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Evaluation of a tool for investigating water allocation scenarios: A test case for the Piako catchment

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Taihoro Nukurangi

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A test case for the Piako catchment.

Prepared for Waikato Regional Council.

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Executive summary

The Waikato Regional Council (WRC) is responsible for managing the status of water resources in the Waikato Region. WRC's approach to the protection, allocation and use of water resources is set out in the Waikato Regional Plan: Variation No. 6 – Water Allocation (the Plan), which became operative on 10 April 2012. As required by the National Policy Statement for Freshwater Management (NPSFM), the Plan defines minimum flows and allocation limits for all catchments in the region. As a precursor to the review of flow and allocation limits set in the Plan for the Piako catchment scheduled for 1 July 2014, WRC have initiated investigations in the catchment to support and inform the Plan review process.

The purpose of this project is to evaluate the use of the Environmental Flow Strategic Allocation Platform (EFSAP) to simulate the consequences of water quantity limit scenarios, using the Piako catchment as a case study. The aim is to help WRC understand how EFSAP can be used to characterise the instream and out-of-stream effects of different rules, and how this might be useful in the limit setting process, including managing over-allocation. In this project, EFSAP was used to simulate the spatially explicit consequences for reliability of supply and instream physical habitat of a range of water allocation limits in the Piako catchment. The scenarios developed in consultation with WRC included:

- the Plan water allocation rules for the Piako catchment excluding water harvesting
- current actual allocation (including estimated permitted takes)
- current actual allocation (including estimated permitted takes), excluding takes for irrigation.

Using EFSAP it was possible to demonstrate that under the Regional Plan minimum flow and allocation limits for the Piako catchment, the potential annual average reliability of supply for both the primary and secondary allocation blocks is relatively high for much of the catchment. Median reliability of the primary allocation block is 96%, and 90% of reaches have potential reliability of greater than 80%. For the secondary allocation block, median reliability is 95% and 90% of reaches have a potential reliability of greater than 81%. The predicted impacts on instream physical habitat availability relative to that available at the natural mean annual low flow (MALF) were also relatively small (<10%) for much of the catchment, with the largest effects mainly restricted to smaller headwater streams.

The EFSAP tool was also used to illustrate that estimated permitted takes alone are predicted to result in over-allocation at a reach scale (average reach length 700 m) in approximately 50% of impacted reaches (i.e., those reaches downstream of at least one abstraction) in the Piako catchment. When consented takes are included, over-allocation increases to 70% of the impacted reaches. Relative to the current limits for the Piako, it was shown using EFSAP that most of the Waitoa River from its headwaters to the confluence with the Piako, and the main stem of the Piako between Milliken Road and the Paeroa-Tahuna Road, are over-allocated, assuming limits are applied at a reach scale. In 10% of the impacted reaches, the primary allocation limit is exceeded by 500% or greater. Overall, the results of the EFSAP modelling work suggest that there may be a problem with over-allocation in certain reaches of the Piako catchment when compared to current water quantity limits. This may have significant implications for WRC with respect to fulfilling the requirements of the NPSFM.

The aim of this project was to assess the value of EFSAP to WRC for assisting in the water quantity limit setting process. The EFSAP methodology has been demonstrated to offer an approach that allows water managers to evaluate the consequences of setting different water allocation limits and to characterise the consequences of existing allocation. The integrated use of scientific tools allows transparent and concurrent evaluation of consequences for both instream habitat and reliability of supply for out-of-channel water uses. It also accounts for the interaction between minimum flow and total allocation limits. By modelling a range of scenarios EFSAP also allows resource managers to more effectively communicate to stakeholders the varying consequences of different water resource limits and the trade-offs that are necessary between different values.

1 Introduction

1.1 Background

The Waikato Regional Council (WRC) is responsible for managing the status of water resources in the Waikato Region. WRC's approach to the protection, allocation and use of water resources is set out in the Waikato Regional Plan: Variation No. 6 – Water Allocation (the Plan) (Waikato Regional Council 2012), which became operative on 10 April 2012. As required by the National Policy Statement for Freshwater Management (NPSFM; MfE 2011), the Plan defines minimum flows and allocation limits for all catchments in the region (Table 3-5; Waikato Regional Council 2012). Included within the Plan is a schedule for systematic review of the flow and allocation limits set out in Table 3-5 of the Plan (Table 3-4; Waikato Regional Council 2012).

The scheduled review date for the Piako catchment is 1 July 2014 (Table 3-4; Waikato Regional Council 2012). As a precursor to this review of current flow and allocation limits in the Piako catchment, WRC have initiated investigations in the catchment to support and inform the review process.

1.2 Purpose

Policy 1 of Section 3.3 of the Plan states that when establishing or reviewing allocable or minimum flows WRC must have regard to both the instream (e.g. ecosystem health and natural character) and out-of-stream (e.g. drinking water supply) values of water use. A significant challenge in achieving this is being able to demonstrate the necessary trade-offs between values that are required to achieve this balance. The purpose of this project is to evaluate the use of the Environmental Flow Strategic Allocation Platform (EFSAP) to simulate the consequences of currently operative and alternative water quantity limit scenarios, using the Piako catchment as a case study. The aim is to help WRC understand how EFSAP can be used to characterise the instream and out-of-stream effects of different rules, and how this might be useful in the limit setting process, including managing over-allocation.

1.3 Scope

EFSAP will be tested for simulating the spatially explicit consequences for reliability of supply and instream physical habitat of a range of alternative allocation scenarios in the Piako catchment. The output from the simulation analyses will describe predicted changes in instream physical habitat for target species and changes in water availability (i.e., the estimated total allocation) and reliability (proportion of the time takes are estimated to be fully or partially restricted).

Allocation scenarios to be modelled include:

1. the Plan water allocation rules for the Piako catchment excluding water harvesting
2. current estimated permitted takes
3. current consented allocation (including estimated permitted takes)
4. current consented allocation (including estimated permitted takes), excluding consented takes for irrigation.

2 Methods

2.1 EFSAP model description

EFSAP is a tool designed 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 spatially explicit consequences of multiple 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 models applied across all locations in a spatial framework. Further details of the model structure are described below.

2.1.1 Spatial framework

The spatial framework for EFSAP is the River Environment Classification (REC; Snelder & Biggs 2002), which comprises a digital representation of the New Zealand river network and a classification system that are contained within a Geographic Information System (GIS). Each segment is associated with several attributes including the total catchment area and stream order, as well as the climatic, topographic, geological, and land-cover characteristics of the upstream catchment. The REC classifies all river and stream segments into classes at several levels of detail (Snelder & Biggs 2002).

2.1.2 Hydrological data

EFSAP requires estimates of several hydrological characteristics. For the purposes of the Piako catchment these included: 1 in 5 year mean annual 7-day low flow (Q5), mean flow (Qbar), and the shape of the flow duration curve (FDC). An FDC is a hydrological tool that is used to represent the percentage of time flows are equalled or exceeded for a particular river location (Vogel & Fennessey 1995). This Piako analysis required both all-year (i.e., calculated across the entire year) and monthly (i.e., calculated for individual months) FDCs so that the consequences for availability and reliability of water supply for out-of-channel uses could be reported for the whole year and the most restrictive (summer) month. Approaches for estimating these hydrological characteristics are described by Booker and Woods (2012). See Booker and Snelder (2012) for further technical details of the methods used to estimate FDCs. The methods with the lowest uncertainties have been used with EFSAP to undertake the simulation analyses for this project.

2.1.3 Generalised habitat v. flow relationships

EFSAP utilizes coupled generalised models of reach-averaged wetted width versus flow and habitat quality versus reach-averaged specific discharge (flow/width) to describe the relationship between habitat availability and flow at a site.

Estimating wetted width

Booker (2010) defines a power-law relationship between discharge, Q ($m^3\ s^{-1}$), and mean wetted width, W (m), for each river reach:

$$\log(W) = d_0 + d_1 \log(Q) + d_2 (\log(Q))^2 \quad (1)$$

$$d_0 = a_0 + a_1 \log(A) \quad (a)$$

$$d_1 = b_0 + b_1 \log(A) \quad (b)$$

$$d_2 = c_0 + c_1 \log(A) \quad (c)$$

where A is catchment area (km^2) and a, b, and c take values dependent on REC classes. All logs are to the base 10. These models are used in EFSAP to estimate width-flow relationships for all REC network segments.

Estimating instream physical habitat

Conventional instream physical habitat models link hydraulic model predictions with microhabitat-suitability criteria to predict the availability of suitable habitat for a given species at various discharge rates (e.g. RHYHABSIM; Clausen et al. 2004, Jowett 1996, Jowett & Biggs 2006). The availability of suitable physical habitat is commonly expressed as Weighted Usable Area (WUA) in m^2 per 1000m of river channel (Figure 2-1). WUA is an aggregate measure of physical habitat quality and quantity, and will be specific to a particular discharge and taxa/life stage. Instream physical habitat models can be used to assess WUA over a range of flows and therefore to make predictions of how habitat changes with changes in flow.

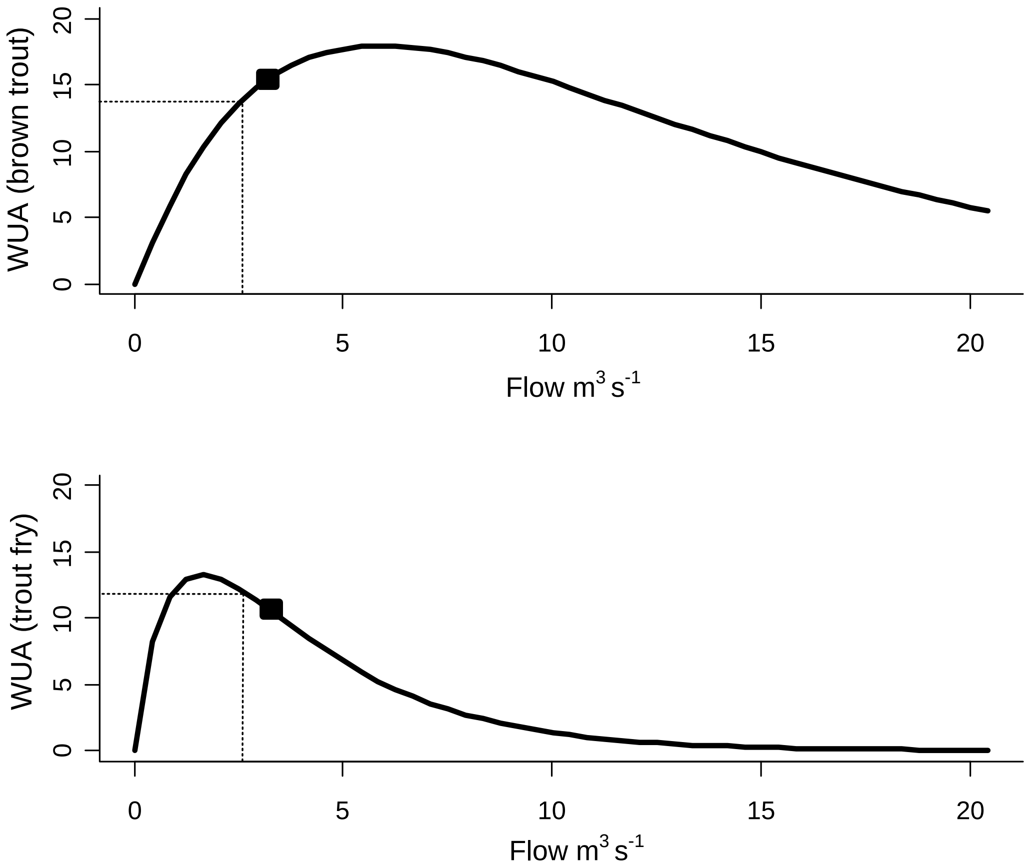

Figure 2-1: WUA versus flow curves for adult brown trout and brown trout fry for a network segment (mean flow = 20 m^3 s^{-1}). These curves were defined by combining equations 1 and 2. MALF for the segment (3.3 m^3 s^{-1}) is shown by the black square on the curve. WUA at the proposed NES minimum flow of 80% MALF are shown by the dashed lines. Note that WUA decreases between MALF and the minimum flow for adult brown trout, but increases for brown trout fry.

Criticisms of instream physical habitat models include lack of biological realism (Orth 1987) and failure of microhabitat-suitability criteria to reflect the detailed mechanisms that lead to density–environment associations (Booker et al. 2004, Davey et al. 2011, Lancaster & Downes 2010, Mathur et al. 1985). However, many microhabitat suitability models have a high degree of transferability between rivers and are therefore useful bases for the management of stream catchments (Lamouroux et al. 2010). The models have been applied throughout New Zealand (Lamouroux & Jowett 2005) and the world (Dunbar & Acreman 2001), primarily to assess impacts of abstraction. PHABSIM in particular has become a legal requirement for many impact studies in the USA (Reiser et al. 1989) and RHYHABSIM (the New Zealand equivalent) a standard tool employed to define minimum flows in New Zealand (Beca 2008).

Generalised instream habitat models (Lamouroux & Jowett 2005) have been developed from the results of many individual habitat studies conducted throughout New Zealand. These models generalise the relationship between flow and habitat in natural stream reaches based on simple reach-average hydraulic characteristics (Lamouroux & Jowett 2005). Therefore, when linked with hydraulic geometry models (i.e., empirical models relating hydraulic parameters such as width, depth, and velocity to discharge), generalised habitat models make it possible to simulate the relationship between flow and habitat over whole river networks (see examples in Jowett 1998, Lamouroux 2008, Lamouroux & Capra 2002, Snelder et al. 2011). We used the generalised instream habitat models provided by Jowett et al. (2008) to estimate WUA as a function of reach-averaged specific discharge (flow/width). The flow-habitat relationships describe a unimodal shape that depends on two coefficients, *j* and *k*, that are specific to a taxa and *i*, which is specific to a reach:

$$WUA = i\left(\frac{Q}{W}\right)^{j} e^{-k\left(\frac{Q}{W}\right)} \quad (2)$$

The ratio of WUA at two discharges depends only on discharge and the width-discharge relationship, but not on the reach coefficient *i*. Consequently, the width-flow relationship (Equation 1) can be combined with Equation 2 to estimate relative changes in habitat with changes in flow over a whole river network (Lamouroux & Souchon 2002).

2.1.4 Analysis options

EFSAP is based on the analysis and simulation of four key variables:

- Flow changes (c.f. total allocation) (ΔQ)
- Minimum flow (Q_min)
- Reliability of supply (R)
- Habitat change (ΔH)

When undertaking a simulation, any two of these variables may be specified and the other two will be calculated at all locations on the river network. For example, to simulate the consequences of the default minimum flow and total allocation limits for small rivers set in the proposed National Environmental Standard for ecological flows and water levels (MfE 2008), flow change (ΔQ) would be set as 30% MALF and minimum flow (Q_min) as 90% MALF, and reliability of supply (R) and habitat change (ΔH) for the target species would be calculated by the model for all locations.

EFSAP can be run in two modes: global and local. Global simulations are used to evaluate the spatial consequences of rules or objectives applied uniformly across the river network e.g., the proposed NES rules. In this mode, all reaches are treated as independent and thus the spatial distribution of takes upstream of a site is not taken into consideration and effects are not accumulated down the river network. The results can therefore be interpreted as representing the consequences of a particular water allocation scenario at each location independently of any upstream allocation. The global mode was used for Scenarios 1 in this project. The local mode allows simulation of the cumulative effects of site specific takes. In this mode, the location, take volume (ΔQ) and minimum flow (Q_min) of every abstraction are specified and the effects are accumulated down the river network. This approach is more suitable for catchment specific investigations where good data are available on the location and characteristics of takes. The local mode was used for Scenarios 2, 3 and 4 in this project. For more details of the scenarios see Section 2.2.3.

2.2 Applying EFSAP in the Piako catchment

2.2.1 Assumptions

The models upon which EFSAP is based are not calibrated for every location on the river network, but instead provide a generalised estimate that, when considered collectively, help to understand regional or catchment scale patterns. Results should therefore be evaluated and interpreted in this context.

Booker and Woods (2012) showed for the Waikato region that characteristics of the FDC can vary between months and monthly FDCs have shapes different to the shape of the all-year FDC. This means that for a given minimum flow and allocation limit, average reliability of supply for out-of-channel uses will vary between months, with the lowest reliability occurring in the month with the greatest frequency of low flows. To allow for this variability, EFSAP simulations for the Piako catchment have been run using the annual FDC and the FDC for March only. The March FDC was chosen for analysis because, on average, the greatest frequency of low flows occurs in this month and therefore it is the most resource limiting month (Edmund Brown, WRC, personal communication). Since inter-annual variability was not considered, results produced using the March FDC should be interpreted as representing conditions in March over many years.

Estimates of reliability of supply were based on the position of various proportions of the 1 in 5 year mean annual 7-day low flow (Q5) on the flow duration curves. Estimates of the naturalised Q5 were derived from a national scale random forest regression model. Results for the Piako catchment are shown in Figure 2-2 and are compared with estimates of non-naturalised Q5 derived from gauged flow records by WRC (Table 2-1).

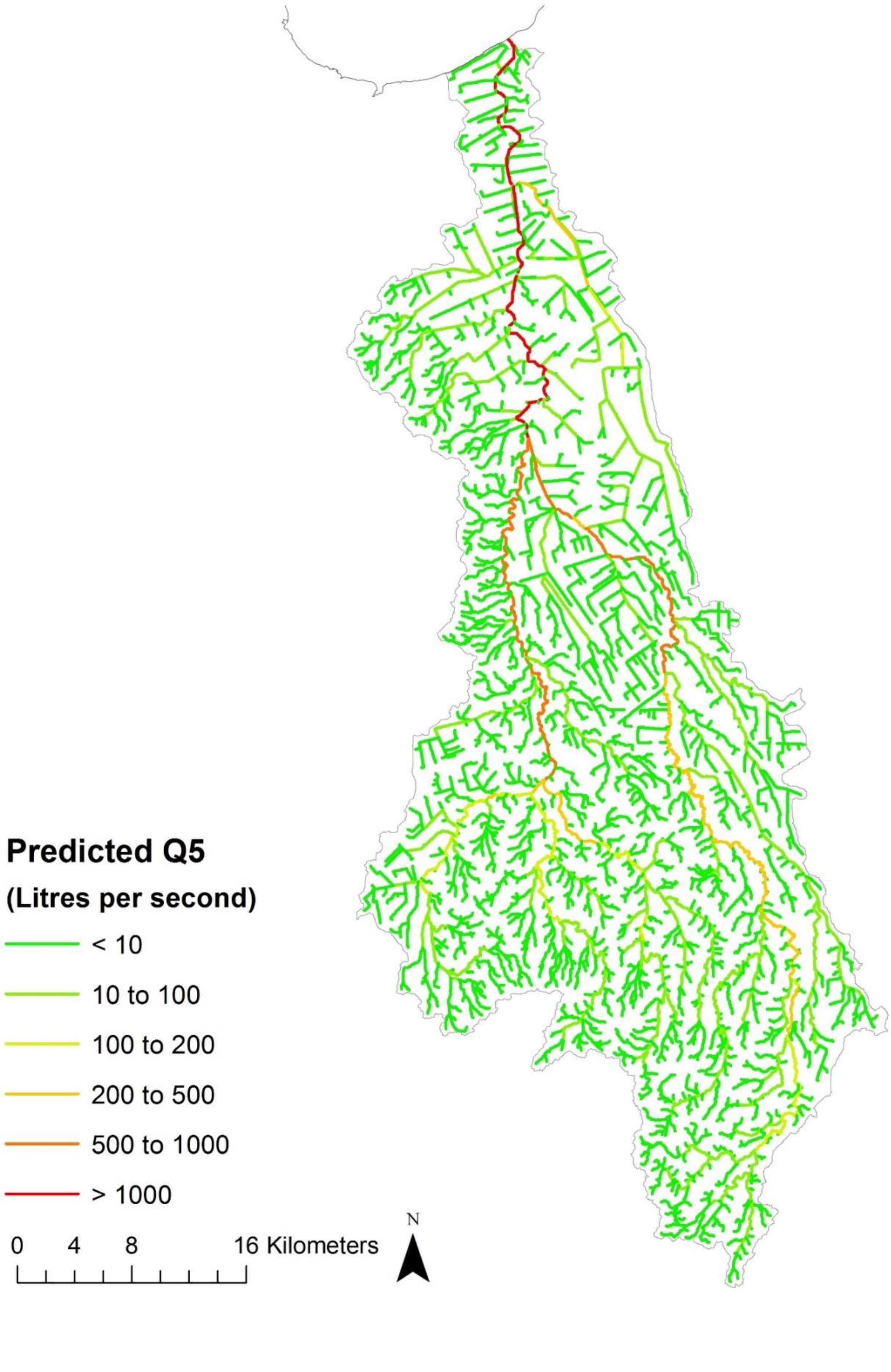

Figure 2-2: Predicted values of Q5 in the Piako catchment. Values are derived from a national scale random forest regression model.

The predicted naturalised and measured Q5 values were similar at both the Kiwitahi and Waharoa gauging sites. However, at the downstream sites, the predicted naturalised Q5 for the main stem of the Piako at Morrinsville and the Paeroa-Tahuna Road are significantly higher than the measured values of Q5. To some extent this may reflect the difference between naturalised (i.e., influence of abstractions removed) and non-naturalised (i.e., influence of abstractions included) estimates produced by the random forest model and from the gauged flow data respectively. However, it seems possible that there may be some over estimation of Q5 in the main stem of the Piako downstream of Morrinsville. Conversely, the predicted naturalised Q5 for the Waitoa at Mellon Road was lower than the measured value of Q5 (Table 2-1).

The implications of these differences for the interpretation of the modelling results are that in the main stem of the Piako downstream of Morrinsville, the absolute quantity of water predicted to be available under the Plan allocation rules will be higher than in reality. Consequently, the percent allocated will be slightly underestimated in these reaches in Scenarios 2, 3 and 4 (see Section 2.2.3 for description of scenarios). However, in the lower reaches of the Waitoa the absolute quantity of water predicted to be available for allocation may be underestimated and thus the percent allocated in Scenarios 2, 3 and 4 will be slightly overestimated.

Table 2-1: Comparison of predicted naturalised and measured estimates of Q5 at selected sites in the Piako catchment.

Site	Easting	Northing	REC reach number	Q5 estimate ($m^3 s^{-1}$)	
				WRC measured	RF predicted naturalised
Piako Paeroa-Tahuna Road	1821506	5845138	3012314	0.55	0.76
Piako Morrinsville	1824757	5829775	3015051	0.32	0.61
Piako Kiwitahi	1830006	5823865	3016180	0.15	0.18
Waitoa Mellon Road	1832407	5843047	3012842	0.81	0.67
Waitoa Waharoa	1841452	5816460	3017588	0.19	0.21

When simulating consequences for environmental state and reliability for out-of-channel uses, it is assumed that the full quantity of allocated water available is taken all of the time. This represents the worst case situation (assuming all abstractions are consented and all permitted takes are accounted for). In reality this is rarely the case, but greatest demand for out-of-channel uses typically occurs when the resource is most limited (i.e., dry summers) and therefore it is important that water resource use limits are designed to provide sufficient protection of environmental values and reliability of supply at full capacity.

EFSAP uses instream physical habitat as a measure of environmental state. The use of physical habitat is based on the assumption that habitat availability, rather than other factors such as water quality or migration barriers, is the primary limiting factor on the target species. Physical habitat is used as a surrogate for the suitability of a site to support the target species, but the availability of suitable habitat does not mean that a species will be present, and the quantity of suitable habitat does not necessarily correlate with species abundance. Factors such as water quality and migration barriers will also be considered as part of the wider review of the ecological impacts of water quantity limits in the Piako catchment.

2.2.2 Indicator species

Generalised habitat models are currently only available for a restricted number of species and life stages in New Zealand (Appendix A, Table A-1). The values for the model coefficients were derived by Jowett et al. (2008) from a dataset of 99 stream reaches in New Zealand. The 'flow demand' (in terms of optimal discharge per unit width; Appendix A, Table A-1) for some species is logical based on our understanding of the traits of the individual species, e.g., torrentfish (which prefer fast flowing riffle habitats), having the highest demand of the native fish species. However, the optimal discharges defined by the Jowett et al. (2008) models are less intuitively logical for other species, e.g., common bully (which have very flexible habitat requirements, but relatively high flow demand). It is possible that this is symptomatic of a sampling bias in the data used to derive the models towards daytime habitats in wadeable gravel rivers. Further work is required to validate the use of these models, and particularly their transferability across different river types. This research would help to reduce uncertainty in the models and their output. It would also be beneficial to expand the range of species and life stages included to provide more flexibility in selecting relevant target species. However, at present these are the best available models and have been widely utilised in New Zealand instream flow assessments.

The indicator species used for this assessment were determined with reference to both known (New Zealand Freshwater Fish Database (NZFFD); Franklin & Bartels 2012, Franklin et al. 2013) and predicted (Leathwick et al. 2008) fish distributions, and in consultation with WRC staff (Table 2-2).

Table 2-2: Indicator species used for EFSAP simulations in the Piako catchment.

Indicator species	Justification
Shortfin eel (<30 cm)	Cultural value and broad distribution
Common bully	Broad distribution
Inanga	Recreational value and sensitive to environmental changes

2.2.3 Scenarios

Five different scenarios were simulated for the Piako catchment as described below:

1. **Piako allocation rules**
   - The EFSAP global mode was used to simulate the consequences of the primary and secondary allocation rules set out for the Piako catchment in Table 3-5 of the Plan (Figure 2-3).
   - All reaches are treated independently.

2. **Piako permitted takes**
   - The EFSAP local mode was used to simulate the consequences of the estimated permitted takes (for details of permitted takes see Appendix B).
   - Effects are accumulated down the river network.

3. **Piako current takes**
   - The EFSAP local mode was used to simulate the consequences of Scenario 2 plus consented takes provided by WRC (see Appendix B).

- Effects are accumulated down the river network.

4. **Piako no irrigation takes**

   - The EFSAP local mode was used to simulate the consequences of removing all consented irrigation takes from Scenario 3.

   - Effects are accumulated down the river network.

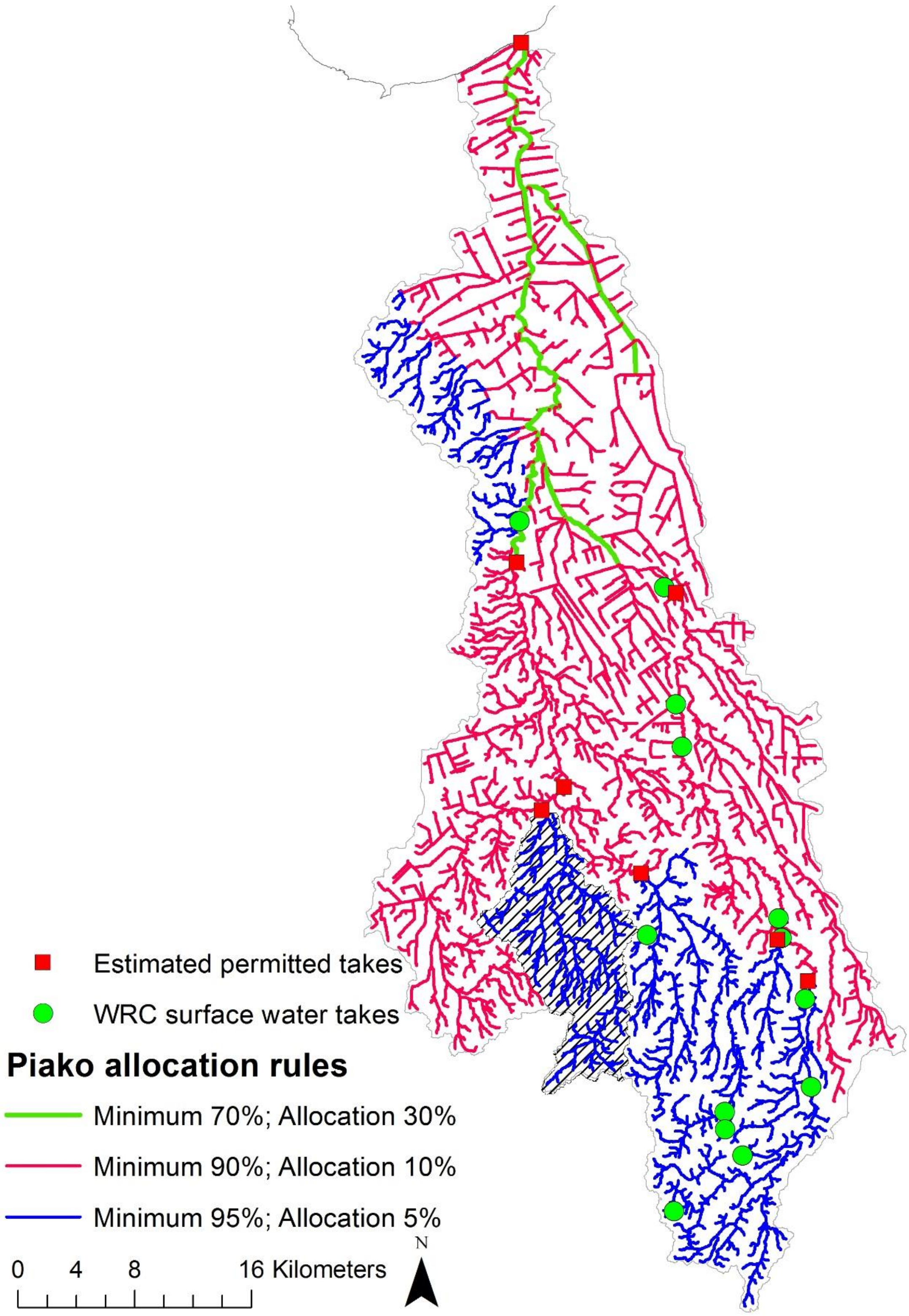

Figure 2-3: Primary allocation rules in the Piako catchment. Rules are defined as a percentage of the 1 in 5 year 7-day mean annual low flow (Q5). Secondary allocation limits are defined as 30% of Q5 minus the Primary Allocation limit. Shaded area is the Topehaehae catchment which was excluded from the analyses in Scenarios 2, 3 and 4 at WRC's request.

2.2.4 Analyses

Reliability of supply was determined for both the proportion of time that abstractions are partially restricted and the proportion of time that no abstraction is possible because natural flows are at or below the minimum flow set in the Plan. These two points were termed 'reliability' and 'restriction' respectively. For Scenario 1, potential reliability and restriction were determined for all locations on the river network. For Scenarios 2, 3 and 4, reliability and restriction were determined at the point of take for all the simulated permitted and consented takes.

The availability of physical habitat was described in terms of the weighted usable area (WUA). The predicted change in habitat availability can be expressed in various ways. In this case, for every segment of the river network, we calculated WUA at MALF from the naturalised FDC and again from the flow at the same percentile on the modified FDC. To allow comparison of all network segments, we expressed the WUA from the modified FDC as a percentage of the WUA at MALF. This measure of habitat change integrates the effects of both the minimum flow and allocation limits on available habitat (since both alter the FDC). It is based on the assumption that habitat is limiting at natural low flows and that fish communities are adapted to cope with that restricted quantity of suitable habitat for a certain proportion of the time (i.e., that which occurs naturally). When the flow regime is modified, the amount of suitable habitat available for that same proportion of time (i.e., same flow percentile) will change. The greater the difference between the two values, the greater the likely impact on WUA and therefore fish communities.

For Scenarios 2, 3 and 4, the cumulative effects of all upstream water takes were calculated for all locations on the river network. The results were presented as a percentage of the allocation limits set out in Table 3-5 of the Plan indicating where in the catchment is predicted to be over allocated (>100% of allocation limit).

2.3 Piako allocation rules

In Scenario 1 EFSAP was used to model the consequences of uniformly applying the allocation rules defined for the Piako catchment in Table 3-5 of the Plan (Waikato Regional Council 2012). This modelling scenario takes no account of potential cumulative effects of multiple takes, but demonstrates the potential reliability of supply and change in predicted suitable instream habitat for the indicator fish species across all reaches in the catchment. The results of the modelling for the annual flow duration curve are summarised in Table 2-3 and presented in Figure 2-4 to Figure 2-10. Results for the March period are presented in Appendix C.

The median predicted annual reliability of supply for the primary allocation is high at 96.4% (Table 2-3). The 10th percentile value (i.e., the value that 90% of reaches in the catchment will exceed) is 87.0%, meaning that the current primary allocation rules provide high potential reliability across most reaches of the catchment as intended by WRC. The main area where predicted reliability of supply is lower occurs around Richmond Downs and the Piakoiti Stream (Figure 2-4). It was predicted that the median annual proportion of time that none of the primary allocation would be available is 3.0%, with greatest predicted restrictions likely to occur around the Richmond Downs and Piakoiti Stream area (Figure 2-5; Table 2-3).

No secondary allocation is available in the lower reaches of the main stem of the river and hence reliability of the secondary allocation is zero in these reaches. 50% of reaches have a reliability of supply for the secondary allocation of > 94.7%, with 90% of reaches having a reliability of greater than 81.1% based on the all-year FDC (Table 2-3). The median proportion of time when the secondary allocation is not available is low at 3.6%, but the proportion of time when the secondary allocation is restricted is again higher in the area around Richmond Downs and the Piakoiti Stream (Figure 2-7; Table 2-3).

The Plan rules also allow for water harvesting to occur, with 10% of the flow available for out-of-stream use when flows are greater than the median flow. Because the minimum flow for this allocation block is the median flow, there will be no water available from this allocation block for 50% of the time.

Table 2-3: Summary of consequences for reliability and habitat change as a result of uniformly applying the allocation rules for the Piako catchment.

Value	Mean	10th percentile	Median	90th percentile
Primary allocation reliability of supply	94.2%	87.0%	96.4%	98.8%
Primary allocation full restriction	5.3%	1.0%	3.0%	11.9%
Secondary allocation reliability of supply	91.7%	81.1%	94.7%	98.0%
Secondary allocation full restriction	9.1%	1.2%	3.6%	16.9%
Common bully habitat change	-8.5%	-14.8%	-9.2%	0.0%
Inanga habitat change	-6.2%	-12.8%	-6.5%	0.0%
Shortfin eel habitat change	-7.3%	-13.3%	-7.6%	0.0%

The evaluation of impacts on instream physical habitat for fish focuses on the expected change relative to the quantity of habitat predicted to be available at MALF (see Section 2.2.4 for details). The spatial pattern of consequences for instream physical habitat change are similar for all three of the indicator fish species (Figure 2-8; Figure 2-9; Figure 2-10). Broadly, the change in habitat appears to be greater in smaller streams and less in the main stems of the Piako and its tributaries. The median annual change in available habitat was a reduction of 6.5%, 7.6% and 9.2% for inanga, shortfin eel and common bullies respectively (Table 2-3). The current primary and secondary allocation limits for the Piako catchment therefore appear to provide a reasonable level of habitat protection for the indicator species on average over a year.

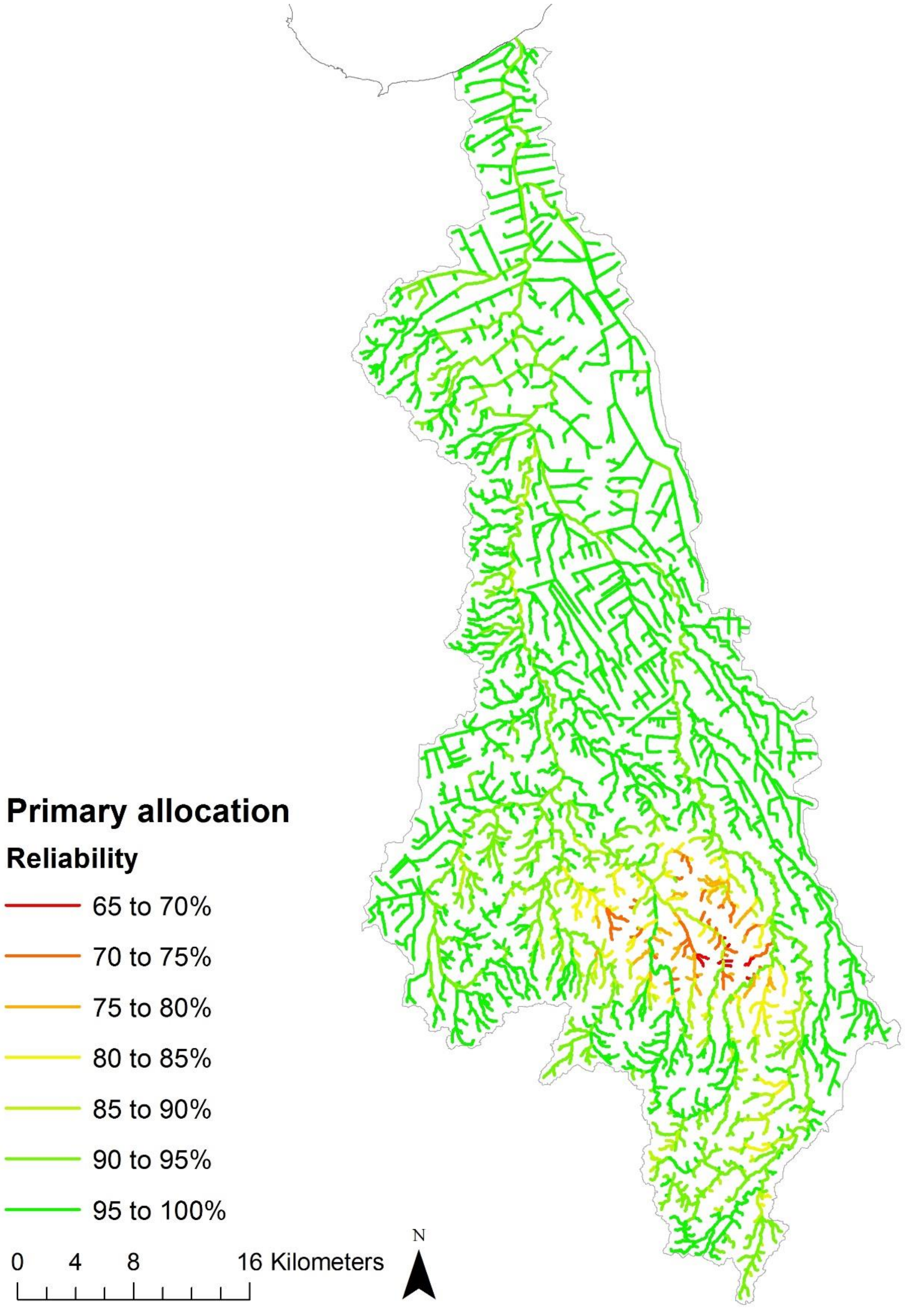

Figure 2-4: Predicted reliability of supply for the Primary Allocation if the Plan rules are applied uniformly (Scenario 1).

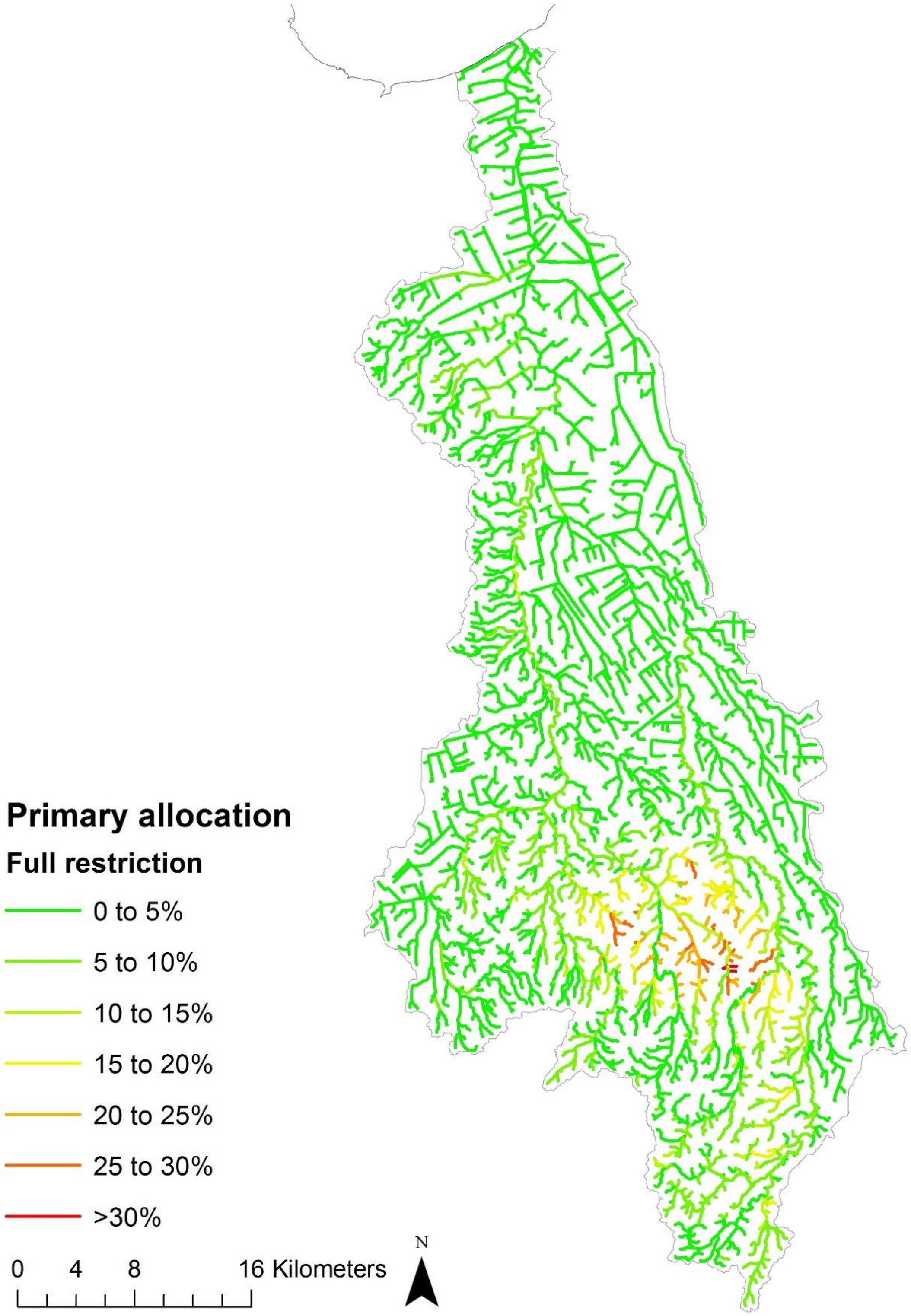

Figure 2-5: Predicted duration of full restriction on Primary Allocation if the Plan rules are applied uniformly (Scenario 1).

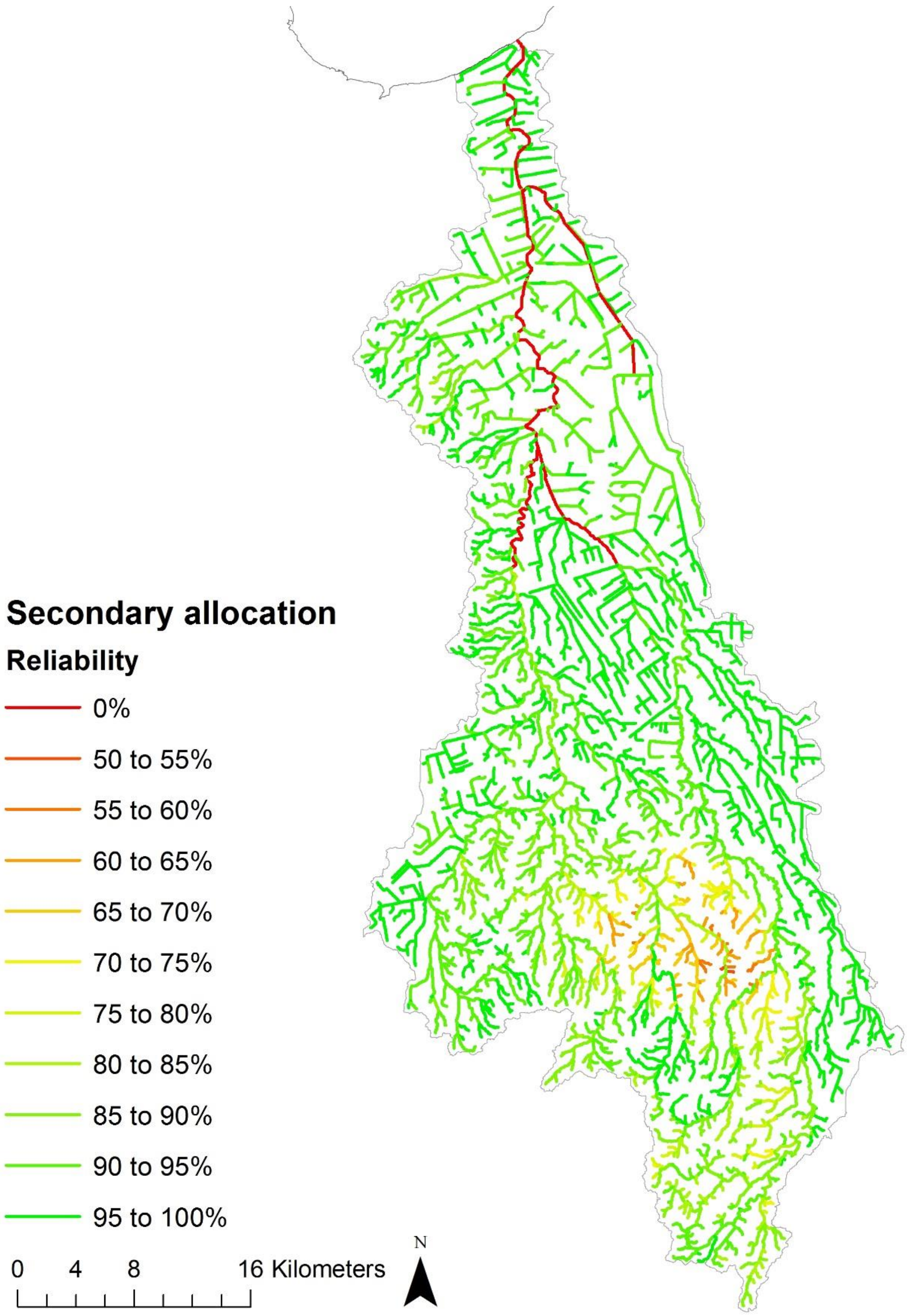

Figure 2-6: Predicted reliability of supply for the Secondary Allocation if the Plan rules are applied uniformly (Scenario 1).

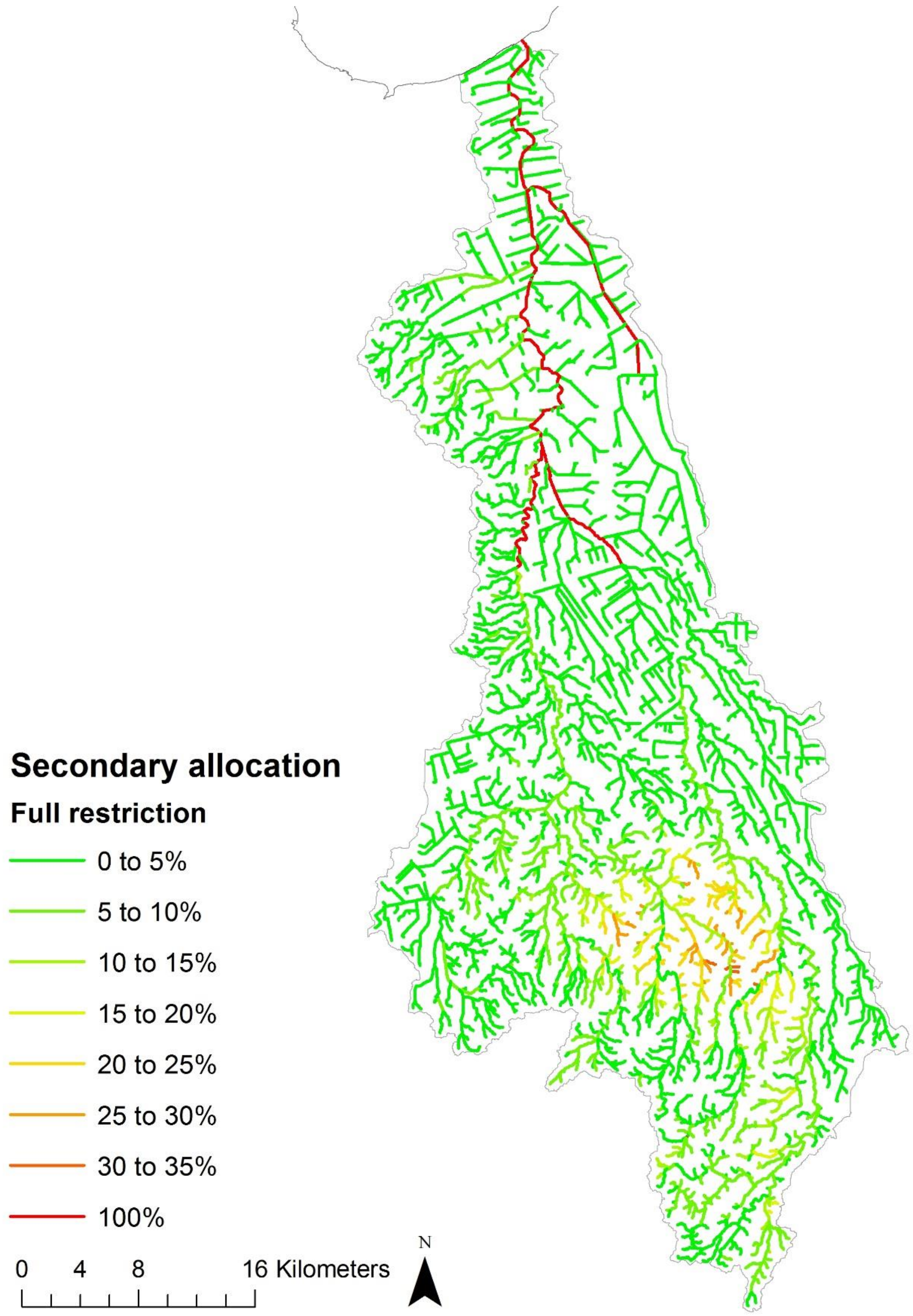

Figure 2-7: Predicted duration of full restriction on Secondary Allocation if the Plan rules are applied uniformly (Scenario 1).

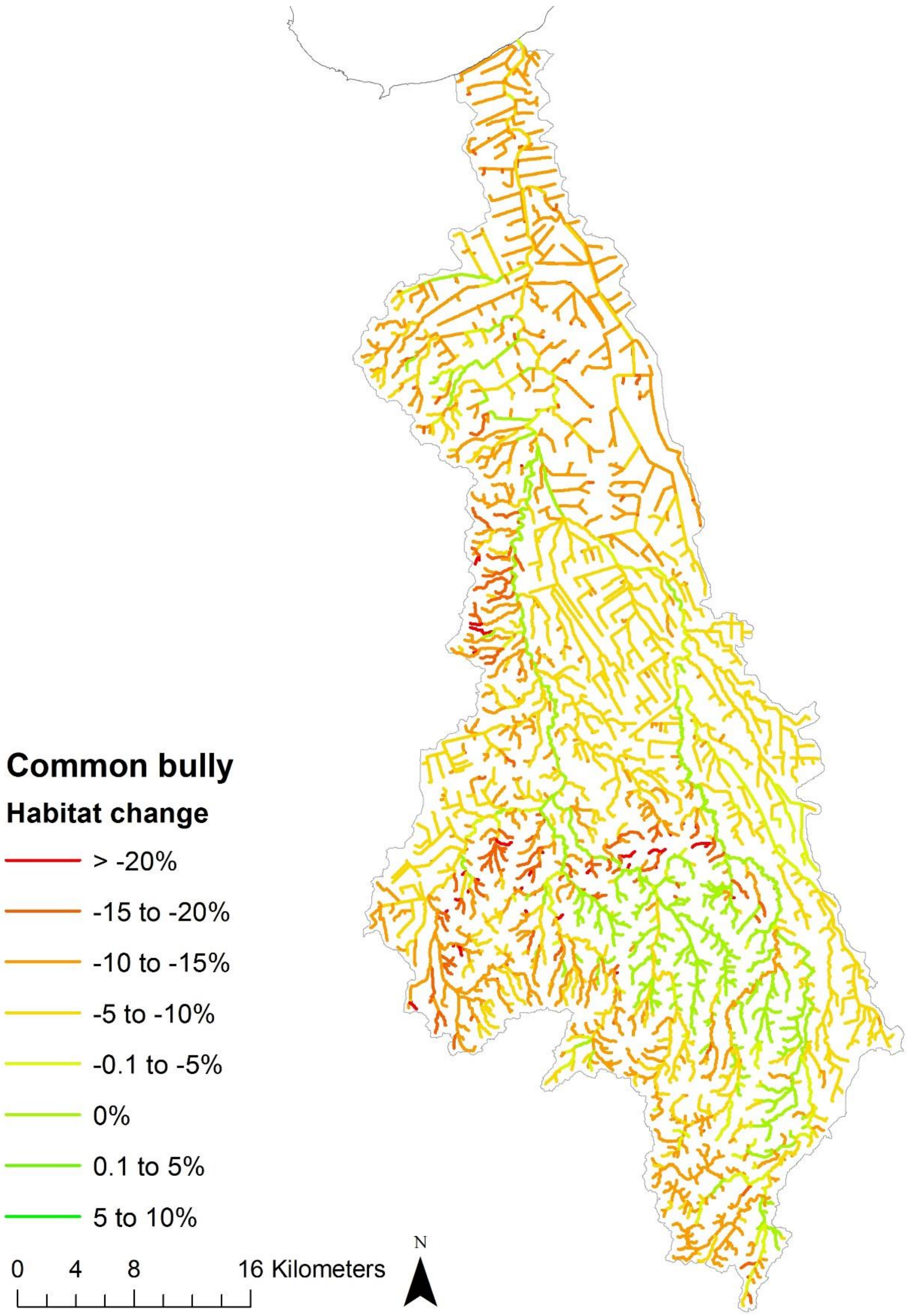

Figure 2-8: Predicted change in common bully habitat availability relative to mean annual low flow when the Primary and Secondary Allocations are fully allocated. Assumes the Plan rules are applied uniformly (Scenario 1).

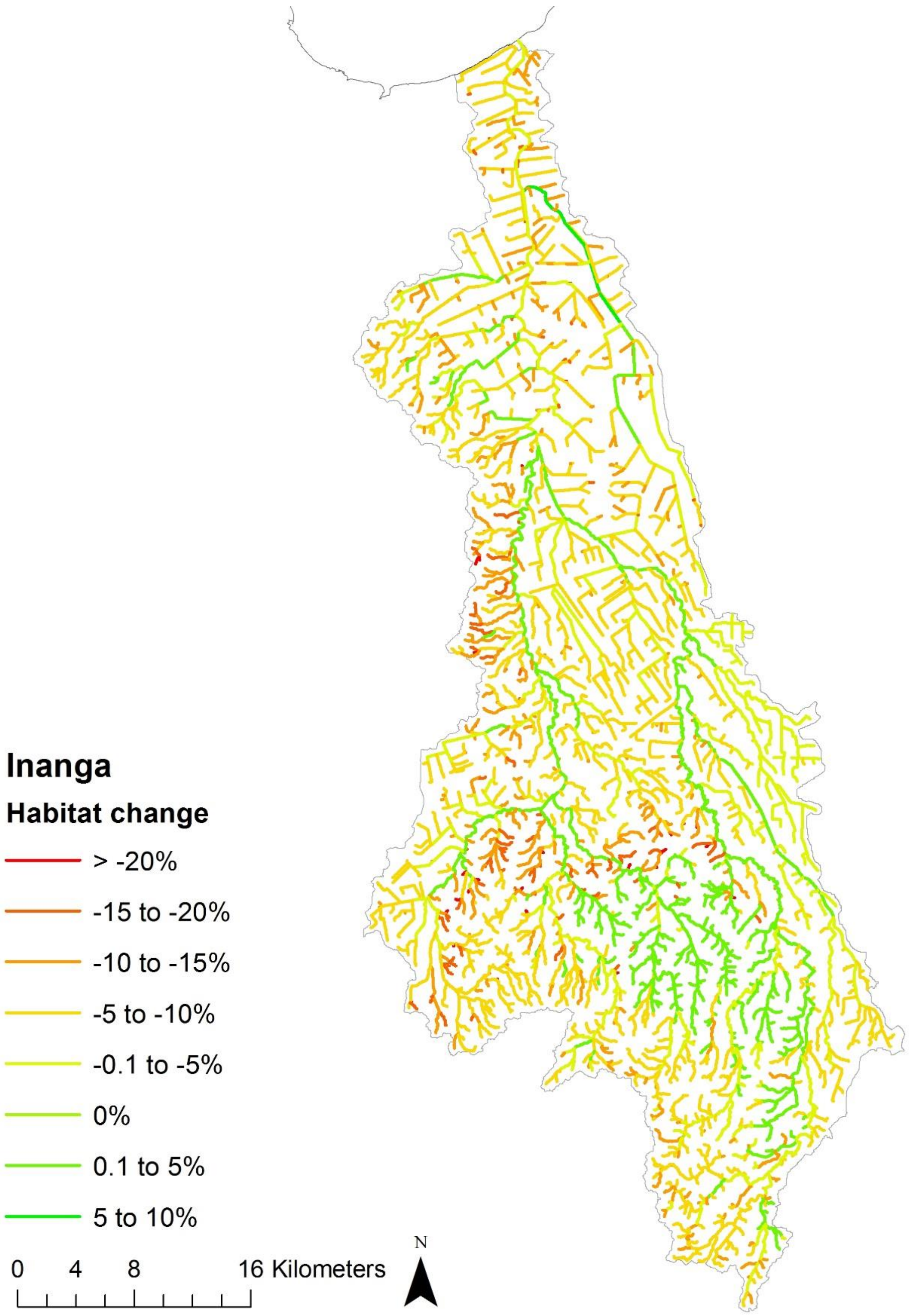

Figure 2-9: Predicted change in inanga habitat availability relative to availability at mean annual low flow when the Primary and Secondary Allocations are fully allocated. Assumes the Plan rules are applied uniformly (Scenario 1).

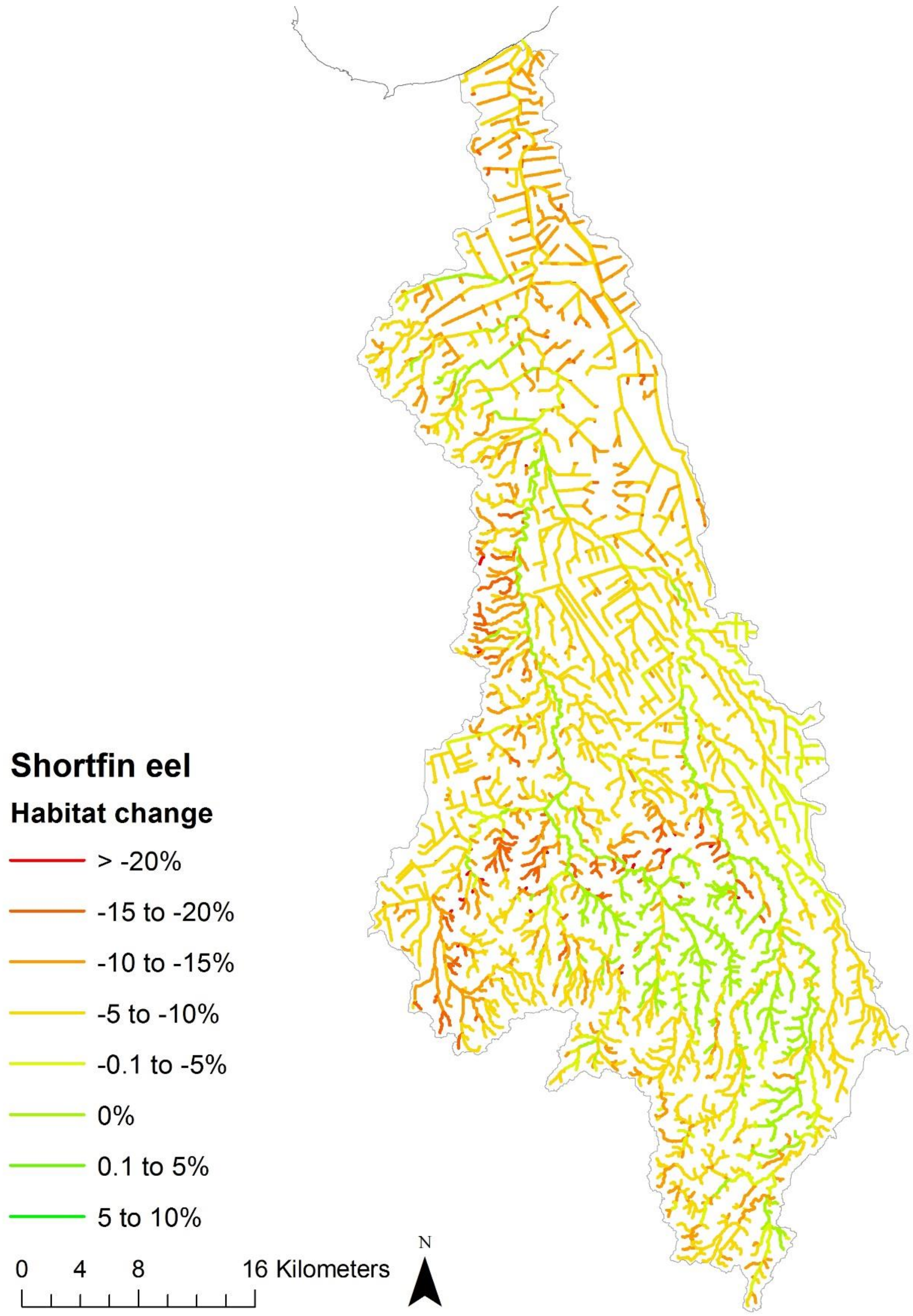

Figure 2-10: Predicted change in shortfin eel habitat availability relative to mean annual low flow when the Primary and Secondary Allocations are fully allocated. Assumes the Plan rules are applied uniformly (Scenario 1).

2.4 Permitted takes

Permitted water takes are those allowed under rule 3.3.4.13 of the Plan and by s14(3)(b) of the Resource Management Act (RMA) and do not require a consent. They are generally limited to no more than 15 m^3 day^{-1}. WRC provided estimates of the total volume of permitted takes for eight sub-catchments within the wider Piako catchment. Scenario 2 involved modelling the consequences of the estimated permitted takes. For the purpose of modelling, each estimate was treated as a single take at the downstream point of the sub-catchment for which they were calculated because the actual locations of permitted takes are not known. The combined effects of the multiple takes were accumulated down the river network. Because the location of the final estimate is at the river mouth, the consequences of these takes are not apparent in Figure 2-11 to Figure 2-14 describing the results for this scenario, but are included in the summary tables below.

A total of 147 reaches (of 2638 in the catchment) were impacted by permitted takes. This means that many reaches are unaffected because they are located upstream of any permitted takes. The number of impacted reaches will be an underestimate compared to reality due to the way the permitted takes are aggregated, estimated and modelled at the downstream point of individual sub-catchments rather than at each point of take. Of the 147 impacted reaches, 71 (or 48%) were over-allocated, i.e., the cumulative upstream take was greater than the allocation limit for the reach (shown where % allocated > 100% on Figure 2-11). All over-allocated reaches occurred upstream of the Paeroa-Tahuna Road due to the increase in primary allocation limits (to 30% of Q5) in the main stem of the river downstream of that location. Overall, 50% of the impacted reaches were less than 77.5% allocated, but 10% of the impacted reaches were more than 160% allocated, i.e., 60% over-allocated relative to the current allocation limits (Table 2-4).

For all three indicator fish species, the median change in instream physical habitat availability in reaches impacted by the estimated permitted takes was negative (Table 2-4). However, for inanga the impact was much less than for common bully or shortfin eel, with 90% of impacted reaches having less than a 2.3% reduction in instream physical habitat, compared to 13.6% and 12.8% reductions for common bully and shortfin eel respectively (Table 2-4; Figure 2-12 to Figure 2-14).

Table 2-4: Summary of consequences for habitat change and percent allocated as a result of estimated permitted takes in the Piako catchment (Scenario 3).

Value	Mean	10th percentile	Median	90th percentile
Percent allocated (Primary allocation)	92.8%	27.3%	77.5%	160.6%
Common bully habitat change	-9.0%	-13.6%	-7.8%	-6.1%
Inanga habitat change	-0.4%	-2.3%	-0.3%	1.8%
Shortfin eel habitat change	-8.4%	-12.8%	-7.9%	-5.1%

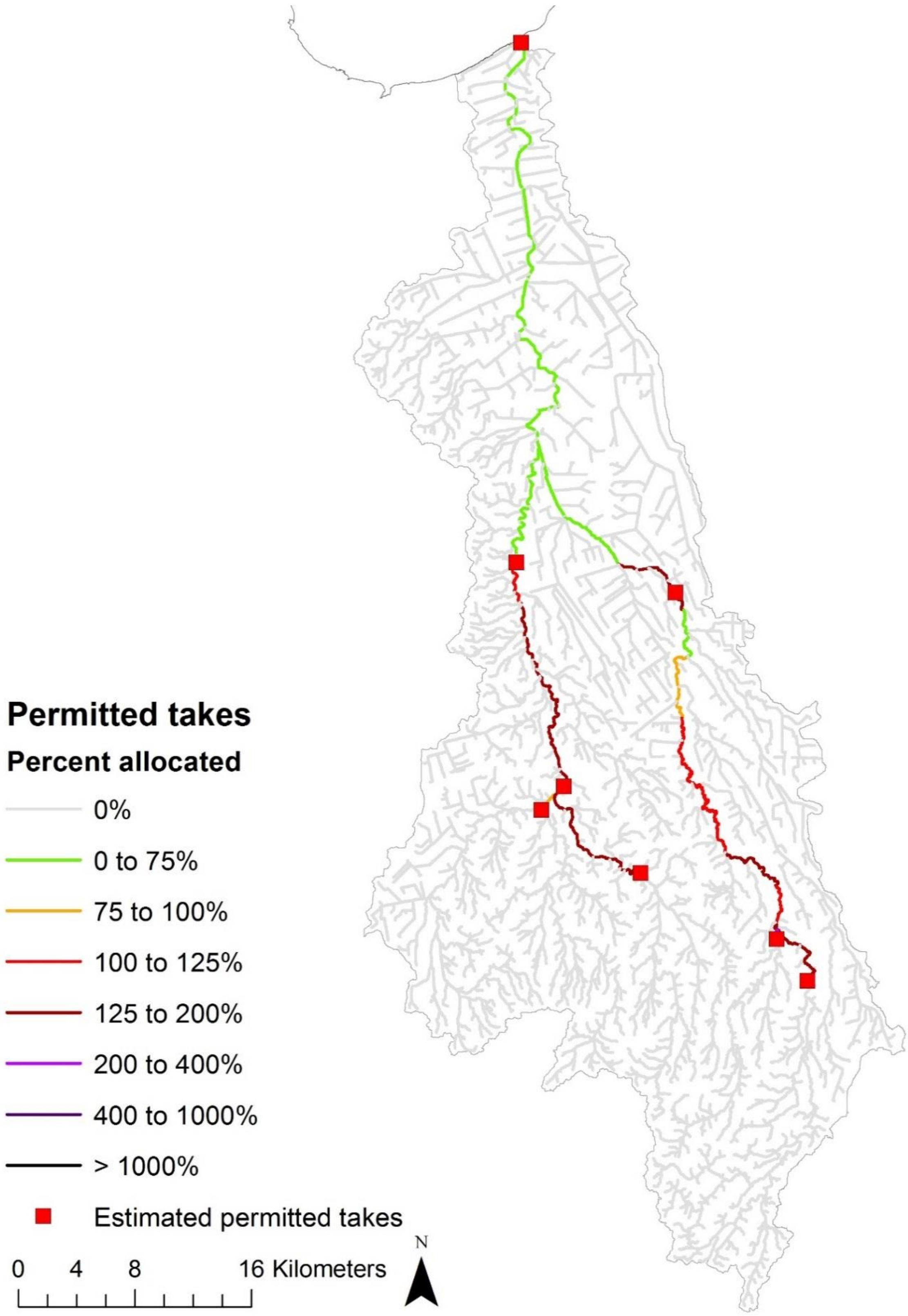

Figure 2-11: Percentage of the primary allocation taken by estimated permitted takes (Scenario 2). Percentage allocation was derived by dividing the total cumulative take in a reach ($L\ s^{-1}$) by the allocation limit for that reach (% of Q5 for the reach expressed in $L\ s^{-1}$).

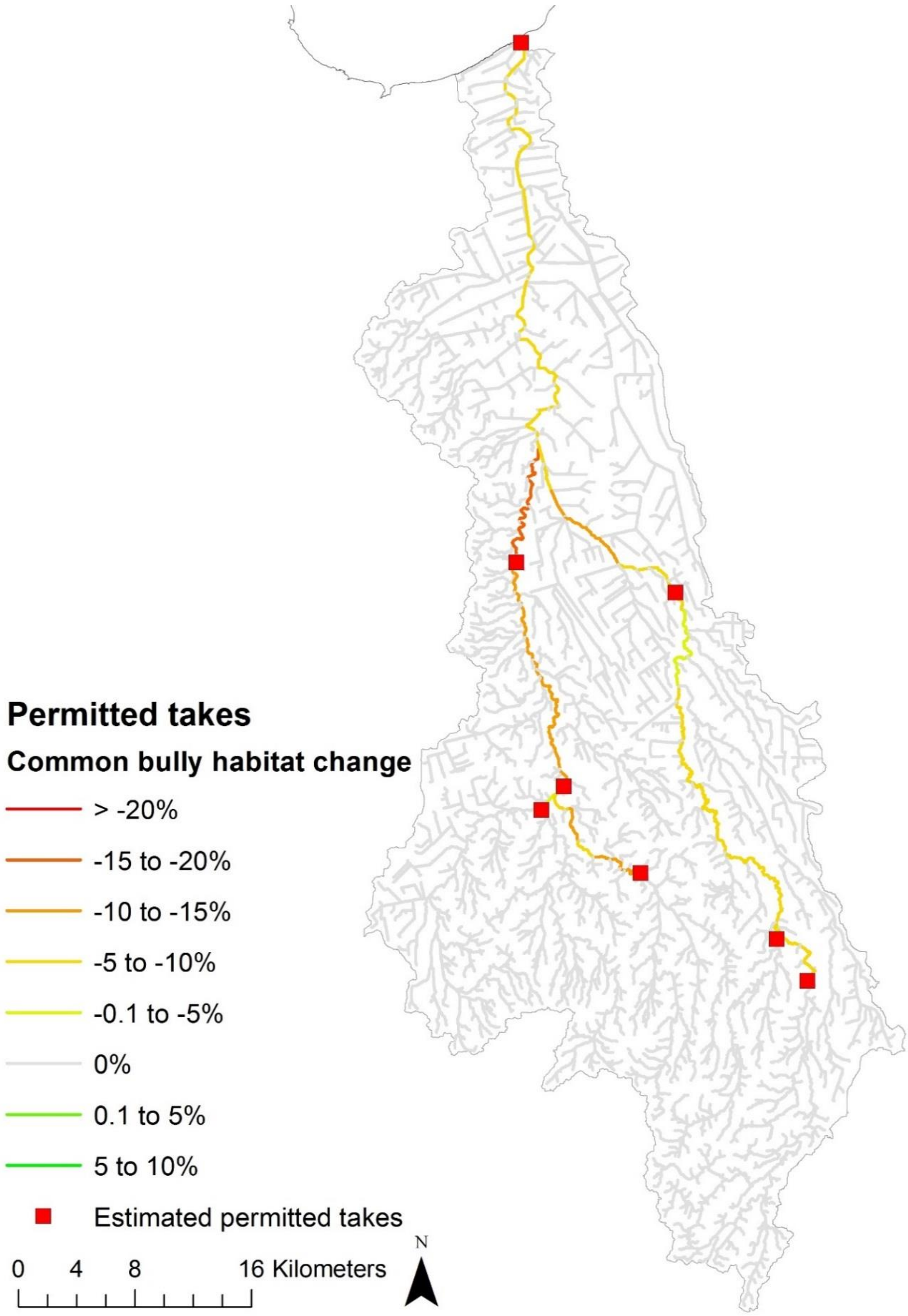

Figure 2-12: Predicted change in common bully habitat availability relative to mean annual low flow as a consequence of the estimated permitted takes (Scenario 2).

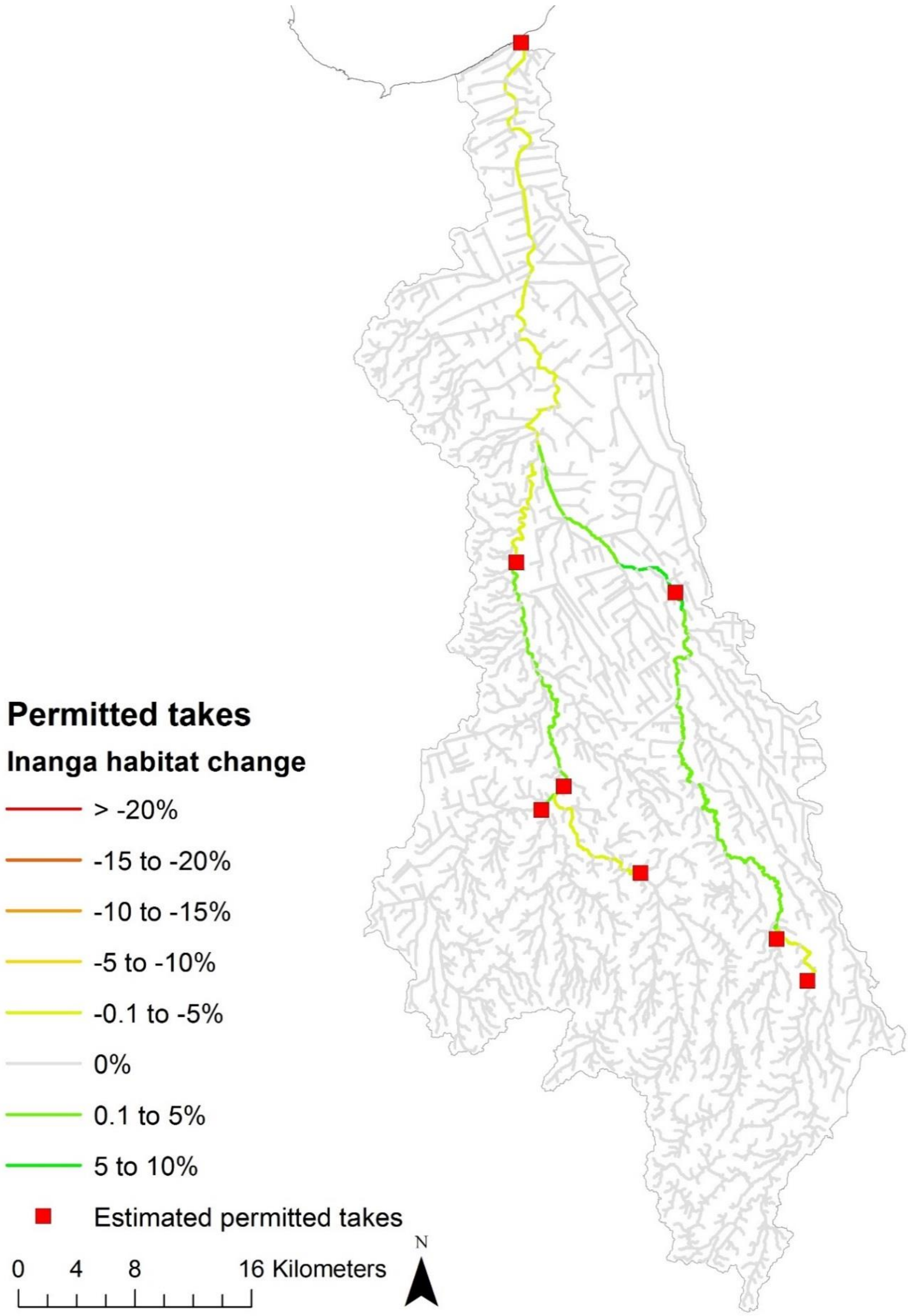

Figure 2-13: Predicted change in inanga habitat availability relative to mean annual low flow as a consequence of the estimated permitted takes (Scenario 2).

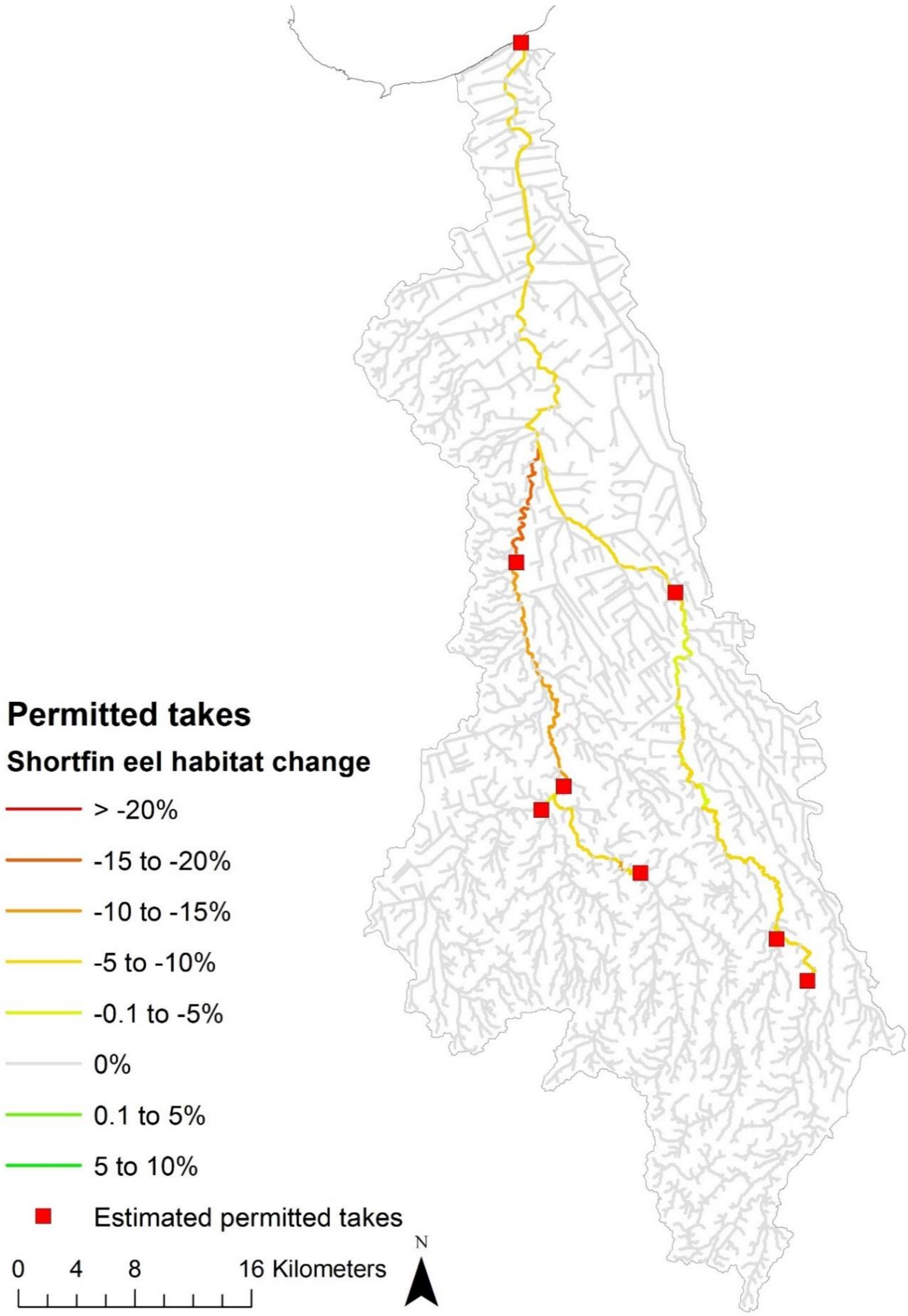

Figure 2-14: Predicted change in shortfin eel habitat availability relative to mean annual low flow as a consequence of the estimated permitted takes (Scenario 2).

The average annual reliability of the total permitted takes for each sub-catchment unit were calculated and are summarised in Table 2-5. Because there is essentially no minimum flow limit enforced on permitted takes, the reliability of supply is high at greater than 96% for all takes.

Table 2-5: Theoretical average annual reliability of supply and restriction for the estimated permitted takes (Scenario 2). Catchment areas refer to WRC sub-catchment definitions (see Appendix B).

Catchment area	Catchment description	Permitted takes	
		Reliability	Full restriction
126	Piako at Paeroa-Tahuna Road	96.3%	3.4%
129	Waitoa at Mellon Road	98.6%	1.1%
133	Piako at Morrinsville	97.3%	2.1%
237	Piako mouth	99.1%	0.9%
240	Upper Piako – Waitoa	98.3%	1.2%
241	Upper Piako – Mangapapa	99.0%	0.7%
242	Piako at Kiwitahi	97.3%	1.9%
243	Upper Piako - Topehaehae	97.5%	1.6%

2.5 Current takes

The aim of Scenario 3 was to characterise the current status of water allocation in the Piako catchment. This scenario includes the eight estimated permitted takes and thirteen consented takes provided by WRC. The conditions associated with the consented takes were used to allocate takes (or parts thereof) to either the primary or secondary allocation block (see Appendix B; Table 2-7). The take associated with the Morrinsville water supply dam in the Topehaehae catchment was excluded from the analysis at the request of WRC, and therefore total allocation will be underestimated for all reaches downstream of the Topehaehae catchment.

A total of 230 reaches in the catchment were predicted to be impacted by abstraction (Figure 2-15), an increase of 83 compared to Scenario 2. Of the 230 impacted reaches, the primary allocation limit was exceeded in 161 reaches (70% of impacted reaches; Figure 2-15) and the secondary allocation limit was exceeded in 70 reaches (30% of impacted reaches; Figure 2-16). 50% of the impacted reaches had a primary block allocation exceeding 160%, with 10% of reaches being more than 500% allocated (Table 2-6). For the secondary allocation block, 50% of reaches had more than 88.2% allocation, with the top ten percent of reaches being more than 430% allocated (Table 2-6).

The current allocation rules in the Piako catchment are such that total allocation from the primary and secondary allocation blocks should not exceed 30% of Q5. The median proportion of Q5 allocated in the impacted reaches is 40%, hence exceeding this limit. In 10% of the impacted reaches, the proportion of Q5 allocated exceeds 132% (Table 2-6). The greatest level of over-allocation occurs in the Waitoa River downstream of Matamata (Figure 2-17).

The impact of current allocation on instream physical habitat is predicted to be lowest for inanga, with a median reduction (over all impacted reaches) of only 0.5% relative to MALF (Table 2-6; Figure 2-19). However, for common bully and shortfin eels the median reduction in available habitat is 10% and 9% respectively. For 10% of the reaches the reduction is greater than 18% and 15% respectively (Table 2-6; Figure 2-18; Figure 2-20).

Table 2-6: Summary of consequences for habitat change and percent allocated as a result of current consented and estimated permitted takes in the Piako catchment (Scenario 3).

Value	Mean	10th percentile	Median	90th percentile
Percent allocated (Primary allocation)	296.9%	55.9%	159.7%	500.4%
Percent allocated (Secondary allocation)	195.6%	28.9%	88.2%	434.3%
Percent Q5 allocated (Total allocation)	64.1%	15.7%	39.8%	132.7%
Common bully habitat change	-9.9%	-18.0%	-8.9%	-1.2%
Inanga habitat change	-2.3%	-4.1%	-0.5%	1.1%
Shortfin eel habitat change	-9.0%	-15.3%	-8.8%	-1.0%

The absence of specified minimum flows for the estimated permitted takes means that the reliability of these takes is essentially unaffected by the consented takes which are more tightly controlled. For the majority of the consented takes the average annual reliability of the consented primary allocation is greater than 90% (Table 2-7). However, a number of the takes have lower reliability, particularly consent number 103276 which has a predicted reliability of only 66.1%. The reason for the low predicted reliability in this case is that the take is located in the headwaters of the catchment on a small stream where flow is predicted to be lower than the maximum allocated take volume for 33.9% of the time. All the remaining takes with an estimated annual reliability of supply of less than 90% are irrigation takes with stricter minimum flow conditions specified in the consent. Most of these takes are restricted to the October to May period and thus their actual reliability of supply is likely to be lower because these are lower flow months.

Table 2-7: Average annual reliability of supply and restriction for the current consented and estimated permitted takes (Scenario 3). *Permitted takes.

Consent number	Primary allocation		Secondary allocation	
	Reliability	Full Restriction	Reliability	Full Restriction
126*	96.3%	3.4%	-	-
129*	98.7%	1.1%	-	-
133*	97.3%	2.1%	-	-
237*	99.1%	0.9%	-	-
240*	98.3%	1.2%	-	-
241*	99.0%	0.7%	-	-
242*	97.3%	1.9%	-	-
243*	97.5%	1.6%	-	-
103276	66.1%	0.1%	-	-
109445	87.5%	6.7%	-	-
118411	97.7%	1.4%	-	-
120425	90.1%	9.5%	-	-
121132	87.8%	11.6%	-	-
121791	80.0%	6.2%	27.4%	19.3%
121791	91.8%	6.7%	78.7%	17.5%
122179	94.2%	5.7%	-	-
122179	94.3%	5.7%	-	-
122238	98.6%	1.2%	74.8%	9.5%
125284	91.3%	8.6%	-	-
930812	98.0%	1.8%	-	-

Consent number	Primary allocation		Secondary allocation	
	Reliability	Full Restriction	Reliability	Full Restriction
960080	99.0%	0.7%	70.2%	22.6%

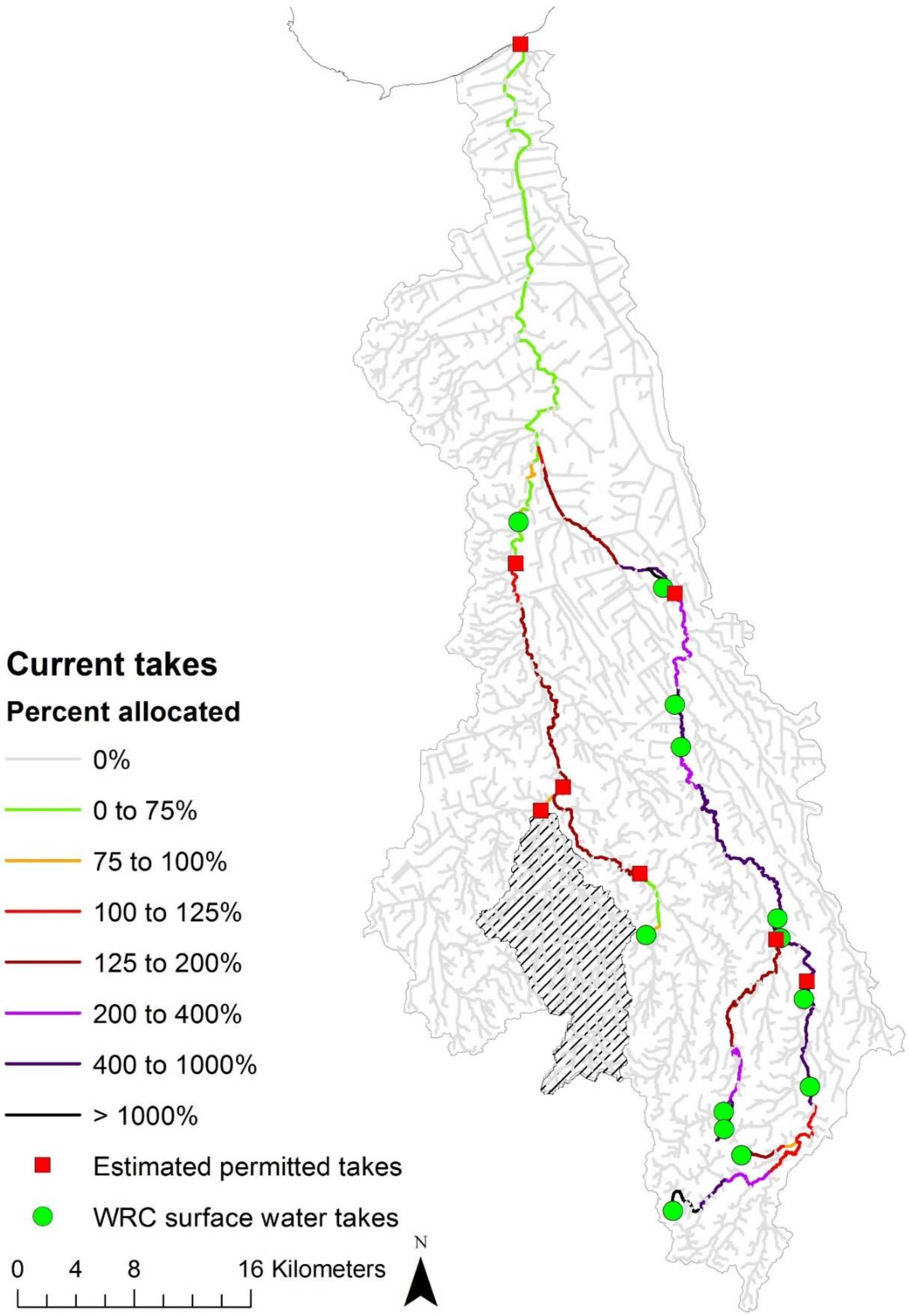

Figure 2-15: Percentage of the primary allocation taken by current consented and estimated permitted takes (Scenario 3). Percentage allocation was derived by dividing the total cumulative take in a reach (L s^{-1}) by the allocation limit for that reach (% of Q5 for the reach expressed in L s^{-1}). The hatched area is the Topehaehae catchment which is not included in the analyses.

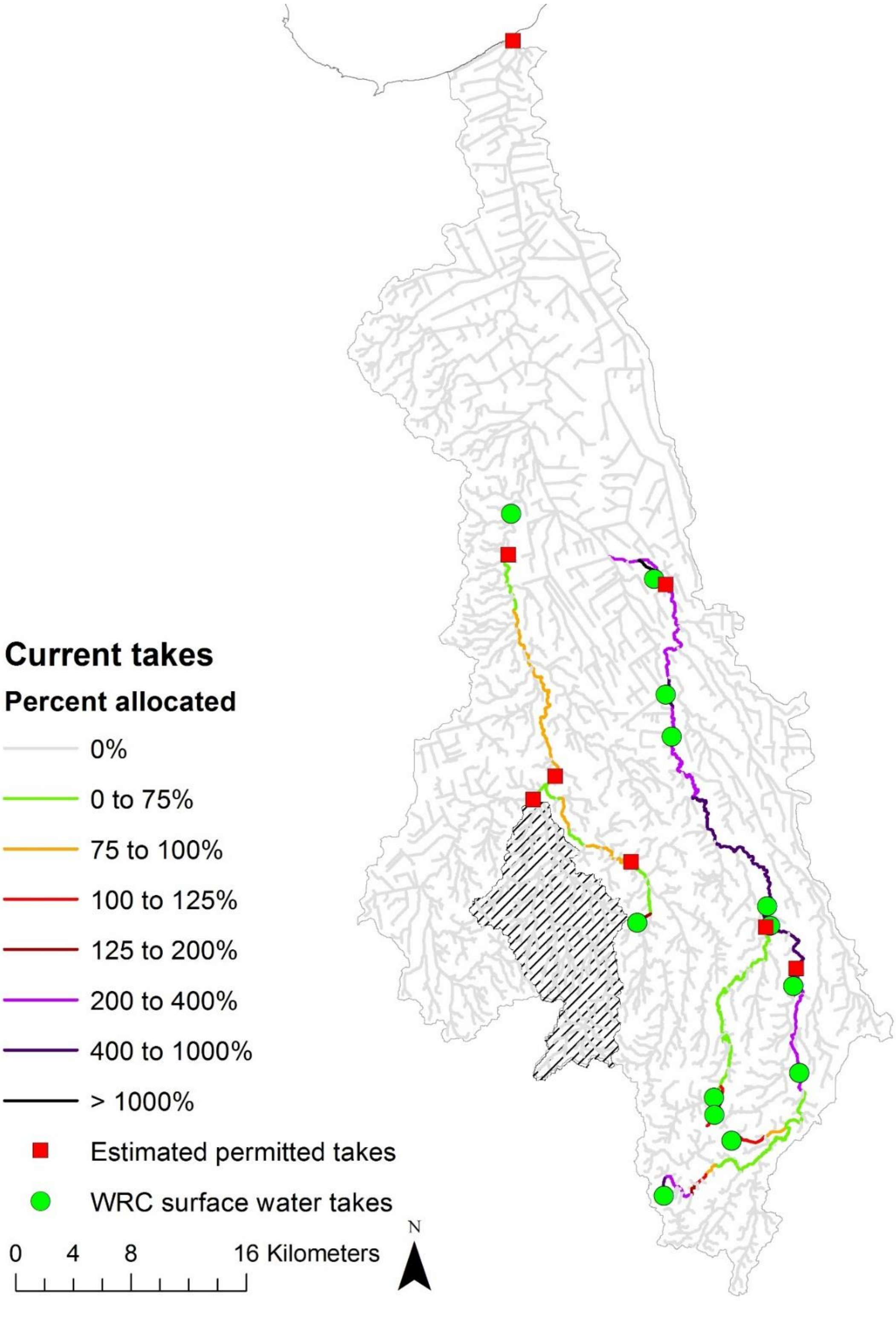

Figure 2-16: Percentage of the secondary allocation taken by current consented and estimated permitted takes (Scenario 3). Percentage allocation was derived by dividing the total cumulative take in a reach (L s^{-1}) by the allocation limit for that reach (% of Q5 for the reach expressed in L s^{-1}). The hatched area is the Topehaehae catchment which is not included in the analyses.

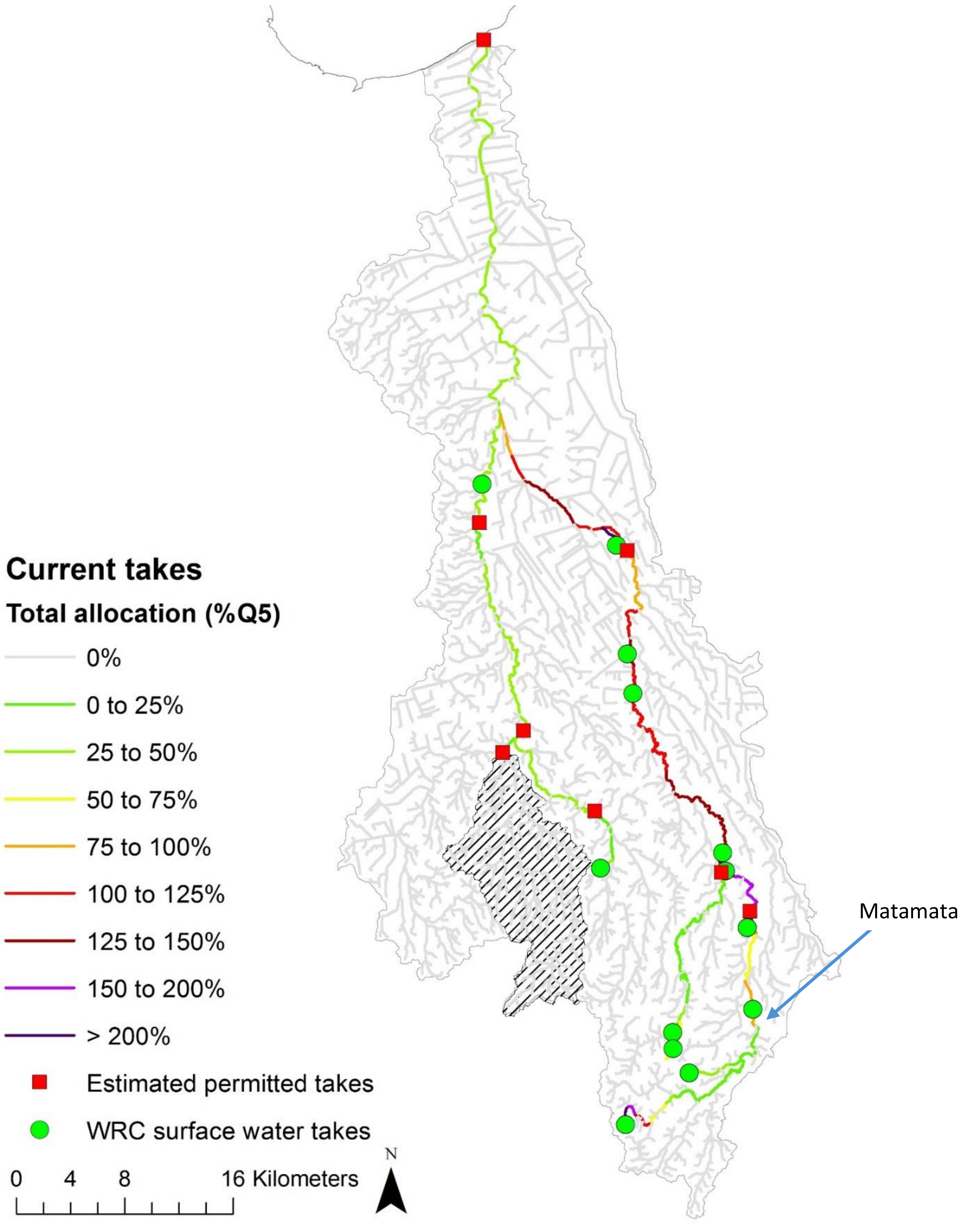

Figure 2-17: Percentage of Q5 taken by current consented and estimated permitted takes (Scenario 3). The hatched area is the Topehaehae catchment which is not included in the analyses.

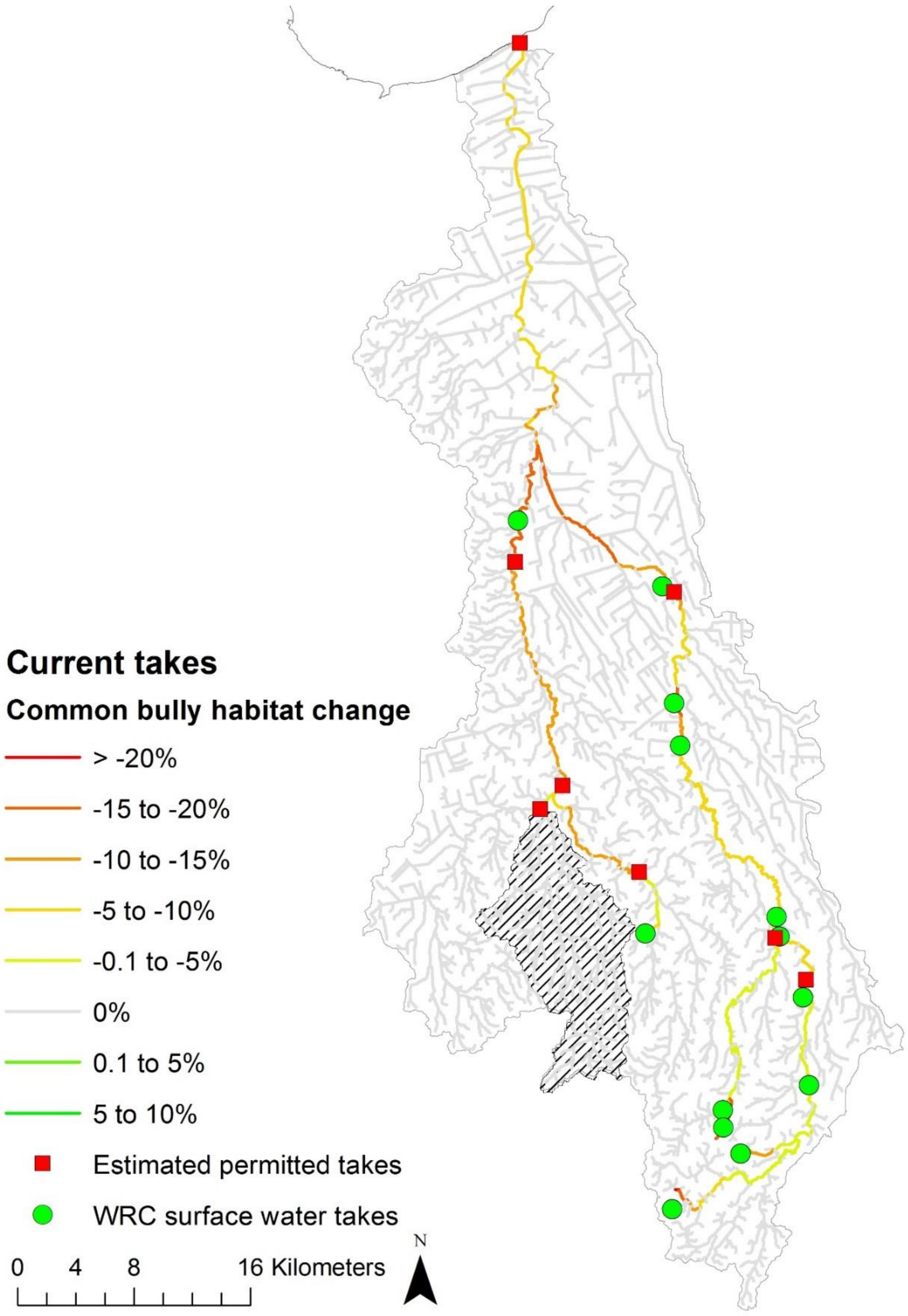

Figure 2-18: Predicted change in common bully habitat availability relative to MALF as a consequence of the current consented and estimated permitted takes (Scenario 3). The hatched area is the Topehaehae catchment which is not included in the analyses.

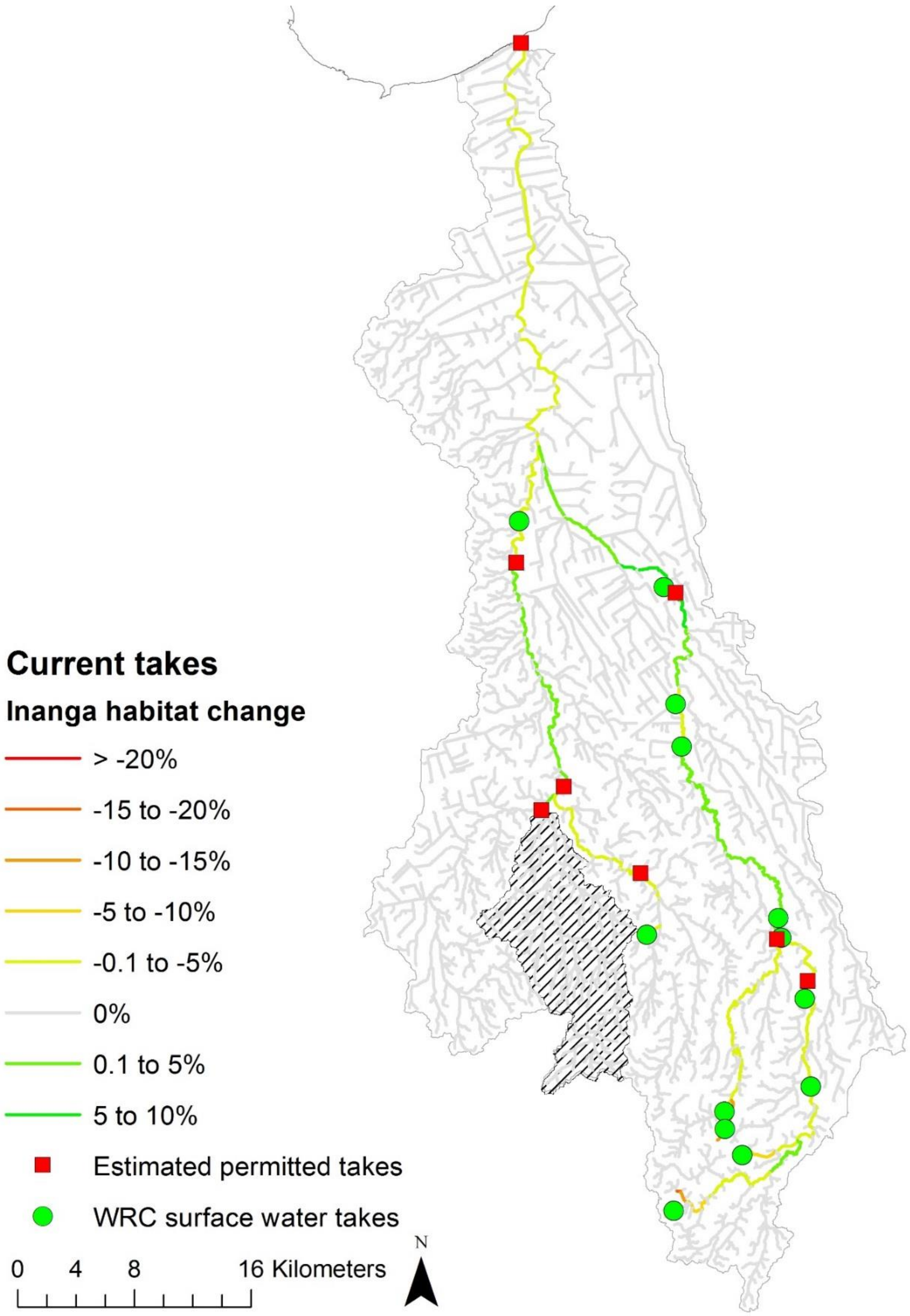

Figure 2-19: Predicted change in inanga habitat availability relative to MALF as a consequence of the current consented and estimated permitted takes (Scenario 3). The hatched area is the Topehaehae catchment which is not included in the analyses.

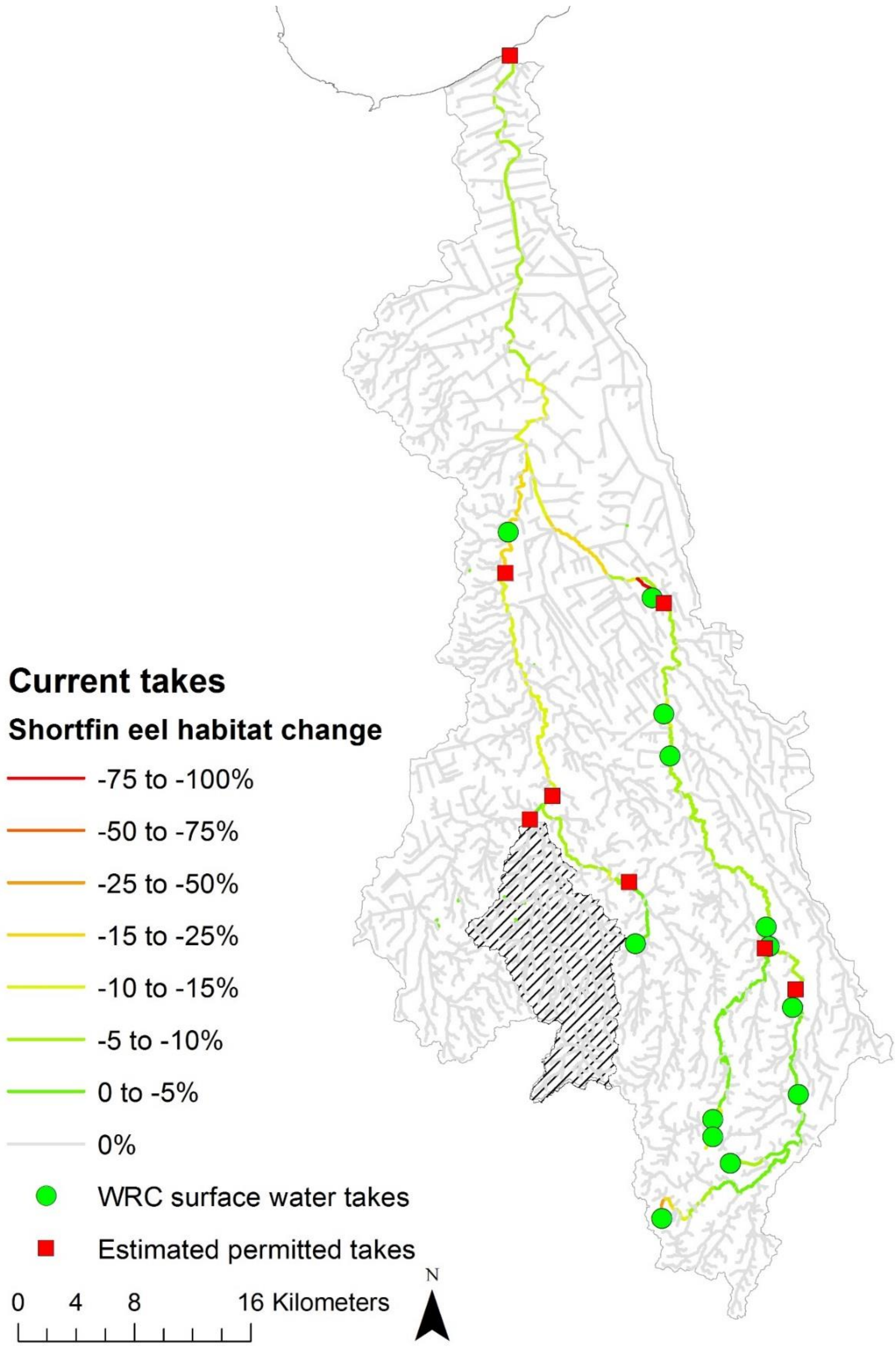

Figure 2-20: Predicted change in shortfin eel habitat availability relative to MALF as a consequence of the current consented and estimated permitted takes (Scenario 3). The hatched area is the Topehaehae catchment which is not included in these analyses.

2.6 No irrigation

The influence of irrigation takes on allocation levels in the Piako catchment was investigated by running a scenario where all currently consented irrigation takes were removed (Scenario 4). The number of impacted reaches was reduced from 230 in the under current consented allocation (Scenario 4) to 196; a 15% reduction. The proportion of impacted reaches where the primary allocation was exceeded was reduced to 58% compared to 70% in Scenario 3. The median percentage allocated of the primary allocation block was reduced from 160% to 114% (Table 2-8; Figure 2-21). Over-allocation was therefore reduced, but still not eliminated under this scenario. The median percentage of Q5 allocated overall did, however, now fall below the 30% limit defined in the current rules for the catchment (Table 2-8). Despite this, there remained 10% of impacted reaches that had more than 52% of Q5 allocated.

The predicted impact on the availability of instream physical habitat for the three indicator fish species was essentially unchanged compared to the Scenario 4 (Table 2-8; Figure 2-22 to Figure 2-24).

Table 2-8: Summary of consequences for habitat change and percent allocated as a result of the no irrigation take scenario (Scenario 4).

Value	Mean	10th percentile	Median	90th percentile
Percent allocated (Primary allocation)	205.0%	34.2%	114.6%	264.3%
Percent allocated (Secondary allocation)	88.1%	18.7%	75.8%	131.2%
Percent Q5 allocated (Total allocation)	35.6%	10.3%	28.4%	52.1%
Common bully habitat change	-9.9%	-18.0%	-9.2%	-0.9%
Inanga habitat change	-1.6%	-4.0%	-0.3%	1.3%
Shortfin eel habitat change	-9.1%	-15.4%	-9.0%	-0.8%

The average annual reliability of supply and restriction for the estimated permitted takes and remaining consented takes were largely unchanged compared to the current situation (Table 2-9). This is because the minimum flows that apply to the irrigation takes mean that they affect a part of the flow duration curve that does not impact on the reliability of the remaining takes.

Table 2-9: Average annual reliability of supply and restriction for the current consented and estimated permitted takes (Scenario 4). *Permitted takes. +Irrigation consents not modelled.

Consent number	Primary allocation		Secondary allocation	
	Reliability	Full Restriction	Reliability	Full Restriction
126*	96.3%	3.4%	-	-
129*	98.7%	1.1%	-	-
133*	97.3%	2.1%	-	-
237*	99.1%	0.9%	-	-
240*	98.3%	1.2%	-	-
241*	99.0%	0.7%	-	-
242*	97.3%	1.9%	-	-
243*	97.5%	1.6%	-	-
103276	66.1%	0.1%	-	-
109445+	-	-	-	-
118411	97.7%	1.4%	-	-
120425+	-	-	-	-
121132+	-	-	-	-
121791+	-	-	-	-
121791+	-	-	-	-
122179+	-	-	-	-
122179+	-	-	-	-
122238+	-	-	-	-
125284+	-	-	-	-
930812	98.0%	1.8%	-	-
960080	99.0%	0.7%	70.2%	22.6%

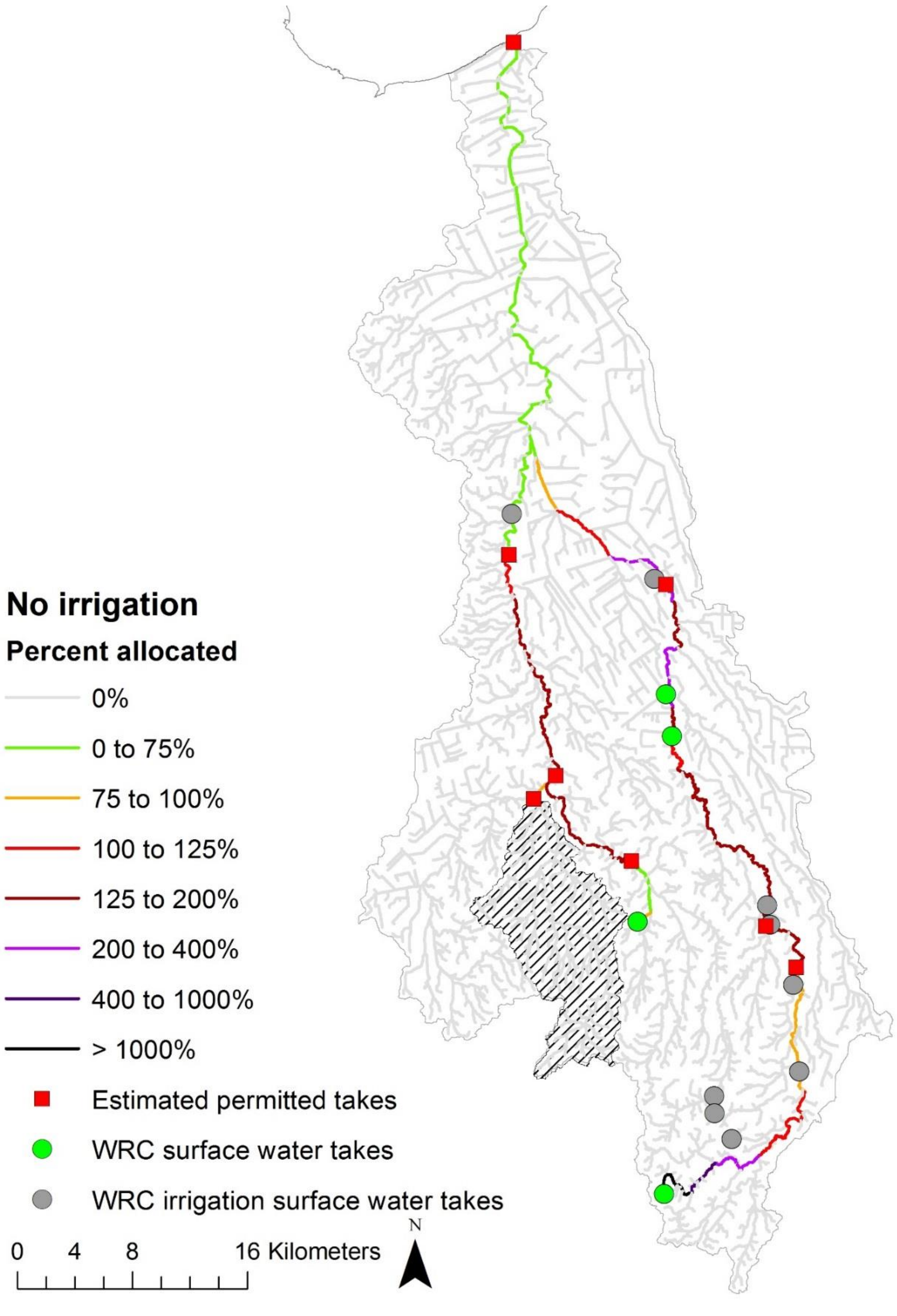

Figure 2-21: Percentage of the primary allocation taken by non-irrigation consented takes and estimated permitted takes (Scenario 4). Percentage allocation was derived by dividing the total cumulative take in a reach (L s^{-1}) by the allocation limit for that reach (% of Q5 for the reach expressed in L s^{-1}). The hatched area is the Topehaehae catchment which is not included in the analyses.

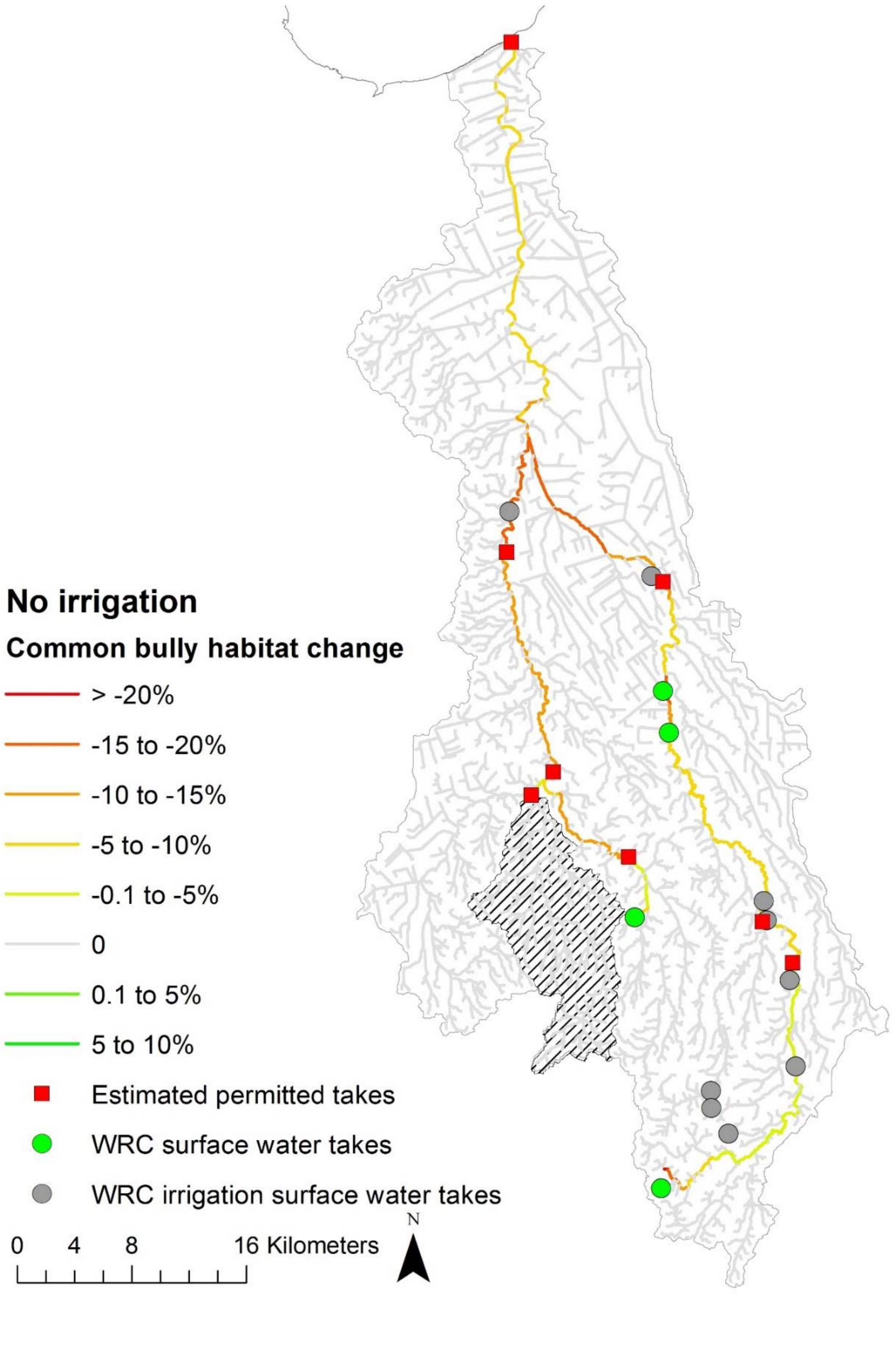

Figure 2-22:Predicted change in common bully habitat availability relative to MALF for the no irrigation scenario (Scenario 4). The hatched area is the Topehaehae catchment which is not included in these analyses.

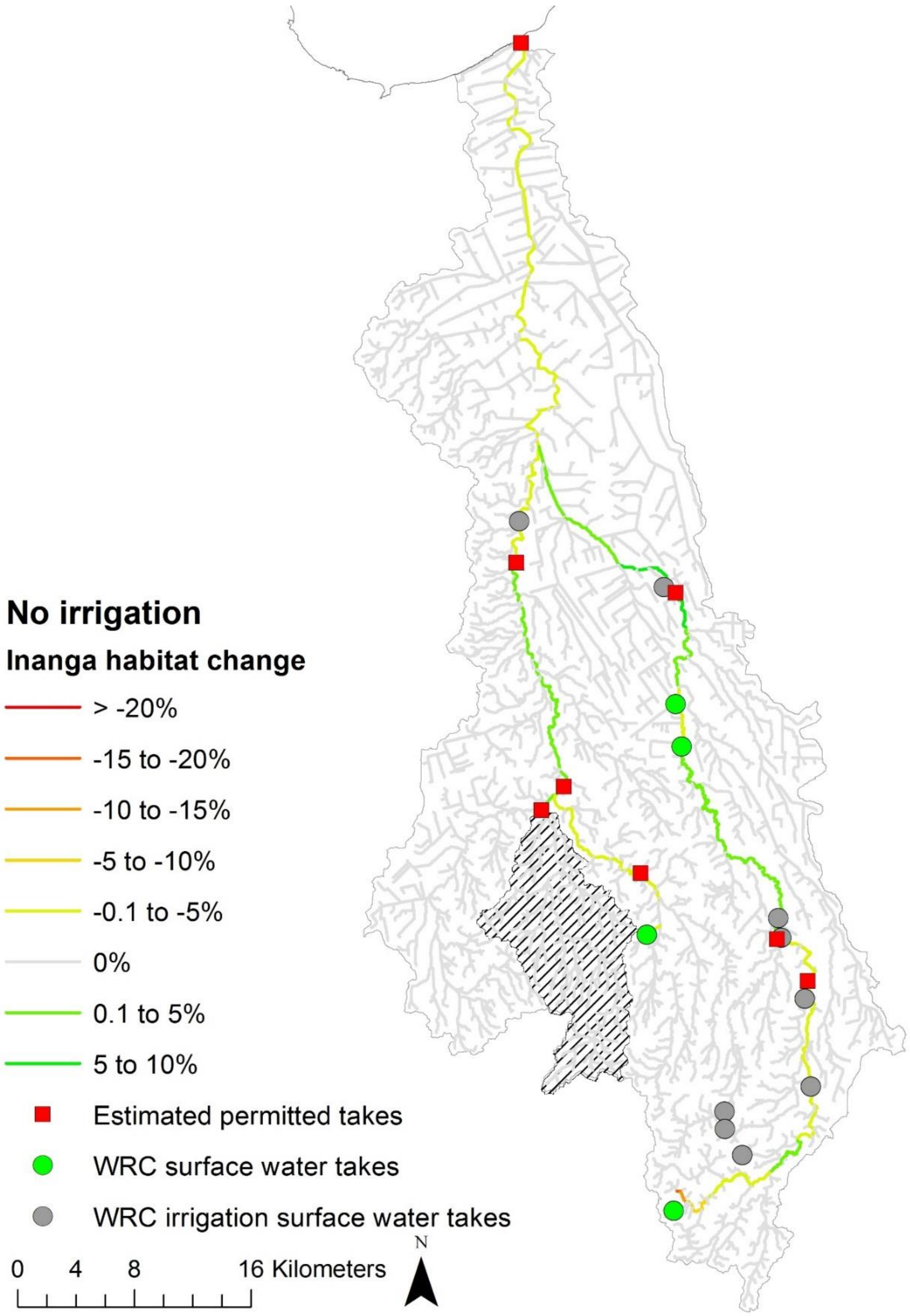

Figure 2-23: Predicted change in inanga habitat availability relative to MALF for the no irrigation scenario (Scenario 4). The hatched area is the Topehaehae catchment which is not included in these analyses.

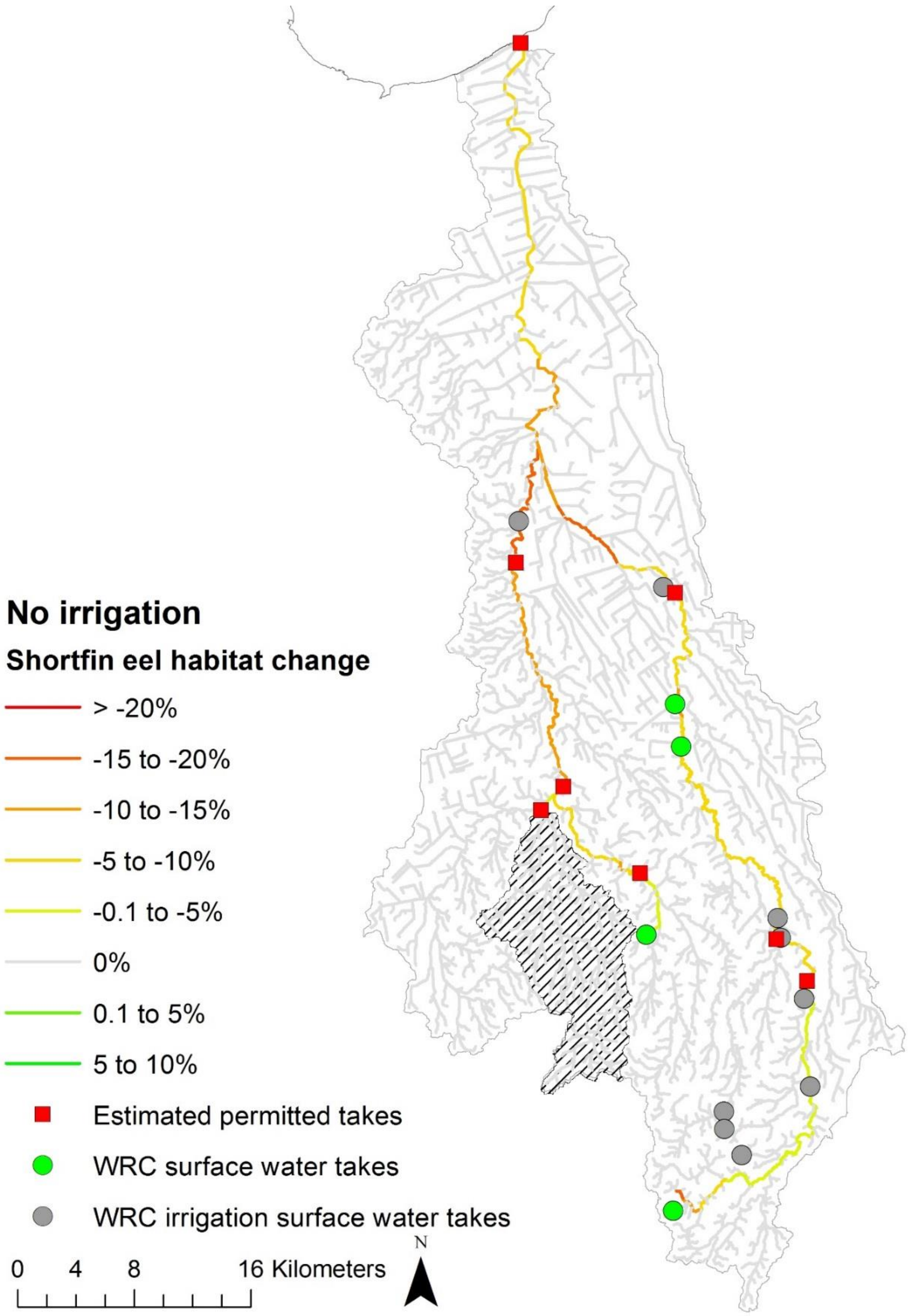

Figure 2-24: Predicted change in shortfin eel habitat availability relative to MALF for the no irrigation scenario (Scenario 4). The hatched area is the Topehaehae catchment which is not included in these analyses.

2.7 Comparison of scenarios

It has been demonstrated for the Piako catchment that estimated permitted takes alone (Scenario 2) result in over-allocation in 48% of reaches influenced by abstraction (impacted reaches). With the addition of currently consented takes (Scenario 3), the number of impacted reaches increases by 56% and the proportion of impacted reaches that are over-allocated increases to 70%. Removal of consented irrigation takes (Scenario 4) reduces the number of both impacted and over-allocated reaches in the catchment compared to the current situation (Scenario 3), but over-allocation still occurs in 58% of impacted reaches (Figure 2-25). Management of both permitted and currently consented takes would therefore be required to avoid over-allocation as required by the NPSFM.

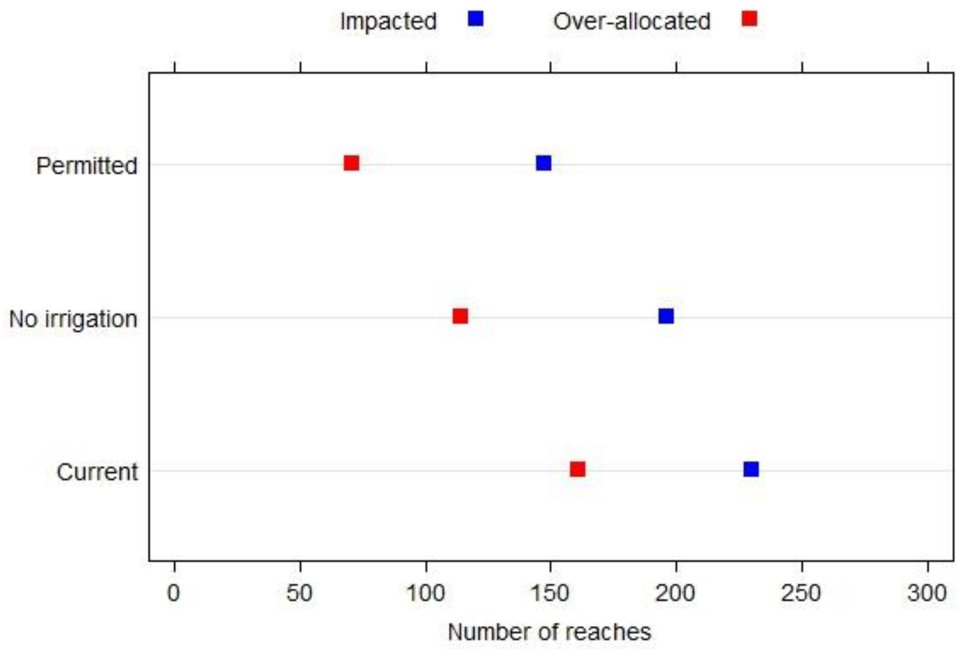

Figure 2-25: Comparison of the predicted number of reaches impacted and over-allocated under each modelled scenario.

The allocation status of the primary allocation block is compared for Scenarios 2, 3 and 4 in Figure 2-26. This indicates that the magnitude of over-allocation also increases between the permitted (Scenario 2) and current take (Scenario 3) scenarios. The greatest effect of removing currently consented irrigation takes (Scenario 4) from the catchment is to reduce the number of impacted reaches that are significantly (>200%) over-allocated, but the majority of reaches remain over-allocated under this scenario (Figure 2-26).

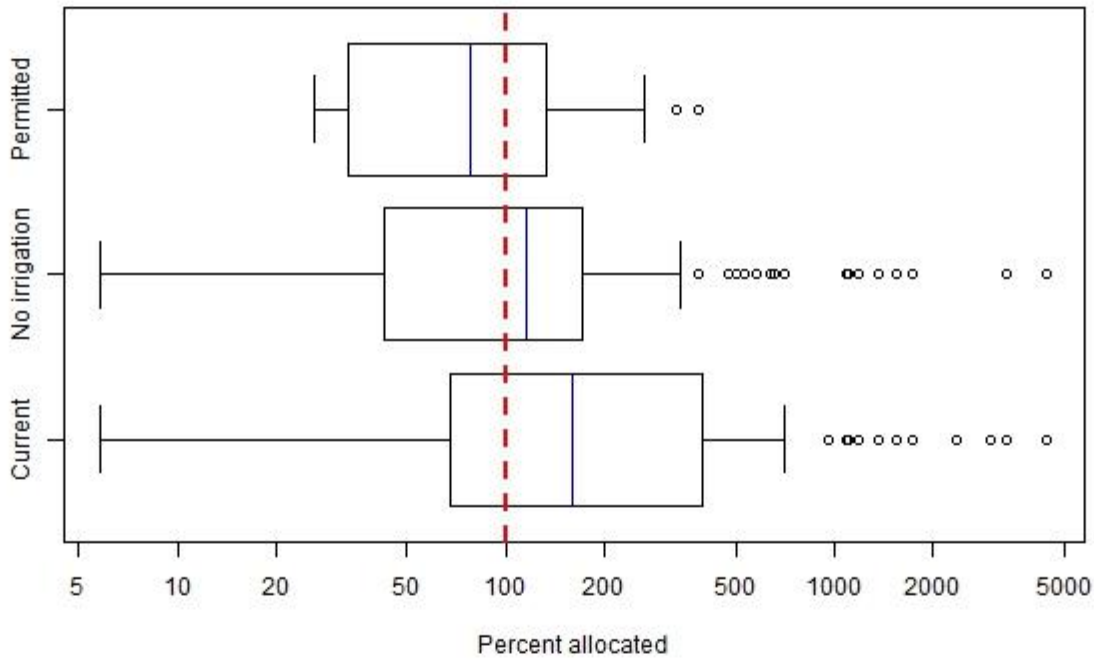

Figure 2-26: Comparison of primary allocation in impacted reaches under each modelled scenario. Scenario 2 = Permitted; Scenario 3 = Current; Scenario 4 = No irrigation. Each box encloses 50% of the data, with the median value displayed as a blue line. The whiskers show the range of values, with outliers displayed as individual points. The red dashed line indicates where reaches are considered fully allocated relative to the limits defined in the Plan.

With respect to predicted impacts on instream physical habitat for the indicator fish species, the variability in the magnitude of change was similar for common bully and shortfin eel, but lower for inanga (Figure 2-27). The magnitude of change in habitat for inanga was predicted to be smaller than that for the other species under Scenarios 2, 3 and 4 and also displayed less variation between these scenarios. For common bully and shortfin eel, both the median and range of variation in habitat change increased between the permitted take (Scenario 2) and consented take (Scenario 3) scenarios (Figure 2-27). The removal of currently consented irrigation takes (Scenario 4) reduced the number of reaches impacted by small changes in habitat, but makes little difference to the median response or those impacted by larger changes in habitat.

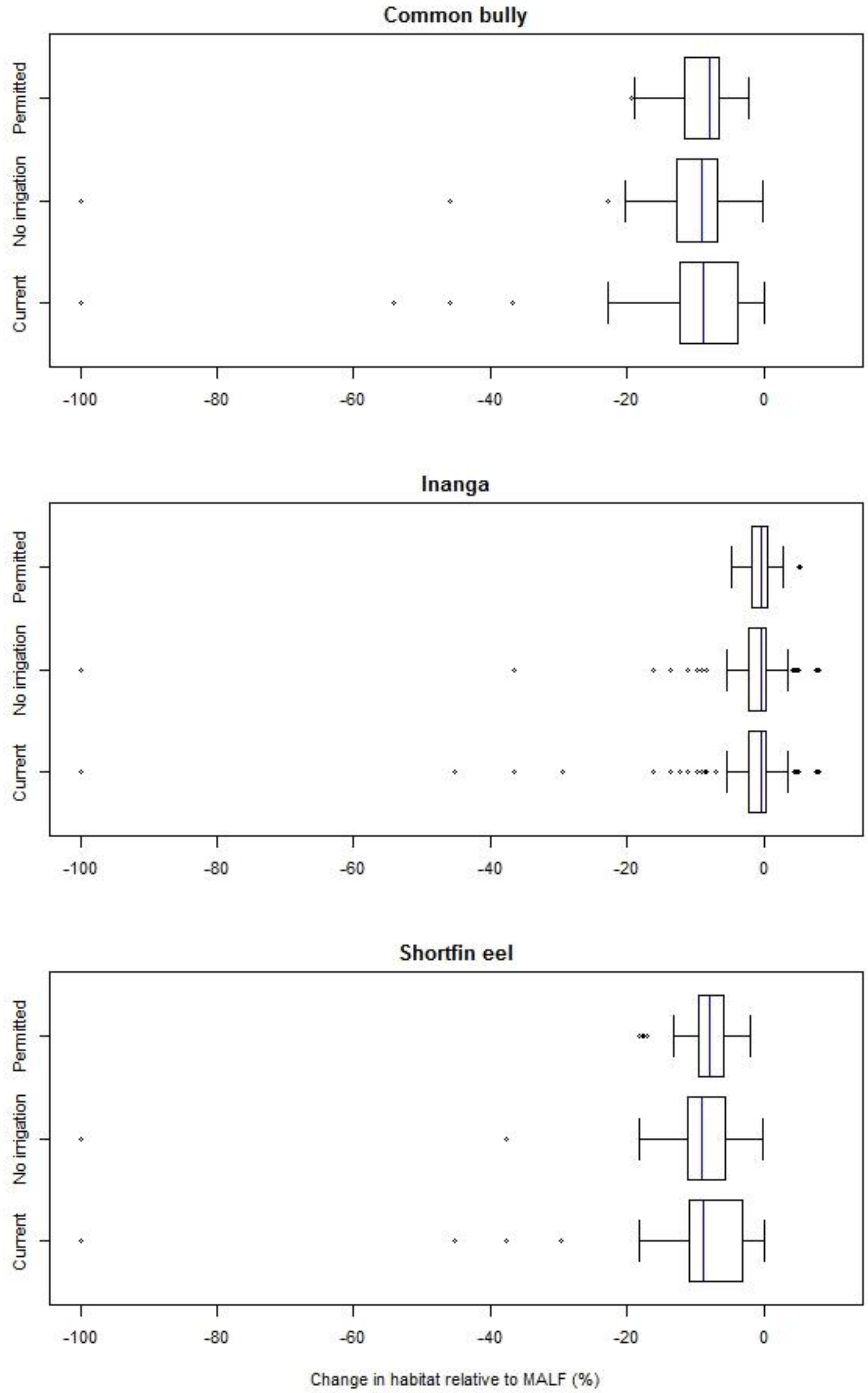

Figure 2-27: Comparison between scenarios of the consequences for instream physical habitat availability for the three indicator fish species. Scenario 2 = Permitted; Scenario 3 = Current; Scenario 4 = No irrigation.

Modelled results based on the March FDC indicate that under the current Piako allocation rules the median and 90th percentiles for potential reliability of supply for the primary allocation block are relatively similar to those for the annual FDC (Appendix C, Table C-1). However, reliability for the lowest 10% of reaches is significantly reduced from 87% for the annual FDC to 65% reliability for the March FDC. The reaches most impacted by this reduction in reliability occur mainly in the area to the north-west of Matamata around the Richmond Downs area. Similarly, most reaches in the catchment are predicted to be subject to minimal periods of full restriction under both the annual and March FDCs. However, the proportion of time for which full restriction is predicted for the 10% worst affected reaches increases from 12% annually to 30% of the time during March (Table C-1). This means that full restriction will be in place for a few locations for longer proportions of the time.

A similar pattern is observed for the secondary allocation block, with the 10th percentile for reliability decreasing from 81% under the annual FDC to 47% under the March FDC. This means that there will be far lower reliability of supply in the late summer compared to other times of the year. The 90th percentile for full restriction in the secondary allocation block increases from 17% for the annual FDC to 46% for the March FDC. No differences are observed in the median, 10th and 90th percentile values for change in the availability of instream physical habitat between the annual and March FDCs.

Predicted reliability of supply for the estimated permitted takes was high under both the annual and March FDCs (Table C-3). For the currently consented takes, reliability for many of the takes was similar for both the annual and March FDCs. However, for some takes predicted reliability of supply was notably lower for the March FDC (

Table C-5). The most severely impacted take is consent #103276, where predicted annual reliability was 66%, but for the March FDC was only 24.6%. This most likely reflects the large size of the take relative to the size of the stream at the point of take. Other takes predicted to have notably lower reliability for the March FDC compared to the annual FDC include consents #121132 and #121791, which are both irrigation takes. The reliability of all takes that were allocated to the secondary allocation block was significantly lower for the March FDC when compared over the annual FDC (

Table C-5). Minimal differences were observed between the consequences for instream physical habitat for the annual and March FDCs under the Permitted Take (Scenario 2), Current Take (Scenario 3) and No Irrigation Take (Scenario 4) scenarios.

3 Discussion

The EFSAP modelling has been used to demonstrate that under the Plan minimum flow and allocation limits for the Piako catchment, the potential annual average reliability of supply for both the primary and secondary allocation blocks is predicted to be relatively high (median of 96% and 95% respectively) for much of the catchment. The predicted impacts on instream physical habitat availability, relative to that available at natural MALF, were also relatively small for much of the catchment, with the largest effects mainly restricted to smaller headwater streams.

Evaluation of the current water allocation status of the Piako catchment indicates that estimated permitted takes alone (Scenario 2) are predicted to result in over-allocation in approximately 50% of impacted reaches (i.e. those reaches downstream of at least one take). When consented takes are also included (Scenario 3), the number of impacted reaches is predicted to increase from 147 to 230, and over-allocation increases to 70% of the impacted reaches. Relative to the Plan limits for the Piako, the majority of the Waitoa River from its headwaters to the confluence with the Piako, and the main stem of the Piako between Milliken Road and the Paeroa-Tahuna Road, are over-allocated, assuming limits are applied at a reach scale. In 10% of the impacted reaches, the primary allocation limit is predicted to be exceeded by 500% or greater.

Predicted average annual reliability of supply for the estimated permitted takes and most of the consented takes was relatively high. In the case of the permitted takes, the high reliability reflects the fact that there is essentially no enforceable minimum flow limits for these takes. Many of the non-irrigation consented takes also have no minimum flow limit defined in their consent conditions. Consequently, as long as the flow in the river exceeds the total estimated or consented take volume, the water is treated as being available within EFSAP. Most of the consented irrigation takes have lower predicted reliability, reflecting the influence of minimum flow limits in consent conditions for these takes. As a consequence of how the limits are applied to the consented takes, removal of the irrigation takes (Scenario 4) has little influence on the reliability of the remaining takes. However, the proportion of reaches that are currently considered as over-allocated and the magnitude of over-allocation relative to the existing Plan limits are reduced.

EFSAP has been demonstrated to provide a way of summarising the current status of water allocation, and the consequences of alternative scenarios, in a catchment. The results can be used to highlight the main allocation bottlenecks and help to quantify the potential magnitude of over-allocation. EFSAP also helps to identify where water may remain available for future allocation (e.g., the lower reaches). This may help WRC to communicate some of the key issues regarding allocation in a catchment and the trade-offs that are necessary between instream and out-of-stream values. However, it must also be acknowledged that the results are subject to a number of limitations and assumptions that must be accounted for when interpreting results for management.

Snelder et al. (2011) identified six limitations associated with the methodology that has been used for this study. First, the concept of flow variability was not explicitly considered in the analysis. Flow variability is increasingly acknowledged as being critical for ecosystem health and therefore should be considered in setting environmental flows (Poff et al. 1997, Poff et al. 2010). The EFSAP methodology is primarily designed to evaluate the effects of run-of-river abstractions, where total allocation is low relative to the mean flow. This type of water use primarily affects the flow regime in terms of the magnitude and duration of low flows, but tends to have relatively little effect on medium to high flows. Where more intensive water resource development that significantly alters the flow regime has occurred or is expected to occur (e.g., damming, flood harvesting or water diversion), a more detailed, site specific assessment would be required that explicitly considered the effects on flow variability. The importance of flow variability in the life history of native fish species should be accounted for when considering allocation of higher flows. For example, flow variability is important for spawning for some fish species (e.g. Charteris et al. 2003) and may play an important role in providing cues for migration.

Flow variability is also an important requirement for the removal of nuisance algae and flushing of fine sediments.

A second limitation is that FDCs provide no information regarding the temporal sequencing of flows. It is therefore not possible to determine whether periods of restriction or time at minimum flows occur consecutively or scattered through time. This is partially alleviated by providing results based on monthly FDCs. In this study, for example, we have reported results for the March FDC as being representative of the most resource restrictive period. Analysis of natural flow time series would be required if more detail on the timing and temporal sequencing of restrictions was needed. This is also necessary if the effects of extreme events such as droughts are required.

Another limitation of this study was that, although estimates were compared to observed data, the uncertainties associated with any estimate were not evaluated. The analysis was dependent on estimates of MALF, Q5 and FDCs. Uncertainties around the estimation of these parameters at individual locations can be large, especially around the low flows that this analysis focussed on (Booker & Woods 2012). In addition, the at-a-station hydraulic geometry and generalised physical habitat model uncertainties propagate through the various analyses. Future research work planned by NIWA will aim to quantify the total uncertainty of the predictions, as well as decrease the uncertainties associated with component predictive models.

A fourth limitation to the approach is that the complexity of flow management was simplified. In the EFSAP global mode we treated each stream segment as independent and made an assessment of the consequences on instream physical habitat and reliability of supply as though the minimum flow was observed at that segment and that allocation, and therefore total abstraction occurred in its upstream catchment. In reality, abstractions are distributed unevenly in space and the consequences accumulate down the river network in a non-uniform manner. This means that consequences for physical habitat retention and reliability across the network can be more variable than shown in our analysis. In the EFSAP local mode the spatial distribution of takes and cumulative downstream effects of multiple takes was accounted for. However, it was assumed that the total consented take is abstracted all of the time. In reality, this is rarely the case, with abstractors not taking the full volume of water they are entitled to or only taking water at certain times of the year. The modelled scenarios therefore represent a worst case situation. An alternative option could be to include more detailed supply/demand analyses linked to pasture production, for example, to provide more realistic estimates of water use. However, this would add significant complexity and a much greater data requirement to achieve. Furthermore, only surface water abstractions were included and groundwater abstractions that may affect river flows in a different and less direct way were not accounted for.

A fifth limitation concerns the assumption that the quantity of physical habitat is an appropriate indicator of ecosystem protection during low flow periods. We used a measure of the proportional change in the availability of physical habitat at a reference low flow to compare the consequences for instream values. This assumes that ecosystems are naturally stressed at low flows, but this may not always be the case. Alternative indices of the impact on habitat could also be used, which may give different outcomes. This could include the total change in habitat, for example, which better integrates the affects across the whole flow regime, but may not be representative of the main constraints on fish community dynamics. In some locations, for some species, factors other than physical habitat, such as water quality, temperature and migration pathways, may be more important controls. Water quality has been highlighted as a potential limitation on fish in some parts of the Piako catchment. Other flow dependent values such as removal of nuisance algae, recreation or cultural values may also be more significant. Despite these limitations, the use of changes in physical habitat to evaluate the consequences of flow change is well established in New Zealand and worldwide (Beca 2008, MfE 1998).

Another limitation is that this analysis was restricted to only selected indicator taxa. These taxa were selected based on known and predicted distributions (i.e. NZFFD; Leathwick et al. 2008) and their conservation status (Allibone et al. 2010) to maximise their relevance, but the choice of taxa was still restricted to those for which generalised habitat models are available (Table A-1). A full analysis for environmental flow setting would include multiple species and life stages, and an acknowledgement of the interdependence between taxa and life stages. Ideally, water resource use limits would also be based on linking physical habitat availability and quality to population dynamics (e.g. Capra et al. 2003).

A further limitation specific to this study relates to the inclusion of permitted takes. The number of reaches impacted by permitted takes will be under-estimated because permitted takes are currently accounted for at a sub-catchment scale rather than at a reach scale. Given the extent of over-allocation predicted to occur as a consequence of the estimated permitted takes, it will be important to gain more detailed information on this type of take within the Piako catchment in order to better manage the consequences of water allocation in the catchment.

Finally, a worse-case situation was assumed in which all takes were fully exercised all of the time. This is a necessary assumption when calculating over-allocation, but in reality this may not be the case.

4 Conclusion

The NPSFM (MfE 2011) requires that Regional Councils define environmental flow limits that include both minimum flows and total allocation limits. It also requires that over-allocation be avoided. The EFSAP methodology has been demonstrated to provide an approach that allows water managers to evaluate the consequences of setting different water allocation limits and to characterise the consequences of existing allocation. The integrated use of scientific tools allows concurrent evaluation of consequences for both instream habitat and reliability of supply for out-of-channel water uses. It also accounts for the interaction between minimum flow and total allocation limits. By modelling a range of scenarios EFSAP also allows resource managers to more effectively communicate to stakeholders the varying consequences of different water resource limits.

The EFSAP analyses in this project have been used to demonstrate there may be a problem with over-allocation in certain parts of the Piako catchment, when compared to current water quantity limits contained in the Plan. This could have significant implications with respect to fulfilling the requirements of the NPSFM in the Piako catchment. The EFSAP outputs help to illustrate the importance of how over-allocation is defined and accounted for. For example, total allocation at the river mouth is estimated at 37% of Q5, but in the Waitoa at Mellon Road it is 99% of Q5 and on the Piako at the Paeroa-Tahuna Road it is 40% of Q5. Across the catchment, total allocation as a percentage of Q5 varies from 0% to 598%, with a median in the impacted reaches of 40%. Consequently, depending on where total allocation is measured, the degree of over-allocation relative to the existing limits can vary significantly. Given that the NPSFM requires that over-allocation be defined at a scale relevant to freshwater objectives, it is likely that the reach scale outputs of EFSAP provide a more representative reflection of the current status of over-allocation in the catchment than an assessment at any individual point in the catchment, e.g. a gauging station.

The EFSAP modelling has also been able to highlight the significant role that permitted takes have in the management of allocation within the Piako catchment, with many reaches predicted to be over-allocated based only on permitted takes. This suggests that it will be necessary for WRC to manage both permitted and consented takes within the catchment in order to effectively manage over-allocation as required by the NPSFM.

The absence of specified minimum flow limits in the consent conditions for many current takes means that predicated reliability of supply is high, despite the high level of allocation. However, there are likely to be significant consequences with respect to the frequency and duration of low flows in the catchment as a result of this. It is recommended that WRC also account for the potential ecological and water quality impacts of the absence of specified minimum flow limits for many current takes when reviewing the status of water quantity limits in the catchment.

5 Acknowledgements

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Appendix A Habitat model parameters

Table A-1: Species for which generalised habitat models are available in New Zealand. The model parameters c and k are displayed and optimum discharge per unit width provides an indication of relative flow demand (Source: Jowett et al. (2008)).

Species	*c*	*k*	Optimum discharge per unit width ($m^2\ s^{-1}$)
Inanga	0.19	19.74	0.01
Shortjaw kokopu	0.19	16.35	0.01
Upland bully	0.11	8.63	0.01
Cran's bully	0.09	6.84	0.01
Banded kokopu (juvenile)	0.19	13.3	0.01
Canterbury galaxias	0.03	2.29	0.01
Roundhead galaxias	0.31	10.64	0.03
Flathead galaxias	0.28	9.11	0.03
Longfin eel (<30 cm)	0.07	2.07	0.03
Lowland longjaw galaxias	0.33	9.35	0.04
Redfin bully	0.26	7.39	0.04
Shortfin eel (<30 cm)	0.13	2.32	0.05
Common bully	0.39	6.51	0.06
Brown trout fry	0.86	10.21	0.08
Brown trout yearling	0.40	4.18	0.09
Nesameletus	0.26	2.62	0.10
Brown trout spawning	1.24	9.89	0.13
Bluegill bully	1.01	6.13	0.16
Rainbow trout spawning	1.49	8.78	0.17
Deleatidium	0.33	1.92	0.17
Torrentfish	0.88	4.05	0.22
Brown trout adult	1.17	4.35	0.27
Food producing habitat	1.19	4.25	0.28
Rainbow trout feeding (30-40 cm)	0.93	2.89	0.32
Coloburiscus humeralis	1.35	4.17	0.32
Aoteapsyche	1.44	3.17	0.45
Zelandoperla	1.71	3.40	0.50

Table B-1: Summary of Piako take data used as the input for EFSAP.

Consent number	Take type	Primary allocation (L s^{-1})		Secondary allocation (L s^{-1})	
		Minimum flow	Allocation limit	Minimum flow	Allocation limit
126	Permitted	0	41	-	-
129	Permitted	0	64	-	-
133	Permitted	0	47	-	-
237	Permitted	0	78	-	-
240	Permitted	0	28	-	-
241	Permitted	0	11	-	-
242	Permitted	0	29	-	-
243	Permitted	0	32	-	-
103276	Consented	0	8	-	-
109445	Consented	815	13.9	-	-
118411	Consented	0	28.9	-	-
120425	Consented	181	9.26	-	-
121132	Consented	759	46.3	-	-
121791	Consented	350	32	181	64
121791	Consented	350	32	181	64
122179	Consented	385	5	-	-
122179	Consented	385	2.3	-	-
122238	Consented	0	0.77	180.5	2.3
125284	Consented	900	16	-	-
930812	Consented	0	26.6	-	-
960080	Consented	0	0.5	12.5	3

Scenario 1: Piako allocation rules

Table C-1: Summary of consequences for reliability and habitat change as a result of uniformly applying the allocation rules for the Piako catchment.

Value	Mean	10th percentile	Median	90th percentile
Primary allocation reliability of supply	90.3%	65.3%	99.5%	100%
Primary allocation full restriction	8.3%	0.0%	0.1%	30.6%
Secondary allocation reliability of supply	83.8%	46.7%	96.0%	100%
Secondary allocation full restriction	13.0%	0.0%	0.6%	46.3%
Common bully habitat change	-8.5%	-14.8%	-9.1%	0.0%
Inanga habitat change	-6.2%	-12.8%	-6.5%	0.0%
Shortfin eel habitat change	-7.3%	-13.3%	-7.6%	0.0%

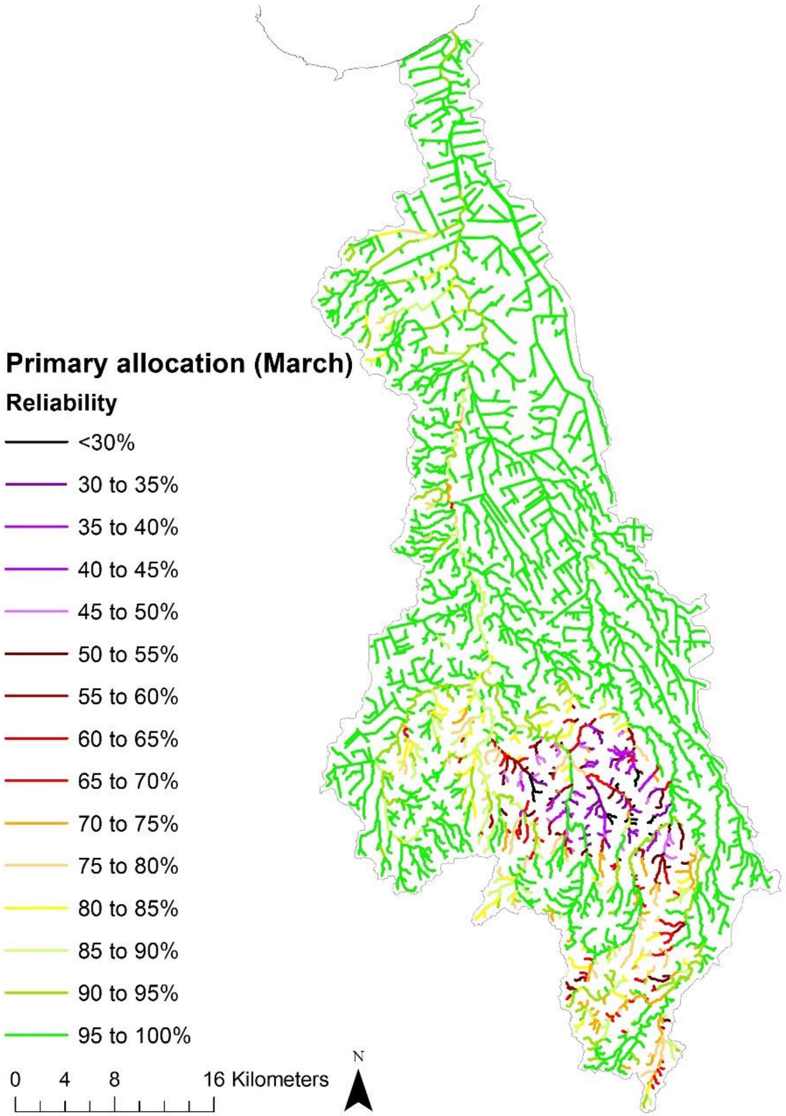

Figure C-1: Predicted reliability of supply for the Primary Allocation if the Plan rules are applied uniformly. March FDC.

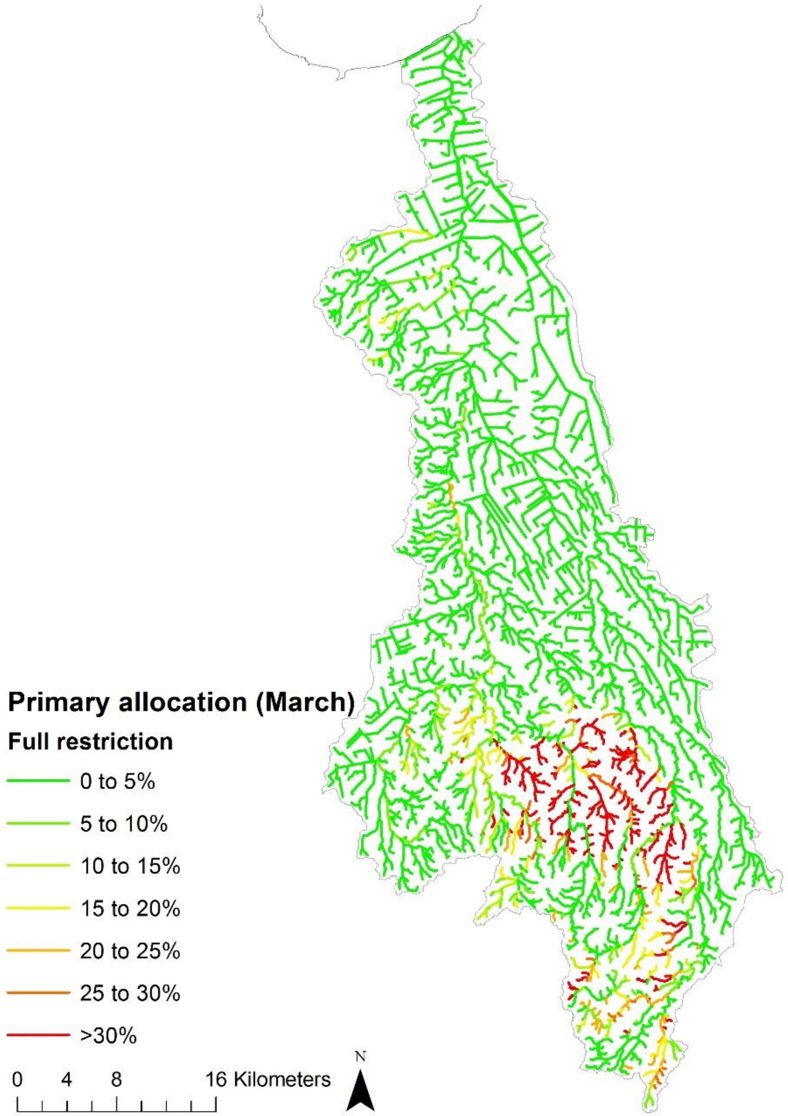

Figure C-2: Predicted duration of full restriction on Primary Allocation if the Plan rules are applied uniformly.
March FDC.

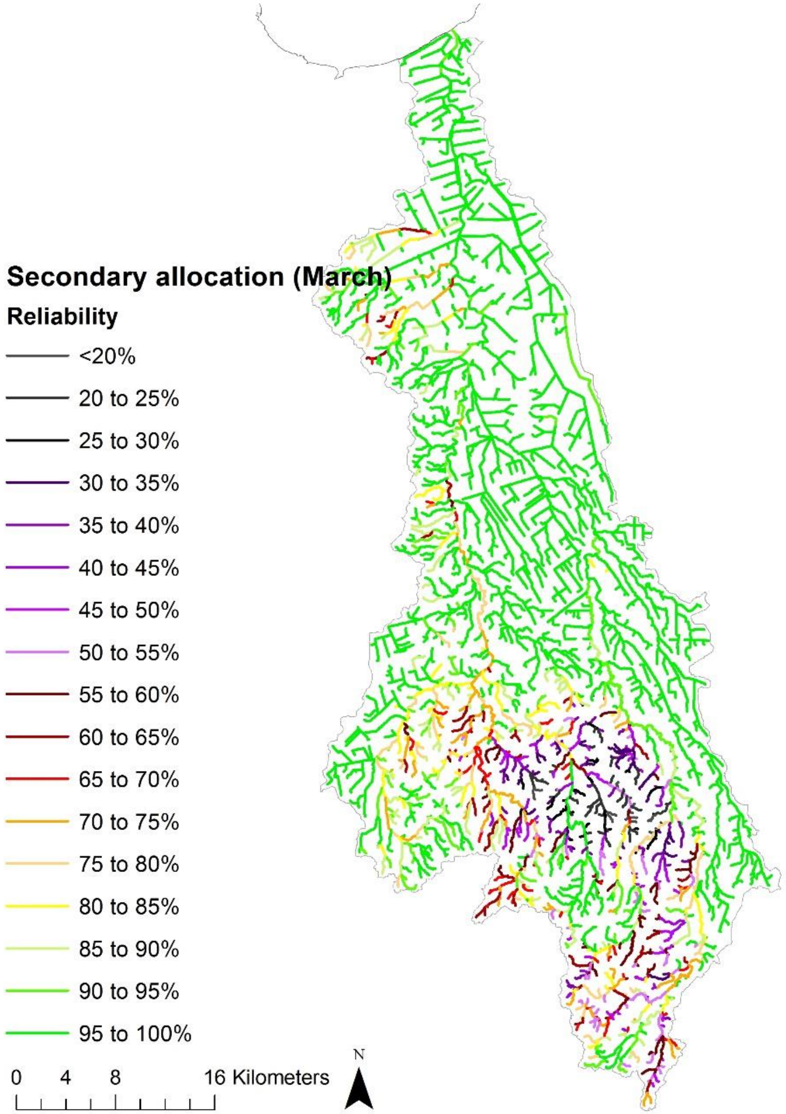

Figure C-3: Predicted reliability of supply for the Secondary Allocation if the Plan rules are applied uniformly. March FDC.

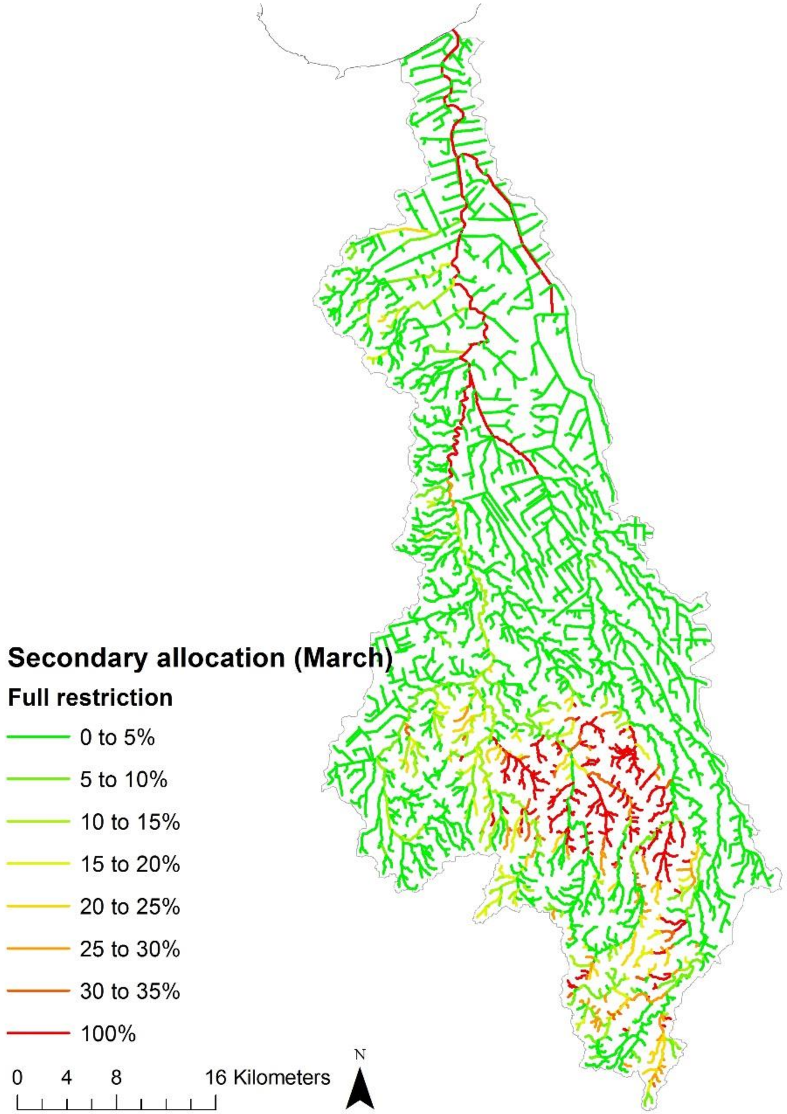

Figure C-4: Predicted duration of full restriction on Secondary Allocation if the Plan rules are applied uniformly. March FDC.

Scenario 2: Permitted takes

Impacted reaches: 147

Over-allocated reaches: 71

Table C-2: Summary of consequences for instream physical habitat as a result of estimated permitted takes in the Piako catchment.

Value	Mean	10th percentile	Median	90th percentile
Common bully habitat change	-9.1%	-13.7%	-7.9%	-6.1%
Inanga habitat change	-0.5%	-2.3%	-0.4%	1.8%
Shortfin eel habitat change	-8.5%	-12.9%	-7.9%	-5.1%

Table C-3: Theoretical average annual reliability of supply and restriction for the estimated permitted takes. Catchment areas refer to WRC sub-catchment definitions (see Appendix B).

Catchment area	Catchment description	Permitted takes	
		Reliability	Full restriction
126	Piako at Paeroa-Tahuna Road	100.0%	0.0%
129	Waitoa at Mellon Road	100.0%	0.0%
133	Piako at Morrinsville	100.0%	0.0%
237	Piako mouth	100.0%	0.0%
240	Upper Piako – Waitoa	100.0%	0.0%
241	Upper Piako – Mangapapa	100.0%	0.0%
242	Piako at Kiwitahi	100.0%	0.0%
243	Upper Piako - Topehaehae	100.0%	0.0%

Scenario 3: Current takes

Impacted reaches: 230

Over-allocated reaches: Primary allocation block = 161; Secondary allocation block = 70

Table C-4: Summary of consequences for instream physical habitat as a result of current consented and estimated permitted takes in the Piako catchment.

Value	Mean	10th percentile	Median	90th percentile
Common bully habitat change	-10.2%	-18.4%	-8.8%	-1.2%
Inanga habitat change	-2.3%	-4.2%	-0.5%	1.0%
Shortfin eel habitat change	-9.3%	-15.8%	-9.0%	-1.2%

Table C-5: Theoretical average annual reliability of supply and restriction for the current consented and estimated permitted takes. *Permitted takes.

Consent number	Primary allocation		Secondary allocation	
	Reliability	Full Restriction	Reliability	Full Restriction
126*	100.0%	0.0%	-	-
129*	100.0%	0.0%	-	-
133*	100.0%	0.0%	-	-

Consent number	Primary allocation		Secondary allocation	
	Reliability	Full Restriction	Reliability	Full Restriction
237*	100.0%	0.0%	-	-
240*	100.0%	0.0%	-	-
241*	100.0%	0.0%	-	-
242*	100.0%	0.0%	-	-
243*	100.0%	0.0%	-	-
103276	24.6%	0.0%	-	-
109445	84.5%	4.1%	-	-
118411	100.0%	0.0%	-	-
120425	80.5%	16.5%	-	-
121132	71.2%	25.2%	-	-
121791	48.2%	0.6%	4.6%	59.7%
121791	92.0%	1.6%	35.0%	54.7%
122179	100.0%	0.0%	-	-
122179	100.0%	0.0%	-	-
122238	100.0%	0.0%	36.9%	16.3%
125284	84.3%	14.6%	-	-
930812	100.0%	0.0%	-	-
960080	100.0%	0.0%	29.5%	59.1%

Scenario 4: No irrigation takes

Impacted reaches: 196

Over-allocated reaches: Primary allocation block = 114; Secondary allocation block = 23

Table C-6: Summary of consequences for instream physical habitat and percent allocated as a result of the no irrigation take scenario.

Value	Mean	10th percentile	Median	90th percentile
Common bully habitat change	-10.0%	-18.2%	-9.2%	-0.9%
Inanga habitat change	-1.7%	-4.1%	-0.4%	1.2%
Shortfin eel habitat change	-9.2%	-15.3%	-9.0%	-0.7%

Table C-7: Theoretical average annual reliability of supply and restriction for the current consented and estimated permitted takes. *Permitted takes. +Irrigation takes.

Consent number	Primary allocation		Secondary allocation	
	Reliability	Full Restriction	Reliability	Full Restriction
126*	100.0%	0.0%	-	-
129*	100.0%	0.0%	-	-
133*	100.0%	0.0%	-	-
237*	100.0%	0.0%	-	-
240*	100.0%	0.0%	-	-
241*	100.0%	0.0%	-	-
242*	100.0%	0.0%	-	-
243*	100.0%	0.0%	-	-
103276	24.6%	0.0%	-	-
109445+	-	-	-	-
118411	100.0%	0.0%	-	-
120425+	-	-	-	-
121132+	-	-	-	-
121791+	-	-	-	-
121791+	-	-	-	-
122179+	-	-	-	-
122179+	-	-	-	-
122238+	-	-	-	-
125284+	-	-	-	-
930812	100.0%	0.0%	-	-
960080	100.0%	0.0%	29.5%	59.1%