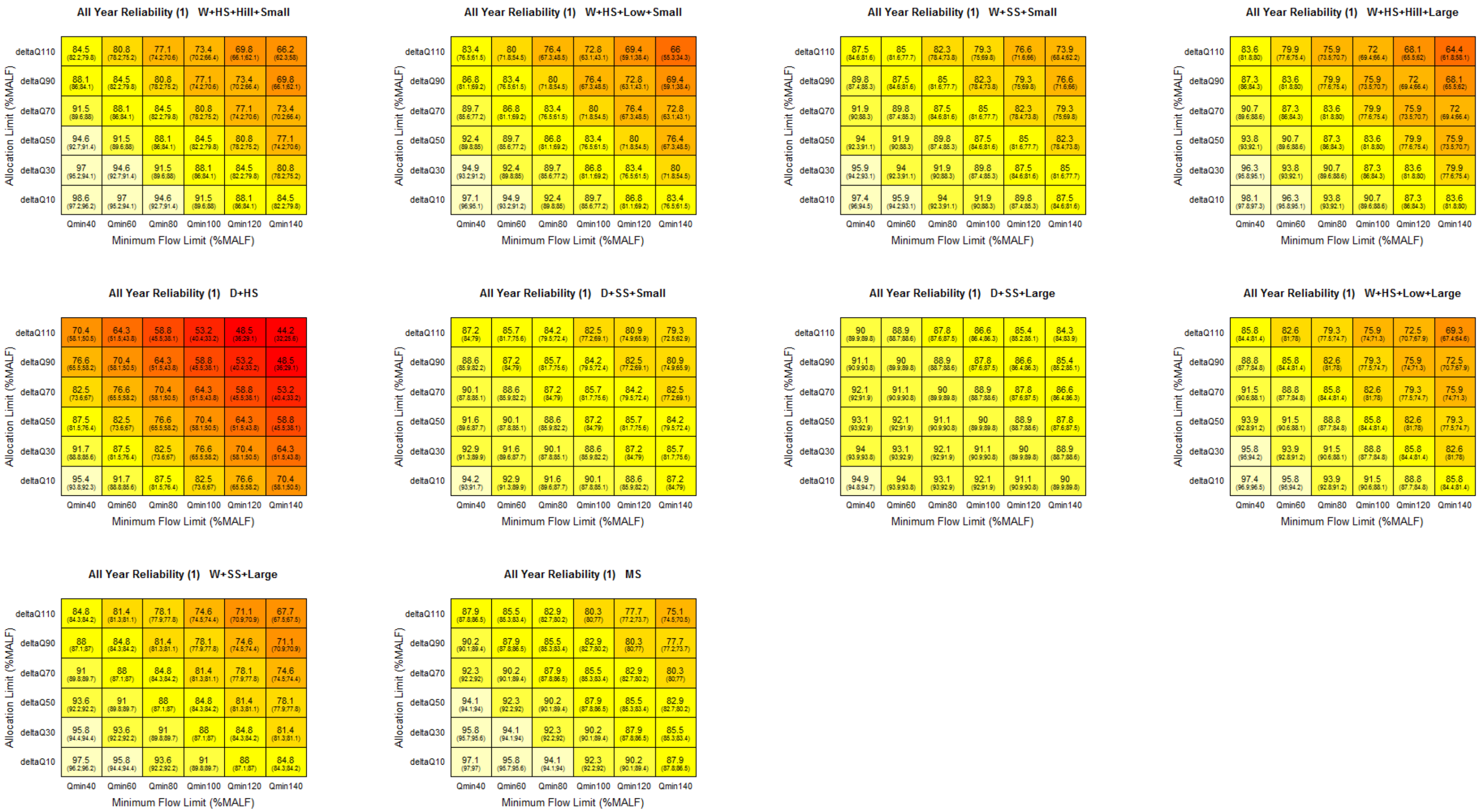

Figure 30: Decision space diagrams for the water quantity management zones for reliability at management flow for the whole year.

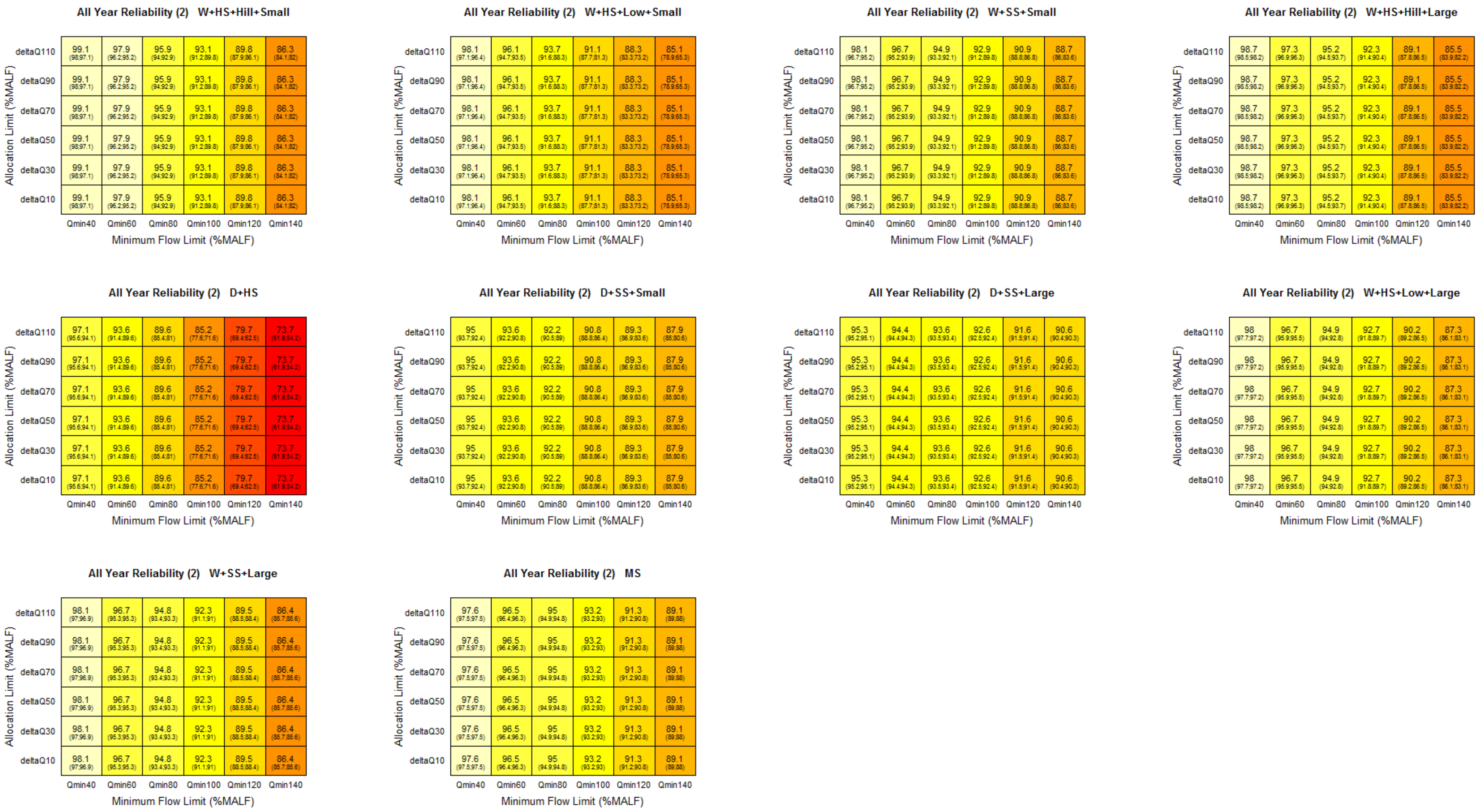

Figure 31: Decision space diagrams for the water quantity management zones for reliability at minimum flow for the whole year.

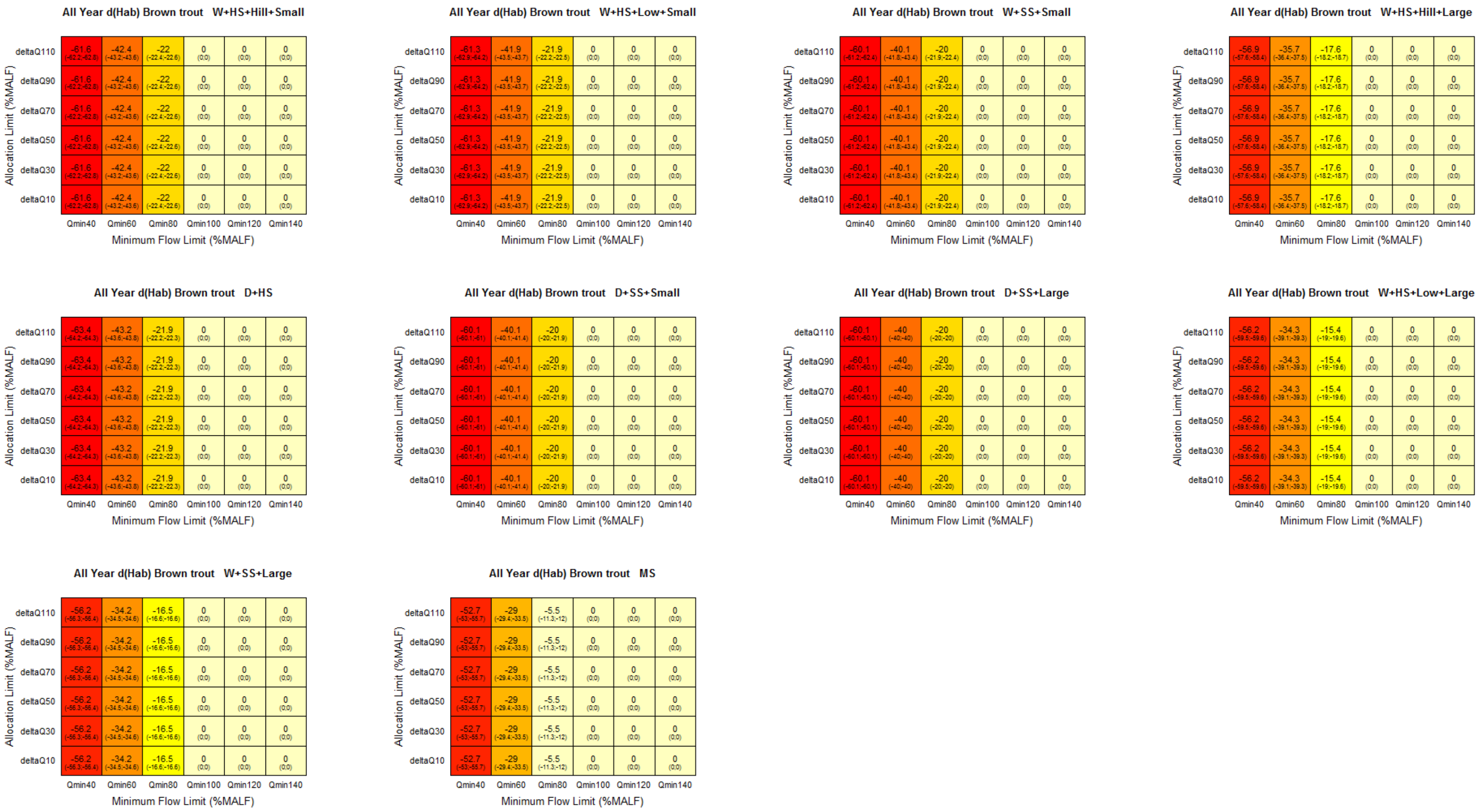

Figure 32: Decision space diagrams for the water quantity management zones for change in brown trout habitat for the whole year.

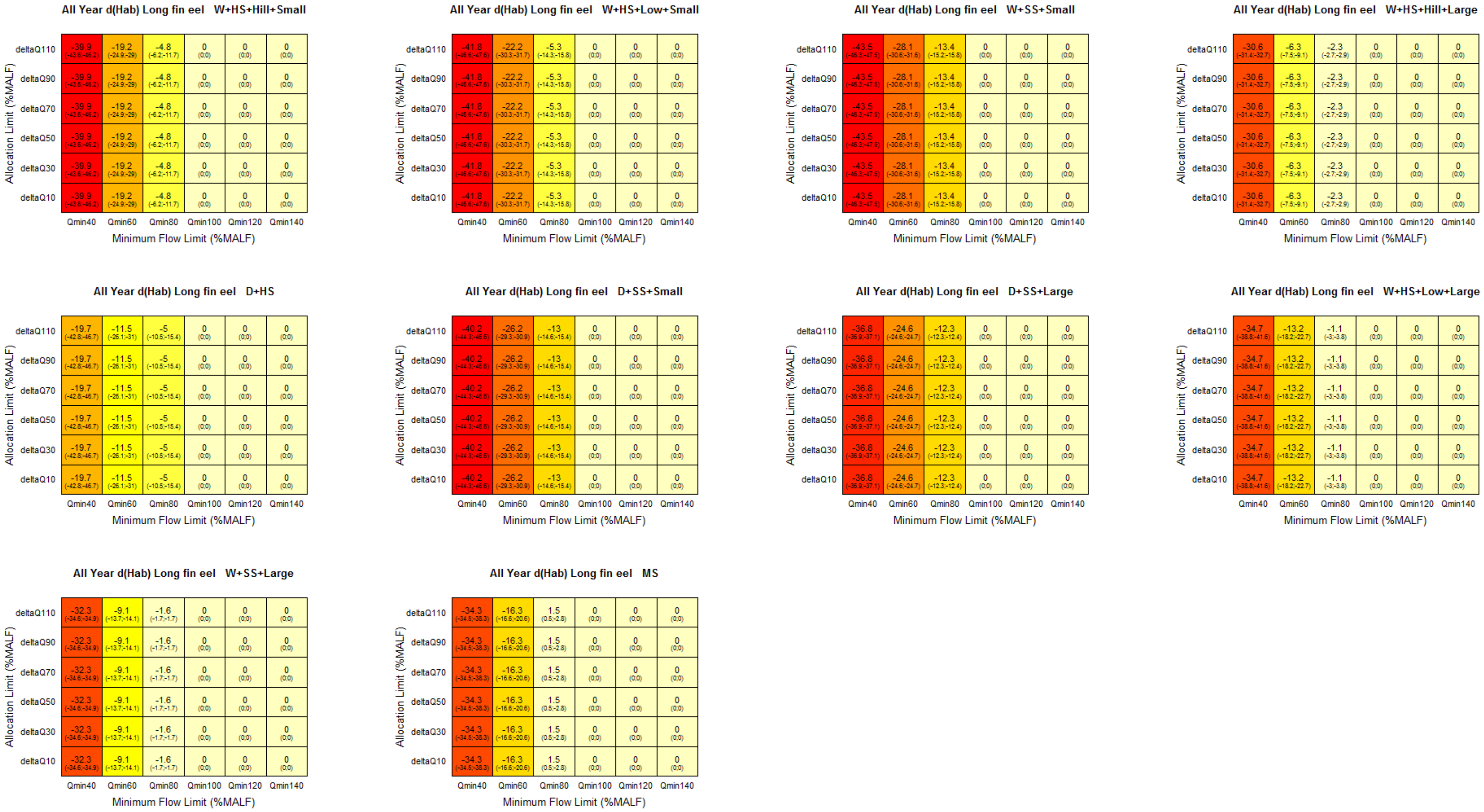

Figure 33: Decision space diagrams for the water quantity management zones for change in long fin eel habitat for the whole year.