Flow requirements for instream habitat in Northland

RHYHABSIM assessment for the Waitangi, Mangere and Hatea catchments

Prepared for Northland Regional Council

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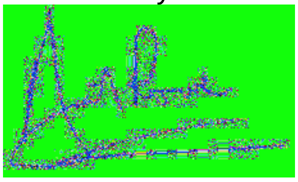

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Executive summary

Northland Regional Council (NRC) are in the process of developing a new water quantity management framework. In high priority catchments NRC have initiated a programme of detailed catchment-specific investigations to support the process of setting catchment water quantity limits. NRC requested that NIWA undertake physical habitat surveys and modelling in the Waitangi, Mangere and Hatea River catchments with the aim of:

1. assessing the effects of variations in flow on the amount of instream habitat available for key fish species, and
2. characterising the consequences of different minimum flow limits for instream physical habitat for key fish species.

Four representative habitat survey sites were established in the Waitangi catchment and one site each in the Mangere and Hatea catchments. Fieldwork was carried out between February and May 2013. Instream physical habitat modelling was undertaken using the River Hydraulic Habitat Simulation (RHYHABSIM) model and relationships between suitable habitat and flow were developed for indicator native fish species at each site. The consequences of alternative minimum flow limits based on proportions of the mean annual low flow (MALF) for the species' instream physical habitat were evaluated. For those sites where sufficient hydrological data were available (the Hatea and three sites in the Waitangi), the potential impacts of different combinations of minimum flow and allocation limits (Table 1-1) were also characterised. It is emphasised that these scenarios are not exhaustive and that NRC may choose alternative water quantity limits following evaluation of all instream and out-of-stream values.

Table 1-1: Water quantity limit scenarios assessed.

Scenario	Minimum flow	Allocation limit
Naturalised	NA	NA
Current	85% MALF	Maximum consented take volume
Proposed NES	90% MALF	30% MALF
Proposed NES +10%	90% MALF	40% MALF
Proposed NES -10%	90% MALF	20% MALF

The availability of suitable instream physical habitat generally declined as flow was reduced below MALF for the majority of indicator species and life-stages at all sites in all three catchments. It is suggested that NRC develop a values-based approach to defining protection levels for instream values similar to that utilised by Bay of Plenty Regional Council. An example is provided based on the conservation and biodiversity status of fish species. At most sites a minimum flow of 90-95% of MALF was required to meet the exemplary protection levels. This is similar to the minimum flow limit (90% of MALF) suggested for small rivers (mean flow <5 $m^3 s^{-1}$) in the proposed National Environmental Standard for Ecological Flows and Water Levels (proposed NES; MfE 2008).

Consented allocation is currently extremely high in all three catchments ranging from a low of 45% of MALF at the Waiaruhe site in the Waitangi catchment to a high of 1675% of MALF in the Waipapa site in the same catchment. At all six sites, the degree of hydrological alteration would be considered ‘very high’ based on the thresholds identified in the proposed NES. The alternative flow management scenarios modelled in this study would reduce the level of hydrological alteration in most cases to medium (proposed NES +10% allocation scenario) or low (proposed NES and proposed NES -10% allocation). However, for most of the locations, implementation of these limits would result in the catchments being deemed highly over-allocated and would therefore require ‘claw back’ of water from current users.

The habitat analyses highlighted that the impacts of flow regime change were different between species and locations, and that the impacts varied between years based on natural hydrological variation. It was also noted that the largest impacts on instream physical habitat were often not in the driest years when flows are naturally very low and therefore habitat availability is naturally constrained. They were mainly in years when flows were regularly between the minimum flow and management flow (minimum flow + allocation limit).

The National Policy Statement for Freshwater Management (MfE 2011) requires that all councils set freshwater objectives and associated water quantity limits. NRC will therefore have to set freshwater objectives for each catchment and determine appropriate protection levels for instream values. The results of this study can be used to identify the water quantity limits that will provide the desired levels of protection for instream physical habitat for fish. In doing this, however, NRC will need to be cognisant of the fact that this study has only evaluated the consequences of changes in flow on instream physical habitat for fish. It makes no attempt to account for other influences on fish habitat, such as water quality, and does not establish direct links between habitat suitability/availability and fish populations. It also does not evaluate the impacts of other controls on fish populations such as food availability or barriers to migration which restrict recruitment. Other values, e.g., cultural, aesthetic, economic, are also important in determining freshwater objectives and therefore the appropriate protection levels and associated limits for different values. NRC will therefore need to make informed value judgements that balance all values when selecting water quantity limits.

1 Introduction

1.1 Background

Developing a sustainable water management framework is essential to ensuring that water resources are managed in a way that protects environmental values as well as allowing for economic growth. The current framework for managing water quantity in Northland requires updating to provide security of water supply, protect environmental values and meet the requirements of the National Policy Statement on Freshwater Management (NPSFM) (MfE 2011, 2013).

The establishment of robust water quantity limits is essential for providing both environmental protection and more efficient, equitable and sustainable resource use. The process of setting water quantity limits should be transparent, defensible and based on scientific methods (Snelder et al. 2013). Northland Regional Council (NRC) are in the process of developing a new water quantity management framework. As part of this review process NIWA were commissioned to provide advice regarding the most appropriate methods for determination of ecological flow requirements and allocation limits for rivers in Northland (Franklin 2010, Franklin 2011). The Environmental Flow Strategic Allocation Platform (EFSAP) has been used to help develop regional scale interim default minimum flow and allocation limits for low priority catchments (Franklin et al. 2013). In high priority catchments NRC have initiated a programme of detailed catchment-specific investigations to support the process of setting catchment water quantity limits. The Waitangi, Mangere and Hatea catchments have been identified as priority catchments for detailed investigations. This study contributes to the evaluation of ecological flow requirements in these catchments.

1.2 Study scope

NRC requested that NIWA undertake physical habitat surveys and modelling in the Waitangi, Mangere and Hatea River catchments with the aim of:

1. assessing the effects of variations in flow on the amount of instream habitat available for key fish species, and
2. characterising the consequences of different minimum flow limits for instream physical habitat for key fish species.

This project focused on physical habitat as defined by the combination of water depths, water velocities and substrates found in the rivers. Additional factors influencing habitat conditions such as geomorphological changes, water quality and water temperature were not investigated. No assessment was made of other factors that may limit fish populations, such as river connectivity, food availability, predation and competition.

2 Overview of the environmental flow setting process

2.1 Background

The allocation of water for environmental or ecological needs has increasingly become a key element of integrated water resources management. In New Zealand, the NPSFM defines environmental flows as a type of limit which describes the amount of water in a body of freshwater that is required to meet freshwater objectives (MfE 2011). Freshwater objectives describe the intended environmental outcome for a water body and may include, for example, ecosystem health, human health, tangata whenua values, recreational, amenity, landscape and natural character (MfE 2013). The proposed amendments to the NPSFM (MfE 2013) include a National Objectives Framework which will set some of these objectives, e.g., ecosystem health, at a national level. However, the values provided for and the level of protection afforded to each value will depend on the characteristics of an individual catchment and may be determined in a variety of ways.

This project is focussed on identifying flow regime requirements for instream ecological values in priority catchments. Physical habitat modelling and related techniques were used to assess the effects of changes in flows on the availability and suitability of instream physical habitat for specified ecological values. In developing water quantity limits for these catchments NRC will need to determine an acceptable balance between the flows identified as protecting instream ecological values, with those required to sustain other instream values (e.g., cultural, recreational, natural character) and with the economic and social benefits of out-of-stream water use.

2.2 Options for methods to determine instream ecological flow requirements

Many factors influence the health of river ecosystems including temperature, oxygen, light, geomorphology and flow (Norris & Thoms 1999). However, flow has been described as a master variable that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing waters (Poff et al. 1997). All elements of a flow regime are important, as described by their magnitude, duration, frequency, timing and rate of change (Bunn & Arthington 2002, Poff et al. 1997, Richter et al. 1997). A holistic approach to the management of river systems must therefore take account of all of these factors and their interactions.

A variety of approaches and frameworks exist for assessing instream flow requirements (Acreman & Dunbar 2004, Tharme 2003). The majority of methodologies can be classified into four groups: (i) hydrological; (ii) hydraulic; (iii) habitat; and (iv) holistic. Hydrological methods are typically used for broad-scale planning and are based on hydrological indices (e.g., Tennant 1976). Hydraulic methods involve establishing functional relationships between simple hydraulic variables (e.g., wetted width; Booker 2010) and flow as a guide for establishing minimum flow requirements. Habitat modelling methodologies attempt to assess ecological flow requirements based on the quantity and suitability of physical habitat available to a target species under different flow regimes (e.g., PHABSIM; Bovee 1982). Holistic methods are more closely aligned to the 'natural flow paradigm' (Poff et al. 1997) and are based on the premise that the natural flow regime has intrinsic value or important ecological function that will be maintained by retaining key elements of the natural flow regime. Typically, these approaches build on understanding of functional links between different components of the flow regime and ecology, geomorphology, water quality, social, recreational or other objectives of river management (Poff et al. 2010). Hydrologic, hydraulic and habitat approaches can all be components of a holistic assessment (Acreman & Dunbar 2004).

Discussion of the different approaches which can be used for environmental flow setting in a New Zealand context is provided in Jowett and Biggs (2008), Jowett et al. (2008), MfE (1998) and Beca (2008).

2.3 Physical habitat modelling

The interaction between flow and channel morphology determines water depth and velocity in a river and in turn provides physical habitat for plants, invertebrates and fish (Booker & Acreman 2007). The direct relationship between physical habitat and flow provides a means for assessing the ecological impact of changing the flow regime of a river. Assessment of river management options often involves evaluating scenarios that fall outside the range of observed conditions and thus predictive models are required. The Physical Habitat Simulation (PHABSIM) system (Bovee 1982) was the first systematic physical habitat modelling framework to be developed and many models based on a similar concept have been produced including CASiMIR in Germany, EVHA in France and RHYHABSIM in New Zealand. Essentially these models quantify the relationship between physical habitat, defined in terms of the combination of water depth, velocity and substrate, and various flows (Jowett 1997, Tharme 2003). Criticisms of this approach include lack of biological realism (Hudson et al. 2003, Orth 1987) and mechanism (Mathur et al. 1985). Nevertheless, the models have been applied widely throughout the world, primarily to assess the impacts of abstraction or river impoundment (Dunbar & Acreman 2001). In New Zealand, RHYHABSIM has been applied to many rivers (Lamouroux & Jowett 2005). Jowett and Biggs (2006) reviewed the results from six rivers in which habitat-based methods had been applied to setting flow limits. They found that in five of these cases the biological response and the retention of desired instream values was achieved.

The approach adopted in many physical habitat studies is described by Clausen et al. (2004) and Jowett (1997). This includes: identification of river sectors and species of interest; identification of habitats that exist within the sectors of interest; selection of cross-sections which represent replicates of each habitat type; and the collection of model calibration data (water surface elevation, depth and velocity). The calibration data are used to determine the spatial distribution of depths and velocities across each cross-section and the relationship between water levels at each cross-section and the quantity of water flowing in the river.

The calibration data are collected in order to simulate hydraulic conditions in the river for a range of flows, which can then be compared with habitat suitability criteria for the target species. This allows prediction of usable physical habitat for the species of interest at a range of flows. Usable physical habitat is commonly expressed as Weighted Usable Area (WUA) in m^2 per m of river channel. WUA is an aggregate measure of physical habitat quality and quantity and will be specific to a particular discharge and species. Assessment of the changes in WUA which might occur as a result of any proposed changes in flow regime can then be made.

In New Zealand, habitat modelling has typically followed one of two methods. The first method is known as the ‘habitat mapping’ method. The number and distribution of habitat types within the reach of interest are identified using habitat mapping techniques. Stage-discharge relationships are applied to simulate hydraulic conditions at isolated cross-sections placed throughout the reach of interest. Identification of the habitat type and several observations of water surface levels and discharge are required at each cross-section. Modelled conditions at these cross-sections are then used in conjunction with results from habitat mapping to weight each cross-section and therefore represent conditions in the reach of interest. The advantage of the habitat mapping method is that it does not require the selection of a representative reach from within the length of river that is of interest.

The second method is known as the ‘representative reach’ method. One-dimensional hydraulic modelling approaches are applied to a series of cross-sections located contiguously along the river to form a study site within the length of river that is of interest. The habitat types of each cross-section may be identified and can be used to assess the representativeness of the modelled reach. The advantage of the representative reach approach is that it allows more physically based methods to be used in hydraulic simulation.

Regardless of the method of data collection, simulated hydraulic conditions are then compared with the habitat suitability criteria in order to assess how the combined quality and quantity of physical habitat varies as flow changes. The habitat value at each point is calculated as a joint function of depth, velocity and substrate type using the method shown in Figure 2-1. This is then repeated within the habitat assessment model for the depth/velocity/substrate characteristics at every point in every cross-section and the area that each point represents is multiplied by the point suitability. These areas, which have been weighted by their respective point suitability values, are then summed to give a measure of the total area of suitable physical habitat for the given species at the given flow. This process is then repeated for a series of other flows. The total area of suitable physical habitat is then plotted as a function of flow to show how the area of suitable physical habitat for a given species changes with flow. Variations in the amount of suitable habitat with flow are then used to assess the effect of different flows for target organisms. Flows can then be set so that they achieve particular management goals, such as meeting freshwater objectives defined in a regional plan.

Various approaches can be taken to assess appropriate flow limits for protecting instream values based on the results of instream habitat modelling. In New Zealand, this has typically focussed on defining minimum flow requirements. One approach involves identifying a breakpoint (or ‘inflection point’) on the habitat/flow relationship (Jowett 1997). This has possibly been the most commonly used procedure in New Zealand for defining minimum flow limits based on habitat methods. While there is no percentage or absolute value associated with a breakpoint, it is a point of diminishing return, where proportionally more habitat is lost with decreasing the flow than is gained by increasing the flow. Another approach involves maintaining a percentage of the maximum habitat area or a proportion of the habitat available at mean annual low flow. The Bay of Plenty Regional Council have adopted an approach along these lines, with differing protection levels prescribed for species/communities based on their value (e.g., rare species have 100% protection level, less significant communities have an 85% habitat protection level). This approach is better aligned with the principles of the NPSFM.

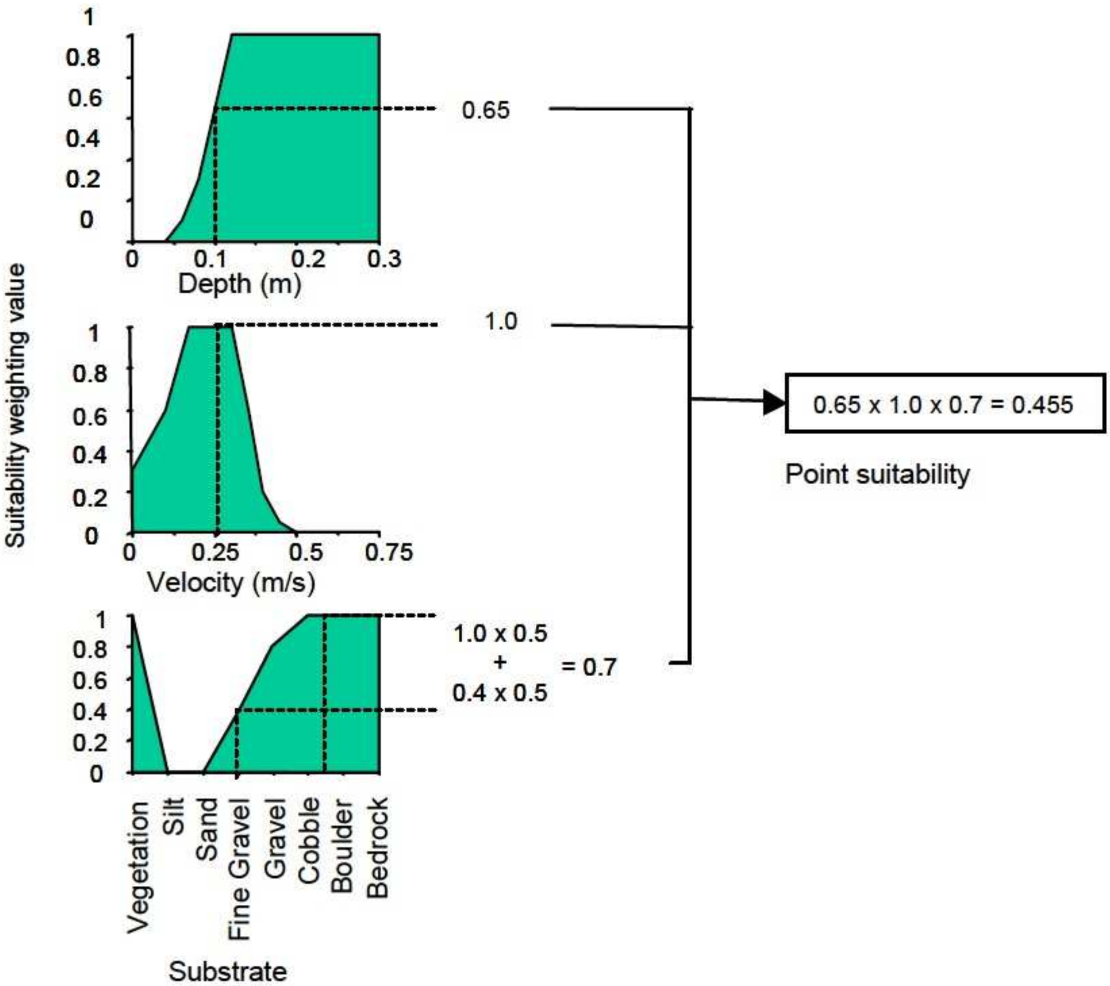

Figure 2-1: Calculation of habitat suitability for a given fish species. Each graph shows the habitat preferences of the given species. At the point of interest, water depth is 0.1 m, water velocity 0.25 m s^{-1}, and substrate comprises 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0) and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.

In New Zealand, physical habitat modelling has not been widely used for evaluation of allocation limits. However, internationally the method has been used for comparing the instream consequences of alternative flow scenarios, particularly downstream of impoundments. Typically, this involves combining the habitat-flow relationship with flow time-series for alternative flow management scenarios and comparing the consequences for instream physical habitat (e.g., Capra et al. 1995).

3 Methodology

3.1 Site locations

Study reaches in each river catchment were selected based on access, interest from a water management perspective and on their proximity to existing monitoring locations (e.g., hydrological gauging stations). For each river, the relevant lengths of river channel were initially inspected for significant changes in channel characteristics from aerial photographs and points of access.

Four study sites were selected in the Waitangi catchment, representing the main stem of the river and the main tributaries (Table 3-1). One site each was selected in the lower reaches of the Mangere and Hatea catchments (Table 3-1). In both these catchments, large waterfalls impede the upstream migration of fish species, therefore restricting community diversity and species abundance in upstream reaches. In recognition of this, the study reaches were therefore located downstream of the waterfalls. There is also a waterfall which will impede upstream fish migrations in the Waitangi catchment. However, this is located at the river mouth and therefore it is not possible to have a reach downstream of this waterfall.

Table 3-1: Location of study reaches in the three catchments.

Catchment	Site name	Easting	Northing
Waitangi	Haruru	1693957	6095249
	Waimate North Road	1682025	6093675
	Waipapa	1684069	6095267
	Waiaruhe	1684169	6087917
Mangere	Knight's Road	1702441	6048745
Hatea	Riding school	1721059	6049052

3.2 Habitat mapping

Habitat mapping was undertaken during a walk-over survey at all reaches prior to locating survey cross-sections. Habitat mapping was always carried out over a long reach (approximately 1 km). Cross-sections were then set up throughout a shorter reach located within the habitat mapping reach, with cross-sections placed to represent the different habitat types identified. Habitat type definitions followed those in Table 3-2.

Table 3-2: Habitat type definitions used in this study (adapted from Maddock 1999).

Mesohabitat type	Hydraulic character	Brief description
Fall	Turbulent and very fast	Vertical drops of water over the full span of the channel, commonly found in bedrock and step-pool stream reaches.
Cascade	Turbulent and very fast	Highly turbulent series of short falls and small scour basins, frequently characterised by very large substrate and a stepped profile.
Chute	Turbulent and very fast	Narrow steep slots or slides in bedrock.
Rapid	Turbulent and fast	Moderately steep channel units with coarse substrate, unlike cascades possess planar profile.

Mesohabitat type	Hydraulic character	Brief description
Riffle	Turbulent and moderately fast	Most common type of turbulent fast water mesohabitat in low gradient alluvial channels. Substrate is finer than other fast turbulent mesohabitats. Less white water, with some substrate breaking the surface.
Run	Non-turbulent and moderately fast	Moderately fast and shallow gradients with ripples on the water surface. Deeper than riffles with little, if any, substrate breaking the surface.
Glide	Non-turbulent and moderately slow	Smooth ‘glass-like’ surface, with visible flow movement along the surface. Relatively shallow compared to pools.
Pool	Non-turbulent and slow	Relatively deep and slow flowing (compared to glides), with fine substrate. Usually little surface water movement visible. Consists of transition from pool-head, mid-pool and pool-tail.
Backwater	Non-turbulent and slow	Area of minimal current velocity, partially isolated from channel during low flow.
Other		To be used in unusual circumstances where feature does not fit any recognised type.

3.3 Instream habitat surveys

Each site comprised fifteen cross-sections. The habitat mapping approach was used to locate cross-sections within each survey reach. For all sites there was at least one cross-section for any habitat type that covered more than 5% of the habitat mapped. Surveying pegs were used to mark, relocate and resurvey each cross-section. Water velocities, depths and substrate composition were recorded at each cross-section at one discharge. Water levels and discharge values were then measured at further discharges. The discharges at which calibration data were collected were near to MALF, i.e., flows in both rivers were near to their normal annual low flows during the calibration runs.

Water surface levels relative to survey pegs were measured using a survey staff. Depth, velocity and substrate were measured at even distances across each cross-section or where large changes in conditions occurred. Mean column velocities were measured using a Marsh-McBirney Flo-mate 2000 electromagnetic current meter placed at 0.4 of the depth from the bed for a 30 second time period. Depths were measured using a wading rod. In all cases percentage substrate composition was observed and recorded using an eight class substrate classification as determined by the habitat suitability criteria of: vegetation, silt (<0.06 mm), sand (0.06-2 mm), fine gravel (2-8 mm), gravel (8-64 mm), cobble (64-256 mm), boulder (>256 mm) and bedrock.

3.4 Habitat suitability criteria

The habitat suitability curves chosen for a study must be appropriate for the species known to occur, or likely to occur, in the study river. The New Zealand Freshwater Fish Database (NZFFD) contains several records for all three catchments. Species recorded in the NZFFD and captured during surveys undertaken by NRC in 2013 are listed for each catchment in Table 3-3.

Table 3-3: Fish species recorded in the Waitangi, Mangere and Hatea catchments. Source: NZFFD accessed 07/03/2014; Carol Nicholson, NRC, pers. com.

Species	Common name	Waitangi	Mangere	Hatea
Anguilla dieffenbachii	Longfin eel	✓	✓	✓
Anguilla australis	Shortfin eel	✓	✓	✓
Galaxias maculatus	Inanga			✓
Galaxias fasciatus	Banded kokopu	✓	[1]	✓
Galaxias brevipinnis	Koaro			✓
Gobiomorphus gobioides	Giant bully			✓
Gobiomorphus huttoni	Redfin bully			✓
Gobiomorphus cotidianus	Common bully	✓[2]	✓[3]	✓[4]
Gobiomorphus basalis	Cran's bully	✓	✓	✓
Cheimarrichthys fosteri	Torrentfish			✓
Neochanna diversus	Black mudfish	✓		
Neochanna heleios	Northland mudfish	✓		
Onchorhynchus mykiss	Rainbow trout			✓
Tinca tinca	Tench	✓		
Gambusia affinis	Mosquito fish	✓		✓
Scardinius erythrophthalmus	Rudd	✓		
Ameiurus nebulosus	Catfish			✓
Cyprinus carpio	Koi carp			✓

[1] Likely to be present in headwater streams, but these have not been surveyed
[2] Only downstream of Haruru Falls
[3] It is relatively likely that this is a mis-identification of Cran's bully. Both Wairoa and Mangere Falls would be a complete barrier to migration for common bullies and it is therefore more likely that the non-diadromous Cran's bully would be present in the Mangere catchment.
[4] Only downstream of Whangerei Falls

Habitat suitability indices (HSIs) used in this study were selected from those available in the literature and are listed in Table 3-4. The HSIs are included in Appendix A for reference. The indicator species selected for analysis in each catchment were chosen based on their presence (Table 3-3) or expected presence in the catchments and their fishery and biodiversity values.

Table 3-4: Fish species and habitat suitability indices used in this study.

Species	HSI name	HSI source	Waitangi	Mangere	Hatea
Longfin eel	Longfin eel <300 mm	Jowett and Richardson (2008)	✓	✓	✓
	Longfin eel >300 mm	Jowett and Richardson (2008)	✓	✓	✓
Shortfin eel	Shortfin eel <300 mm	Jowett and Richardson (2008)	✓	✓	✓
	Shortfin eel >300 mm	Jowett and Richardson (2008)	✓	✓	✓
Cran's bully	Cran's bully	Jowett and Richardson (2008)	✓	✓	✓
Common bully	Common bully	Jowett and Richardson (2008)		✓	
Banded kokopu	Banded kokopu juvenile	Jowett and Richardson (2008)	✓	✓	✓
	Banded kokopu adult	Jowett and Richardson (2008)	✓	✓	✓
Torrentfish	Torrentfish	Jowett and Richardson (2008)			✓
Redfin bully	Redfin bully	Jowett and Richardson (2008)			✓
Inanga	Inanga feeding	Jowett (2002)			✓

3.5 Habitat analysis

The habitat analysis proceeded as follows for a range of discharges at each site:

1. Discharges were computed from depth and velocity measurements for each cross-section.
2. A stage-discharge relationship was developed for each cross-section using a least squares fit to the logarithms of the measured flows and stages (water levels) where appropriate including an estimated stage at zero flow.
3. Water depths were computed at each measurement point across each cross-section for a range of simulated flows using measured bed topography data and calculated stage-discharge relationships. Water velocities were computed for each cell at each flow using the flow conveyance method to disaggregate velocity across each cross-section based on the measured pattern of velocity distribution.
4. Habitat suitability was evaluated at each measurement point from habitat suitability curves for each fish species.
5. The weighted usable area (WUA) for each simulated flow was calculated as the sum of the habitat suitability indices across each cross-section, weighted by the proportion of the habitat type which each cross-section represented in the river.
6. Weighted usable area was plotted against flow and the resulting curves examined to analyse minimum flow requirements.

7. Weighted usable area against flow relationships were combined with flow time series data for different flow management scenarios (see Section 3.6) to create habitat time series. Habitat time series were compared to evaluate potential impacts of alternate flow management scenarios.

3.6 Hydrology

3.6.1 Waitangi

Modelled naturalised flow time series (40 year record) produced by the rainfall-runoff model TOPNET were available for all four sites in the Waitangi catchment (Diettrich & Hicks 2014). Estimates of MALF calculated from the modelled flows were compared with NRC estimates of MALF and flows measured at the time of the habitat surveys to assess confidence in the low flow calibration of the model. The only site where there was a large difference between the estimates of MALF was at Waiaruhe (modelled 0.187 $m^3 s^{-1}$; NRC 0.460 $m^3 s^{-1}$). It was agreed after consultation with NRC that the level of uncertainty in the modelled low flows for this site meant that they should not be used for the analyses of alternative water quantity limit scenarios in this project. At the three other sites in the Waitangi catchment alternative flow management scenarios were synthesised from the modelled naturalised flow time series by applying different combinations of minimum flow and allocation limits to the flow data (Table 3-6). Estimates of the 7-day mean annual low flow (MALF) were available from NRC for the Haruru and Waiaruhe reaches (Table 3-5). For the remaining sites MALF was estimated from the modelled naturalised flow time series (Table 3-5). Estimates of maximum total upstream take at each site were calculated from data provided by NRC on consent conditions (Table 3-5). These estimates do not take account of the influence of dam storage on water quantity. Incorporation of this is outside the scope of this project.

3.6.2 Mangere

Modelled naturalised flow time series (40 year record) produced by the rainfall-runoff model TOPNET were available for the site in the Mangere catchment (Diettrich & Hicks 2014). However, comparison of MALF estimated from the modelled flow time series (0.238 $m^3 s^{-1}$) and that estimated by NRC for the Mangere at Knight's Road (0.119 $m^3 s^{-1}$; Table 3-5) indicated a high level of uncertainty in the calibration of the modelled low flow data. Consequently, it was agreed in consultation with NRC that the time series and allocation limit analyses would not be undertaken for this site. Estimates of maximum total upstream take at each site were calculated from data provided by NRC on consent conditions (Table 3-5). These estimates do not take account of the influence of dam storage on water quantity, which is outside the scope of this project.

3.6.3 Hatea

Observed flow time series data for the Hatea River are available from the hydrological gauging site at Whareora Road (16 year record with a gap between 1995 and 2007). The District Council public water supply take, which is located upstream of the gauging station, accounts for approximately 95% of total consented allocation in the catchment. Monthly take records are available for the District Council take. These were used to synthesise a 'naturalised' flow time series by assuming that the total monthly take was evenly distributed across all days in that month and adding the daily take to the observed flows at the Whareora Road gauging station. It is recognised that the actual volume of water taken is likely to vary between days and therefore on some days the 'naturalised' flow will be over-estimated and on others under-estimated. However, this effect will average out over any given month so that the net effect of the adjustment is accurate. The effects of alternative water quantity limit scenarios (Table 3-6) were then synthesised based on the 'naturalised' flow time series data. Estimates of MALF for this site were provided by NRC based on the measured flow record at Whareora Road (Table 3-5).

Table 3-5: Estimated 7-day mean annual low flows (MALF) and current total consented abstraction.

Catchment	Site	MALF ($m^3 s^{-1}$)	MALF source	Upstream maximum consented allocation ($m^3 s^{-1}$)
Waitangi	Haruru	1.019	NRC	1.252
Waitangi	Waimate North Road	0.145	Diettrich and Hicks (2014)	0.263
Waitangi	Waipapa	0.024	Diettrich and Hicks (2014)	0.402
Waitangi	Waiaruhe	0.460	NRC	0.209
Mangere	Knight's Road	0.119	NRC	0.137
Hatea	Whareora Road	0.145	NRC	0.122

3.6.4 Allocation limit scenarios

A range of water quantity limit scenarios were derived and modified flow time series synthesised where flow data were available to analyse potential impacts on instream habitat availability (Table 3-6). In all cases it was assumed that the total allocation limit was taken all of the time, e.g., if the allocation limit was 10% of MALF, this quantity was subtracted from the whole of the estimated naturalised flow time series. It is acknowledged that this is a precautionary approach representing a worst case scenario. However, an efficient allocation regime should achieve close to full allocation to maximise the economic benefits from out-of-stream use and highest water demand typically occurs when least water is available (i.e., dry summers). Consequently, it is considered appropriate to take this approach. A minimum flow of 85% MALF was used to model the current scenario as this was considered the closest approximation to rules currently applied in Northland (Susie Osbaldiston, NRC, Pers. Com.). The alternative scenarios were based on the limits included for small rivers (mean flow <5 $m^3 s^{-1}$) in the proposed National Environmental Standard on Ecological Flows and Water Levels (proposed NES; MfE 2008). It should be made clear that these scenarios are not exhaustive and that a range of alternative options could be investigated or selected for use by NRC.

Table 3-6: Water quantity limit scenarios assessed.

Scenario	Minimum flow	Allocation limit
Naturalised	NA	NA
Current	85% MALF	Maximum consented take volume (see Table 3-5)
Proposed NES	90% MALF	30% MALF
Proposed NES +10%	90% MALF	40% MALF
Proposed NES -10%	90% MALF	20% MALF

4 Waitangi catchment

4.1 Haruru

4.1.1 Site description

The Haruru habitat survey reach was located on the Waitangi River approximately 2 km upstream of Haruru Falls (Figure 4-1). Habitat mapping was carried out over approximately 2 km. The upper sections of the habitat mapping reach were characterised by rapids and a bedrock substrate. The middle and lower reaches were more varied in character, with a combination of runs, riffles and pools (Table 4-1; Figure 4-2).

Mean wetted width at the time of the survey was 17.2 m. The habitat survey was carried out at a flow of 0.944 $m^3 s^{-1}$, which is equivalent to 92.6% of MALF (Table 4-2). Only one calibration survey was completed (0.869 $m^3 s^{-1}$; 85.3% MALF) due to a flood event resulting in the loss of the majority of cross-section markers and subsequent high flows preventing access to the remaining cross-sections.

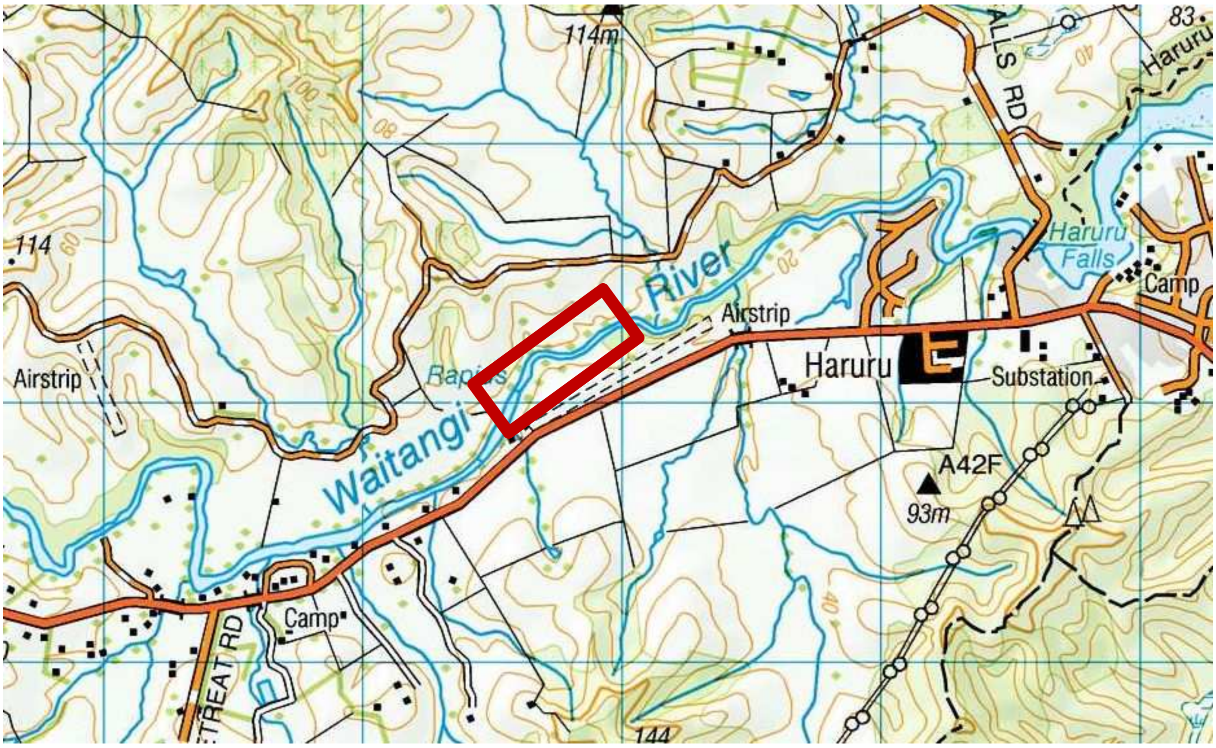

Figure 4-1: Location of the Haruru habitat survey reach (red box).

Figure 4-2: Mid-section of the Haruru habitat survey reach.

Table 4-1: Habitat mapping results for the Haruru site. Habitat type definitions are given in Table 3-2.

Habitat type	Percentage of reach
Rapid	40.0
Riffle	17.5
Run	35.0
Pool	7.5

Table 4-2: Summary of survey and calibration flows for the Haruru site. Flood flows had resulted in the loss of most cross-section markers prior to the third calibration survey and flows were too high to safely access the remaining cross-sections.

Date	Flow ($m^3 s^{-1}$)	Percentage of MALF
27/02/2013	0.944	92.6
11/04/2013	0.869	85.3
16/05/2013	NA	NA

4.1.2 WUA v. flow relationship

No fish surveys have been carried out in the Waitangi River close to this site. However, given that longfin eels, shortfin eels and banded kokopu occur upstream of this site, it is reasonable to assume that these species must also be present in the lower river for at least some of the time. Cran's bully have also been recorded in nearby tributaries, suggesting that it is also likely this species will be present. However, the presence of the Haruru Falls at the bottom of the Waitangi catchment means that most species (particularly swimming species such as inanga) are prevented from accessing the catchment.

Optimum WUA was outside of the range of modelled flows (>3 $m^3 s^{-1}$) for four of the indicator species (Table 4-3; Figure 4-3). Optimum WUA occurred at around 2 $m^3 s^{-1}$ (96% MALF) for small eels, but for Cran's bully was at a flow of only 0.38 $m^3 s^{-1}$ (37% MALF).

WUA is predicted to decline continuously as flow falls below MALF for all indicator species except Cran's bully and juvenile banded kokopu (Table 4-3; Figure 4-3). For Cran's bullies and juvenile banded kokopu, WUA remains fairly stable as flow declines from MALF to c. 0.3 $m^3 s^{-1}$, but then drops away as flow falls below this threshold.

Table 4-3: Flow at optimum WUA and changes in WUA at various proportions of MALF for the Haruru habitat survey reach. Optimum flow is outside the range modelled where optimum is >3.00 $m^3 s^{-1}$.

Species	Optimum flow ($m^3 s^{-1}$)	WUA at MALF ($m^2 m^{-1}$)	Percentage of WUA at MALF available at:							
			95% MALF	90% MALF	85% MALF	80% MALF	75% MALF	70% MALF	60% MALF	50% MALF
Shortfin eel <300 mm	1.93	7.95	97.3	93.8	91.3	88.3	84.6	81.5	75.6	68.9
Shortfin eel >300 mm	>3.00	6.57	96.7	93.5	90.4	87.2	84.1	80.7	73.7	65.6
Longfin eel <300 mm	2.70	4.77	96.1	90.6	86.0	82.4	78.1	74.8	68.3	60.9
Longfin eel >300 mm	>3.00	6.42	96.6	93.4	90.1	86.8	93.4	79.8	72.0	62.8
Banded kokopu juvenile	>3.00	2.53	98.6	98.6	97.5	96.4	95.4	94.6	93.9	97.0
Banded kokopu adult	>3.00	4.40	95.9	92.3	88.3	85.2	82.4	79.5	73.6	68.4
Cran's bully	0.38	1.75	100.2	100.2	100.5	100.5	100.3	99.9	99.9	98.5

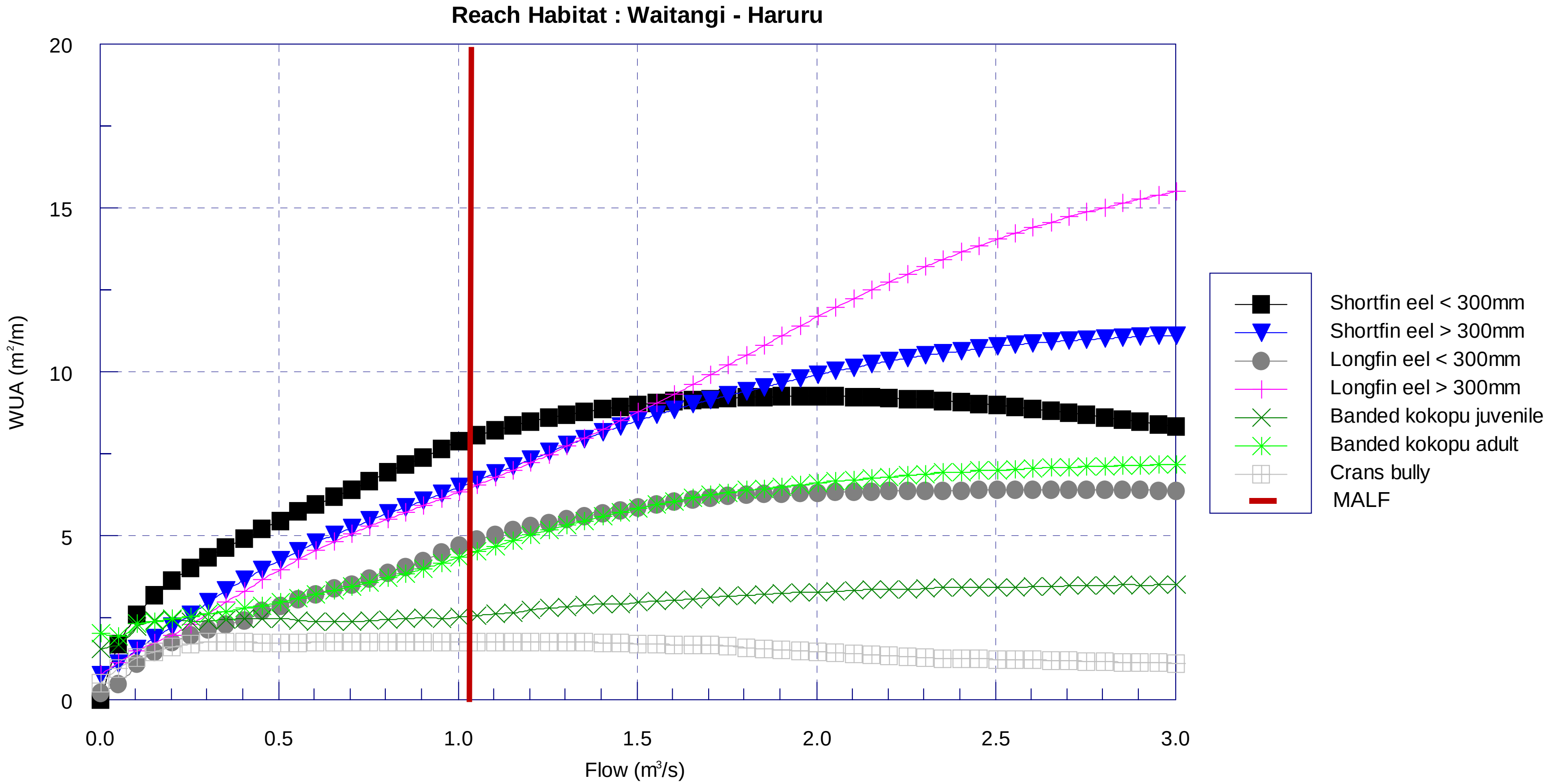

Figure 4-3: Predicted WUA versus flow relationship for target fish species in the Waitangi Stream at the Haruru habitat survey site. Estimated MALF (1.019 $m^3 s^{-1}$) is shown by the vertical red line.

4.1.3 Allocation limits and WUA

Current total maximum consented allocation in the catchment upstream of the Haruru habitat survey reach is estimated to be 1.25 $m^3 s^{-1}$ (Table 3-5). This equates to 123% of MALF at the Haruru habitat survey reach. The hydrological consequences of current allocation rules and the alternative management scenarios based on the proposed NES rules are compared in Figure 4-4. The currently consented maximum allocation is high relative to the limits in the proposed NES, which is reflected in the much greater modification of the flow duration curve relative to the naturalised flows than for the NES based scenarios. In particular, the duration for which flows are at the minimum flow (i.e., the duration of flat-lining) is significantly higher under the current allocation rules (Figure 4-4). The proportion of time that flow is at or below the minimum flow has been used as an indicator of potential ecological impact (MfE 2008). It is based on the assumption that ecological communities are adapted to the natural range of conditions (including low flows) that they are exposed to (Poff et al. 1997). Consequently, if those conditions are altered, for example by humans taking water, ecological communities come under increasing stress and there is an elevated risk of undesirable ecological changes occurring. On average over the 40 year flow time series, the current allocation rules result in flow being at or below the minimum flow for approximately 30% of the year (Table 4-4; Figure 4-5). For the NES based scenarios, the annual average varies between 10 and 13% of the year depending on the allocation limit and for the majority of years is less than 100 days (Table 4-4; Figure 4-5). As expected, the number of days at or below the minimum flow is on average lowest for the proposed NES -10% allocation scenario (Figure 4-5).

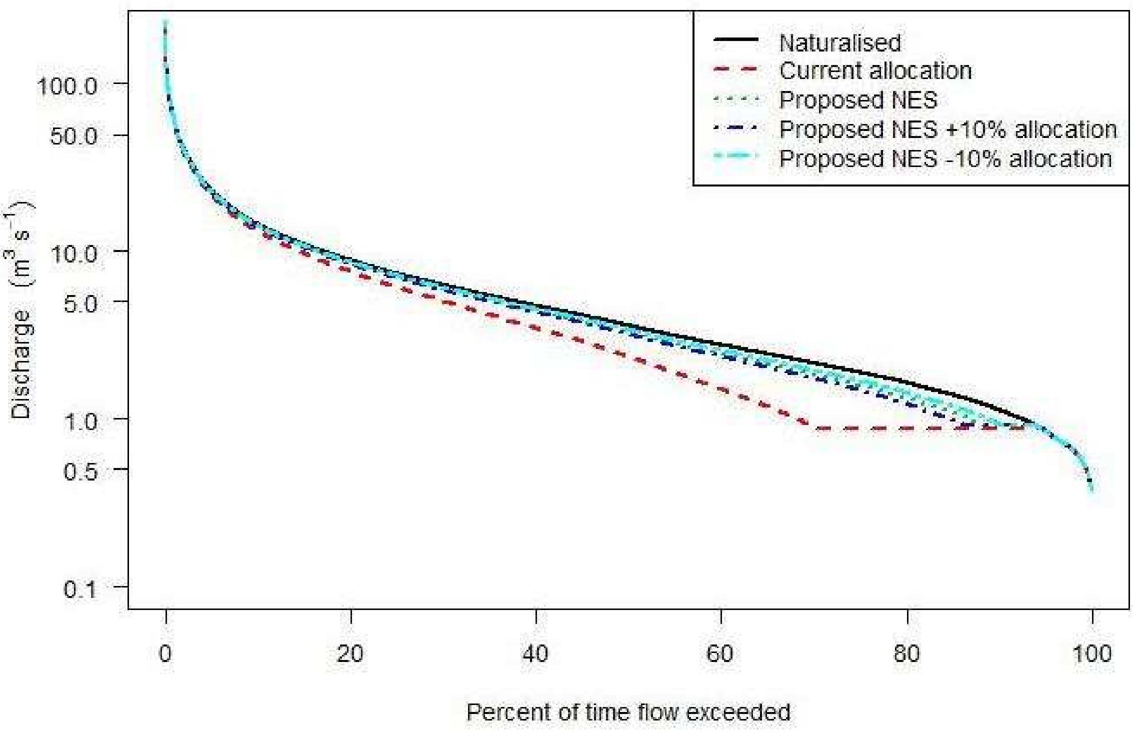

Figure 4-4: Flow duration curves for the Haruru site for each of the water quantity limit scenarios based on a forty year flow time series (1972-2012).

Table 4-4: Summary of the impact of the alternative water quantity limit scenarios on the duration when flow is at or below the minimum flow for the Haruru site. Results are calculated based on the 40 year flow time series from 1972 to 2012.

Scenario	Annual mean number of days at or below minimum flow	Increase in mean number of days at or below minimum flow relative to naturalised flows (days)	Annual maximum number of days at or below minimum flow	Water year of maximum
Current allocation	105	86	199	2006-7
Proposed NES	42	20	166	2009-10
Proposed NES +10%	49	27	169	2009-10
Proposed NES -10%	36	14	161	2009-10

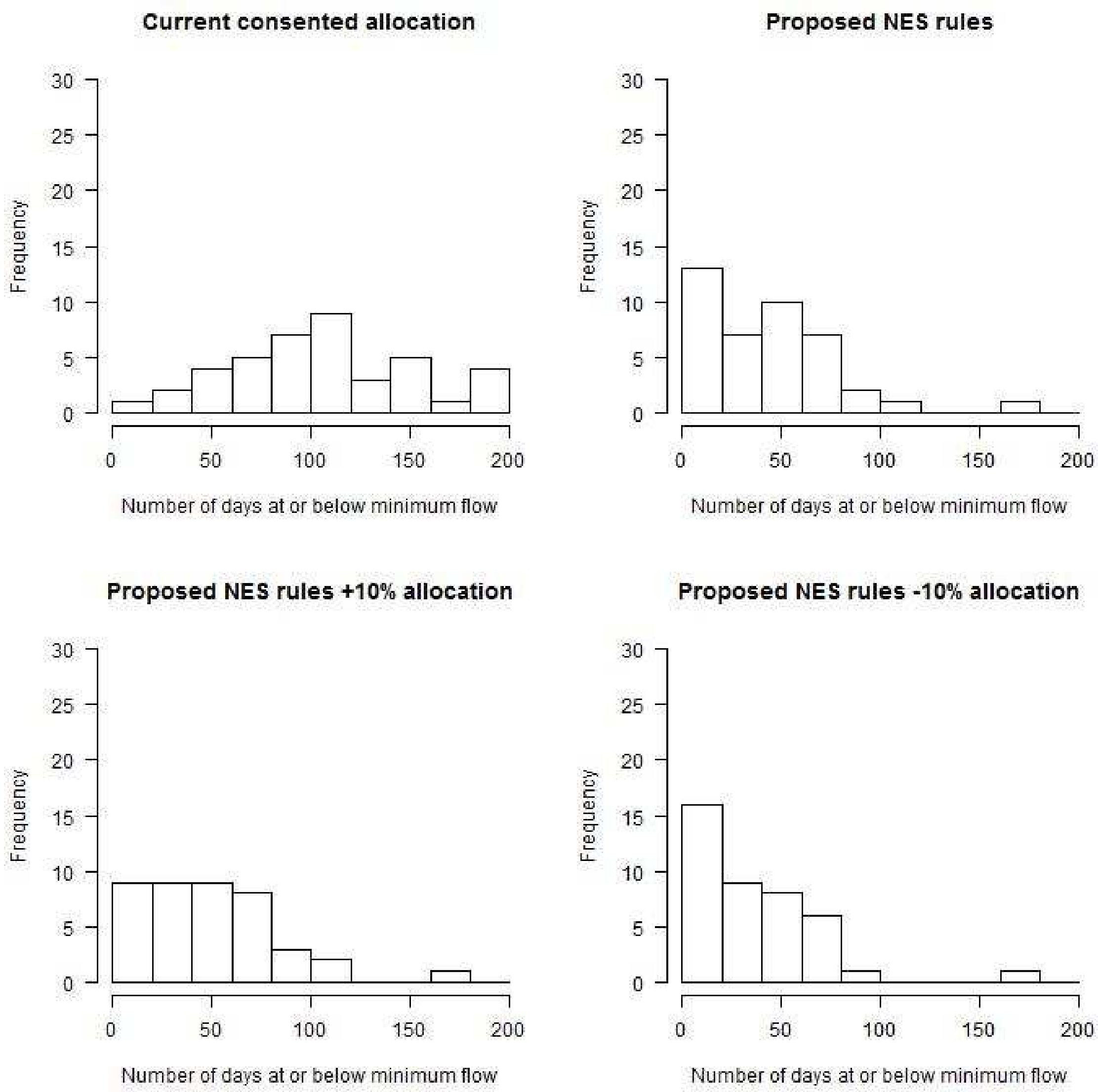

Figure 4-5: Number of days per year (1972-2012) that flows are at or below the minimum flow for each of the water quantity limit scenarios for the Haruru site. Years are water years from 01 July to 30 June.

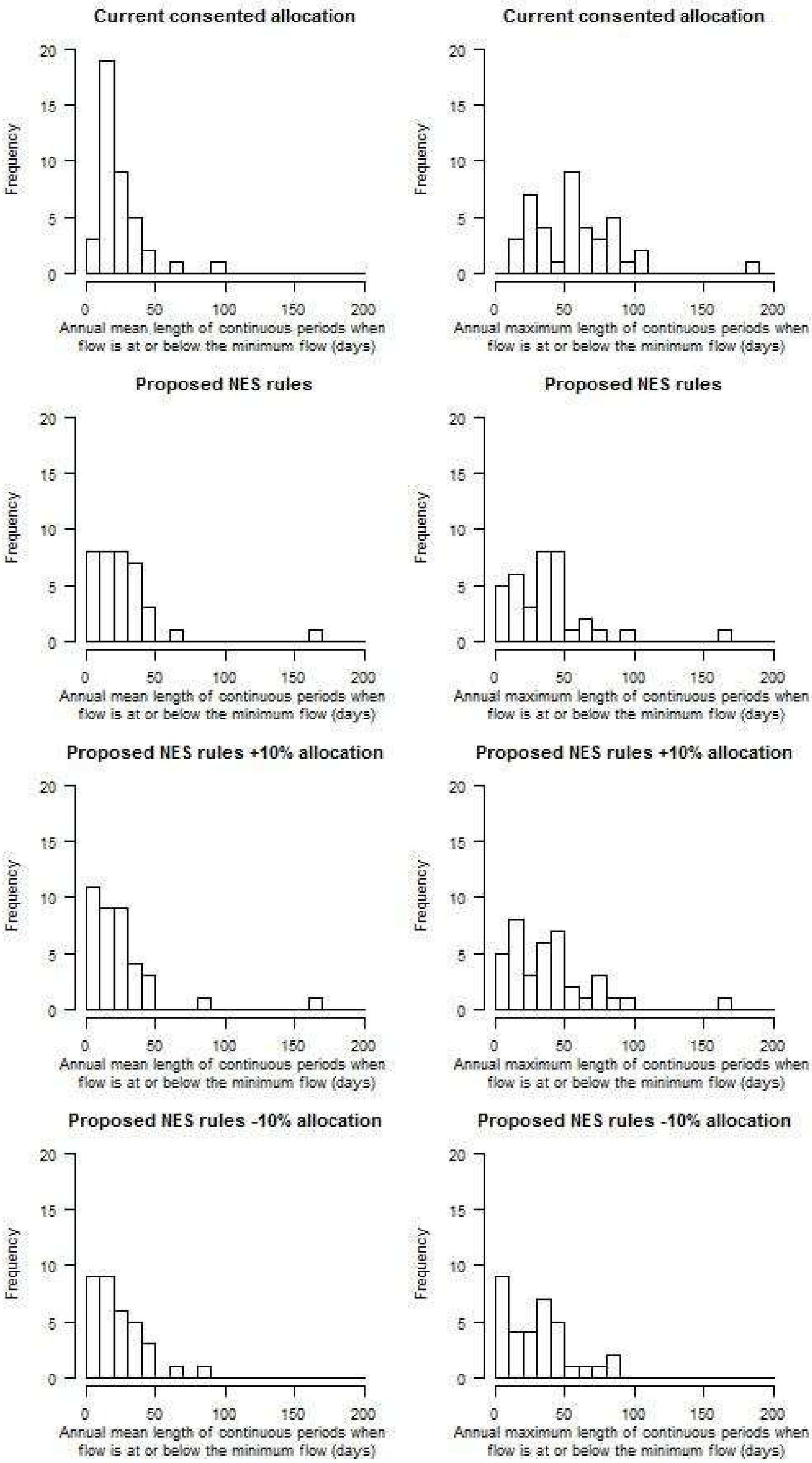

Figure 4-6: Mean and maximum length of continuous periods in each year (1972-2012) when flows are at or below the minimum flow for each of the water quantity limit scenarios for the Haruru site. Years are water years from 01 July to 30 June.

It is important to consider not only the total number of days of flat-lining, but also whether those days all occur in a single continuous period or are spread out through the year. In general, as both the mean and maximum length of continuous flat-lining increases, the greater the stress on aquatic communities is likely to be as habitat is limited for longer and the influence of additional stressors such as elevated water temperatures also increase. Figure 4-6 shows that the mean length of flat-lining appears to be lowest under the current allocation scenario. However, this is misleading because the greater the total number of days that flat-lining occurs, the greater the frequency of additional short periods of flat-lining, which reduce the overall average duration. This is reflected in the histograms of maximum length of continuous flat-lining which shows a much greater frequency of continuous flat-lining periods of greater than 50 days for the current allocation scenario, relative to the NES based scenarios (Figure 4-6).

Analyses of the impacts on instream physical habitat for fish were restricted to low flows in order to avoid over-extrapolating the WUA versus flow relationships beyond the calibration flow range (Figure 4-3). The impact on WUA for each fish species was quantified by calculating the cumulative annual difference in available WUA between the naturalised flows and alternative flow management scenarios and is demonstrated for the period 2006-2007 (Figure 4-7 to Figure 4-19). The greatest impact on WUA was observed for large (>300 mm) eels, particularly longfin eels (Figure 4-9 & Figure 4-13). WUA for adult banded kokopu was also impacted more significantly than for juveniles, although this reach is not likely to be a main habitat for adult banded kokopu (Figure 4-15 & Figure 4-17). These results suggest that deeper, low velocity pool habitats are being impacted by reduced flows. WUA for Cran's bully increases slightly under all modified scenarios, relative to naturalised flow conditions (Figure 4-19 & Figure 4-20).

For all species, the current allocation scenario results in a larger impact on WUA than any of the proposed NES based scenarios, relative to WUA availability under naturalised flow conditions. The relatively high level of allocation currently consented means that there is a comparatively large absolute change in WUA availability, but also that WUA is 'flat-lined' more regularly and for a greater duration. Of the management scenarios evaluated, the greatest protection level for WUA is provided by the proposed NES -10% allocation scenario.

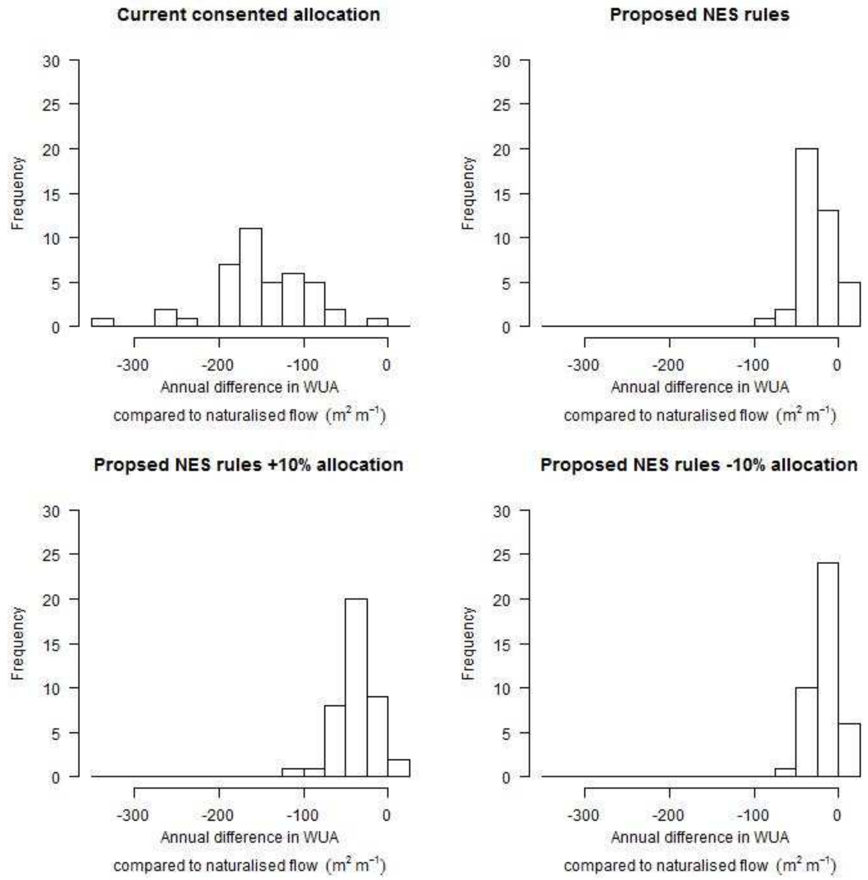

Figure 4-7: Annual changes (1972-2012) in WUA for shortfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Haruru site.

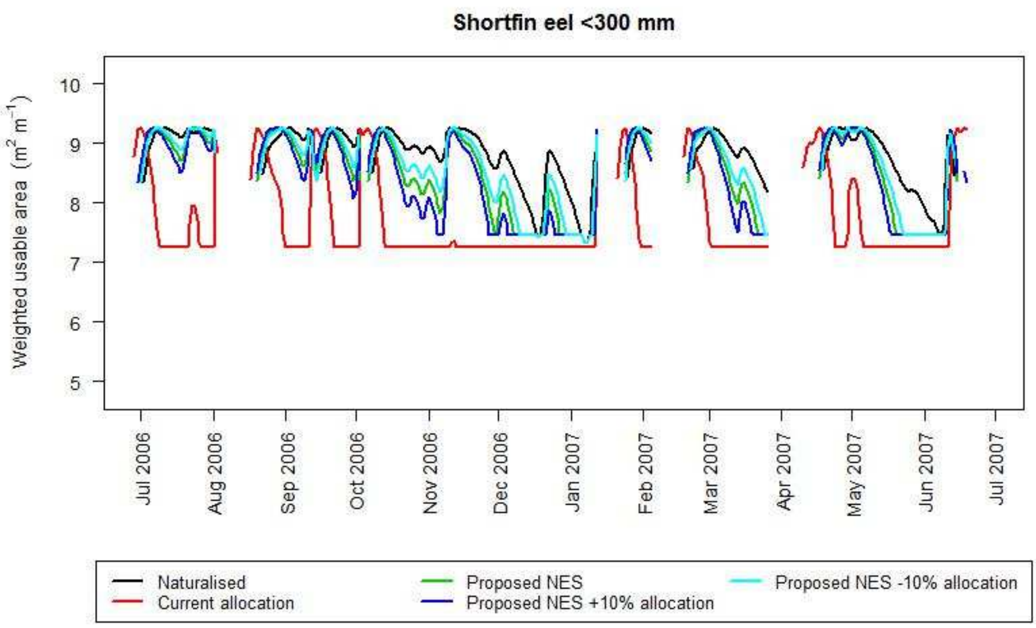

Figure 4-8: WUA time series for shortfin eels (<300 mm) for 2006-7 for the Haruru site.

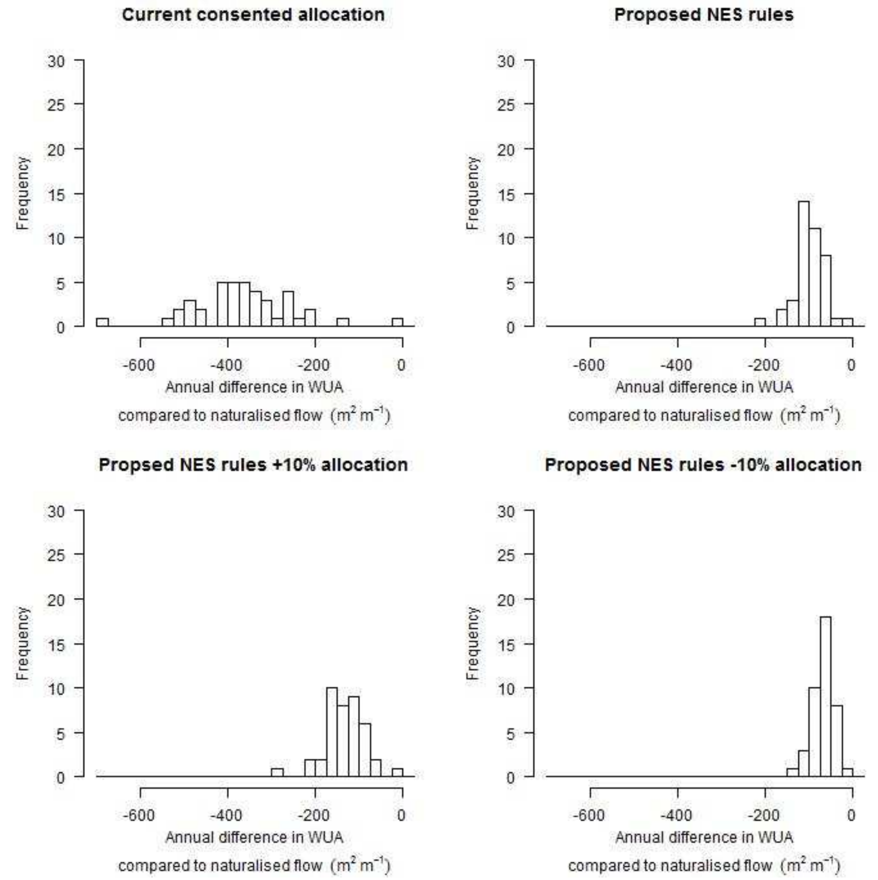

Figure 4-9: Annual changes (1972-2012) in WUA for shortfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Haruru site.

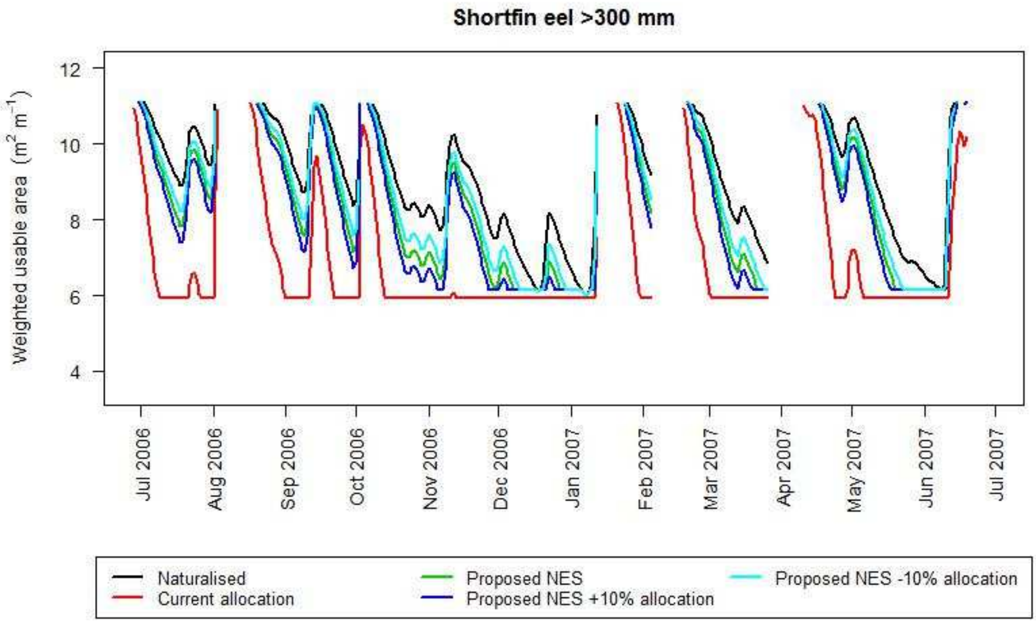

Figure 4-10: WUA time series for shortfin eels (>300 mm) for 2006-7 for the Haruru site.

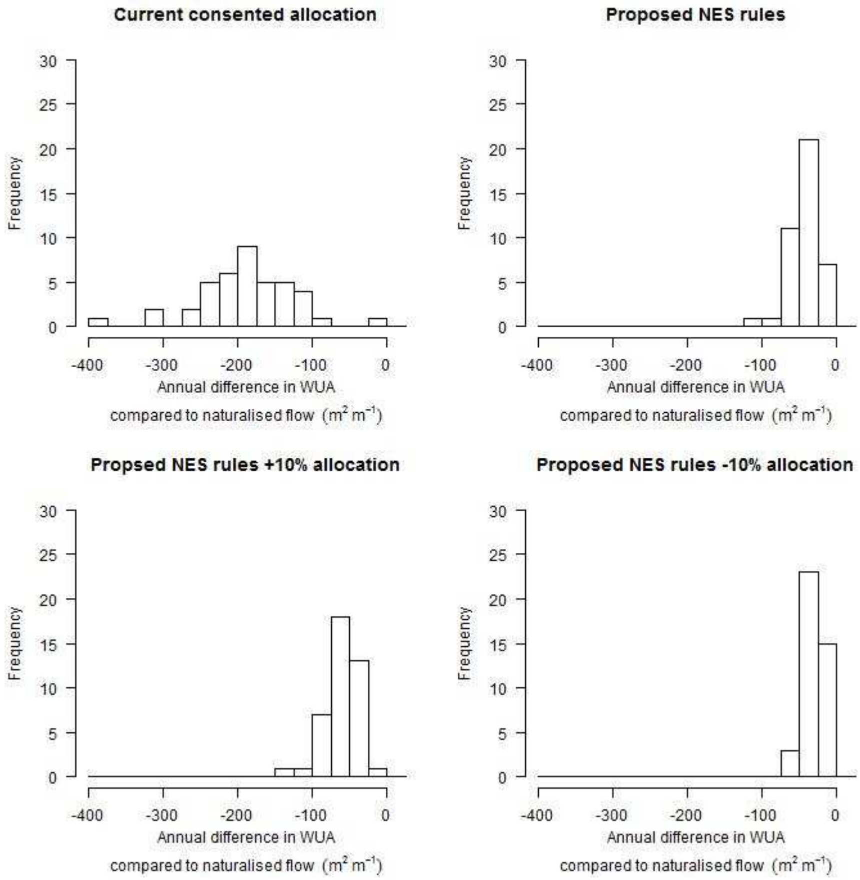

Figure 4-11: Annual changes (1972-2012) in WUA for longfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Haruru site.

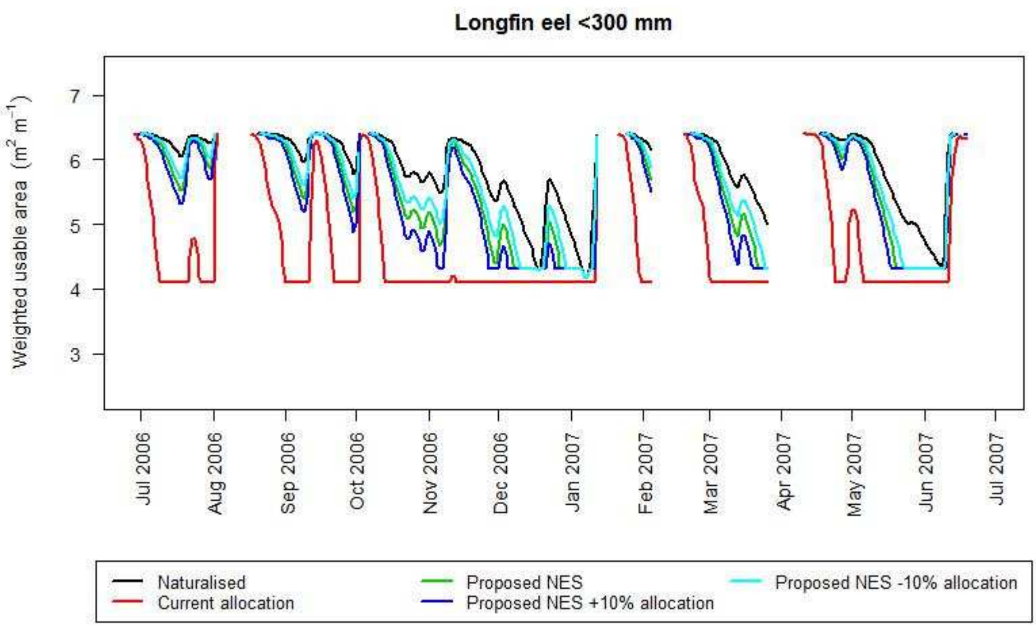

Figure 4-12: WUA time series for longfin eels (<300 mm) for 2006-7 for the Haruru site.

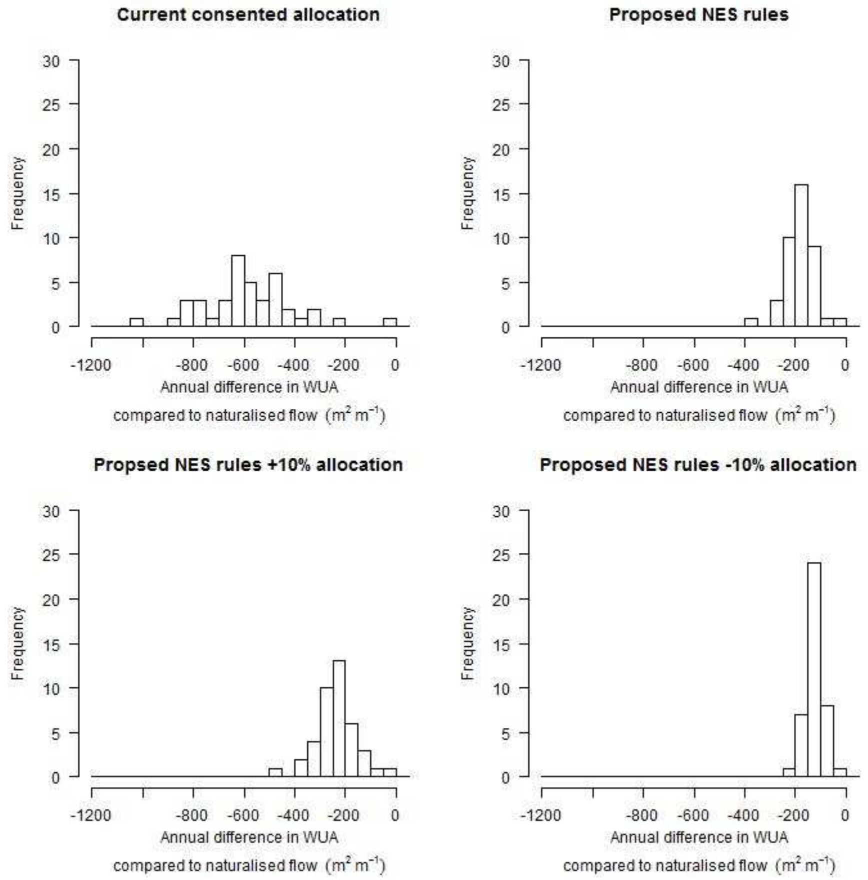

Figure 4-13: Annual changes (1972-2012) in WUA for longfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Haruru site.

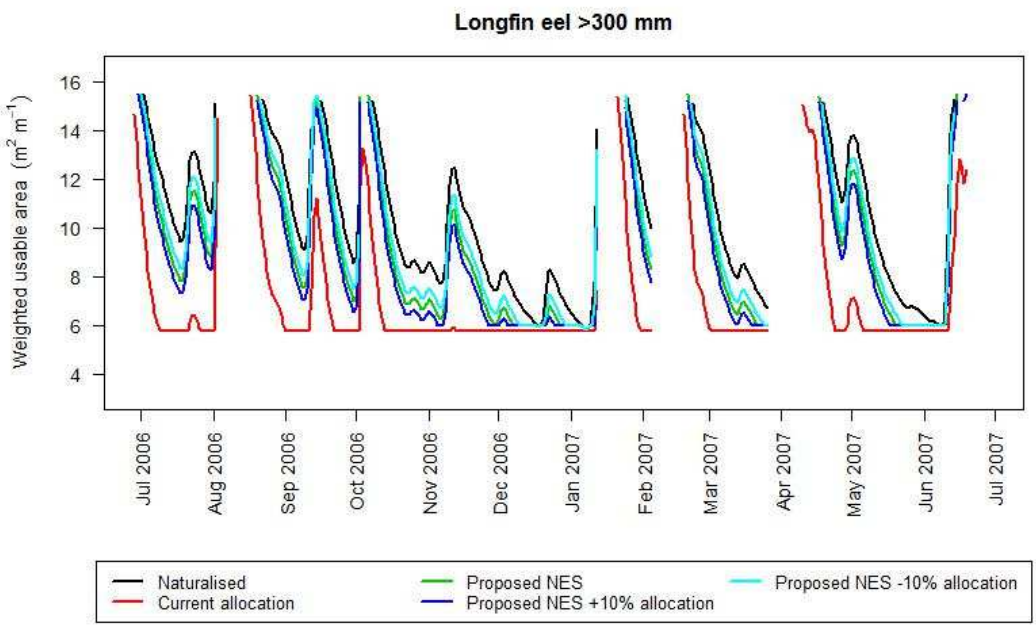

Figure 4-14: WUA time series for longfin eels (>300 mm) for 2006-7 for the Haruru site.

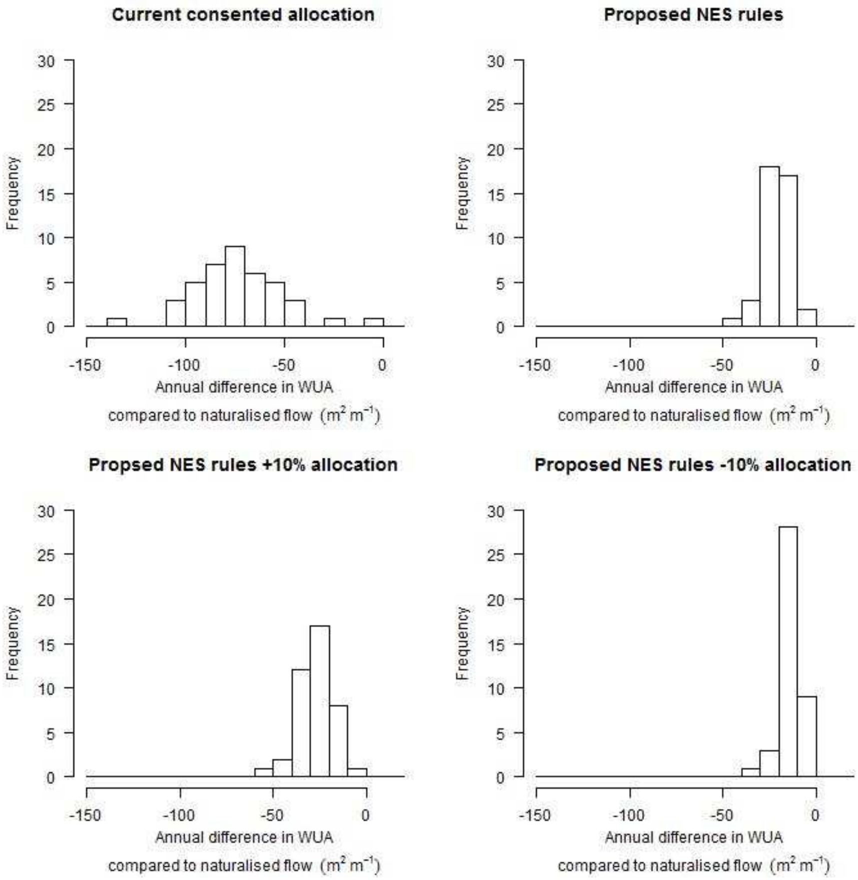

Figure 4-15: Annual changes (1972-2012) in WUA for juvenile banded kokopu under low flows, relative to WUA available under naturalised flow conditions for the Haruru site.

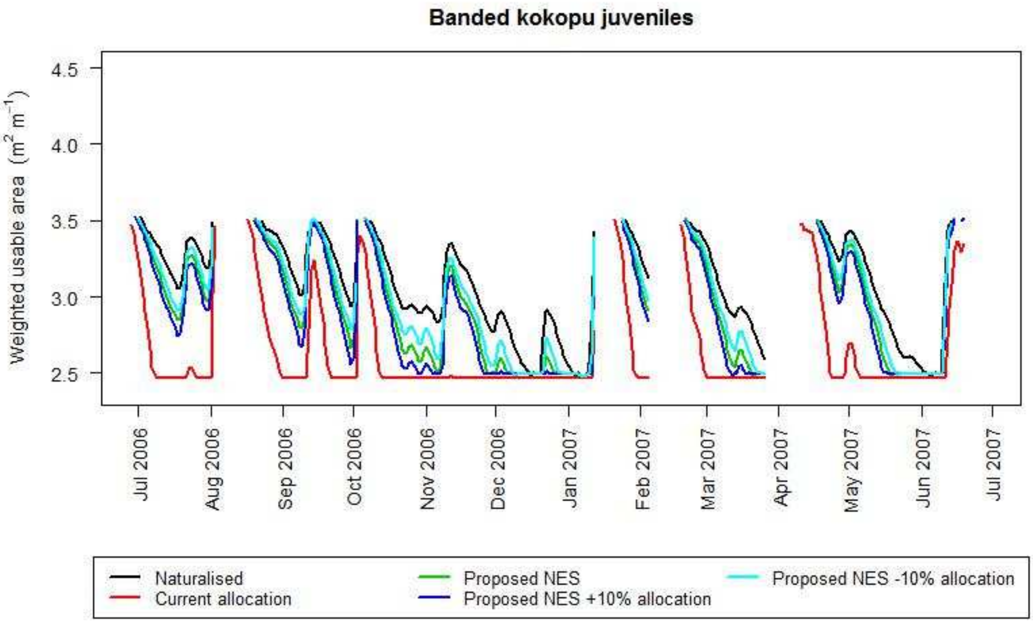

Figure 4-16: WUA time series for juvenile banded kokopu for 2006-7 for the Haruru site.

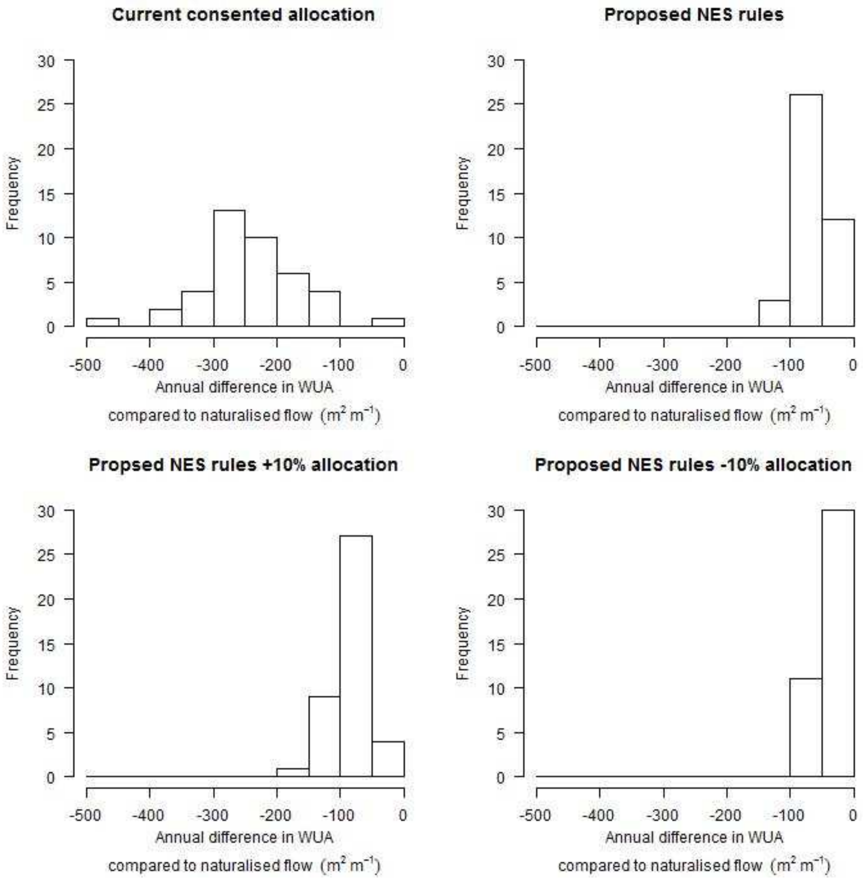

Figure 4-17: Annual changes (1972-2012) in WUA for adult banded kokopu under low flows, relative to WUA available under naturalised flow conditions for the Haruru site.

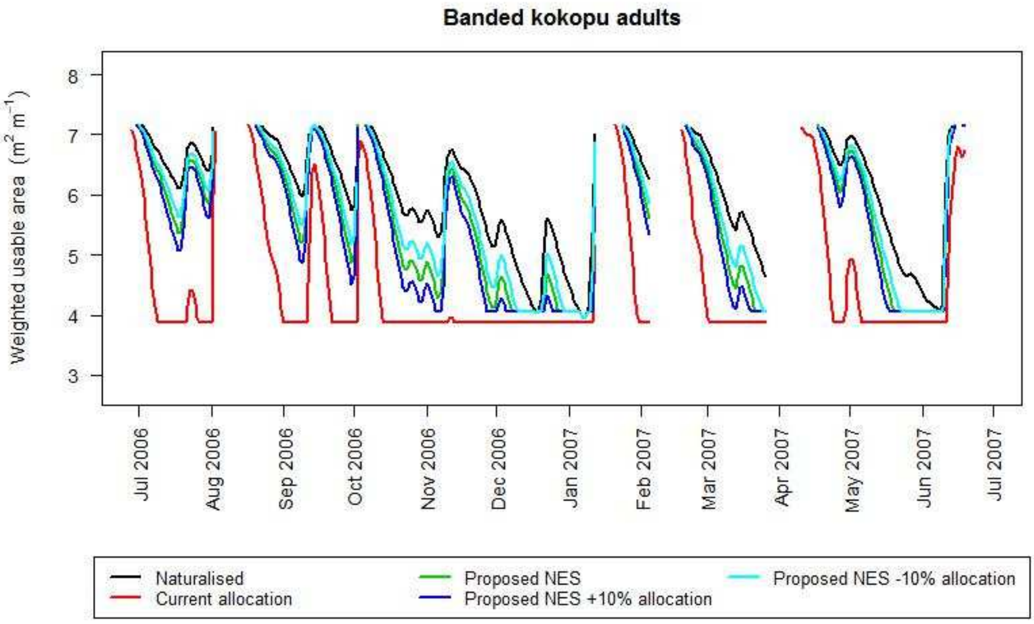

Figure 4-18: WUA time series for adult banded kokopu for 2006-7 for the Haruru site.

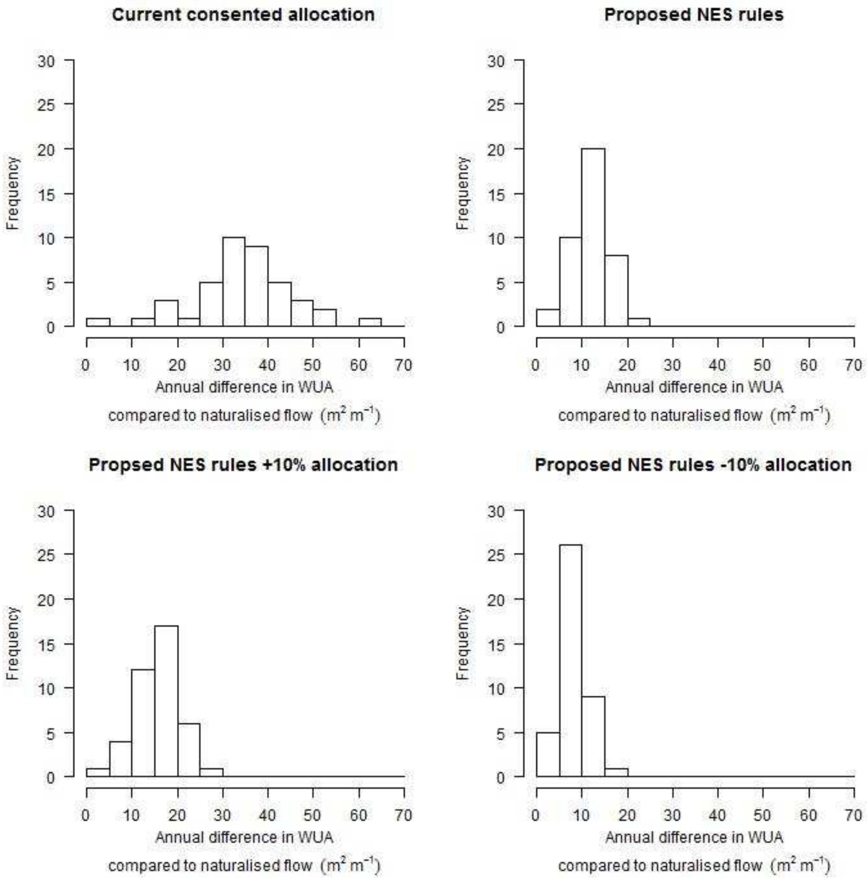

Figure 4-19: Annual changes (1972-2012) in WUA for Cran's bully under low flows, relative to WUA available under naturalised flow conditions for the Haruru site.

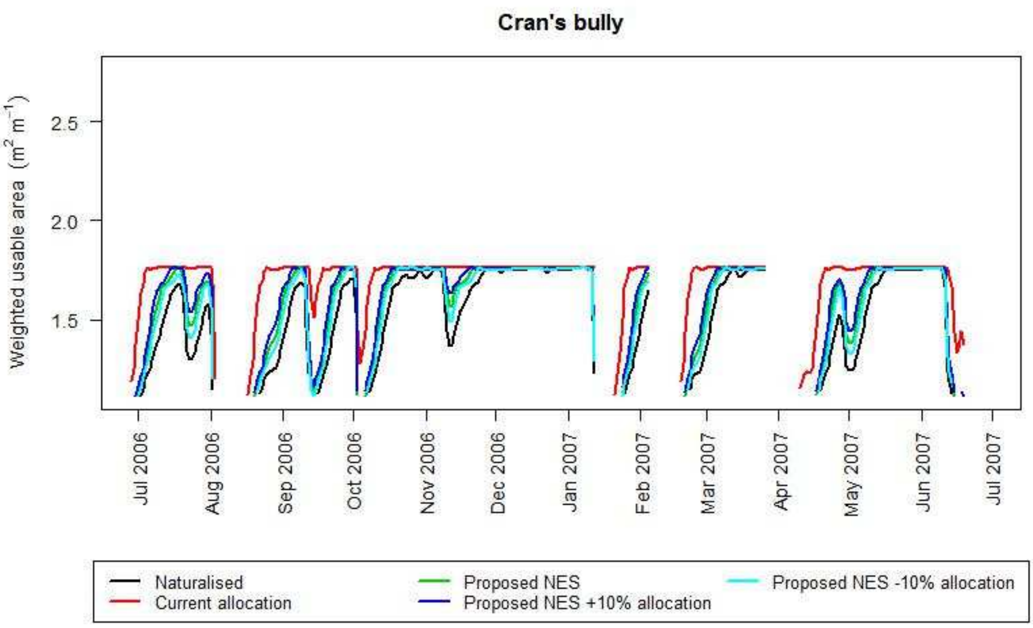

Figure 4-20: WUA time series for Cran's bully for 2006-7 for the Haruru site.

4.2 Waimate North Road

4.2.1 Site description

The Waimate North Road habitat survey reach was located on the Waitangi River approximately 13 km upstream of the SH10 road crossing (Figure 4-21). Habitat mapping was carried out over approximately 1 km. The whole reach was characterised by a fairly even mix of pools, riffles, runs and glides (Table 4-5; Figure 4-22).

Mean wetted width at the time of the survey was 4.6 m. The habitat survey was carried out at a flow of 0.162 $m^3 s^{-1}$, which is equivalent to 111.7% of MALF (Table 4-6). Calibration surveys were carried out at flows of 0.139 and 0.980 $m^3 s^{-1}$ (Table 4-6).

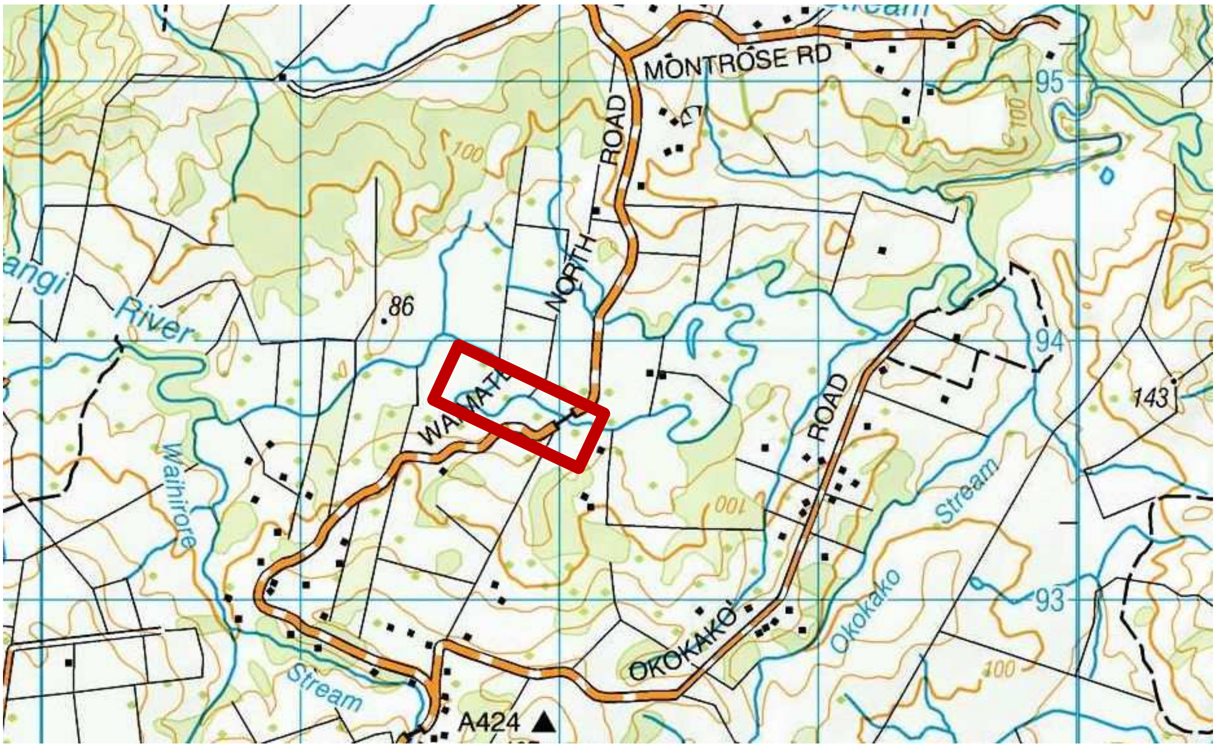

Figure 4-21: Location of the Waimate North Road habitat survey reach (red box).

Figure 4-22: View of the lower reaches of the Waimate North Road habitat survey reach.

Table 4-5: Habitat mapping results for the Waimate site. Habitat type definitions are given in Table 3-2.

Habitat type	Percentage of reach
Riffle	28.0
Run	27.0
Glide	23.0
Pool	22.0

Table 4-6: Summary of survey and calibration flows for the Waimate site.

Date	Flow ($m^3 s^{-1}$)	Percentage of MALF
28/02/2013	0.162	111.7
12/04/2013	0.139	95.9
16/05/2013	0.980	675.9

4.2.2 WUA v. flow relationship

Both species of eel and Cran's bully were recorded as present at this site in the NRC fish surveys carried out in 2013. The relative dominance of shortfin and longfin eels in an eel population is important for evaluating both the biodiversity and cultural value of the fish community and therefore in defining appropriate protection levels. However, nearly 90% of the eels captured during the NRC survey were not identified to species level and therefore the relative value of the fish community cannot be established. Banded kokopu have also been recorded upstream of this site and therefore it can be assumed that suitable habitat for migrant juveniles is required.

Optimum WUA was outside of the modelled flow range for large longfin eels. For small longfin and shortfin eels, and large shortfin eels, the optimum flows were at 172%, 207% and 310% of MALF respectively (Table 4-7 & Figure 4-23). The maximum WUA for Cran's bully is very close to MALF (103%), but for both life stages of banded kokopu, maximum WUA occurs at very low flows (34% MALF).

For both eel species and Cran's bully, WUA declines as flow falls below the MALF, with the most rapid decline being for small longfin eels (Table 4-7 & Figure 4-23). A minimum flow of 90% of MALF would be required to avoid >5% habitat loss for all species relative to that available at MALF, and a minimum flow of 85% of MALF would be required to avoid a >10% reduction in WUA for all species. Due to the very low optimum flow for banded kokopu, WUA increases as flow reduces from MALF, such that a minimum flow of 80% of MALF is predicted to increase WUA for this species by nearly 20% for the juvenile life stage and nearly 10% for adults.

Table 4-7: Flow at optimum WUA and changes in WUA at various proportions of MALF for the Waimate North Road habitat survey reach. Optimum flow is outside the range modelled where optimum is >2.00 $m^3 s^{-1}$.

Species	Optimum flow ($m^3 s^{-1}$)	WUA at MALF ($m^2 m^{-1}$)	Percentage of WUA at MALF available at:							
			95% MALF	90% MALF	85% MALF	80% MALF	75% MALF	70% MALF	60% MALF	50% MALF
Shortfin eel <300 mm	0.30	1.538	98.9	97.7	96.5	95.1	93.5	91.8	87.9	83.2
Shortfin eel >300 mm	0.45	1.510	98.3	96.6	94.9	93.0	91.2	89.3	85.4	81.4
Longfin eel <300 mm	0.25	0.864	97.8	95.0	92.0	89.0	85.8	82.8	77.1	71.0
Longfin eel >300 mm	>2.00	1.122	98.2	96.5	94.8	93.1	91.4	89.7	86.6	83.2
Banded kokopu juvenile	0.05	0.881	104.5	109.1	113.5	118.2	122.6	126.2	131.3	135.6
Banded kokopu adult	0.05	1.127	102.2	104.5	106.9	109.5	112.2	115.2	122.7	131.9
Cran's bully	0.15	1.212	99.7	99.0	98.0	96.9	95.9	95.1	94.1	93.5

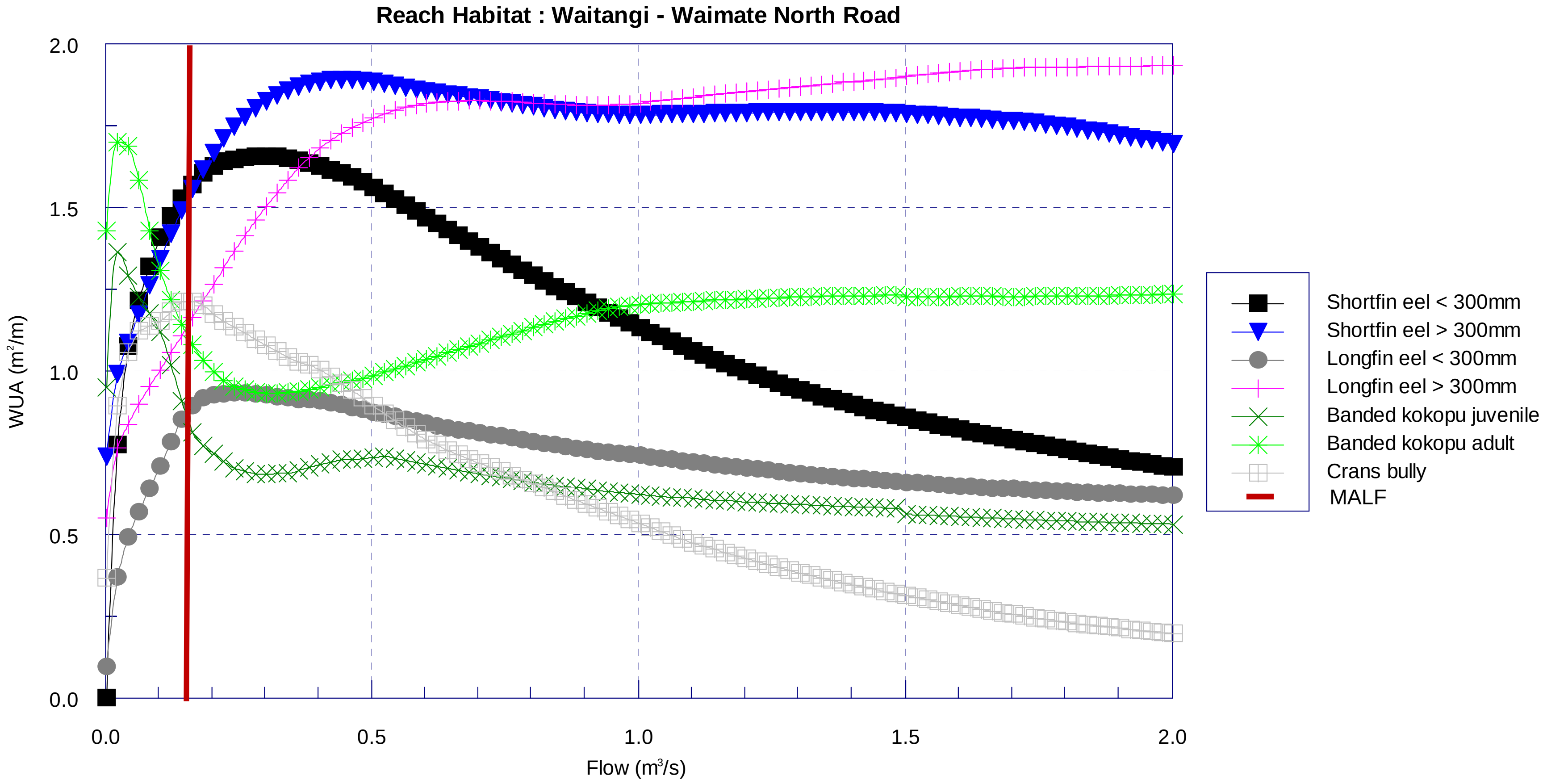

Figure 4-23: Predicted WUA versus flow relationship for target fish species in the Waitangi Stream at the Waimate North Road habitat survey site. Estimated MALF (0.145 m^3 s^{-1}) is shown by the vertical red line.

4.2.3 Allocation limit scenarios

Current total maximum consented allocation in the catchment upstream of the Waimate North Road habitat survey reach is estimated to be 0.263 $m^3\ s^{-1}$ (Table 3-5). This equates to 181% of MALF at the Waimate North Road habitat survey reach. The hydrological consequences of current allocation rules and the alternative management scenarios based on the proposed NES rules are compared in Figure 4-24. The potential degree of hydrological alteration under current allocation is significantly greater than under any of the proposed NES based scenarios. The mean number of days per year at or below the minimum flow under current allocation rules is 115, compared to 28 under the proposed NES rules (Table 4-8). In the majority of years, the mean number of days at or below the minimum flow was less than 50 for the three scenarios based on the proposed NES limits (Figure 4-25). The maximum number of days in a year when flow was predicted to be at or below the minimum flow was 230 in 2006-7 under current allocation, and 156 in 2009-10 under the proposed NES rules.

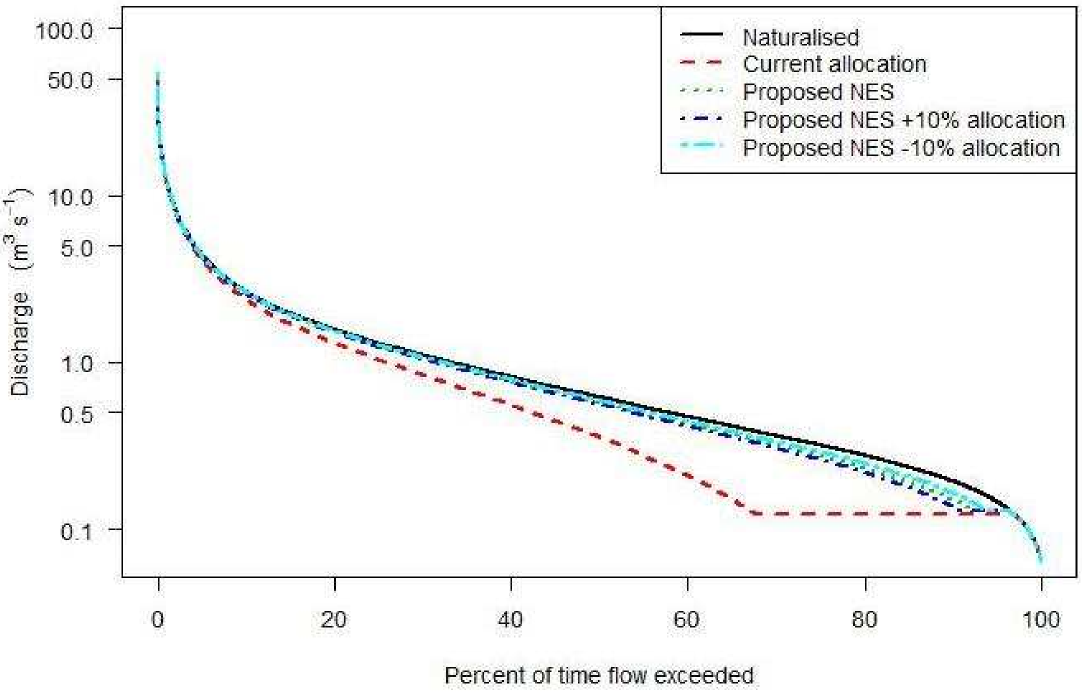

Figure 4-24: Flow duration curves for each of the water quantity limit scenarios for the Waimate site.

Table 4-8: Summary of the impact of the alternative water quantity limit scenarios on the duration when flow is at or below the minimum flow for the Waimate site. Results are calculated based on the 40 year flow time series from 1972 to 2012.

Scenario	Annual mean number of days at or below minimum flow	Increase in mean number of days at or below minimum flow relative to naturalised flows (days)	Annual maximum number of days at or below minimum flow	Water year of maximum
Current allocation	115	104	230	2006-7
Proposed NES	28	15	156	2009-10
Proposed NES +10%	33	20	163	2009-10

Scenario	Annual mean number of days at or below minimum flow	Increase in mean number of days at or below minimum flow relative to naturalised flows (days)	Annual maximum number of days at or below minimum flow	Water year of maximum
Proposed NES -10%	22	9	148	2009-10

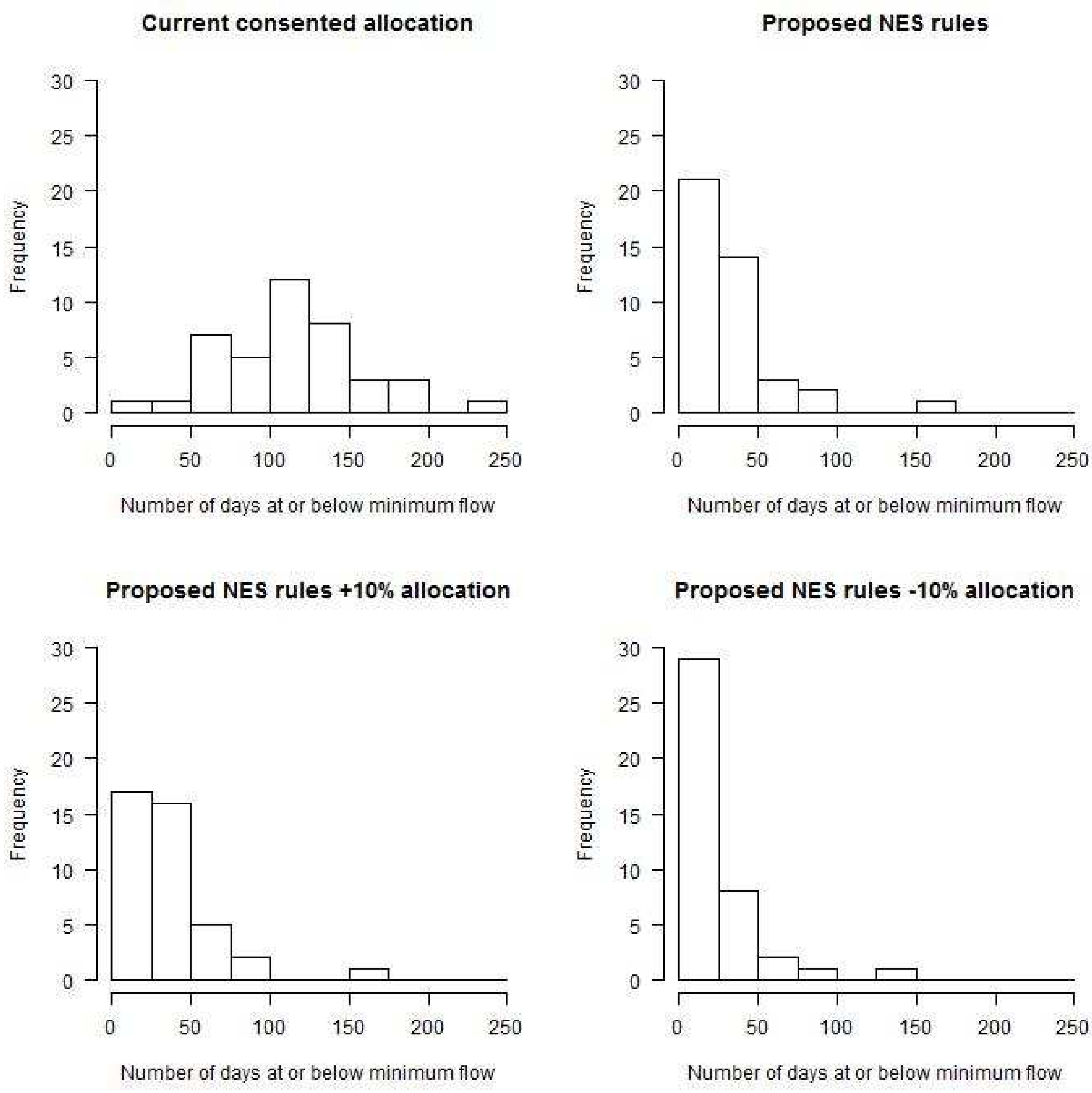

Figure 4-25: Number of days per year (1972-2012) that flows are at or below the minimum flow for each of the water quantity limit scenarios for the Waimate site. Years are water years from 01 July to 30 June.

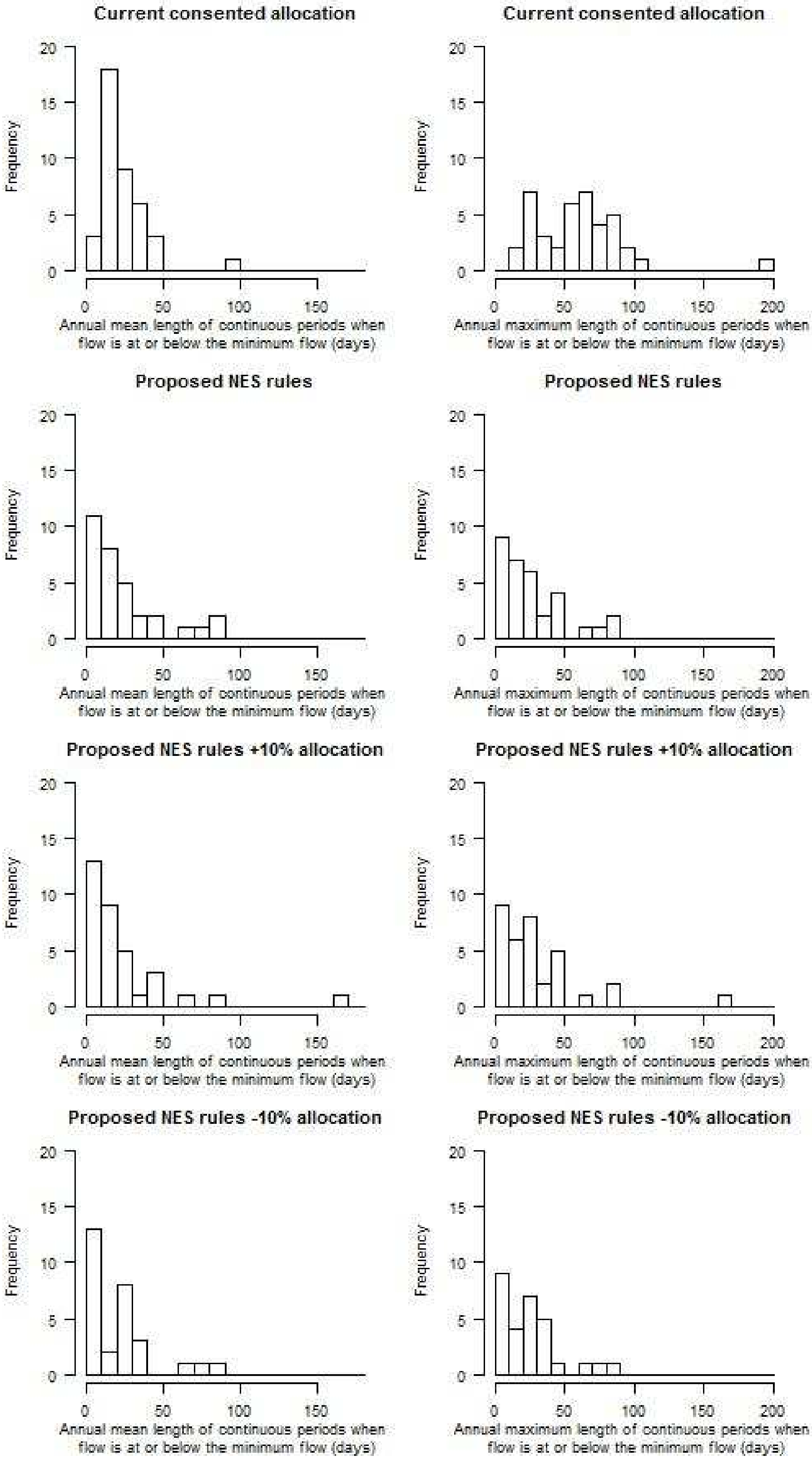

Figure 4-26: Mean and maximum length of continuous periods in each year (1972-2012) when flows are at or below the minimum flow for each of the water quantity limit scenarios for the Waimate site. Years are water years from 01 July to 30 June.

The mean continuous number of days that flows would be at or below the minimum flow was lowest for the current allocation scenario (Figure 4-26). However, this is again an artefact of the number of periods of flat-lining being greater than under the alternative scenarios, but most of those additional flat-lining periods being of short duration. This is reflected in the annual maximum durations of flat-lining, which are significantly greater under the current allocation scenario when compared to the proposed NES based scenarios (Figure 4-26). Over the 40 year flow time series under current allocation rules about 65% of years have a maximum continuous flat-lining period of greater than 50 days. However, for all of the proposed NES based scenarios, less than 10% of years have a maximum duration of greater than 50 days (Figure 4-26).

On average over the 40 year analysis period, WUA increased slightly relative to naturalised flow conditions for small shortfin eels under all four alternative flow management scenarios (Figure 4-27). However, for larger (>300 mm) shortfin eels, WUA was generally reduced relative to that available under naturalised flow conditions (Figure 4-29). For small longfin eels, the predicted changes in WUA relative to naturalised flow conditions were very small for all of the proposed NES based scenarios and on average WUA was slightly lower under current allocation rules (Figure 4-31). For large longfin eels (>300 mm), WUA was reduced compared to naturalised conditions under all flow management scenarios, and was most significantly impacted under the current allocation rules. WUA was generally increased for banded kokopu (Figure 4-35 & Figure 4-37) and Cran's bully (Figure 4-39) under all management scenarios, but the magnitude of the changes for these species was small when compared to the impacts on adult eels. The impact on WUA was greatest under the current allocation scenario for all indicator species.

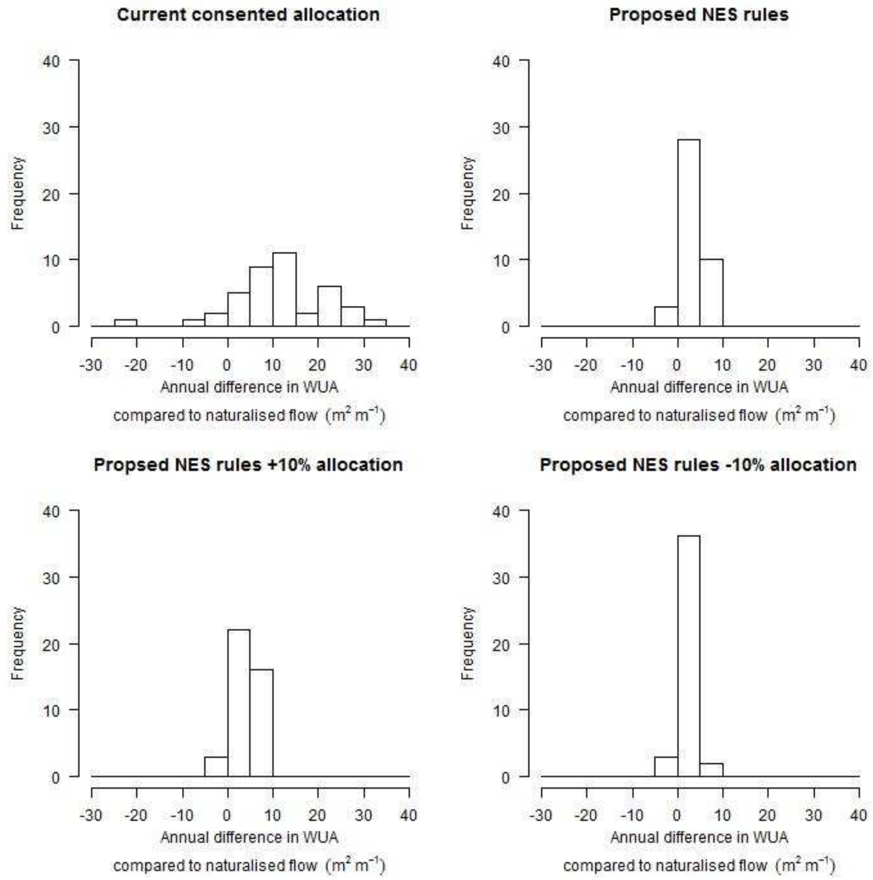

Figure 4-27: Annual changes (1972-2012) in WUA for shortfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waimate site.

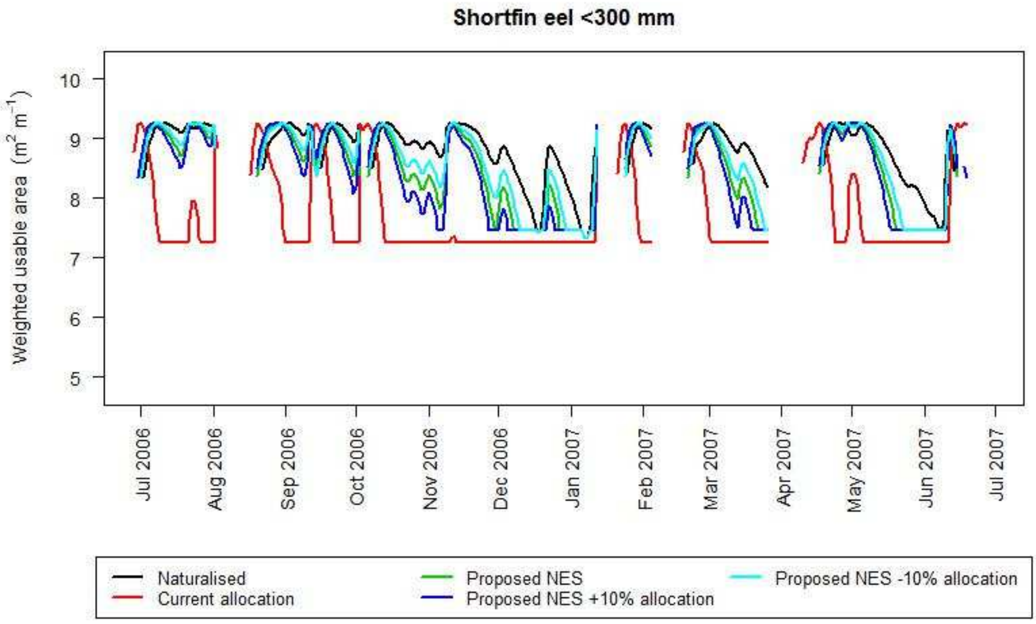

Figure 4-28: WUA time series for shortfin eels (<300 mm) for 2006-7 for the Waimate site.

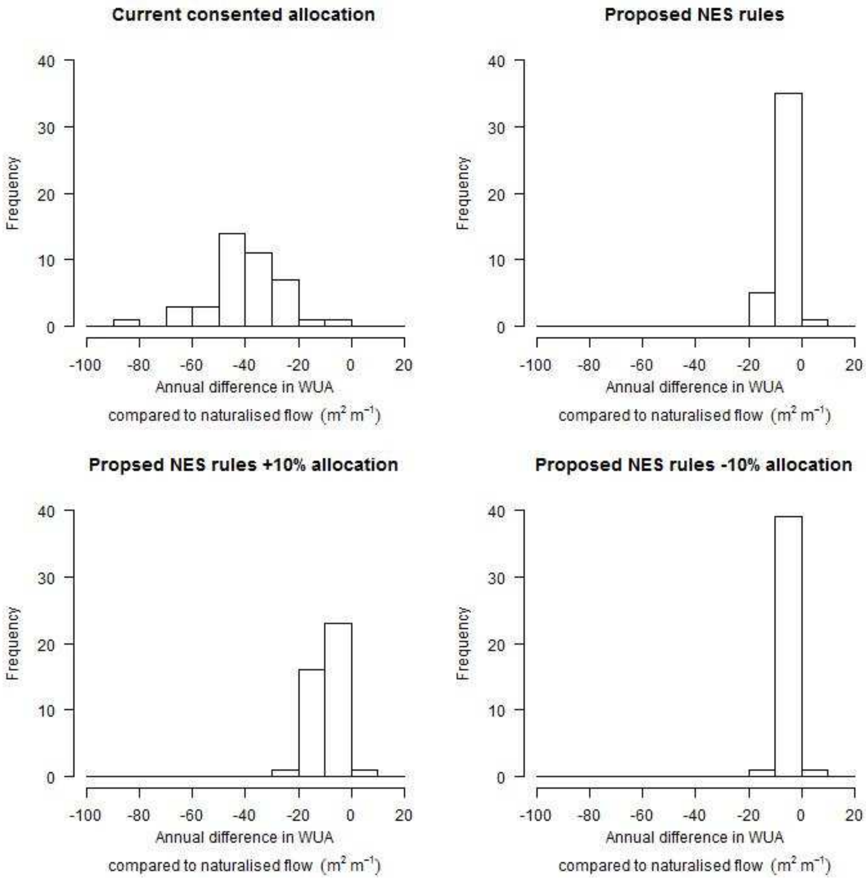

Figure 4-29: Annual changes (1972-2012) in WUA for shortfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waimate site.

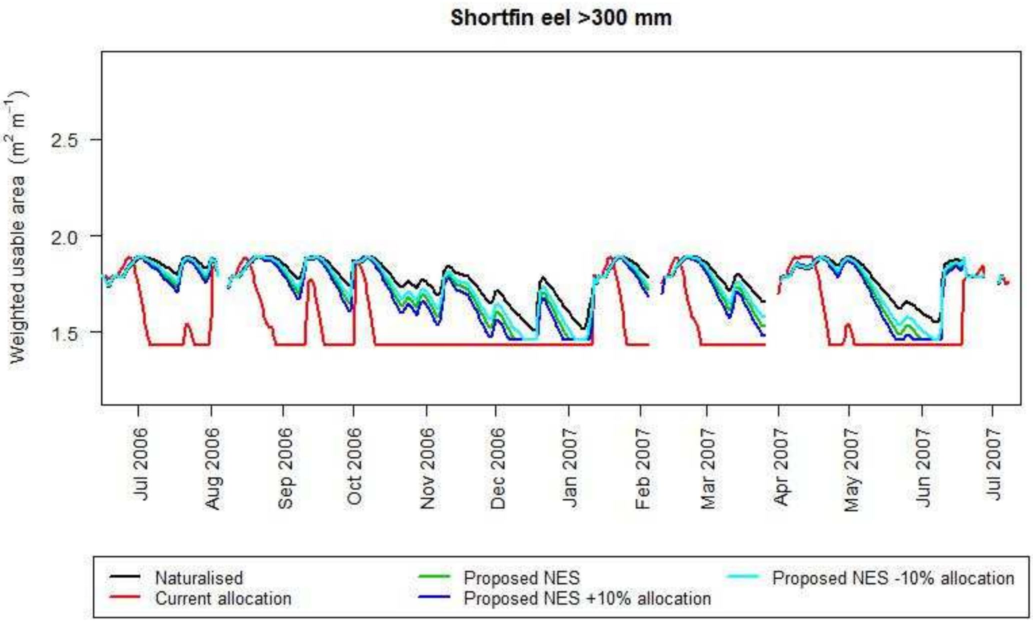

Figure 4-30: WUA time series for shortfin eels (>300 mm) for 2006-7 for the Waimate site.

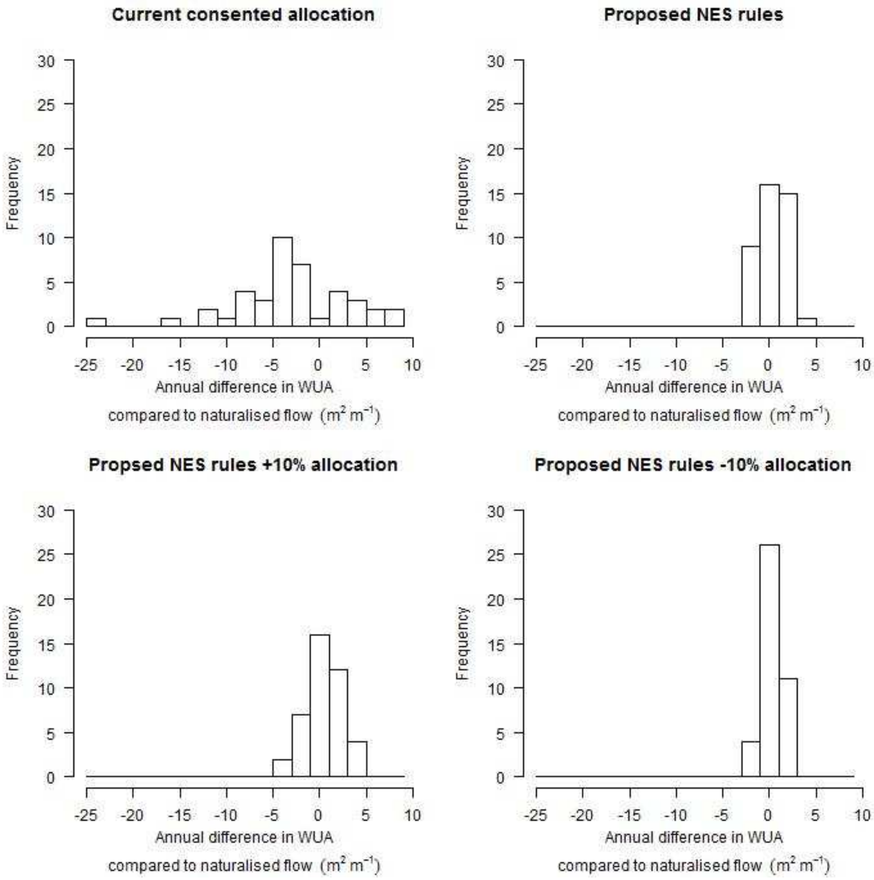

Figure 4-31: Annual changes (1972-2012) in WUA for longfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waimate site.

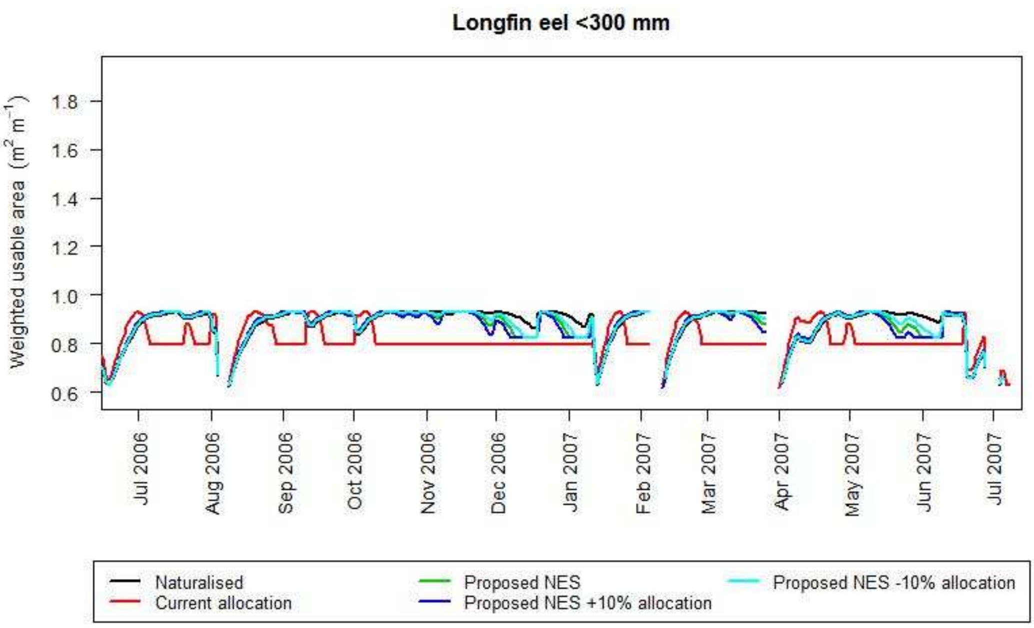

Figure 4-32: WUA time series for longfin eels (<300 mm) for 2006-7 for the Waimate site.

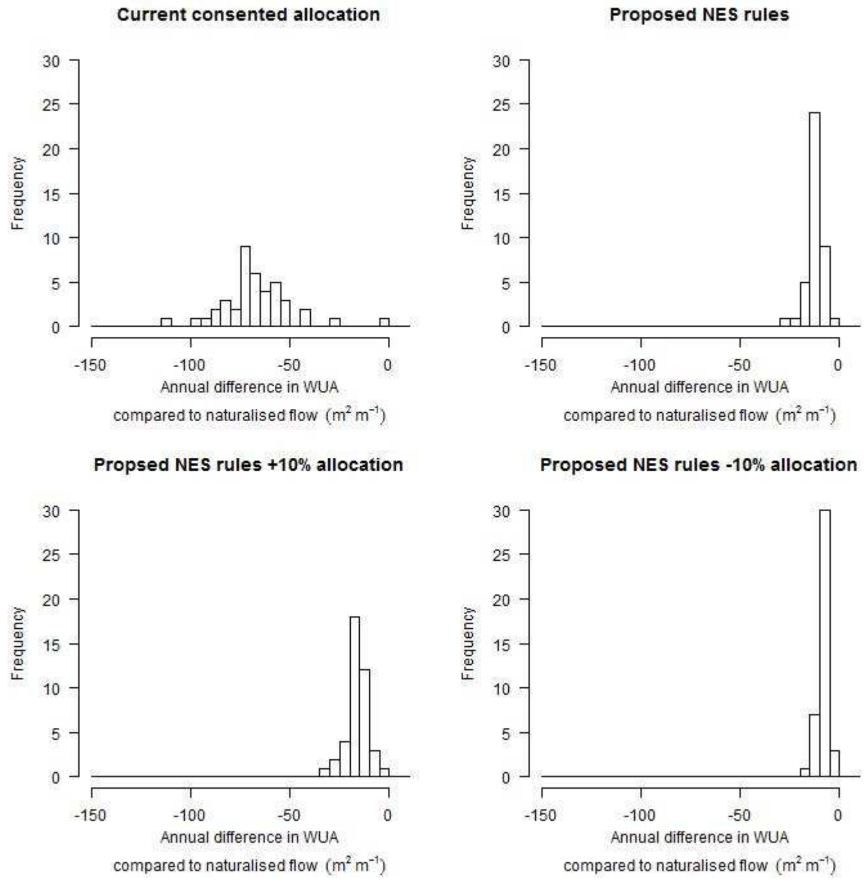

Figure 4-33: Annual changes (1972-2012) in WUA for longfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waimate site.

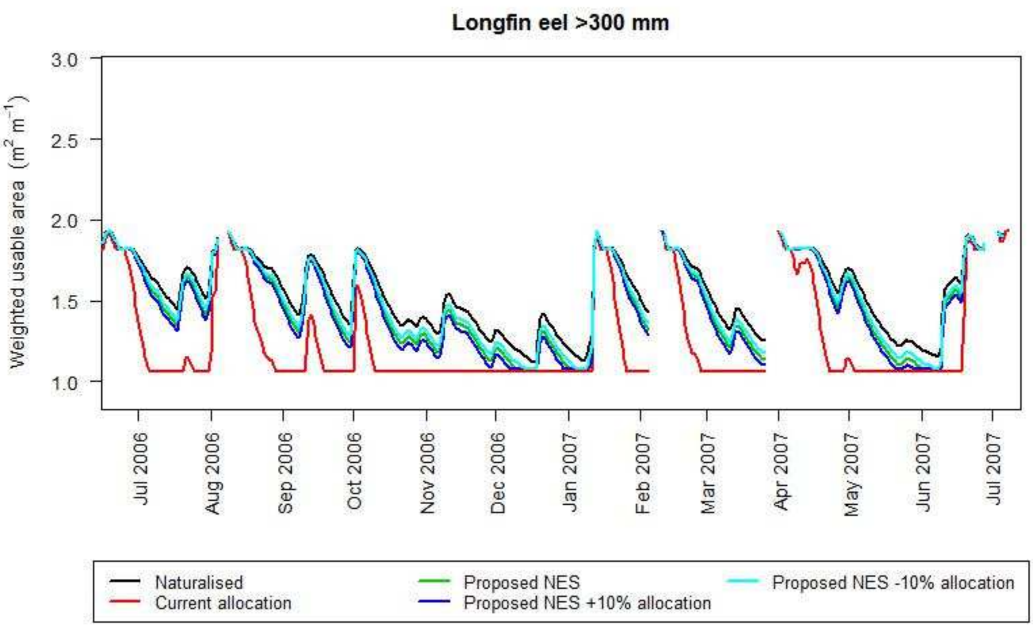

Figure 4-34: WUA time series for longfin eels (>300 mm) for 2006-7 for the Waimate site.

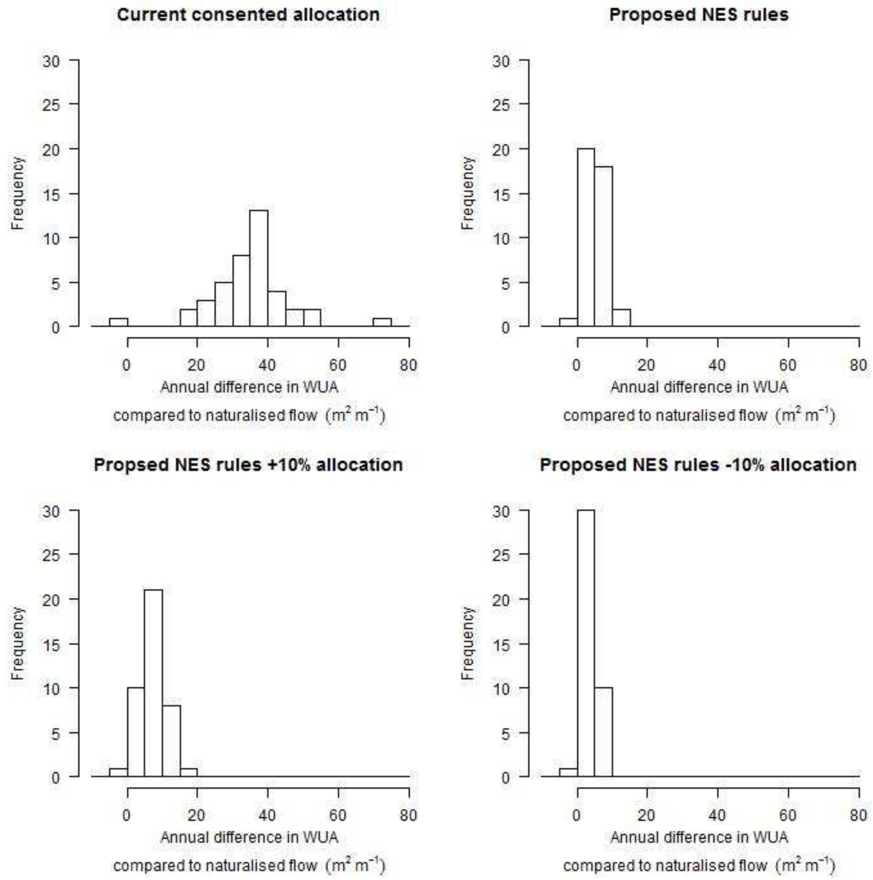

Figure 4-35: Annual changes (1972-2012) in WUA for banded kokopu juveniles under low flows, relative to WUA available under naturalised flow conditions for the Waimate site.

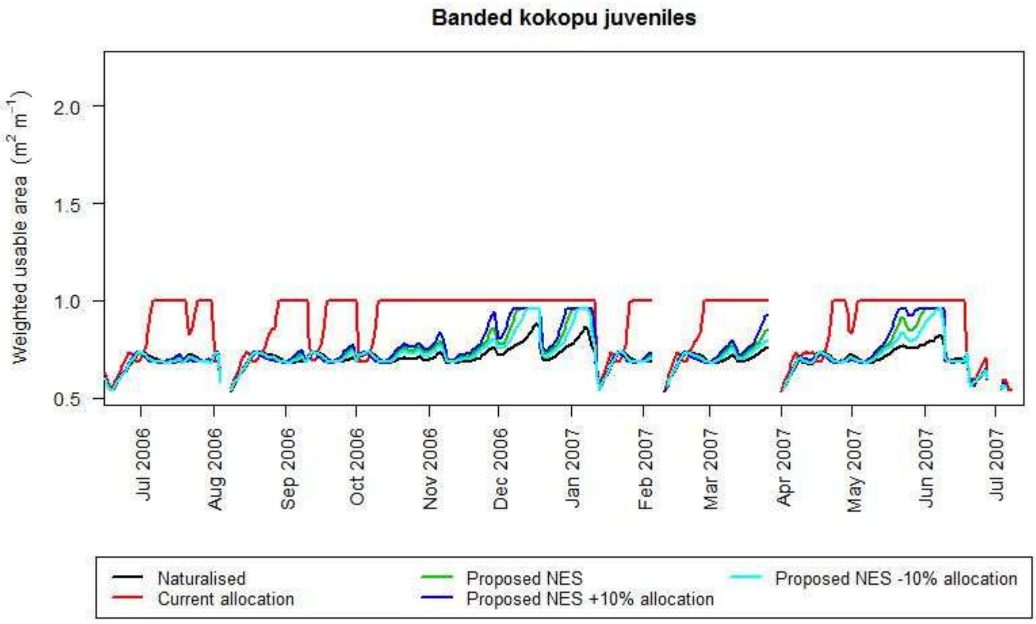

Figure 4-36: WUA time series for banded kokopu juveniles for 2006-7 for the Waimate site.

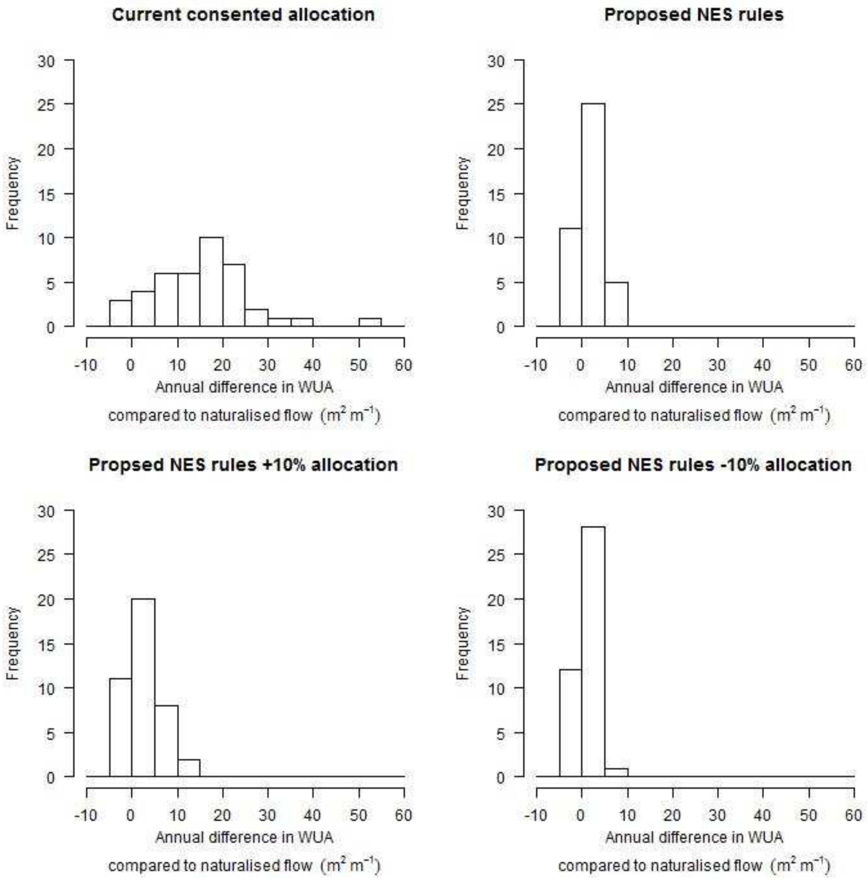

Figure 4-37: Annual changes (1972-2012) in WUA for banded kokopu adults under low flows, relative to WUA available under naturalised flow conditions for the Waimate site.

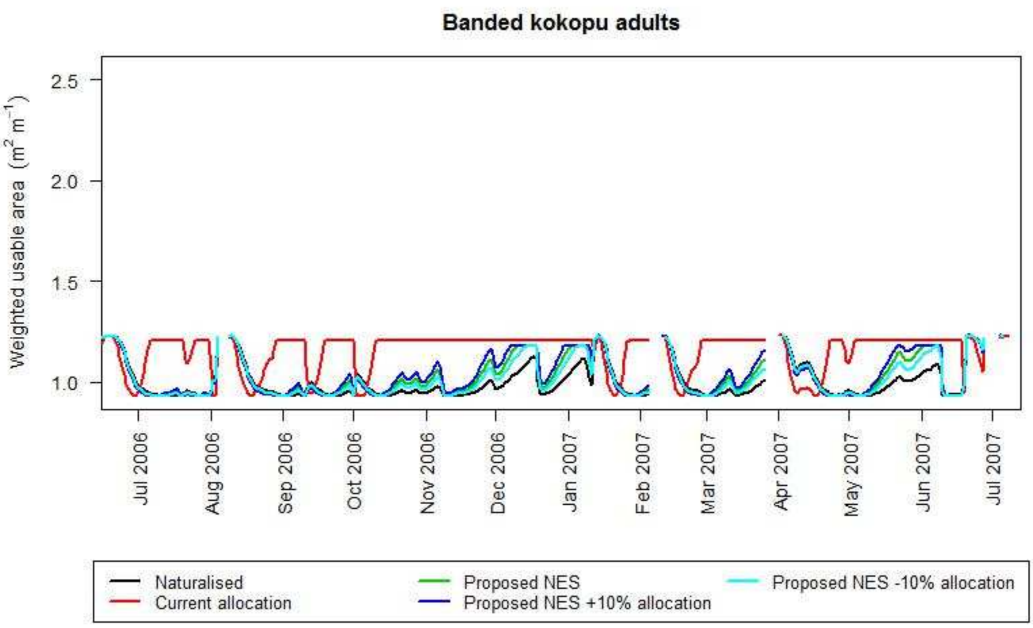

Figure 4-38: WUA time series for banded kokopu adults for 2006-7 for the Waimate site.

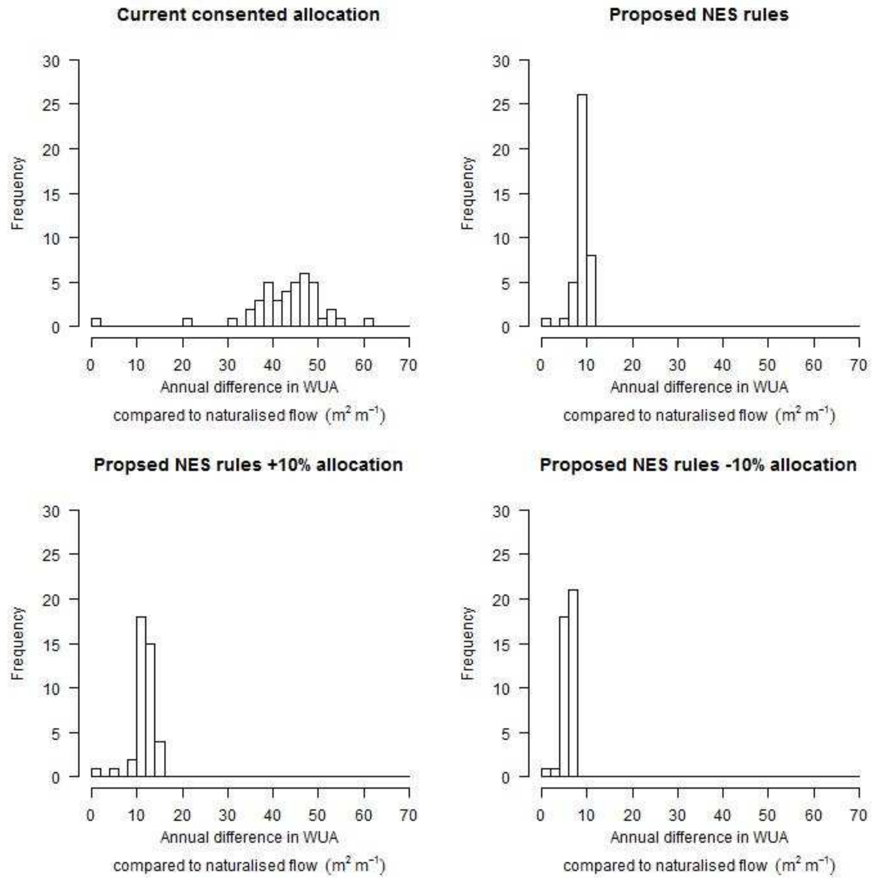

Figure 4-39: Annual changes (1972-2012) in WUA for Cran's bully under low flows, relative to WUA available under naturalised flow conditions for the Waimate site.

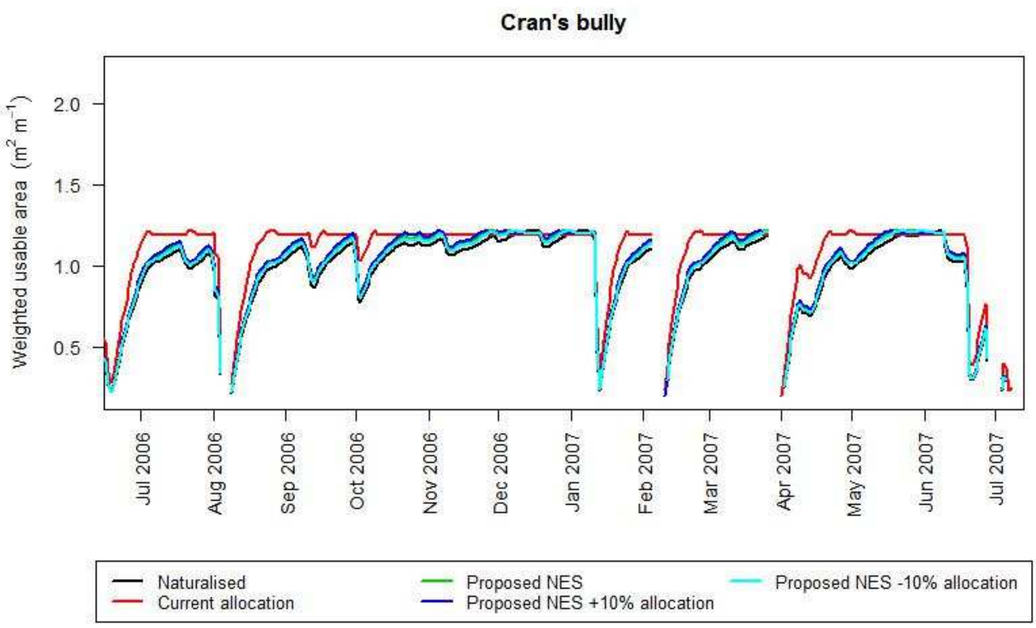

Figure 4-40: WUA time series for Cran's bully for 2006-7 for the Waimate site.

4.3 Waipapa

4.3.1 Site description

The Waipapa habitat survey reach was located on the Waipapa Stream approximately 300 m upstream of the confluence with the Waitangi River (Figure 4-41). Habitat mapping was carried out over approximately 1 km. The habitat was relatively diverse with the most dominant mesohabitat types being runs and riffles (Table 4-9; Figure 4-42).

Mean wetted width at the time of the survey was 4.4 m. The habitat survey was carried out at a flow of 0.040 $m^3\ s^{-1}$, which is equivalent to 166.7% of MALF (Table 4-10). Only one calibration survey was completed at a flow of 0.006 $m^3\ s^{-1}$ (Table 4-10). An extreme flood event prior to the third calibration survey resulted in the loss of all cross-section marker pegs.

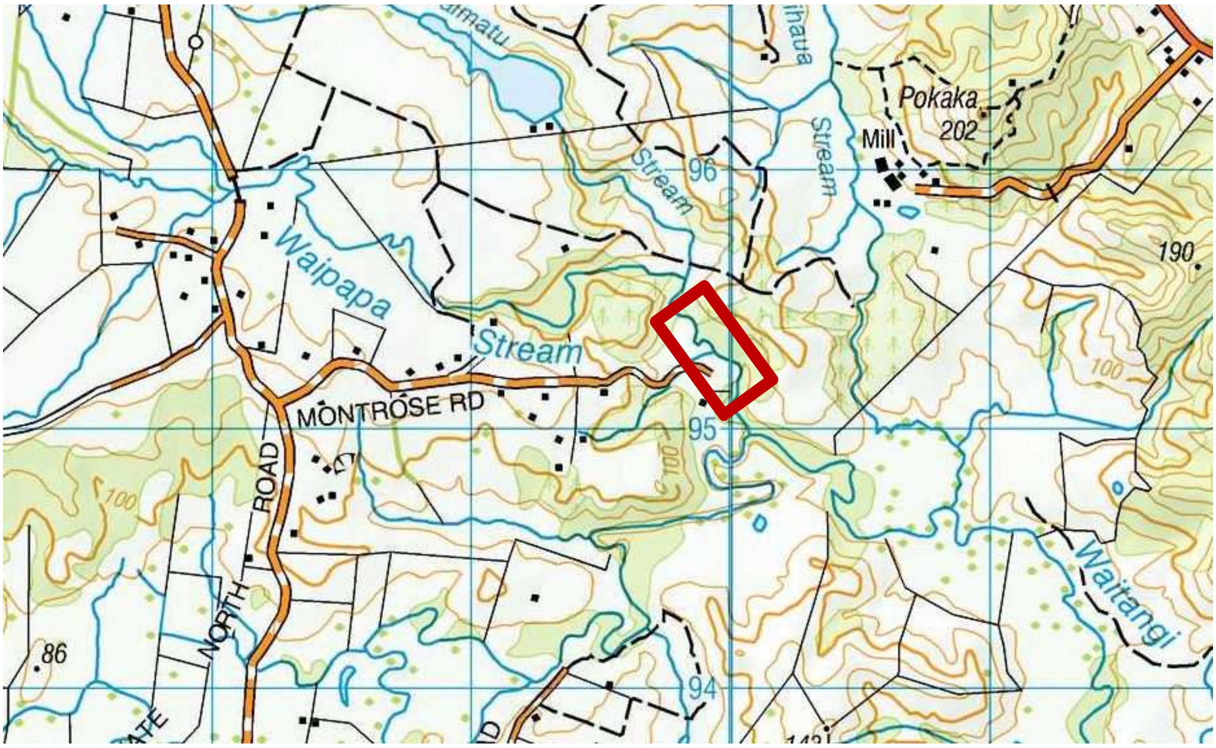

Figure 4-41: Location of the Waipapa habitat survey reach (red box).

Figure 4-42: View of the middle section of the Waipapa habitat survey reach.

Table 4-9: Habitat mapping results for the Waipapa site. Habitat type definitions are given in Table 3-2.

Habitat type	Percentage of reach
Riffle	30.0
Run	35.0
Glide	10.0
Pool	25.0

Table 4-10: Summary of survey and calibration flows for the Waipapa site. Flood flows had resulted in the loss of most cross-section markers prior to the third calibration survey and flows were too high to safely access the remaining cross-sections.

Date	Flow ($m^3 s^{-1}$)	Percentage of MALF
28/02/2013	0.040	166.7
12/04/2013	0.006	25.0
16/05/2013	NA	NA

4.3.2 WUA v. flow relationship

The NRC fish surveys recorded longfin eels and banded kokopu as being present in the Waipapa Stream. Bullies and shortfin eels were also observed at the site during the habitat survey.

Optimum habitat was outside of the modelled flow range for the eel species (Table 4-11 & Figure 4-43). Maximum WUA for juvenile banded kokopu occurs at MALF and for adult banded kokopu is at 50% of MALF. For Cran's bully, the flow which equates to maximum WUA is equal to 217% of MALF.

With the exception of adult banded kokopu, WUA declines as flow is reduced below MALF for all species and life stages. The most significant reductions are predicted for small shortfin and longfin eels (Table 4-11 & Figure 4-43). To avoid a reduction in habitat of >5% for all species and life stages, a minimum flow of 95% of MALF is required. To maintain WUA at greater than 90% of the WUA available at MALF for all species, the minimum flow would need to be at least 85% of MALF.

Table 4-11: Flow at optimum WUA and changes in WUA at various proportions of MALF for the Waipapa habitat survey reach. Optimum WUA is outside the range modelled where optimum is >0.10 $m^3\ s^{-1}$.

Species	Optimum flow ($m^3\ s^{-1}$)	WUA at MALF ($m^2\ m^{-1}$)	Percentage of WUA at MALF available at:							
			95% MALF	90% MALF	85% MALF	80% MALF	75% MALF	70% MALF	60% MALF	50% MALF
Shortfin eel <300 mm	>0.100	1.220	97.4	94.9	92.1	89.4	86.6	83.6	77.4	70.5
Shortfin eel >300 mm	>0.100	1.191	99.6	99.3	98.9	98.6	98.2	97.7	96.9	96.1
Longfin eel <300 mm	>0.100	0.721	98.2	96.3	94.4	92.5	90.6	88.7	84.9	80.9
Longfin eel >300 mm	>0.100	1.040	99.7	99.3	99.0	98.5	98.2	97.8	96.9	96.0
Banded kokopu juvenile	0.023	2.396	100.1	100.1	99.9	99.5	99.0	98.6	97.9	97.0
Banded kokopu adult	0.012	2.577	100.7	101.4	102.1	102.8	103.4	104.0	105.0	105.4
Cran's bully	0.052	1.901	99.6	99.2	98.7	98.2	97.6	97.0	95.7	93.9

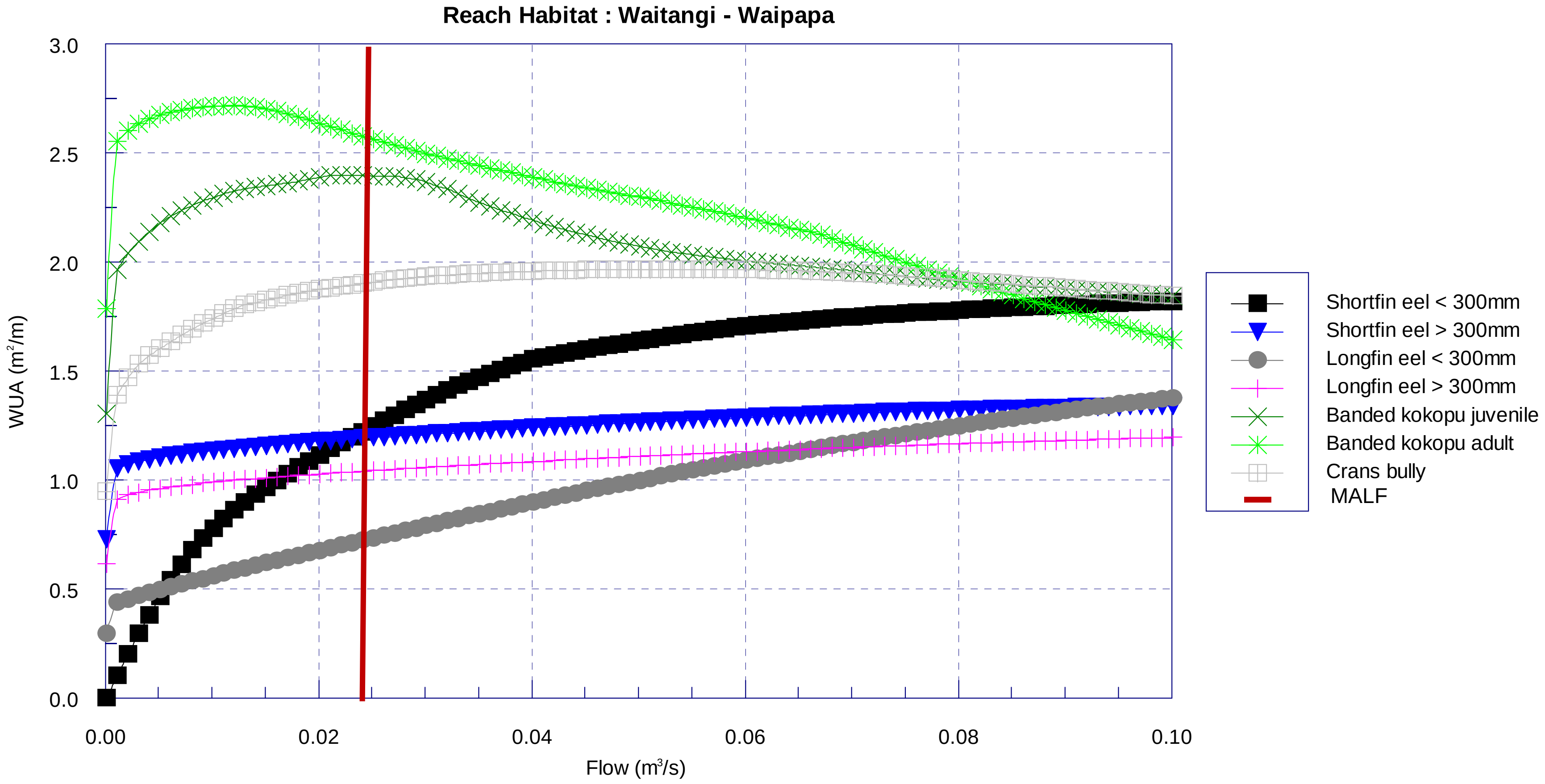

Figure 4-43: Predicted WUA versus flow relationship for target fish species at the Waipapa Stream habitat survey site. Estimated MALF (0.024 $m^3 s^{-1}$) is shown by the vertical red line.

4.3.3 Allocation limit scenarios

Current total maximum consented allocation in the catchment upstream of the Waipapa habitat survey reach is estimated to be 0.402 $m^3 s^{-1}$ (Table 3-5). This equates to 1675% of MALF at the Waipapa habitat survey reach. The hydrological consequences of current allocation rules and the alternative management scenarios based on the proposed NES rules are compared in Figure 4-44. The current allocation rules allow significant hydrological alteration at this site, with flows predicted to be at or below the minimum flow for on average 82% of the year, or an average of 301 days per year (Table 4-12 & Figure 4-44) if the full allocation is utilised. By comparison, the management scenarios based on the proposed NES rules would result in flows being at or below the minimum flow for on average 30 days per year (Table 4-12). Under current consented allocation, the annual number of days at or below the minimum flow is greater than 250 days for the majority of years. In contrast, under the proposed NES based scenarios, the number of days at or below the minimum flow is generally less than 100 days and primarily less than 50 days per year (Figure 4-45). Annual mean duration of continuous periods at or below the minimum flow are generally below 50 days for all management scenarios (Figure 4-46). However, the maximum duration of continuous flat-lining is greater than 50 days almost every year and greater than 100 days two thirds of the time under the current allocation regime (Figure 4-46). For the proposed NES based scenarios, maximum duration of continuous flat-lining does not exceed 50 days for any more than 20% of years (Figure 4-46).

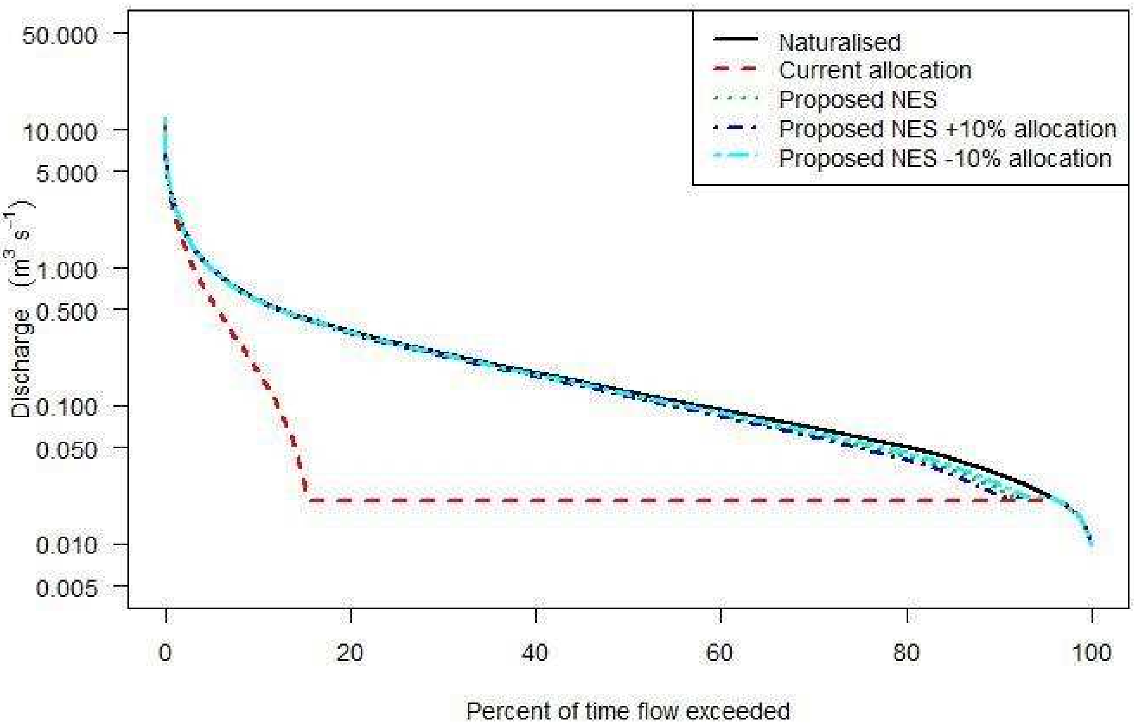

Figure 4-44: Flow duration curves for each of the water quantity limit scenarios for the Waipapa site.

Table 4-12: Summary of the impact of the alternative water quantity limit scenarios on the duration when flow is at or below the minimum flow for the Waipapa site. Results are calculated based on the 40 year flow time series from 1972 to 2012.

Scenario	Annual mean number of days at or below minimum flow	Increase in mean number of days at or below minimum flow relative to naturalised flows (days)	Annual maximum number of days at or below minimum flow	Water year of maximum
Current allocation	301	288	343	2006-7
Proposed NES	30	15	155	2009-10
Proposed NES +10%	35	20	158	2009-10
Proposed NES -10%	25	10	151	2009-10

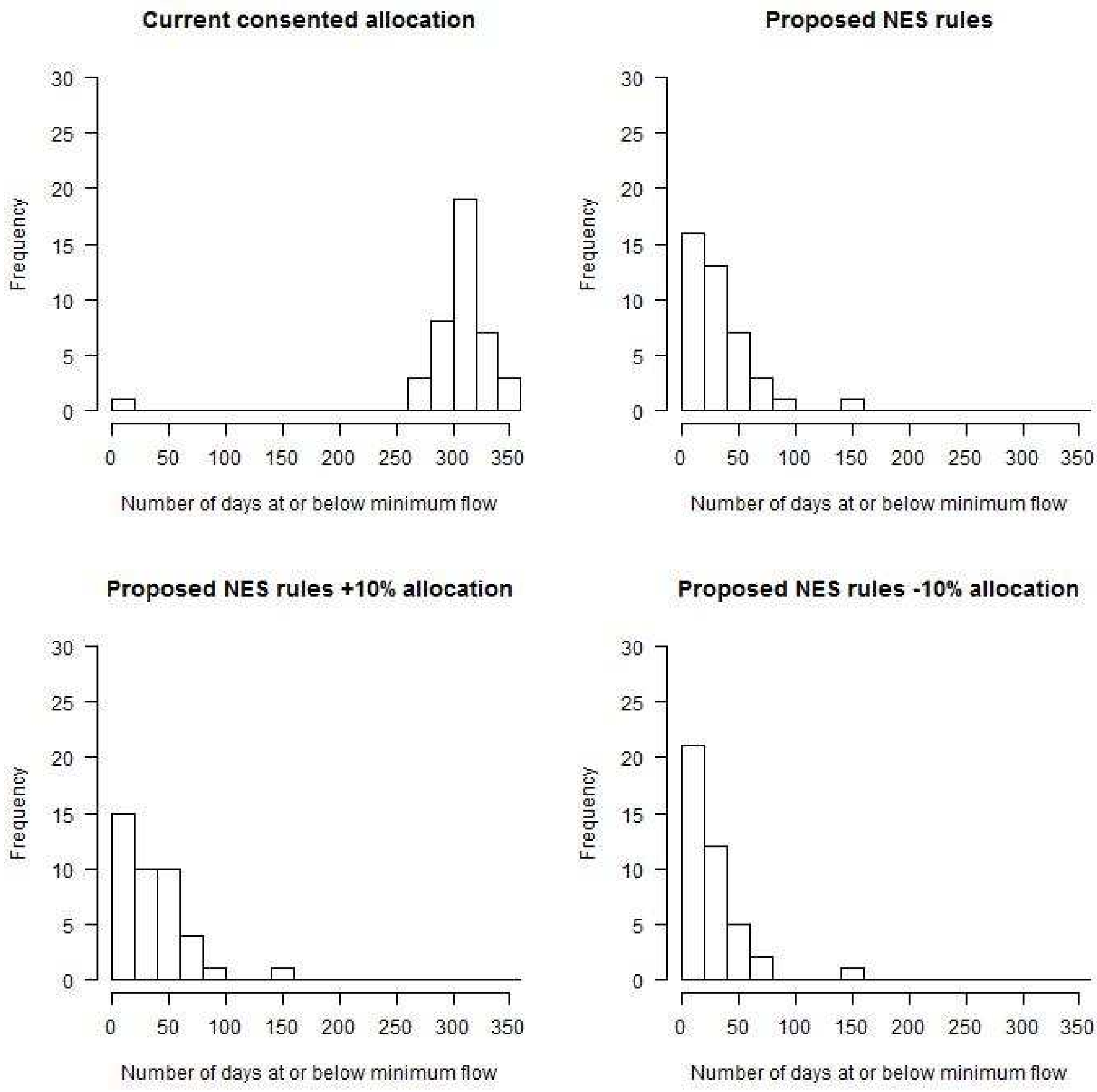

Figure 4-45: Number of days per year (1972-2012) that flows are at or below the minimum flow for each of the water quantity limit scenarios for the Waipapa site. Years are water years from 01 July to 30 June.

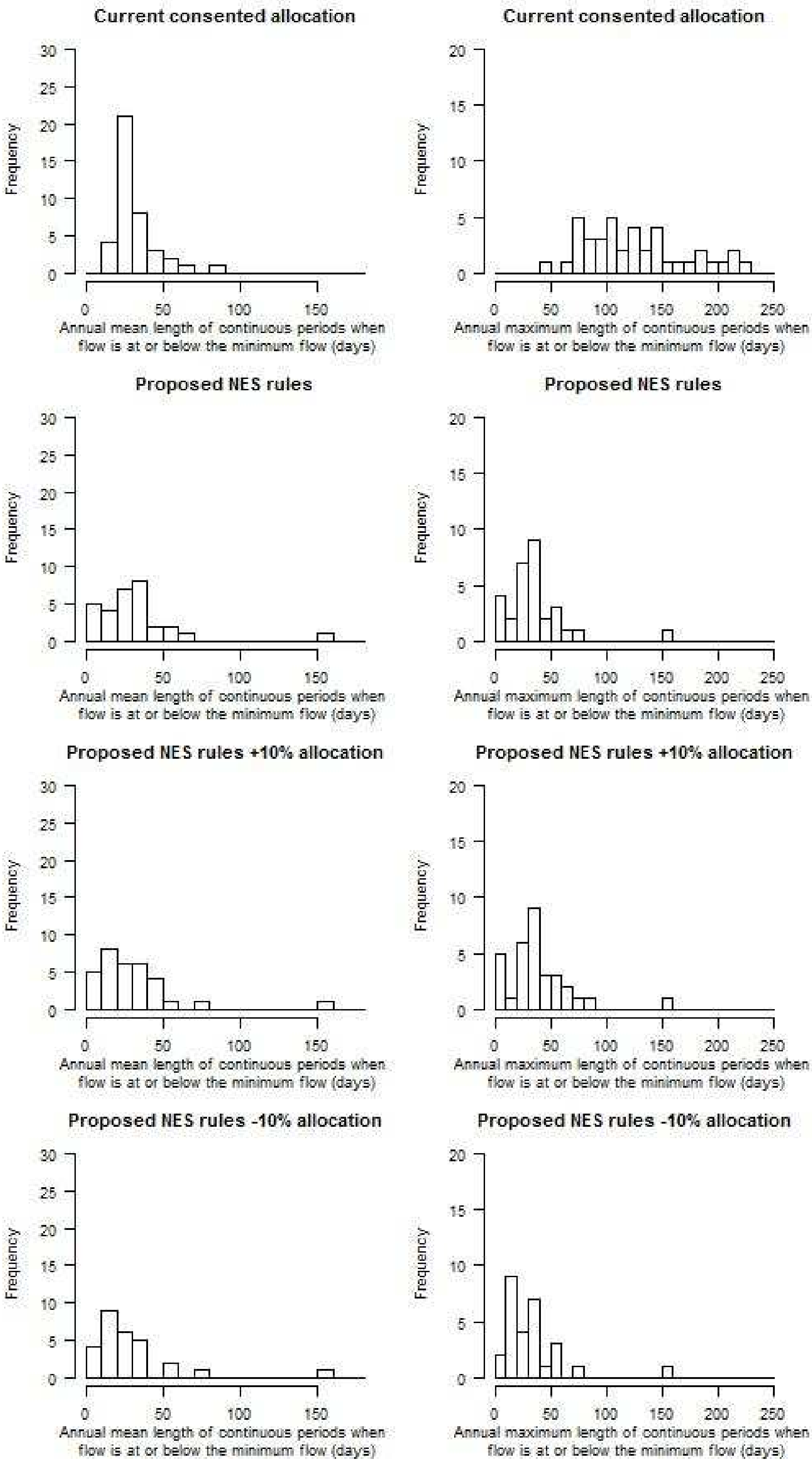

Figure 4-46: Mean and maximum length of continuous periods in each year (1972-2012) when flows are at or below the minimum flow for each of the water quantity limit scenarios for the Waipapa site. Years are water years from 01 July to 30 June.

The predicted change in WUA relative to naturalised flow conditions was comparatively small for all species and life stages (Figure 4-47 to Figure 4-60). The largest effect was predicted for small shortfin eels (<300 mm) with a loss of >50 m^2 m^{-1} yr^{-1} in most years under current allocation rules (Figure 4-47 & Figure 4-48). However, this loss was reduced to <10 m^2 m^{-1} yr^{-1} in most years under the proposed NES -10% allocation scenario (Figure 4-47). WUA was predicted to increase relative to naturalised conditions for both the juvenile and adult life stages of banded kokopu under all flow management scenarios (Figure 4-55 & Figure 4-57). The greatest increases were predicted under the current allocation rules (e.g., Figure 4-56 & Figure 4-58) and reducing allocation limits is predicted to reduce those increases relative to naturalised flow conditions.