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REGIONAL COUNCIL
Te Pane Matua Taiao

Minimum flow and allocation options for the Ruamāhanga River and major tributaries

A technical assessment to support decision-making by the Ruamāhanga Whaitua Committee

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GW/ESCI-T-18/64

September 2017

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The report may be cited as:

Thompson M. 2018. *Minimum flow and allocation options for the Ruamāhanga River and major tributaries: A technical assessment to support decision-making by the Ruamāhanga Whaitua committee.* Greater Wellington Regional Council, Publication No. GW/ESCI-T-18/64, Wellington.

Executive summary

Greater Wellington Regional Council is currently conducting a change to the proposed Natural Resources Plan (pNRP) with respect to water management in the Ruamāhanga River catchment. This catchment, known as the Ruamāhanga Whaitua, is one of five whaitua that make up the Wellington Region.

This report presents the results of a number of discrete but related pieces of analysis undertaken to support decision-making by the Ruamāhanga Whaitua Committee ('the committee') about allocation (water quantity). Attention is focused on eight of the larger river sub-catchments of the Ruamāhanga Whaitua, including the upper and lower main stem reaches of the Ruamāhanga River itself.

Assessing the consequences of different minimum flows and allocation limits relied primarily on the EFSAP (Environmental Flows Strategic Allocation Platform) modelling tool as well as catchment-specific hydraulic-habitat survey data. Torrentfish was selected by the committee as a key species of interest for habitat modelling, due to being indigenous, of value throughout the Ruamāhanga Whaitua and relatively sensitive to flow (i.e. having the highest flow demands of all indigenous species known to be present).

The advantage of using EFSAP is that it can be run quickly, and generates outputs in a format (e.g. decision space diagrams) that provides a transparent link between objectives and allocation management regimes that are likely to support those objectives. However there are also important limitations to EFSAP (and therefore the interpretation of results in this report), most notably relating to simplification of real world complexity. This means that predictions of likely outcomes should be considered indicative only.

Key results include:

- Minimum flows (the flows currently being used to control most consented takes) and allocation levels in the pNRP are likely to meet, or nearly meet, relatively conservative habitat objectives in six of the eight sub-catchments studied (the Kopuaranga, Waingawa, Waiohine, Mangatarere, Tauherenikau and lower Ruamāhanga rivers). Increases to the minimum flows or decreases to the allocation limits in these sub-catchments would not be expected to accrue significant habitat benefits for the species of interest.

- Two sub-catchments (the Upper Ruamāhanga and Waipoua rivers) stand out as having minimum flows that offer a level of habitat protection that is at the lower end of what is considered acceptable based on the committee's fishery values and objectives. Increases in minimum flows in the order of 20 percent of mean annual low flow (MALF) would be required in each of these sub-catchments to bring the level of protection up to meet the most conservative objectives (i.e. to retain 90 percent of available habitat).

After consideration of initial instream modelling results, the committee wanted to understand what the consequences for reliability of supply would be for water users if minimum flows in the Waipoua and Upper Ruamāhanga rivers were increased to meet the most conservative objectives. Spreadsheet analysis of historical flow data was undertaken to assess this. Also included in this assessment were the reliability consequences of increasing minimum flows to levels required to sustain cultural values (based on recommendations from a 2011 report).

Notwithstanding analytical limitations relating mainly to assumptions of constant water demand during low flow periods and lack of account for climate change, the key results are:

- Under higher minimum flows being considered by the committee for the Waipoua (0.335 m^3/sec) and Upper Ruamāhanga (3.250 m^3/sec), average summer reliability could reduce by about seven percent and ten percent respectively for existing consent holders. Existing average reliability is higher in the Upper Ruamāhanga than the Waipoua, meaning these reductions would result in both catchments ending up with a summer reliability of about 85 percent. Percentage reductions in summer reliability in a dry year would be more severe again (about 12 and 18 percent, respectively).

- Reductions in average summer reliability under higher minimum flows recommended for sustaining cultural values are substantial in four sub-catchments (greater than 15 percent for the Kopuaranga, Waipoua, Waingawa and Upper Ruamāhanga catchments), and more modest in the Waiohine (five percent) and Tauherenikau (one percent) catchments. In dry years in the four most affected catchments, the number of days of cease take would outweigh the number in which water is available, and by a large margin in the case of the Upper Ruamāhanga and Kopuaranga rivers. This means there would essentially be no water available for extended periods during the summer months.

It is not the purpose of this report to recommend any changes to allocation regimes, this being the role of the committee based on discussions that include a broader range of catchment values and variables than is described here.

Should higher minimum flows (or other policies representing more restrictive conditions on water users) be favoured, consideration should be given to how the effectiveness of any changes will be determined in the future. While actual benefits (e.g. to fish population abundance and health) of minimum flow changes would be very difficult to quantify with any certainty, there are improvements that could be made to long-term monitoring programmes to enable the data to be more informative. Of particular value would be higher intensity of native fish sampling, and increased frequency of low flow habitat surveys at a finer spatial scale.

Contents

1. Introduction

1.1 The Ruamāhanga Whaitua process

Greater Wellington Regional Council is currently conducting a change to the proposed Natural Resources Plan (pNRP) with respect to water management in the Ruamāhanga River catchment. This catchment, known as the Ruamāhanga Whaitua, is one of five whaitua that make up the Wellington Region.

The Ruamāhanga Whaitua plan change involves setting policies on water quality and quantity in rivers, streams, wetlands, lakes and groundwater. Any changes will be based on recommendations made by a collaborative group (comprised of local Territory Authority and iwi partners and community members) called the Ruamāhanga Whaitua Committee ('the committee'). The committee comprises about 14 members who represent various community interests and points of view.

The Ruamāhanga Whaitua plan change is conducted within the legal framework of New Zealand resource management law. In particular, it must give effect to the Resource Management Act and the National Policy Statement for Freshwater Management (NPS-FM 2017). With respect to water quantity, the NPS-FM requires councils to *set environmental flows and/or levels for all freshwater management units* in its region to protect identified instream values (including those relating to ecosystem health and indigenous aquatic species). Environmental flows for rivers and streams include, at the least, a minimum flow and an allocation limit.

1.2 This report

Decision-making by the committee on environmental flows is being supported with information and knowledge from a range of sources. Some is quantitative (e.g. measured flow data, model outputs) and some is more qualitative (e.g. community perspectives on values and flow requirements). This report focuses on the former, and in particular, a branch of technical work that provided model predictions to the committee for consequences of different minimum flow and allocation limits.

2. Approach and scope

2.1 Background

To assist decision-making by the committee, various models (covering physical, ecological, social and economic domains) have been linked together to form a 'complex' model (as part of what has been known as the Collaborative Modelling Project). Outputs from this model are being generated for several scenarios developed by the committee that incorporate different management actions.

The original intent was to include various minimum flow and allocation scenarios within the bundle of management actions to be tested through the model. However in early 2017 it was decided by the committee to test minimum flow and allocation options outside of the model. This decision was made primarily for the following reasons:

- The time required to run a full scenario through the model is significant. The total number of scenarios was therefore limited to three; Business as Usual (BAU), Silver and Gold. Relying on just these three scenarios to explore allocation options was considered too restrictive.

- It was considered that the focus of the model should be on testing for water quality outcomes under various land management controls (e.g. land retirement, planting and stream bank fencing). Varying allocation regimes across the scenarios in addition to the land management actions was expected to increase the difficultly in isolating cause and effect from the model outputs.

As a result of the above considerations the allocation regime was held static (at BAU conditions) in all three model scenarios. Allocation has been assessed separately as described in the next section.

2.2 Approach to allocation assessment

The general approach to assessing allocation spanned several of the committee workshops. It involved the following:

1. Identification by the committee of instream management objectives for sub-catchments of the Ruamāhanga River

2. Review of the extent to which instream objectives were supported by the allocation regime in the pNRP

3. Adjustment of the pNRP allocation regime where it was considered necessary to better meet the instream objectives

4. Assessment of the extent to which a change in the allocation regime would impact water users.

This report describes the technical work undertaken to support decision-making by the committee through these steps.

2.3 Scope of report

2.3.1 Spatial coverage

The allocation assessments described in this report apply to the following rivers and streams within the Ruamāhanga Whaitua:

- Kopuaranga River
- Waipoua River
- Waingawa River
- Mangatarere Stream (Upper and Lower catchments)
- Waiohine River
- Tauherenikau River
- Ruamāhanga River (Upper/Middle and Lower catchments)

All of these rivers and streams currently have minimum flows and allocation limits listed in the pNRP. The spatial coverage of these rivers and streams are shown in Figure 2.1.

The following three stream sub-catchments also have minimum flows and allocation limits listed in the pNRP. However, they are not addressed in this report:

- Parkvale Stream (including Booths Creek)
- Otukura Stream
- Papawai Stream

Allocation regimes for these sub-catchments (and any others not covered by the above) are being addressed separately. The choices about which rivers have been chosen for assessment in this report are discussed in section 3.2.

2.3.2 Minimum flow and allocation decision-making

Mininum flow and allocation decisions made by the committee are not exclusively a product of results set out in this report. Other knowledge, not described in this report, is being considered alongside these results (for example cultural flow preferences and existing river and stream condition, present trends in low flows and future implications of a warming climate).

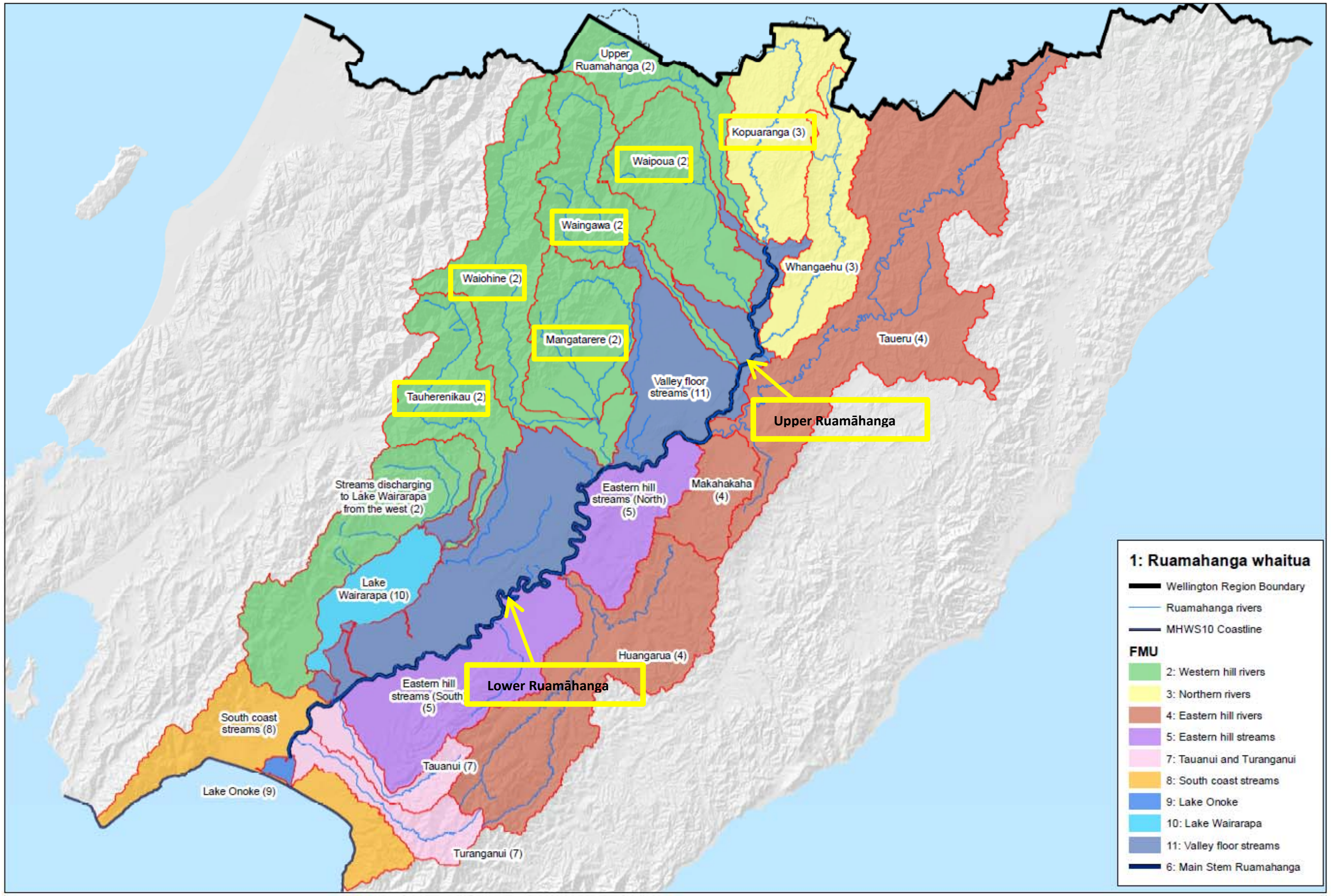

Figure 2.1: Location of the rivers/sub-catchments assessed in the Ruamāhanga whaitua. Proposed Freshwater Management Units (FMU) are shown. The boundary between the Upper and Lower Ruamāhanga River segments occurs at the confluence of the Waiohine River.

3. Methodology

3.1 Whaitua committee workshops

Water allocation (quantity) has been a topic of conversation for the committee throughout the whaitua process. The workshops that focused most substantively on reviewing the minimum flow and allocation provisions were held between May and July 2017. The workshops began with the scope of the allocation assessments being set and the committee establishing their preferences (objectives) for instream outcomes to be assessed through the modelling work. This was followed by an iterative process of draft model results being presented, and allocation parameters refined based on committee discussions.

3.2 Selection of rivers and streams

The rivers and streams selected for assessment were listed in Section 2.3.1 and shown in Figure 2.1. The main stems of most of these waterways have similar physical and morphological characteristics; flow regimes that are driven largely by the hill country of the Tararua Range, and predominantly gravel bed (or hard bottom) channels dominated by riffle and run reaches. These similarities mean that flow-dependent attributes are likely to respond in broadly similar ways across the catchments to hydrological alteration. It is also expected that objectives and management interventions for these rivers will be broadly similar.

Of the selected rivers, the Kopuaranga and Lower Ruamāhanga main stem are most distinct in character from the others (and lie in a different Freshwater Management Unit as shown in Figure 2.1). Arguably there is a reasonable case for assessing these sub-catchments separately from the others. This was not done for the generation of modelling results however distinctions between sub-catchments were discussed with the committee when interpreting these results. Furthermore, some model disaggregation into sub-catchments was undertaken later (discussed further in Section 3.4.1 and Appendix 5). These results suggest the outcomes interpreted by the committee would not have been substantially different to those when all sub-catchments were lumped together.

3.3 Instream management objectives

In a workshop held on 22 May 2017, the committee considered a range of flow-related values for rivers and streams in the Ruamāhanga Whaitua. These were summarised in a presentation from the project team[1] and included:

- Recreational values as described by community members during a round of engagement in May 2017
- Mana whenua values as summarised by Caleb Royal in his 2012 report *Cultural Values for Wairarapa Waterways*
- Ecological values, with a focus on fish.

[1] http://www.gw.govt.nz/assets/Ruamahanga-Whaitua/Presentation-by-Mike-Thompson-and-Alton-Perrie-on-water-quantity-limits-to-RWC-22.05.2017.pdf

A key point arising from the discussion was that quantitative data regarding the rate of flow necessary to support many values are very scarce. This is partly because values are often highly location-specific and have not been historically addressed by broader scale flow monitoring and flow setting studies. Also, many values that have some flow dependency are often strongly (and sometimes predominantly) influenced by a range of other factors. One such example is swimming. While the amount of flow is important, the characteristics of a river that determine the quality of a swimming experience are more likely to be related to water quality and the depth and shape of pools ('swimming holes'). These latter two characteristics are normally more sensitive to changes in the structural form of the channel than flow. Channel structure is in turn heavily influenced by factors outside of the control of an allocation regime, such as bed re-contouring for flood management.

With respect to fish, the discussion focused on which species were present in the Ruamāhanga sub-catchments (see Appendix 1) and what value the committee attached to different species. Values of most importance related primarily to customary activities such as mahinga kai and intrinsic values associated with indigenous biodiversity[2]. However values associated with the exotic trout fishery were also considered. From this discussion, the species in Table 3.1 were shortlisted as being both of particular interest/value and having some technical understanding of their flow preferences.

Table 3.1: Fish species of particular interest to the committee for which habitat suitability curves (to allow for flow-habitat modelling) are also available

Fish species	Relative flow preferences
Torrentfish	High
Brown trout	High
Longfin tuna (eel)	Moderate
Shortfin tuna (eel)	Moderate
Inanga	Moderate to low

Rather than focusing on a single instream management objective relating to the species in Table 3.1, the committee initially wanted to understand what level of habitat protection (i.e. retention) at low flows is afforded by the existing allocation and minimum flow limits in the pNRP. In this study, natural 7 day mean annual low flow (MALF) was chosen as the statistic to define low flows and habitat retention levels of 90, 80 and 70 percent of that available at MALF were modelled. This is consistent with the approach advocated by the NPS-FM.

MALF is commonly used as a flow index when objectives relate to sustaining aquatic ecosystems. This is because it is a measure of water availability during periods of relative stress. Flows less than MALF occur on average about once every two years. Thus, setting minimum flows to preserve habitat that is a little

2 Taonga species in the Ruamāhanga catchment previously identified by the committee included long fin eel, short fin eel, inanga, brown mud fish, lamprey and flounder.

less than that available at MALF means that habitat for fish (and other aquatic species) is maintained, to the extent possible, at levels not too reduced from natural low flows occuring in most years. The underlying assumption is that rivers and their instream values are robust to some degree to reduction in flow and/or that some level of impact is an acceptable trade off for the utility gained from the use of the water (LWP, 2016).

Past flow studies have also shown that if the habitat needs of fish with the highest demands are met then it is likely that many other flow-dependent values will be guarded to a reasonable degree (as long as other factors affecting those values remain favourable). For example, boat passage in the Ruamāhanga River was considered adequately supported by the existing minimum flows, as was water depth for swimming at the local marae in the Papawai Stream. However, while this is a useful principle to work from it is also acknowledged to be untested against specific local scale values in this work.

With respect to reliability of supply, the committee preference was to first determine the management requirements for meeting an instream objective and then consider whether any impacts on reliability were acceptable or could be mitigated by water being acquired from elsewhere to meet any new shortfall (e.g. storage of higher flows). That is, the committee did not wish to establish a specific reliability of supply objective.

3.4 Modelling tools

Assessing the consequences of different minimum flows and allocation relied primarily on the EFSAP (Environmental Flows Strategic Allocation Platform) modelling tool as well as catchment specific hydraulic-habitat survey data.

3.4.1 EFSAP

EFSAP is a tool designed by NIWA to enable planners and water allocation decision-makers to simulate and compare spatially explicit water management scenarios at catchment, regional and national scales. It is able to simulate the consequences of cumulative takes on both out-of-stream and in-stream values, demonstrate the trade-off between environmental state and resource use, and allow comparison of different water allocation management scenarios. It is based on the application of generalised flow and physical habitat models applied across all river reaches in a spatial framework (in this case the River Environment Classification, REC). Further details of the model structure are described in Snelder et al. (2011) and Franklin and Dietrich (2015).

The advantage of using EFSAP for a committee process is that it can be run quickly and generates outputs in a format (e.g. decision space diagrams) that provides a transparent link between objectives and allocation management regimes that are likely to support those objectives. However, there are also important limitations to EFSAP and these are described in more detail in section 3.6. The limitations mean that the model is best used, as it has been in this work, to make comparisons at a broad scale (catchment to regional) and as an indicative ‘screening’ tool.

(a) Model set up

In this study, the spatial framework (REC) was constrained to larger (greater than Order 4) segments of the rivers and streams listed in Section 2.3.1. This resulted in a total of 477 individual reaches and excluded all minor tributaries. The purpose of this constraint was to focus the assessment on the main stems where direct depletion from surface takes and connected groundwater is concentrated (see Figure 3.1) and a broader range of community values are typically held. It is also expected that uncertainty in the EFSAP model prediction increases for the smaller streams, especially as many have flow regimes strongly influenced by groundwater.

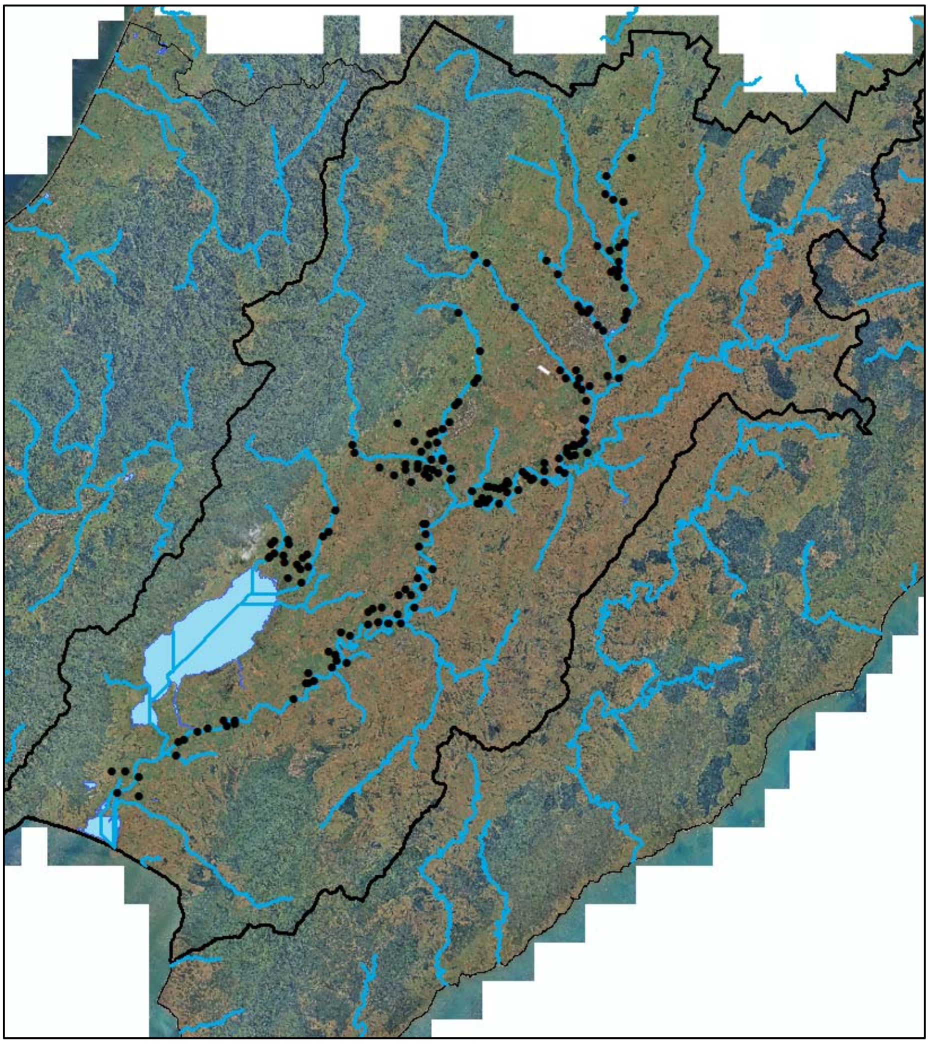

Figure 3.1: Distribution of abstraction consents (direct surface water and highly connected groundwater takes) considered in this study. Only the larger river segments (Order 4 and higher) are shown. The Ruamāhanga Whaitua boundary is depicted by the thick black line.

While excluded from this assessment, the allocation regimes in smaller tributaries of the higher order rivers that also have relatively high use (generally on the Wairarapa valley floor) will be considered separately by the committee (as described in Section 2.3.1). Other minor tributaries of the main stems (from which there is generally much lower use) are the subject of rules in the pNRP that require local scale effects of abstractions to be considered.

(b) EFSAP calculations performed in this study

In EFSAP, generalised models are used to predict flow statistics (such as mean flow and seven day MALF) as well as flow duration curves for each river reach of the REC. Flow duration curves indicate the frequency (or amount of time) that flows are equal to, or greater than any particular flow. For example, the 95th percentile flow is a low flow and is exceeded 95 percent of the time.

By combining flow predictions with predictions from generalised fish habitat models[3] within EFSAP, the proportion of habitat available at certain flows for certain species can be determined. In this study the natural flow duration curve has been modified to reflect different combinations (in increments of 10% of MALF) of minimum flow and abstraction and the change in habitat availability for each combination calculated. These calculations were made for each reach in a study area and results aggregated to inform catchment-wide statistics (which is explained further in section 3.4.1e)

The modified flow duration curve was also used to calculate how the proportion of time spent below MALF might change (from the natural flow duration curve) under different combinations of minimum flow and allocation.

Change in median flow under different allocation scenarios is not an automatically available calculation in EFSAP. This calculation was performed offline by comparing natural and modified flow time series outputs from EFSAP. Again, reach-based results were aggregated to catchment-wide statistics.

(c) Hydrological component testing

EFSAP is an uncalibrated model. While the flow statistic and duration curve predictions are derived from statistical analysis of national observed flow datasets (including those from GWRC gauging stations), individual reaches have not been calibrated to measured flow data. This means that the model is best used at catchment to regional/national scale as an indicative tool with emphasis placed on assessing relative change between allocation scenarios rather than absolute numbers. Nevertheless, it is still important that the flow predictions are reasonably realistic.

To check the performance of EFSAP, predicted and measured flow duration curves for several natural flow gauging stations in the sub-catchments of interest are compared in Appendix 3 (Figures A3.1). The flow axes (vertical) of the curves have been constrained to emphasise mid to low flow range. There are some model under-predictions at high flows (above median) and at the very bottom end (below MALF) but in general the model performs well in the mid- to low flow range. The shape and gradient of the measured curves in this flow range is generally well represented by the model and the relative differences across sub-catchments captured. The least well represented is the Kopuaranga River where the rate of decline in flow from about the 90th percentile is more rapid than observed. This is likely due to groundwater spring base flow support that is not captured by EFSAP.

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3 In this study, generalised habitat curves described by Jowett et al (2008) have been used.

Comparison of flow duration curves with measured data from three additional GWRC gauge sites located lower in the catchments is shown in Appendix 3, Figure A3.2. The shape of the Ruamāhanga River at Wardells curve is well predicted. The match for the Mangatarere Stream at SH2, located at the bottom of this catchment, is not as good but close inspection of the measured data (blue line) between about the 80th and 100th percentiles shows a slight kink that is consistent with a real abstractive effect (the Mangatarere Stream has a high allocation relative to low flows). Since EFSAP provides a prediction of natural flow, the discrepancy between measured and predicted at low flows may be partly genuine (rather than model error). The prediction for the Lower Ruamāhanga River is reasonably good for most of the mid to low flow range but the divergence between modelled and measured begins earlier than at most other sites and progressively increases (with the model under-predicting). The most likely explanation for this is base flow support from groundwater in the lower reaches of the river (which is not represented in EFSAP).

A further check on the quality of hydrology predictions from the EFSAP model involved comparing median and MALF, both of which are important statistics in the context of this study. Comparative plots of these are shown in Appendix 3 in Figures A3.3 and A3.4. EFSAP MALF predictions compare well with measured natural MALF for the headwater gauge site locations. Lower down the catchments (at generally ungauged locations) the quality of the match is a little poorer, as expected, when comparing EFSAP predictions with GWRC estimated for natural MALF[4]. On the whole, however, MALF comparisons provide confidence that EFSAP is representing this aspect of the sub-catchment hydrology reasonably well. Similarly, the predicted and observed median flows shown in Figure A3.4 compare well.

Overall, the comparison of flow duration curves and flow statistics provides confidence that the hydrological predictions utilised by EFSAP are reasonable for the purpose and scale of assessment in this study.

(d) Running EFSAP – lumped catchment

In this study, the EFSAP model was run in order to:

(1) assess how well existing allocation and minimum flow rules in the pNRP are likely to support the the committee instream objectives; and

(2) determine what order of shift in allocation and/or minimum flow values might be needed (if objectives are not being met).

To do this, EFSAP was initially run for all 477 reaches in the spatial framework lumped together. Individual sub-catchment allocation and minimum flow rules were then mapped on to the EFSAP results to check where they fell in relation to a management regime that satisfies objectives. While some spatial variability between sub-catchments is masked in taking this approach, it was considered preferable to operating with a much smaller sample size of reaches (sometimes well under 50 reaches) at the sub-catchment scale (i.e. where

[4] These are based on flow naturalisation described in Thompson (2012) and Keenan (2009).

individual reach outcomes can start to have a large influence on the statistics presented).

Spatial variability in low flow hydrology (as indicated by the MALF percentile) is shown in Figure 3.2. While there is some spread within the main distribution (between about 91 and 97 percent on the histogram) there is also a small number of reaches (associated with the larger river sections) that are quite separate (with MALF between about 86 and 91 percent on the histogram). With respect to predicted habitat loss (Figure 3.3), there is again a single dominant distribution showing between about -20 and -25 percent habitat change. However a spread of lower magnitude habitat changes are evident as well. The spread is attributable primarily to reaches in the main stem of the Ruamāhanga River, the lower reaches in particular comprising habitat that is comparatively insensitive to habitat change.

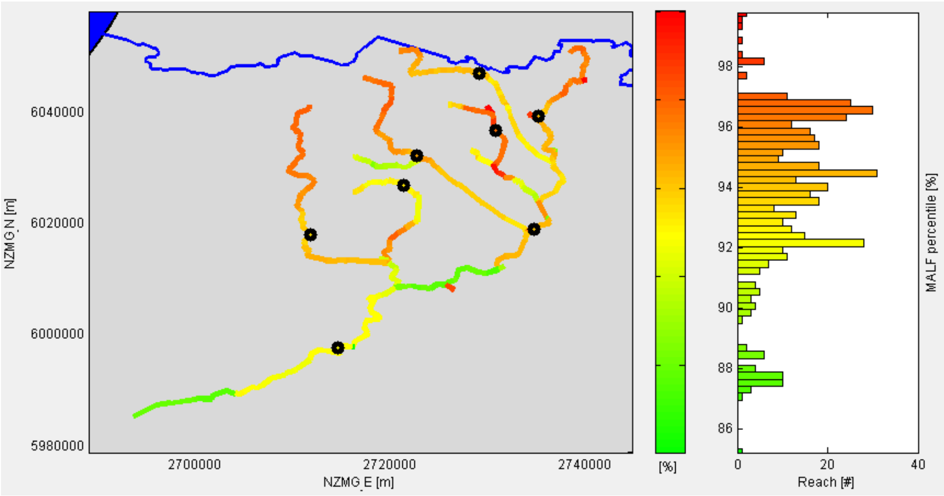

Figure 3.2: EFSAP map and histogram showing MALF as a flow percentile for individual reaches of the Ruamāhanga sub-catchments

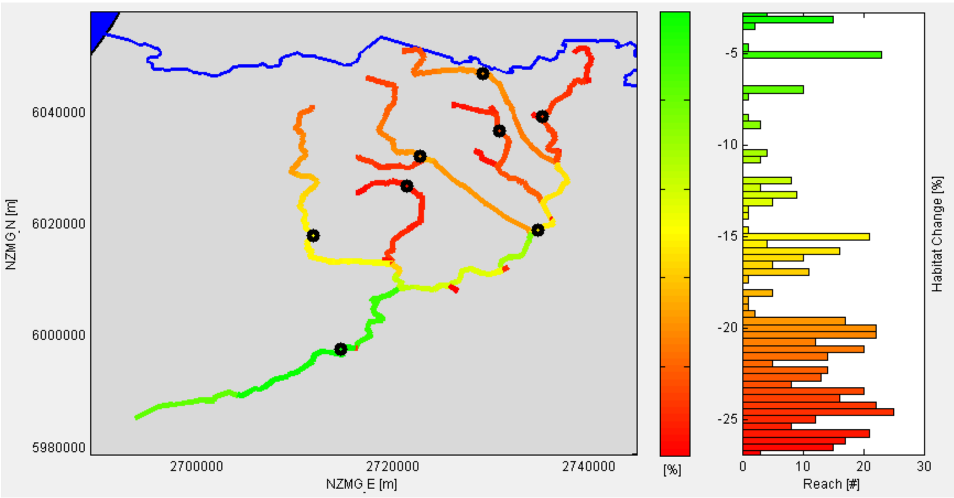

Figure 3.3: EFSAP map and histogram showing the expected habitat change (as a percentage of MALF) for torrentfish for individual reaches of the Ruamāhanga sub-catchments. In this example the allocation rules being applied are minimum flow equal to 70 percent of MALF and allocation equal to 50 percent of MALF.

A potential consequence of the observed spread in outcomes when lumping all reaches for the EFSAP assessment is that large changes in habitat in some reaches (under a given allocation scenario) may be masked by smaller changes in others. To address this in part, a relatively conservative reporting format was chosen, whereby consideration was given to achieving instream objectives in 90 percent as well as 50 percent of reaches. The apparent distinction between the higher order (larger) river reaches and other parts of the catchment was further addressed by placing more emphasis on the actual habitat survey data available for these reaches rather than relying solely on EFSAP outputs to fully interpret the likely consequences of allocation regimes (see following Section 3.4.2).

Further discussion of the differences between lumped and disaggregated catchment analysis is provided in Appendix 5.

(e) Reporting EFSAP results

In this study EFSAP is being used to help the committee to identify where in the Ruamāhanga catchment pNRP allocation rules are:

(1) likely to be satisfying (or close to satisfying) objectives, or;

(2) not likely to be satisfying objectives. Where objectives are not being met by quite some margin, what scale of policy change might be required?

With this scale of application in mind, EFSAP results were reported in decision space diagrams with relatively coarse incremental changes of 10 percent for minimum flow and allocation limit. This does not allow for the development of finely nuanced management thresholds but does allow for the level of sub-catchment interrogation described above.

An example of a decision space output is provided in Figure 3.4. In this case it shows predicted change in habitat for long fin eel (as a percentage of habitat available at MALF). The area enclosed by the dashed line shows the different combinations of minimum flow and allocation limit that are expected to meet an objective of *80 percent habitat retention in 90 percent of modelled reaches*. Similar decision space diagrams were generated for alternative scenarios (i.e. other species, different increments of habitat retention, other indicators such as duration of low flows and other criteria relating to the proportion of reaches in which the objective should be achieved).

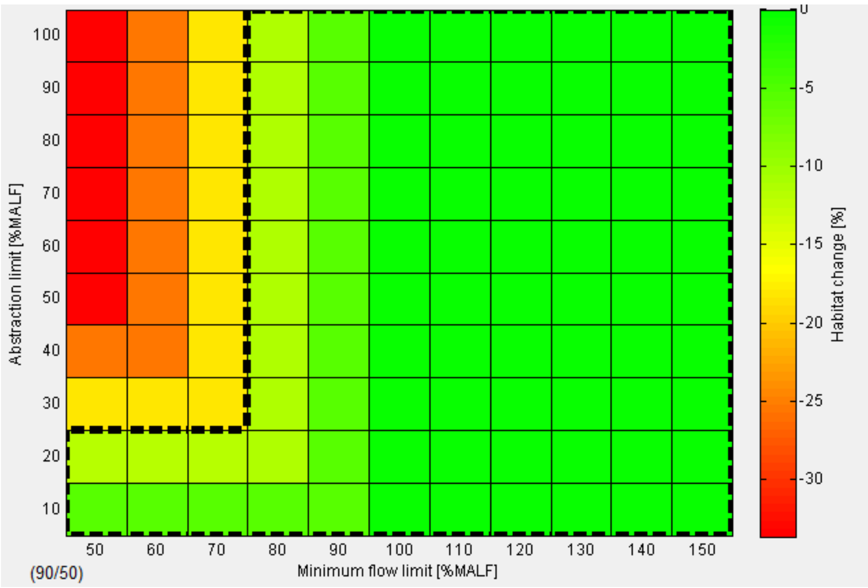

Figure 3.4: Example of decision space diagram; objective = habitat change of no more than 20 percent for long fin eel (in 90 percent of reaches)

Once the committee had settled on torrentfish as the species upon which they wanted to base their instream objective, decision space diagrams for this species were presented with existing sub-catchment total allocation and minimum flow provisions (summarised in Appendix 2) mapped on top (as depicted by the blue squares in Figure 3.5).

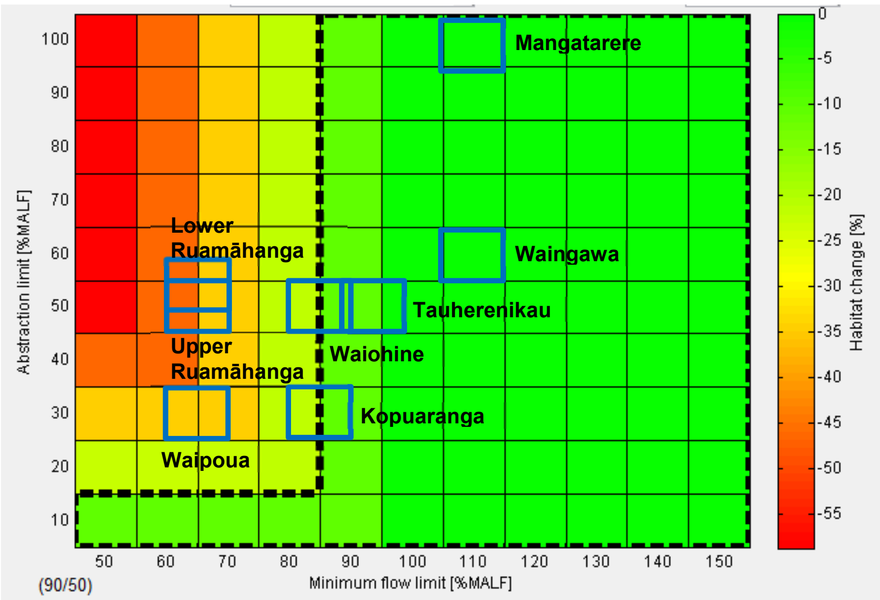

Figure 3.5: Example of decision space diagram with existing sub-catchment provisions (allocation limit and minimum flow) mapped on top (blue squares); the objective in this example is habitat change of no more than 20 percent for torrentfish (in 90 percent of reaches).

In addition to changes in habitat space, two further indicators of hydrological alteration under different allocation regimes were reported using EFSAP (in a similar way to the example decision space diagram shown in Figure 3.5). The first was *change in duration of low flows* (i.e. flows below MALF) and the second was the *change in median flow*. Longer and more severe low flows can lead to undesirable conditions such as increased water temperatures, reduced aquatic habitat and water velocities and increased risk of nuisance algae growth. Large reductions in median flow associated with abstractions indicate significant changes to the recession behaviour of a stream (i.e. alteration of mid- to low range flows). While the impact of such changes remains an emerging area of research, one current school of thought (eg, Hayes et al 2016) is that reductions in mid- to low range flows in certain river systems can reduce benthic invertebrate production and, as a result, diminish the quality of drift feeding opportunities for some fish (research in this country has so far focused on trout). Change in median flow is a coarse indicator and not intended to explicitly represent these complex instream processes. However, it is included in this study to recognise that, in addition to changes in physical habitat and other variables at low flows, it may be prudent to also consider risks associated with core allocation at higher flows.

(f) Aggregating EFSAP results – rationale for describing risk

In an effort to synthesise the multiple indicator and scenario outputs from EFSAP into more manageable information for the committee to consider, risk matrix tables were produced. The structure of these tables is shown for each indicator in Figure 3.6. The aim of the tables was to show the extent to which existing minimum flow and allocation limits (in the pNRP) are likely to satisfy various categories of instream protection. The language and percentage thresholds used in the tables to describe the different categories are not intended to be absolute but rather offer a subjective characterisation for the purpose of looking at relative spread of likely outcomes across sub-catchments. That said, the categories are not entirely arbitrary either and are grounded in a general knowledge of risk associated with hydrological alteration.

For example, preserving a proportion of habitat equal to 90 percent (or more) of that available at MALF (for a given species of interest) is widely considered to be relatively ecologically conservative (e.g. Beca 2008, Young and Hay 2017). That is, assuming habitat is a limiting factor for instream values and notwithstanding all other catchment factors that impact river condition, it is reasonable to expect that an allocation regime that achieves this level of protection will prevent aquatic population changes of any consequence. In this study, 90 percent habitat retention has therefore been described as ‘safe’ or ‘optimum’ (noting that optimum is used here in the sense of what can realistically be applied while allowing for some meaningful out of stream use rather than a true habitat optimum for all species which can sometimes occur well over MALF).

In a similar vein, a general principle has been applied to the other indicators (duration of low flows and summer median) that any change of less than 10 percent from natural is very unlikely to be either measureable or, by itself, consequential. Therefore, hydrological alteration falling into this category can also be considered 'safe' from an instream effects point of view. For the change in duration of low flows indicator, a threshold of 5 percent has been used to define 'safe'. This threshold is based on a proportion of time relating to the annual flow distribution. Since annual low flows in the Wellington Region occur almost entirely within a six month summer window, a 5 percent change based on annual distribution effectively equates to a 10% change in summer low flow duration. A change of this magnitude is considered unlikely to extend low flows for the rivers in question up to, or significantly beyond, the 30 day threshold that Beca (2008) suggest as a risk inflection point[5].

[5] Previous analyses in Thompson and Mzila (2015) show that the annual average number of naturally occuring low flow days (i.e. below MALF) ranged from about 5 to 20 in tributary rivers of the Ruamāhanga catchment.

Key to interpreting all matrix tables

Shading	Are minimum flows and allocation limits in the pNRP allowing objectives to be met?
	Yes
	Almost
	No

Change in habitat (relative to habitat available at MALF)

Sub-catchment	*Safe* **or** *Optimum*		*Good*		*Bottom line?*	
	Habitat retention of **90%** to be achieved in...		Habitat retention of **80%** to be achieved in...		Habitat retention of **70%** to be achieved in...	
	Most reaches	At least half reaches	Most reaches	At least half reaches	Most reaches	At least half reaches
River X						
River Y						
River Z						

Change in duration of flows below MALF

Sub-catchment	*Safe*		*Good*		*Bottom line?*	
	No more than **5%** increase in duration of time under MALF in...		No more than **10%** increase in duration of time under MALF in...		No more than **15%** increase in duration of time under MALF in...	
	Most reaches	At least half reaches	Most reaches	At least half reaches	Most reaches	At least half reaches
River X						
River Y						
River Z						

Change in summer median flows

Sub-catchment	*Safe*	*Probably OK*	*Potentially noticeable impacts?*
	No more than **10%** decrease in summer median flow	No more than **20%** decrease in summer median flow	No more than **30%** decrease in summer median flow
	Median	Median	Median
River X			
River Y			
River Z			

Figure 3.6: Risk matrix tables developed to assist the committee interpret a range of outcomes across sub-catchments. Results displayed in the matrix cells are for illustrative purposes only. The term "most reaches" refers to the 90th percentile of results (for the modelled sample of reaches) and "at least half of reaches" refers to the 50th percentile/median result. For the change in summer median flows objective (bottom table) only median results are presented as there was very little variation in the degree of change between reaches in the modelled sample.

Beyond the 10 percent thresholds suggested above, the risks of adverse instream impact rises progressively with increased allocation and/or lower minimum flows. Actual effects are not particularly predictable and vary between locations according to a wide range of factors and values held. Nevertheless, the thresholds in Figure 3.6 described with terms such as 'Good', 'OK' and 'Bottom line?' attempt to provide some colloquial discrimination of risk based on the values and objectives expressed by the committee as well as reference to commonly held views in the scientific community.

For example, retention of 70 percent habitat of a species of value (in particular those with high flow demands) is at the lowest end of the range applied in flow setting studies both in the Wellington Region and around the country in recent years. A broad interpretation is that the risks associated with limiting the natural potential and carrying capacity of the river move from acceptable to unacceptable across this threshold. In a similar way the categories for the other indicators are intended to represent points at which the departure from a natural flow regime has moved sufficiently from a 'safe' area that the acceptance of further risk becomes more questionable.

It is acknowledged that trying to define an indisputable 'bottom line' can be contentious. A deliberate choice was therefore made to retain a question mark against this category description (as in the paragraph above and column headings in Figure 3.6).

3.4.2 Habitat retention based on historical survey data

In addition to using EFSAP to predict broad scale consequences of allocation regimes, historic hydraulic and habitat survey data were re-assessed in this study to further consider flow requirements on particular rivers. The reassessment made use of existing hydraulic-habitat models (based on field survey data) for the Kopuaranga, Waingawa, Waiohine and Ruamāhanga (upper and lower reaches) rivers but also took into account updated flow statistics and committee preferences for target species and protection levels.

The assessment was carried out by Freshwater Scientist Joe Hay from Cawthron Institute and the method is described further in Appendix 5 (Hay 2017). Results from this assessment were considered alongside other information presented to the committee and used in particular to cross reference some of the EFSAP modelling results.

3.5 Impact on reliability of supply

The committee preference was to determine the management requirements for meeting an instream objective and then consider whether any impacts on reliability were acceptable or could be mitigated by water being acquired from elsewhere to meet any new shortfall (e.g. storage of higher flows). That is, they opted not to establish a specific objective relating to reliability of supply (to test alongside the instream objective).

Once alternative minimum flow options had been identified by the committee, daily flow records for the relevant GWRC management sites were analysed to test for the reliability consequences. This was done in particular for the minimum flow recommendations put forward by Royal (2012) for sustaining cultural values and to assess the impact of potential changes (as identified by the committee) in the minimum flows for the Waipoua and Upper/Middle Ruamāhanga rivers.

Reliability consequences are characterised in this study as a change in the number of days of cease take (based on recent historical flow data). Changes are expressed in a number of ways from average annual values to summer and month-specific values. It is beyond the scope of this report to assess the actual economic implications of the reliability change but this is being estimated by another modelling component.

3.6 Assumptions and limitations

Some of the important assumptions and limitations of the flow modelling and reliability of supply assessments have already been mentioned in previous sections. Key among these are assumptions relating to physical habitat being a limiting factor in the rivers in question and the somewhat subjective nature of thresholds for defining risk (discussed in section 3.4.1f). Limitations associated with aggregating results from reach to lumped catchment scale are discussed in section 3.4.1d and Appendix 5. Some other assumptions worth noting include:

- The EFSAP modelling is a theoretical exercise and assumes that all consents conform completely to the minimum flow and allocation rules that are set; for example, that all takes progressively ramp down as river flows reduce towards the minimum flow. In reality, there is a variation in how individual consents are managed with some conforming more than others to behaviour modelled by EFSAP. For practical reasons, reductions in take are normally made in one or two steps rather than being progressive. Nevertheless, at the scale at which EFSAP has applied in this study, the discrepancy between the model and real world is not thought to substantially detract from the approach taken. Furthermore, the management of consents in practice was part of subsequent committee discussions when interpreting these results and also part of the broader context for decision making about allocation;

- The way EFSAP has been applied in this study is that allocation is distributed more or less evenly throughout the sub-catchments. In reality there is spatial variation in allocation pressure and clustering of takes in some places (see Figure 3.1). However, Figure 3.1 also shows that takes are broadly distributed along the main stem systems such that the assumption of even spread is probably not unreasonable at the scale of model application;

- With respect to both the EFSAP and reliability of supply assessments, there is an assumption of climate stationarity. In other words, both assessments rely on historical climate and flow data to make predictions about the future and therefore assume that the future climate will be the same as the past. While recent reports for the Wellington Region (e.g. Pearce et al 2017) highlight the likelihood of a drying climate for many parts of the Wairarapa, the uncertainty in how this might manifest in river base flows means there is limited value in trying to explicitly account for it in the assessments undertaken. Nevertheless, it is a factor that should be considered by the committee as part of their broader thinking on future river resilience and allocation regimes;

- The reliability of supply analysis in this study is based on how often flows fall below a restriction threshold and assumes when this happens that reliability is zero (i.e. that there is a constant demand for water throughout the summer). However, in practice there can be occasions when rivers fall below restriction thresholds but demand for water is low or non-existent because irrigation requirement has not been triggered (e.g. because soil moisture remains elevated). Therefore, once demand is more fully accounted for, actual reliability could be expected to be higher (better) than characterised in this report.

4. Results

Results are summarised here in two subsections corresponding to instream objectives (EFSAP modelling and physical survey habitat recalculations) and out of stream uses (reliability of supply consequences).

4.1 Instream objectives

4.1.1 EFSAP results

(a) Habitat space

Decision space diagrams showing how well different objectives relating to changes in habitat space are met under different combinations of minimum flow and allocation limits are provided in Figure 4.1 for torrentfish and Appendix 4 (Figures A4.1 to A4.5) for other individual species from Table 3.1. For each species, allocation regimes that provide for 90, 80 and 70 percent habitat retention are shown, and for each level of habitat retention, two options are given; one in which the habitat criteria would be satisfied in 90 percent of modelled reaches and the other, 50 percent of reaches.

These diagrams show that torrentfish and adult brown trout have the highest flow demands and are the most sensitive species (in terms of habitat changes) to flow reductions below MALF. At the relatively coarse scale that the EFSAP modelling has been undertaken (i.e. allocation and minimum flow increments of 10 percent) these two species are represented by very similar decision space plots meaning habitat objectives are satisfied by broadly the same allocation regime; for example, for an objective of *90 percent habitat retention in 90 percent of reaches,* the lowest the minimum flow could be for both species would be between 90 and 100 percent of MALF (for any level of allocation above zero). A less conservative objective of *70 percent habitat retention in 50 percent of reaches* could be achieved with a minimum flow as low as 70-80 percent of MALF for torrentfish and 60-70 percent for trout even with moderate to high levels of allocation (>30% MALF).

Flow demands for inanga (based on suitability curves for food producing habitat) are also relatively high while tuna (eel) are less sensitive to flow reductions with the most conservative objectives (90 percent habitat retention) being met with minimum flows in the range 70-90 percent of MALF (combined with unconstrained allocation) and the least conservative objectives satisfied with minimum flows of 50-60 percent.

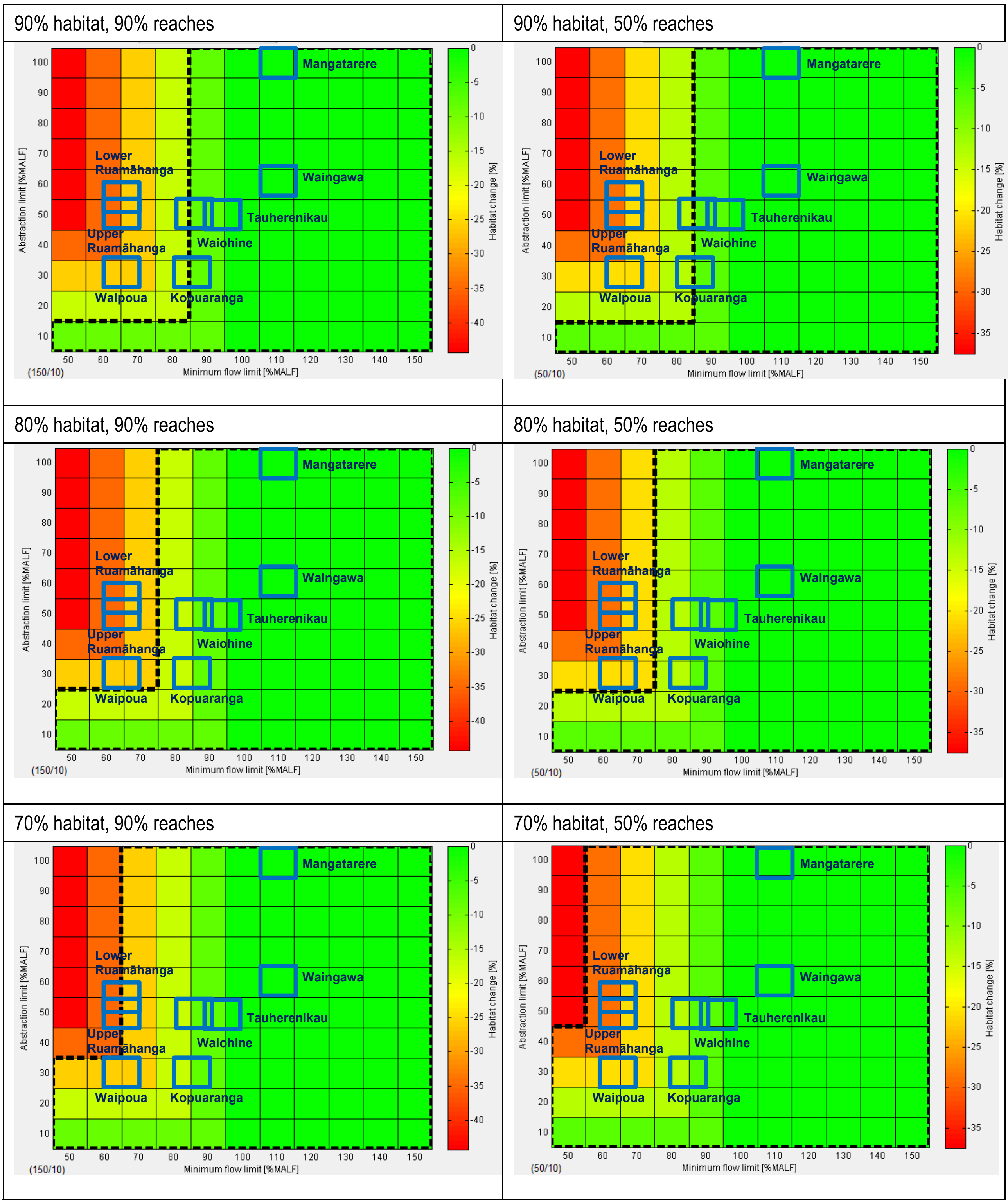

Figure 4.1: Predicted habitat change (percent) for torrentfish for different combinations of minimum flow and allocation. Enclosed within the black dashed box are the combinations that satisfy the objectives relating to percent habitat retention (90 percent, 80 percent and 70 percent) as well as proportion of reaches these objectives apply to. The blue boxes depict the combination of minimum flow and allocation limit for each sub-catchment in the PNRP.

(b) Change in duration of flows below MALF

Figure 4.2 presents decision space diagrams showing how well objectives relating to the duration of flows below MALF are likely to be met under different combinations of minimum flow and allocation.

The only way a relatively conservative objective (e.g. no more than *5 percent reduction in duration of flows below MALF in 90 percent of reaches*) can be met, while also allowing for moderate to high levels of allocation (>20%) is by having a minimum flow that equates to at least MALF. If the objective is relaxed such that a *15 percent change in duration of flows below MALF in 50 percent of reaches* is deemed acceptable, then the minimum flow could be much lower (reduced to 50 percent of MALF) while still allowing for allocation levels of up to 80 percent of MALF.

(c) Reduction in summer median flow

Figure 4.3 shows the extent of reduction in summer median flows expected under different allocation regimes. The plot shows that changes in minimum flow do not affect median flows but rather it is the level of allocation that is important. Low to moderate allocation levels of up to 20 percent of MALF will result in only small reductions in median flow of up to about 8 percent. High allocation levels of about 100 percent of MALF will result in much more substantial reductions in mid-range flows or around 40 percent. The general pattern is one of a reduction in median flow of 3-5 percent for a 10 percent increase in allocation.

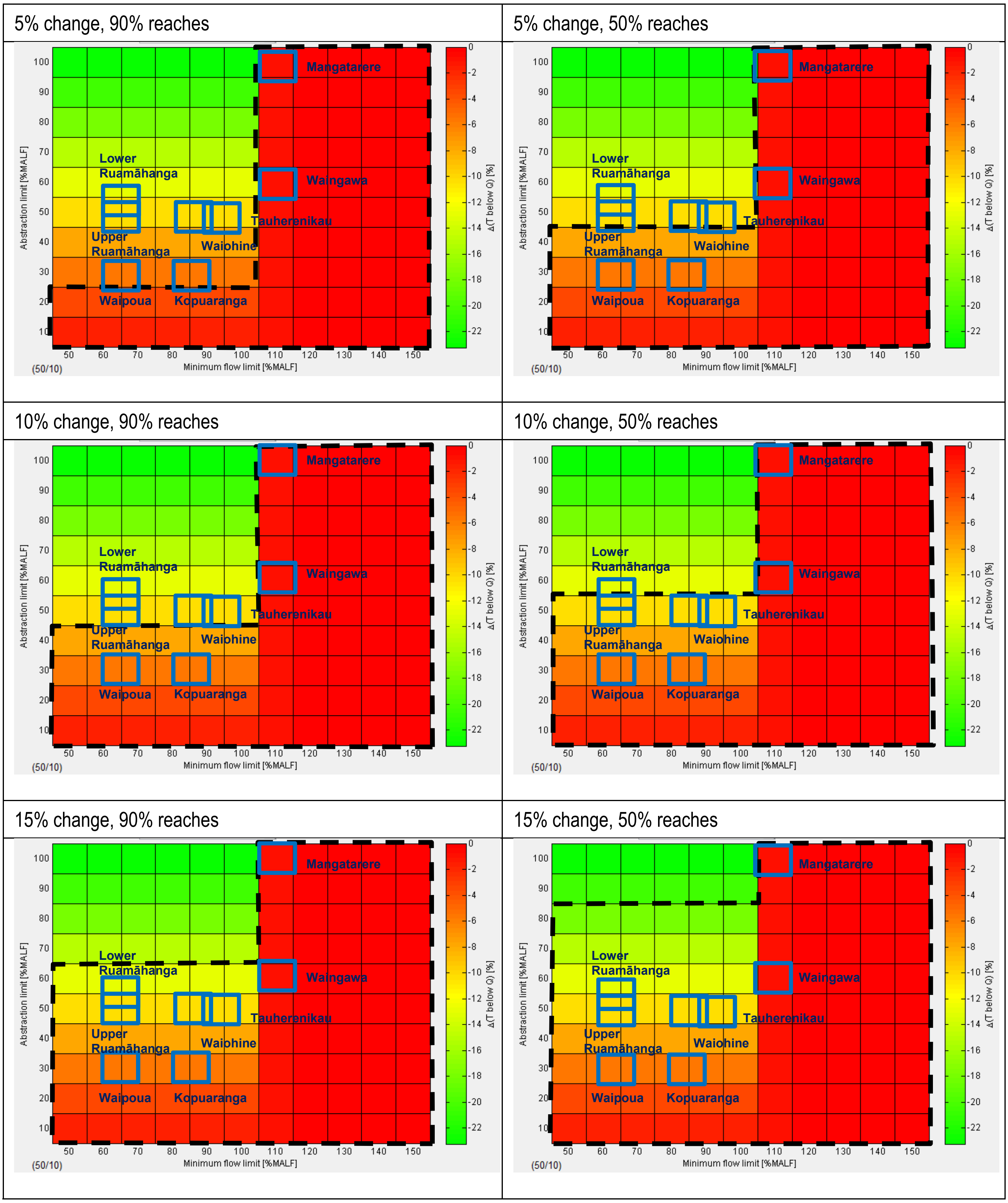

Figure 4.2: Predicted change in the duration of flows below MALF that result from different combinations of minimum flow and allocation. Enclosed within the black dashed boxes are the combinations that satisfy the objectives relating to percent flow reductions (5 percent, 10 percent and 15 percent) as well as the proportion of reaches these objectives apply to. The blue boxes depict the combination of minimum flow and allocation limit for each sub-catchment in the PNRP.

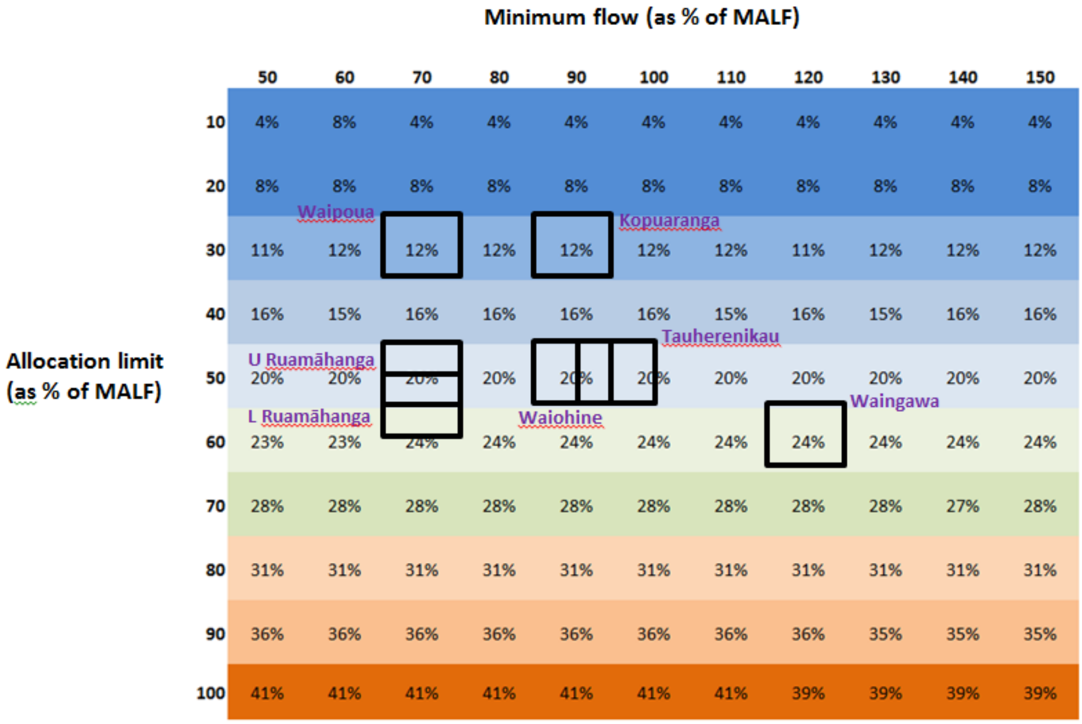

Figure 4.3: Predicted reductions in the summer median flow (i.e. median percentage reduction from modelled summer natural median flow) resulting from different combinations of minimum flow and fully exercised allocation. The blue boxes depict the combination of minimum flow and allocation for each sub-catchment in the PNRP (with the exception of the Mangatarere Stream catchment; reduction in summer median flows in this catchment lie outside the scale of the figure and are predicted to be about 60 percent)

4.1.2 Interpreting EFSAP results - summary matrix table

For the indicators just discussed, the pNRP allocation regime has been assessed for each sub-catchment. Sub-catchment allocation and minimum flow provisions (from Appendix 2) were mapped on to the decision space diagrams in Figure 4.1-4.3 and Appendix 4 and the outcomes from this were used to generate the summary results table in Figure 4.4 (based on the rationale described earlier in section 3.4.1e).

(a) Kopuaranga River

The pNRP allocation regime is predicted to result in only minor changes to indicators in the Kopuaranga catchment. The pNRP minimum flow is already relatively conservative (87 percent of MALF) and, combined with a default allocation amount of 30 percent of MALF, it is predicted that the most conservative objectives expressed by the committee will be met or almost met.

(b) Waipoua River

The Waipoua River has a pNRP default allocation amount similar to the Kopuaranga River (30 percent of MALF) however, the minimum flow is proportionally much lower (67 percent of MALF). The primary consequence of this, as shown in Figure 4.4, is that only the least conservative habitat retention objective (*70 percent of torrentfish habitat relative to MALF retained in 50 percent of reaches*) is predicted to be satisfied. Achieving habitat objectives of 80 or 90 percent would require an approximately proportionate increase in minimum flow of 10 and 20 percent of MALF, respectively.

(c) Waingawa River

The 'effective' pNRP minimum flow for the Waingawa River[6] is already higher than MALF and therefore EFSAP predicts all objectives relating to changes below MALF will automatically be met, irrespective of allocation. However, the allocation allowable under the pNRP is high in this sub-catchment relative to most others and a consequence of this is that summer mid-range flows are predicted to be more heavily impacted (although probably not to the extent that significant and/or noticeable impacts are apparent).

[6] See footnote to minimum flow table in Appendix 2 for description of 'effective' minimum flow. In the case of the Waingawa, the flow at which irrigation takes are most heavily controlled (suspended or cut back) is 1,700 L/sec (which is higher than MALF of 1,420 L/sec and the minimum flow listed in the pNRP of 1,100 L/sec).

Key to interpreting results table

Shading	Are mimum flows and allocation limits allowing objectives to be met?
Green	Yes
Yellow	Almost
Orange	No

Sub-catchment	Habitat Loss						Change in duration of low flows						Change in median flow		
	Safe or Optimum		*Good*		*Bottom line?*		*Safe*		*Good*		*Bottom line?*		*Safe*	*Probably OK*	*Potentially noticeable impacts*
	Habitat retention of **90%** to be acheived in...		Habitat retention of **80%** to be acheived in...		Habitat retention of **70%** to be acheived in...		No more than **5%** increase in duration of time under MALF in...		No more than **10%** increase in duration of time under MALF in...		No more than **15%** increase in duration of time under MALF in...		No more than **10%** decrease in summer median flow	No more than **20%** decrease in summer median flow	No more than **30%** decrease in summer median flow
	Most reaches	At least half reaches	Most reaches	At least half reaches	Most reaches	At least half reaches	Most reaches	At least half reaches	Most reaches	At least half reaches	Most reaches	At least half reaches	Median	Median	Median
Kopuaranga	Almost	Almost	Yes	Yes	Yes	Yes	Almost	Yes	Yes	Yes	Yes	Yes	Almost	Yes	Yes
Waipoua	No	No	No	No	No	Almost	Almost	Yes	Yes	Yes	Yes	Yes	Almost	Yes	Yes
Waingawa	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Almost	Yes
Upper Ruamahanga	No	No	No	No	No	Almost	No	Almost	Almost	Yes	Yes	Yes	No	Yes	Yes
Mangatarere	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Waiohine	Almost	Almost	Yes	Yes	Yes	Yes	No	Almost	Almost	Yes	Yes	Yes	No	Yes	Yes
Tauherenikau	Yes	Yes	Yes	Yes	Yes	Yes	Almost	Yes	Almost	Yes	Yes	Yes	No	Yes	Yes
Lower Ruamahanga	No	No	No	No	No	Almost	No	Almost	No	Almost	Yes	Yes	No	Almost	Yes

Figure 4.4: EFSAP results summarised for three indicators (habitat loss, change in duration of low flows and change in summer median flow) to show how well allocation provisions in the pNRP satisfy various objectives. Note that habitat loss relates to torrentfish only.

An important point to note for the Waingawa River is that EFSAP is providing a more favourable (i.e. less conservative) view of the impact of allocation regime than is likely the case in practice. This is because the public water supply and water race takes comprise approximately two thirds of the total water use and a significant proportion of these takes can persist below the 'effective' minimum flow. Whereas EFSAP is predicting the consequences associated with all water use being suspended at the minimum flow. This was a compromise in modelling approach made in order to standardise the application of the model across sub-catchments (at which scale the volume of water use by takes that are controlled most heavily at the modelled thresholds substantially outweighs the volume associated with takes that are not). Nevertheless, it is an important caveat for the committee to bear in mind when it comes to consideration of the full package of allocation options for this catchment in particular.

(d) Upper Ruamāhanga River

The pNRP minimum flow for the Upper Ruamāhanga River[7] is a relatively low proportion of MALF (68 percent). EFSAP results suggest that the primary consequence of this, as shown in Figure 4.4, is that only the least conservative habitat retention objective (*70* percent *of torrentfish habitat relative to MALF retained in 50* percent *of reaches*) is likely to be satisfied. Achieving habitat objectives of 80 or 90 percent would require an approximately proportionate increase in minimum flow of 10 and 20 percent of MALF, respectively. The most conservative objectives relating to duration of low flows and mid-range flows are also not likely to be met as a consequence of both the minimum flow and pNRP allocation amount (50 percent of MALF), although the alternative objectives with slightly less stringent criteria are largely met.

(e) Mangatarere Stream

The pNRP minimum flow for the Mangatarere Stream is well above MALF and, relative to natural catchment flow, is the highest of all sub-catchments considered in this study. This means that the most conservative objectives relating to habitat retention and duration of flows below MALF are predicted by EFSAP to be met. The caveat to this statement is similar to that for the Waingawa; there is a significant water race take from the Mangatarere Stream that persists (under restrictions) below minimum flow, so the EFSAP predictions present a more favourable view of impacts than will be the case in reality. That is, fully achieving the predicted EFSAP outcomes would likely require a more stringent approach to managing some takes.

Allocation under the pNRP from the Mangatarere Stream catchment is relatively high (compared with both other catchments and default criteria) and is an amount equivalent to almost 1.5 times MALF. While the high minimum flow provides a good level of instream protection at flows below MALF, the main consequence of the high allocation is that mid-range flows are more

[7] In this study the Upper Ruamāhanga sub-catchment extends from the headwaters to the confluence of the Waiohine River, incorporating both the 'Upper' and 'Middle' Ruamāhanga sub-catchments as defined in the pNRP. The two units have been combined because they are both controlled by the same minimum flow (at Wardells monitoring) and also have very similar existing allocation levels and pNRP allocation amounts.

heavily impacted than elsewhere (see Figure 4.4); effectively, the onset of abstraction pulls flow down to base flows more quickly. While EFSAP results highlight an increased risk relating to allocation levels, the actual consequence of this hydrological alteration for instream values in the Mangatarere catchment is not quantifiable in this study.

(f) Waiohine River

The 'effective' pNRP minimum flow for the Waiohine River[8] equates to about 85 percent of MALF at the flow control site and EFSAP predicts this will almost satisfy the most conservative habitat retention objective. When combining this minimum flow with the pNRP allocation (50 percent of MALF), the reduction in duration of flows below MALF is expected to be kept to less than 10 percent and the reduction in median flow kept to less than 20 percent , although neither of the most conservative objectives tested for these two indicators are met (Figure 4.4).

(g) Tauherenikau River

The 'effective' pNRP minimum flow for the Tauherenikau River[9] equates to about 95 percent of MALF and therefore EFSAP predicts all objectives relating to changes below MALF will automatically be met (or largely so), irrespective of allocation. When combined with a pNRP allocation equating to 50 percent of MALF there is a reduction in summer median flow of greater than 10 percent meaning the most conservative criteria in Figure 4.4 cannot be met. However median flow reduction is less than 20 percent.

(h) Lower Ruamāhanga River

The pNRP minimum flow for the Lower Ruamāhanga River is a relatively low proportion of MALF (68 percent). EFSAP results suggest that the primary consequence of this, as shown in Figure 4.1, is that only the least conservative habitat retention objective (*70* percent *of torrentfish habitat relative to MALF retained in 50* percent *of reaches*) is likely to be satisfied. Achieving habitat objectives of 80 or 90 percent would require an approximately proportionate increase in minimum flow of 10 and 20 percent of MALF, respectively. The most conservative objectives relating to duration of low flows and mid-range flows are also not likely to be met as a consequence of both the minimum flow and pNRP allocation amount (50 percent of MALF), although the alternative objectives with slightly less stringent criteria are largely met.

It is important to note here that the lower reaches of the Ruamāhanga River are somewhat unique from the upper catchment and other large tributaries included in this study. The channel morphology is dominated more by deeper runs and pools than elsewhere and the lumped EFSAP modelling is therefore expected

[8] See footnote to minimum flow table in Appendix 2 for description of 'effective' minimum flow. In the case of the Waiohine, the flow at which irrigation takes are most heavily controlled (suspended or cut back) is 3,040 L/sec (rather than the minimum flow of 2,300 L/sec listed in the pNRP).

[9] See footnote to minimum flow table in Appendix 2 for description of 'effective' minimum flow. In the case of the Tauherenikau, the flow at which irrigation takes are most heavily controlled (suspended or cut back) is 1,300 L/sec (rather than the slightly lower minimum flow of 1,100 L/sec listed in the pNRP).

to overstate flow requirements in this environment. This point is expanded upon in the next section which considers actual hydraulic-habitat survey data.

4.1.3 Comparing EFSAP results for a lumped and disaggregated model

During peer review of this report some concern was raised about the extent to which the lumped-catchment EFSAP model may provide misleading results at a sub-catchment scale. In response to this concern, further analysis was undertaken to compare lumped with disaggregated catchment results. This analysis and findings from it are summarised in Appendix 5.

The main conclusion is that, while further disaggregation in the original model would have been preferable, the lumped catchment approach has characterised most sub-catchments well enough to reasonably inform the indicator summary data (and results are therefore fit for informing committee discussions). Where the lumped model has performed poorly (lower Ruamāhanga in particular), other data and advice has been given greater weight in committee discussions (see following section).

4.1.4 Hydraulic habitat recalculations

The full results of the habitat recalculations undertaken by Hay (2017) are presented in Table 2 of Appendix 6, along with some commentary from the author. A summary of results for torrentfish and adult brown trout are re-presented in Table 4.1 and Table 4.2. Along with the flows required to meet a range of habitat protection levels, the table also shows what proportion of MALF these flows equate to (in square brackets).

Table 4.1: Flows required to retain habitat for torrentfish

Reach	MALF	Flow (m^3/sec) that retains 90% habitat at MALF [%MALF]	Flow (m^3/sec) that retains 80% habitat at MALF [%MALF]	Flow (m^3/sec) that retains 70% habitat at MALF [%MALF]
Kopuaranga (Palmers)	0.32	0.3 [94]	0.29 [91]	0.28 [87]
Waingawa (Aerodrome)	1.82	1.56 [86]	1.33 [73]	1.12 [62]
Upper Ruamāhanga (Wardells)	3.61	3.25 [90]	2.91 [81]	2.56 [71]
Waiohine (Lower)	3.55	2.95 [83]	2.46 [70]	2.05 [58]
Lower Ruamāhanga (Morrisons Bush)	11.94	8.1 [68]	5.31 [44]	3.87 [32]
Lower Ruamāhanga (Pahautea)	12.57	6.58 [52]	4.26 [34]	3.23 [26]

Note – MALF estimates vary slightly in some cases from those in Appendix 2 because they relate to the location of the survey reaches (which is not always aligned with the point at which MALF has been estimated for allocation purposes).

Table 4.2: Flows required to retain habitat for adult brown trout

Reach	MALF	Flow (m^3/sec) that retains 90% habitat at MALF [%MALF]	Flow (m^3/sec)that retains 80% habitat at MALF [%MALF]	Flow (m^3/sec)that retains 70% habitat at MALF [%MALF]
Kopuaranga (Palmers)	0.32	0.26-0.28 [81-88]	0.2-0.23 [63-72]	0.16-0.19 [50-59]
Waingawa (Aerodrome)	1.82	1.43-1.67 [79-92]	1.1-1.50 [60-82]	0.82-1.38 [45-76]
Upper Ruamāhanga (Wardells)	3.61	2.94-3.26 [81-90]	2.36-2.93 [65-81]	1.89-2.6 [52-72]
Waiohine (Lower)	3.55	2.94-3.02 [83-85]	2.41-2.53 [68-71]	1.91-2.05 [54-58]
Lower Ruamāhanga (Morrisons Bush)	11.94	9.07-9.43 [76-79]	7.36-7.38 [61-62]	5.74-6.03 [48-51]
Lower Ruamāhanga (Pahautea)	12.57	6.99-9.64 [56-77]	5-7.43 [42-62]	3.76-5.76 [31-46]

Note – MALF estimates vary slightly in some cases from those in Appendix 2 because they relate to the location of the survey reaches (which is not always aligned with the point at which MALF has been estimated for allocation purposes).

For the top four sites/rows in each table, the results show that while there is some variability between locations, the flow required to meet a 90 percent habitat protection level for torrentfish is broadly equivalent to the same proportion of MALF, ranging between 83 percent (Waiohine) and 94 percent (Kopuaranga). For adult trout, the range of flow (as a proportion of MALF) to meet the 90 percent protection level is slightly lower, between 79 and 92 percent, depending on which habitat suitability curve is considered. Flows are similarly scaled to MALF for the lower protection thresholds of 80 and 70 percent for these four sites. Overall, the results corroborate the impression of flow requirements being generated by EFSAP (and summarised in Figure 4.1), with EFSAP perhaps tending towards a slightly more conservative prediction (i.e. predicting more flow than is necessary to meet objectives).

For the bottom two sites in each table, both of which are for survey reaches in the lower Ruamāhanga River, the results from the habitat re-calculations are quite different to the EFSAP results. The survey results indicate that habitat reductions below MALF do not occur in proportion with flow reductions below MALF to the same extent as other parts of the catchment. For example, flows of between about 50 and 60 percent of MALF will still retain 90 percent of the habitat available at MALF for torrentfish. For adult trout, flows of between about 55 and 80 percent of MALF will meet the 90 percent habitat objective. These flows are substantially lower than the flows predicted by the EFSAP. The likely reasons for this were noted earlier in section 4.1.2(h), i.e. a pool and run dominated channel morphology in the lower Ruamāhanga River that is not well represented in the aggregated approach to EFSAP modelling.

For the lower Ruamāhanga River, the model results from surveyed reaches described in this section are therefore considered to provide a more reliable indication of flow requirements for habitat retention than EFSAP. In practical terms this means that the interpretation of habitat retention objectives in Figure 4.4 for the lower Ruamāhanga River is likely to be overly pessimistic; the pNRP allocation regime is in fact more likely to be retaining between 80 and 90 percent of habitat at MALF for the most flow demanding fish species.

4.2 Out of stream impacts

As mentioned in earlier in section 3.3, no specific out-of-stream objective (i.e. reliability of supply) was expressed by the committee. Rather they were interested to see how alternative allocation regimes might impact on existing reliability.

4.2.1 Existing reliability of supply

Table 4.3 presents the existing reliability of supply for water users whose takes are governed by control points on the rivers included in this study (based on the minimum flows in Appendix 2). Reliability is presented as both an annual average (based on just over 20 years of recent flow data – with the exception of two sites with shorter records) and an irrigation season average. For the latter, the number of days of restriction in each year has simply been divided by 180 to represent reliability within a nominal six month summer irrigation period.

Table 4.3: Existing reliability of supply (based on the period July 1993 to June 2015)

Sub-catchment unit	**Average annual reliability** (% of time)	**Average irrigation season reliability** (% of time)
Kopuaranga River	97	95
Waipoua River[2]	95	89
Waingawa River	92	85
Upper Ruamāhanga River	98	95
Mangatarere Stream[3]	90 [upper] 93 [lower]	79 [upper] 87 [lower]
Waiohine River	99	97
Tauherenikau River	96	93
Lower Ruamāhanga River	97	94

[2] Data only available from 2007 to 2015

[3] Data only available from 1999 to 2015

Average annual reliability ranges between 90 percent for the Upper Mangatarere catchment and 99 percent for the Waiohine catchment. Average irrigation season reliability ranges between 79 percent (Upper Mangatarere) and 97 percent (Waiohine). The general pattern is one of higher reliability with sustained base flows in the larger Tararua-fed rivers, and lower reliability in the smaller rivers that have less catchment storage and more rapid base flow recessions.

The reliability numbers in Table 4.3 are based on climate/flow only, i.e. when river flow at the control site falls below the flow at which consented takes are required to cease, reliability is considered to be zero. Absent from this approach is consideration of demand. For example, if soil moisture remains elevated during a period of low flows (when theoretical reliability is zero) then reliability, in practice, is not compromised. Furthermore, while the flow thresholds used in the analysis generally require cease take, public water supply or water race abstractions and some groundwater takes are not required to cease and there is also some variability between individual consents with respect to how conditions of cease take are implemented. For the reasons just described, the numbers in Table 4.3 probably slightly understate the actual annual and seasonally-averaged reliability. An important counter-point however is that reliability in dry years and peak summer months (e.g. Jan, Feb, Mar) will be substantially lower than the annual and seasonal averages; this is discussed further in section 4.2.3.

Existing reliability can be regarded as a good surrogate for reliability under allocation regime of the pNRP. All minimum flows for the rivers in this study remain unchanged in the pNRP while allocation changes that could potentially occur under the pNRP would not be expected to significantly impact reliability of downstream users[10].

4.2.2 Flows for cultural values

In 2011, Caleb Royal from Ohau Plants Ltd was commissioned by GWRC to prepare a report on flows to support cultural values in the Wairarapa Valley. The report produced by Royal (2011) looked at 13 sub-catchments of the Ruamāhanga River, including six of the eight rivers that are the subject of this report. For each sub-catchment, Royal (2011) identified mana whenua values of significance and made recommendations about minimum flows that were required to support these values. Table 4.4 summarises the Royal (2011) minimum flow recommendations for the rivers in this study and compares these values with the existing (and pNRP) minimum flows.

[10] The only reasonably significant allocation that could be taken up under the pNRP is in the Waiohine and Upper/Middle Ruamāhanga catchments. This would potentially reduce the reliability for water users in the lower Ruamāhanga River (governed by the Waihenga flow control site). However, for the extra allocation to be taken up in the Waiohine and Upper Ruamāhanga catchments, a roughly equivalent amount would need to be relinquished from elsewhere in the broader Ruamāhanga catchment, such that reliability for users controlled by Waihenga would remain largely unchanged.

Table 4.4: Minimum flows recommended by Royal (2011) to support cultural values

Sub-catchment unit	**Existing (and pNRP) minimum flow** (m^3/sec)	**Minimum flow recommended by Royal (2011)** (m^3/sec) [% of MALF]	**Percentage increase in minimum flow**
Kopuaranga River	0.27	0.50 [160%]	85
Waipoua River	0.25	0.50 [135%]	100
Waingawa River	1.70	2.50 [175%]	47
Upper Ruamāhanga River	2.40	10.00 [275%]	320
Waiohine River	3.05	3.75 [105%]	23
Tauherenikau River	1.3	1.35 [100%]	4

Most of the recommended increases are substantial (>20 percent). The magnitude of the consequential change in reliability has been calculated by assessing the change in the average number of days of cease take during an irrigation season for each sub-catchment. The results of this assessment are presented in Table 4.5. Percentage reductions are substantial in four of the six sub-catchments (>15 percent) and more modest in the Waiohine (5 percent) and Tauherenikau (1 percent) catchments. In dry years in the four most affected catchments, the number of days of cease take in summer would outweigh the number in which water is available, by a large margin the case of the Upper Ruamāhanga and Kopuaranga). There would essentially be no water available for extended periods during the peak months of summer.

Table 4.5: Consequences of minimum flows recommended by Royal (2011) for existing reliability of supply (based on average days of cease take over the period 1993 to 2015)

Sub-catchment unit	**Average summer (Oct-Apr) reliability under existing minimum flows** (% of time some water available)	**Average summer (Oct-Apr) reliability under recommended minimum flows** (% of time some water available)	**Percentage reduction in average summer reliability**	**Number of days of cease take in a dry year, 2013** Existing [New]
Kopuaranga River	95	67	-30	34 [130]
Waipoua River	90	75	-17	47 [93]
Waingawa River	85	70	-17	64 [94]
Upper Ruamāhanga River	95	42	-56	38 [148]
Waiohine River	97	92	-5	22 [34]
Tauherenikau River	93	92	-1	28 [32]

4.2.3 Higher minimum flows on the Waipoua and Upper Ruamāhanga rivers

During the course of the committee workshops on allocation it became apparent that higher minimum flows were being favoured for the Upper Ruamāhanga and Waipoua sub-catchments for a number of reasons[11]. The committee were therefore interested to know what the consequences of a potential increase in minimum flow for reliability of supply for existing users would be. This was assessed in much the same way as for the cultural flow preferences described in the previous section and results are summarised here.

Table 4.6 summarises the change in minimum flow that has been signalled and the number of potentially affected consent holders. Table 4.7 shows the reduction in reliability of supply that is likely to result (assuming no change to any other aspect of supply and in the absence of any other management interventions).

Table 4.6: Potential changes in minimum flow and number of consents/total consented take in each sub-catchment

Sub-catchment unit	Existing (and pNRP) minimum flow (m^3/sec)	Minimum flow preference signalled by committee (m^3/sec)	Number of consent holders with minimum flow restrictions	Total allocation held by all consent holders (m^3/sec)
Waipoua River	0.25	0.335	6 direct surface water 3 Category A groundwater	0.125
Upper Ruamāhanga River	2.400	3.250	11 direct surface water 61 Category A groundwater	1.780

Table 4.7: Reduction in reliability of supply under higher minimum flows for the Upper Ruamāhanga and Waipoua sub-catchments

Sub-catchment unit	Average summer (Oct-Apr) reliability under existing minimum flows (% of time some water available)	Average summer (Oct-Apr) reliability under recommended minimum flows (% of time some water available)	Percentage reduction in average summer reliability	Percentage reduction in a 'dry year' (defined as the 80th percentile result)
Waipoua River	90	84	7	12
Upper Ruamāhanga River	95	85	10	18

[11] The full reasoning is not described here but incorporated perspectives and experiences from community engagement as well as some of the predicted outcomes presented in this report

On average, it could be expected that summer reliability will reduce by about seven per cent for existing consent holders in the Waipoua sub-catchment and about 10 per cent for users in the Upper Ruamāhanga sub-catchment. Existing average reliability is higher in the Upper Ruamāhanga than the Waipoua such that the potential reductions would result in both catchments ending up with a summer reliability of about 85%.

Committee members most familiar with irrigation dynamics emphasised that, while the average changes are useful to an extent for long term business planning, it is the change in reliability in dry years and peak summer months that is of most direct consequence to the shorter term farm operations. The following paragraphs are focused on this question.

The final column in Table 4.7 shows that reliability reductions in a relatively dry year are expected to be 12 percent for the Waipoua sub-catchment and 18 per cent in the Upper Ruamāhanga. A dry year was defined to be the 80th percentile in the annual flow record available for each site.

With respect to seasonal changes, Figure 4.5 for the Upper Ruamāhanga shows that the proportional reductions in reliability are much higher in peak summer months when demand is highest (February to March) than shoulder months when demand is lower. The impact in March is most severe with an expected average reduction in reliability of 20 percent (from 85 percent to 65 percent).

The seasonal picture is more severe again when considering a particularly dry year. Figure 4.6 shows that reliability would have been between about 20 percent (February and April) and 45 percent (January and March) lower in the summer months of 2014/15 with the increased minimum flow.

Further data on predictions of supply reliability changes in the Upper Ruamāhanga and Waipoua sub-catchments are presented in Appendix 6. Included is an assessment of incremental change in reliability if the suggested minimum flows were implemented in stages over time.

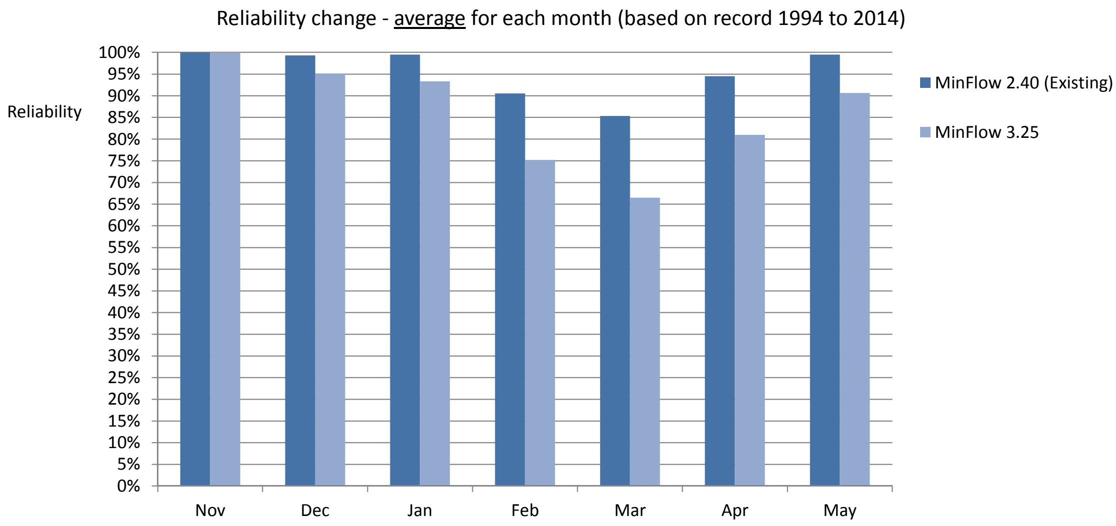

Figure 4.5: Expected change in average monthly reliability over summer with increased minimum flow in the Upper Ruamāhanga sub-catchment

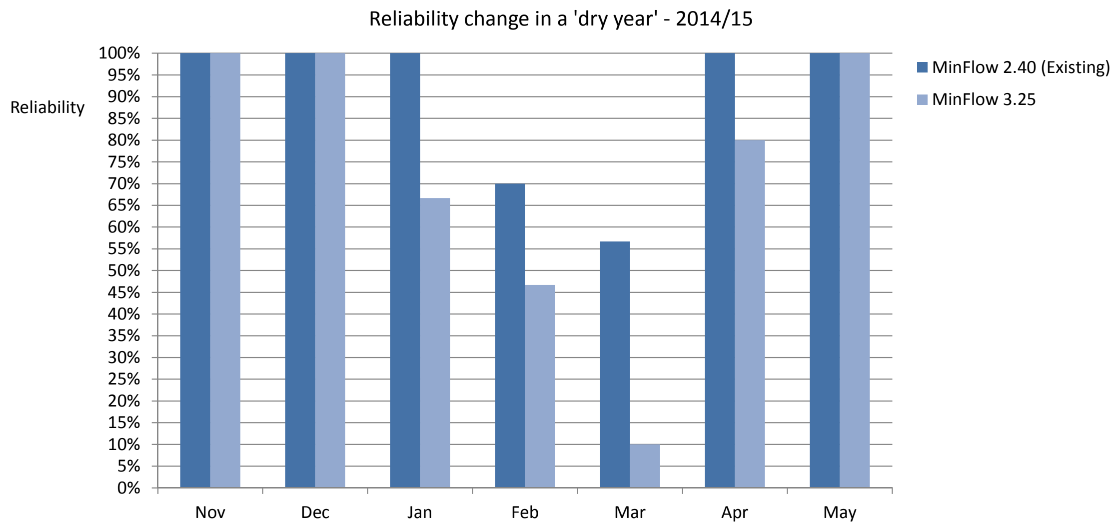

Figure 4.6: Expected change in monthly reliability during a very dry summer (2014/15) with increased minimum flow in the Upper Ruamāhanga sub-catchment

5. Summary

This report has presented the results of a number of discrete, but related, pieces of analysis undertaken to support decision-making by the Ruamāhanga Whaitua Committee about water allocation (quantity). Some of the key results and findings are summarised here. It is not the purpose of this work to recommend any changes to allocation regimes, this being the role of the committee based on discussions that include a broader range of values and variables.

5.1 Instream considerations

Assessing the consequences of different minimum flows and allocation limits relied primarily on the EFSAP modelling tool as well as catchment specific hydraulic-habitat survey data.

The advantage of using EFSAP is that it can be run quickly and generates outputs in a format (e.g. decision space diagrams) that provides a transparent link between objectives and allocation management regimes that are likely to support those objectives. However, there are also important limitations to EFSAP that mean that the model is best used, as it has been in this work, to make comparisons at a broad scale (catchment to regional) and as an indicative 'screening' tool.

One notable limitation (among others described in Section 3.6) is that modelling is based on a necessarily simplified representation of how water is actually taken and controlled (e.g. an assumption of full conformity of takes with model rules). In reality, there is substantial variation within and between sub-catchments in how takes are restricted. Of particular relevance are public water supply takes and groundwater takes with direct hydraulic connection to surface water (Category A), both of which currently persist to some degree below minimum flows. Because of the model simplifications, it is important that, beyond the broad conclsuions in this report, care is taken to also examine some of the more subtle aspects of catchment-specific allocation regimes (and how any changes to these regimes might impact on instream values and users).

Notwithstanding the limitations just described, modelling of physical habitat and hydrological changes has indicated that:

- Minimum flows[12] and allocation levels in the pNRP are likely to meet, or nearly meet, relatively conservative habitat objectives in five of the eight sub-catchments studied (the Kopuaranga, Waingawa, Waiohine, Mangatarere and Tauherenikau rivers). Increases to the minimum flows or decreases to the allocation limits in these sub-catchments would not be expected to accrue significant habitat benefits for the species of particular interest.

- Two sub-catchments (Upper Ruamāhanga and Waipoua rivers) stand out as having minimum flows that offer a level of habitat protection that is at the lower end of a range that is considered appropriate based on the

[12] Including the concept of 'effective' minimum flows described in Section 4.1.2 and Appendix 2.

committee's fish values and objectives. Increases in minimum flows in the order of 20 percent of MALF would be required in each of these sub-catchments to bring the level of protection up to meet the most conservative objectives (ie, to retain 90 percent of habitat available at MALF).

- One further sub-catchment (Lower Ruamāhanga River) also stood out in the original EFSAP modelling as having an allocation regime (minimum flows in particular) that offer a relatively low level of habitat protection. However, distinct morphological differences between the lower reaches of the Ruamāhanga River and other sub-catchments (not well captured by the modelling – as highlighted in Appendix 5) mean that this interpretation is likely to be overly pessimistic. Actual hydraulic-habitat survey data suggest that the pNRP allocation regime is in fact more likely to be retaining between 80 percent and 90 percent of habitat at MALF for the most flow demanding fish species.
- With respect to other indicators of hydrological alteration (change in duration of low flows and reduction in summer median flows), which are mainly influenced by allocation amounts, stand-out results are less apparent. The most notable result was for the Mangatarere Stream, where allocation as a proportion of low flows is particularly high and one consequence of this is that summer mid-range flows are heavily reduced. The extent to which this compromises instream values is not known (although there has been some acknowledgement of the impacts of high allocation in this catchment when setting relatively conservative minimum flows).

With respect to justification for increasing minimum flows, the actual benefits to fish populations (abundance and health) of making such changes would be very difficult to quantify with high certainty. It would require a highly targeted and intensive long term monitoring programme, the likes of which is very rarely achieved (due to the difficulties of isolating cause and effect in such complex environments and the associated costs of attempting to do so). What can be said is that, if the assumption of habitat being a limiting population factor holds true, then the likelihood of noticeable instream benefits increases with more conservative minimum flows.

Nevertheless, there are improvements to long term monitoring programmes (that can be achieved at much more modest costs) that would at least help inform future considerations about whether some of the anticipated benefits of changing minimum flows have eventuated. Of particular value would be higher intensity native fish sampling and increased frequency of low flow/habitat surveys at finer scale than has occurred in the past.

5.2 Reliability of supply

In this report modelling of the consequences of changes in minimum flow has relied on spreadsheet analysis of historical flow data. An important limitation to note is that the analysis has does not taken into account demand (based on factors such as antecedent soil moisture conditions) and could therefore be exaggerating both existing and future reliability shortfalls (in terms of absolute numbers of days per season under restriction). On the other hand, the assessment also does not account for a probable drying climate which would most likely result in an understatement of the predicted shortfalls.

Notwithstanding these limitations, modelling of the consequences of changes in minimum flow for reliability of supply has indicated the following:

- Reductions in average summer reliability under higher minimum flows recommended for sustaining cultural values are substantial in four sub-catchments (>15 percent) and more modest in the Waiohine (5 percent) and Tauherenikau (1 percent) catchments. In dry years in the four most affected catchments, the number of days of cease take in summer would outweigh the number in which water is available, by a large margin in the case of the Upper Ruamāhanga and Kopuaranga. There would essentially be no water available for extended periods during the peak months of summer.

- Under higher minimum flows being considered by the committee for the Waipoua (0.335 m^3/sec) and Upper Ruamāhanga (3.250 m^3/sec), average summer reliability will reduce by about seven per cent and ten per cent, respectively, for existing consent holders. Existing average reliability is higher in the Upper Ruamāhanga than the Waipoua such that the future reductions would result in both catchments ending up with a summer reliability of about 85 percent. Percentage reductions in summer reliability in a dry year in both sub-catchments would be more severe again (12 and 18 percent, respectively).

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Appendix 1: Fish distribution in the Ruamāhanga catchment

Gray shading = habitat suitability curves for modelling available

Species	**Where have they been found?** * indicates those rivers listed in pNRP with indigenous fish values							**Flow demands**	**Choice of species to model as representative of different flow demands**
	Main stem*	Kopuaranga	Waipoua*	Waingawa	Waiohine*	Mangatarere*	Tauherenikau		
Exotic									
Brown trout – adult	✓	✓	✓	✓	✓	✓	✓	High	Yes
Rainbow trout – adult					✓	✓		High	
Trout spawning	✓ (top)	✓	✓	✓ (top)	✓ (top)	✓		High	Yes
Native									
Torrentfish	✓	✓	✓	✓	✓	✓	✓	High	Yes
Longfin eel (>300 mm)	✓	✓	✓	✓	✓	✓	✓	Moderate	Yes
Shortfin eel (>300 mm)	✓	✓	✓	✓	✓	✓	✓	Moderate	Yes
Redfin bully	✓		✓	✓	✓	✓	✓	Low	
Common bully	✓	✓	✓	✓	✓	✓	✓	Low	Yes
Upland bully	✓		✓	✓	✓	✓		Low	
Crans bully	✓		✓		✓	✓		Low	
Bluegill bully	✓							Low	
Dwarf galaxias			✓		✓	✓	✓	Moderate	
Smelt	✓	✓	✓	✓	✓	✓	✓	Moderate	
Lamprey	✓	✓	✓		✓	✓	✓	Low	Yes
Koaro	✓	✓						Low	
Brown mudfish	✓		✓		✓	✓		Low	
Giant Kokopu	✓		✓		✓	✓		Moderate?	
Banded kokopu	✓							Low	
Black flounder								Low	
Inanga		✓	✓	✓	✓	✓	✓	??	Yes – Food Producing Habitat

Appendix 2: PNRP minimum flows and allocation amounts

Table A2.1: Minimum flows in the pNRP

River [flow management site]	Minimum flow (L/s)	Flow at which non-public suppy/water race takes cease (L/s)[1]	7D natural MALF (L/s)[2]	Minimum flow as proportion of 7D natural MALF[3]
Kopuaranga River [Palmers]	270		310	87%
Waipoua River [Mikimiki Bridge]	250		375	67%
Waingawa River [Kaituna]	1,100	1,700	1,420	120%
Upper Ruamāhanga River [Wardells]	2,400		3,605*	68%
Mangatarere Stream [Gorge]	240 (Upper) 200 (Lower)		165	120%
Waiohine River [Gorge]	2,300	3,040	3570	85%
Tauherenikau River [Gorge]	1,100	1,300	1,350	95%
Lower Ruamāhanga River [Waihenga]	8,500		12,565*	68%

[1] Flows in this column are the 'effective minimum flows' since they apply to all takes except the non-public water supply and water race takes and are therefore deemed to be the most appropriate in this study to test management objectives against

[2] Measured natural 7D MALF at the relevant flow monitoring/management control station. Those values with an asterisk on the main stem Ruamāhanga river are estimates based on calculations described in Thompson (2014).

[3] Percentages in this column are derived from whichever of the 'minimum flow' or 'flow at which non-essential takes cease' columns has been grey shaded.

Table A2.2: Allocation limits

Sub-catchment unit	Existing allocation (L/s)	Maximum allocation permitted under the pNRP (L/s)[1]	7D natural MALF (L/s)[2]	Max permitted allocation as proportion of 7D natural MALF[3]
Kopuaranga River	150	180	605	30%
Waipoua River	130	145	490	30%
Waingawa River	1,200	1,200	1,835	65%
Upper Ruamāhanga River[4]	1,925	2,440	2,400	50%
Mangatarere Stream	475	475	330	145%
Waiohine River	1,005	1,590	3,180	50%
Tauherenikau River	235	410	820	50%
Lower Ruamāhanga River [Waihenga]	8,045	8,045	15,070	54%

[1] As described in Appendix 1 of Thompson and Mzila (2015). Where the number in this column is higher than that in the 'Existing allocation' column to the left, there is technically further surface water available for allocation under the pNRP (although it could only be allocated if the whole of catchment limit was sufficiently reduced below existing levels).

[2] 7D MALF values are estimates for the downstream-most point of the discrete management unit (as described in Thompson & Mzila 2015).

[3] Percentages in this column are based on the grey shaded column.

[4] The Upper and Middle Ruamāhanga River management units in the pNRP have been combined for this study into a single unit because they are both controlled by a common minimum flow (Wardells) and also have very similar existing allocation levels and pNRP limits. Therefore, the Upper Ruamāhanga River unit in this study extends from the headwaters to the confluence with the Waiohine River.

Appendix 3: Hydrological statistics comparison

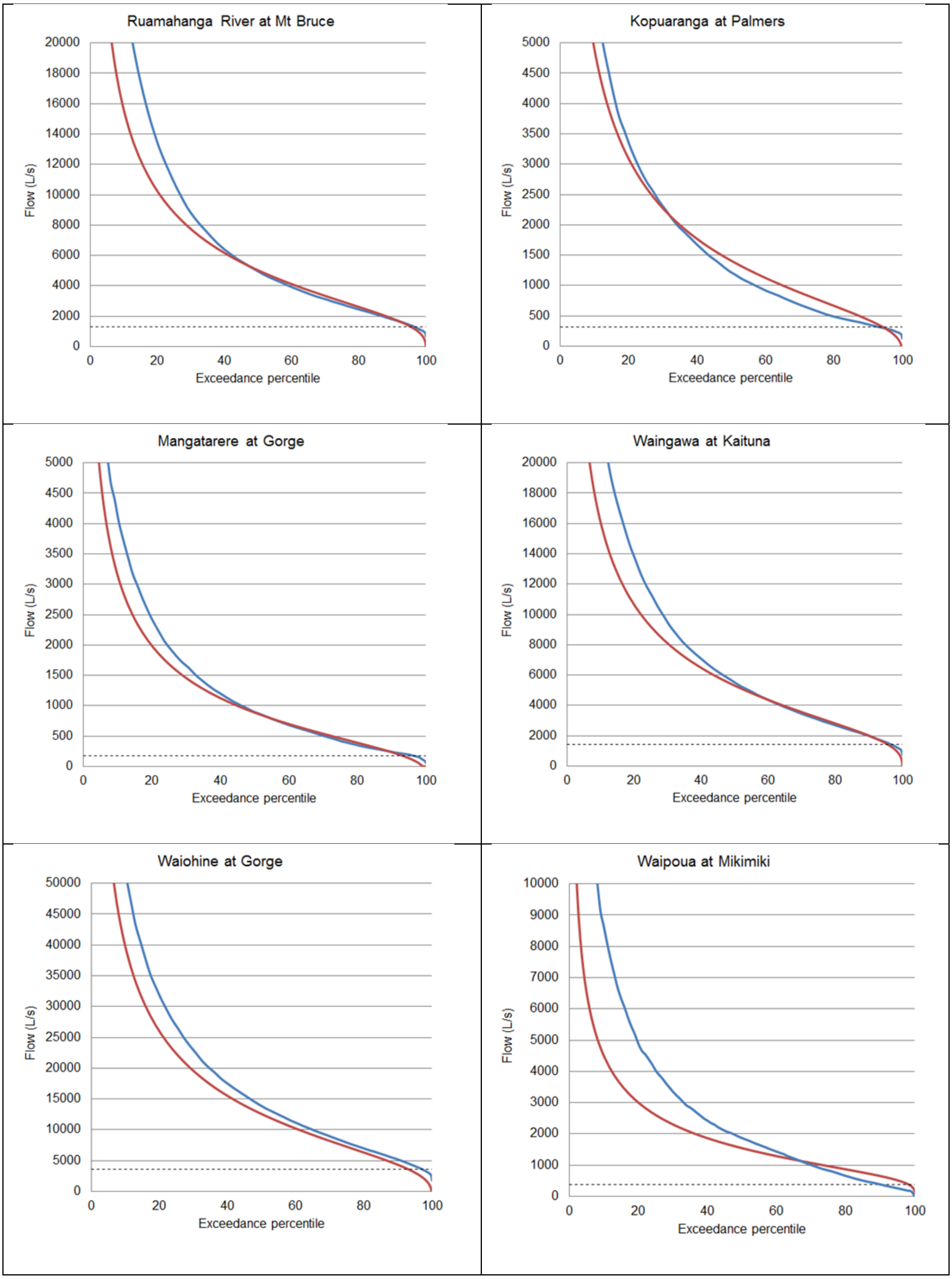


Figure A3.1: Comparison of predicted (red) and observed (blue) flow duration curves for six natural flow gauging stations (observed MALF is shown as the dashed horizontal line)

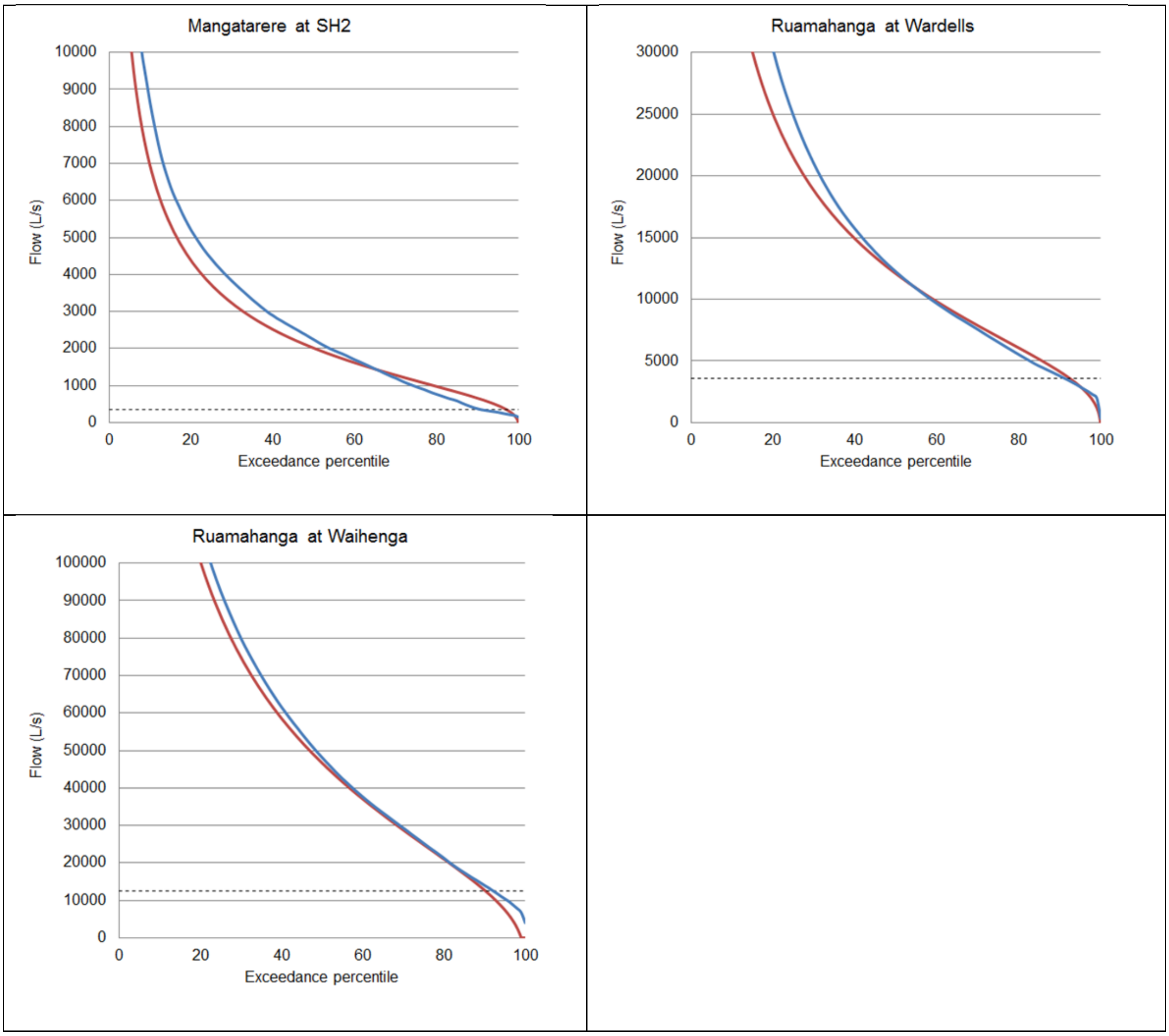
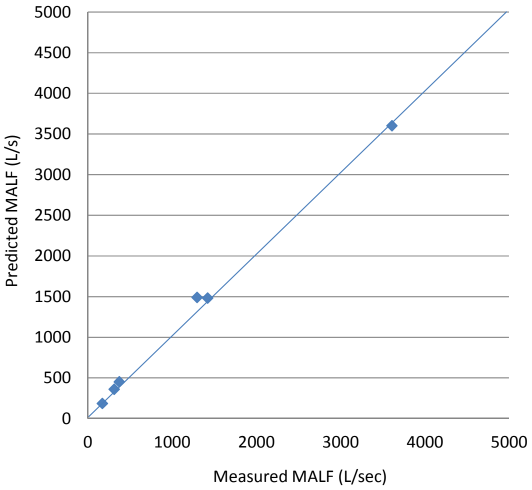


Figure A3.2: Comparison of predicted (red) and observed (blue) flow duration curves for gauging stations in lower parts of the Ruamāhanga catchment (estimated natural MALF is shown as the dashed horizontal line)



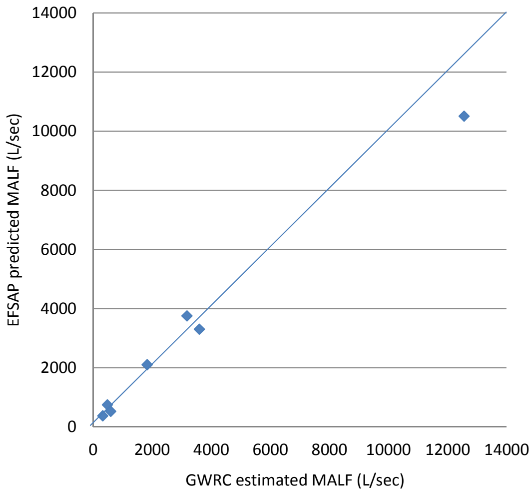


Figure A3.3: Left plot: comparison of predicted and observed MALF for natural flow gauging stations (diagonal line indicates an exact match between observed and predicted). Right plot: comparison of natural MALF predictions (EFSAP and GWRC) for ungauged locations at the bottom of sub-catchments (diagonal line indicates an exact match between predictions)

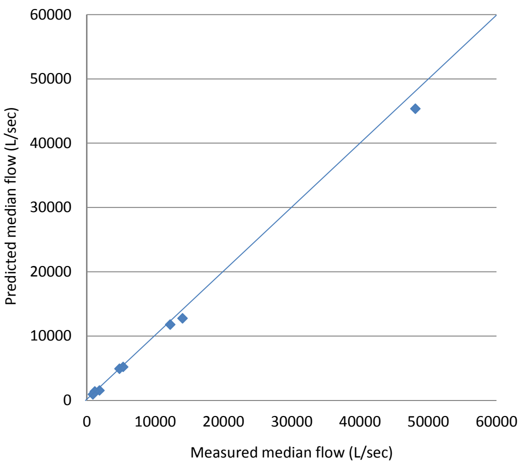


Figure A3.4: Comparison of predicted and observed median for eight flow gauging stations (diagonal line indicates an exact match between observed and predicted)

Appendix 4. EFSAP decision space outputs

Figure A4.1: Habitat retention for Longfin eel (tuna)

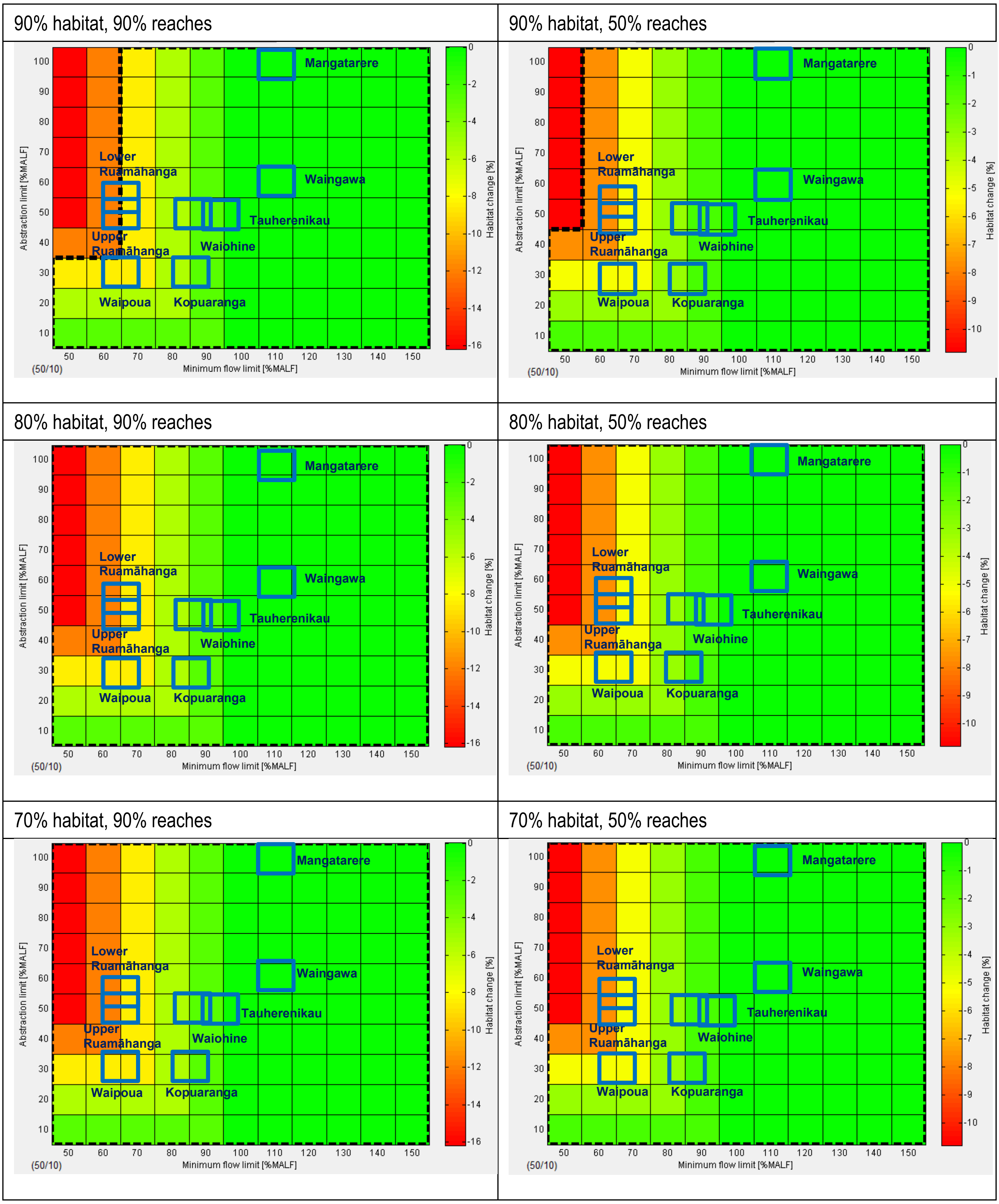
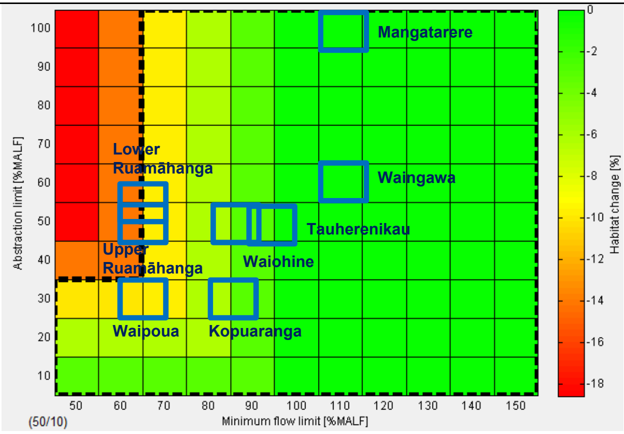
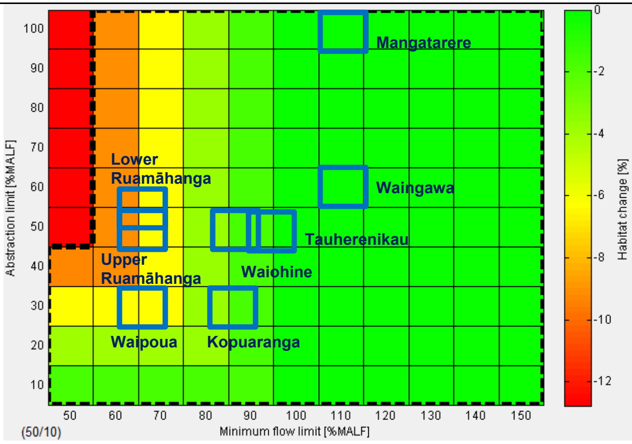


Figure A4.2: Habitat retention for Shortfin eel (tuna)

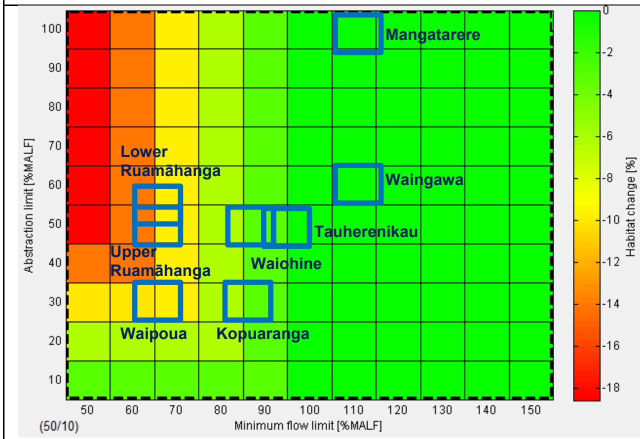
90% habitat, 90% reaches



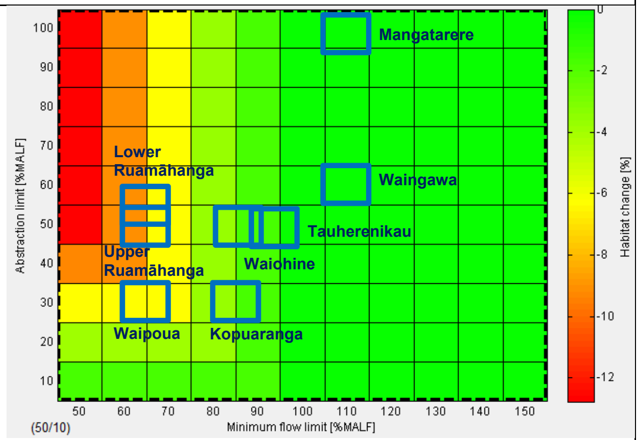
90% habitat, 50% reaches



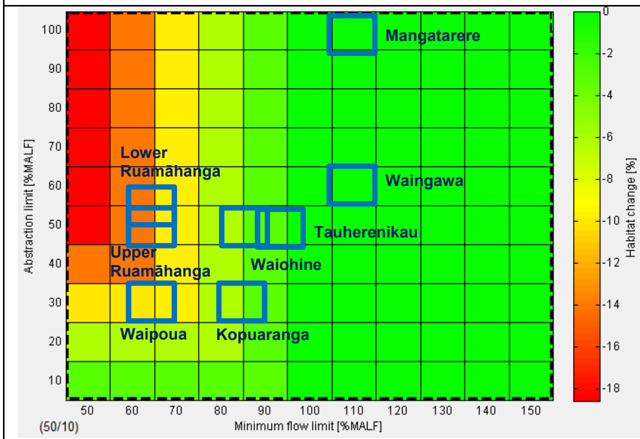
80% habitat, 90% reaches



80% habitat, 50% reaches



70% habitat, 90% reaches



70% habitat, 50% reaches

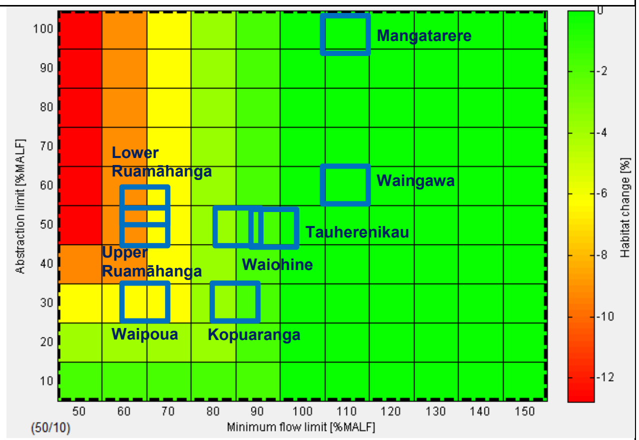


Figure A4.3: Habitat retention for Inanga

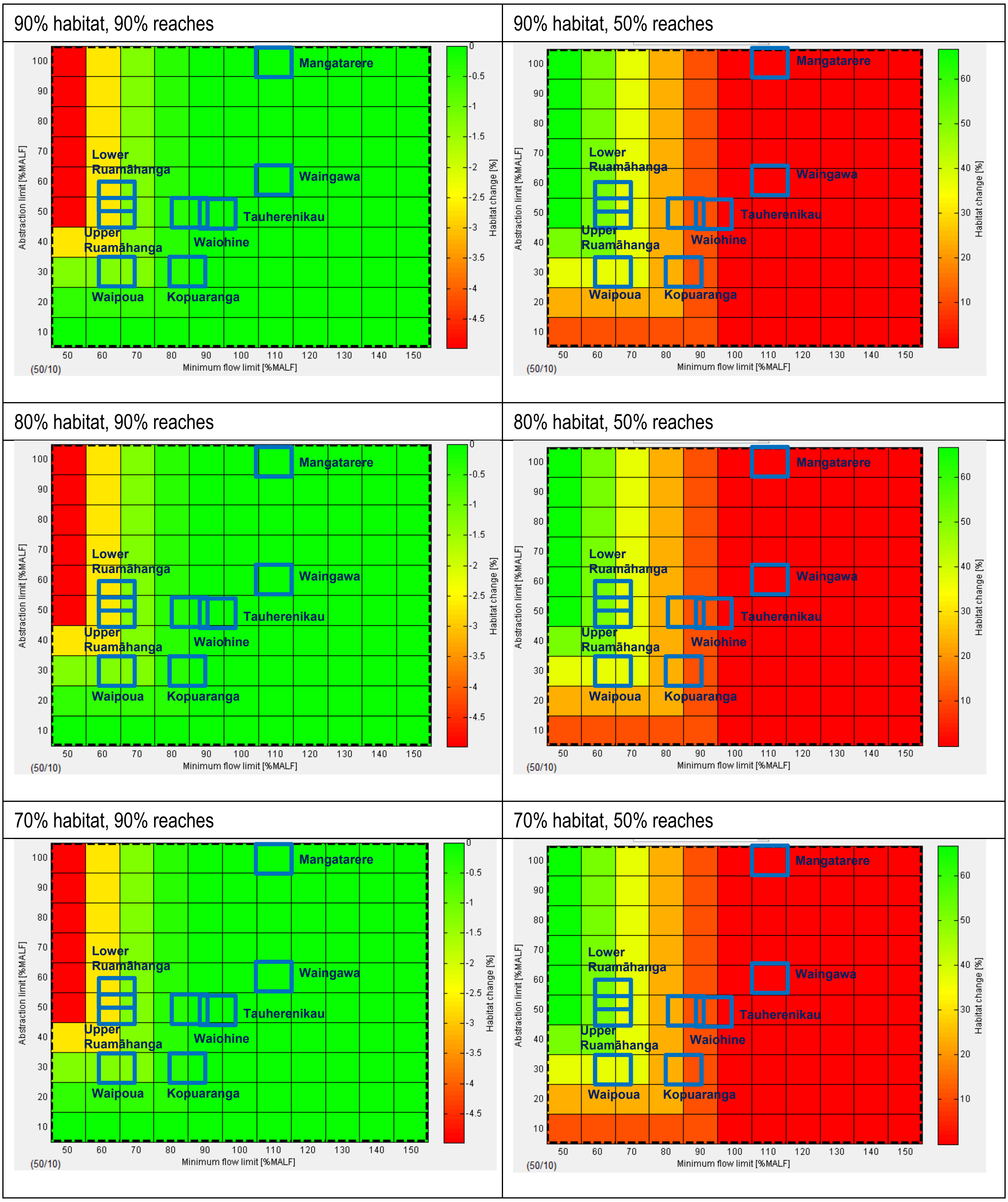


Figure A4.4: Habitat retention – Food producing habitat

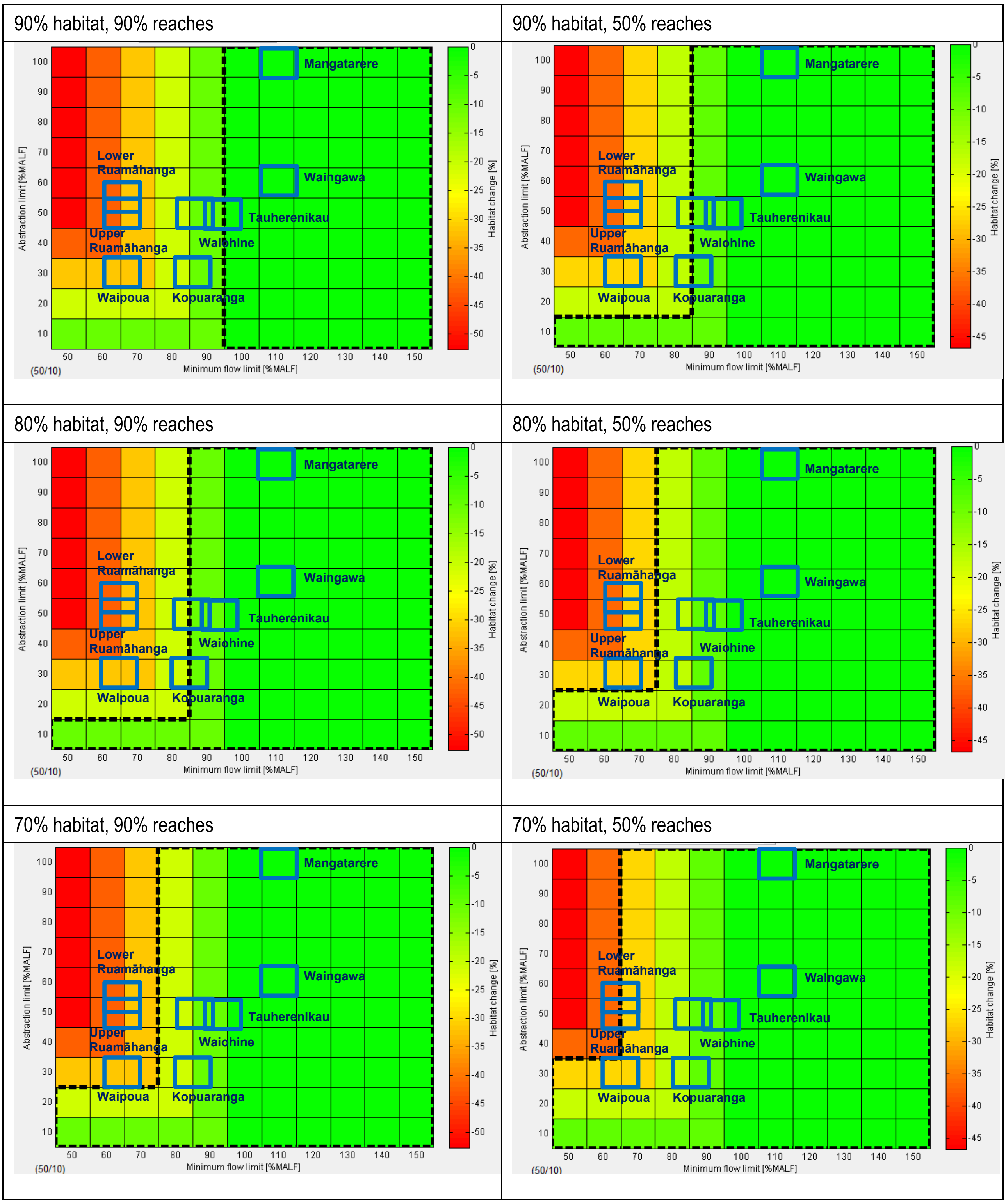
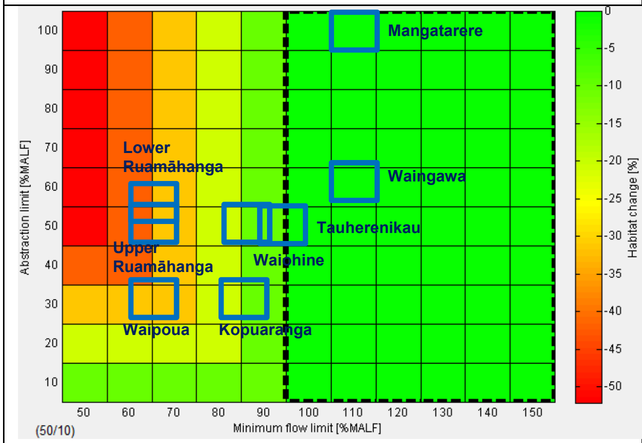
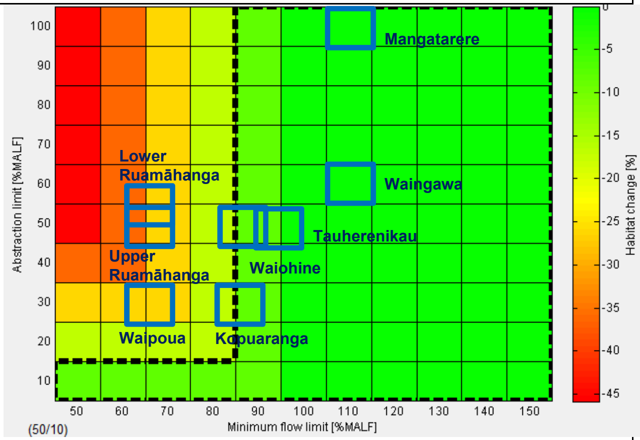


Figure A4.5: Habitat retention for brown trout (adult)

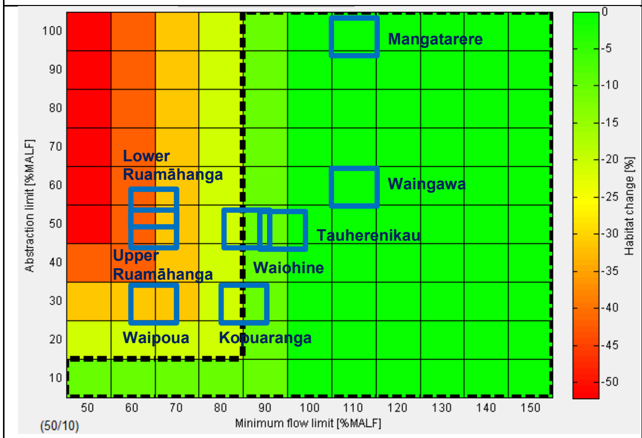
90% habitat, 90% reaches



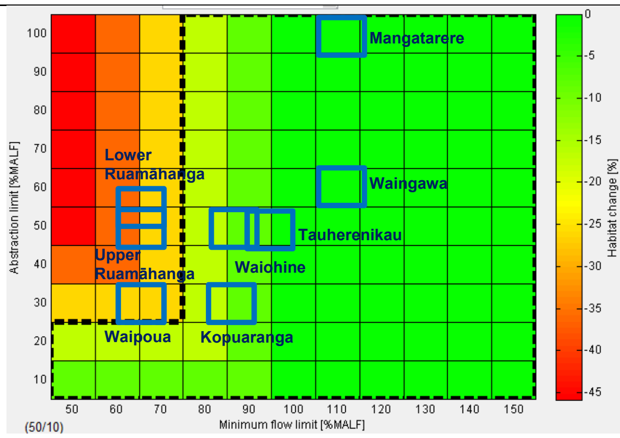
90% habitat, 50% reaches



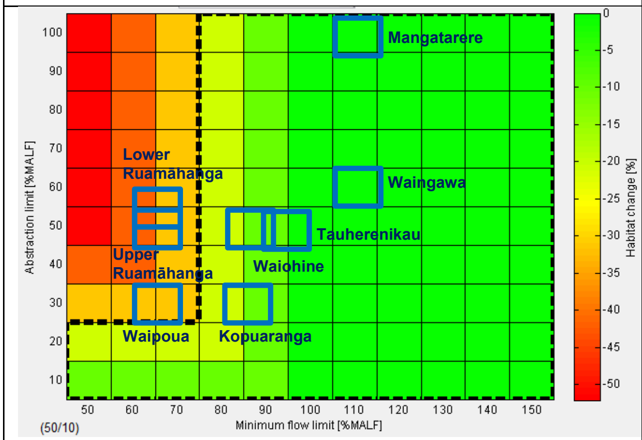
80% habitat, 90% reaches



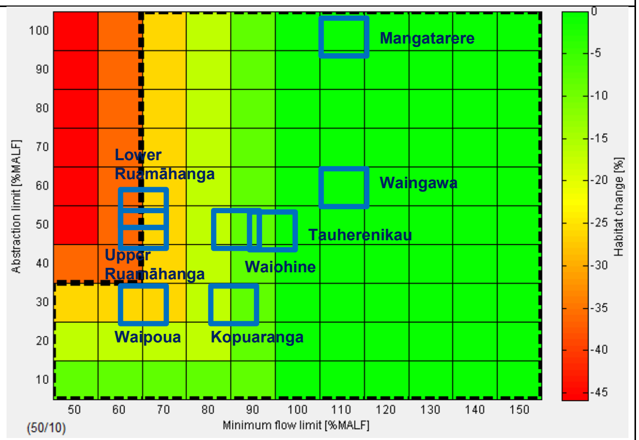
80% habitat, 50% reaches



70% habitat, 90% reaches



70% habitat, 50% reaches



Appendix 5: Responding to peer review comments: Comparing disaggregated sub-catchment with lumped catchment results

The most substantive peer review comment from Caroline Fraser (LWP, 2017) related to the possible risks of lumping catchment hydrological characteristics in EFSAP when interpreting results at a sub-catchment scale. It was suggested that a comparison of EFSAP results for lumped versus disaggregated catchments be undertaken to determine whether any differences were sufficiently important to warrant revising the original approach.

This appendix compares EFSAP decision space outcomes for the lumped catchment model with those where sub-catchment reaches have been disaggregated. Comment is made about whether the differences would result in changes to the summary indicator information provided to the committee during their workshops (Figure 4.4 in the main body of this report).

Results for the Kopuaranga and Lower Ruamāhanga River sub-catchments are presented here as these sub-catchments are the most distinct from others within the lumped model (and therefore would be expected to show the greatest differences in predicted outcomes once disaggregated).

For the Kopuaranga River, comparisons of outcomes for habitat change under lumped and disaggregated models for both the torrentfish and long fin eel are presented while just the torrentfish is assessed for the Lower Ruamāhanga. Comparisons of changes in outcomes relating to the duration of low flows under each type of model are also presented for both sub-catchments. For each indicator comparisons are presented for the 90^{th} percentile (i.e. predicted outcome for 90% of reaches) and median (50% of reaches).

Results of comparison

Kopuaranga River

Figure A.5.1 shows that the combinations of minimum flow and allocation that support the most conservative committee objectives for habitat (applying to 90 percent of reaches) are the same for both the lumped and disaggregated models. When a less conservative objective is considered (i.e. applying to 50 percent of reaches rather than 90 percent), the decision spaces for the lumped and disaggregated models are also the same for the higher levels of habitat protection (90 and 80 percent) but slightly different for the lowest level of habitat protection of 70 percent (Figure A5.2). For a habitat protection level of 70 in 50 percent of reaches, a slightly more stringent allocation regime is specified for the Kopuaranga by the disaggregated model.

The comparisons for long fin eel habitat are similar to those for torrentfish for the ‘90 percent of reaches’ scenario, i.e. no difference between the lumped and disaggregated model results (Figure A5.3). However, when looking at the ‘50 percent of reaches’ scenario (Figure A.5.4) the results are notably different. In this case the disaggregated model suggests that a more relaxed allocation regime (i.e. lower minimum flows and/or higher allocation) could meet committee objectives than the lumped model, although the difference is minor for the highest protection level.

With respect to duration of low flows, the comparison of models again shows some differences (Figures A.5.5 and A.5.6) In general, the disaggregated model suggests higher allocation from the Kopuaranga River could be achieved than is suggested by the lumped model (for the same objectives). However, existing allocation sits well within the decision spaces for both models across the range of objectives tested, the only exception being the most conservative one (no more than 5 percent change in the indicator in 90 percent of reaches). For this objective the lumped model suggests that the objective is almost met while the disaggregated model suggests it is comfortably met.

Lower Ruamāhanga River

Figure A.5.7 shows that the lumped and disaggregated model decision spaces are the same for the most conservative committee objective for torrentfish habitat (applying to 90 percent of reaches). However, when a less conservative objective is considered (i.e. applying to 50 percent of reaches rather than 90 percent), the decision spaces for the lumped and disaggregated models are markedly different (Figure A.5.8). The disaggregated model suggests that significantly lower minimum flows and higher allocation rates could be allowed (whilst still achieving objectives) than is indicated by the lumped model.

Furthermore, closer inspection of the data suggests that the large difference between lumped and disaggregated model results occurs when objectives applying to only slighter less than 90 percent of reaches are considered. This appears to be related to a small handful of main stem reaches that have quite different hydrological predictions to the rest of the disaggregated model sample. It would seem reasonable therefore to consider the ‘90 percent of reaches’ results described in the previous paragraph somewhat of an anomaly that probably gives the impression of more similarity (between the lumped and disaggregated models for the main stem lower Ruamāhanga River) than is actually the case.

With respect to duration of low flows, the comparison of lumped and disaggregated models again shows some marked differences (Figures A.5.9 and A.5.10) that reinforce the notion that the lower Ruamāhanga River responds quite uniquely to allocation rules. The disaggregated model suggests higher allocation from the lower Ruamāhanga River could be achieved than is suggested by the lumped model (for the same objectives).

Discussion

The results just described show that lumped and disaggregated EFSAP models do indeed generate different decision spaces for the same objectives in some circumstances.

In the context of this study, particularly relating to the application of EFSAP as an indicative screening tool, the differences observed for the Kopuaranga River are considered relatively minor. In the opinion of this author it is unlikely that the committee would have reached a substantially different position on minimum flows and allocation if they had been presented with disaggregated model results. For example, the only change to Table 4.1 for the Kopuaranga River would have related to the existing allocation being considered to ‘meet’ a conservative objective for the low flow duration indicator as opposed to ‘almost meeting’ it. It is considered unlikely the committee would have opted to increase available allocation (rather than capping it as was the draft position they had reached by March 2018) on the basis of this distinction.

While not presented here, similar comparisons between the lumped and disaggregated model results for habitat and low flow duration were made for the Mangatarere, Waipoua and upper Ruamāhanga River main stem sub-catchments. The differences can be characterised as similar to, or of a lower magnitude, than those observed for the Kopuaranga. Conclusions regarding likely consequences for committee decision making to date are therefore similar to those described above.

The main stem of the lower Ruamāhanga River is clearly mis-represented by the original EFSAP results. In particular, the extent to which habitat objectives for torrentfish are likely to be met by existing allocation and minimum flows is understated by the indicator summaries in Table 4.1. However, this weakness of the lumped model for the lower Ruamāhanga River was anticipated to an extent and expressed to the committee as they deliberated results; they were advised to place less faith in the modelling than for other parts of the catchment and the draft position on allocation and minimum flows that they came to reflected, in part, this advice.

Conclusion

The analysis prompted by the peer review has been helpful to understand how taking a different modelling approach might have influenced results.

In retrospect, it would have been preferable to disaggregate to sub-catchment level in the original modelling (at least separating the lower Ruamāhanga River, and probably the Kopuaranga River). Nevertheless, it is considered that the lumped catchment approach has characterised most sub-catchments well enough to reasonably inform the indicator summary data and be used as the basis for informing committee discussions. Where the lumped model has performed poorly (lower Ruamāhanga in particular), other data and advice has been given greater weight in committee discussions.

Figure A5.1: Kopuaranga River habitat retention for Torrentfish (90 percent of reaches)

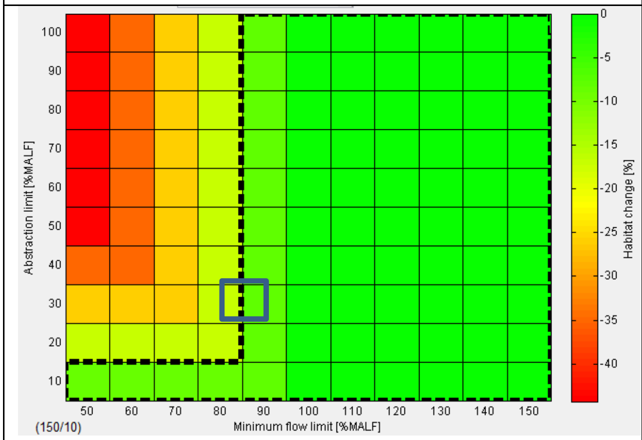
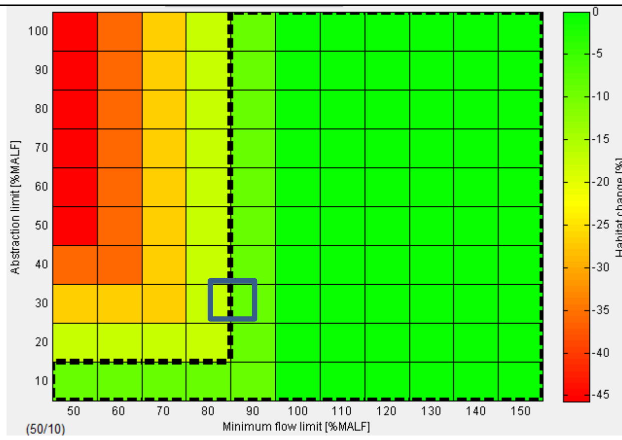
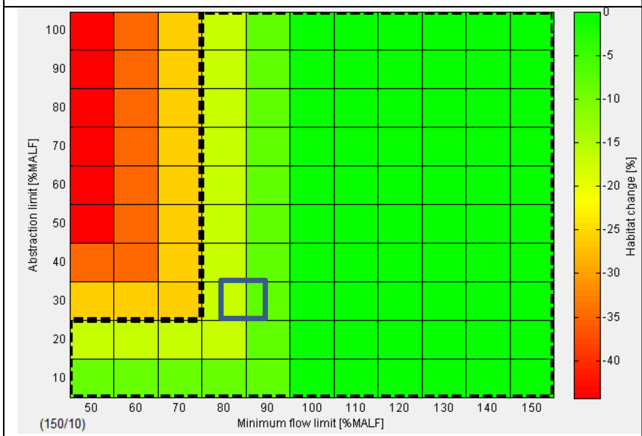
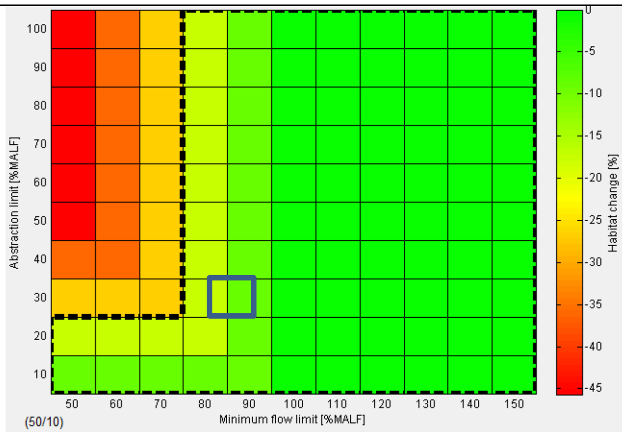
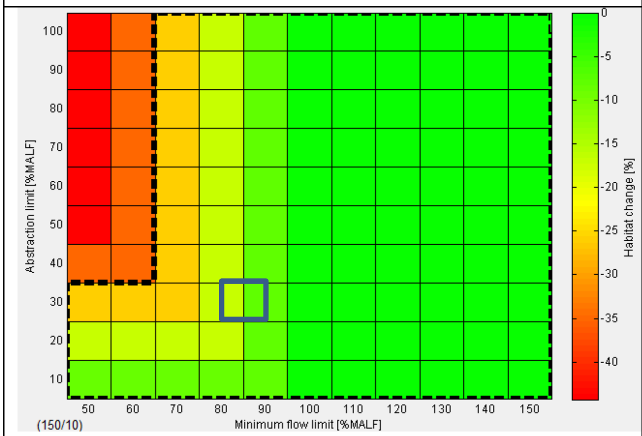
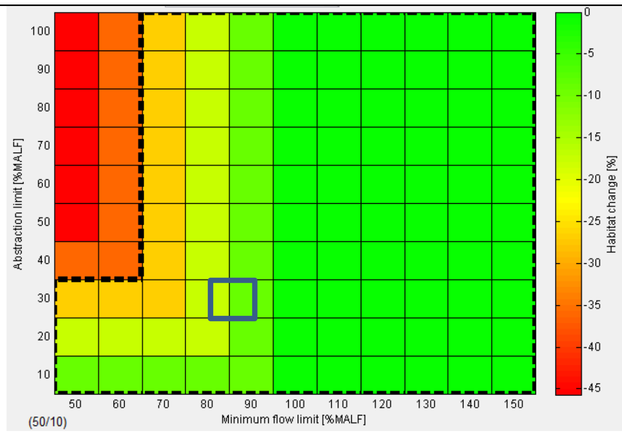
Lumped catchment	Kopuaranga River sub-catchment only
90% habitat	90% habitat
	
80% habitat	80% habitat
	
70% habitat	70% habitat
	

Figure A5.2: Kopuaranga River habitat retention for Torrentfish (50 percent of reaches)

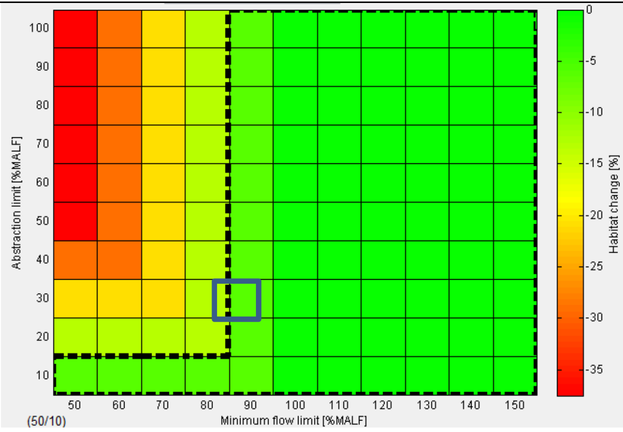
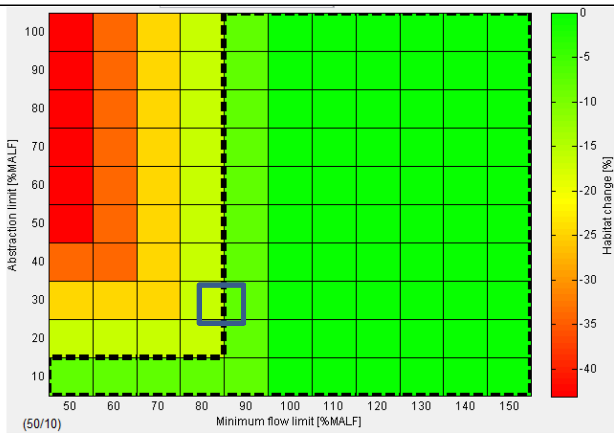
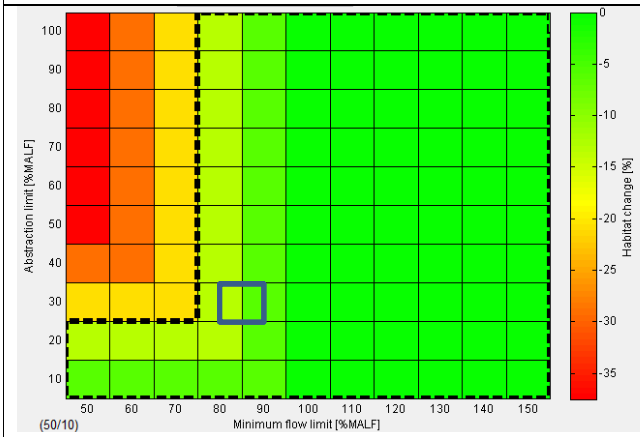
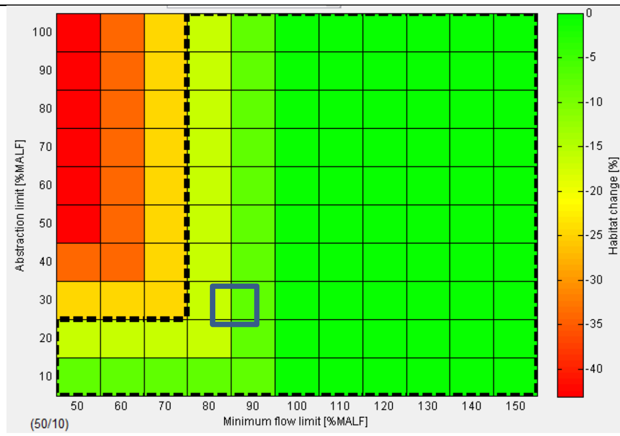
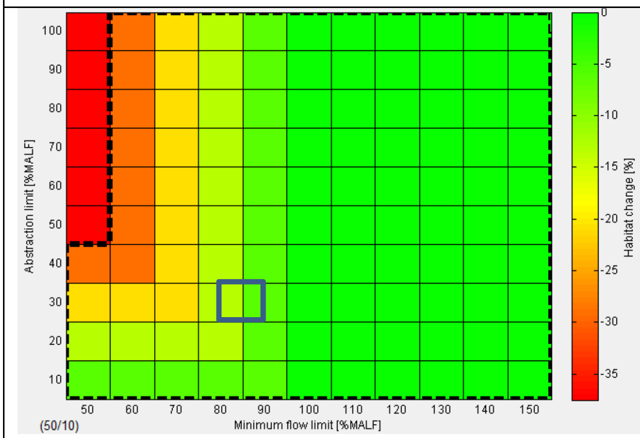
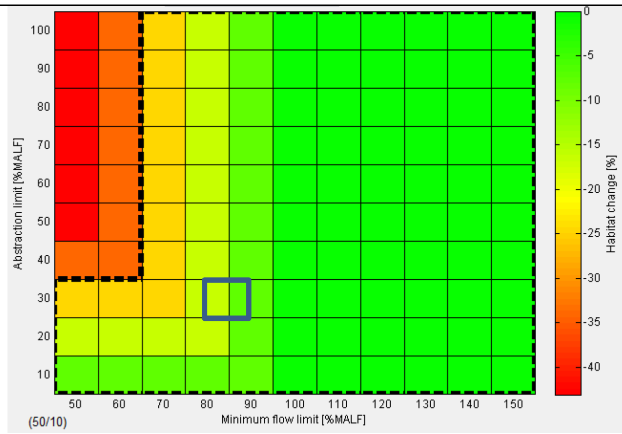
Lumped catchment	Kopuaranga River sub-catchment only
90% habitat	90% habitat
	
80% habitat	80% habitat
	
70% habitat	70% habitat
	

Figure A5.3: Kopuaranga River habitat retention for long fin eel (90 percent of reaches)

<table>
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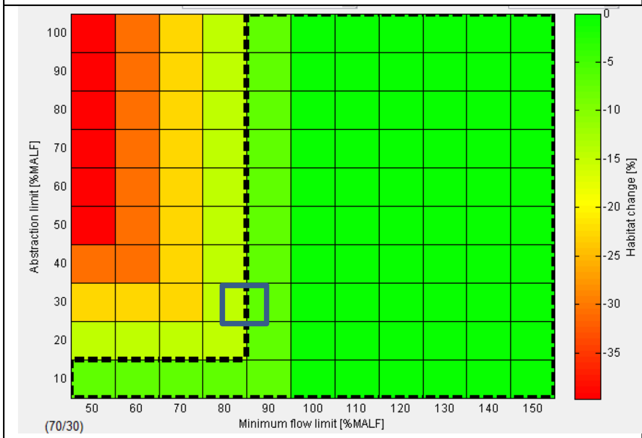
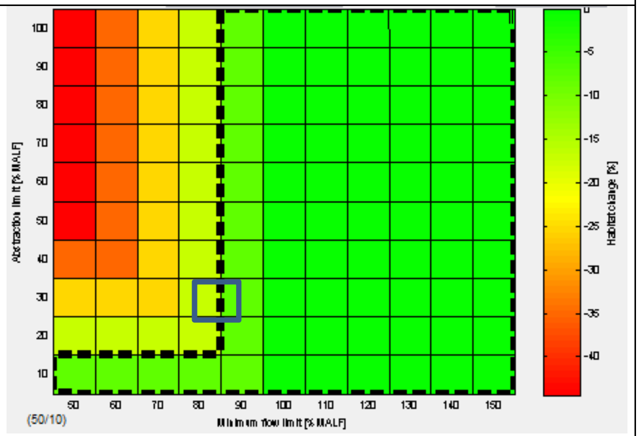
<tr><td>90% habitat</td><td>90% habitat</td></tr>
<tr><td></td><td></td></tr>
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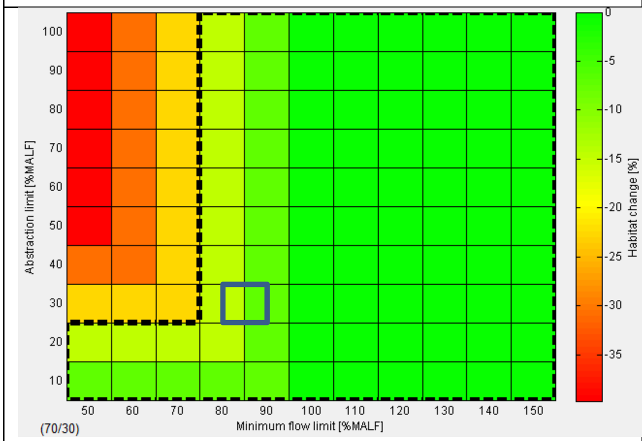
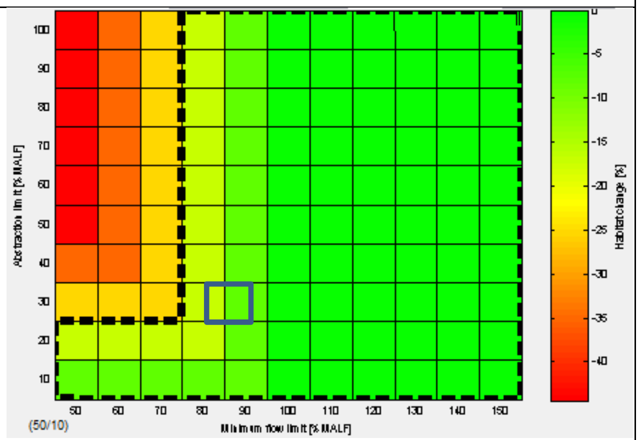
<tr><td></td><td></td></tr>
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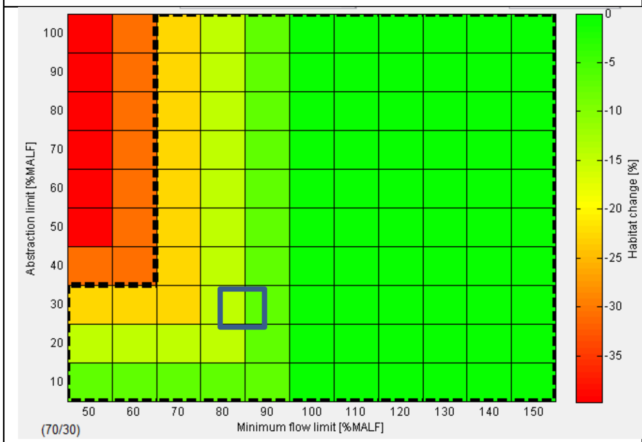
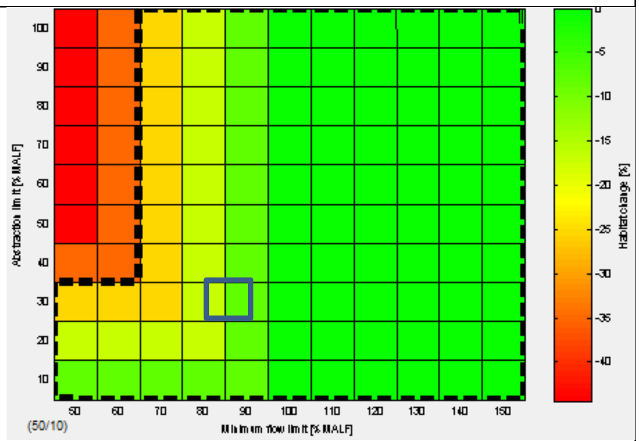
<tr><td></td><td></td></tr>
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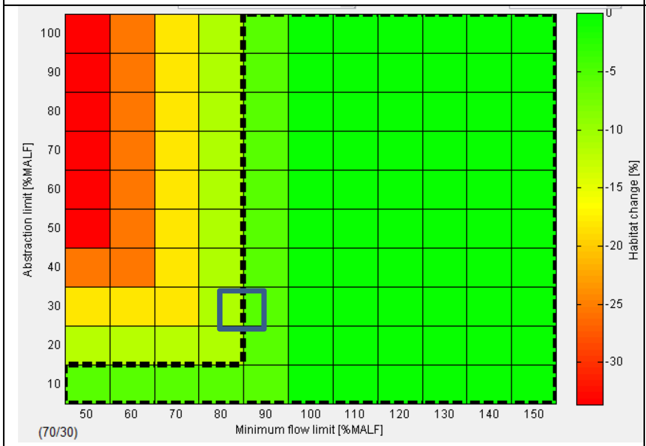
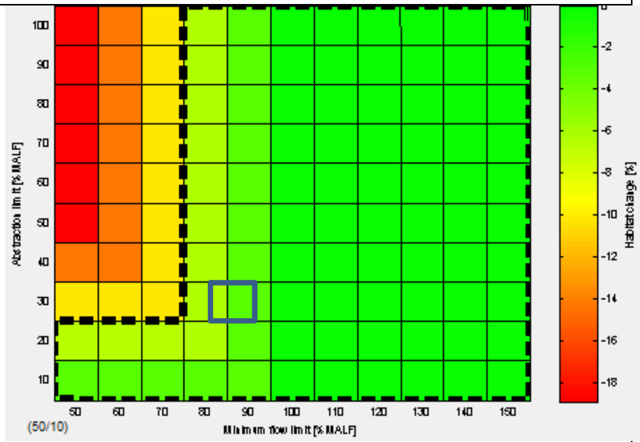
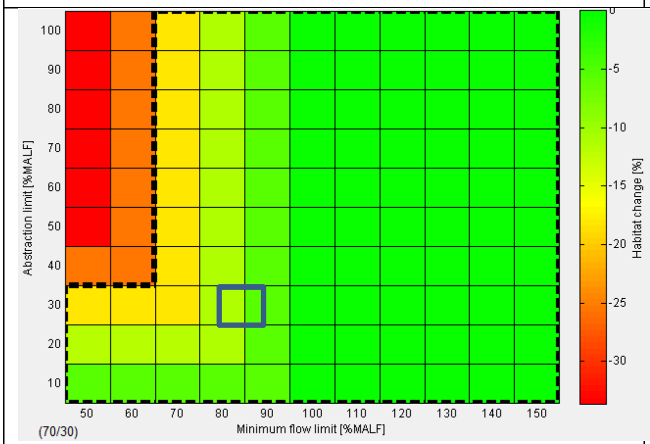
Figure A5.4: Kopuaranga River habitat retention for long fin eel (50 percent of reaches)

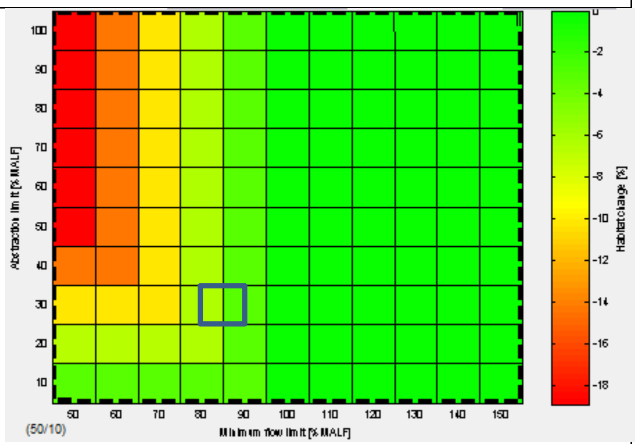
Lumped catchment	Kopuaranga River sub-catchment only
90% habitat	90% habitat



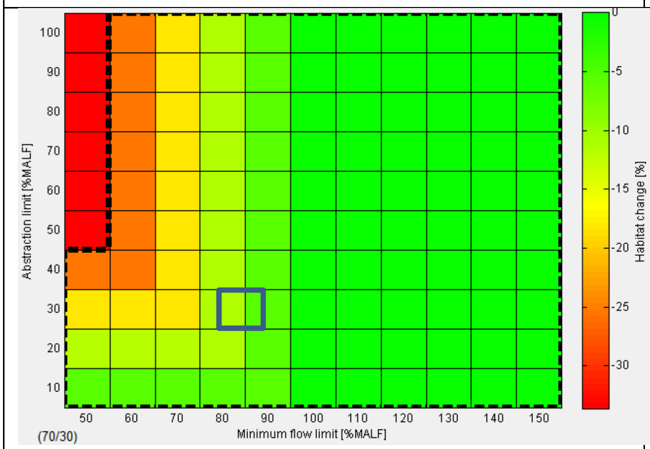


Lumped catchment	Kopuaranga River sub-catchment only
80% habitat	80% habitat





Lumped catchment	Kopuaranga River sub-catchment only
70% habitat	70% habitat



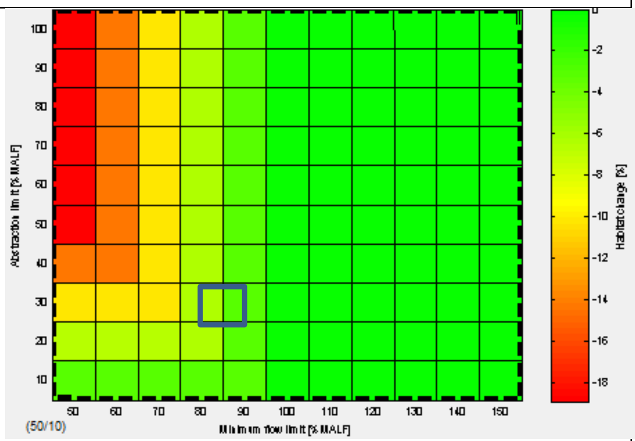
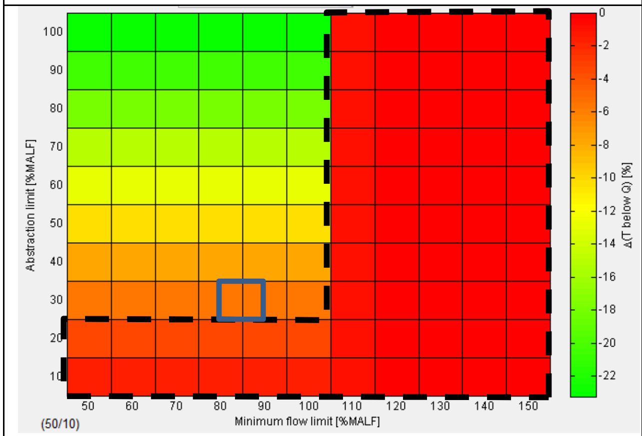


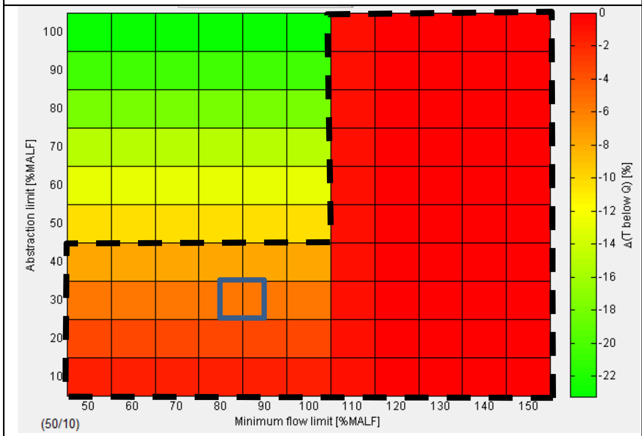
Figure A5.5: Kopuaranga River – Change in duration of time below MALF (90 percent of reaches)

Lumped catchment

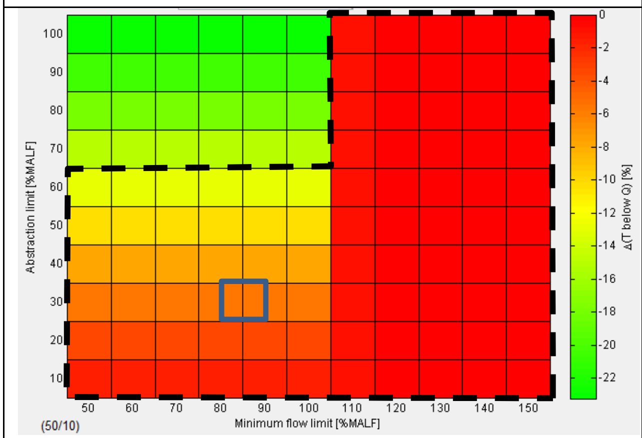
5% change



10% change

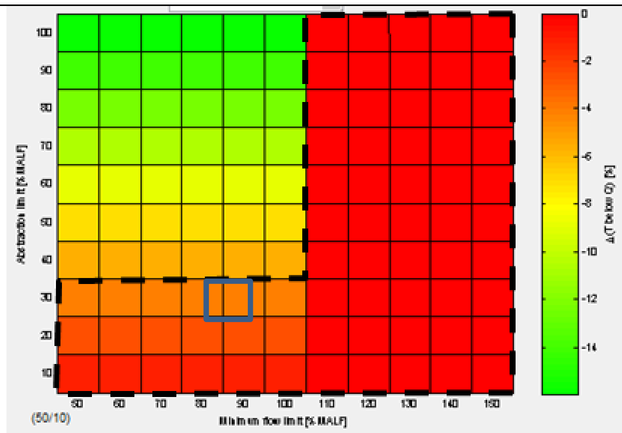


15% change

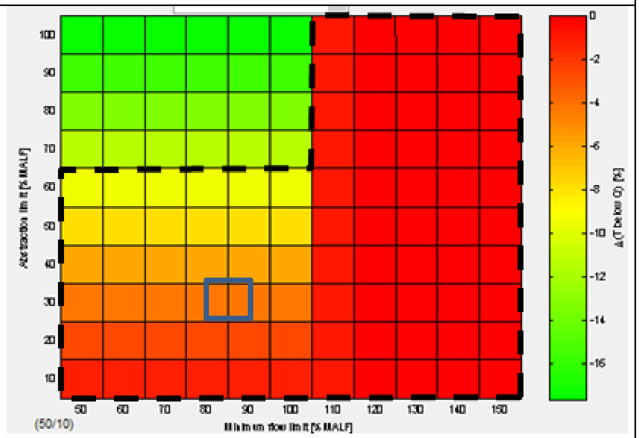


Kopuaranga River sub-catchment only

5% change



10% change



15% change

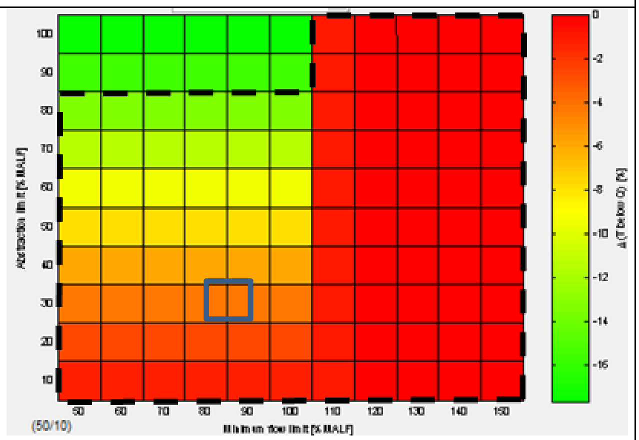


Figure A5.6: Kopuaranga River – Change in duration of time below MALF (50 percent of reaches)

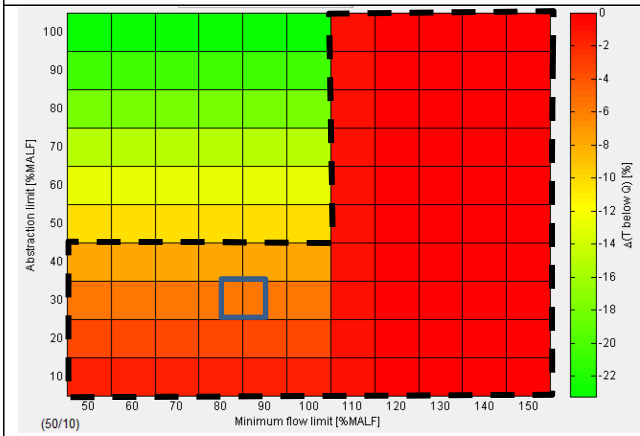
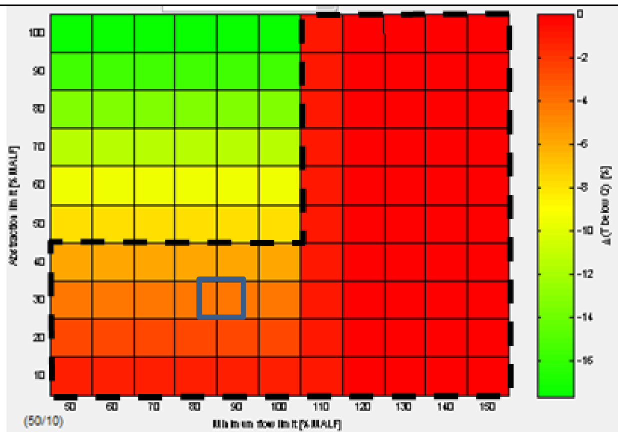
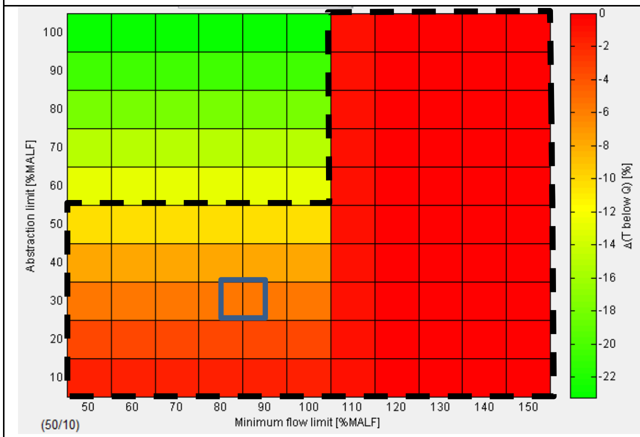
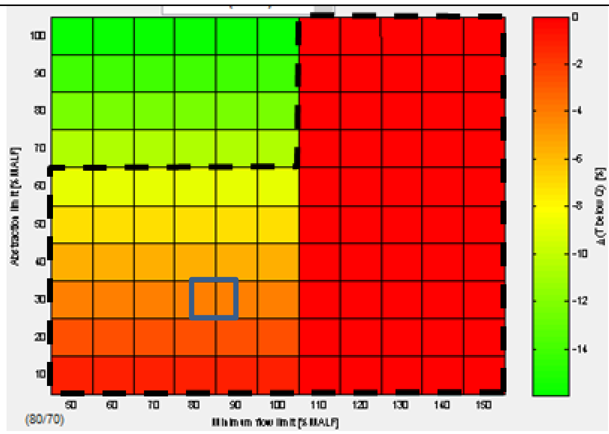
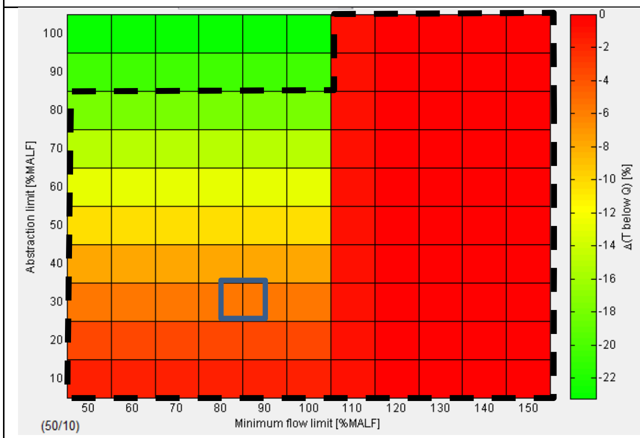
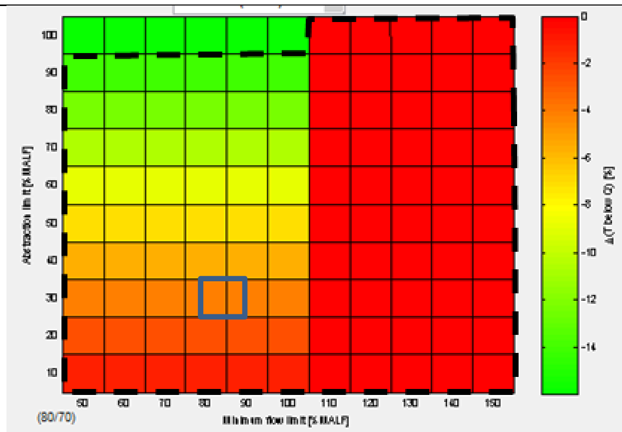
Lumped catchment	Kopuaranga River sub-catchment only
5% change	5% change
	
10% change	10% change
	
15% change	15% change
	

Figure A5.7: Lower Ruamāhanga River habitat retention for Torrentfish (90 percent of reaches)

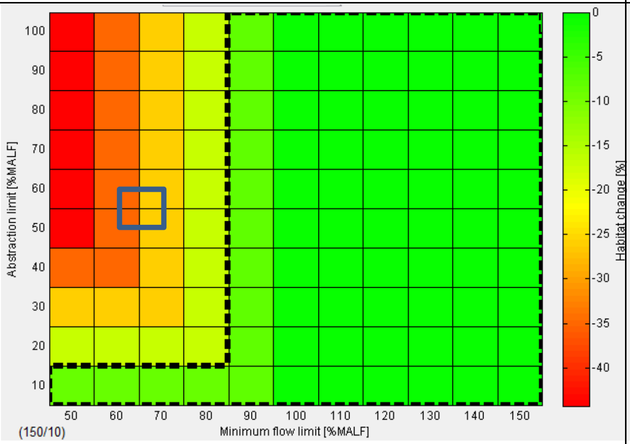
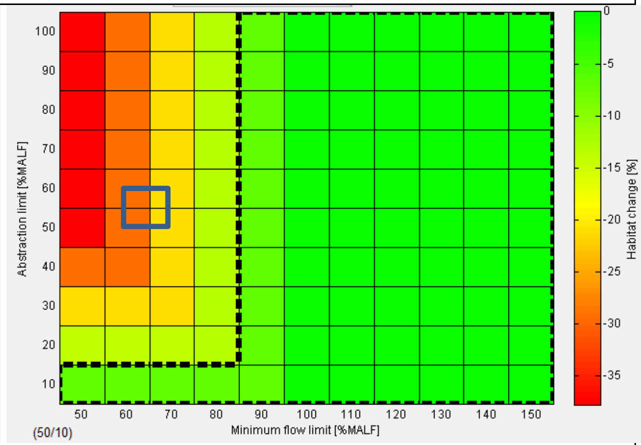
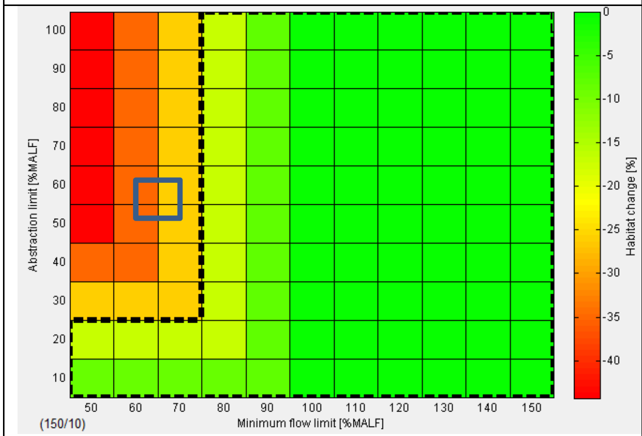
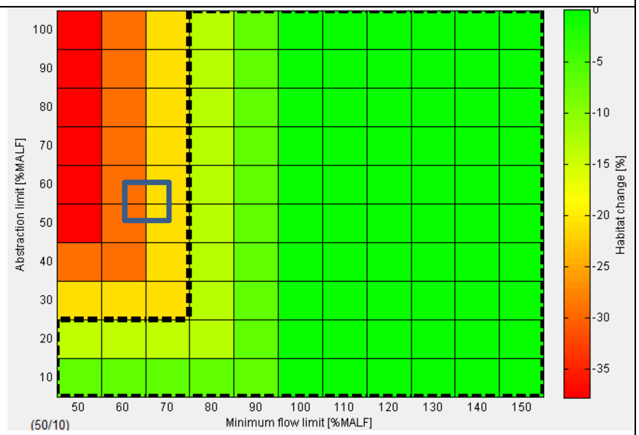
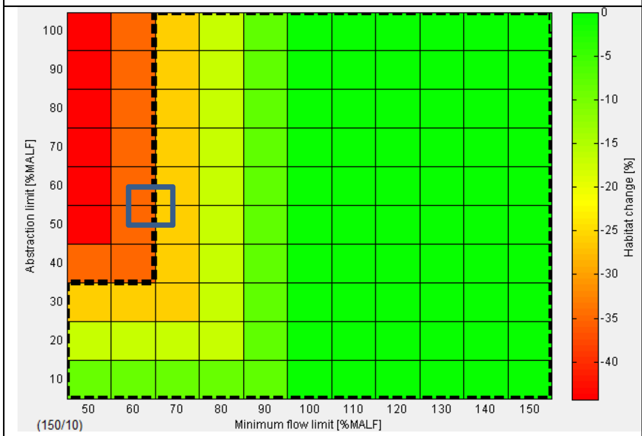
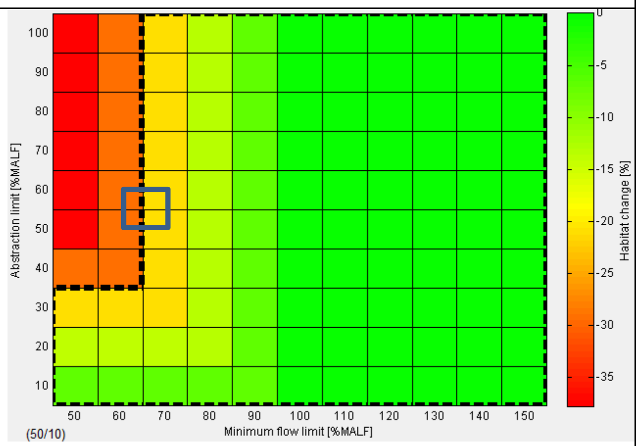
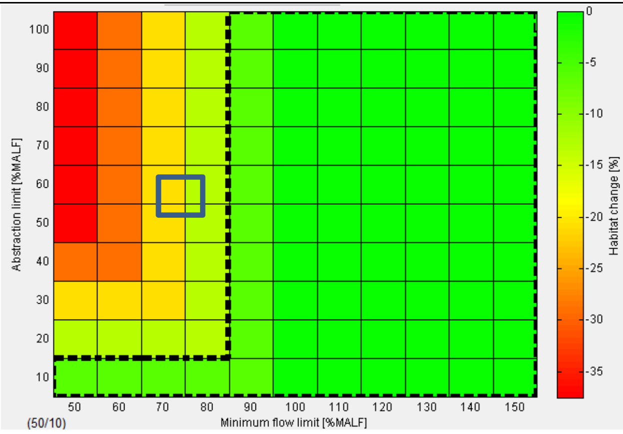
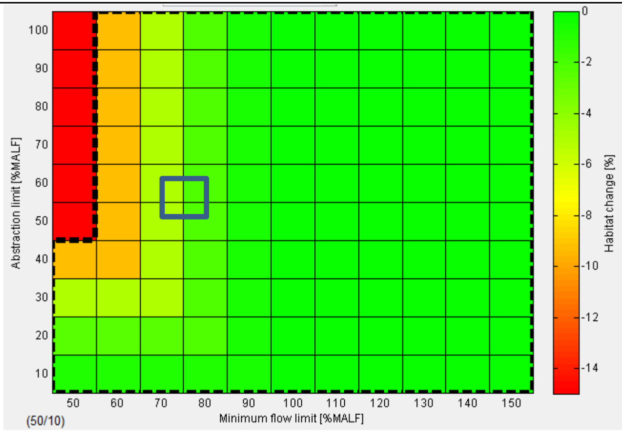
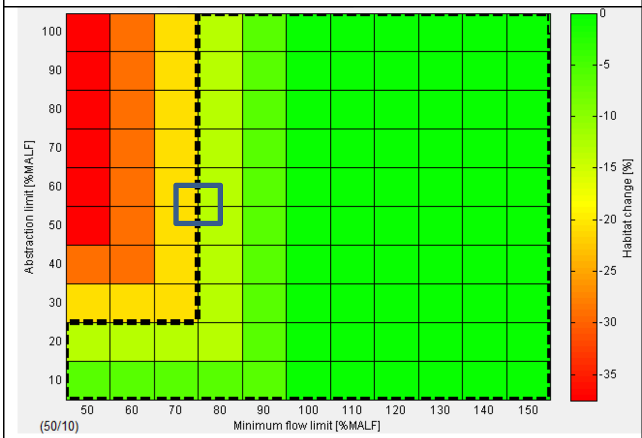
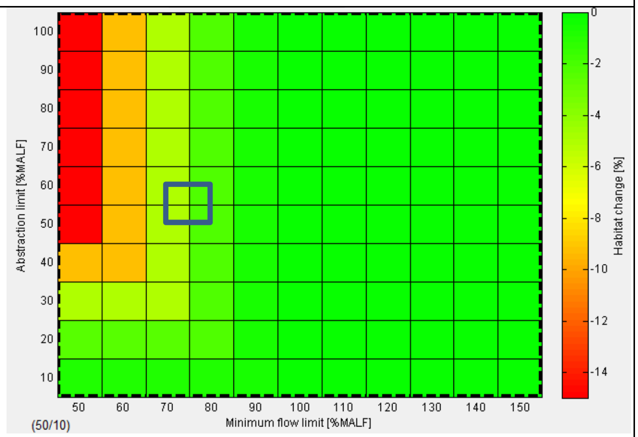
Lumped catchment	Lower Ruamāhanga River sub-catchment only
90% habitat	90% habitat
	
80% habitat	80% habitat
	
70% habitat	70% habitat
	

Figure A5.8: Lower Ruamāhanga River habitat retention for Torrentfish (50 percent of reaches)

Lumped catchment	Lower Ruamāhanga River sub-catchment only
90% habitat,	90% habitat
	
80% habitat	80% habitat
	
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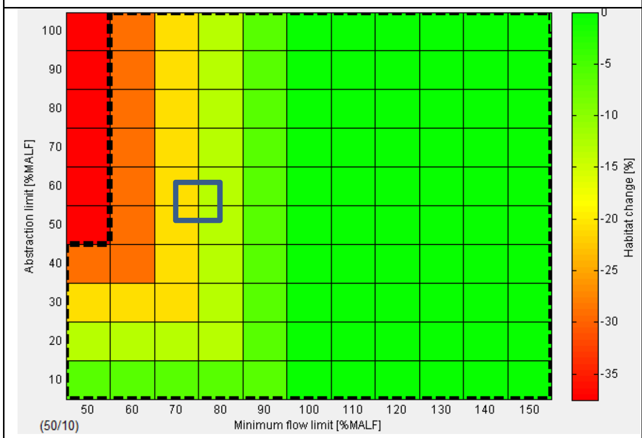	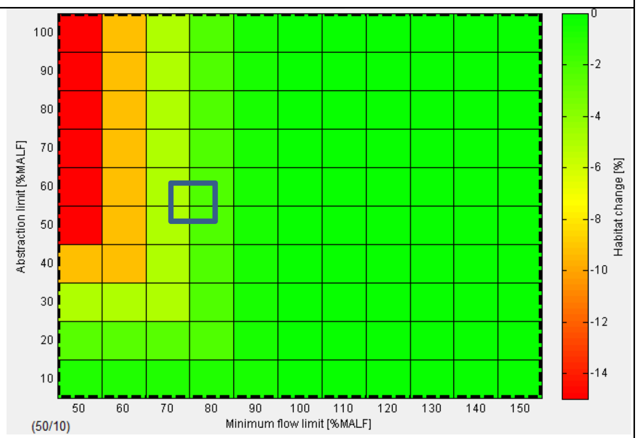

Figure A5.9: Lower Ruamāhanga River – Change in duration of time below MALF (90 percent of reaches)

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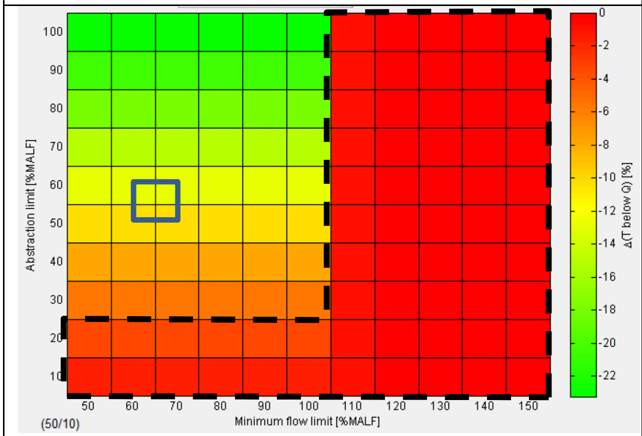
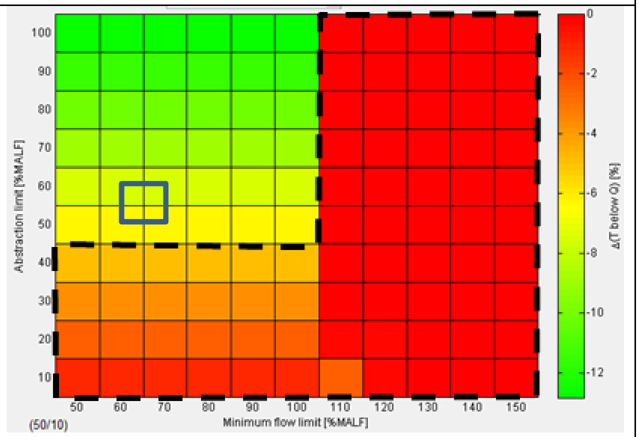
<tr><td>
</td><td>
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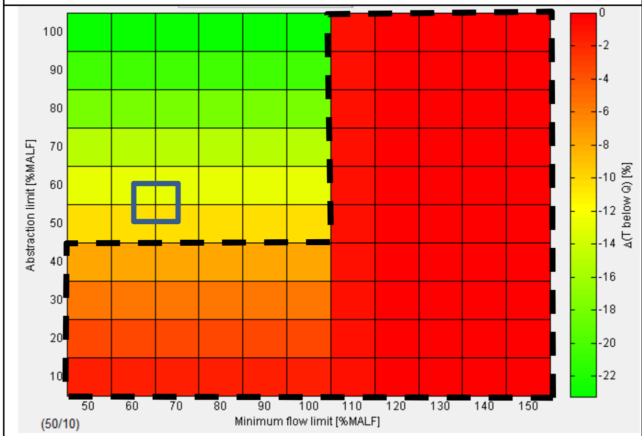
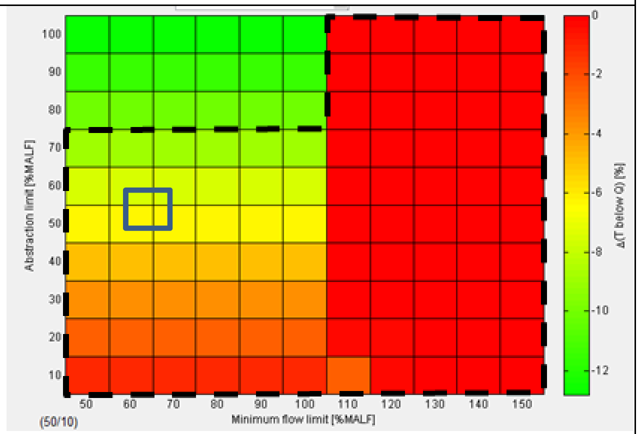
<tr><td>
</td><td>
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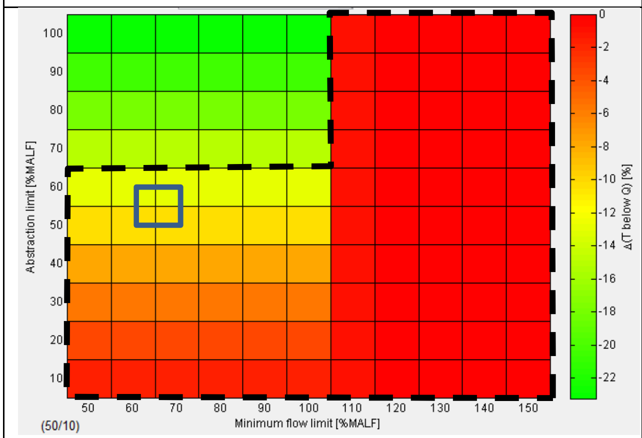
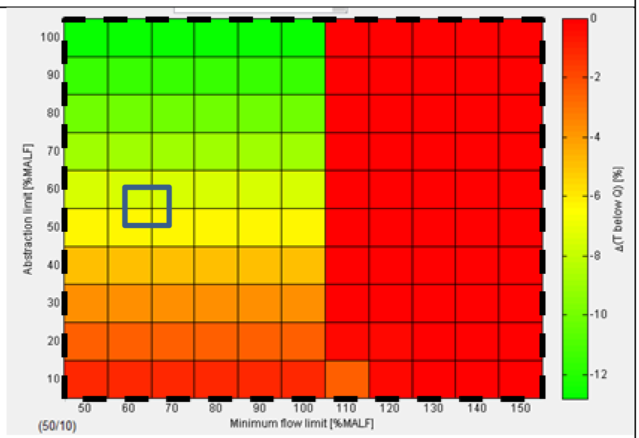
<tr><td>
</td><td>
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Figure A5.10: Lower Ruamāhanga River – Change in duration of time below MALF (50 percent of reaches)

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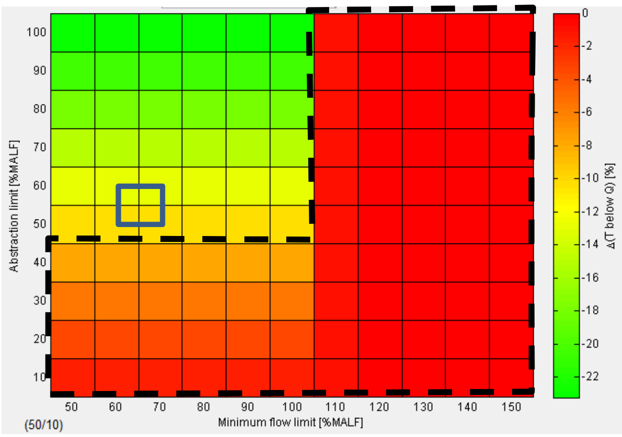
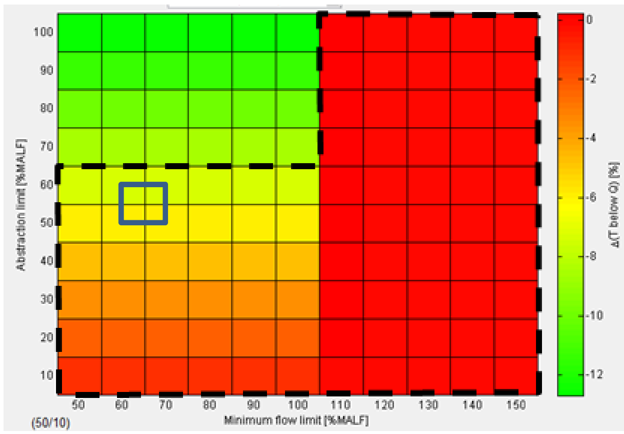
<tr><td>
</td><td>
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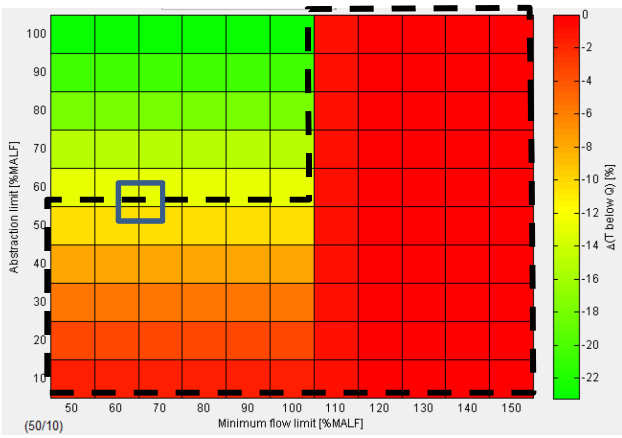
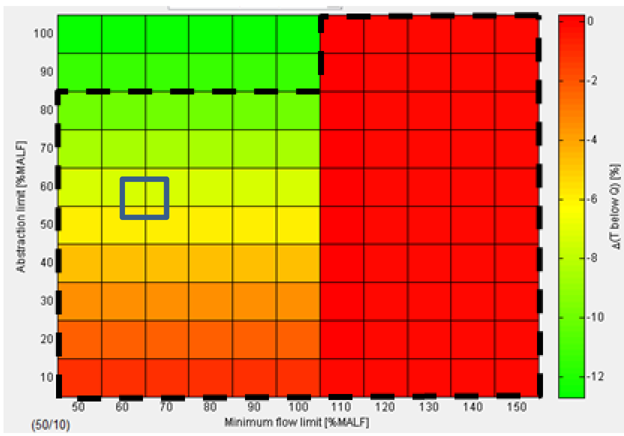
<tr><td>10% change</td><td></td></tr>
<tr><td>
</td><td>
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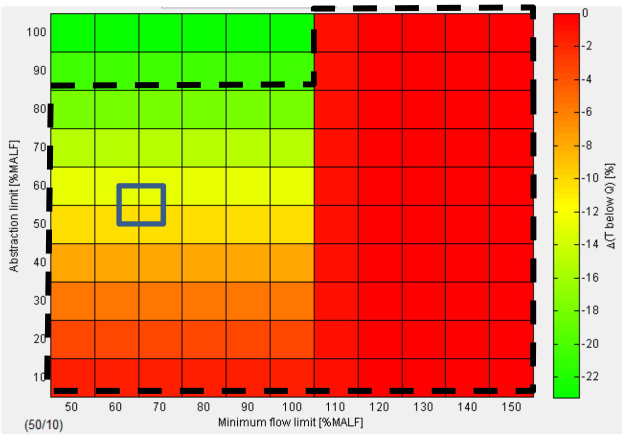
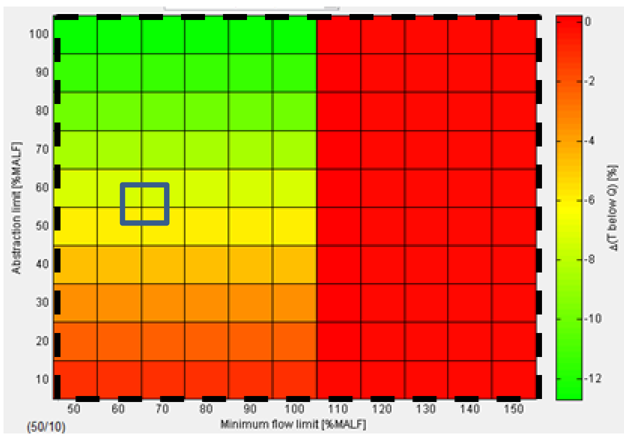
<tr><td>15% change</td><td></td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Appendix 6: Recalculated habitat retention results

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7 July 2017 ID:1728

Mike Thompson
Senior Environmental Scientist, Hydrology
Greater Wellington Regional Council
Shed 39
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Dear Mike

RE-CALCULATING HABITAT RETENTION FOR RIVERS IN THE RUAMAHANGA CATCHMENT

This letter provides prospective minimum flows based on habitat retention, relative to habitat at the 7-day mean annual low flow (MALF), for several rivers in the Ruamahanga catchment, using predictions from hydraulic-habitat models. As described in the project scope document you provided, in the past GWRC has primarily used the 1-day MALF as the reference statistic for benchmarking habitat changes in minimum flow setting. More recently, GWRC has adopted 7-day MALF for these type of studies (and its allocation policy work more generally). This is because it is considered a more appropriate index for sustained low flows and is more consistent with other regional approaches and national guidance. Consequently, you requested a re-calculation of habitat retention using natural 7-day MALF estimates for a number of historical survey points in the Ruamahanga River catchment. The Ruamahanga Catchment Committee specified the following habitat objectives, to be applied across the Ruamahanga River mainstem and all large tributaries:

- To retain 90% of torrentfish habitat available at MALF
- To test alternative habitat retention levels of 80% and 70% for comparison.

While it was not requested by the catchment committee, you suggested it would also be worth calculating the same retention levels for adult brown trout in these rivers, based on the 7-day MALF estimates you provided in Table 1.

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Table 1. Natural 7-day MALF estimates for hydraulic-habitat modelling reaches in the Ruamahanga catchment.

River	Survey Reach	Previous MALF used (m3/s)	Revised MALF (m3/s) 7D natural estimate	Who did original survey
Ruamahanga (lower)	Morrisons Bush	10.80	11.94	Cawthron
	Pahautea Reach	11.70	12.57	Cawthron
Ruamahanga (upper)	Wardells	1.93	3.61	Jowett
Kopuaranga	Palmers	0.24	0.32	Jowett
Waingawa	Aerodrome	1.18	1.82	Jowett
Waiohine	Lower	3.05	3.55	Cawthron

METHODS

The origins of the hydraulic-habitat models used for these analyses were described by Hay 2008 (two lower Ruamahanga reaches), Hay 2009 (Waiohine lower reach), and Jowett 1993 (all other reaches). In the Kopuaranga River (data provided by Ian Jowett) three reaches had been surveyed in an attempt to cover the variety of habitat in the river[1]. These three reaches were merged during analysis, to predict the habitat response for the broader river section overall.

All modelling was conducted in RHYHABSIM Version 5.1 (developed by I Jowett). In all cases flow was assumed to remain constant between cross-sections. The Habitat Suitability Criteria (HSC) applied are depicted in Appendix 1.

The HSC applied for torrentfish were developed by Jowett & Richardson (2008), based on records at 1,217 locations in 37 rivers. Torrentfish were usually found in water less than 0.4 m deep and in velocities in excess of 0.5 m/s, but all were found in velocities less than 1.3 m/s. However, there was relatively little sampling effort in water over 0.6 m deep and, since the sampling method used was electric fishing capture, efficiency would decline with increasing water depth. Consequently, these HSC are likely to be less reliable for predicting habitat in deeper rivers (e.g. the lower Ruamahanga).

Recent research has raised doubts over the rationale we have been using for assessing fish flow requirements in New Zealand and, in the case of drift-feeding fish (salmonids in particular), whether minimum flows and allocation limits based on habitat modelling provide sufficient environmental protection (Hayes et al. in review). When habitat modelling is undertaken, Hayes et al. suggest care should be taken to demonstrate the range of habitat

[1] These reaches had been surveyed using a representative reach approach (see Jowett et al. 2008 for technical details on alternative methods), and modelled using water surface profiling. Consequently, each reach was relatively restricted in length and several short reaches were used to cover the full range of meso-habitat variability. In more recent surveys a habitat mapping approach has been used, which allows stratified sampling of meso-habitats over a larger section of river, and modelled using individual stage/discharge relationships for each cross-section. Thus, the habitat variability is more readily able to be covered in a single dataset.

vs. flow relationships that can be generated from various HSC available, and that the most appropriate empirical trout HSC, based on frequency of use or density data, are those developed on actively drift-feeding fish in larger rivers (e.g. Bovee (1995) and Jowett & Davey (2007) (Clutha River)).

Hayes and Jowett's (1994) adult brown trout feeding HSC were applied in all of the original analyses for these rivers (Jowett 1993; Hay 2008; Hay 2009). The Bovee (1995) HSC for brown trout were also applied in the original lower Ruamahanga analysis (Hay 2008), and HSC for rainbow trout from the same source were applied in the Waiohine (Hay 2009). In this analysis I have also applied Jowett & Davey's (2007) brown trout HSC from the Clutha River.

Hayes and Jowett's (1994) HSC were based on observations of feeding trout in three moderately-sized New Zealand rivers (2.8-4.6 m^3/s), and these HSC have been the most widely applied adult trout criteria in New Zealand since their development. However, recent research suggests that these HSC have a bias toward low water velocity, which makes them less reliable than formerly recognised for use in large rivers (Hayes et al. 2016). In particular, the former belief that the habitat and population response of adult trout can be optimised at flows below the MALF in larger rivers (i.e., the 10 – 16 m^3/s minimum flow range commonly prescribed from habitat modelling based on the Hayes and Jowett 1994 HSC) is not supported by drift transport and NREI modelling and comprehensive habitat modelling (Hayes et al. 2016).

The other brown trout HSC I have applied here (i.e. Bovee (1995), and Jowett & Davey (2007) (Clutha River)) were developed on substantially larger rivers, the South Platte in Colorado (flow range during observations 7-18 m^3/s) and the upper Clutha River (> 100 m^3/s). Although the optimum velocity of all three of these brown trout HSC is similar (0.5 m/s), the maximum suitable velocity for the South Platte and Clutha River HSC is substantially higher than that of the Hayes & Jowett HSC (approximately 1.7 m/s cf. 1 m/s, respectively), and velocities between the optimum and maximum have proportionally higher suitability weighting.

RESULTS AND DISCUSSION

Table 2 provides prospective minimum flows based on three levels of habitat retention (90, 80, and 70%) cf. that at MALF for each of the HSC modelled, as requested. Where there are a range of HSC available (as is the case for adult trout) basing minimum flows on those that are most flow demanding provides a degree of environmental conservatism.

On the other hand, drift feeding trout HSC (such as those applied here) may overestimate the flow requirements of trout in slow sinuous channels like the lower Ruamahanga, where trout would tend to rely more heavily on benthic foraging and piscivory than in higher gradient reaches upstream (where trout rely more on drift feeding) (as discussed in Hay 2008).

The two lower Ruamahanga reaches that I surveyed and modelled (Hay 2008) were dominated by pool and deep run habitat (typical of the lower river). Consequently, there is not much typical torrentfish habitat in these reaches. Therefore, modelled habitat for torrentfish in these reaches is relatively insensitive to flow, which means that prospective minimum flows calculated to retain torrentfish habitat relative to the MALF are quite low (e.g. ~50% of MALF for 90% torrentfish habitat retention cf. that at the MALF in the Pahautea reach).

Table 2. Prospective minimum flows based on three levels of habitat retention cf. that at MALF for torrentfish and adult brown trout in rivers of the Ruamahanga catchment based on available hydraulic-habitat modelling data.

Reach	MALF (m^3/s) *	Habitat Suitability Criteria	Flow that retains 90% of WUA at MALF (m^3/s)	Flow that retains 80% of WUA at MALF (m^3/s)	Flow that retains 70% of WUA at MALF (m^3/s)
Ruamahanga (Lower) Morrisons Bush	11.94	Torrentfish (Jowett & Richardson 2008)	8.10	5.31	3.87
		Brown trout adult (Hayes & Jowett 1994)	9.07	7.37	6.03
		Brown trout adult (Bovee 1995) no substrate	9.30	7.36	5.81
		Brown trout > 40 cm (Clutha) (Jowett & Davey 2007)	9.43	7.38	5.74
Ruamahanga (Lower) Pahautea	12.57	Torrentfish (Jowett & Richardson 2008)	6.58	4.26	3.23
		Brown trout adult (Hayes & Jowett 1994)	6.99	5.00	3.76
		Brown trout adult (Bovee 1995) no substrate	7.64	5.60	4.23
		Brown trout > 40 cm (Clutha) (Jowett & Davey 2007)	9.64	7.43	5.76
Ruamahanga (Upper) Wardells	3.61	Torrentfish (Jowett & Richardson 2008)	3.25	2.91	2.56
		Brown trout adult (Hayes & Jowett 1994)	3.26	2.93	2.60
		Brown trout adult (Bovee 1995) no substrate	3.19	2.79	2.39
		Brown trout > 40 cm (Clutha) (Jowett & Davey 2007)	2.94	2.36	1.89
Kopuaranga (Palmers)	0.32	Torrentfish (Jowett & Richardson 2008)	0.30	0.29	0.28
		Brown trout adult (Hayes & Jowett 1994)	0.28	0.23	0.19
		Brown trout adult (Bovee 1995) no substrate	0.28	0.23	0.19
		Brown trout > 40 cm (Clutha) (Jowett & Davey 2007)	0.26	0.20	0.16
Waingawa (Aerodrome)	1.82	Torrentfish (Jowett & Richardson 2008)	1.56	1.33	1.12
		Brown trout adult (Hayes & Jowett 1994)	1.67	1.52	1.38
		Brown trout adult (Bovee 1995) no substrate	1.65	1.48	1.31
		Brown trout > 40 cm (Clutha) (Jowett & Davey 2007)	1.43	1.10	0.82
Waiohine (Lower)	3.55	Torrentfish (Jowett & Richardson 2008)	2.95	2.46	2.05
		Brown trout adult (Hayes & Jowett 1994)	2.97	2.45	1.99
		Brown trout adult (Bovee 1995) no substrate	2.94	2.41	1.93
		Brown trout > 40 cm (Clutha) (Jowett & Davey 2007)	2.94	2.41	1.91
		Rainbow trout adult (Bovee 1995) no substrate	3.02	2.53	2.05

Interestingly, in the smaller rivers (MALF <10 m^3/s) the prospective minimum flows based on the Hayes & Jowett HSC were slightly more conservative than those based on the larger river HSC (i.e. Bovee (1995) and Jowett & Davey (2007)). This is probably due to a similar phenomenon to that discussed with regard to the relative insensitivity of predicted torrentfish habitat in the lower Ruamahanga reaches. Since there is predicted to be relatively little habitat in the modelled reaches on the basis of these HSC, the rate of decline in habitat with flow reduction is relatively flat. Therefore, a given percentage reduction in habitat requires a larger change in flow.

As discussed in my original reports, it is important that appropriate allocation limits are considered in conjunction with setting minimum flows, to maintain flow variability (in order to maintain channel and riparian structure, control periphyton, and sustain invertebrate productivity and fish feeding opportunities). Recently emerging research has reinforced the importance of maintaining flows in the low to mid-flow range to support drift-feeding fish, in particular (Hayes et al. In review).

Please contact us if you require any further advice.

Yours sincerely

Scientist:

Joe Hay
Freshwater Scientist
Cawthron Institute

Reviewed by:

Roger Young
Freshwater Group Manager
Cawthron Institute

References:

Bovee 1995. South Platte River drift-feeding brown trout and rainbow trout HSC sourced directly from Ken Bovee.

Jowett IG. 1993. Minimum flow assessments for instream habitat in Wellington Rivers. Report prepared for Wellington Regional Council. NIWA. NZ freshwater miscellaneous report No. 63. 33p.

Hay, J. 2008. Instream Flow Assessment for the Lower Ruamahanga River. Prepared for Greater Wellington Regional Council. Cawthron Report No. 1403. 43p plus appendices

Hay J 2009. Instream Flow Assessment for the Waiohine River. Prepared for Greater Wellington Regional Council. Cawthron Report No. 1649. 40 p.

Hayes JW, Jowett IG 1994. Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. North American Journal of Fisheries Management 14 (4): 710-725.

Hayes J, Hay J, Gabrielsson R, Jellyman P, Booker D, Wilding T, Thompson M. In review. Review of the rationale for assessing fish flow requirements and setting ecological flow and allocation limits for them in New Zealand. Prepared for Envirolink, Hawkes Bay Regional Council, Greater Wellington Regional Council and NIWA. Cawthron Report No. 3040.

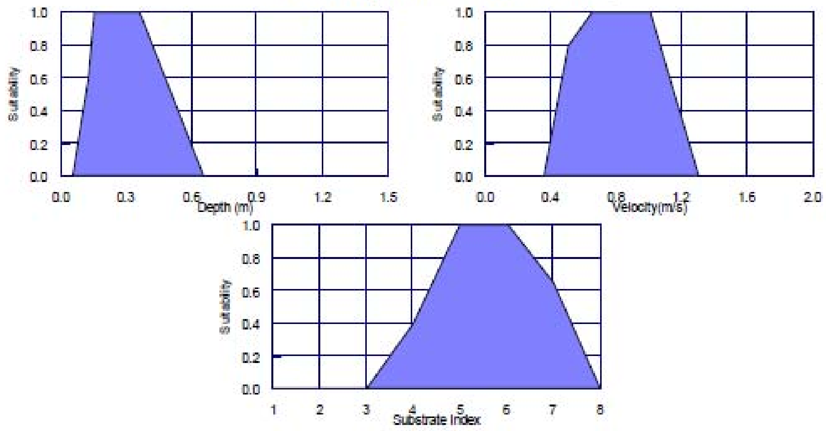
Jowett IG, Davey AJH 2007. A comparison of composite habitat suitability indices and generalized additive models of invertebrate abundance and fish presence-habitat availability. Transaction of the American Fisheries Society 136: 428-444.

Jowett IG, Hayes JW, Duncan MJ 2008. A guide to instream habitat survey methods and analysis. NIWA Science and Technology Series 54, NIWA Wellington, 121 p.

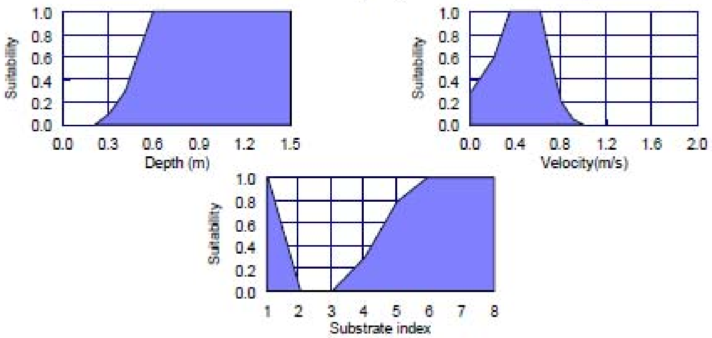
Jowett IG, Richardson J 2008. Habitat use by New Zealand fish and habitat suitability models. NIWA Science and Technology Series No. 55. NIWA Wellington, 148 p.

Appendix 1. Habitat suitability criteria used in the modelling described in this letter.

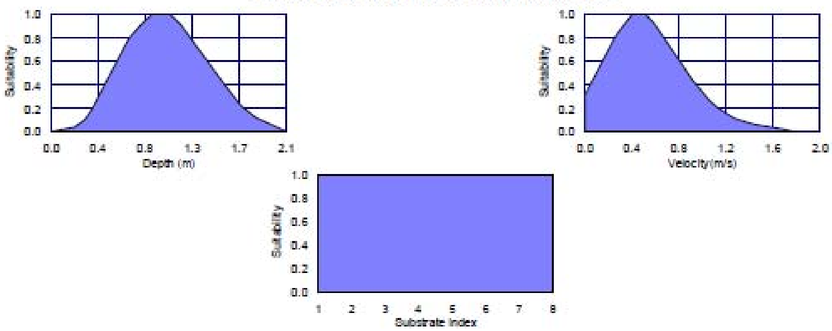
Torrentfish (Jowett & Richardson 2008)



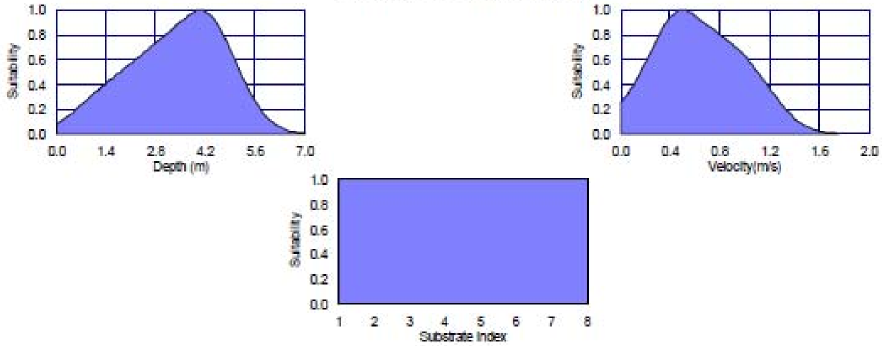
Brown trout adult (Hayes & Jowett 1994)



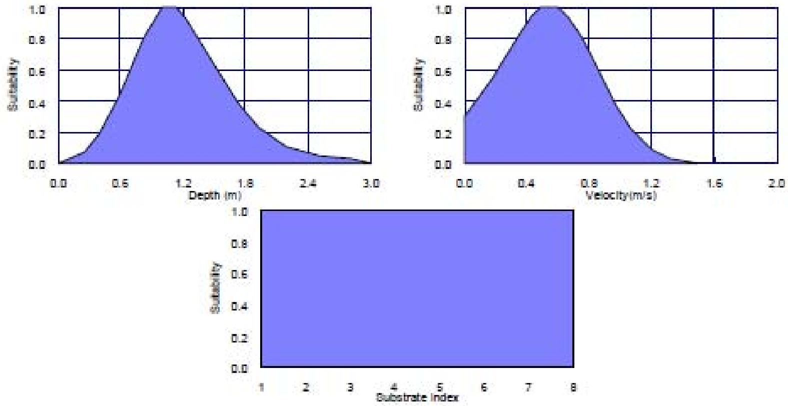
Brown trout adult (Bovee 1995) no substrate



Brown trout > 40 cm (Clutha)



Rainbow trout adult (Bovee 1995) no substrate



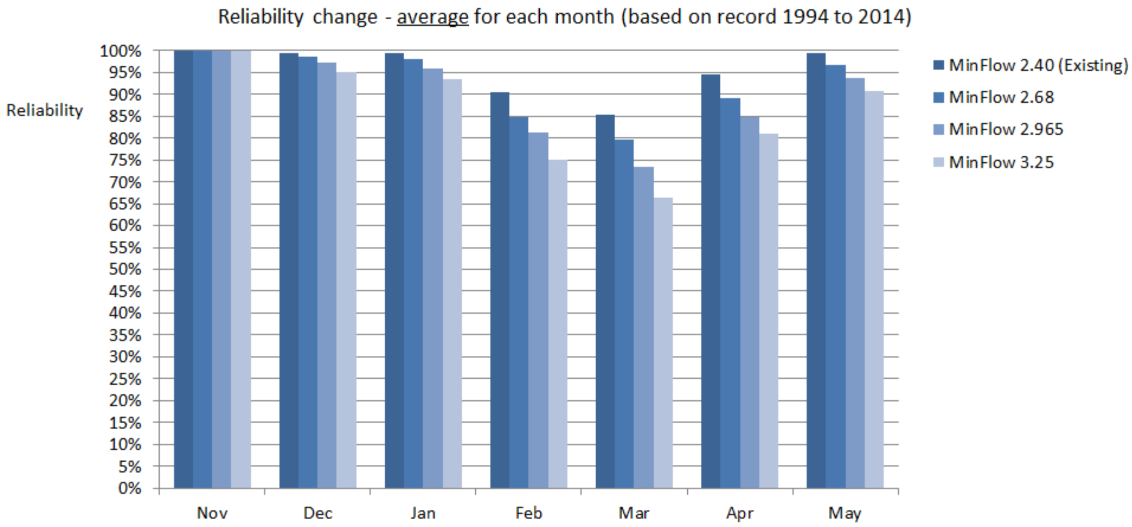
Appendix 7: Consequence of increasing minimum flows for reliability of supply

Table A7.1: Average reliability changes for Upper Ruamāhanga based on a six month summer (Nov-Apr) – minimum flow increased in three equal steps

Summer reliability - Upper Ruamahanga River (Wardells)							
Year	**Existing minimum flow (2,400 L/s)**	**Stage1 minimum flow (2,680 L/s)**	**Stage1 reduction in reliability**	**Stage2 minimum flow (2,965 L/s)**	**Stage2 reduction in reliability**	**Stage3 minimum flow (3,250 L/s)**	**Stage3 reduction in reliability**
1993	96%	85%	11%	77%	18%	70%	26%
1994	100%	99%	1%	96%	4%	91%	9%
1995	100%	100%	0%	99%	1%	97%	3%
1996	100%	100%	0%	100%	0%	100%	0%
1997	99%	98%	1%	97%	3%	94%	6%
1998	94%	89%	5%	87%	8%	84%	11%
1999	96%	94%	2%	93%	3%	89%	7%
2000	96%	88%	8%	82%	14%	77%	19%
2001	100%	100%	0%	100%	0%	100%	0%
2002	91%	81%	11%	74%	17%	65%	26%
2003	100%	100%	0%	98%	2%	98%	2%
2004	98%	97%	2%	96%	3%	94%	4%
2005	100%	98%	2%	97%	3%	96%	4%
2006	94%	89%	5%	86%	9%	78%	16%
2007	74%	66%	8%	57%	17%	48%	26%
2008	91%	87%	4%	82%	8%	78%	12%
2009	100%	100%	0%	100%	0%	98%	2%
2010	100%	98%	2%	92%	8%	87%	13%
2011	100%	100%	0%	100%	0%	100%	0%
2012	79%	72%	7%	68%	11%	67%	12%
2013	100%	100%	0%	99%	1%	94%	6%
2014	88%	82%	6%	74%	14%	67%	21%
Mean	**95%**	**92%**	**3%**	**89%**	**7%**	**85%**	**10%**
Worst year	74%	66%	11%	57%	18%	48%	26%
95th Percentile	79%	73%	10%	68%	17%	65%	26%

Table A7.2: Average reliability changes for Waipoua based on a six month summer (Nov – Apr) – minimum flow increased in three equal steps

Summer reliability - Waipoua River (Mikimiki Bridge)							
Year	Existing minimum flow (250 L/s)	Stage1 minimum flow (280 L/s)	Stage1 reduction in reliability	Stage2 minimum flow (310 L/s)	Stage2 reduction in reliability	Stage3 minimum flow (335 L/s)	Stage3 reduction in reliability
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001				NO LOW FLOW DATA UNTIL 2007			
2002							
2003							
2004							
2005							
2006							
2007	78%	72%	6%	69%	8%	67%	11%
2008	90%	89%	1%	88%	2%	87%	3%
2009	100%	100%	0%	100%	0%	100%	0%
2010	98%	96%	2%	92%	6%	87%	11%
2011	100%	100%	0%	100%	0%	100%	0%
2012	74%	68%	6%	63%	11%	61%	13%
2013	98%	98%	0%	98%	0%	98%	0%
2014	85%	79%	6%	73%	12%	69%	16%
Mean	**90%**	**88%**	**3%**	**86%**	**5%**	**84%**	**7%**
Worst year	74%	68%	6%	63%	12%	61%	16%
95th Percentile	75%	70%	6%	65%	11%	63%	15%



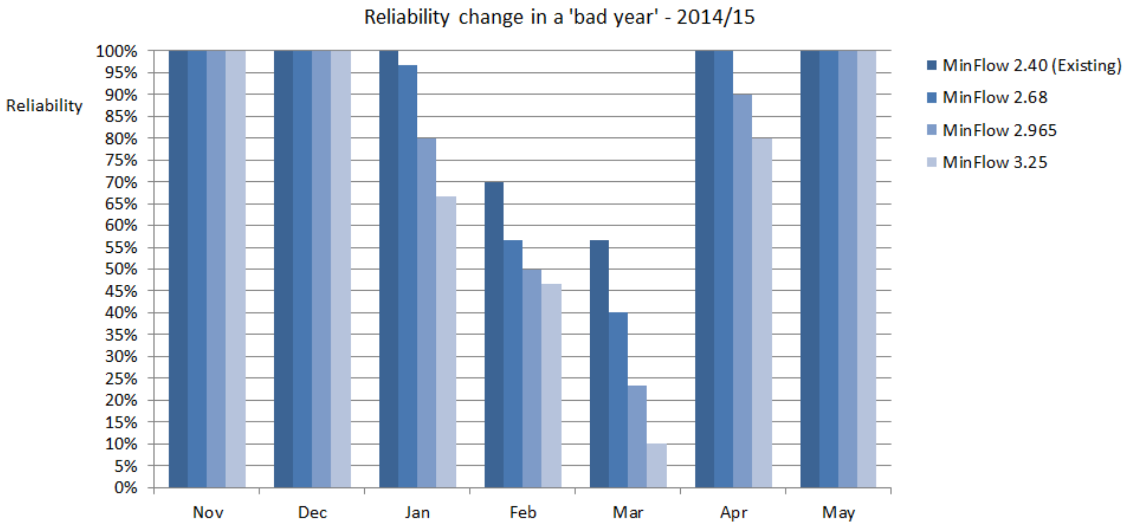


Figure A7.1: Reliability changes on a monthly basis for Upper Ruamāhanga (minimum flow increased in three equal steps). Top graph shows average reliability for each month over the years 1993-2014, whereas the bottom graph depicts a dry year.

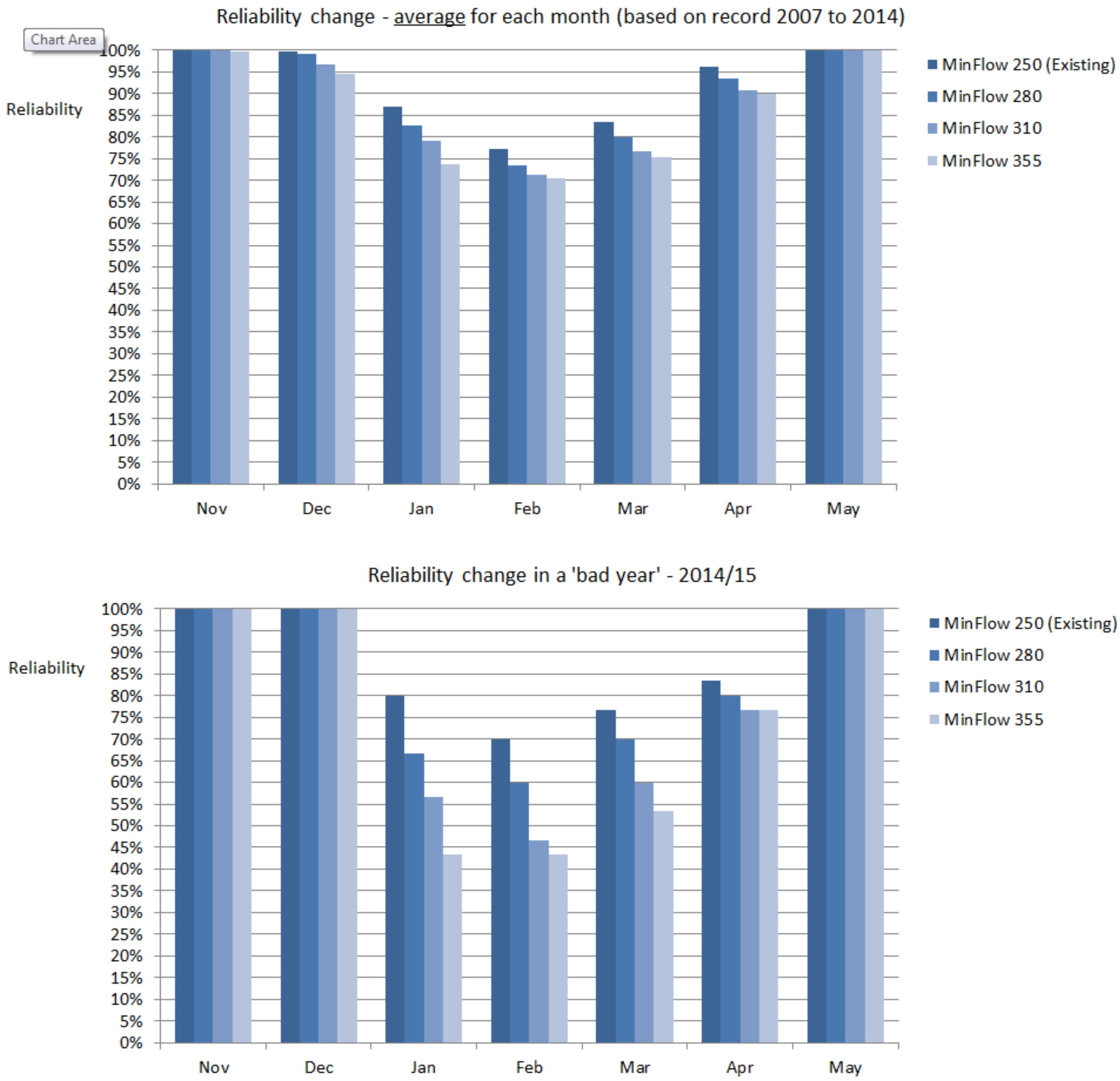


Figure A7.2: Reliability changes on a monthly basis for Waipoua (minimum flow increased in three equal steps). Top graph shows average reliability for each month over the years 2007-2014, whereas the bottom graph depicts a dry year.