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Defining a biophysical framework for Freshwater Management Units for the Bay of Plenty Region

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

The Bay of Plenty Regional Council (BoPRC) intends to implement the NPSFM via a series of plan changes for each of nine Water Management Areas (WMAs) that the region has been divided into. This report offers a regionally consistent framework as a bio-physical starting point for defining FMUs for rivers within each WMA. 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 with future work. The framework uses a modified version of the national River Environment Classification (REC) system to define a spatial subdivision of the bio-physical characteristics of the region's rivers and catchments that are relevant to managing water quality and quantity. In this document the bio-physically defined units are referred to as proposed FMUs but it is assumed that these may be modified, as BoPRC's planning processes proceed, following additional considerations such as specific values, human rather than bio-physical factors and/or additional bio-physical factors of particular water bodies.

For water quantity, regional default limits for water allocation already exist, but these default limits apply broadly to all rivers; more specific and justifiable objectives and limits could be provided if FMUs were defined for water quantity. No default limits currently exist for water quality, so a generalised management framework applying to the entire region is needed in the first instance, as well as ultimately consideration of more specific objectives and limits in areas where this is justified. Once generalised management frameworks have been developed for both water quality and quantity, BoBRC's intention is to develop specific objectives, policies and methods for FMUs within each of the nine WMAs based on individual consultation with community groups and tangata whenua in each WMA.

Definition of spatial management frameworks, as represented by FMUs, is therefore integral to setting objectives, policies and methods within each WMA. Consequently, it is important that the process of defining FMU boundaries is transparent and alternative options can be considered by decision-makers. This report considers alternative approaches to defining FMUs for the Bay of Plenty region and proposes an approach. Some iterative refinement of the FMUs proposed in this report is likely to be necessary as part of the development of new plan provisions in each WMA.

The FMUs proposed in this report form a framework of spatial units (i.e. there are layers of spatial units designed to serve different purposes and some units overlap each-other), rather than being a simple subdivision of the region. There are several reasons that a framework of spatial units is necessary including:

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

The proposed FMUs were developed in three steps. The first step was to classify the region's rivers for water quality and quantity management. The region's rivers were represented as individual segments of a digital river network and each segment was classified on the basis of physiographic drivers of water quality and quantity. 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 proposed water quality management classification is comprised of three classes: Non-Volcanic, Volcanic+Hill and Volcanic+Low. Individual segments were classified as Non-Volcanic class if the dominant geological category in their upstream catchments was not classified as Volcanic by the REC. Segments classified as Volcanic were assigned to the Hill category if the average slope of the upstream catchment was greater than 10 degrees and Low (lowland) if the average slope was less than 10 degrees. The proposed water quantity management classification comprises the previous three classes and a further river size subdivision of “Large” (mean flow $>10m^3s^{-1}$) or “Small” (mean flow $<10m^3s^{-1}$).

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

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

Because of the relationship between objectives and management zones, different objectives to those that have been assumed in this report (to provide examples of how the approach works) may result in differences in the zones defined (and mapped) in this report. 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.

The third step recognises that administration and accounting for contaminant discharges and water takes must occur within individual catchments. A minimum set of individual catchments are defined by the points in the drainage network where there is a change in the management zone. These points represent a framework of *administrative points*, each of which defines a sub-catchment or catchment. This results in a large number of administrative points but this need not result in a complicated plan because administrative units are of relevance to plan implementation whereas plan provisions apply only to the management classes (water quality and quantity objectives) and associated management zones (controls on use and development). Quantitative limits (e.g., contaminant mass loads and volumetric allocation rates) can be determined for each individual administrative 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 management classifications 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 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 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 in each WMA 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 and these approaches are described in this report. However, the proposed approach has a number of benefits over these two alternatives, including:

1. The use of classifications provides arguably appropriate resolution of variation in the characteristics of relevance 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 criteria,

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 easily repeatable allowing the criteria to be varied and for the definition of FMUs to be integral to the plan development process,

6. The level of detail of the plan provisions can be as coarse or fine (simple or complex) as required based on the level of classification detail used,

7. Aspects of the plan's implementation (e.g., consenting and accounting for resource use) can be undertaken at appropriately fine levels of spatial resolution defined by the administrative points,

8. The framework provides an efficient and justifiable basis for water quality monitoring and reporting at the regional level based on having a representative number of monitoring sites in each management class, and

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

The proposed approach is based on simple three and six class classifications for water quality and quantity respectively as the starting point for defining FMUs. The coarse level of classification and subsequent discrimination of characteristics is consistent with the requirements of a broad regional approach to management that requires trading off detail (specificity) with coverage and simplicity. As mentioned above 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 sedimentation issues in some harbours and estuaries. Thus, it is anticipated that a final FMU framework will ultimately require deciding how much complexity is appropriate beyond the three and six class units that are proposed by this study.

The framework of FMUs presented here represents a regional-scale bio-physical subdivision of the region's rivers for water quality and quantity management. This is intended to provide a regionally consistent starting point for defining FMUs within WMAs. This regional and coarse scaled approach to defining FMUs can be further modified by including additional considerations so that values, objectives and policies can be developed for WMAs or specific catchments that have particular issues.

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 develop freshwater objectives that express numerically (where practicable) the desired environmental state of water bodies.[1] Under the NPS-FM, freshwater objectives must strike a balance between enabling water resource use and sustaining other values of water. However, they must also provide for overall maintenance or enhancement of regional water quality.[2] In addition the NPS-FM requires councils to set objectives that are above specified minima or 'national bottom lines'.[3] Councils must develop policies, which may include limits and other management actions, to achieve the freshwater objectives.[4] Where objectives are not currently being achieved the NPS-FM directs regional councils to determine how and over what timeframes, those goals are to be achieved.[5]

As part of its implementation of the NPS-FM, Bay of Plenty Regional Council (BoRC) has identified nine Water Management Areas (WMAs). These WMAs are regarded as being a useful scale to break the region up into for prioritisation purposes to implement the requirements of the NPS-FM, and for consultation with communities within each WMA. Discussions with communities in each of these WMAs are planned on how to implement the NPS-FM, and in particular how to set limits for water quantity and quality.

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 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 objective[6] (purpose) and for freshwater accounting and management purposes. A plan that addresses water management at the regional scale (a region-wide plan) requires a spatial framework of FMUs that subdivides the region at an appropriate spatial scale for managing water quality and quantity.

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[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.

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

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 the development of the regional water plan, the methodology should be transparent and the decision maker should be able to consider and weigh up alternative options.

The scale of FMUs is a key consideration. Large FMUs may not provide sufficient resolution of values, community aspirations for water quality maintenance and enhancement, and current state; 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 administer, resulting in inefficient water resource management.

1.3 Bay of Plenty Regional Water Plan

BoPRC currently intends to implement the NPS-FM by changing its existing Regional Water and Land Plan. For water quantity, a plan change process is currently underway that formalises the setting of regional default allocation limits and minimum flows, which will achieve objectives for habitat protection and reliability of supply. This draft plan change has set a default minimum flow of 90% of the Q5 seven-day low flow, and an allocation limit of 10% of the Q5 seven-day low flow. These limits will be applied uniformly across all rivers in the region, unless superseded with more specific limits applied through WMA plan changes. Under such conditions, more intensive investigations will be needed to determine appropriate minimum flows and allocation limits.

Applying a uniform default flow limit throughout the region achieves BoPRC's immediate NPS-FM requirement for setting water quantity limits region-wide, but does not allow for environmental variation that affects the response of different rivers to flow reduction. For example, larger rivers generally are less sensitive to abstraction than smaller rivers and therefore it is often justifiable to be more enabling of resource use in these systems compared to small rivers. Accounting for regional variation in river characteristics would enable more specific and justifiable objectives to be set and would allow more specific and equitable rules for minimum flows and allocation limits to be defined to replace the interim limits in due course. Appropriately accounting for regional variation in rivers with respect to their responses to abstraction can be achieved by classifying them into management groups,

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[7] Plan provisions refers to objectives, polices, methods and rules that are defined in the regional plan.

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

which would form the basis of water quantity FMUs. Once these FMUs have been developed, community consultation will be undertaken within each WMA to help identify values, and subsequently set objectives, policies and limits.

A similar process is envisaged for water quality including the classification of the rivers for water quality management purposes and the definition of specific FMUs, followed by community consultation within each WMA to help identify values, objectives policies and limits. Thus, although FMU development for both water quantity and quality is based on a regional classification as the starting point, modifications could be made during the process of setting objectives, policies and limits for each FMU within individual WMAs as part of the community consultation process.

1.4 Developing ideas for FMUs in the Bay of Plenty

The study that is the subject of this report commenced with initial consideration of FMUs for rivers by BoPRC staff (Suren and Carter, 2015). That report examined and tested a number of potential river classification systems and considered how these could be used as a basis for defining FMUs for the region. A subsequent review of this followed by a workshop that was held at BoPRC in October 2015 further explored options for defining FMUs for the region’s rivers. It was broadly concluded at the workshop that FMUs based on a classification system have several advantages over the alternative approaches. This report further develops these ideas and derives a regionally consistent framework as a bio-physical starting point for defining FMUs for rivers within each WMA. 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 with future work.

In this document the bio-physically defined units are referred to as proposed FMUs. However, it is assumed that these may be modified, as the planning process proceeds, by considering additional aspects such as specific values, human rather than bio-physical factors or additional bio-physical factors of particular water bodies. The existing Water Quality Classifications in the current Regional Water and Land Plan (RWLP) are based on some previously identified values for the region but do not distinguish bio-physical river types. The RWLP classes may be a logical starting point to consider how values might interact with the bio-physically defined units identified in this report. BoPRC’s response to the NPS-FM will be an ongoing process in which these and other issues will need to be considered.

1.5 Structure of this report

This report is structured as follows:

- Section 2 provides an overview of the nature of FMUs, looks at alternative approaches to defining them and sets out a proposed approach for establishing FMU’s for the rivers of the Bay of Plenty region,
- Section 3 proposes a regionally consistent bio-physical framework as a starting point for defining FMUs for managing river water quality,
- Section 4 proposes a regionally consistent bio-physical framework as a starting point for defining FMUs for managing river water quantity, and
- Section 5 discusses the findings.

2 Alternative approaches to defining FMUs

2.1 Overview

Most regional councils have either developed region-wide water plans or are in the process of doing so. Some councils have operational second generation plans that were developed prior to the release of the NPS-FM, but nevertheless these plans address many of its requirements of including numeric objectives and limits. All regional councils have had to account for regional-scale differences in the values and other aspects 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 that will need to be consistent with 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 limits to be defined for each zone. To assess compliance with the objectives and limits, a monitoring site is required at the downstream end of each zone. It is anticipated that some management functions will occur at the subzone level (e.g. surface water allocation), while other management functions will occur at the zone level (e.g. water quality monitoring).

Environment Canterbury has defined management units at various scales. At the regional level, 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 rivers and lakes. 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) that are defined by "nodes". Nodes are points of significance that are tied to particular actions and resource use limits such as contaminant loads and water quantity limits. 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 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

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

addition, one FMU differentiates three non-contiguous “Outstanding” rivers and their catchments.

For the purposes of collaborative planning processes, the Greater Wellington Regional Council has defined six “whaitua” that encompass sub-regions that contain whole catchments. It is anticipated each whaitua will be further sub-divided into catchments and sub-catchments that reflect internal differences in values and objectives, but the methods for defining these further divisions have not yet been explored.

Finally, Northland Regional Council (NRC) has considered how to define FMUs for their geographically complex region. Northland comprises over 1300 “sea-draining” catchments that exhibit considerable variation in natural factors such as topography, geology and land use. As with many other regions, data describing aspects of these water bodies is limited. For example, long term water quality is monitored at only 35 sites. 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 has been to define FMUs based on grouping water bodies into 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. Suren and Carter (2015) identified that the bio-physical classification-based approach taken by NRC may be an appropriate approach for defining a framework of FMUs for BoPRC. This report has built on Suren and Carter (2015) to define draft FMUs based on classification of water bodies and their catchments using similar methods as NRC.

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

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[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 physiographic 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.

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

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

A sea-draining catchment 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 FMUs based on sea-draining catchments and WMAs

One way that FMUs could be defined is by treating each individual sea-draining catchment in the region as a unit. In the Bay of Plenty region there are approximately 170 sea draining catchments. However, while the sea-draining catchments are appropriate units for managing land impacts on the coastal environment (where there are water quality impairment issues), the freshwater bodies that are contained within these catchments are generally variable (i.e. are heterogeneous) and so further subdivision would likely be required.

As part of its implementation of the NPS-FM, BoPRC has divided the region into nine Water Management Areas (WMAs: Figure 1). The WMAs are a basis to prioritise targeted work associated with plan development and to involve communities in the NPS-FM process, in particular how to set limits for water quantity and quality. Some WMAs may be sufficiently homogeneous to allow a single set of plan provisions to be consistently and justifiably applied. However, treating each of the nine WMAs as individual units also leads to practical problems. The WMAs are generally heterogeneous with respect to values, capacity for use and management requirements. This is because as water in a catchment drains from its

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[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.”

[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.

upper reaches in the hills to its mouth at the coast, its quality and quantity are affected by changes in geology, soils, land cover, taking, use, damming, diversion and discharges[14]. Often the upper areas of catchments are characterised by steep land dominated by natural and exotic woody vegetation. Water bodies in these areas have physical characteristics (e.g. rocky and eroding stream beds) and water quality state that reflect these characteristics. By contrast, lowland areas of catchments are often characterised by flat land that is used for intensive agriculture or urban development. The water bodies in lowland areas generally exhibit different physical characteristics (e.g. soft muddy stream beds) and their state may be strongly influenced by the economic use of their resources.

An example of this heterogeneity is the variation in current water quality state within WMAs (Figure 2). Figure 2 shows the available water quality data for 40 long term monitoring sites in Bay of Plenty. *Table 1* provides a summary of the number of BoPRC monitoring sites (water quality and invertebrates). Figure 2 shows that state (i.e. water quality) is very variable in WMAs that have more than one site within each WMA. In other words, water quality state in the current WMAs is likely to be too heterogeneous for a single set of plan provisions to be justifiably applied for the purposes of managing some freshwater values. It is shown later that the same issue of heterogeneity occurs within WMAs when considering management of water quantity.

Where WMAs contain a heterogeneous mix of waterbodies and cannot be considered appropriate single units (i.e. FMUs) for management, they need to be sub-divided to smaller, more homogenous sub-catchments. Different plan provisions would then be applied to these various sub-catchments. One way to sub-divide the WMAs is an ad hoc approach (i.e. subjective splitting of some catchments and sub-catchments within the WMAs on a pragmatic basis using qualitative criteria and judgement). The problem with this approach is that it is subjective in the sense that different people might produce different outcomes and the reasons for the individual decision may be difficult to justify. The following sub-sections describe a more objective approach to establishing a regionally consistent bio-physical starting point for defining FMUs that is more justifiable, repeatable and easily modified in response to the identification of other key factors in a catchment that may justify different management objectives.

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[14] NPSFM objective A1 and B1

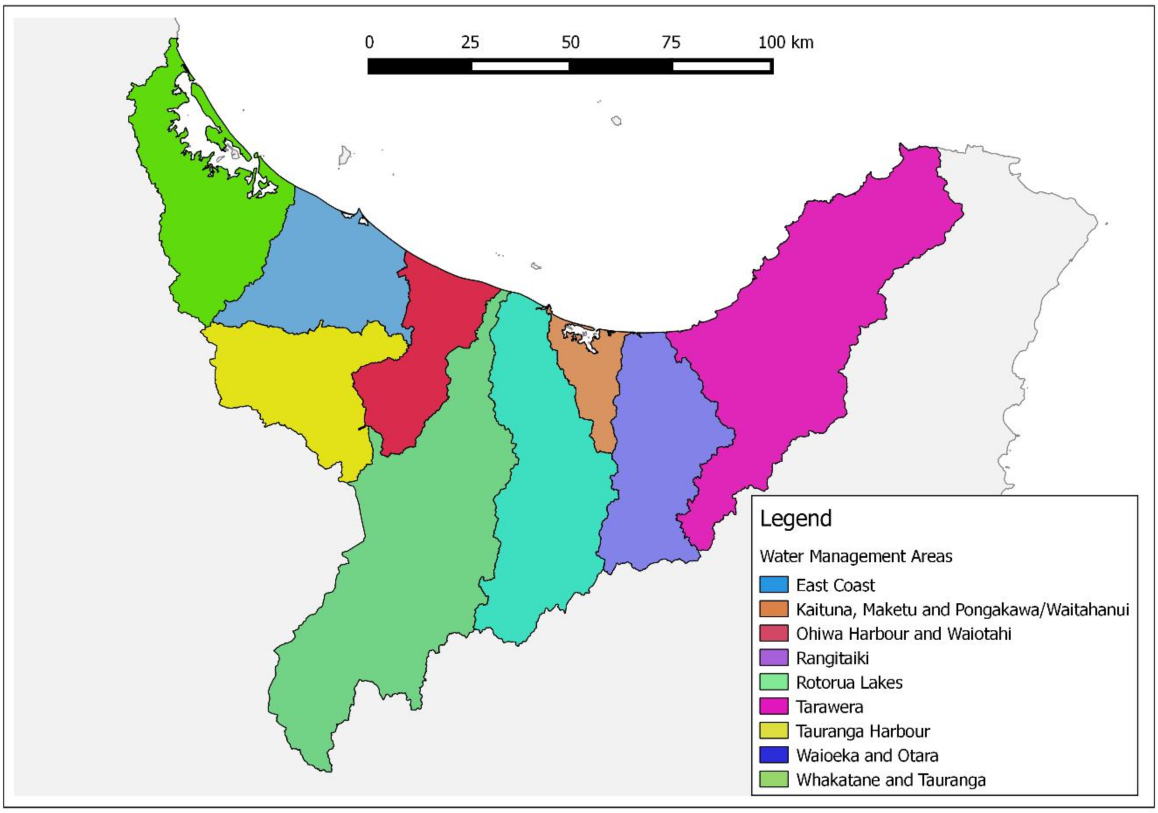

Figure 1: BoPRC Water Management Areas.

Table 1: Summary of number of monitoring sites per WMA.

WMA	**No. WQ Sites**	**No. Invertebrate Sites**
East Coast	3	8
Kaituna, Maketu and Pongakawa	6	15
Ohiwa Harbour and Waiotahi	1	9
Rangitaiki	5	10
Rotorua Lakes	4	15
Tarawera	3	16
Tauranga Harbour	14	32
Waioeka and Otara	1	2
Whakatane and Tauranga	3	9

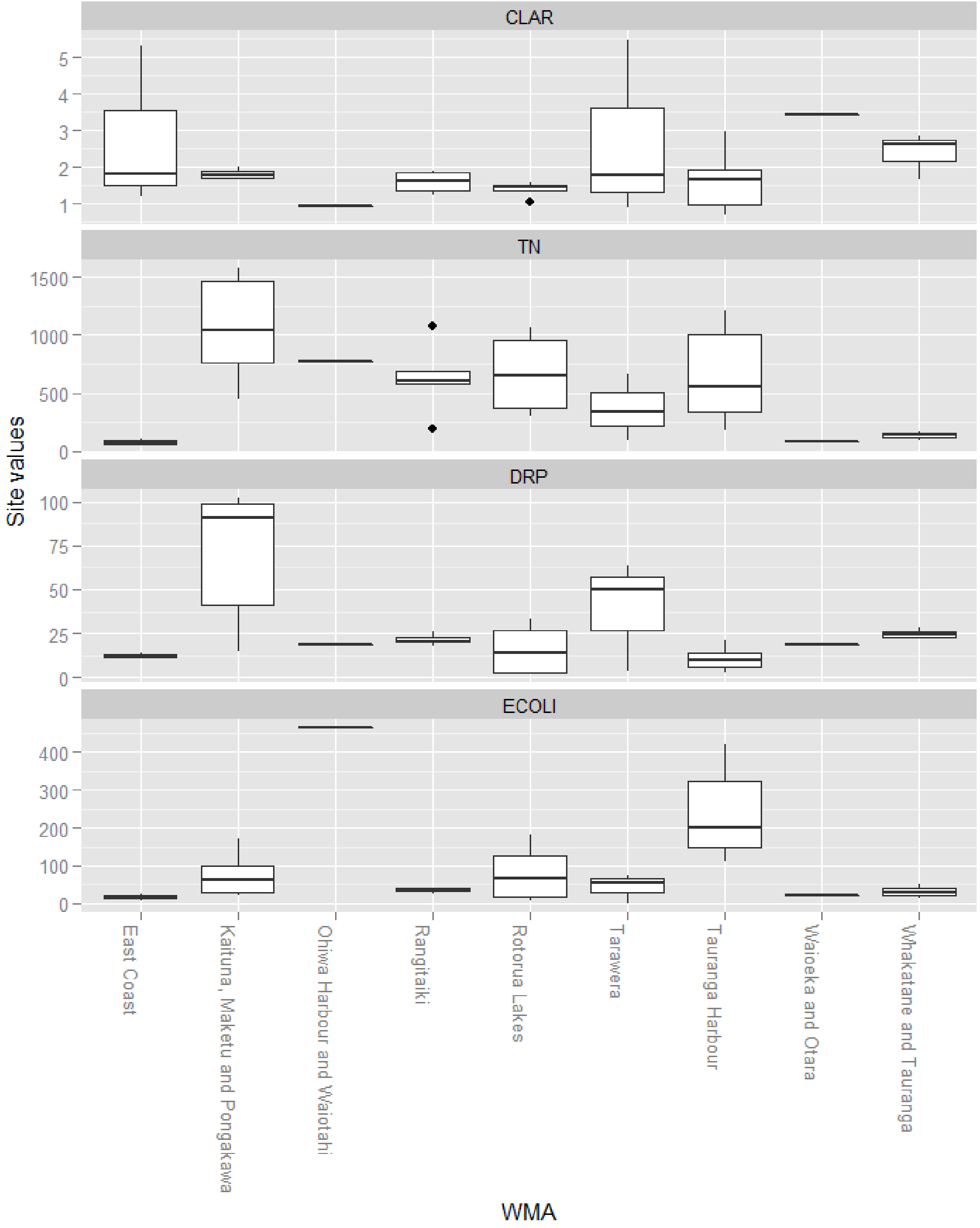

Figure 2: Box and whisker plot showing the variation in current water quality within WMAs. The central horizontal line in each box indicates the median and the bottom and top of the box indicate the 25th and 75th percentile values. The 'whiskers' (vertical lines) extend to the 10th and 90th percentiles. Where the number of sites exceeded 10, the black points indicate the 5th and 95th percentiles. Where the sea-draining catchments are represented by only one site, the median values are plotted as single lines. The number of sites in each WMA are shown in Table 1.

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

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

An alternative to the above approaches to the definition of FMUs is an approach that starts with a bio-physical classification that resolves important differences in relatively unchanging and natural aspects of the environment (including topography, geology and river size, which are termed factors in this report) that are relevant to the management of water quality and quantity. The approach subdivides the factors into specific categories according to criteria, for example, ‘hill’ and ‘low’ topography is discriminated by average catchment slopes of greater than and less than 10 degrees. 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 criteria-based approach is that the basis for FMUs is transparent and alterable (by changing the criteria) and can be applied generally to an entire region.

The 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 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). 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. Suren and Carter (2015) considered and tested a range of biophysical classification systems and this report has used and built on these results to define proposed management classifications.

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 sea-draining catchment and recur in a patchwork across a region. In addition, individual sea-draining catchments may comprise more than one and different *management zone*s. *Management zone*s need to be defined so that management actions and limits that apply to them provide for the achievement of the *most restrictive downstream objective*. For example, in some circumstances land may drain to a river segment that is relatively insensitive to the effects of nutrient concentrations. However, further downstream, perhaps several kilometres away, the destination of water may be a lake or estuary 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 for that lake or estuary is achieved. *Management zone*s clarify these important concepts and clearly define land and associated development that needs to be managed to achieve a particular objective in a water body.

The third step defines the ***administrative points***. *Administrative points* recognise that controls on contaminant discharges and water takes must occur and be accounted for within individual catchments and sub-catchments. Therefore, a subdivision of the region into individual catchments and sub-catchments should occur at least at points in the drainage network where there is a change in the *management zone*. *Administrative points* are locations at which 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 *management zones* on a scalable basis. Scalable limits can be based on a proportion of a flow statistic that reflects stream size such as the

Mean Annual Low Flow (MALF) for water quantity and an aerial basis for 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 with a region-wide framework of FMUs that are defined based on the drainage network. First, classifying the region's water bodies based on bio-physical factors allows spatially discrete but similar water bodies (e.g. located in different sea-draining catchments) to be managed under a common set of plan provisions where values and objectives are also similar. 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 would enable more specific objectives (desired environmental outcomes) and more nuanced policies and limits, but would increase the effort and data needed to justify them and the complexity and detail of the plan's final provisions. There is also likely to be tension between the level of detail that is technically and scientifically justifiable (and achievable) and other considerations such as catering for the desire of stakeholders for spatially nuanced policies and limits. 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 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.

2.6 A proposed approach for Bay of Plenty

The remainder of this report presents a proposed approach to defining a framework of FMUs for Bay of Plenty's rivers that is based on a bio-physical classification of the drainage network. In this document the bio-physically defined units are referred to as 'proposed 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 regional plan decision making process. This report also builds on the investigation of performance of various *management classification*s for describing variation in the current state of water quality, invertebrate and freshwater fish communities by Suren and Carter (2015).

The approach that follows is built using the REC as the basis for describing the Bay of Plenty region's river network at 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 Bay of Plenty region with approximately 28,000 unique river segments, with a mean segment length of 704 m, defined by upstream and downstream confluences with tributaries (the 'water bodies'). A key feature of the REC is a system of labels for the segments and their associated sub-catchments that allows rapid analysis of upstream–downstream connectivity and accumulation of catchment characteristics (e.g. land areas having different geological or land cover categories) in the downstream direction.

3 Water quality FMUs

This section proposes a network based approach for defining a regional framework of biophysical units that could provide the basis for FMUs for managing river water quality in the Bay of Plenty. The framework is an example that could easily be altered by changing the criteria and other details that are presented in this section.

3.1 Water quality management classification

A proposed 'water quality *management classification*' is a coarse subdivision of the region's water bodies for management purposes. The classification takes into account not only variation of environmental and ecological characteristics and the current observed water quality of the region's rivers, but also incorporating expert knowledge of the likely mechanisms that lead to this variability. The classification is based on the geology and average upstream slope of the catchment of each network segment's unique sub-catchment. The earlier report by Suren and Carter (2015) recommended a *management classification* based on geology and substrate size, as this classification explained, when tested statistically using BoPRC datasets, the most variability in water quality, invertebrate and fish communities from among various alternative classifications. However, their report also acknowledged that predictions of substrate size on which their classification was based were relatively weak, and they discussed the merits of using average upstream catchment slope as a potential classification factor. Benefits of the slope classification include the availability of more accurate characterisations of average upstream catchment slope (compared to substrate), its close links to hydraulic factors such as water velocity and substrate size, and its influence on catchment land use. Suren and Carter (2015) also showed that the combined geology/slope classification explained more of the variation of several specific water quality variables than the geology/substrate classification.

Each of the factors in the geology-slope classification has two categories: geology as Volcanic or Non-Volcanic, and upstream catchment slope as hill or low (based on a 10-degree splitting threshold). This results in four potential *management classes*. However, one of the classes (Non-Volcanic+Low) makes up less than 1% of the streams within the region and hence these areas were joined with the other non-volcanic areas. We have also checked the distribution of this small class within the WMAs, and found that it represented at most 5% of any given WMA (maximum observed for the Tauranga Harbour WMA). Removing this *management class* from the analysis is likely to have minor impacts on the management of the land and water resources but the absence of monitoring of sites in the

Non-Volcanic+Low class means we are unable to be sure of the consequences of this. Figure 3 shows the region’s rivers colour coded based on this geology-slope classification.

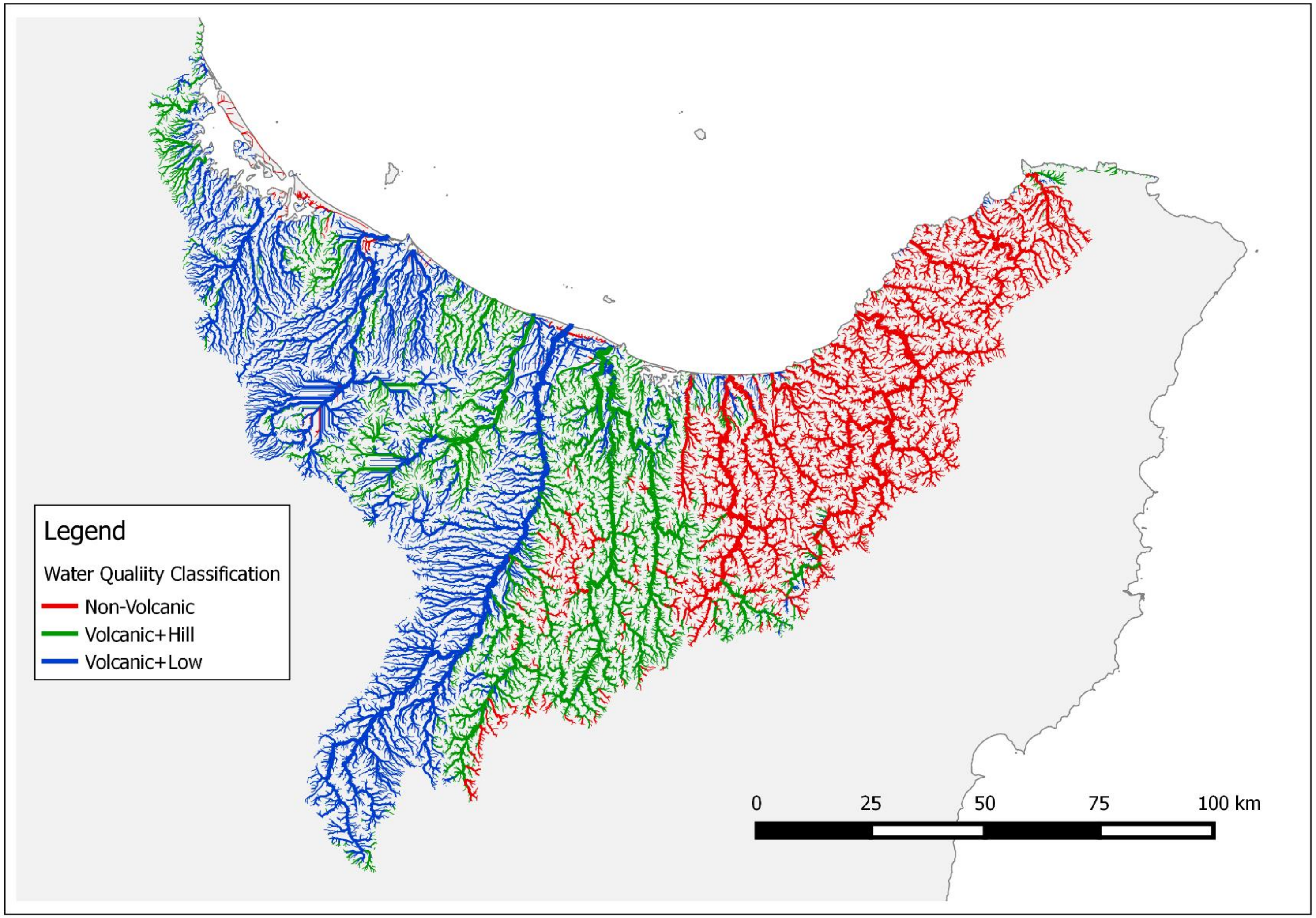

Figure 3: Water quality Management Classification of the Bay of Plenty drainage network based on geology and the average slope of the upstream catchment. The slope threshold differentiating the Volcanic+Hill and Volcanic+Low classes was 10-degrees.

3.2 Potential water quality objectives

This section assesses potential 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 values have been clarified.

For the purposes of explaining the application of the FMU framework, it was 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 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 plan 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 that “ecosystem health” and “human health for secondary contact recreation” are compulsory water quality and quantity related values that must be provided for in all water bodies. However, regional councils have the discretion to 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 the numeric “freshwater” objectives. Attributes are defined in the NPS-FM to mean “a measurable characteristic of freshwater, including physical, chemical and biological properties, which supports particular values.” The NPS-FM attributes enable communities to choose the level of protection for values by defining numeric attribute states or “bands” (A, B or C bands) and also defines 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. BoPRC has only recently started monitoring periphyton at waterways throughout the region (see Suren and Carter 2015), so long-term data summarising periphyton biomass are not currently available. To overcome this lack of periphyton data, nutrient concentrations for total nitrogen (TN) and dissolved reactive phosphorus (DRP) were used as proxies for periphyton biomass following the nutrient concentration criteria provided by Larned et al. (2015).

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

Larned et al. (2015) derived TN and DRP criteria to meet the three periphyton biomass thresholds that define the NOF periphyton attribute states using regression models that were fitted to National River Water Quality Network data and predictions made using these models stratified by REC "Source of Flow" (SoF) classes. The REC SoF classes explain significant variation in the observed national periphyton data because they discriminate differences in the physical drivers of periphyton (e.g. flow characteristics, temperature and solar radiation). Therefore, Larned et al. (2015) define nutrient criteria for each SoF class for each of the three periphyton biomass thresholds defined by the NOF of 50, 120 and 200 mg chl-*a*/m^2 (milligrams chlorophyll-*a* per square metre). These values are relevant for hard bottomed streams that support conspicuous blooms of periphyton.

We assessed the predicted current state of periphyton biomass at each of BoPRC's monitoring sites using the criteria provided by Larned et al. (2015) for that site's REC SOF class. For this analysis, each of the periphyton nutrient thresholds (Table 2) were evaluated independently, and then the modelled periphyton band in each NZReach in the region was assigned based on the nutrient that was associated with the lower biomass. It is emphasised that the criteria derived by Larned et al. (2015) have large uncertainty and that ideally actual periphyton data should be used to make an assessment of current state in the region. The criteria provided by Larned et al. (2015) are proxies for actual periphyton biomass data and enabled us to make a preliminary assessment of the current state of region's rivers with respect to the NOF periphyton attribute. More detailed consideration of the periphyton, including analysis of available actual data is recommended.

Three additional potential attributes were also selected for analysis in this report: 1) *E.coli* levels for primary contact recreation; 2) water clarity; 3) Macroinvertebrate Community Index (MCI: see Stark 1985) and its quantitative variant (QMCI). Bands for optional objectives for water bodies valued for primary contact recreation (swimming) are defined by the NPS-FM 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 for water bodies that are valued 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 so could also be evaluated.

The MCI attributes are indicators of ecological health, which is a compulsory value in the NPS-FM). We used four bands suggested by Stark and Maxted (2007) for both the MCI and QMCI scores. Thus, the A band indicates streams in "Excellent" condition, and the D band referred to streams in "Poor" condition. More detailed and specific criteria provided by Stark (2014) are possibly appropriate and could be evaluated. All potential water quality objectives are summarised in Table 2 and **Error! Reference source not found.**.

Table 2: Attribute state bands. The asterisk indicates attributes that are compulsory under the NPS-FM.

Value	**Attribute**	**Units**	**Statistic**	**Criteria for bands**			
				A (Excellent)	**B (good)**	**C (Poor)**	**D (Unacceptable)**
Human health – secondary contact*	E.coli*	E.coli/100 ml	Median	x ≤ 260	260≤ x ≤540	540 ≤ x ≤ 1000	x ≤ 1000
Human health – primary contact	E.coli	E.coli/100 ml	95th	x ≤ 260	260 ≤ x ≤ 540	540 ≤ x ≤ 1000	x ≤ 1000
Ecosystem Health	NO_3N toxicity*	mg/m^3	Median	x<1000	1000< x < 2400	2400 < x < 6900	>6900
		mg/m^3	95th	x<1500,	1500 < x < 3500	3500 < x < 9800	>9800
Ecosystem Health	NH_4N toxicity*	mg/m^3	Median	x<30	30 < x < 240	240 < x < 1300	>1300
		mg/m^3	95th	x<50	50 < x < 400	400 < x < 2200	>2200
Ecosystem Health	MCI	NA	Median	x >119	100 < x < 119	80 < x <100	x < 80
Ecological Health	QMCI	NA	Median	x >4	4 < x < 5	5 < x < 6	x < 6
Human health – primary contact	Visual clarity	m	Median			>1.6	X < 1.6

Table 3: Potential attribute state bands for Periphyton. Periphyton is a compulsory attribute under the NPS-FM. The TN and DRP concentration criteria for periphyton are from Larned et al. (2015) and are shown for the 16 REC Climate/Source of Flow classes that occur in the Bay of Plenty region.

Attribute	**Units**	**Statistic**	**Climate /SOF**	**Criteria for Bands**			
				A (Excellent)	**B (good)**	**C (Poor)**	**D (Unacceptable)**
Periphyton* (proxy measure based on TN)	mg/m^3	Median	CD/L	<4	4 < x < 162	162 < x < 389	> 389
			CW/H	<7	7 < x < 299	299 < x < 633	> 633
			CW/L	<6	6 < x < 269	269 < x < 541	> 541
			CW/Lk	<4	4 < x < 217	217 < x < 426	> 426
			CW/M	<5	5 < x < 267	267 < x < 549	> 549
			CX/H	<249	249 < x < 846	846 < x < 1667	> 1667
			CX/L	<233	233 < x < 731	731 < x < 1399	> 1399
			CX/Lk	<5	5 < x < 250	250 < x < 537	> 537
			CX/M	<92	92 < x < 591	591 < x < 1148	> 1148
			WD/L	<3	3 < x < 6	6 < x < 230	> 230
			WW/H	<11	11 < x < 339	339 < x < 709	> 709
			WW/L	<4	4 < x < 58	58 < x < 336	> 336
			WW/Lk	<3	3 < x < 213	213 < x < 420	> 420
			WX/H	<7	7 < x < 293	293 < x < 606	> 606
			WX/L	<5	5 < x < 261	261 < x < 560	> 560
			WX/Lk	<5	5 < x < 261	261 < x < 560	> 560
Periphyton* (proxy measure based on DRP)	mg/m^3	Median	CD/L	<0.3	0.3 < x < 1	1 < x < 14.2	> 14.2
			CW/H	<0.5	0.5 < x < 15.9	15.9 < x < 61.2	> 61.2
			CW/L	<0.4	0.4 < x < 4.4	4.4 < x < 33.2	> 33.2
			CW/Lk	<0.3	0.3 < x < 1.1	1.1 < x < 24.7	> 24.7
			CW/M	<0.4	0.4 < x < 17.8	17.8 < x < 71.4	> 71.4
			CX/H	<13.5	13.5 < x < 140.9	140.9 < x < NA	> NA
			CX/L	<5.4	5.4 < x < 91.9	91.9 < x < 350.3	> 350.3
			CX/Lk	<0.3	0.3 < x < 12.2	12.2 < x < 48.7	> 48.7
			CX/M	<6.6	6.6 < x < 88.8	88.8 < x < 335.9	> 335.9
			WD/L	<NA	NA < x < 0.3	0.3 < x < 12.2	> 12.2
			WW/H	<0.6	0.6 < x < 17	17 < x < 62.5	> 62.5
			WW/L	<0.3	0.3 < x < 0.6	0.6 < x < 11.2	> 11.2
			WW/Lk	<0.3	0.3 < x < 0.4	0.4 < x < 20.5	> 20.5
			WX/H	<0.4	0.4 < x < 13.6	13.6 < x < 61.5	> 61.5
			WX/L	<0.4	0.4 < x < 8.9	8.9 < x < 38.8	> 38.8
			WX/Lk	<0.4	0.4 < x < 8.9	8.9 < x < 38.8	> 38.8

3.3 Assessment of current state of river water quality

We evaluated the current state of river water quality and ecological health using the council's long-term monitoring data collected as part of its Natural Environment Resource Monitoring Network (NERMN) programme. We assumed that the water quality data available for the NERMN sites broadly reflects the characteristics of the catchments upstream of the sites and that collectively the sites within each of the proposed FMUs represent the overall state of the FMU. A total of 40 sites were used for the water quality variables, and 114 sites for the invertebrate variables; the sites are shown in **Error! Reference source not found.**. provides a summary of the number of sites within each of the *management classes*.

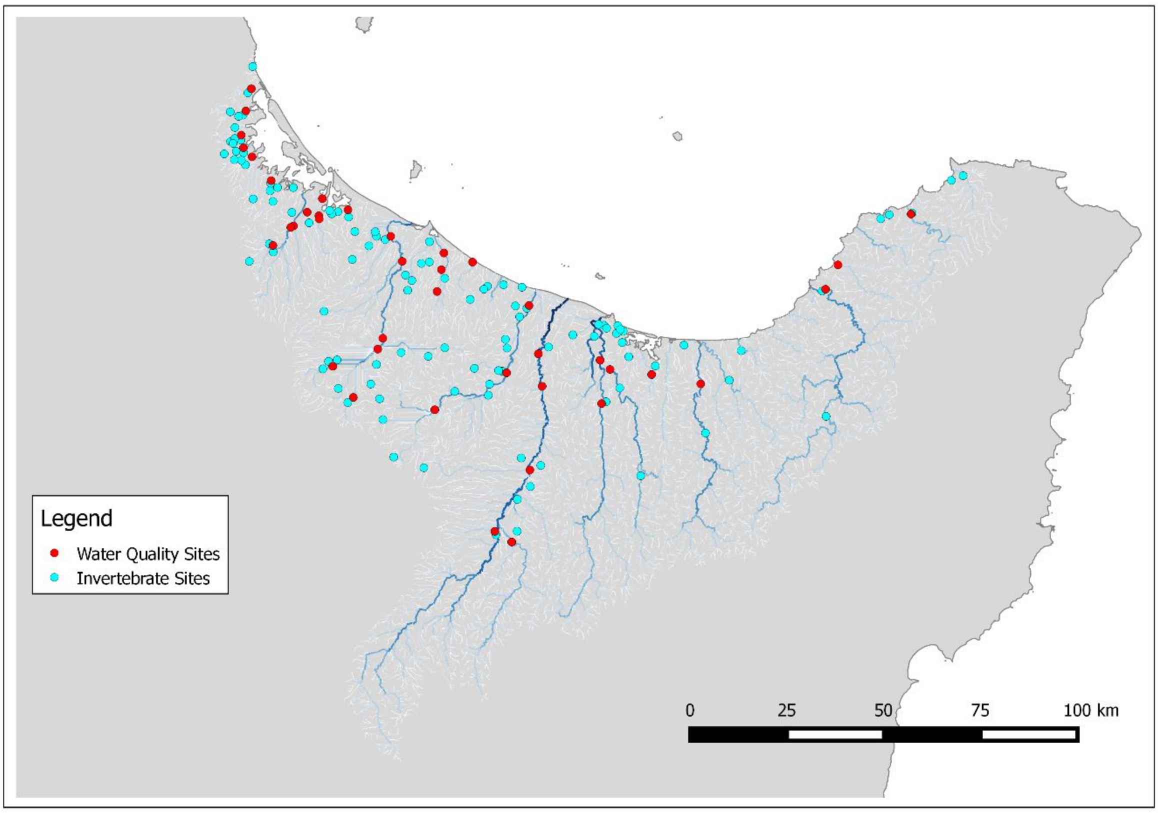

Figure 4 Location of water quality and invertebrate monitoring sites.

Table 4: Distribution of water quality and invertebrate monitoring sites within the proposed management classes.

Water Quality Class	**Number of Water quality sites**	**Number of invertebrate sites**
Non-Volcanic	4	10
Volcanic+Hill	12	57
Volcanic+Low	24	49

In this report, we present current water quality state as the median water quality state over the five-year period 2009-2013. As invertebrate sampling is less frequent, we present MCI and QMCI values as the median of annual values for a ten-year monitoring period (2003-2013). MCI and QMCI values used in this analysis were based on invertebrate monitoring data and were calculated by BoPRC staff using methods defined by Stark and Maxted (2007) for both hard-bottomed and soft-bottomed streams, where stream substrate is based on field assessments of the dominant substrate size at each site.

The current state of rivers and streams in Bay of Plenty is illustrated in Figure 5 as the distribution of site median values for the water quality variables, QMCI, MCI and 95th percentile values for *E.coli*. The distributions are shown for the three classes in the proposed water quality *management classification* (Volcanic+Hill, Volcanic+Low and Non-Volcanic). Figure 5 indicates that in general concentrations of nutrients are lowest in waterways in the Non-Volcanic management class, and highest in the Volcanic-Low class. MCI and water clarity were generally highest in the Non-Volcanic class, and lowest in the Volcanic+Low class.

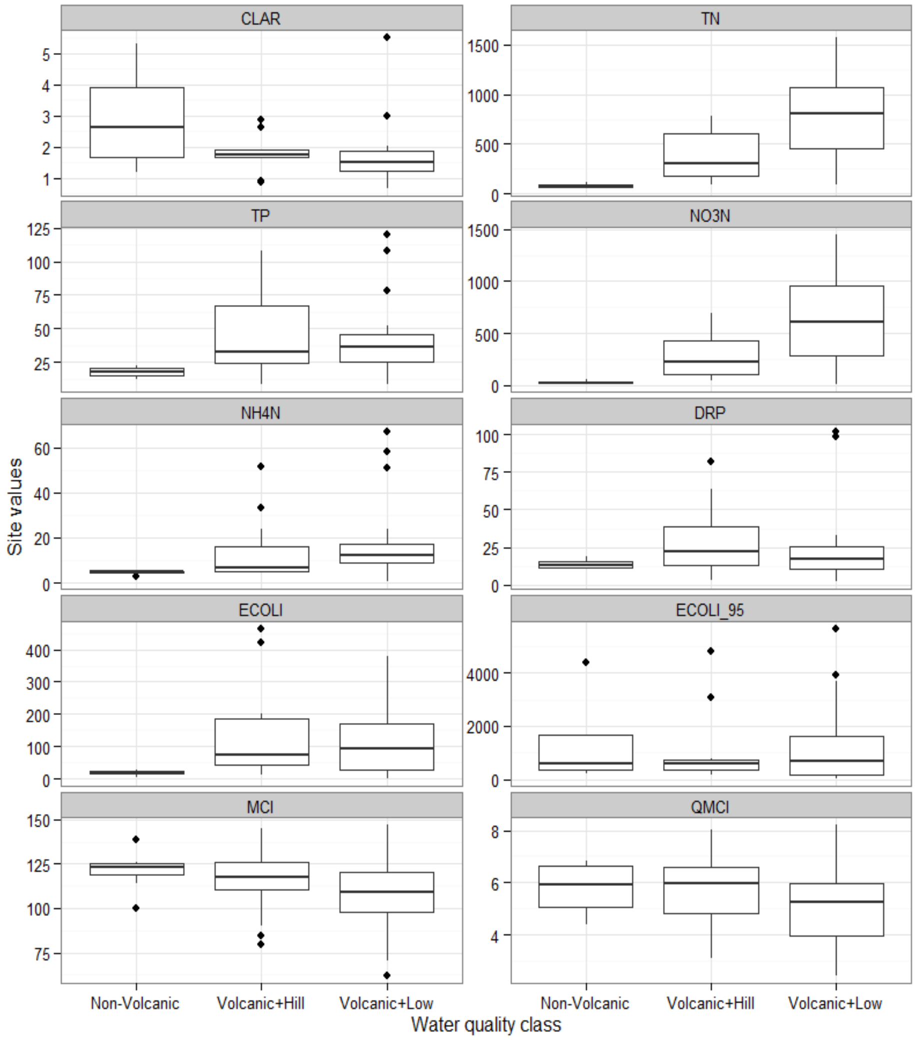

Figure 5: Box and whisker plot showing the distributions of site median values of water quality variables measured at council's long-term monitoring sites. The variables include; clarity (CLAR), macroinvertebrate community index (MCI), Quantitative macroinvertebrate community index (QMCI), dissolved 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 40 water quality monitoring sites and 114 invertebrate sites (MCI and QMCI). The data are grouped by the three proposed water quality management classes; Non-Volcanic, Volcanic+Hill and Volcanic+Low. The individual water quality site values were derived from data for the 5 year period ending 2013 and for the invertebrate data for the 10 year period ending 2013. 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 three water quality *management classes* relative to the potential (example) objectives (listed in Table 2 and 3) is shown in Table 5. 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 in Table 2 and 3.

Table 5: Current state of the three water quality classes compared to several potential objectives. The selected objective could be state band A, B or C, recognising that D band fails NPS-FM bottom lines. 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**	**Water quality management class**		
		Non-Volcanic	**Volcanic+Hill**	**Volcanic+Low**
Number of Sites		10	57	49
MCI	A	70%	44%	29%
	B	30%	42%	43%
	C	0%	12%	24%
	D	0%	2%	4%
QMCI	A	40%	49%	24%
	B	30%	25%	33%
	C	30%	16%	16%
	D	0%	11%	27%
Number of Sites		4	12	24
Clarity	Pass	75%	83%	62%
	Fail	25%	17%	38%
Periphyton* (Modelled, based on either TN and DRP, whichever was lower)	A	25%	0%	0%
	B	75%	56%	17%
	C	0%	33%	75%
	D	0%	11%	8%
E.coli (Primary contact recreation)	Pass	75%	82%	59%
	Fail	25%	18%	41%
Ecoli (Secondary contact recreation)*	A	100%	82%	86%
	B	0%	18%	14%
	C	0%	0%	0%
	D	0%	0%	0%
NH_4-N toxicity*	A	100%	82%	59%
	B	0%	18%	41%
	C	0%	0%	0%
	D	0%	0%	0%
NO_3-N toxicity*	A	100%	100%	82%
	B	0%	0%	18%
	C	0%	0%	0%
	D	0%	0%	0%

The assessment indicates that the periphyton bottom line is not met at 11% and 8% of Volcanic+Hill and Volcanic+Low hard bottomed water quality monitoring sites respectively, but is met in all hard bottomed Non-Volcanic sites[16]. It is important to reiterate that this report

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[16] Note that streams with soft (mud or sand) beds will not grow conspicuous periphyton and the objective does not therefore apply to these types of environment. This analysis has differentiated soft bed streams at the regional level u the FENZ (Leathwick et al., 2010) characteristic "substrate" where sites with substrate <3 defined as soft bottomed.

has used NO_3N and DRP concentrations as a surrogate for actual periphyton data, and therefore these findings should be treated with caution.

All sites in all classes are above the bottom line for human health - secondary contact recreation. The Volcanic classes are in a marginally poorer state for secondary contact recreation (18% and 14% in B compared to 0% for Non-Volcanic). 41% of sites in the Volcanic+Low class are in the D state for primary contact recreation and 15% of the Volcanic+Hill sites are in the D state (note this is not a compulsory NPS-FM national bottom line). In addition, 25% of the Non-Volcanic class are in the D state for primary contact recreation.

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 Non-Volcanic sites and predominantly in the A band in the Volcanic classes. For NO_3-N sites are entirely (100%) in the A band in the Non-Volcanic and Volcanic+Hill classes and predominantly in the A band (82%) in the Volcanic+Low class.

Median site MCI scores were consistently lower in the Volcanic classes with one site in each class in the D band and more than 40% of sites in the C band. By contrast, no sites in the Non-Volcanic class were in the D or C bands and 70% of sites were in the A band.

A number of sites failed to meet MfE water clarity guidelines in all classes and this was a marginally higher rate in the Volcanic+Low (38%) than Volcanic+Hill (17%) and Non-Volcanic (25%) classes.

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 given in Appendix A1, along with supplementary figures. Table 6 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, 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 the Non-Volcanic class to evaluate trends, as such it was not possible to make meaningful comparisons of the trend distributions with the other classes.

Clarity was generally improving in monitored waterways in the Volcanic classes, although one site in the Volcanic+Low class exhibited a degrading trend. Trends for MCI and QMCI at most sites were uncertain for all *management classes*. There were no sites with degrading *E. coli* trends. NH_4-N was generally improving in the Volcanic+Hill sites, but was degrading at 30% of Volcanic+Low sites.

The majority (70%) of Volcanic+Low sites had degrading NO_3-N trends (i.e., concentrations were increasing), and 40% of Volcanic+Hill also showed a degrading trend. However, the remaining 60% of Volcanic+Hill sites showed improving NO_3-N trends (i.e., concentrations were decreasing). TN concentrations were also decreasing in 80% of Volcanic+Hill sites, with no sites showing degradation; in contrast only 30% of Volcanic+Low sites had improving TN trends, and 20% of sites Volcanic+Low had degrading TN trends. DRP was improving at 40% and 60% of Volcanic+Hill and Volcanic+Low sites, respectively, with one Volcanic+Hill site showing a degrading trend and the remainder of sites having an uncertain trend. TP trends were degrading at 40% of sites in the two Volcanic classes.

Table 6: Summary of trends for the period 2003-2013 for the three 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**	**Water quality management class**		
		Non-Volcanic	**Volcanic+Hill**	**Volcanic+Low**
Clarity	No. of Sites	2	5	7
	Degrade			14%
	Improve	50%	80%	57%
	Uncertain	50%	20%	29%
MCI	No. of Sites	12	58	50
	Degrade		7%	4%
	Improve		5%	2%
	Uncertain	100%	88%	94%
QMCI	No. of Sites	12	58	50
	Degrade	8%	9%	4%
	Improve	0%	10%	16%
	Uncertain	92%	81%	80%
E. coli	No. of Sites	1	3	7
	Improve	100%	100%	86%
	Uncertain			14%
NH4N	No. of Sites	2	5	10
	Degrade	50%		30%
	Improve	50%	80%	20%
	Uncertain		20%	50%
NO3N	No. of Sites	2	5	10
	Degrade	0%	40%	70%
	Improve	50%	60%	10%
	Uncertain	50%	0%	20%
TN	No. of Sites	2	5	10
	Degrade			20%
	Improve	50%	80%	30%
	Uncertain	50%	20%	50%
DRP	No. of Sites	2	5	10
	Degrade		20%	
	Improve		40%	60%
	Uncertain	100%	40%	40%
TP	No. of Sites	2	5	10
	Degrade		40%	40%
	Improve	50%	20%	30%
	Uncertain	50%	40%	30%

The analysis indicates that current water quality is highest in the Non-Volcanic class, followed by the Volcanic+Hill class and then the Volcanic+Low class. Further, overall there appears to be more degrading trends within the Volcanic+Low class compared to the Volcanic+Hill class. This is consistent with the observed higher intensity land use being concentrated in the catchments of water bodies belonging to the Volcanic+Low class.

The minimum requirement of the NPS-FM is to maintain the overall quality of fresh water within a region. 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., Volcanic+Low class). 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 5 and Table 6, if the objective to maintain current state were selected, it is likely that justifiable objectives will be more environmentally protective (i.e., nutrient, *E. coli* or periphyton values will be lower) in the Non-Volcanic class than the Volcanic+Hill class, which in turn will be more protective than the Volcanic+Low class. Under these circumstances, policies and in particular limits, may need to be more restrictive (less enabling of resource use) in the catchments of the Non-Volcanic class, followed by the catchments of Volcanic+Hill then Volcanic+Low. 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.

3.4 Water quality management zones

The *management zone* for any given location should be defined to allow the setting of policies and limits to achieve objectives in both the local *management class* and any downstream *management class*. It follows that the policies and limits should be set to ensure the most restrictive downstream objective is achieved. Because this study precedes the development of policies and limits, it is not yet possible to identify the most restrictive policies and limits for any location. However, at this stage the assumption that the upstream catchments, (i.e. Volcanic+Hill and Non-Volcanic) will be associated with the most restrictive policies and limits (because they will likely have more protective objectives), means that the *management zones* for these classes take precedence to the Volcanic+Low class. This structure of management zones would enable more restrictive policies and limits to be defined in the upper parts of catchments and is illustrated in Figure 6. The assumption underlying Figure 6 that the upstream class is the “more restrictive” class needs to be tested against the actual differences in objectives and rules sets that are derived during the plan development process.

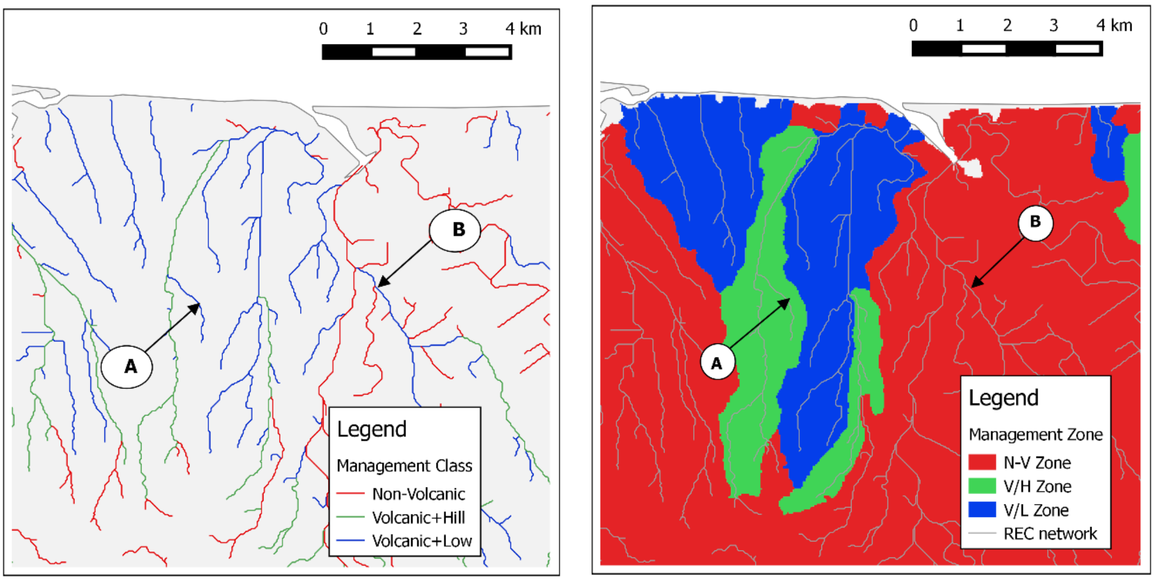

Figure 6: Zoomed view of the relationship between the water quality management classification of the network (left) and the management zones (right). The arrow marked A indicates segments belonging to the Volcanic+Low (blue) class flowing into segments belonging to the more restrictive Volcanic+Hill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

If during plan development it becomes apparent that more restrictive policies and limits are required to meet objectives in downstream areas, the zones could either be merged or more restrictive policies could be applied in the upper catchments (i.e. the Volcanic+Hill and Non-Volcanic zones) for the purpose of achieving the downstream (i,e, Volcanic+Low class) objectives. Therefore, the definition (and mapping) of water *management zones* may need adjustment as the plan process evolves. However, the *management zones* proposed here (Figure *7*) provide a logical starting point and the approach preserves flexibility to make adjustments.

Figure 7shows small, isolated patches of land in some zones that are surrounded by large contiguous areas that belong to another zone. Some of these areas are possibly too small for the practical application of policies, and these could be merged with the surrounding zone. An objective method of handling small isolated patches is to merge 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 *management zone* 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.

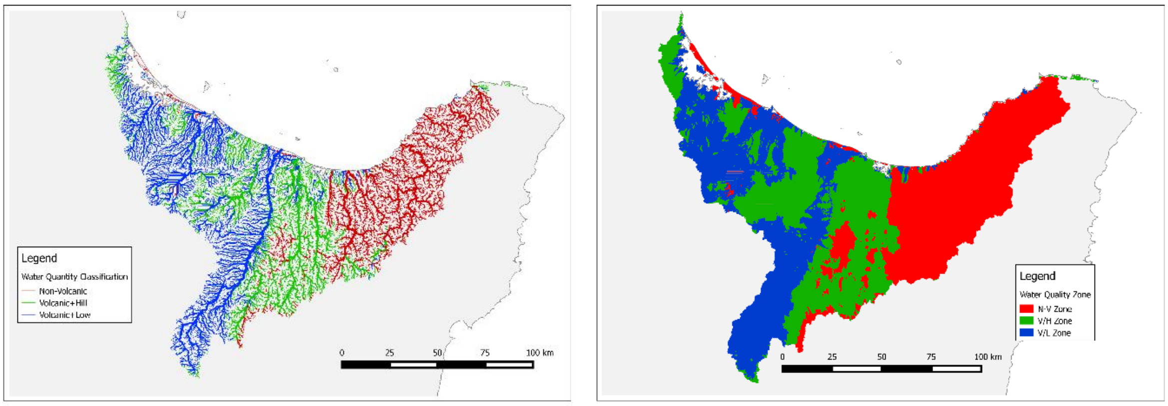

Figure 7: The proposed water quality management classes and management zones for the Bay of Plenty region. The classes; Volcanic+Hill, Volcanic_Low, Non-Volcanic management classes and shown on the left, and the associated management zones are shown on the right.

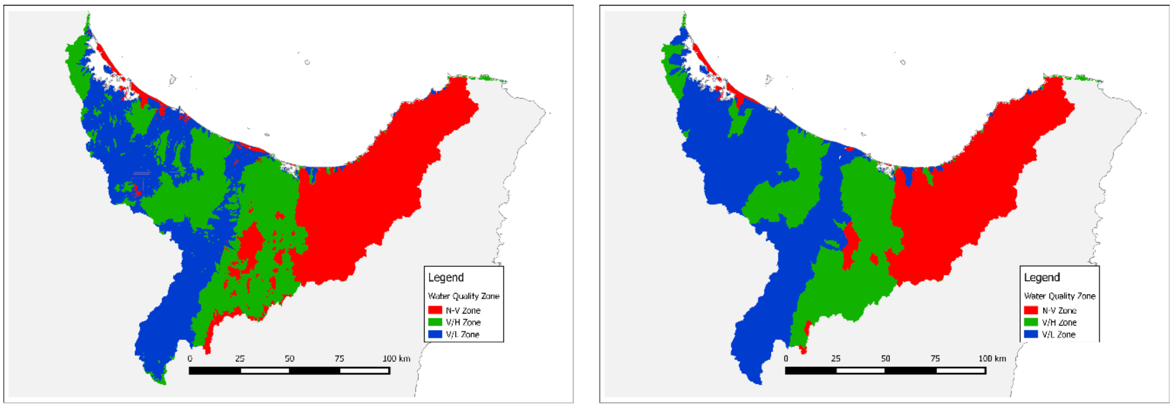

Figure 8: Reduction in the spatial detail of management zones based on stream order. The potential water quality management zones of the Bay of Plenty region including all river segments (left) and including river segments of stream order 3 and above (right).

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

3.5 Water quality administrative points

The points where the *management zones* 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 might need to 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*.

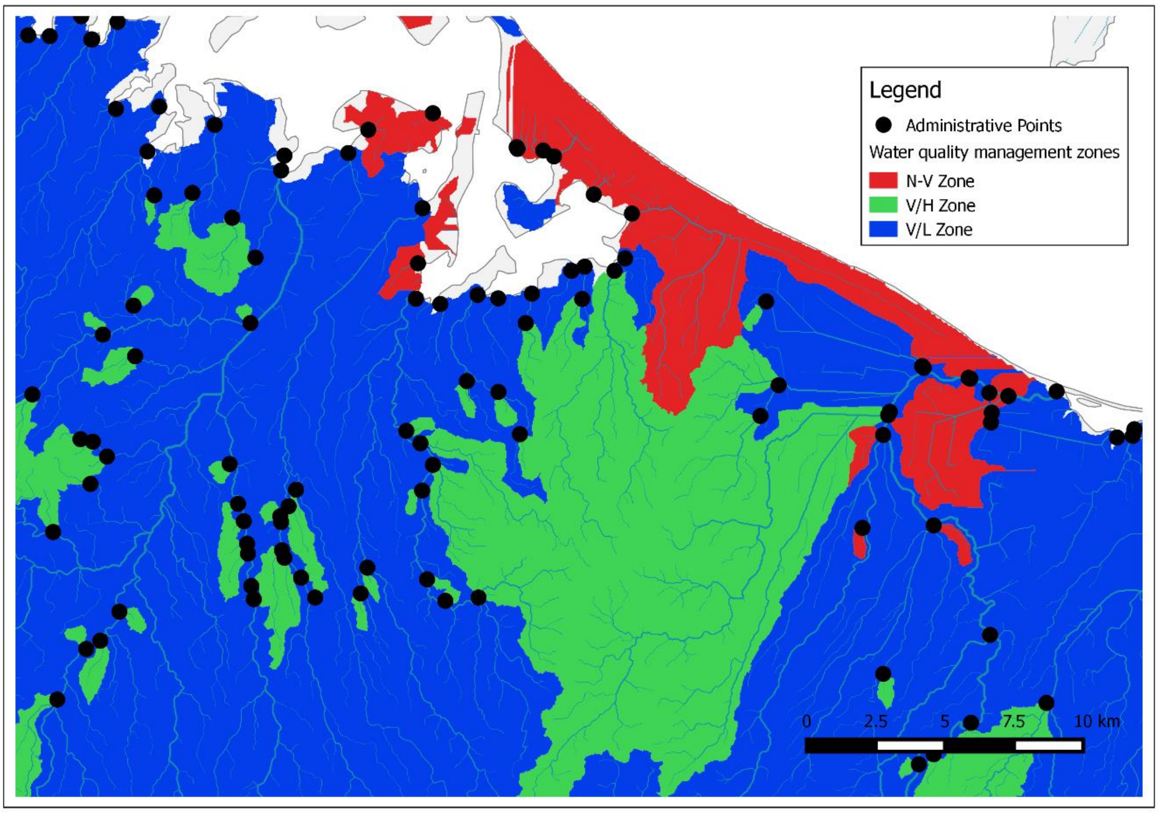

Figure 9: Zoomed in view of the management zones. The blue lines represent the drainage network. The red zones represent area that drain to segments in the Non-Volcanic class, the green zones represent areas that drain to segments in the Volcanic+Hill class and the red zones represent areas that drain to segments belonging to only the Volcanic+Low class. The black dots represent points at which the management zone 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 management zones (Figure 8) will also decrease the number of *administrative points*. A minimum possible number of *administrative points* for the region is 170, which is the total number of sea draining catchments within the region. Table 7 demonstrates how the number of *administrative points* reduces as the stream order threshold varies.

Table 7: Variation in number of administrative points with increasing coarseness of management zones. Rivers less than or equal to the minimum order threshold are excluded.

Minimum order threshold	**No. Administrative Points**
All segments	1130
1	512
2	285
3	214
4	197
5	192

3.6 Special FMUs

It is recognised that some water bodies have specific values or water quality issues that are not discriminated by the water quality *management classification* but which may need to be provided for by a region-wide plan. 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 in the region-wide plan and specific objectives related to their particular values can be defined. The catchments upstream of these water bodies would be special *management zones* for which specific limits and policies would apply to achieve the objective. The combination of the water body and the upstream catchment are collectively ‘special FMUs’.

A potential example of a special FMU is the catchment of the Kaituna River and the Ongatoro/Maketu Estuary (Figure 10). The Kaituna River drains from Lakes Rotorua and Rotoiti and used to flow into the Ongatoro/Maketu Estuary. The river was diverted from the estuary to discharge directly to the sea in 1956 via the Te Tumu Cut. A partial re-diversion of flow into the estuary was implemented in 1996, at Fords Cut. BoPRC has recently been granted consent to re-divert an additional 15% (for a total of 20%) of the Kaituna River’s flow through Fords Cut in an attempt to improve the water quality and ecology of the estuary, the condition of which has decreased following the original diversion out to sea. A major concern for the estuary is the potential for increased nutrients and bacterial contamination from the river entering the estuary, and its potential effect on mahinga kai such as shellfish. For this reason, it may be more appropriate to set both nutrient and microbiological objectives for the estuary and these objectives and their associated policies and limits may be more restrictive than those required for the Kaituna River.

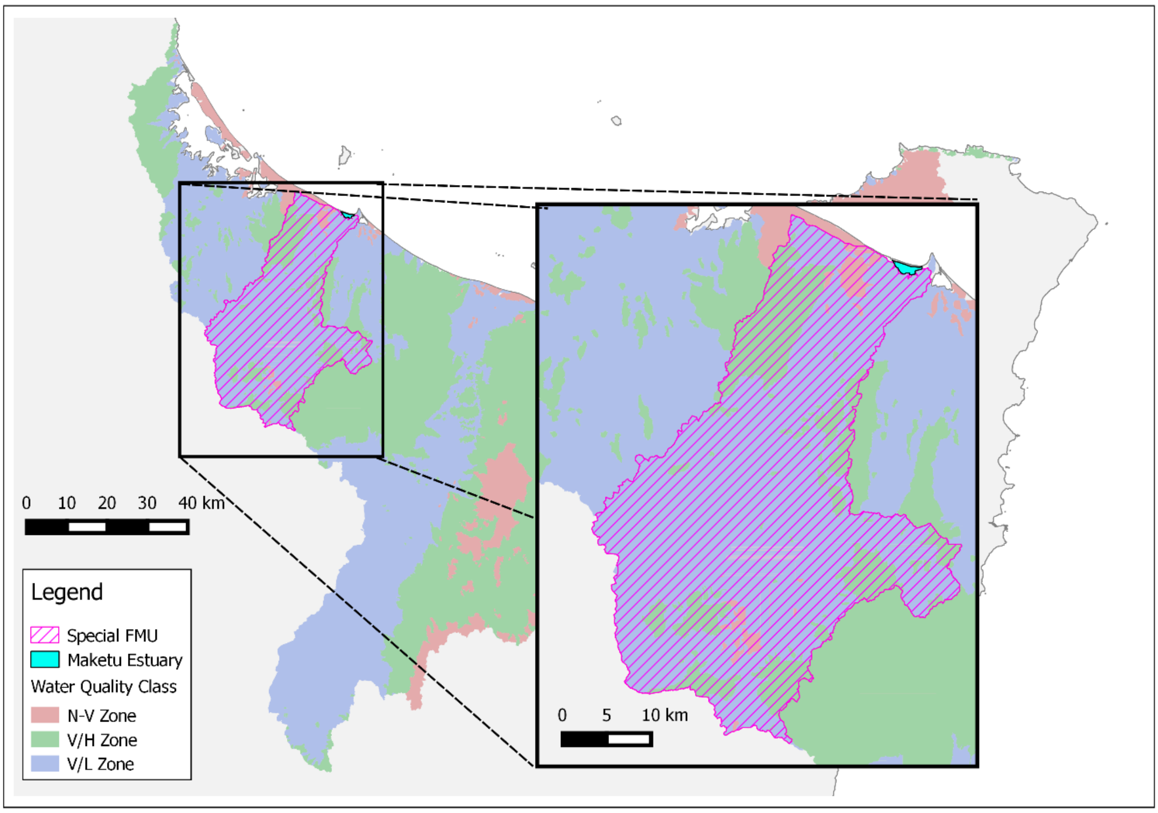

Figure 10: Example of a water body with special water management issues that may require a special FMU. The figure shows the Ongatoro/Maketu Estuary and its upstream catchment (the management zone). The objectives set for the Ongatoro/Maketu Estuary may not be achieved by policies and limits that are relevant to the objectives set for the management class that the upstream water body (the Kaituna River) belongs to. A special FMU that comprised the entire catchment of the Ongatoro/Maketu Estuary would enable policies and limits that are relevant to the estuary's objectives to over-ride those set for the Kaituna River.

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 three water quality management classes. In broad terms, the Non-Volcanic class has better water quality than the Volcanic+Hill and the Volcanic+Low class has the poorest water quality. In particular, for the Volcanic+Hill and the Volcanic+Low classes there are sites in the D-band for the nominated ecological variables and the D-band for the compulsory NOF periphyton attribute (but note the current state of periphyton has been estimated from nutrient concentrations and associated criteria – actual data is currently being collected). In addition, there are important differences in the trends for at least some of the water quality variables between the water quality management classes. In particular degrading trends in nutrients are occurring in the Volcanic+Hill and Volcanic+Low management classes. It is also noted that the majority of sites in the Volcanic+Hill and Volcanic+Low management classes are in the D band for *E.coli* primary contact recreation (i.e. not safe for swimming) but this is not a compulsory national bottom line. No sites in any class are below the national bottom line for *E.coli* secondary contact recreation. There were a large number of sites in the nominated (example) D-band for visual clarity in all management classes. This may indicate that the example visual clarity objectives are unrealistic or that there is a particular issue with sediment in the region; both of which require further consideration as part of the plan development process.

It might be concluded from this that objectives in the Non-Volcanic class need to generally maintain water quality. Objectives for the Volcanic+Hill and Volcanic+Low classes might need to focus on improving water quality, and particularly on reducing the input of nutrients that support periphyton, and other aspects associated with ecological health (e.g. to improve MCI values). Furthermore, it might be concluded that sediment management is needed across the whole region as clarity is broadly poor. It is also noted that sediment, nutrients and *E.coli* are recognised issues in the coastal environment of the Bay of Plenty region and the NPS-FM requires the regional plan to have regard to this. The relevant policies could be a mixture of regulatory and non-regulatory measures and the NPS-FM requires the plan to establish clear limits to resource use. These limits could be linked to policies that ensure future significant land use changes or other developments that impact water quality are adequately controlled.

Assuming the above conclusions, or similar, were adopted water quality objectives for the Non-Volcanic class water quality *management class* would be more restrictive than the Volcanic+Hill and Volcanic+Low classes. Each class would be subject to specific and different policies and limits that would apply to the respective *management zones*. Note that the objectives would apply to the water quality *management classes* but the policies and limits would apply to the *management zones* (i.e. the catchments which include both the land and the river network the land drains to).

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 three classes and an established period of record. Assessing the achievement of objectives, based on the monitoring data, would be carried out in a similar manner to the present study with the aggregate results for the class being used to evaluate the class at the regional scale.

Where particular sites indicate there are water quality issues (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 class within a WMA or to a specific site. These could be implemented using plan changes that apply to individual WMAs as planned or a region-wide plan change followed by locally specific plan changes, and there are advantages and disadvantages to either approach which need to be considered.

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 management zone changes or the coast. *Administrative points* (Figure 7) would be relevant in assessments related to consents or any investigation associated with objectives that are not being achieved. There are a large number of *administrative points* but these are important only in terms of implementation and 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 the limits need to be defined in terms of loads but in some regions this has been the approach taken (e.g. Canterbury and Horizons). Management based on contaminant load limits was considered necessary in these regions due to significant existing and increasing pressure on water quality. It remains to be determined whether load based contaminant limits are necessary and how they could work for the BoPRC region-wide plan, 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 starting point offered in this report represents an initial step of a planning process that BoPRC intends to undertake at the level of each WMA. Those processes and in particular the consideration of values, objectives, limits and other plan provisions may identify reasons to review and refine the FMUs proposed 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 proposed 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.

The first 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 allowed under the current BoPRC Regional Water and Land Plan (RWLP), including water takes for stock drinking and reasonable domestic use[17].

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 (including ecological, social and cultural) values and water resource use can be specifically evaluated and used to inform decisions about water quantity objectives. Broadly, surface water quantity (i.e. river flow) is managed through the application of two resource use limits: minimum flows and a total allocation (see Snelder *et al.* 2013 for details). The minimum flows and total allocation are imposed to achieve objectives that reflect both environmental and resource use objectives. These objectives can be thought of as defining a maximum level of habitat[18] loss, and both a maximum and a minimum level of

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[17] Under the current plan, it is a permitted activity to take water at a rate not exceeding 15 m^3 per day (Rule 41). Rule 41c also states that the rate of abstraction should not exceed 2.5 L per second, or 10% of the estimated five-year low flow at the point of abstraction, whichever is the lesser.

[18] 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).

reliability of supply. Moreover, habitat and reliability of supply can be considered as specific attributes 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 and volume.

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 are, 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.

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).

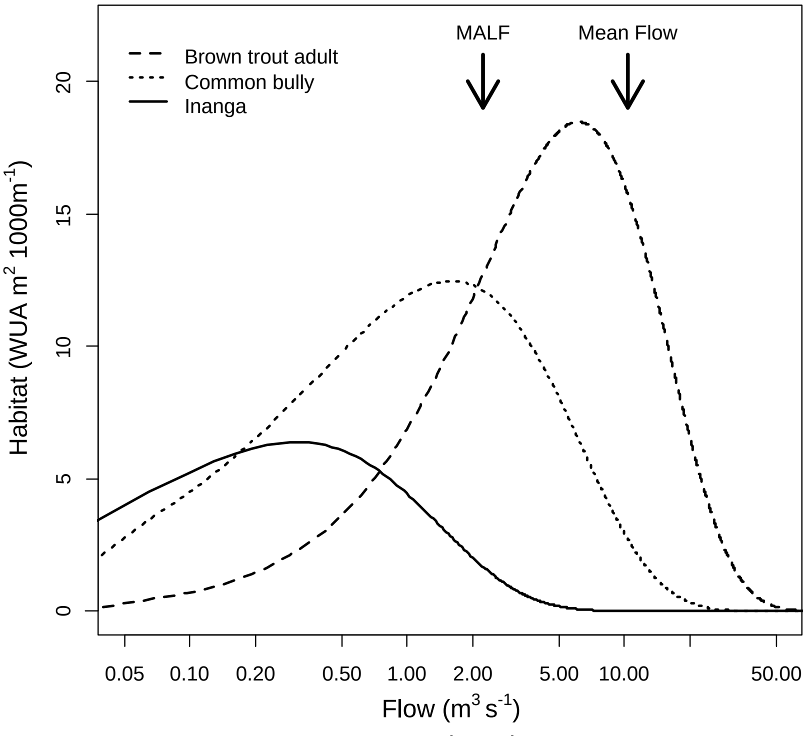

Figure 11: Change in hydraulic habitat with change in flow. The plot shows how Weighted Usable Area (WUA) changes with flow for three common fish species at a site. The natural Mean Annual Low Flow (MALF) and mean flow at the site are shown. The plot shows that reduction in habitat with flow varies by 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 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 critical 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 should 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. It is noted that this assessment should take into account the total allocation and the shape of the flow duration curve, which varies at different river sites. The details of these analyses are explained in detail by Snelder *et al.* (2013).

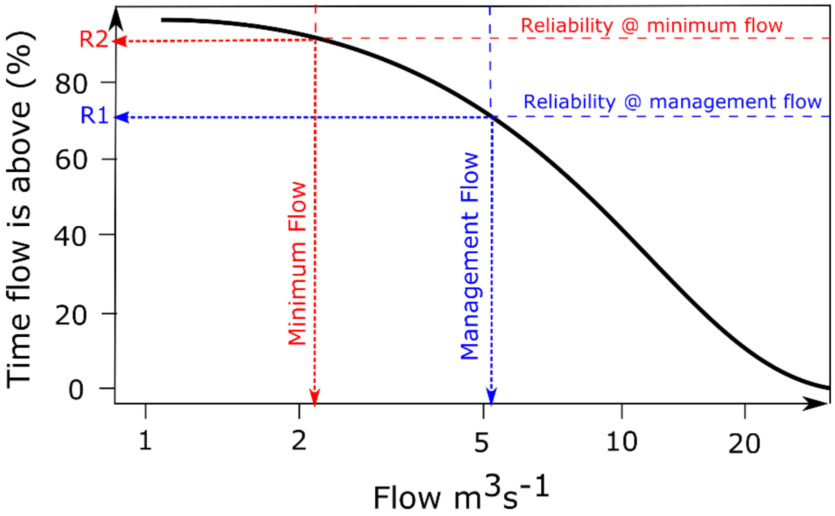

Figure 12: Example FDC used in the EFSAP analysis. The minimum flow and management flows and their reliabilities (% of time these flows are exceeded) are indicated as positions on the FDC.

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[19] 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. Although the Q5 7-day low flow is used by BoPRC in its RWLP, we have used MALF in the following analysis because model simulations undertaken for BoPRC by NIWA concerning regional minimum flows and allocation limits (Booker et al., 2014) were based on MALF. 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.

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[19] 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).

Flows less than MALF generally occur on average once in every two years (as opposed to flows less than the Q5 7-day, which occur on average less than once every 5 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.

This report uses model simulations to explore different between minimum flow and allocation limits impact on reliability and environmental outcomes for all river segments 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 Water quantity management classification

In this section we propose a water quantity *management classification*. We considered a number of alternative classifications, including the existing WMAs, as well as combinations with the factors used in the water quality classification (Slope and Geology), which discriminates variation in regional hydrological regimes (Snelder and Biggs, 2002) and an additional factor to describe the size of the river as "Large" (mean flow >10m^3s^{-1}) or "Small" (mean flow >10m^3s^{-1}) rivers. 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. It is noted that the threshold for discriminating large and small rivers of 10m^3s^{-1} is nominal and was primarily chosen to discriminate the main stem rivers in the Bay of Plenty region that are highly valued for trout, but that this needs further consideration[20]. Using flow magnitude to further classify rivers is also consistent with the approach used in the proposed National Environmental Standard (NES) for Flows and Levels (MFE 2008).

We statistically tested the ability of eight alternative classifications as well as the existing WMAs, to discriminate variation in habitat and reliability (R1 and R2; Figure 12); the results are demonstrated in Appendix A2. No single classification simultaneously optimised explained variation across all variables. On balance, the best performing classification was the water quality classification (Geology+Slope) combined with the river size categories resulting in a total of 6 water quantity management classes (Figure 13).

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[20] It is noted that the proposed NES (MfE 2008) 5 m^3 s^{-1} threshold to distinguish large and small rivers is for default use at national scale and is also nominal. There is no reason why an alternative threshold, such as 10 m^3 s^{-1}, cannot be nominated and justified for use at regional scale.

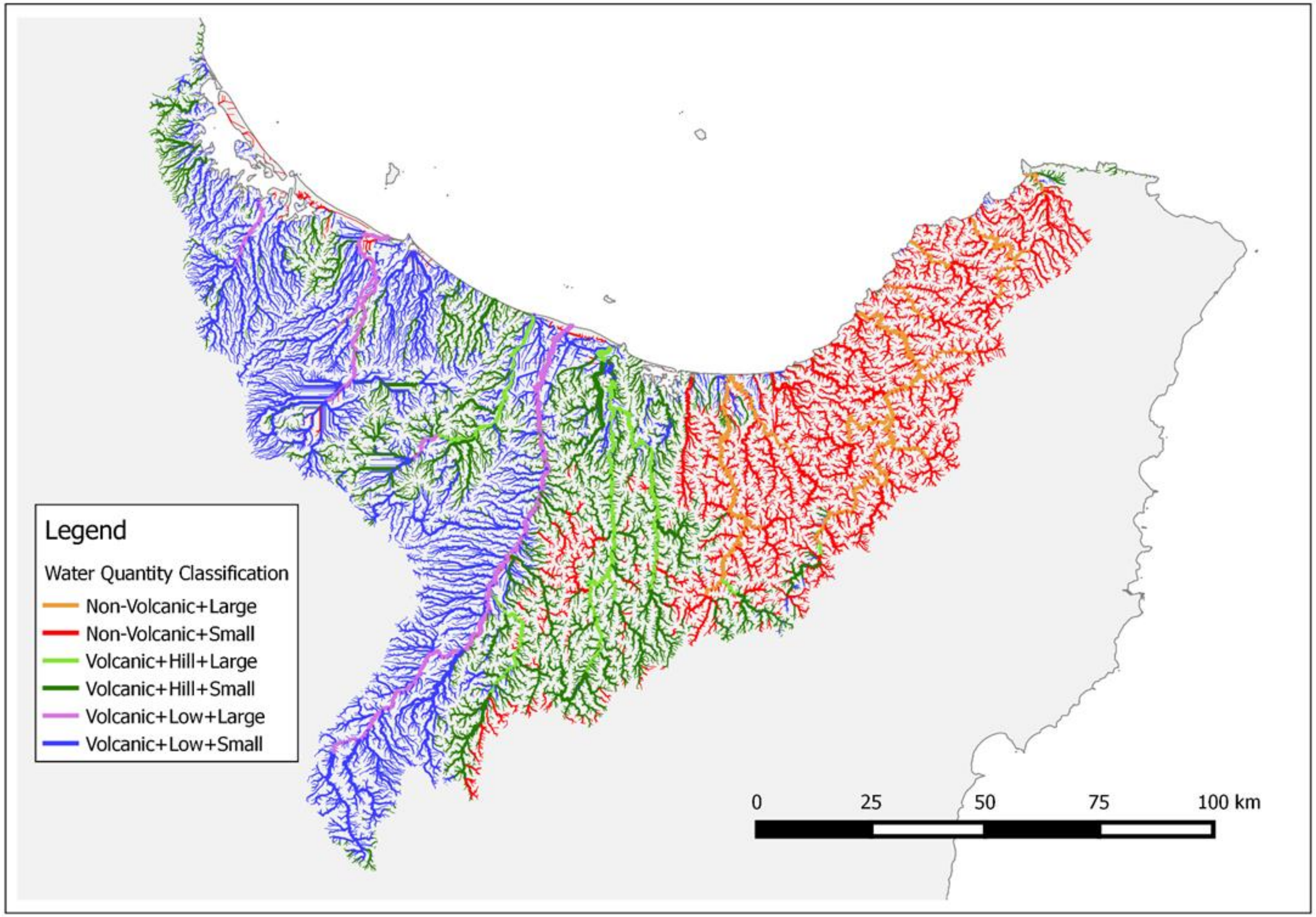


Figure 13: Proposed water quantity management classes.

4.3 Potential water quantity objectives and limits

This section provides an example of water quantity objectives and associated limits for the six water quantity *management classes*, based on size, geology and slope. 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 only for a couple of fish species. 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 have been clarified.

Limits to meet potential (i.e. example) objectives for each of the six water quantity management classes were determined using model predictions from the Environmental Flow Strategic Assessment Platform (EFSAP) tool (Booker et al., 2014). The EFSAP tool has been developed by NIWA 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 EFSAP 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 that define flow duration curves and other hydrological estimates;
3. generalised fish habitat – flow relationship (based on known habitat suitability curves) that provide hydraulic habitat estimates for a variety of target fish species at different flows.

The regional hydrology models that are used by EFSAP were built using the digital river network that is the basis for the REC (see Booker et al., 2014). However, the models do not use REC classes to make predictions and are based on a range of continuous variables that describe characteristics of each network segment’s catchment including climate, topography, geology and land cover. These models therefore implicitly account for many factors that influence regional variation in hydrology including the degree of ground water influence and differences in precipitation.

EFSAP 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. EFSAP assessments are produced for all segments of the REC river network with specific inputs being various scenarios for limits that are defined in terms of the natural MALF, which can be estimated in several ways for any river location in the region. For example, limits for minimum flow may be set at 80% MALF and for total allocation at 90% of MALF. EFSAP calculates resultant outputs, showing habitat reduction for selected fish species and reliability of supply for these scenarios. The outcomes for selected “critical values” are expressed as changes in habitat at natural MALF (e.g. 90% of trout habitat at MALF). Further details about the EFSAP model and its application in the Bay of Plenty region are provided by Booker et al (2014) and Booker (2015).

Results of a large number of EFSAP 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 EFSAP 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 example objectives for hydraulic habitat retention and reliability of supply to determine the minimum flow and allocation limits required to meet these example objectives for each of the proposed *management classes*.

We adopted both trout and torrent fish as critical species to define the potential objectives. These two species were chosen because they have the highest flow requirements of an assemblage of species that occupy the region's rivers. Choosing other critical species, for example tuna (eels) which are highly valued and specifically mentioned in iwi Treaty Settlement documents, would have the effect of decreasing the minimum flows and increasing the total allocation because eels generally have lower flow requirements than trout and torrent fish. In other words, using trout and torrent fish for the analysis will provide ample flows for tuna. The relevant information for deriving minimum flows and total allocations for additional species was produced as part of this study and could be used to explore other objectives than the examples reported here.

We performed the analysis with each of two scenarios: (1) trout as the critical species for all rivers, and (2) trout as the critical species for the large rivers and torrent fish as the critical species for small rivers. Trout (and in particular rainbow trout) are widely distributed throughout the region, are valued for recreation and have relatively high flow requirements compared with many of the native fish species within the region. Torrent fish, in contrast, have lower flow requirements and are more sensitive to flow reductions in small streams. For the example classification included below, the objective for habitat reduction was no more than 20% of the habitat compared to that available at MALF for at least 75% of sites within each *management class*.

We examined the reliability of supply measures for February only, looking at both the reliability at minimum flow (R2) and the reliability at management flow (R1). February was chosen as this generally represents the time when abstraction pressure is the highest and flows are naturally the lowest. We defined the reliability as the % of time that the flow is at or above the specified flow. The example objectives for reliability are a total reliability of no less than 80% for R2 and 75% for R1 for at least 75% of segments within a particular *management class*.

The variability in habitat and reliability outcomes across the six proposed water quantity *management classes* is demonstrated in Figure 14. These density plots are based on EFSAP outputs for a management scenario with a minimum flow of 90% of MALF and a total allocation of 50% of MALF. In general, the habitat outcomes are similar for all Small classes (see d(Hab) Brown Trout and d(Hab) Torrent fish) in Figure 14). This similarity in habitat outcomes reflects the fact that reduction in hydraulic habitat with flow reduction is higher for both species in smaller streams than larger rivers, and supports the proposed use of stream size as a classification variable. The results for the Volcanic+Low+Large class indicates a distinct distribution for changes in habitat, particularly for Trout habitat, which generally have a smaller (or even positive) change in habitat (Figure 14). These rivers could potentially sustain greater abstractions than rivers in the other "Large" classes; if the additional water quality classification were not included and the classification were only based on river size, abstractions would be unnecessarily restrictive in the Volcanic+Low+Large class, but would achieve poorer habitat outcomes for the remaining "Large" river classes.

Reliability at management flow (R1; Figure 12) shows the most distinctive differences between classes. For example, most large streams in the non-volcanic class showed the highest reliability of supply at management flow, while Volcanic+Low+Large class had the lowest reliability (See Figure 14). Although the changes in habitat were more strongly influenced by the river size, reliability at management flow appears to be more strongly related to the Geology+Slope classification; this provides further support for the inclusion of all three variables within this example water quantity classification. Such differences may reflect the inherent differences in hydrological regimes in streams draining volcanic and non-volcanic catchments (see Suren and Carter 2015). Further explanation and discussion of the rationale for the selection of the classification regime over possible others is provided in Appendix A2.

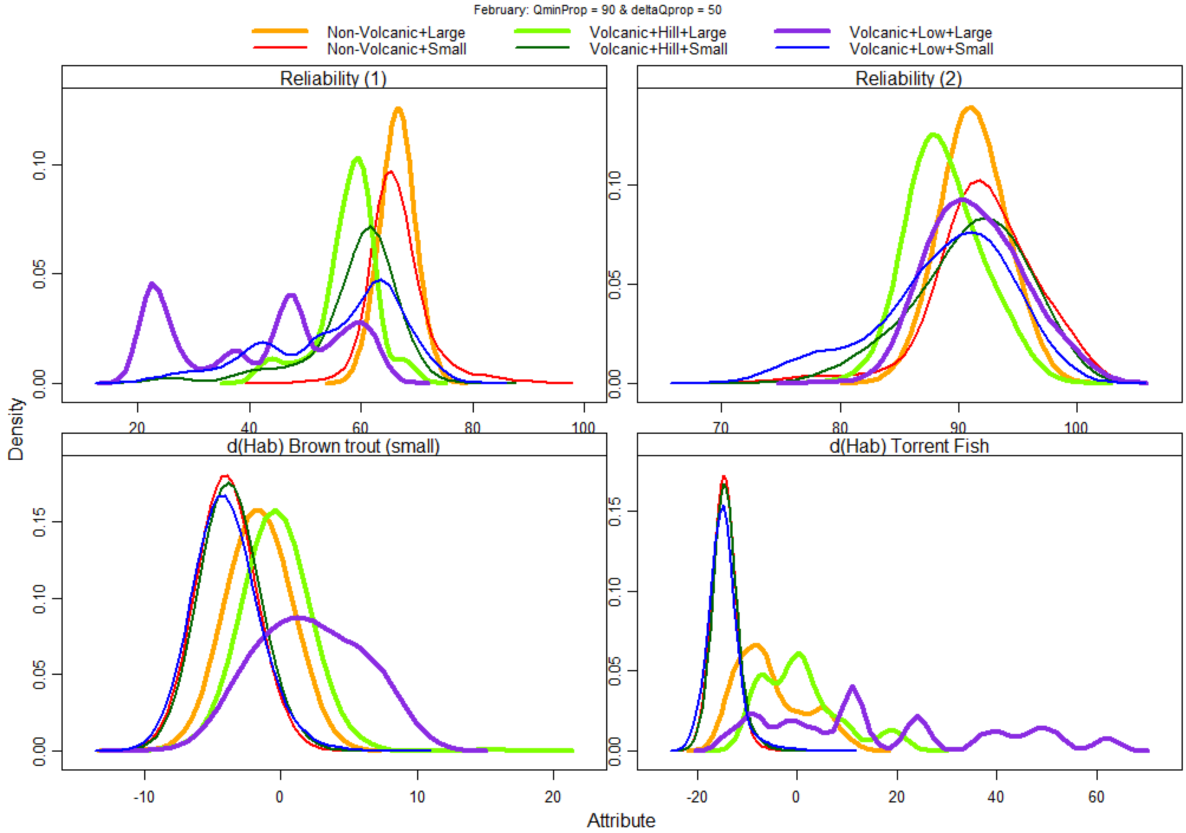
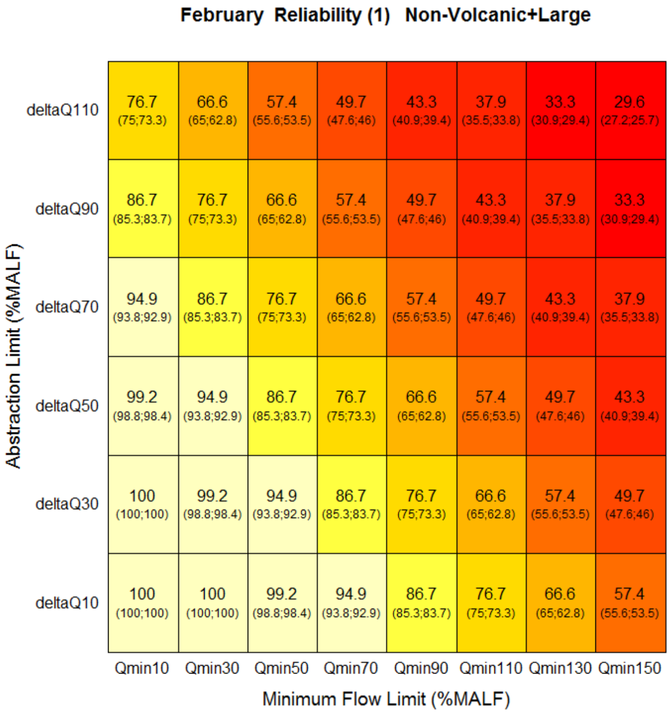


Figure 14: Density plots showing variation in reliability of supply at both the management flow (R1) and minimum flow (R2) and changes to predicted instream habitat (d(Hab)) of both trout and torrent fish. The density plots are shown for the six proposed FMUs for a management scenario with a minimum flow of 90% of MALF and a total allocation of 50% of MALF. The y-axis (labelled Density) shows the relative likelihood of any individual reach to be equal a given outcome (the x-axis).

The existing EFSAP 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 or less environmentally conservative limits could be explored by requiring the objectives to be met at 90% or 50% of sites (as compared to 75% 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 90% 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 EFSAP 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. In this way, it is possible to identify the management scenarios for any given attribute that will provide acceptable outcomes for a given *management class*. Figure 15 provides an example of a decision space diagram.



	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	76.7 (75;73.3)	66.6 (65;62.8)	57.4 (55.6;53.5)	49.7 (47.6;46)	43.3 (40.9;39.4)	37.9 (35.5;33.8)	33.3 (30.9;29.4)	29.6 (27.2;25.7)
deltaQ90	86.7 (85.3;83.7)	76.7 (75;73.3)	66.6 (65;62.8)	57.4 (55.6;53.5)	49.7 (47.6;46)	43.3 (40.9;39.4)	37.9 (35.5;33.8)	33.3 (30.9;29.4)
deltaQ70	94.9 (93.8;92.9)	86.7 (85.3;83.7)	76.7 (75;73.3)	66.6 (65;62.8)	57.4 (55.6;53.5)	49.7 (47.6;46)	43.3 (40.9;39.4)	37.9 (35.5;33.8)
deltaQ50	99.2 (98.8;98.4)	94.9 (93.8;92.9)	86.7 (85.3;83.7)	76.7 (75;73.3)	66.6 (65;62.8)	57.4 (55.6;53.5)	49.7 (47.6;46)	43.3 (40.9;39.4)
deltaQ30	100 (100;100)	99.2 (98.8;98.4)	94.9 (93.8;92.9)	86.7 (85.3;83.7)	76.7 (75;73.3)	66.6 (65;62.8)	57.4 (55.6;53.5)	49.7 (47.6;46)
deltaQ10	100 (100;100)	100 (100;100)	99.2 (98.8;98.4)	94.9 (93.8;92.9)	86.7 (85.3;83.7)	76.7 (75;73.3)	66.6 (65;62.8)	57.4 (55.6;53.5)

Figure 15: Example decision space diagram showing change in reliability at management flow (R1) in the Non-Volcanic+Large management class. Numbers in the cells are the median change in % reliability across all reaches within the management class for each management scenario. 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 an optimal management scenario (i.e. a set of limits) that meet all specified criteria. An example of a combined decision space diagram is shown in Figure 16.

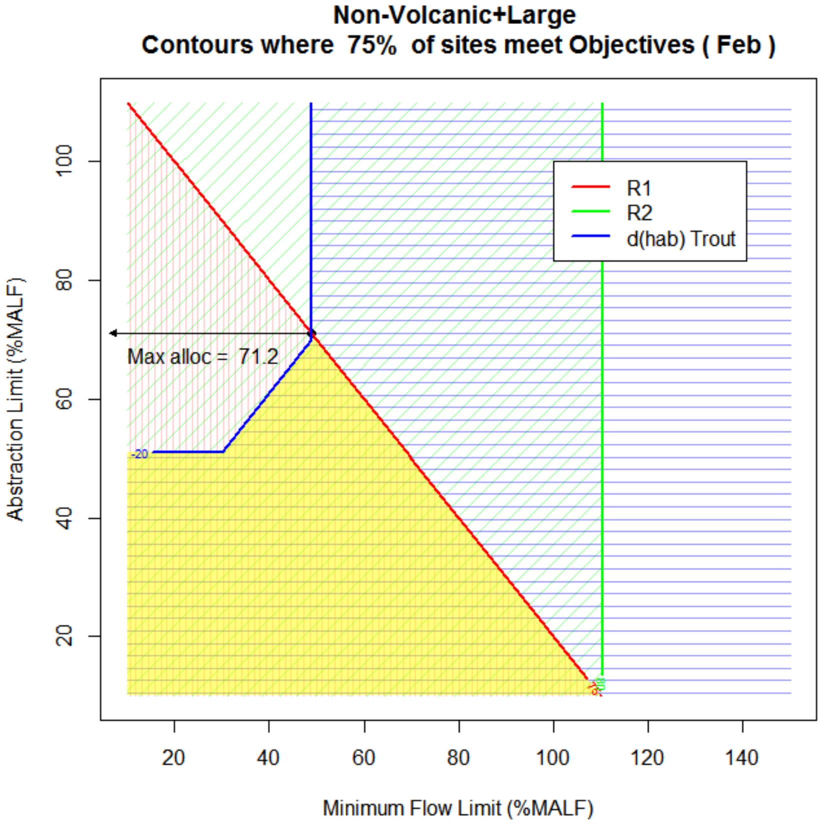


Figure 16: Combined decision space diagram for Non-Volcanic+Large class. Solid lines are contours that achieve the minimum acceptable outcomes for each of: reliability at management flow (R1), reliability at minimum flow (R2) and change in trout habitat (d(Hab)Trout). The area within the decision space 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 75% of sites within the class is 71.2% of MALF and is demonstrated by an arrow.

The potential objectives are summarised in Table 8 and Table 9. The two tables use the same objectives, but for the first table small rivers are managed for torrent fish and large rivers for trout, and for the second table all rivers are managed for trout. We have used combined decision space diagrams for each water quantity *management class* to identify the limits that achieve the proposed objectives for 75% of segments within each *management class*. 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 8: Potential objectives for habitat retention for trout and reliability of supply for the six water quantity management classes and the limits (minimum flows and allocations) that will achieve these objectives. The limits have been derived from an EFSAP analysis and reflect the largest allocation and (then) highest minimum flow that satisfies all objectives for 75% of sites within the class.

Water Quantity management class	**Critical value**	**Habitat reduction (% at MALF)**	**Reliability at minimum flow in Feb (% time)**	**Reliability at management flow (in Feb % time)**	**Minimum flow (proportion of MALF)**	**Allocation rates (proportion of MALF)**
Non-Volcanic + Large	Trout	-20%	80%	75%	0.49	0.71
Non-Volcanic + Small	Torrent	-20%	80%	75%	0.62	0.56
Volcanic + Hill + Large	Trout	-20%	80%	75%	0.37	0.73
Volcanic + Hill + Small	Torrent	-20%	80%	75%	0.61	0.50
Volcanic + Low + Large	Trout	-20%	80%	75%	0.31	0.70
Volcanic + Low + Small	Torrent	-20%	80%	75%	0.60	0.45

Table 9: Potential objectives for habitat retention for trout in large rivers and torrent fish in small rivers, and reliability of supply for the six water quantity management classes and the limits (minimum flows and allocations) that will achieve these objectives. The limits have been derived from an EFSAP analysis and reflect the largest allocation and (then) highest minimum flow that satisfies all objectives for 75% of sites within the class.

Water Quantity management class	**Critical value**	**Habitat reduction (% at MALF)**	**Reliability at minimum flow in Feb (% time)**	**Reliability at management flow (in Feb % time)**	**Minimum flow (proportion of MALF)**	**Allocation rates (proportion of MALF)**
Non-Volcanic + Large	Trout	-20%	80%	75%	0.49	0.71
Non-Volcanic + Small	Trout	-20%	80%	75%	0.86	0.32
Volcanic + Hill + Large	Trout	-20%	80%	75%	0.37	0.73
Volcanic + Hill + Small	Trout	-20%	80%	75%	0.83	0.27
Volcanic + Low + Large	Trout	-20%	80%	75%	0.31	0.70
Volcanic + Low + Small	Trout	-20%	80%	75%	0.81	0.24

Appendix A3 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, and for both the entire year and for the month of February. 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 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

The allocation limits for both sets of potential objectives (Table 8 and Table 9) have the same order of restrictiveness (based on allocation rates) for the management classes; which can be ordered from the most restrictive (i.e. least resource enabling) to the least restrictive as: Volcanic+Hill+Large, Non-Volcanic+Large, Volcanic+Low+Large, Non-Volcanic+Small, Volcanic+Hill+Small, Volcanic+Low+Small. Based on this ordering, we have defined the water quantity *management zones* following the approach used for the water quality *management zones*, where any given segment is assigned to the zone of the most restrictive downstream class (Figure 17).

It is important to note that if BoPRC ultimately selects different objectives from those assessed here (i.e., those in Tables 8 and 9) this could lead to different allocation limits and different relative ordering of the *management classes*, which in turn could lead to differences in the way that the water *management zones* are defined (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.

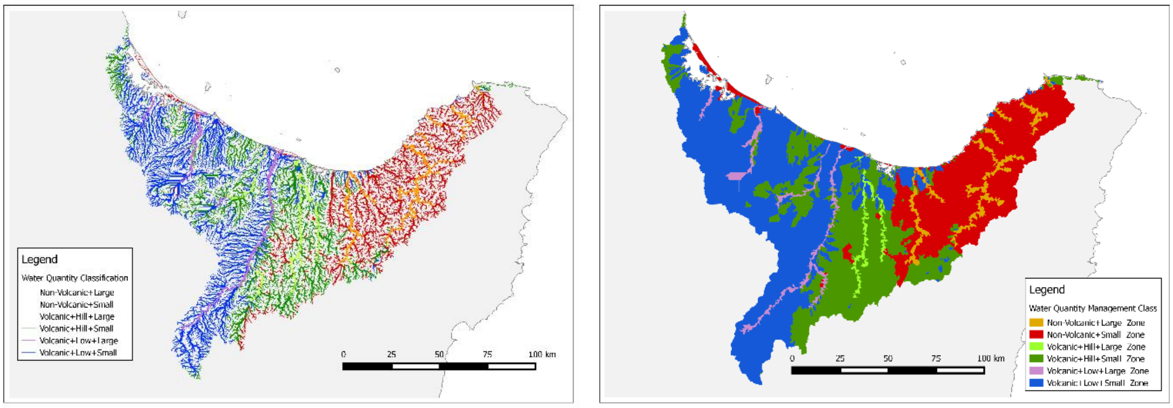


Figure 17: The proposed water quantity management classification (left) and associated management zones (right).

As for the water quality *management classes*, small and isolated patches of land in some zones are possibly too small for the practical application of policies, and these could be merged with the surrounding zone. To remove some of the small isolated patches we merged segments that were below a defined threshold based on stream order (a measure of the river size) with the *management zone* assigned to the next downstream segment, irrespective of their own *management zone* assignment. Figure 18 demonstrates the difference in the *management zones* for stream order of 1 (all river network reaches included) and a minimum stream order of 3.

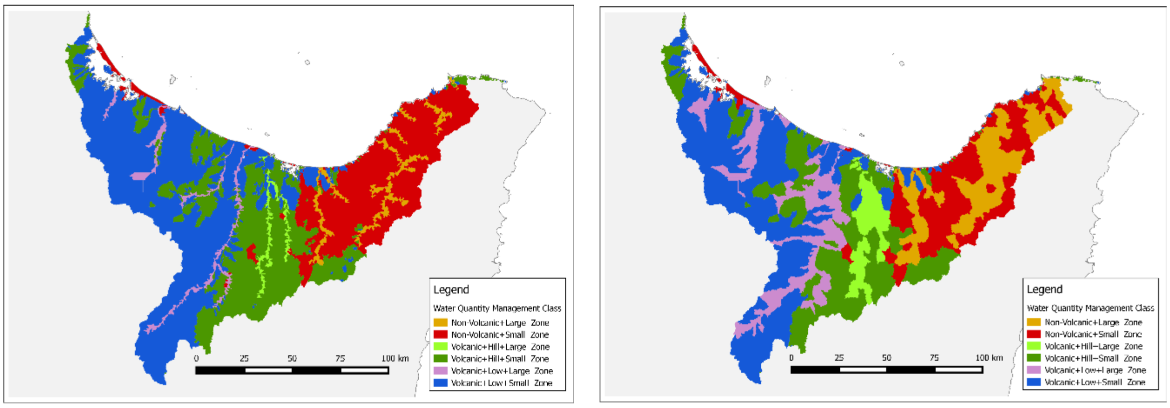


Figure 18: The proposed water quality management zones of the Bay of Plenty region. The map on the left includes all river segments and the map on the right includes river segments of order 3 and above.

4.5 Water quantity administrative points

The water quantity *administrative points* have also been derived following the same methodology used to derive the water quality *administrative points*. We have similarly also explored how the number of *administrative points* varies with varying minimum stream order thresholds. Table 10 demonstrates how the number of water quantity *administrative points* reduces as the minimum order threshold increases.

Table 10: 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	No. Administrative Points
0	2774
1	1163
2	607
3	346
4	225
5	195

4.6 Next steps – water quantity FMUs

4.6.1 Developing plan provisions

Having defined possible (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 8 or Table 9) 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 8 or Table 9.

Because the EFSAP tool is based on generalised models, the derived limits (e.g., the options in Table 8 and Table 9) are broadly accurate but are subject to larger uncertainties at the site scale than more detailed site specific analyses. Note, however, that we believe that our use of the EFSAP tool to help test the applicability of the proposed geology+slope+size FMU classification is more robust than the current default water allocation and minimum flow assessments that are applied across all stream types in the region.

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 coupled with analysis of relevant hydrological data. These assessments provide the most accurate analysis of the effect of a proposed take relative to objectives but they are expensive and time consuming and 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 EFSAP 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 8 or Table 9, which are based on the EFSAP tool, could be used. Applications for water takes in situations where the current and new takes are “large”, relative to the limits, however would need to be supported by more detailed analyses.

4.7 Accounting for groundwater takes

An additional step required to complete the definition of the water quantity FMUs involves the consideration of groundwater takes. The FMUs presented here are based only on surface water catchments. However, surface water quantity management must take into account the effects of groundwater takes on the surface water resource and the groundwater takes must be limited to achieve the surface water objectives.

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 BoPRC's changes to the regional water plan in response to the NPS-FM. A key finding of this project is that when considering the region 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 region. There are several reasons that a framework of spatial units is likely to be necessary. These include the need for plans to manage different issues (e.g. water quality versus water quantity) and to provide a basis for different management functions (e.g. setting objectives versus defining policies and accounting for resource use and consenting water takes).

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

The proposed approach to defining FMUs for the BoPRC regional water plan 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 *administrative points*. It is important to note that an administrate 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.

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

Some water bodies have specific values or management issues that are not discriminated by the *management classifications* but which may need to be provided for. These water bodies can be associated with special FMUs that over-ride the objectives set for the *management classes*. Examples of water bodies requiring separate management objectives may be sites of significance 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 FMUs for which specific plan provisions (objectives and policies) would apply. It is noted that special FMUs 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 FMUs 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 and these approaches are described in this report. However, the proposed approach has a number of benefits over these two alternatives, including:

1. The use of classifications provides arguably appropriate resolution of variation in the characteristics of relevance 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 criteria,

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 easily repeatable allowing the criteria to be varied and for the definition of FMUs to be integral to the plan development process,

6. The level of detail of the plan provisions can be as coarse or fine (simple or complex) as required based on the level of classification detail used,

7. Aspects of the plan’s implementation (e.g., consenting and accounting for resource use) can be undertaken at appropriately fine levels of spatial resolution defined by the administrative points,

8. The framework provides an efficient and justifiable basis for water quality monitoring and reporting at the regional level based on having a representative number of monitoring sites in each management class, and

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

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 proposed 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 proposed 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 that is proposed 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 WMAs 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 WMA-level processes. In these cases, more specific and nuanced objectives and policies may be developed that apply to the general FMUs but within particular WMAs or for specific locations.

6 Acknowledgements

We would like to thank Sharon Pimlott of the Bay of Plenty Regional Council for providing a sounding board and feedback during the course of this study. Thanks also to Jan Diettrich (NIWA Christchurch) for providing updated EFSAP analysis results and for assistance with their interpretation. We thank Tim Kerr of Aqualinc Research for assistance with coding some of the network function required to define the management zones and identify the administrative points.

7 References

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A1 Water quality trends

An analysis of trends in the seven water quality variables and two invertebrate variables was undertaken for the 10-year period ending at the end of 2013. 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 and QMCI, 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) were able to be represented.

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

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

The majority of significant trends (i.e. sites for which $p<0.05$) indicated improving water quality. The most significant exceptions were degrading trends for NO_3-N and TP, which had a greater number of significantly degrading trends than increasing trends. There were a large number of insignificant trends, for MCI and QMCI in particular. This indicates that the water quality variables have large variation (‘noise’) and therefore that a definite trend cannot be detected.

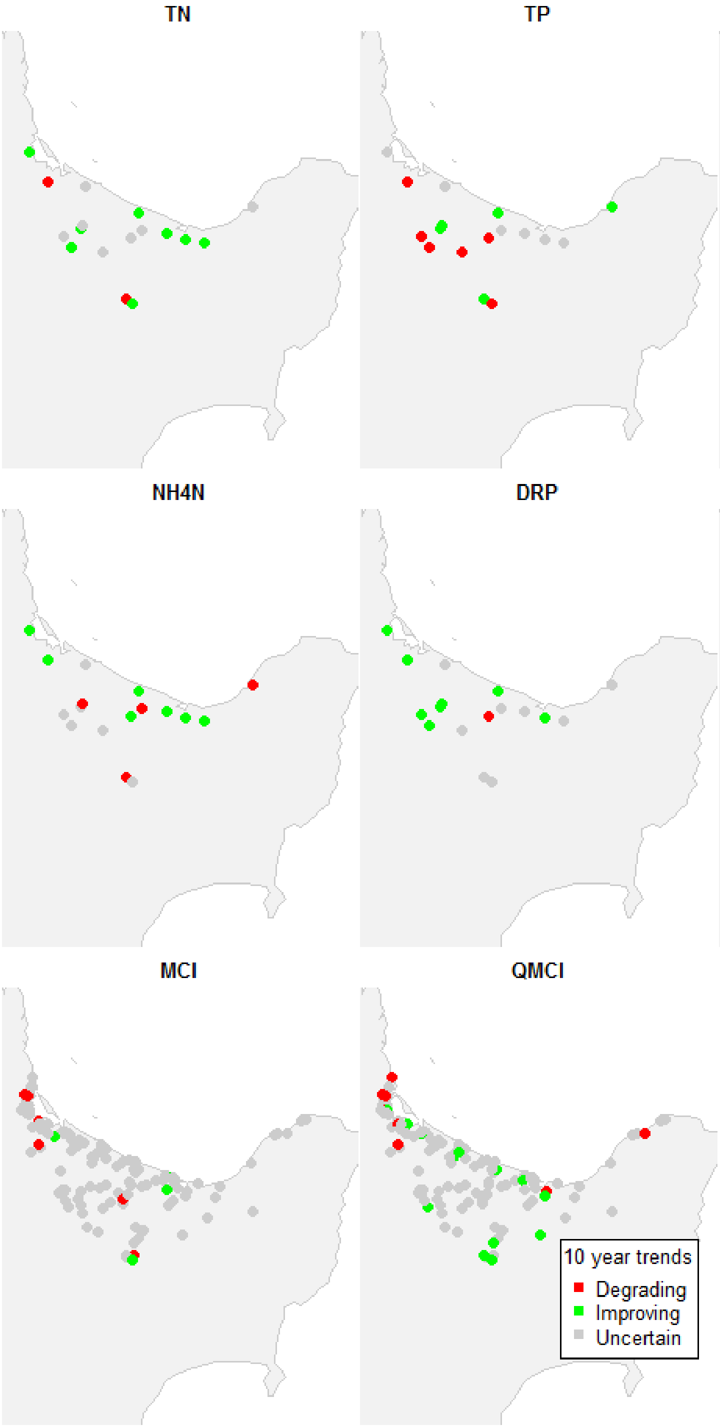


Figure 19: Maps showing the 10-year trends at monitoring sites. Where the trend tests were significant (i.e. the Kendal test p-value < 0.05) the direction of the trend is indicated as improving or degrading. Where the test was not significant the trend is indicated as "uncertain" meaning the test can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

A2 Water quantity classification testing

The ability of 8 alternative classifications to explain regional variation in the outcomes of specific water allocation limits was evaluated using analysis of variance (ANOVA). An ANOVA was performed on four EFSAP modelled outcomes: reliability at management flow (R1), reliability at minimum flow (R2), change in trout habitat and change in torrent fish habitat. For the analysis we used predictions for a management scenario with a minimum flow of 90% of MALF and a total allocation of 50% of MALF and have normalised the observations where necessary. 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 in Table 11.

Table 11: ANOVA r^2 values for each EFSAP outcome for the eight alternative water quantity management classifications. Values shown in grey had p values < 0.05. NS indicates that the ANOVA statistic was not significant at the 5% level.

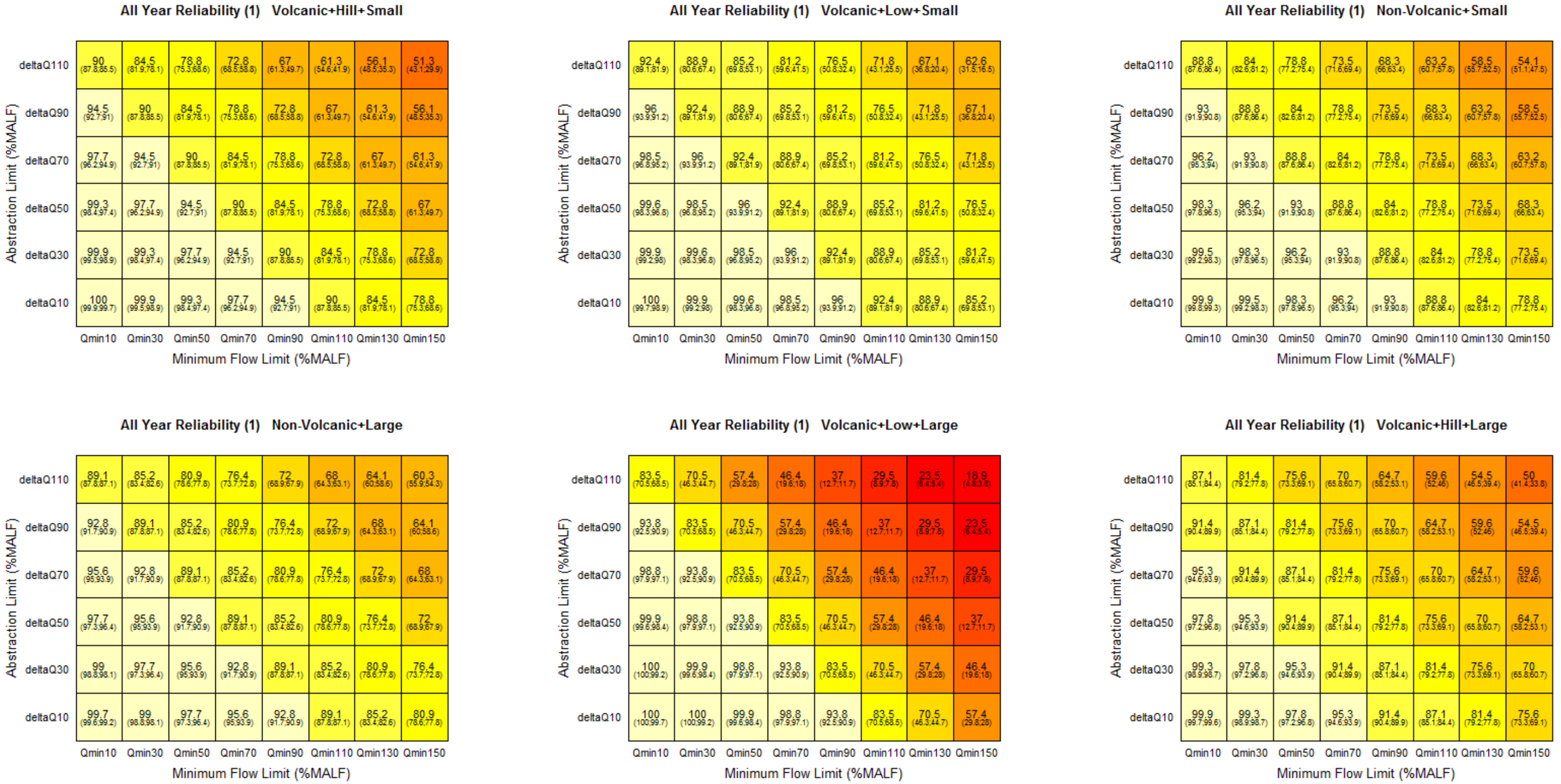
Classification	**No. classes**	**R^2**				
		R1	**R2**	**d(hab) Trout**	**d(hab) Torrent Fish**	**Median r^2 value of each classification**
Slope	2	0.03	0.10	NS	0.00	0.01
Geology	2	0.00	0.13	0.00	0.00	0.00
Size	2	0.03	0.02	0.36	0.47	0.20
Slope+Geology	3	0.02	0.15	0.00	0.00	0.01
Slope+Size	4	0.10	0.13	0.41	0.51	0.27
Geology+Size	4	0.06	0.14	0.40	0.50	0.27
Slope+Geology+Size	6	0.10	0.18	0.42	0.52	0.30
WMAs	9	0.14	0.24	0.03	0.01	0.09

The reliability at management flow (R1) was best explained by the WMA classification (Table 11); probably because it had the most number of classes in it (and therefore the highest degree of freedom). The WMAs also explained the greatest variation in the predicted reliability at minimum flow (R2). No individual factor (e.g. slope, geology) performed particularly well, but the combination of Geology+Slope+ Size had the greatest median r^2 values for the EFSAP outcomes, suggesting it displayed the greatest differences in outcomes. Geology alone explained a reasonable degree of the observed variation to R2, with some moderate improvements in the explanatory power with the introduction of both the Slope and Size factors. Despite their importance in explaining variability to R1 or R2, WMAs, Slope and Geology had almost zero explanatory power for the predicted change in fish habitat. Instead, the majority of the observed variance was explained by Size alone, although there were some marginal improvements by adding the Slope and Geology to the classification. For this reason, we recommended the Geology+Slope+Size management classification as a basis of water quantity FMUs.

A3 EFSAP tables

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, as well as outputs for the reliability critical values for the month of February (EFSAP predicted habitat outcomes do not change by month). Each figure includes six 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).



All Year Reliability (1) Volcanic+Hill+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	90 (87.8;85.5)	84.5 (81.9;78.1)	78.8 (75.3;68.6)	72.8 (68.5;58.8)	67 (61.3;49.7)	61.3 (54.6;41.9)	56.1 (48.5;35.3)	51.3 (43.1;29.9)
deltaQ90	94.5 (92.7;91)	90 (87.8;85.5)	84.5 (81.9;78.1)	78.8 (75.3;68.6)	72.8 (68.5;58.8)	67 (61.3;49.7)	61.3 (54.6;41.9)	56.1 (48.5;35.3)
deltaQ70	97.7 (96.2;94.9)	94.5 (92.7;91)	90 (87.8;85.5)	84.5 (81.9;78.1)	78.8 (75.3;68.6)	72.8 (68.5;58.8)	67 (61.3;49.7)	61.3 (54.6;41.9)
deltaQ50	99.3 (98.4;97.4)	97.7 (96.2;94.9)	94.5 (92.7;91)	90 (87.8;85.5)	84.5 (81.9;78.1)	78.8 (75.3;68.6)	72.8 (68.5;58.8)	67 (61.3;49.7)
deltaQ30	99.9 (99.5;98.9)	99.3 (98.4;97.4)	97.7 (96.2;94.9)	94.5 (92.7;91)	90 (87.8;85.5)	84.5 (81.9;78.1)	78.8 (75.3;68.6)	72.8 (68.5;58.8)
deltaQ10	100 (99.9;99.7)	99.9 (99.5;98.9)	99.3 (98.4;97.4)	97.7 (96.2;94.9)	94.5 (92.7;91)	90 (87.8;85.5)	84.5 (81.9;78.1)	78.8 (75.3;68.6)

All Year Reliability (1) Volcanic+Low+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	92.4 (89.1;81.9)	88.9 (80.6;67.4)	85.2 (69.8;53.1)	81.2 (59.6;41.5)	76.5 (50.8;32.4)	71.8 (43.1;25.5)	67.1 (36.8;20.4)	62.6 (31.5;16.5)
deltaQ90	96 (93.9;91.2)	92.4 (89.1;81.9)	88.9 (80.6;67.4)	85.2 (69.8;53.1)	81.2 (59.6;41.5)	76.5 (50.8;32.4)	71.8 (43.1;25.5)	67.1 (36.8;20.4)
deltaQ70	98.5 (96.8;95.2)	96 (93.9;91.2)	92.4 (89.1;81.9)	88.9 (80.6;67.4)	85.2 (69.8;53.1)	81.2 (59.6;41.5)	76.5 (50.8;32.4)	71.8 (43.1;25.5)
deltaQ50	99.6 (98.3;96.8)	98.5 (96.8;95.2)	96 (93.9;91.2)	92.4 (89.1;81.9)	88.9 (80.6;67.4)	85.2 (69.8;53.1)	81.2 (59.6;41.5)	76.5 (50.8;32.4)
deltaQ30	99.9 (99.2;98)	99.6 (98.3;96.8)	98.5 (96.8;95.2)	96 (93.9;91.2)	92.4 (89.1;81.9)	88.9 (80.6;67.4)	85.2 (69.8;53.1)	81.2 (59.6;41.5)
deltaQ10	100 (99.7;98.9)	99.9 (99.2;98)	99.6 (98.3;96.8)	98.5 (96.8;95.2)	96 (93.9;91.2)	92.4 (89.1;81.9)	88.9 (80.6;67.4)	85.2 (69.8;53.1)

All Year Reliability (1) Non-Volcanic+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	88.8 (87.6;86.4)	84 (82.6;81.2)	78.8 (77.2;75.4)	73.5 (71.6;69.4)	68.3 (66;63.4)	63.2 (60.7;57.8)	58.5 (55.7;52.5)	54.1 (51.1;47.5)
deltaQ90	93 (91.9;90.8)	88.8 (87.6;86.4)	84 (82.6;81.2)	78.8 (77.2;75.4)	73.5 (71.6;69.4)	68.3 (66;63.4)	63.2 (60.7;57.8)	58.5 (55.7;52.5)
deltaQ70	96.2 (95.3;94)	93 (91.9;90.8)	88.8 (87.6;86.4)	84 (82.6;81.2)	78.8 (77.2;75.4)	73.5 (71.6;69.4)	68.3 (66;63.4)	63.2 (60.7;57.8)
deltaQ50	98.3 (97.8;96.5)	96.2 (95.3;94)	93 (91.9;90.8)	88.8 (87.6;86.4)	84 (82.6;81.2)	78.8 (77.2;75.4)	73.5 (71.6;69.4)	68.3 (66;63.4)
deltaQ30	99.5 (99.2;98.3)	98.3 (97.8;96.5)	96.2 (95.3;94)	93 (91.9;90.8)	88.8 (87.6;86.4)	84 (82.6;81.2)	78.8 (77.2;75.4)	73.5 (71.6;69.4)
deltaQ10	99.9 (99.8;99.3)	99.5 (99.2;98.3)	98.3 (97.8;96.5)	96.2 (95.3;94)	93 (91.9;90.8)	88.8 (87.6;86.4)	84 (82.6;81.2)	78.8 (77.2;75.4)

All Year Reliability (1) Non-Volcanic+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	89.1 (87.8;87.1)	85.2 (83.4;82.6)	80.9 (78.6;77.8)	76.4 (73.7;72.8)	72 (68.9;67.9)	68 (64.3;63.1)	64.1 (60;58.6)	60.3 (55.9;54.3)
deltaQ90	92.8 (91.7;90.9)	89.1 (87.8;87.1)	85.2 (83.4;82.6)	80.9 (78.6;77.8)	76.4 (73.7;72.8)	72 (68.9;67.9)	68 (64.3;63.1)	64.1 (60;58.6)
deltaQ70	95.6 (95;93.9)	92.8 (91.7;90.9)	89.1 (87.8;87.1)	85.2 (83.4;82.6)	80.9 (78.6;77.8)	76.4 (73.7;72.8)	72 (68.9;67.9)	68 (64.3;63.1)
deltaQ50	97.7 (97.3;96.4)	95.6 (95;93.9)	92.8 (91.7;90.9)	89.1 (87.8;87.1)	85.2 (83.4;82.6)	80.9 (78.6;77.8)	76.4 (73.7;72.8)	72 (68.9;67.9)
deltaQ30	99 (98.8;98.1)	97.7 (97.3;96.4)	95.6 (95;93.9)	92.8 (91.7;90.9)	89.1 (87.8;87.1)	85.2 (83.4;82.6)	80.9 (78.6;77.8)	76.4 (73.7;72.8)
deltaQ10	99.7 (99.6;99.2)	99 (98.8;98.1)	97.7 (97.3;96.4)	95.6 (95;93.9)	92.8 (91.7;90.9)	89.1 (87.8;87.1)	85.2 (83.4;82.6)	80.9 (78.6;77.8)

All Year Reliability (1) Volcanic+Low+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	83.5 (70.5;68.5)	70.5 (46.3;44.7)	57.4 (29.8;28)	46.4 (19.6;18)	37 (12.7;11.7)	29.5 (8.9;7.8)	23.5 (6.4;5.4)	18.9 (4.8;3.8)
deltaQ90	93.8 (92.5;90.9)	83.5 (70.5;68.5)	70.5 (46.3;44.7)	57.4 (29.8;28)	46.4 (19.6;18)	37 (12.7;11.7)	29.5 (8.9;7.8)	23.5 (6.4;5.4)
deltaQ70	98.8 (97.9;97.1)	93.8 (92.5;90.9)	83.5 (70.5;68.5)	70.5 (46.3;44.7)	57.4 (29.8;28)	46.4 (19.6;18)	37 (12.7;11.7)	29.5 (8.9;7.8)
deltaQ50	99.9 (99.6;98.4)	98.8 (97.9;97.1)	93.8 (92.5;90.9)	83.5 (70.5;68.5)	70.5 (46.3;44.7)	57.4 (29.8;28)	46.4 (19.6;18)	37 (12.7;11.7)
deltaQ30	100 (100;99.2)	99.9 (99.6;98.4)	98.8 (97.9;97.1)	93.8 (92.5;90.9)	83.5 (70.5;68.5)	70.5 (46.3;44.7)	57.4 (29.8;28)	46.4 (19.6;18)
deltaQ10	100 (100;99.7)	100 (100;99.2)	99.9 (99.6;98.4)	98.8 (97.9;97.1)	93.8 (92.5;90.9)	83.5 (70.5;68.5)	70.5 (46.3;44.7)	57.4 (29.8;28)

All Year Reliability (1) Volcanic+Hill+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	87.1 (85.1;84.4)	81.4 (79.2;77.8)	75.6 (73.3;69.1)	70 (65.8;60.7)	64.7 (58.2;53.1)	59.6 (52;46)	54.5 (46.5;39.4)	50 (41.4;33.8)
deltaQ90	91.4 (90.4;89.9)	87.1 (85.1;84.4)	81.4 (79.2;77.8)	75.6 (73.3;69.1)	70 (65.8;60.7)	64.7 (58.2;53.1)	59.6 (52;46)	54.5 (46.5;39.4)
deltaQ70	95.3 (94.6;93.9)	91.4 (90.4;89.9)	87.1 (85.1;84.4)	81.4 (79.2;77.8)	75.6 (73.3;69.1)	70 (65.8;60.7)	64.7 (58.2;53.1)	59.6 (52;46)
deltaQ50	97.8 (97.2;96.8)	95.3 (94.6;93.9)	91.4 (90.4;89.9)	87.1 (85.1;84.4)	81.4 (79.2;77.8)	75.6 (73.3;69.1)	70 (65.8;60.7)	64.7 (58.2;53.1)
deltaQ30	99.3 (98.9;98.7)	97.8 (97.2;96.8)	95.3 (94.6;93.9)	91.4 (90.4;89.9)	87.1 (85.1;84.4)	81.4 (79.2;77.8)	75.6 (73.3;69.1)	70 (65.8;60.7)
deltaQ10	99.9 (99.7;99.6)	99.3 (98.9;98.7)	97.8 (97.2;96.8)	95.3 (94.6;93.9)	91.4 (90.4;89.9)	87.1 (85.1;84.4)	81.4 (79.2;77.8)	75.6 (73.3;69.1)

Figure 20: Decision space diagrams for the water quantity management zones for reliability at management flow for the whole year.

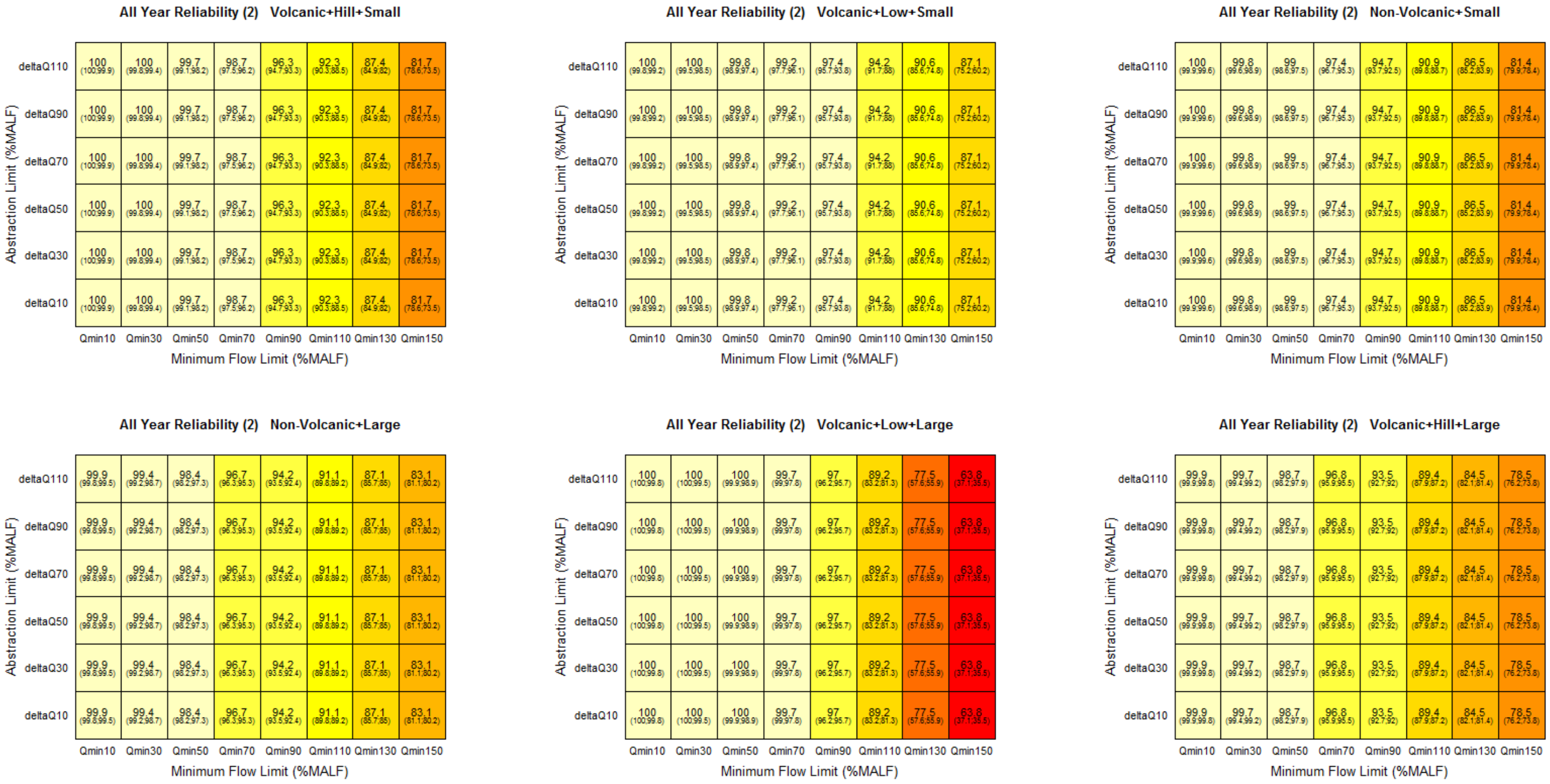
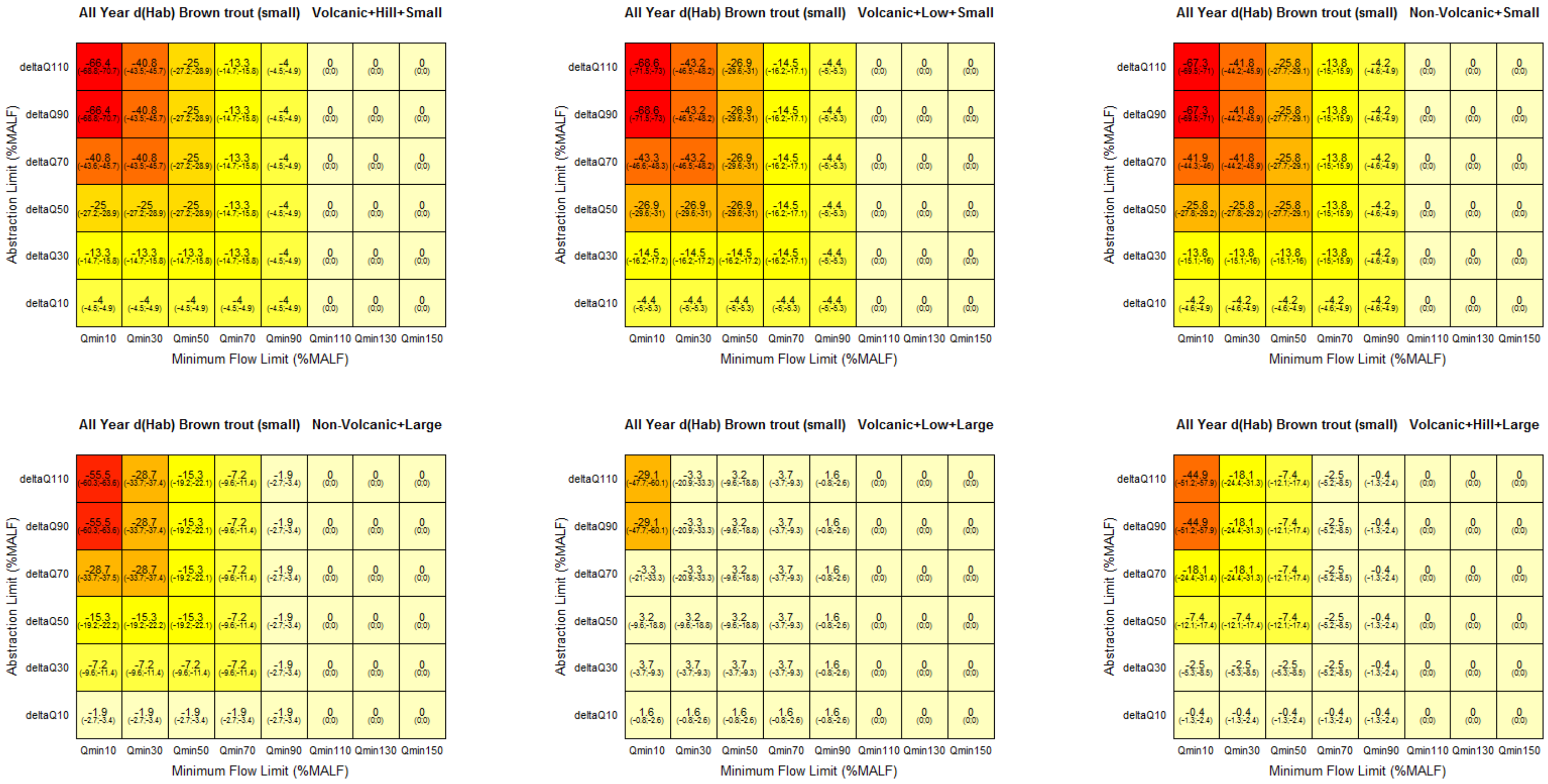


Figure 21: Decision space diagrams for the water quantity management zones for reliability at minimum flow for the whole year.



All Year d(Hab) Brown trout (small) Volcanic+Hill+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-66.4 (-68.8;-70.7)	-40.8 (-43.5;-45.7)	-25 (-27.2;-28.9)	-13.3 (-14.7;-15.8)	-4 (-4.5;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-66.4 (-68.8;-70.7)	-40.8 (-43.5;-45.7)	-25 (-27.2;-28.9)	-13.3 (-14.7;-15.8)	-4 (-4.5;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-40.8 (-43.6;-45.7)	-40.8 (-43.5;-45.7)	-25 (-27.2;-28.9)	-13.3 (-14.7;-15.8)	-4 (-4.5;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-25 (-27.2;-28.9)	-25 (-27.2;-28.9)	-25 (-27.2;-28.9)	-13.3 (-14.7;-15.8)	-4 (-4.5;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-13.3 (-14.7;-15.8)	-13.3 (-14.7;-15.8)	-13.3 (-14.7;-15.8)	-13.3 (-14.7;-15.8)	-4 (-4.5;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-4 (-4.5;-4.9)	-4 (-4.5;-4.9)	-4 (-4.5;-4.9)	-4 (-4.5;-4.9)	-4 (-4.5;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Brown trout (small) Volcanic+Low+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-68.6 (-71.5;-73)	-43.2 (-46.5;-48.2)	-26.9 (-29.6;-31)	-14.5 (-16.2;-17.1)	-4.4 (-5;-5.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-68.6 (-71.5;-73)	-43.2 (-46.5;-48.2)	-26.9 (-29.6;-31)	-14.5 (-16.2;-17.1)	-4.4 (-5;-5.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-43.3 (-46.6;-48.3)	-43.2 (-46.5;-48.2)	-26.9 (-29.6;-31)	-14.5 (-16.2;-17.1)	-4.4 (-5;-5.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-26.9 (-29.6;-31)	-26.9 (-29.6;-31)	-26.9 (-29.6;-31)	-14.5 (-16.2;-17.1)	-4.4 (-5;-5.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-14.5 (-16.2;-17.2)	-14.5 (-16.2;-17.2)	-14.5 (-16.2;-17.2)	-14.5 (-16.2;-17.1)	-4.4 (-5;-5.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-4.4 (-5;-5.3)	-4.4 (-5;-5.3)	-4.4 (-5;-5.3)	-4.4 (-5;-5.3)	-4.4 (-5;-5.3)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Brown trout (small) Non-Volcanic+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-67.3 (-69.5;-71)	-41.8 (-44.2;-45.9)	-25.8 (-27.7;-29.1)	-13.8 (-15;-15.9)	-4.2 (-4.6;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-67.3 (-69.5;-71)	-41.8 (-44.2;-45.9)	-25.8 (-27.7;-29.1)	-13.8 (-15;-15.9)	-4.2 (-4.6;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-41.9 (-44.3;-46)	-41.8 (-44.2;-45.9)	-25.8 (-27.7;-29.1)	-13.8 (-15;-15.9)	-4.2 (-4.6;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-25.8 (-27.8;-29.2)	-25.8 (-27.8;-29.2)	-25.8 (-27.7;-29.1)	-13.8 (-15;-15.9)	-4.2 (-4.6;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-13.8 (-15.1;-16)	-13.8 (-15.1;-16)	-13.8 (-15.1;-16)	-13.8 (-15;-15.9)	-4.2 (-4.6;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-4.2 (-4.6;-4.9)	-4.2 (-4.6;-4.9)	-4.2 (-4.6;-4.9)	-4.2 (-4.6;-4.9)	-4.2 (-4.6;-4.9)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Brown trout (small) Non-Volcanic+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-55.5 (-60.3;-63.6)	-28.7 (-33.7;-37.4)	-15.3 (-19.2;-22.1)	-7.2 (-9.6;-11.4)	-1.9 (-2.7;-3.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-55.5 (-60.3;-63.6)	-28.7 (-33.7;-37.4)	-15.3 (-19.2;-22.1)	-7.2 (-9.6;-11.4)	-1.9 (-2.7;-3.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-28.7 (-33.7;-37.5)	-28.7 (-33.7;-37.4)	-15.3 (-19.2;-22.1)	-7.2 (-9.6;-11.4)	-1.9 (-2.7;-3.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-15.3 (-19.2;-22.2)	-15.3 (-19.2;-22.2)	-15.3 (-19.2;-22.1)	-7.2 (-9.6;-11.4)	-1.9 (-2.7;-3.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-7.2 (-9.6;-11.4)	-7.2 (-9.6;-11.4)	-7.2 (-9.6;-11.4)	-7.2 (-9.6;-11.4)	-1.9 (-2.7;-3.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-1.9 (-2.7;-3.4)	-1.9 (-2.7;-3.4)	-1.9 (-2.7;-3.4)	-1.9 (-2.7;-3.4)	-1.9 (-2.7;-3.4)	0 (0;0)	0 (0;0)	0 (0;0)

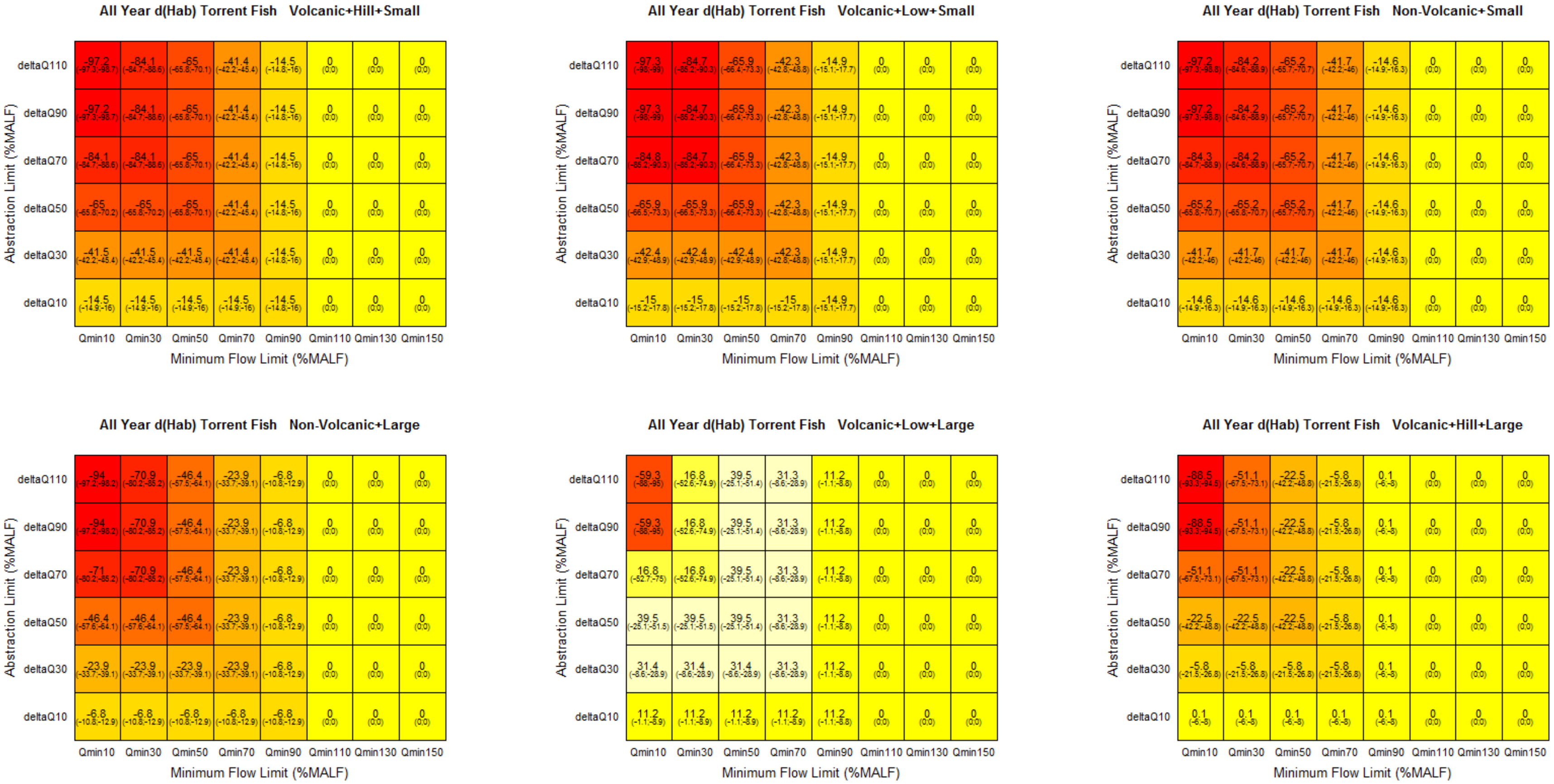
All Year d(Hab) Brown trout (small) Volcanic+Low+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-29.1 (-47.7;-60.1)	-3.3 (-20.9;-33.3)	3.2 (-9.6;-18.8)	3.7 (-3.7;-9.3)	1.6 (-0.8;-2.6)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-29.1 (-47.7;-60.1)	-3.3 (-20.9;-33.3)	3.2 (-9.6;-18.8)	3.7 (-3.7;-9.3)	1.6 (-0.8;-2.6)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-3.3 (-21;-33.3)	-3.3 (-20.9;-33.3)	3.2 (-9.6;-18.8)	3.7 (-3.7;-9.3)	1.6 (-0.8;-2.6)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	3.2 (-9.6;-18.8)	3.2 (-9.6;-18.8)	3.2 (-9.6;-18.8)	3.7 (-3.7;-9.3)	1.6 (-0.8;-2.6)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	3.7 (-3.7;-9.3)	3.7 (-3.7;-9.3)	3.7 (-3.7;-9.3)	3.7 (-3.7;-9.3)	1.6 (-0.8;-2.6)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	1.6 (-0.8;-2.6)	1.6 (-0.8;-2.6)	1.6 (-0.8;-2.6)	1.6 (-0.8;-2.6)	1.6 (-0.8;-2.6)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Brown trout (small) Volcanic+Hill+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-44.9 (-51.2;-57.9)	-18.1 (-24.4;-31.3)	-7.4 (-12.1;-17.4)	-2.5 (-5.2;-8.5)	-0.4 (-1.3;-2.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-44.9 (-51.2;-57.9)	-18.1 (-24.4;-31.3)	-7.4 (-12.1;-17.4)	-2.5 (-5.2;-8.5)	-0.4 (-1.3;-2.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-18.1 (-24.4;-31.4)	-18.1 (-24.4;-31.3)	-7.4 (-12.1;-17.4)	-2.5 (-5.2;-8.5)	-0.4 (-1.3;-2.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-7.4 (-12.1;-17.4)	-7.4 (-12.1;-17.4)	-7.4 (-12.1;-17.4)	-2.5 (-5.2;-8.5)	-0.4 (-1.3;-2.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-2.5 (-5.3;-8.5)	-2.5 (-5.3;-8.5)	-2.5 (-5.3;-8.5)	-2.5 (-5.2;-8.5)	-0.4 (-1.3;-2.4)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-0.4 (-1.3;-2.4)	-0.4 (-1.3;-2.4)	-0.4 (-1.3;-2.4)	-0.4 (-1.3;-2.4)	-0.4 (-1.3;-2.4)	0 (0;0)	0 (0;0)	0 (0;0)

Figure 22: Decision space diagrams for the water quantity management zones for change in brown trout habitat for the whole year.



All Year d(Hab) Torrent Fish   Volcanic+Hill+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-97.2 (-97.3;-98.7)	-84.1 (-84.7;-88.6)	-65 (-65.8;-70.1)	-41.4 (-42.2;-45.4)	-14.5 (-14.8;-16)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-97.2 (-97.3;-98.7)	-84.1 (-84.7;-88.6)	-65 (-65.8;-70.1)	-41.4 (-42.2;-45.4)	-14.5 (-14.8;-16)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-84.1 (-84.7;-88.6)	-84.1 (-84.7;-88.6)	-65 (-65.8;-70.1)	-41.4 (-42.2;-45.4)	-14.5 (-14.8;-16)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-65 (-65.8;-70.2)	-65 (-65.8;-70.2)	-65 (-65.8;-70.1)	-41.4 (-42.2;-45.4)	-14.5 (-14.8;-16)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-41.5 (-42.2;-45.4)	-41.5 (-42.2;-45.4)	-41.5 (-42.2;-45.4)	-41.4 (-42.2;-45.4)	-14.5 (-14.8;-16)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-14.5 (-14.9;-16)	-14.5 (-14.9;-16)	-14.5 (-14.9;-16)	-14.5 (-14.9;-16)	-14.5 (-14.8;-16)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Torrent Fish   Volcanic+Low+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-97.3 (-98;-99)	-84.7 (-85.2;-90.3)	-65.9 (-66.4;-73.3)	-42.3 (-42.8;-48.8)	-14.9 (-15.1;-17.7)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-97.3 (-98;-99)	-84.7 (-85.2;-90.3)	-65.9 (-66.4;-73.3)	-42.3 (-42.8;-48.8)	-14.9 (-15.1;-17.7)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-84.8 (-85.2;-90.3)	-84.7 (-85.2;-90.3)	-65.9 (-66.4;-73.3)	-42.3 (-42.8;-48.8)	-14.9 (-15.1;-17.7)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-65.9 (-66.5;-73.3)	-65.9 (-66.5;-73.3)	-65.9 (-66.4;-73.3)	-42.3 (-42.8;-48.8)	-14.9 (-15.1;-17.7)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-42.4 (-42.9;-48.9)	-42.4 (-42.9;-48.9)	-42.4 (-42.9;-48.9)	-42.3 (-42.8;-48.8)	-14.9 (-15.1;-17.7)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-15 (-15.2;-17.8)	-15 (-15.2;-17.8)	-15 (-15.2;-17.8)	-15 (-15.2;-17.8)	-14.9 (-15.1;-17.7)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Torrent Fish   Non-Volcanic+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-97.2 (-97.3;-98.8)	-84.2 (-84.6;-88.9)	-65.2 (-65.7;-70.7)	-41.7 (-42.2;-46)	-14.6 (-14.9;-16.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-97.2 (-97.3;-98.8)	-84.2 (-84.6;-88.9)	-65.2 (-65.7;-70.7)	-41.7 (-42.2;-46)	-14.6 (-14.9;-16.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-84.3 (-84.7;-88.9)	-84.2 (-84.6;-88.9)	-65.2 (-65.7;-70.7)	-41.7 (-42.2;-46)	-14.6 (-14.9;-16.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-65.2 (-65.8;-70.7)	-65.2 (-65.8;-70.7)	-65.2 (-65.7;-70.7)	-41.7 (-42.2;-46)	-14.6 (-14.9;-16.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-41.7 (-42.2;-46)	-41.7 (-42.2;-46)	-41.7 (-42.2;-46)	-41.7 (-42.2;-46)	-14.6 (-14.9;-16.3)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-14.6 (-14.9;-16.3)	-14.6 (-14.9;-16.3)	-14.6 (-14.9;-16.3)	-14.6 (-14.9;-16.3)	-14.6 (-14.9;-16.3)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Torrent Fish   Non-Volcanic+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-94 (-97.2;-98.2)	-70.9 (-80.2;-85.2)	-46.4 (-57.5;-64.1)	-23.9 (-33.7;-39.1)	-6.8 (-10.8;-12.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-94 (-97.2;-98.2)	-70.9 (-80.2;-85.2)	-46.4 (-57.5;-64.1)	-23.9 (-33.7;-39.1)	-6.8 (-10.8;-12.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-71 (-80.2;-85.2)	-70.9 (-80.2;-85.2)	-46.4 (-57.5;-64.1)	-23.9 (-33.7;-39.1)	-6.8 (-10.8;-12.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-46.4 (-57.6;-64.1)	-46.4 (-57.6;-64.1)	-46.4 (-57.5;-64.1)	-23.9 (-33.7;-39.1)	-6.8 (-10.8;-12.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-23.9 (-33.7;-39.1)	-23.9 (-33.7;-39.1)	-23.9 (-33.7;-39.1)	-23.9 (-33.7;-39.1)	-6.8 (-10.8;-12.9)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	-6.8 (-10.8;-12.9)	-6.8 (-10.8;-12.9)	-6.8 (-10.8;-12.9)	-6.8 (-10.8;-12.9)	-6.8 (-10.8;-12.9)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Torrent Fish   Volcanic+Low+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-59.3 (-88;-95)	16.8 (-52.6;-74.9)	39.5 (-25.1;-51.4)	31.3 (-8.6;-28.9)	11.2 (-1.1;-8.8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-59.3 (-88;-95)	16.8 (-52.6;-74.9)	39.5 (-25.1;-51.4)	31.3 (-8.6;-28.9)	11.2 (-1.1;-8.8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	16.8 (-52.7;-75)	16.8 (-52.6;-74.9)	39.5 (-25.1;-51.4)	31.3 (-8.6;-28.9)	11.2 (-1.1;-8.8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	39.5 (-25.1;-51.5)	39.5 (-25.1;-51.5)	39.5 (-25.1;-51.4)	31.3 (-8.6;-28.9)	11.2 (-1.1;-8.8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	31.4 (-8.6;-28.9)	31.4 (-8.6;-28.9)	31.4 (-8.6;-28.9)	31.3 (-8.6;-28.9)	11.2 (-1.1;-8.8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	11.2 (-1.1;-8.9)	11.2 (-1.1;-8.9)	11.2 (-1.1;-8.9)	11.2 (-1.1;-8.9)	11.2 (-1.1;-8.8)	0 (0;0)	0 (0;0)	0 (0;0)

All Year d(Hab) Torrent Fish   Volcanic+Hill+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	-88.5 (-93.3;-94.5)	-51.1 (-67.5;-73.1)	-22.5 (-42.2;-48.8)	-5.8 (-21.5;-26.8)	0.1 (-6;-8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ90	-88.5 (-93.3;-94.5)	-51.1 (-67.5;-73.1)	-22.5 (-42.2;-48.8)	-5.8 (-21.5;-26.8)	0.1 (-6;-8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ70	-51.1 (-67.5;-73.1)	-51.1 (-67.5;-73.1)	-22.5 (-42.2;-48.8)	-5.8 (-21.5;-26.8)	0.1 (-6;-8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ50	-22.5 (-42.2;-48.8)	-22.5 (-42.2;-48.8)	-22.5 (-42.2;-48.8)	-5.8 (-21.5;-26.8)	0.1 (-6;-8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ30	-5.8 (-21.5;-26.8)	-5.8 (-21.5;-26.8)	-5.8 (-21.5;-26.8)	-5.8 (-21.5;-26.8)	0.1 (-6;-8)	0 (0;0)	0 (0;0)	0 (0;0)
deltaQ10	0.1 (-6;-8)	0.1 (-6;-8)	0.1 (-6;-8)	0.1 (-6;-8)	0.1 (-6;-8)	0 (0;0)	0 (0;0)	0 (0;0)

Figure 23: Decision space diagrams for the water quantity management zones for change in torrent fish habitat for the whole year.

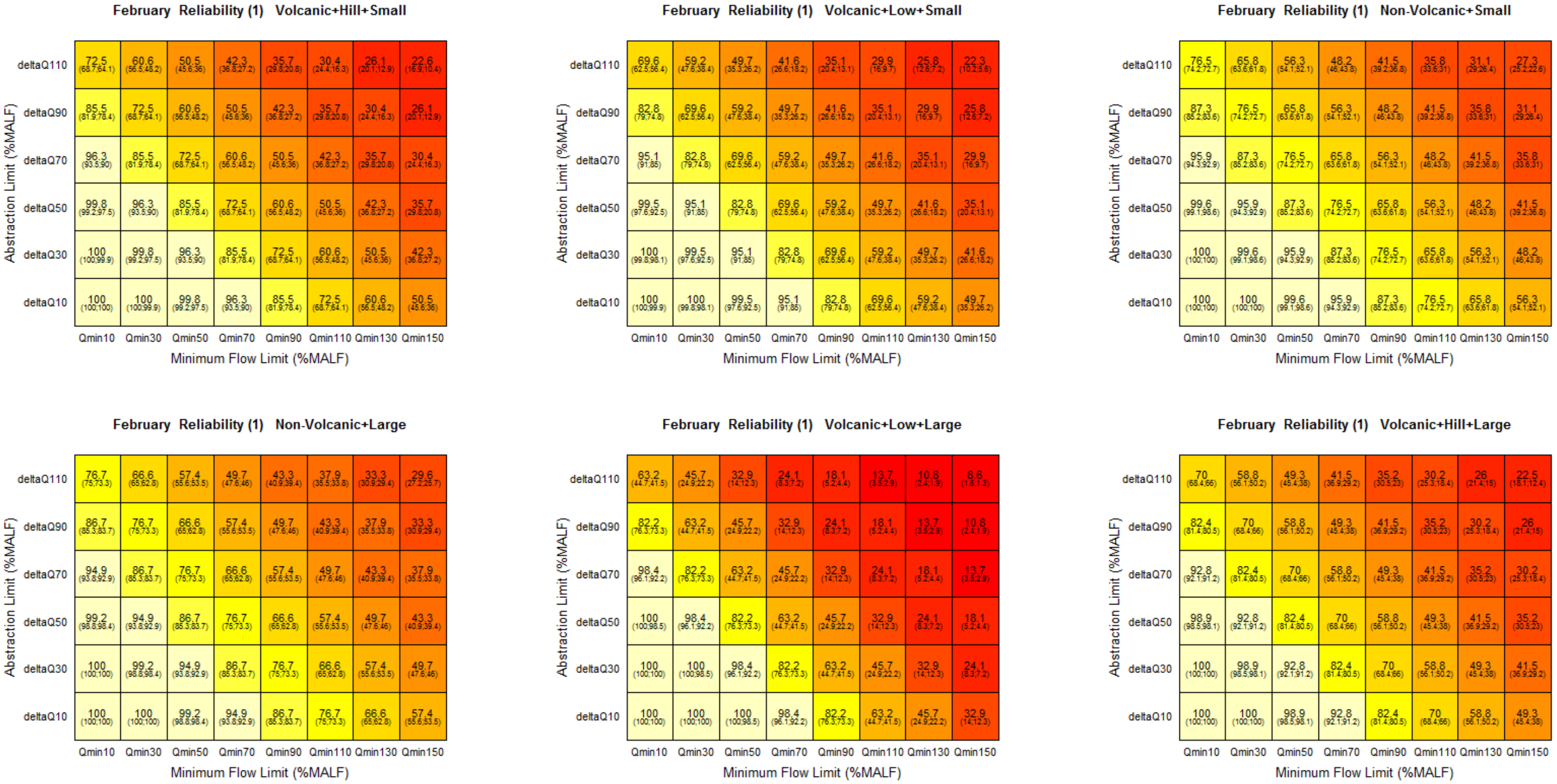
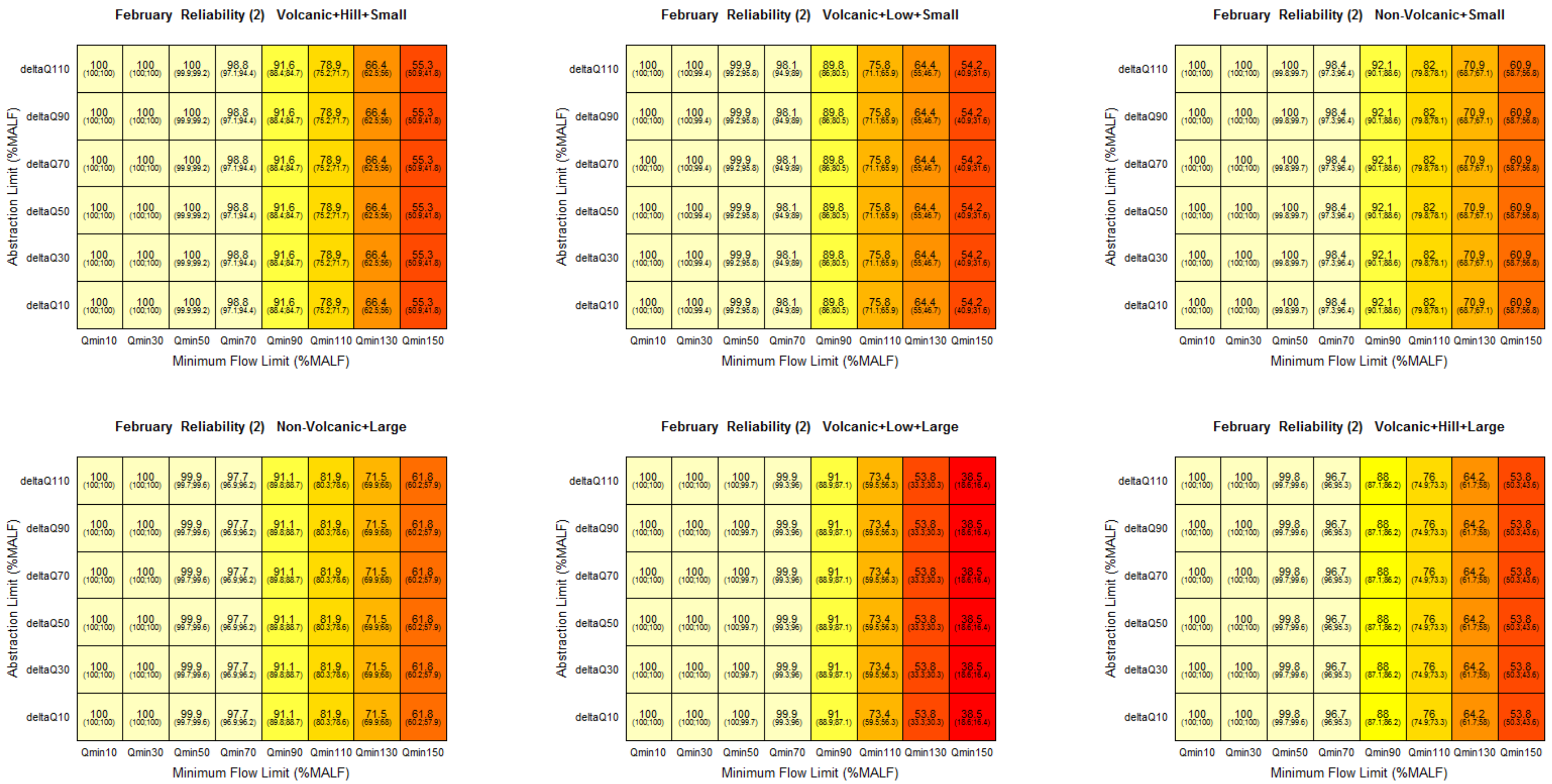


Figure 24: Decision space diagrams for the water quantity management zones for reliability at management flow for February.



February Reliability (2) Volcanic+Hill+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	100 (100;100)	100 (100;100)	100 (99.9;99.2)	98.8 (97.1;94.4)	91.6 (88.4;84.7)	78.9 (75.2;71.7)	66.4 (62.5;56)	55.3 (50.9;41.8)
deltaQ90	100 (100;100)	100 (100;100)	100 (99.9;99.2)	98.8 (97.1;94.4)	91.6 (88.4;84.7)	78.9 (75.2;71.7)	66.4 (62.5;56)	55.3 (50.9;41.8)
deltaQ70	100 (100;100)	100 (100;100)	100 (99.9;99.2)	98.8 (97.1;94.4)	91.6 (88.4;84.7)	78.9 (75.2;71.7)	66.4 (62.5;56)	55.3 (50.9;41.8)
deltaQ50	100 (100;100)	100 (100;100)	100 (99.9;99.2)	98.8 (97.1;94.4)	91.6 (88.4;84.7)	78.9 (75.2;71.7)	66.4 (62.5;56)	55.3 (50.9;41.8)
deltaQ30	100 (100;100)	100 (100;100)	100 (99.9;99.2)	98.8 (97.1;94.4)	91.6 (88.4;84.7)	78.9 (75.2;71.7)	66.4 (62.5;56)	55.3 (50.9;41.8)
deltaQ10	100 (100;100)	100 (100;100)	100 (99.9;99.2)	98.8 (97.1;94.4)	91.6 (88.4;84.7)	78.9 (75.2;71.7)	66.4 (62.5;56)	55.3 (50.9;41.8)

February Reliability (2) Volcanic+Low+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	100 (100;100)	100 (100;99.4)	99.9 (99.2;95.8)	98.1 (94.9;89)	89.8 (86;80.5)	75.8 (71.1;65.9)	64.4 (55;46.7)	54.2 (40.9;31.6)
deltaQ90	100 (100;100)	100 (100;99.4)	99.9 (99.2;95.8)	98.1 (94.9;89)	89.8 (86;80.5)	75.8 (71.1;65.9)	64.4 (55;46.7)	54.2 (40.9;31.6)
deltaQ70	100 (100;100)	100 (100;99.4)	99.9 (99.2;95.8)	98.1 (94.9;89)	89.8 (86;80.5)	75.8 (71.1;65.9)	64.4 (55;46.7)	54.2 (40.9;31.6)
deltaQ50	100 (100;100)	100 (100;99.4)	99.9 (99.2;95.8)	98.1 (94.9;89)	89.8 (86;80.5)	75.8 (71.1;65.9)	64.4 (55;46.7)	54.2 (40.9;31.6)
deltaQ30	100 (100;100)	100 (100;99.4)	99.9 (99.2;95.8)	98.1 (94.9;89)	89.8 (86;80.5)	75.8 (71.1;65.9)	64.4 (55;46.7)	54.2 (40.9;31.6)
deltaQ10	100 (100;100)	100 (100;99.4)	99.9 (99.2;95.8)	98.1 (94.9;89)	89.8 (86;80.5)	75.8 (71.1;65.9)	64.4 (55;46.7)	54.2 (40.9;31.6)

February Reliability (2) Non-Volcanic+Small

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	100 (100;100)	100 (100;100)	100 (99.8;99.7)	98.4 (97.3;96.4)	92.1 (90.1;88.6)	82 (79.8;78.1)	70.9 (68.7;67.1)	60.9 (58.7;56.8)
deltaQ90	100 (100;100)	100 (100;100)	100 (99.8;99.7)	98.4 (97.3;96.4)	92.1 (90.1;88.6)	82 (79.8;78.1)	70.9 (68.7;67.1)	60.9 (58.7;56.8)
deltaQ70	100 (100;100)	100 (100;100)	100 (99.8;99.7)	98.4 (97.3;96.4)	92.1 (90.1;88.6)	82 (79.8;78.1)	70.9 (68.7;67.1)	60.9 (58.7;56.8)
deltaQ50	100 (100;100)	100 (100;100)	100 (99.8;99.7)	98.4 (97.3;96.4)	92.1 (90.1;88.6)	82 (79.8;78.1)	70.9 (68.7;67.1)	60.9 (58.7;56.8)
deltaQ30	100 (100;100)	100 (100;100)	100 (99.8;99.7)	98.4 (97.3;96.4)	92.1 (90.1;88.6)	82 (79.8;78.1)	70.9 (68.7;67.1)	60.9 (58.7;56.8)
deltaQ10	100 (100;100)	100 (100;100)	100 (99.8;99.7)	98.4 (97.3;96.4)	92.1 (90.1;88.6)	82 (79.8;78.1)	70.9 (68.7;67.1)	60.9 (58.7;56.8)

February Reliability (2) Non-Volcanic+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	100 (100;100)	100 (100;100)	99.9 (99.7;99.6)	97.7 (96.9;96.2)	91.1 (89.8;88.7)	81.9 (80.3;78.6)	71.5 (69.9;68)	61.8 (60.2;57.9)
deltaQ90	100 (100;100)	100 (100;100)	99.9 (99.7;99.6)	97.7 (96.9;96.2)	91.1 (89.8;88.7)	81.9 (80.3;78.6)	71.5 (69.9;68)	61.8 (60.2;57.9)
deltaQ70	100 (100;100)	100 (100;100)	99.9 (99.7;99.6)	97.7 (96.9;96.2)	91.1 (89.8;88.7)	81.9 (80.3;78.6)	71.5 (69.9;68)	61.8 (60.2;57.9)
deltaQ50	100 (100;100)	100 (100;100)	99.9 (99.7;99.6)	97.7 (96.9;96.2)	91.1 (89.8;88.7)	81.9 (80.3;78.6)	71.5 (69.9;68)	61.8 (60.2;57.9)
deltaQ30	100 (100;100)	100 (100;100)	99.9 (99.7;99.6)	97.7 (96.9;96.2)	91.1 (89.8;88.7)	81.9 (80.3;78.6)	71.5 (69.9;68)	61.8 (60.2;57.9)
deltaQ10	100 (100;100)	100 (100;100)	99.9 (99.7;99.6)	97.7 (96.9;96.2)	91.1 (89.8;88.7)	81.9 (80.3;78.6)	71.5 (69.9;68)	61.8 (60.2;57.9)

February Reliability (2) Volcanic+Low+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	100 (100;100)	100 (100;100)	100 (100;99.7)	99.9 (99.3;96)	91 (88.9;87.1)	73.4 (59.5;56.3)	53.8 (33.3;30.3)	38.5 (18.6;16.4)
deltaQ90	100 (100;100)	100 (100;100)	100 (100;99.7)	99.9 (99.3;96)	91 (88.9;87.1)	73.4 (59.5;56.3)	53.8 (33.3;30.3)	38.5 (18.6;16.4)
deltaQ70	100 (100;100)	100 (100;100)	100 (100;99.7)	99.9 (99.3;96)	91 (88.9;87.1)	73.4 (59.5;56.3)	53.8 (33.3;30.3)	38.5 (18.6;16.4)
deltaQ50	100 (100;100)	100 (100;100)	100 (100;99.7)	99.9 (99.3;96)	91 (88.9;87.1)	73.4 (59.5;56.3)	53.8 (33.3;30.3)	38.5 (18.6;16.4)
deltaQ30	100 (100;100)	100 (100;100)	100 (100;99.7)	99.9 (99.3;96)	91 (88.9;87.1)	73.4 (59.5;56.3)	53.8 (33.3;30.3)	38.5 (18.6;16.4)
deltaQ10	100 (100;100)	100 (100;100)	100 (100;99.7)	99.9 (99.3;96)	91 (88.9;87.1)	73.4 (59.5;56.3)	53.8 (33.3;30.3)	38.5 (18.6;16.4)

February Reliability (2) Volcanic+Hill+Large

	Qmin10	Qmin30	Qmin50	Qmin70	Qmin90	Qmin110	Qmin130	Qmin150
deltaQ110	100 (100;100)	100 (100;100)	99.8 (99.7;99.6)	96.7 (96;95.3)	88 (87.1;86.2)	76 (74.9;73.3)	64.2 (61.7;58)	53.8 (50.3;43.6)
deltaQ90	100 (100;100)	100 (100;100)	99.8 (99.7;99.6)	96.7 (96;95.3)	88 (87.1;86.2)	76 (74.9;73.3)	64.2 (61.7;58)	53.8 (50.3;43.6)
deltaQ70	100 (100;100)	100 (100;100)	99.8 (99.7;99.6)	96.7 (96;95.3)	88 (87.1;86.2)	76 (74.9;73.3)	64.2 (61.7;58)	53.8 (50.3;43.6)
deltaQ50	100 (100;100)	100 (100;100)	99.8 (99.7;99.6)	96.7 (96;95.3)	88 (87.1;86.2)	76 (74.9;73.3)	64.2 (61.7;58)	53.8 (50.3;43.6)
deltaQ30	100 (100;100)	100 (100;100)	99.8 (99.7;99.6)	96.7 (96;95.3)	88 (87.1;86.2)	76 (74.9;73.3)	64.2 (61.7;58)	53.8 (50.3;43.6)
deltaQ10	100 (100;100)	100 (100;100)	99.8 (99.7;99.6)	96.7 (96;95.3)	88 (87.1;86.2)	76 (74.9;73.3)	64.2 (61.7;58)	53.8 (50.3;43.6)

Figure 25: Decision space diagrams for the water quantity management zones for reliability at minimum flow for February.