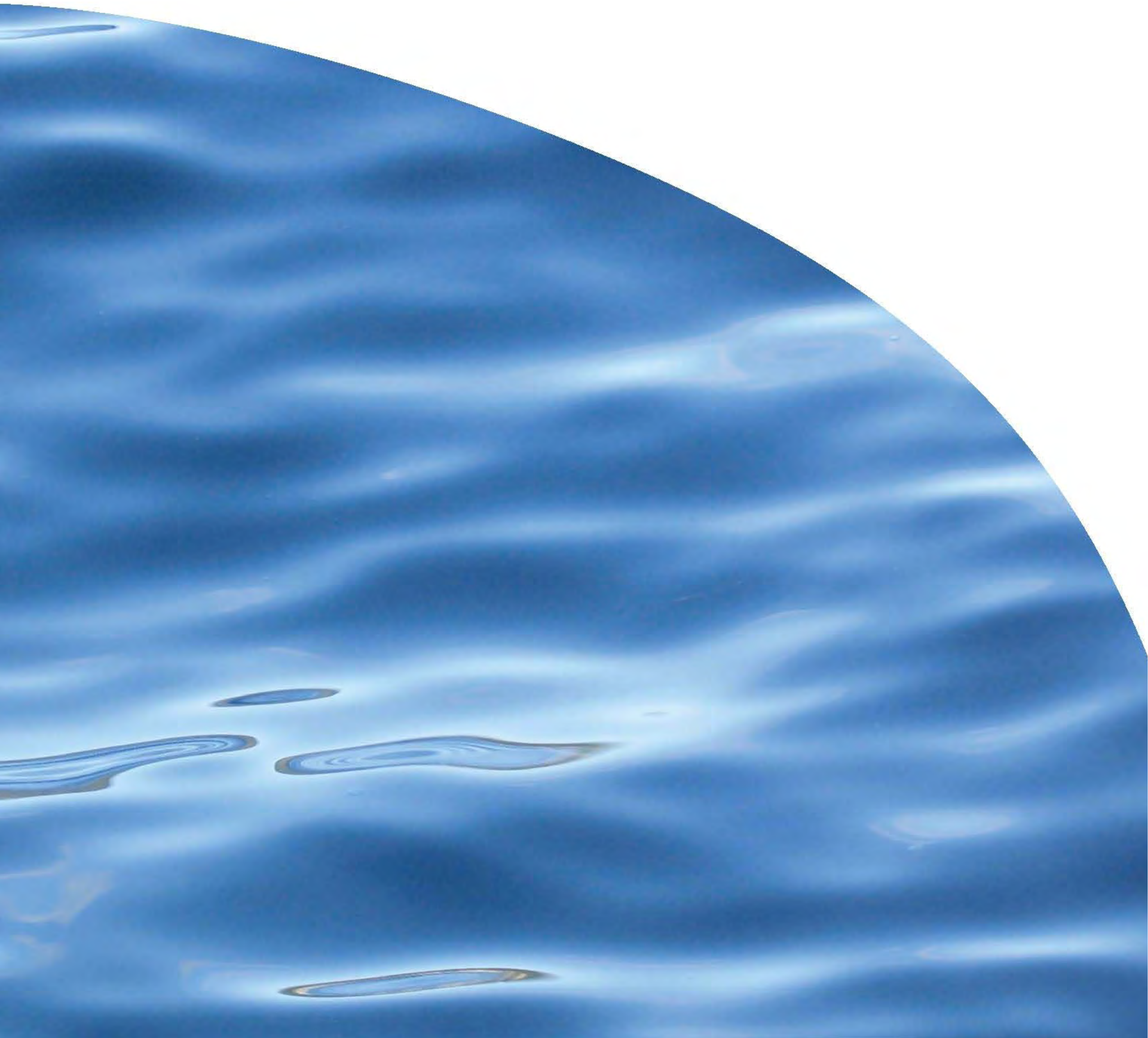
REPORT NO. 2307

RUATANIWHA WATER STORAGE SCHEME – AQUATIC ECOLOGY ASSESSMENT OF EFFECTS



RUATANIWHA WATER STORAGE SCHEME – AQUATIC ECOLOGY ASSESSMENT OF EFFECTS

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May 2013

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ISSUE DATE: 2 May 2013

RECOMMENDED CITATION: Young RG, Allen C, Shearer KA, Doehring K, Berkett N, Holmes R, Hay J. 2013. Ruataniwha Water Storage Scheme – Aquatic Ecology Assessment of Effects. Prepared for Hawke's Bay Regional Investment Company Limited. Cawthron Report No. 2307. 194 p. plus appendices.

EXECUTIVE SUMMARY

This assessment of aquatic ecological effects of the proposed Ruataniwha Water Storage Scheme (the Scheme) informs a wider assessment of environmental effects that will be lodged as part of the resource consent application process. The Hawke's Bay Regional Investment Company Limited (HBRIC) engaged the Cawthron Institute (Cawthron) to review the Tukituki catchment's aquatic values, summarise the state of the existing environment, provide an assessment of effects on aquatic ecology as a result of the Scheme, and identify mitigation and monitoring options. This report is an updated and revised version of the initial assessment of effects on aquatic ecology report that was prepared as part of the feasibility stage of the project (Young *et al.* 2012) and assesses the effects of the Scheme as described in the project description (Tonkin & Taylor May 2013a).

Current values

Values that apply to the whole of the Tukituki Catchment include: life supporting capacity, mauri, contact recreation, water use (quality and economic), and fish passage.

Values that may vary across the catchment include: natural state, wetlands, riverine bird habitat, inanga spawning, native fish habitat, trout spawning and habitat and contact recreation (amenity).

Potential Scheme effects

The key potential effects of the construction and operation of the Scheme on aquatic ecology and associated values are:

- Disturbance of the riverbed during construction and associated mobilisation of sediment that could influence water clarity and have effects on periphyton, invertebrates and fish (both native and introduced species)
- Effects of changes in bed geomorphology downstream of the dam on periphyton, invertebrates and fish
- Effects on water quality associated with water storage within the proposed reservoir
- Blockage/interruption of upstream and downstream fish passage by the dam
- Permanent loss of riverine habitat resulting from inundation by the proposed reservoir
- Reductions in the quantity and quality of spawning habitat for rainbow trout
- Changes to angling opportunities
- Changes in water quality associated with changes in the flow regime downstream of the dam
- Changes in periphyton abundance and distribution as a result of changes in the flow regime
- Effects of changes in the flow regime downstream of the dam (including short-term fluctuating flows associated with changes in irrigation demand and hydro-peaking) on habitat availability for invertebrates and fish
- Effects of flow changes on fish stranding

- Diversion of fish into the water distribution network at the irrigation intake
- Instream and riparian habitat disturbance associated with changes in land use on the Ruataniwha Plain associated with the Scheme
- Changes in water quality and effects on periphyton, invertebrates and fish associated with changes in land use.

Assessments undertaken

A combination of existing data, models, interviews, field studies and literature reviews were used to identify the key values associated with the Tukituki catchment and the state of the existing environment. Similarly, our assessment of effects of the Scheme was conducted using the information gathered on the state of the existing environment, modelling of how water quality and instream habitat are affected by changes to the flow regime, and guidelines/knowledge associated with sediment effects, periphyton, invertebrate and fish habitat requirements. Concurrent work on water quality in the reservoir (NIWA May 2013c), predicted changes to the flow regime (Tonkin & Taylor 2011; HBRC Science May 2013a; Aquanet May 2013), predicted changes to sediment transport and geomorphology (Tonkin & Taylor May 2013b), surveys of trout spawning and juvenile trout density (Maclean 2011; 2012), predicted effects of land use on water quality and periphyton (NIWA May 2013a, b) and new information on nitrate toxicity thresholds (Hickey 2013a, b) have been incorporated into our assessments.

Results of assessments

- Effects of construction on water quality are predicted to reduce rapidly once the working site is adequately stabilised. However, deposition of mobilised sediment downstream of the proposed dam site may have longer term effects that take 6-months to one year for full recovery. The effects will be most marked close to the proposed dam site and have less influence downstream of the Waipawa and Tukituki confluences.
- The reduction in bed aggradation, due to sediment retention in the proposed dam, is likely to result in a reduction of gravel extraction from the channel, and associated reduction in habitat disturbance. This is likely to have a net benefit to the aquatic ecosystem. The coarsening of the bed substrate is also likely to have a net benefit for many species of native fish which prefer coarse substrates. However, bed coarsening and armouring will potentially increase the suitability of habitat for nuisance periphyton growth and reduce the availability of suitable spawning gravels for rainbow trout downstream of the dam.
- Modelling (NIWA May 2013c) predicts that changes in water quality associated with storage of water within the reservoir are expected to be relatively minor. Water quality will be continuously monitored and an aerator is recommended to be installed near the upstream face of the dam to manage any unforeseen changes in water quality. Problems with levels of dissolved oxygen, nutrients and sediment released downstream from the reservoir are not expected.
- Movement of fish, both upstream and downstream, past the dam will be affected by the presence of the dam. The seven migratory native fish species currently present in

the vicinity of the dam are unlikely to sustain self-supporting populations above the dam. Consequently, these species would be lost from the fish community above the dam over time, unless fish passage is provided. While the loss of the seven migratory species within the Makaroro River upstream of the proposed dam would restrict the geographic range of these species within the wider Tukituki catchment, the loss of the upper Makaroro River populations of these species is not expected to result in a significant increase to their threat of extinction from elsewhere in the catchment. Nevertheless habitat loss for any indigenous or valued species is not desirable, so we recommend that an upstream and downstream trap and transfer programme and habitat enhancement initiatives be used to mitigate the effects.

- The creation of a 372 ha reservoir will result in a loss of approximately 7 km of flowing water habitats. Some of the native fish species currently found in the river habitat are also commonly found in still-water habitats and will be able to use the newly formed lake-like habitat of the reservoir. However, other species (*e.g.* torrentfish, bluegill bully, redfin bully, Cran's bully, and dwarf galaxias) are unlikely to use the still-water habitat in the reservoir, and for these species the inundation of streams in this area will represent a loss of habitat. Many of the invertebrate species found in the Makaroro River are also unlikely to use the still-water habitat in the reservoir, although invertebrates that prefer still water will replace them to some extent and provide food for fish living in the reservoir.
- A trout population of between 1000-2000 adult fish is likely to develop in the reservoir and support a full season fishery for small rainbow trout, rather than the current early and late season fishery for post- or pre-spawning rainbow trout of average size. Juvenile trout production from these adult trout may be enhanced compared with the status quo as a result of the reservoir. It is very likely that some of these juvenile trout will successfully pass downstream through the turbines or over the spillway and make a substantial contribution to the fishery in the Waipawa and Tukituki rivers. The benefits to be derived from the juvenile trout that will pass downstream are difficult to quantify precisely and hence so are the overall effects on the trout fishery of the inundation and loss of spawning habitat associated with the reservoir and the blockage of the spawning migration from downstream caused by the dam.
- The Scheme will result in substantial changes to the flow regime downstream of the dam. In the reach between the dam and the irrigation intake there will be higher flows in the summer irrigation period and lower flows in late autumn and winter. Flood frequency will be reduced particularly during late autumn and winter when floods will be captured within the refilling reservoir. Downstream of the irrigation intake, there will be a general reduction in median flows throughout the year as a result of the Scheme, but an increase in the lowest flows. The changes in flow are most significant in the Makaroro and Waipawa rivers. Downstream in the Tukituki River, the changes in the flow regime are smaller because flow inputs from the upper Tukituki River and other tributaries are largely unaffected by the Scheme.
- Increases to low flows are predicted to occur when the Scheme is in operation, particularly if current surface and ground water abstractions are 'migrated' to the

Scheme water (HBRC Science May 2013a). This is expected to be a net benefit to the river ecosystem.

- At times, the water temperatures within the Tukituki catchment currently approach levels that will begin to stress sensitive aquatic life. The Scheme will result in higher summer flows and cooler summer water temperatures between the dam and the irrigation intake because of the flow releases of cool water sourced from the dam. Therefore, this is expected to be a net benefit to the river ecosystem in these reaches. Downstream of the irrigation intake, there will be a decrease in median flows, but higher minimum flows than occurs under the status quo. Any effects of changes to the flow regime itself on water temperature will be at most, minor (predictions of no change to mean temperature and < 0.5 °C increase in maximum temperature).
- The general reduction in median flows downstream of the irrigation intake will reduce the capacity of the river to dilute contaminants at moderate flows. However, in contrast the general increase in minimum flows will result in an increase in dilution of contaminants at low flows.
- The change in the flow regime in the Makaroro River will provide better hydraulic conditions for the growth of undesirable long and short filamentous algae on the river bed, but reduce habitat suitability for desirable diatoms. This is considered to be a net negative effect on the river ecosystem, but periphyton growth is not expected to be problematic in this reach because nutrient concentrations are relatively low. Further downstream and below the irrigation intake, the changes in flow regime on habitat suitability for different components of the periphyton community are mixed, with increases in suitability in some months and decreases or no change in other months. The frequency of flows large enough to flush periphyton from the river bed is more important in controlling periphyton biomass than general hydraulic suitability for periphyton. The frequency of flows capable of flushing periphyton will be reduced, particularly during the irrigation season and during late autumn/winter when the reservoir will be refilling. However, the Scheme design has incorporated the capacity for four flushing flows of up to 30 m^3/s to be released from the dam per year to aid the management of periphyton growth in reaches downstream of the dam, including the lower Tukituki River. These flushing flows will be very effective in the Makaroro and Waipawa rivers downstream of the dam. However, evidence suggests that they are also likely to provide significant benefits in the Tukituki River below the Waipawa confluence, particularly if the flow releases are timed to coincide with small natural freshes from the upper Waipawa and upper Tukituki rivers. Therefore, nuisance periphyton accumulations will be able to be managed to a large extent using these flushing flows. This is a clear environmental benefit of the Scheme over the status quo and will help to meet the periphyton objectives of the proposed Tukituki Plan Change 6.
- The broad-scale changes to the flow regime will result in both gains and losses in habitat suitability for invertebrate species. While there will be changes to the composition of invertebrate communities in the Makaroro as a result of changes to the flow regime, the predicted habitat losses will not affect the viability of populations

below the dam down into the Tukituki system. The largest effect of the proposed flow regime on the invertebrate community relates to the regular short-term fluctuations in flow that result from changes in irrigation demand during the summer and from hydro-peaking during winter. These flow fluctuations will have negative effects on habitat suitability for species with limited mobility. Margins of the channel that are suitable at the high end of the flow fluctuation cycle will dry out or become too shallow during the low flow part of the fluctuating cycle, while areas in mid-channel that are suitable at the low end of the fluctuating cycle may become too fast at the high end of the cycle. These flow fluctuations are predicted to result in a 50% reduction in habitat availability for invertebrates (and up to a 100% reduction *i.e.* complete removal in habitat availability for rainbow trout spawning) in the Makaroro and Waipawa rivers downstream of the proposed dam. The effects in the Tukituki River will be much lower due to flow contributions from other parts of the catchment making the relative change in flow smaller, and downstream attenuation of the flow fluctuations themselves. It should be noted however, that these predictions do not take into account the effects of natural flow fluctuations and therefore are probably an overestimate.

- The degree to which fish abundance and/or growth rate may be affected by this reduction in invertebrate habitat is uncertain, because it depends on whether fish are currently food limited. But given that the predicted reduction in invertebrate habitat is potentially large (around 50% for *Deleatidium* which represents a riverine trout's main food source), this may have some adverse effect on food intake by fish -- with a consequent adverse effect on growth rates and/or survival.
- Fluctuations in flow that result from changes in irrigation demand during the summer and from hydro-peaking during winter may result in relatively fast declines in flow within the Makaroro River at times, potentially resulting in fish stranding. However, the shape of the Makaroro River channel means that there will be limited areas where isolated pools are likely to be formed by rapid dewatering. Therefore, the effects of flow reductions on fish stranding in this reach are expected to be minor.
- The main potential effect of the upper irrigation intake structure is the potential entrainment of fish into the canal system. A rockfill infiltration bund is currently proposed to act as a fish screen at the proposed upper intake. The efficacy of this bund as a screen will be dependent on the size of the packing fill used to construct the bund because the fill needs to emulate 3 mm mesh openings in a metal screen. Tonkin & Taylor have confirmed that the packing fill will meet this intent and therefore the effects on fish entrainment should be largely avoided.
- Possible future land use changes may mean that there will be more heavy animals (*i.e.* cattle rather than sheep) and higher stocking rates on the Ruataniwha Plains. These changes to stock type and stocking rate have the potential to increase the amount of physical damage to instream habitat and the riparian margins of streams flowing through the irrigated areas if stock are not excluded from waterways. It is recommended that stock exclusion be an integral part of the overall Scheme design, and in any event it is noted that stock exclusion is a key rule in HBRC's Proposed Tukituki Plan Change 6.

- Modelling of a future land use scenario with no on-farm mitigation predicted that nitrogen and phosphorus inputs for the whole catchment would increase by 32% and 6%, respectively as a result of the land use intensification associated with the Scheme. Nitrogen and phosphorus losses within the irrigation command area are predicted to increase by an average of 81% and 41% respectively (NIWA May 2013a). The resulting increase in phosphorus concentration was predicted to result in faster periphyton growth and higher peak biomasses of periphyton in the lower Waipawa and Tukituki rivers. However, the Scheme is now being progressed on a phosphorus neutral basis, compared with a 2013 baseline. At a whole catchment scale, modelling indicates that fencing to exclude stock from streams and the optimal use of phosphorus fertiliser are predicted to offset the 6% increase in phosphorus losses and make the RWSS close to phosphorus-neutral overall (predicted 1% increase). However, within the irrigation command area, land use change with mitigation is still predicted to increase phosphorus losses by 7% relative to pre-irrigation levels – significantly lower than the predicted 41% predicted without any mitigation, but still not ‘phosphorus-neutral’. The modelling does not capture all of the benefits of stock exclusion, but even so, additional mitigation measures may be required in some irrigated sub-catchments for them to be ‘phosphorus-neutral’ (NIWA May 2013a).
- Prior to construction of the Scheme, the discharges of sewage from Waipukurau and Waipawa will be significantly reduced as part of their consent conditions. This reduction of phosphorus load to the river will reduce periphyton growth rates and peak biomasses in the lower Tukituki and Waipawa rivers.
- The combination of phosphorus neutral status and reduced inputs of phosphorus from the Waipukurau/Waipawa wastewater treatment plants is predicted to result in significant reductions in annual average periphyton biomass, and less frequent periods of high biomass (NIWA May 2013a). Nevertheless, during periods of prolonged low flow, periphyton biomass will continue to reach high levels (NIWA May 2013a). The proposed flushing flows associated with the Scheme are expected to provide additional reduction in the incidence of high periphyton biomass by interrupting the periods of biomass accumulation during prolonged summer low flows.
- High concentrations of nitrate nitrogen can be toxic to aquatic life. Land use changes associated with the Scheme are predicted to increase nitrate concentrations significantly in tributaries draining the irrigation command areas. It is predicted that without mitigation nitrate concentrations will exceed the limits set in the proposed Tukituki Plan Change in five of the tributaries – three affected by point source waste discharges and intensive farming, and the remainder affected by intensive farming only (NIWA May 2013a). To address this issue additional monitoring will be required and particular attention will need to be given to sites that are predicted to be close to, or beyond, the proposed limits. Management actions aimed at reducing nitrogen leaching will be required in any areas that are over the limit to avoid the risk of nitrate toxicity problems. If cost-effective nitrogen mitigation measures are unable to ensure that toxicity limits are not exceeded then it may be necessary to restrict the types of agriculture that will be permitted in some, sensitive, sub-catchments.

Suggested approach for effects identified

A number of initiatives are recommended to mitigate potential adverse effects of the Scheme on aquatic ecology. These include:

- An upstream and downstream trap and transfer programme that will enable migratory native fish to access habitat upstream of the proposed dam, and enable mature longfin eels to move downstream and complete their life cycle.
- Pre- and post-construction monitoring of the age-structure of the eel population upstream of the dam to ensure that the trap and transfer programme is enabling successful recruitment.
- Post-construction monitoring of the efficacy of the rockfill infiltration bund at the upper irrigation intake as a fish screen.

We recommend that these initiatives could be implemented alongside five broad restoration and enhancement packages. These include:

Ruataniwha Reservoir Restoration Buffer and Catchment Enhancement Zone:

This is as proposed in the integrated offset and mitigation approach report (HBRIC, May 2013f). In terms of aquatic ecology the key objectives of this initiative would be to protect and enhance the aquatic habitat within the upper Makaroro River above the dam and other reservoir tributaries such as Dutch Creek. This would also help to limit inputs of nutrients and sediment to the proposed reservoir and maintain reservoir water quality, although this effect would be minor.

Ruataniwha Riparian Enhancement Zone (River Halo Project):

Again, this is as proposed in the Integrated offset and mitigation approach report (HBRIC, May 2013f). The focus of this initiative should be on protection of riparian habitats alongside the Makaroro and Waipawa rivers that are affected by flow fluctuations resulting from the Scheme.

Ruataniwha Threatened Species Habitat Enhancement

This initiative focusses on fostering habitat protection/enhancement for bats throughout Hawke's Bay, terrestrial predator trapping to enhance biodiversity values within the upper Makaroro Catchment and downstream to the upper intake structure, and the upstream and downstream trap and transfer programme for native fish.

Ruataniwha Plains Spring-fed stream Enhancement and Priority Sub-Catchment Phosphorus Mitigation:

The changes in land use associated with the the proposed Scheme will have to be managed carefully. The objectives for this initiative are to protect and enhance the spring-fed streams and other waterways that drain the lower Ruataniwha Plains (*e.g.* tributaries of the lower Mangaonuku, Kahahakuri, Waipawamate, Black Stream, Maharakeke, Tukipo and presumably many unnamed ones). These streams provide good habitat for eels and some other native fish species and also appear to be important locations for spawning and juvenile trout rearing. The package would involve support for landowners with fencing, replanting and ongoing riparian maintenance and legal protection and fencing of any existing wetlands. A focus will be on ensuring that stock are permanently excluded from waterways and sediment/phosphorus inputs are restricted. This project is presented in more detail in the Integrated offset and mitigation approach report (HBRIC, May 2013f).

Restoration of Old Waipawa River Bed / Papanui Stream

The objective of this package is to rehabilitate and enhance water quality and stream habitat in the bed of the old Waipawa River / Papanui Stream subsequent to any works required to meet Zone M irrigation requirements. This will involve funding to contribute to fencing, planting and wetland creation along the riparian margins of the stream.

At a whole-catchment scale, modelling indicates that with stock exclusion and optimal use of phosphorus fertiliser the Scheme can be developed on a near ‘phosphorus-neutral’ basis. Provided the ‘phosphorus-neutral’ status can be achieved in all sub-catchments, the provision of augmented flushing flows, as now proposed, should contribute to reducing periphyton growth in the lower Waipawa and Tukituki rivers. However, within the irrigation command area it appears likely that careful monitoring, additional mitigation measures, and perhaps restrictions on the types of agriculture permitted in some sensitive subcatchments will be required to avoid increases in phosphorus concentrations and exceedances of proposed nitrate toxicity limits in some streams draining the Ruataniwha Plains. If this can be achieved and if all the other mitigation and rehabilitation efforts are in place, the Scheme will have relatively minor effects on the aquatic ecosystem and the Tukituki will continue to support the current wide range of values.

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GLOSSARY

Term	Description
Abstraction scenarios	There are four abstraction scenarios described in this report, which are defined as follows: **Scenario 1: '**Natural state', 'Naturalised' or 'No Dam'. No abstraction or water storage scheme is in place **Scenario 2:** 'Status quo' or 'Abstraction only'. The current consented abstraction continuing into the future. The effects of the Ruataniwha Water Storage Scheme are determined by comparison with this scenario. **Scenario 3:** 'Dam only', where water storage is in place in 2017 and all current consents are discontinued. **Scenario 4:** 'Dam and abstraction', where water storage is in place in 2017 and all current consents continue.
AFDM	Ash-free dry mass
Chl-*a*	Chlorophyll-*a*
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
DRP	Dissolved reactive phosphorus
EPT	Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly), the taxa that determines water quality
NZFFD	New Zealand Freshwater Fish Database
FRE3	A flow statistic that represents the average annual frequency of flows that are greater than three times the median flow widely used by river managers
HBRC	Hawke's Bay Regional Council
HBRIC Ltd	Hawke's Bay Regional Investment Company Limited, also referred to as 'HBRIC'
IFIM	Instream Flow Incremental Methodology
Mahinga kai	Food-gathering places
MALF	Mean Annual Low Flow
Mauri	Life principle, special nature, a material symbol of a life principle, source of emotions
MCI	Macroinvertebrate Community Index
NIWA	National Institute of Water & Atmospheric Research
NTWL	Normal top water level
Overseer	A computer model that calculates and estimates the nutrient flows in a productive farming system and identifies risk for environmental impacts through nutrient loss, including run off and leaching, and greenhouse gas emissions
PD	Project Description
QMCI	Quantitative Macroinvertebrate Community Index

Term	Description
Q_{99}, Q_{98}, Q_{97}	Flow exceedance percentiles, *i.e.* the flow that is statistically exceeded 99%, 98% and 97% of the time, respectively
Reach	This report identifies six potentially affected reaches, which are defined as follows: • **Reach 1**: Makaroro River **upstream** of the footprint of the reservoir • **Reach 2**: The footprint of the reservoir on the Makaroro River from the upstream end (E2786894 N6157464) to the dam site (E2790615 N6153865) • **Reach 3**: The reach of Makaroro River downstream from the dam to the confluence with the Waipawa River (a distance of approximately 9.4 km) • **Reach 4**: The reach of the Waipawa River downstream of its confluence with the Makaroro River, to the site of the irrigation headrace intake (a distance of approximately 9.2 km) • **Reach 5**: The reach of the Waipawa River downstream of the site of the irrigation headrace intake to its confluence with the Tukituki River (a distance of approximately 28 km) • **Reach 6**: The Tukituki River from its confluence with the Waipawa River to its outlet into Hawke Bay (a distance of approximately 66.5 km)
REC	River Environment Classification
Reservoir	The body of water stored behind the dam on the Makaroro River
RRMP	The Hawke's Bay Regional Resource Management Plan, generally referred to as the 'Regional Plan'
RPS	The Hawke's Bay Regional Policy Statement, which forms part of the RRMP
RWSS	Ruataniwha Water Storage Scheme, also referred to as 'the Scheme'
SOE	State of the Environment
SPASMO	Soil Plant Atmosphere System Model; a computer model that provides allocation of irrigation water for chosen crops and land area. It models the transport of water, microbes and solutes through soils integrating variables such as climate, soil, water uptake by plants in relation to farm and orchard practices, and any other factors affecting environmental process and plant production
SQMCI	Semi-quantitative Macroinvertebrate Community Index
TP	Total phosphorus
TRIM	Tukituki River Model; a computer model incorporating models, environmental data and GIS used to manage nutrient inputs , land use and water quality
WUA	Weighted usable area
Zone	These are areas that the scheme is providing water to and are labelled A, B, C, D or M. This term is also used in the planning maps in the Central Hawke's Bay and Hastings district plans.

1. INTRODUCTION

1.1. Introduction

The Ruataniwha Water Storage Scheme (the Scheme) is a water storage and irrigation scheme that is proposed for the Makaroro River and the Ruataniwha Plains, in the central Hawke's Bay region. The Makaroro River is a tributary of the Waipawa River, which in turn flows into the Tukituki River south-east of Waipawa township. Water management within the Tukituki catchment has become a key issue over recent years, particularly as demand for irrigation water has increased. The Hawke's Bay Regional Council's Land and Water Management Strategy (2011) identifies a number of issues for priority action in the Tukituki catchment including; aesthetic water quality, the health of aquatic habitats, over-allocation, further irrigation demand, potential land use intensification, impacts on the trout fishery, and impacts on angling and recreational activities.

The Hawke's Bay Regional Council (HBRC) initiated prefeasibility studies on the Scheme in 2009. The studies coincided with the release of the Council's 2009-2019 Ten Year Plan that specifically outlined the Council's intention to investigate water harvesting and storage opportunities in the region. A full feasibility study and site prioritisation began in December 2010.

As part of those studies, HBRIC engaged the Cawthron Institute (Cawthron) to undertake an assessment of effects on aquatic ecology in the Makaroro River, the Waipawa River downstream of its confluence with the Makaroro River, the Papanui Stream and the Tukituki River downstream of its confluence with the Waipawa River. This report along with related work on predictions of land use change on water quality and periphyton (NIWA May 2013a,b), effects of water storage on water quality within the proposed reservoir (NIWA May 2013c) predictions of the effects of changes in groundwater takes on surface flows (HBRC Science May 2013a; Aquanet May 2013), the characteristics of the Papanui catchment (Lynch 2013; EMS May 2013a) and effects of the dam on terrestrial ecosystems (Kessels & Associates May 2013) will be used to inform a wider assessment of environmental effects of the scheme, as described in the project description (Tonkin & Taylor 2013a), that will be lodged as part of the resource consent application process. This report is an updated and revised version of the initial assessment of effects on aquatic ecology report that was prepared as part of the feasibility stage of the project (Young *et al.* 2012).

The first section of this report outlines the aims of the Ruataniwha Water Storage Scheme (scheme infrastructure and proposed operating regime) and identifies the key aquatic values present in the Tukituki catchment. Section 2 describes the existing environment within the Tukituki catchment, while the third section of the report assesses the potential effects of activities associated with the proposed Scheme including construction, the presence of the dam and reservoir, changes to the flow regime, the presence of the irrigation intake structures and potential land use change on the Ruataniwha Plains and Papanui Catchment (Zone M). Finally, Section 4 examines options to mitigate the aquatic ecology effects, noting that a number of issues have been dealt with in the scheme design and proposed operating regime.

1.2. Description of the Ruataniwha Water Storage Scheme (the Scheme)

1.2.1. Scheme infrastructure

Full details of the Scheme are outlined in Tonkin & Taylor's Feasibility Project Description (Tonkin & Taylor May 2013a). The main elements of the scheme are as follows:

- A concrete faced rockfill dam on the Makaroro River. The proposed dam will be 83 m high at the river's deepest point;
- A 6.2 km long reservoir with a maximum storage volume of 90 million m^3. The surface area of the reservoir at the normal top water level (NTWL) of 469.5 m has been calculated as 372 ha;
- A reservoir outlet structure consisting of a 2100 mm penstock and a 600 mm bypass valve providing for a peak irrigation release of 11.1 m^3/s, but with the ability to release a flushing flow of up to 21 m^3/s;
- Two spillways; a concrete-lined primary spillway that operates for all floods, and an auxiliary spillway that operates for very large floods (events exceeding the 200 year annual exceedance probability);
- A single hydroelectric power station at the base of the dam with a capacity of 6.5 MW;
- An irrigation intake located on the Waipawa River located 22 km downstream of the dam that collects the flows released from the dam and distributes the water via a headrace to a secondary distribution network. The secondary distribution network then transports water to water service zones A, B, C and D (Figure 1);
- Another water intake structure on the Waipawa River, located approximately 1 km upstream of the confluence of the Waipawa and Tukituki rivers that will collect flows released from an outfall located adjacent to the Mangaonuku Stream (within Zone A) and distribute the water via the Papanui Stream (Old Waipawa River channel) and a secondary distribution network for use within Zone M (Figure 1).

1.2.2. Proposed operating regime

The project description (Tonkin & Taylor May 2013a) incorporates a variety of elements to address environmental effects. These include:

- A minimum residual flow at the base of the dam equal to 90% of the 7-day mean annual low flow (7-day MALF).
- Four flushing flows of up to 30 m^3/s will be released from the dam during the irrigation season (1 September–30 April) each with a duration of nine hours.
- An aerator will be installed near the upstream face of the dam to address any issues with anoxia in the bottom waters of the reservoir.
- A rockfill infiltration bund that is consistent with the intent of the NIWA fish screen guidelines (Jamieson *et al.* 2007) is proposed at the upper irrigation intake to avoid entrainment of fish into the secondary distribution network. A fish screen is also proposed for the lower irrigation intake.

Assuming full scheme uptake, the predicted reservoir operation indicates that, on average, the reservoir volume will drop to a minimum of 30% of the full live storage in each year, but this minimum volume would range between about 1% of full live storage volume (exceeded 95% of the time) and 80% of full live storage. The equates to a water level ranging from 30 m below the normal operating level (exceeding 95% of the time) to 6 m below the normal operating level. The minimum annual storage volume would typically occur around March/April/May. The reservoir would typically be full between August and mid-October (Tonkin & Taylor May 2013a).

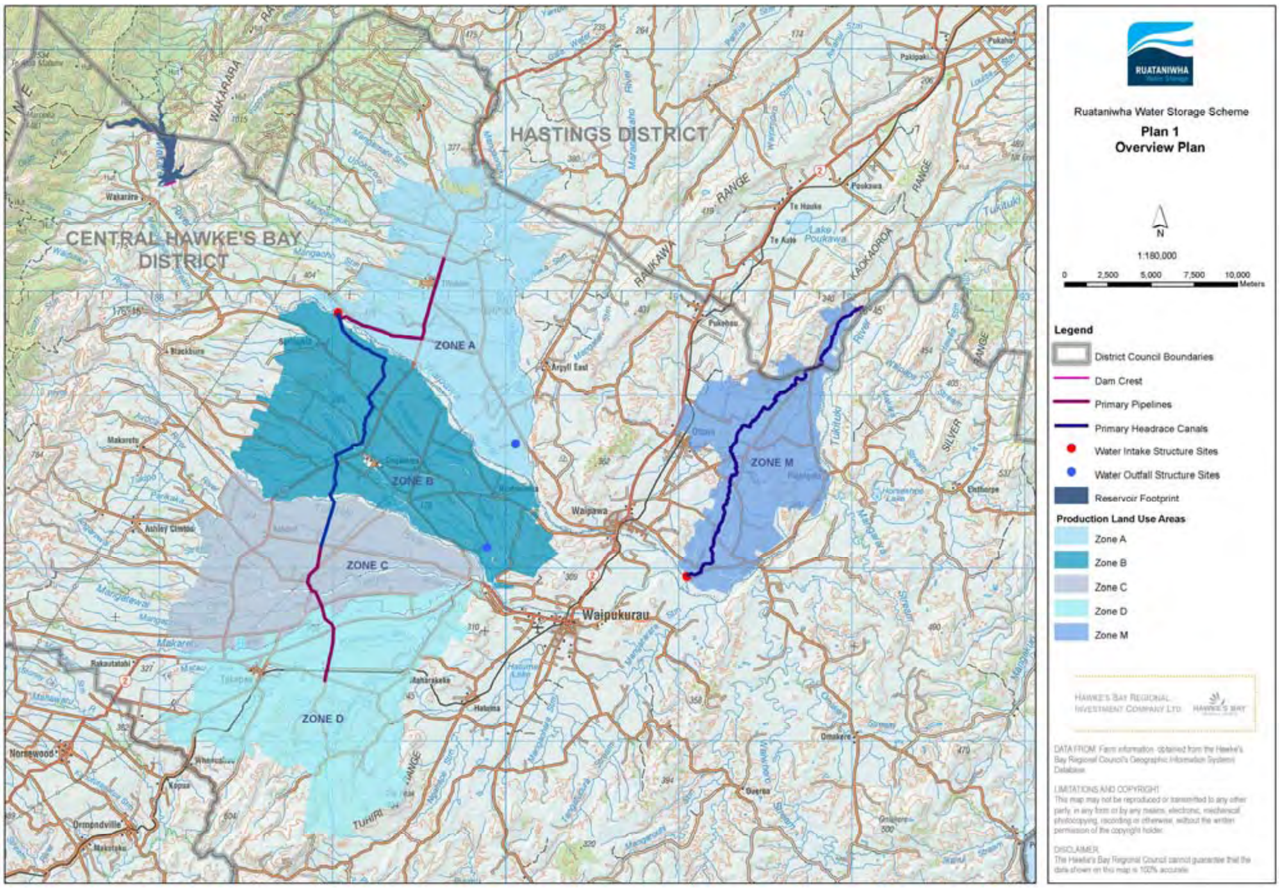

Figure 1. Scheme overview showing dam location, reservoir extent, currently defined water service zones, and proposed headrace centreline and pipe distribution network (from Tonkin & Taylor, May 2013a).

1.2.3. Potential land use changes

The proposed Scheme is expected to provide water for at least 25,000 ha of land on the Ruataniwha Plains and in the Papanui Catchment. The actual irrigated area would depend on the mix of land uses that ultimately establish.

The predominant existing land use within the irrigation zones is pastoral sheep and beef farming, followed by arable cropping and dairy farming. Hawke's Bay Regional Council staff consider that greater overall security of supply of irrigation water will lead to the development of a more integrated production system and value chain (Benson 2010). Currently much of the area shown in Zones A-D and Zone M is un-irrigated, or irrigated from individually held groundwater and surface water consents, with a number being subject to minimum flow cut-offs.

The changes to farms types have been predicted by Macfarlane Rural Business Ltd (2012) in a study that assessed the potential on-farm economics of the Scheme. The 2012 Macfarlane report developed a future land use scenario comprising:

- Little change to sheep and beef extensive farming and mixed livestock farming (constant at 14,175 ha)
- A decrease in mixed/dairy support (5,730 ha to 4,671 ha)
- A decrease in area associated with stock finishing (9,128 ha to 1,800 ha)
- An increase in arable and mixed arable land use (8,100 ha to 9,355 ha)
- Dairy farming increasing from 4,167 ha to 9,175 ha
- An increase in both orchards and vineyards (700 ha to 2,825 ha).

1.3. Location of the potentially affected reaches

The assessment of effects on aquatic ecology has been undertaken at the following key locations (Figure 2):

- The Makaroro River upstream of the footprint of the reservoir (Reach 1)
- The footprint of the reservoir on the Makaroro River from the upstream end (E2786894 N6157464) to the dam site (E2790615 N6153865) (Reach 2)
- The reach of the Makaroro River downstream from the dam to the confluence with the Waipawa River, a distance of approximately 9.4 km (Reach 3)
- The reach of the Waipawa River downstream of its confluence with the Makaroro River, to the site of the irrigation headrace intake (a distance of approximately 9.2 km (Reach 4)
- The reach of the Waipawa River downstream of the site of the irrigation headrace intake to its confluence with the Tukituki River (a distance of approximately 28 km (Reach 5)
- The Tukituki River from its confluence with the Waipawa River (including the Papanui Stream) to its outlet into Hawke Bay — a distance of approximately 66.5 km (Reach 6).

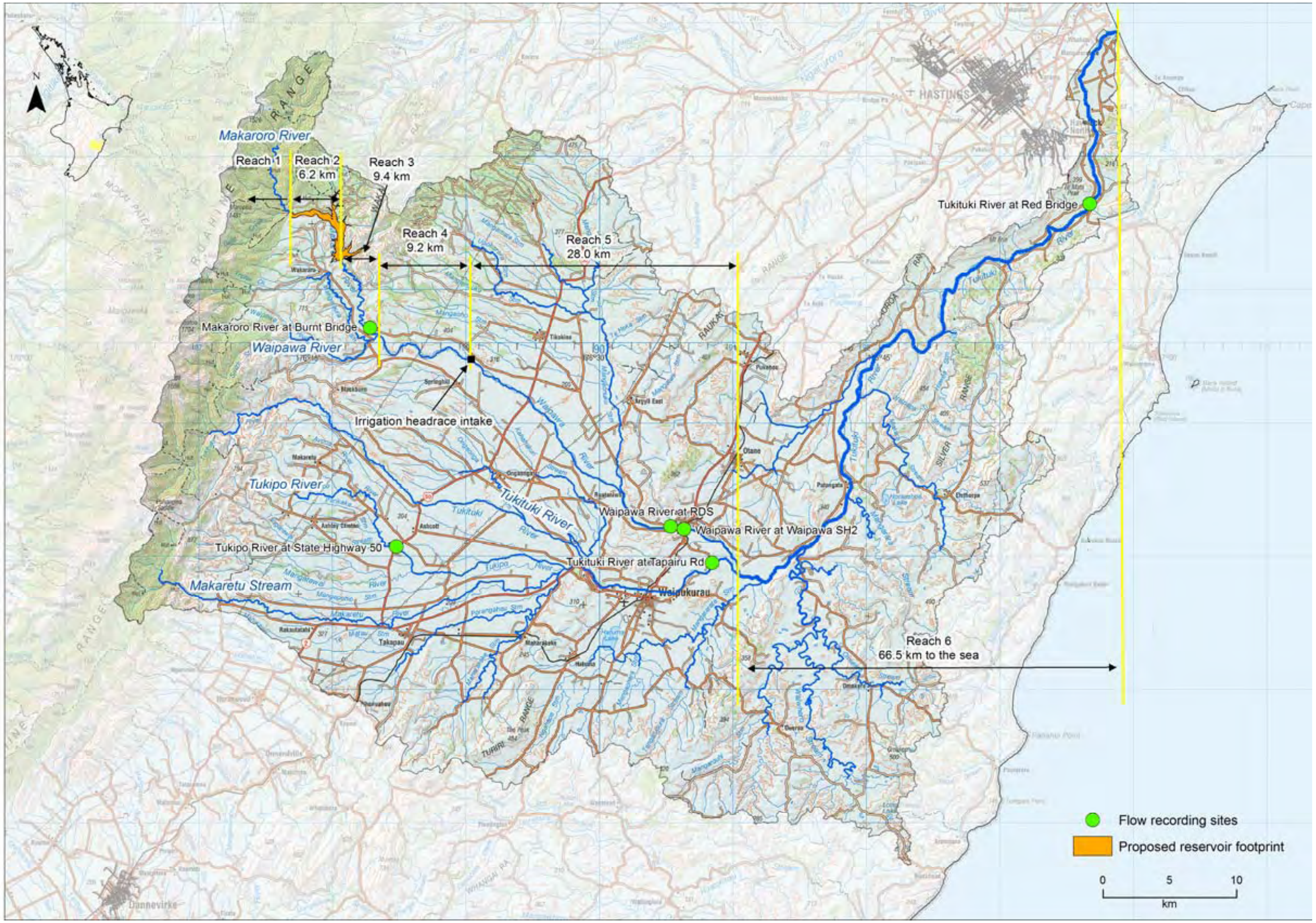

Figure 2. The Tukituki catchment, key monitoring sites and the location of the affected reaches.

1.4. Scope of this report

This report reviews the catchment's aquatic values and provides an assessment of effects on aquatic ecology as a result of the following activities:

- construction activities
- the dam and the reservoir (*i.e.* the impounding of water)
- flow regulation and the irrigation intakes
- land use change.

The report also identifies mitigation and monitoring options.

1.5. Key freshwater values — as expressed in regional planning documents

1.5.1. Introduction

This section provides an outline of the key freshwater values as set out in the HBRC's planning documents and as identified by the Ruataniwha Stakeholder Group at stakeholder workshops and meetings.

1.5.2. Relevant planning documents

1.5.2.1. Introduction

The relevant planning documents for identifying the region's freshwater values as they apply to the proposed Scheme are discussed in this section. This is intended to provide guidance for determining freshwater values as they relate to this aquatic ecology assessment and does not purport to be a complete planning analysis.

1.5.2.2. The Hawke's Bay Land and Water Management Strategy (2011)

The Hawke's Bay Land and Water Management Strategy (the Strategy) is a high level, non-statutory document that outlines the region's strategic direction for the future management of land and water. Section 1.6 of the Strategy identifies the following values attributed to water:

- Clean drinking water is a basic human right
- Freshwater bodies are valued for their natural form, intrinsic qualities and mauri; they provide a sense of place for people and communities and are a source of inspiration
- Water supports the flora and fauna which make up the regional diversity

- Well-functioning waterbodies provide mahinga kai
- Water is a critical ingredient for businesses, including agriculture and processing, that underpin the Hawke's Bay economy
- Water provides opportunities for recreational activities and tourism.

Section 4 of the Strategy summarises the values of each major catchment in Hawke's Bay. The following values have been identified as the key drivers for the Tukituki catchment:

- Cultural values
- Life supporting capacity of rivers, lakes and wetlands
- Existing and potential substantial economic development (including tourism)
- Native and trout fishery
- Recreation.

1.5.2.3. The Hawke's Bay Regional Resource Management Plan (2006)

The Hawke's Bay Regional Resource Management Plan (RRMP) was made operative in August 2006 and includes the Regional Policy Statement (RPS) and the Regional Plan for the integrated management of the region's natural and physical resources. Section 3 contains the RPS policy framework comprising 37 objectives and 66 policies, of which three objectives and 16 policies address surface water resources. The Regional Plan policy framework is contained in Section 5 which provides two objectives and six associated policies addressing surface water quality and quantity.

An outline of the relevant provisions of the Regional Plan is provided below with respect to water quality and water quantity. The RPS policy framework is high level and given the Regional Plan provisions must give effect to the RPS and for the purpose of this aquatic ecology assessment, it is considered the Regional Plan provisions will contain more useful guidance in terms of freshwater values of the region.

Water quality

The key provisions of the Regional Plan that describe the water quality values of the region are as follows:

> ***Objective 40***
> *The maintenance of the water quality of specific rivers in order that the existing species and natural character are sustained, while providing for resource availability for a variety of purposes, including groundwater recharge.*

Policy 71, Environmental Guidelines — Surface Water Quality
To manage the effects of activities affecting the quality of water in rivers, lakes and wetlands in accordance with the environmental guidelines set out in Tables 7 and 8.

The Water Quality Framework focuses on maintaining aquatic ecosystem and natural character values whilst providing for resource use. The environmental guidelines set out in Tables 7 and 8 of the RRMP is summarised in Table 1 below, as they relate to the Tukituki catchment.

Table 1. Environmental guidelines for surface water quality applicable to the Tukituki River.

	Tukituki River and tributaries upstream of SH50	**Tukituki River and tributaries between SH50 and Tamumu Bridge**	**Tukituki River downstream of Tamumu Bridge**
Temperature	The temperature of the water should be suitable for sustaining the aquatic habitat		
Dissolved oxygen (DO)	The concentration of dissolved oxygen should exceed 80% of saturation concentration		
Ammoniacal nitrogen (NH_4-N)	The concentration of NH_4-N should not exceed 0.1 mg/L		
Dissolved reactive phosphorus (DRP)	The concentration of dissolved reactive phosphorus should not exceed 0.015 mg/L		
Clarity	In areas used for contact recreation, the horizontal sighting range of a 200 mm black disk should exceed 1.6 m.		
Faecal coliforms (cfu/100 mL)	< 50	< 200	< 100
Suspended solids (mg/L)	< 10	< 10	< 10

In addition, Policy 72 provides guidance for the implementation of the guidelines set out in Table 1. These guidelines apply after reasonable mixing, with the exception of hydroelectricity discharges for which the guidelines apply at the point of discharge, and disregarding the effect of any natural perturbations that may affect the water body. They also apply (except suspended sediment) to flowing surface water bodies when the flow of water is at or less than the median flow, or for non-flowing water bodies, the level of water is at or less than the median level.

The anticipated environmental results for sustaining aquatic ecosystems are also set out in the RRMP as follows:

- Temperature not changed by more than 3˚C, nor raised above 25˚C
- Dissolved oxygen (DO) not falling below guideline values
- Ammoniacal nitrogen (NH_4-N) levels not exceeding guideline values
- Dissolved reactive phosphorous (DRP) not exceeding guideline values
- Diversity and quantities of fish species or indigenous invertebrates is maintained.

Water quantity

The relevant Regional Plan provisions in the RRMP addressing surface water quantity values include:

Objective 41
The maintenance of the water quantity of specific rivers in order that the existing aquatic species and the natural character are sustained, while providing for resource availability for a variety of purposes, including groundwater recharge.

Policy 73, Environmental Guidelines — Surface Water Quantity

(a) *To sustain aquatic ecosystems by establishing a minimum flow in a river as that level which will maintain the existing ecosystem.*

(b) On rivers (or water management zones) where minimum flows have been established, all takes for which a resource consent is required will be required to cease when the river is flowing at or below the minimum flow. Except that where the taking has, as a primary purpose, the provision of drinking water to people or animals taking could be restricted to the level necessary to maintain human or animal welfare.

(c) To provide a known level of risk to resource users by ensuring that, for rivers with an established minimum flow, the total allocation authorised through the resource consent process does not result in authorised takes being apportioned, restricted or suspended for more than 5% of the time on average during November-April.

(d) To sustain the natural character of the surface water body when determining the minimum flows and allocatable volumes for surface water bodies in Table 9.

The RRMP establishes minimum flows and allocatable volumes to ensure the environmental values listed in Policy 73 are met. The allocatable volume is defined in the Policy 74 as the difference between the average summer 7-day consecutive flow that is exceeded 95% of the time (Q_{95}) and the minimum flow. This process has resulted in a number of stream management zones in the Tukituki catchment being given a zero allocation. The relevant limits set out in Table 9 of the RRMP are summarised in Table 2.

Table 2. Minimum flow and allocatable volumes at relevant sites in the Tukituki catchment.

River	Minimum flow site	Minimum flow (l/s)	Allocable volume (m^3/week)
Tukituki River	At Red Bridge	3,500	1,407,751
Tukituki River	At Tapairu Road	1,900	492,307
Waipawa River	At Waipawa (SH2)	2,300	342,317

1.5.2.4. *Regional Policy Statement change*

The HBRC recently publicly notified a change to their Regional Policy Statement (RPS) as part of the programme to implement the Hawke's Bay Land and Water Strategy and the National Policy Statement for Freshwater Management (2011). Policy LW1 (k) seeks to enable water storage infrastructure which can provide increased security for water users in water-scarce catchments while avoiding, remedying or mitigating adverse effects on freshwater values. Values recognised in the RPS for the Tukituki Catchment include:

- Industrial and commercial water supply
- Native fish and trout habitat
- Urban water supply for towns and settlements
- Water use associated with maintaining or enhancing land-based primary production
- Aggregate supply and extraction in lower Tukituki River
- Amenity for contact recreation (including swimming) in lower Tukituki River
- Recreational trout angling in the middle Tukituki River and tributaries between SH50 and Tapairu Road & middle Waipawa River and tributaries between SH50 and SH2.

1.5.2.5. *The Tukituki Plan Change proposal*

HBRC is currently looking at new approaches for managing the Tukituki River catchment. New policy frameworks are being prepared for the management of water allocation and water quality. At the same time, solutions to discharges to the river and how to meet water shortages are being developed. HBRC has established a group which represents a range of stakeholders with an interest in the management of land

and water in the catchment. This group includes landowners, irrigators, primary industry sectors, statutory agencies and conservation groups. HBRC is collaborating with the group as policy development on the Tukituki Plan Change proposal progresses.

HBRC have identified a range of values relevant to the Tukituki catchment, through various stakeholder meetings including two symposia and the development of the Hawke's Bay Land and Water Management Strategy through an external reference group. Those values that apply to the whole of the catchment include: life supporting capacity, mauri, contact recreation (health), water use (quality and economic), and fish passage.

Values that may vary across the catchment include: natural state, wetlands, riverine bird habitat, inanga spawning, native fish habitat, trout spawning and habitat and contact recreation (amenity).

The Tukituki Plan Change 6 sets limits and/or targets associated with water allocation (based on updated minimum flows) and nutrient management (Uytendaal & Ausseil 2013). The HBRC adopted the Plan Change in February 2013 and it is proposed that the Plan Change and the Scheme consents are called in as a matter of national significance to enable an independent and integrated decision making process to occur through a single Board of Inquiry.

2. EXISTING ENVIRONMENT

2.1. Physical environment of the Tukituki River catchment

2.1.1. Topography, slope, elevation and geology

The Tukituki catchment is located in central Hawke's Bay, extending from the main divide of the Ruahine Ranges to the Pacific Ocean and covering approximately 2,500 km^2 (Figure 2). It is the third largest watershed in the Hawke's Bay region. Approximately 87% of the catchment's land surface lies below 500 m, while 3% is mountainous (> 1000 m). The highest point, Rangioteatua, is 1,715 metres above sea level. The catchment has varied topography, with about half of the land surface having a slope that is moderate to very steep (21-42°) and a quarter with a flat or gently undulating slope (0-3°) (Newsome & Wilde 2008).

The dominant geology is soft sedimentary (35%); alluvial (34%); and hard sedimentary rock (22%). The Ruahine Range is composed mainly of Upper Jurassic alternating sandstones and argillites which have been folded and faulted by tectonic forces (Grant 1982). Large areas of eroded rock above 1000 m are the main source of coarse sediment in the river channels.

2.1.2. River morphology and sediment

River morphology in the Tukituki catchment is characterised by steep headwater streams flowing from the Ruahine Ranges into the major tributaries (including the Waipawa and Makaroro rivers). Rivers within the Tukituki and Waipawa system are typically braided and confined to a managed channel, where there is often a surplus of gravel bed material (Tonkin & Taylor May 2013b). The Makaroro River is laterally confined in a gorge, but braids where valley width permits. In the narrower reaches the river becomes single thread with longitudinal bar sequences.

The lower and middle Tukituki River (Reach 6, Figure 2) has a steady gradient of 0.2% over a distance of 60 km (Tonkin & Taylor May 2013b). Upstream of State Highway 50 (SH50), the Waipawa (Reach 4) and Makaroro (Reach 3) Rivers are characterised by steeper gradients of 0.72%. The gradient through Reach 5 is not specified in the report but is described as decreasing between SH50 and State Highway 2 (SH2).

According to the sediment budget produced by Tonkin & Taylor (May 2013b), the Waipawa River (Reach 4 and 5) has a gravel surplus and is currently aggrading. Tonkin & Taylor (May 2013b) suggests that the Waipawa River supplies about 44% of the gravel to this reach, compared to 56% from the Makaroro River.

Gravel is currently extracted from the Waipawa and lower and middle Tukituki rivers to manage flood risk (Reaches 5 and 6). The extracted volume varies annually. In recent years less than 30,000 m^3 / year has been removed from the lower Tukituki River, while in previous years up to 127,000 m^3 / year was extracted (Tonkin & Taylor May 2013b). More than 100,000 m^3/ year is currently extracted from the Waipawa River. Gravel extraction is monitored by HBRC using river cross-sections every three years.

Flood events of varying frequency and size in the Makaroro River result in a dynamic sediment regime. Bed levels depend on fluxes in sediment supply and changes are not uniform throughout the river (Tonkin & Taylor May 2013b).

A survey of bed sediment size near the head of the proposed reservoir (Makaroro River at Mill) found that the median grain size was 16 mm, with a 10th and 90th percentile of 1.6 mm and 88 mm, respectively (Tonkin & Taylor May 2013b). This was the only site where measurements were made but it was noted that at other locations (such as the gorge at the dam site) larger rocks were more prevalent. An earlier study (Williams 1985) found that the median grain size in the armour layer was 65 mm. This study also showed that there is a reduction of mean grain size with distance downstream.

2.1.3. Land use

According to the NZ Landcover Database 2, most of the Tukituki Catchment (80%) is covered in exotic grassland, short rotational crop land, orchards and other perennial crops, particularly in the lowlands (Figure 3). Native vegetation (including manuka and kanuka forest, broadleaf indigenous hardwoods, subalpine shrubland and tussock grasslands) is the second highest land cover (12%), dominating the steeper hill-slopes of the Ruahine Ranges. Exotic forestry (6%) is also present.

The land use in the proposed reservoir's 12,000 ha catchment is diverse, with a high proportion (75%) of native forest on the Ruahine Ranges to the north and west. The southern part of the reservoir catchment is mainly rolling pasture while much of the northern part of the catchment is dominated by production forestry (NIWA May 2013c).

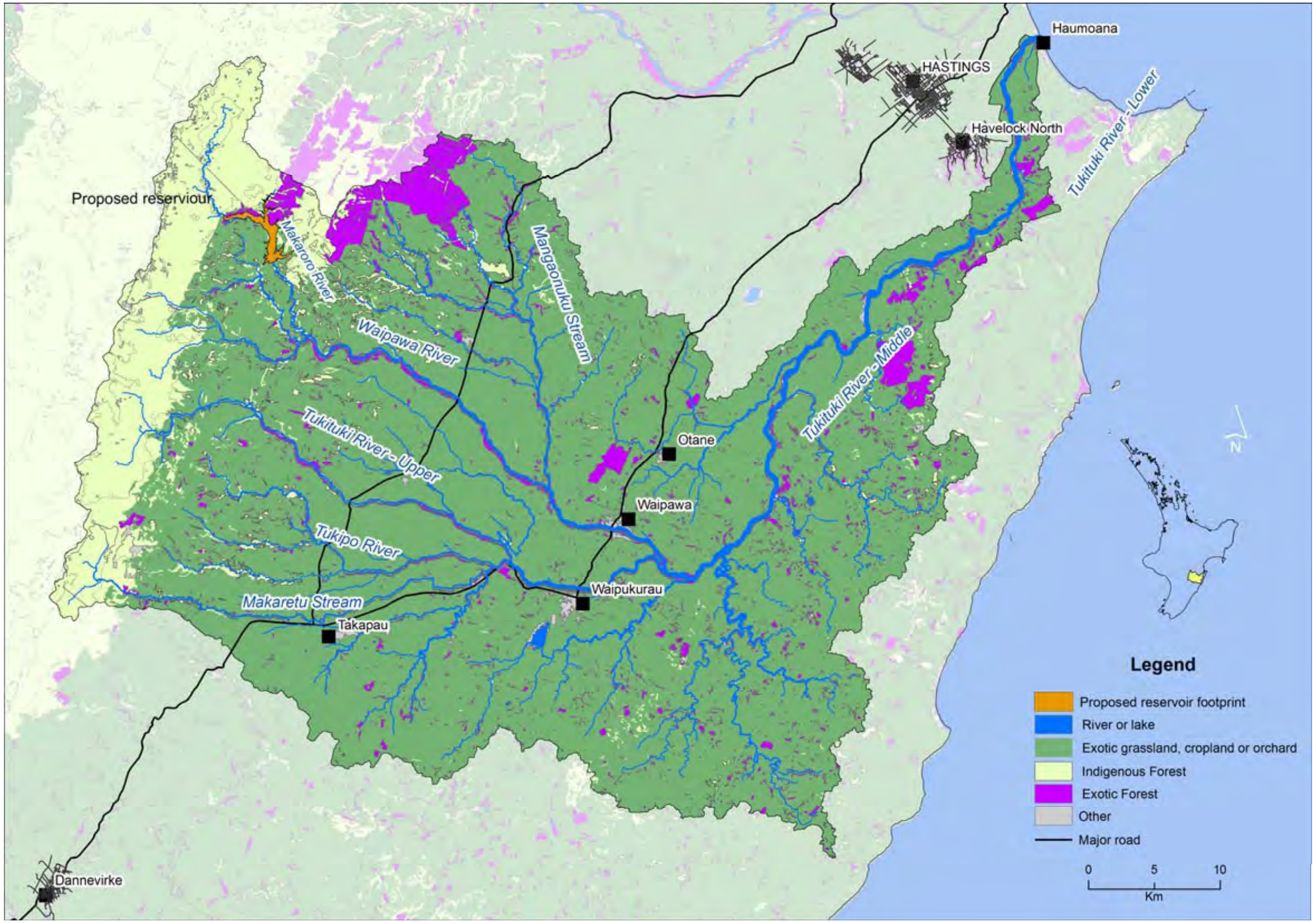

Figure 3. Land use in the Tukituki River catchment. Data derived from the Land Cover Database 2 (Ministry for the Environment 2002).

2.1.4. Climate

Climate in Hawke's Bay is largely influenced by elevation and the airstreams crossing New Zealand. The predominant westerly airflows experienced in the North Island often bring dry settled weather to Hawke's Bay (Thompson 1987). In southerly and easterly airflows the high country enhances precipitation, so low pressure systems arriving from these directions determine the hydrology of rivers in the region. Also of note is the influence of tropical cyclones and subtropical depressions, which are known to cause flooding and landslips.

Mean annual rainfall on the Ruataniwha Plains ranges from 910-1308 mm (Kozyniak 2012). Tonkin & Taylor (2011a) modeled rainfall across the Tukituki catchment. Mean annual rainfall ranged up to 2800 mm near the headwaters of the Makaroro River. Estimated rainfall at four hydrometric sites that are most relevant to this report is summarised in Table 3 (see Figure 2 for the location of these sites). Rainfall is generally highest in the winter months and lowest during the summer (Thompson 1987). Climate change is projected to result in an increase in rainfall in summer and autumn and a decrease in winter and spring. However, drought risk in Hawke's Bay is likely to at least double by the late 21st century and may increase by a factor of four or more depending on the magnitude of climate change (Renwick May 2013).

Table 3. Rainfall at relevant sites in the Tukituki River catchment (from Tonkin & Taylor 2011a; Lynch 2013).

Site	**Adjusted mean annual rainfall (mm)**
Tukituki River — Red Bridge	1240
Tukituki– Shag Rock	1250
Waipawa River — RDS	1440
Makaroro River at proposed dam site	2280
Pukehou (Papanui subcatchment)	800

2.2. The instream physico-chemical environment

2.2.1. Hydrology

2.2.1.1. Current mean, median and low flows

Flow statistics for the most relevant hydrological monitoring sites in the Tukituki catchment are summarised in Table 4. The location of these sites is shown in Figure 2.

Table 4. Summary statistics for historical flow records in the Tukituki catchment (Source: HBRC Science May 2013a; Tonkin & Taylor 2011a)

River and site name	Tukituki River Red Bridge	Tukituki River Tapairu Rd	Waipawa River RDS	[2]Makaroro River Burnt Bridge	Papanui Stream Newmans Ford
[1]Catchment area (km^2)	2,380	756	680	122	58.4
Median flow (m^3/s)	20.7	8.9	8.5	3.7	132
Mean flow (m^3/s)	43.2	15.1	14.6	6.64	411
Mean annual low flow (m^3/s)	5.3	2.2	2.7	1.37	46
Record period: begin	22.05.1968	29.05.1987	22.04.1988	01.01.1972	11.12.1978
Record period: end	08.07.2011	13.07.2011	07.07.2011	31.12.2010	04.06.1991

Notes:

[1] These catchment areas are as reported in the NIWA site index.

[2] Uses the extended flow record (1972–2010).

The Makaroro River (Reach 3) has a relatively short flow record (16 years with gaps) from a site named Burnt Bridge (Figure 2). The site is approximately 10 km downstream from the dam site, so provides the most representative hydrological record for the catchment above the dam. The catchment area at Burnt Bridge is 122 km^2, which is 9% more than that at the toe of the proposed dam (Tonkin & Taylor 2011a). The short period and presence of considerable gaps in the Burnt Bridge flow record meant it was insufficient to model water demand for the dam's feasibility assessment reliably. Consequently Tonkin & Taylor (2011a) synthetically extended the flow record for this site to span a continuous record between January 1972 and December 2010.

2.2.1.2. Seasonal flow regimes

The annual flow regime for the Makaroro River is summarised in Figure 4. There is a strong seasonal pattern where the mean winter flow is more than 2.5 times the summer flow (Tonkin & Taylor 2011a). On average the median flow in winter (June–August) is 6.1 m^3/s, spring (September–November) is 4.2 m^3/s, autumn (March–May) is 2.9 m^3/s and summer (December–February) is 2.3 m^3/s.

A similar annual pattern is seen at other sites throughout the Tukituki catchment (See Section 3.4.2 for more detail).

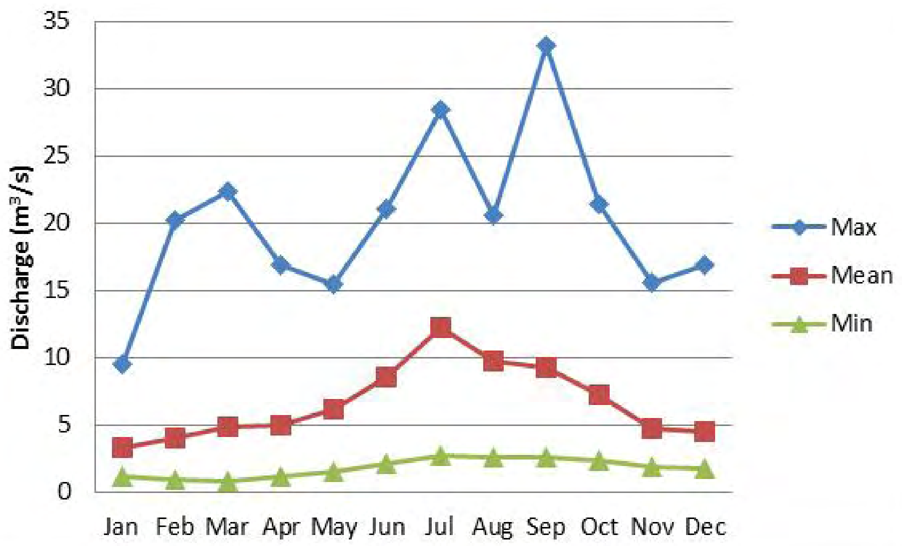

Figure 4. Annual flow regime: mean monthly mean, max and min flow for the extended flow record for Makaroro at Burnt Bridge (1972-2010) (data from Tonkin & Taylor 2011a).

2.2.1.3. Flood and flushing flows

Considerable hydrological analysis and flood modelling was carried out as part of the technical feasibility study by Tonkin & Taylor (2011a). The outputs from this modelling are shown in Table 5.

The FRE3 is a flow statistic that has been widely used by river managers to assess the frequency of freshes. It represents the average annual frequency of flows that are greater than three times the median flow. Clausen & Biggs (1997) discuss FRE3 freshes in the context of aquatic weed removal, noting that a flood of three times the median flow or greater is generally considered sufficient to remove periphyton, thereby having the potential to control nuisance periphyton growths. It should be noted that three times the median flow is not intended as a threshold flow, as flows less than this are still capable of reworking channel sediment and resetting periphyton growth. Studies on the accumulation of river biota in New Zealand rivers have found that in the absence of adequate flushing flows, accrual of aquatic algae can increase exponentially to reach ‘nuisance’ levels after a period of around six weeks if nutrients and sunlight are abundant (Scrimgeour & Winterbourn 1989; Biggs & Stokseth 1996).

Table 5. Flood and flushing flow statistics for key sites in the Tukituki catchment.

	Makaroro at Burnt Bridge[1]	Waipawa at RDS[2]	Tukituki at Red Bridge[2]
Mean annual flood peak (m^3/s)	~95	408	1,407
100-year flood peak (m^3/s)	~280	1187	3,332
Median flow (m^3/s)	3.7	8.4	20.6
Magnitude of FRE3 flow (three times the median flow) (m^3/s)	11.1	25.2	62
Mean annual frequency of FRE3 days	45	39	55
Mean annual frequency of six week periods with no FRE3 flow	2.5	2.4	2.2
Longest period with no FRE3 flows (days)	262	301	298

Notes:
[1] From Tonkin & Taylor 2011a
[2] Flushing flow statistics are calculated using modelled 'Scenario 2' data (the status quo — see Section 3.4.2)

2.2.1.4. Current minimum flow and allocation

The 2006 RRMP defines the current minimum flows for rivers in the Tukituki catchment. These are summarised in Table 6 along with the current surface water allocation.

Table 6. Minimum flows and current surface water allocation for the lower/middle Tukituki and Waipawa rivers (Johnson 2011; pers. comm. Paul Barrett, HBRC, 17 February 2012).

River reach	Site name	Minimum Flow	Currently allocated
Lower / Middle Tukituki	Red Bridge	3500 l/s	834 l/s
Waipawa	SH2	2300 l/s	762 l/s

It should be noted that the current allocation includes water allocated for frost protection purposes. The volume of water used for frost fighting is significant but is only withdrawn as required in early spring, when river levels tend to be above mean annual low flow (MALF).

2.2.1.5. Alternative minimum flow

Johnson (2011) used Instream Flow Incremental Methodology (IFIM) style habitat modeling to review the minimum flows for the lower/middle Tukituki and Waipawa rivers. The critical species and suggested minimum flows for these sites are shown in Table 7.

Table 7. Proposed minimum flow required to provide 90% habitat weighted usable area (WUA) at the MALF at three sites in the Tukituki River catchment (HBRC Science May 2013a; HBRC 2013).

Site	Critical species	Proposed minimum flows
Tukituki River at Red Bridge	Adult rainbow trout	5200 l/s
Tukituki River at Tapairu Rd	Juvenile longfin eel	2300 l/s
Waipawa River at SH2	Juvenile longfin eel	2500 l/s

2.2.2. Physical instream habitat

Habitat mapping undertaken in the lower Tukituki River (Reach 6) shows that the majority of the habitat is run (54%) and riffle (30%), with the remainder being pool (16%) (Johnson 2011). The river becomes more braided in the lower reaches. Instream habitat in the Waipawa River is also dominated by run (58%) and riffle (36%), with a small proportion of pools present (6%). Habitat mapping undertaken in the Makaroro River in November 2011 also found that run (54%) and riffle (34%) habitats were most frequent, with the remainder (11%) being pool/deep run.

2.2.3. Water quality

2.2.3.1. Introduction

Good water quality is an essential value for freshwater ecosystems as it enables aquatic life, such as fish and macroinvertebrates to survive and reproduce. However, good water quality also benefits human values, such as recreational (*e.g.* angling, swimming) and agricultural use (*e.g.* stock drinking, irrigation). Generally, the main water quality characteristics that need to be considered when assessing surface water quality in a waterway are nutrients (which influence the growth of algae and cyanobacteria), faecal indicator bacteria (which are an indicator of risk for contact recreation and water use), water clarity (which influences fish feeding, aesthetics and swimming safety), water temperature (which can be too warm for some species) and dissolved oxygen (which can be too low for sensitive species). At particularly high concentrations, some nutrients (*e.g.* ammonia and nitrate) can be toxic to aquatic life.

2.2.3.2. Available data

The HBRC has records of water quality at 60 sites throughout the Tukituki catchment. However, the records available at each site vary widely and at many sites only a small number of samples have been collected. Water quality has also been measured at the Makaroro River at Burnt Bridge and Tukituki River at Red Bridge sites on a monthly basis since 1989 as part of NIWA's National River Water Quality Network (Smith & Maasdam 1994). A thorough analysis of the data from 14 core sites throughout the Tukituki catchment was conducted by Ausseil (2008). Further work has recently been conducted by HBRC's science team.

2.2.3.3. Nutrients

In general, water quality in the Tukituki catchment declines from upstream to downstream. The main water quality issue appears to be nutrient enrichment between SH50 and SH2, where the level of compliance with ANZECC guidelines was relatively poor for dissolved reactive phosphorus (DRP; 61%) and very poor for dissolved inorganic nitrogen (DIN; 9%, Ausseil 2008). The point-source discharges from the Waipawa and Waipukurau oxidation ponds were the largest sources of DRP, representing up to 70 % of the total DRP inputs to the upper and middle catchment. Nutrient concentrations, particularly nitrogen, improved significantly in the lower catchment (Red Bridge and Black Bridge), although this is due to the assimilation of nutrients by the algal mats, which themselves often exceeded acceptable levels (Ausseil 2008; NIWA May 2013a).

Nutrient concentrations in the Makaroro River at Burnt Bridge complied with all water quality guidelines and were generally lower than that recorded at the other sites in the Tukituki catchment (Figure 5).

The Papanui Stream is a major source of phosphorus to the lower Tukituki River (Lynch 2013). Sampling undertaken by the Council in 2012 show exceedances in the dissolved reactive phosphorus (DRP) concentration targets recommended for this catchment and also relatively high concentrations of total nitrogen (Uytendaal & Ausseil 2013). A study to characterise the environment in the Papanui Stream sub-catchment attributes the input of nutrients to surface water to "the loss of riparian vegetation, inadequate fencing, the conversion of predominantly sheep farming to 'sheep and beef operations', generally unrestrained access of stock to the stream and the underlying mudstone and limestone which is present in the catchment" (Lynch 2013).

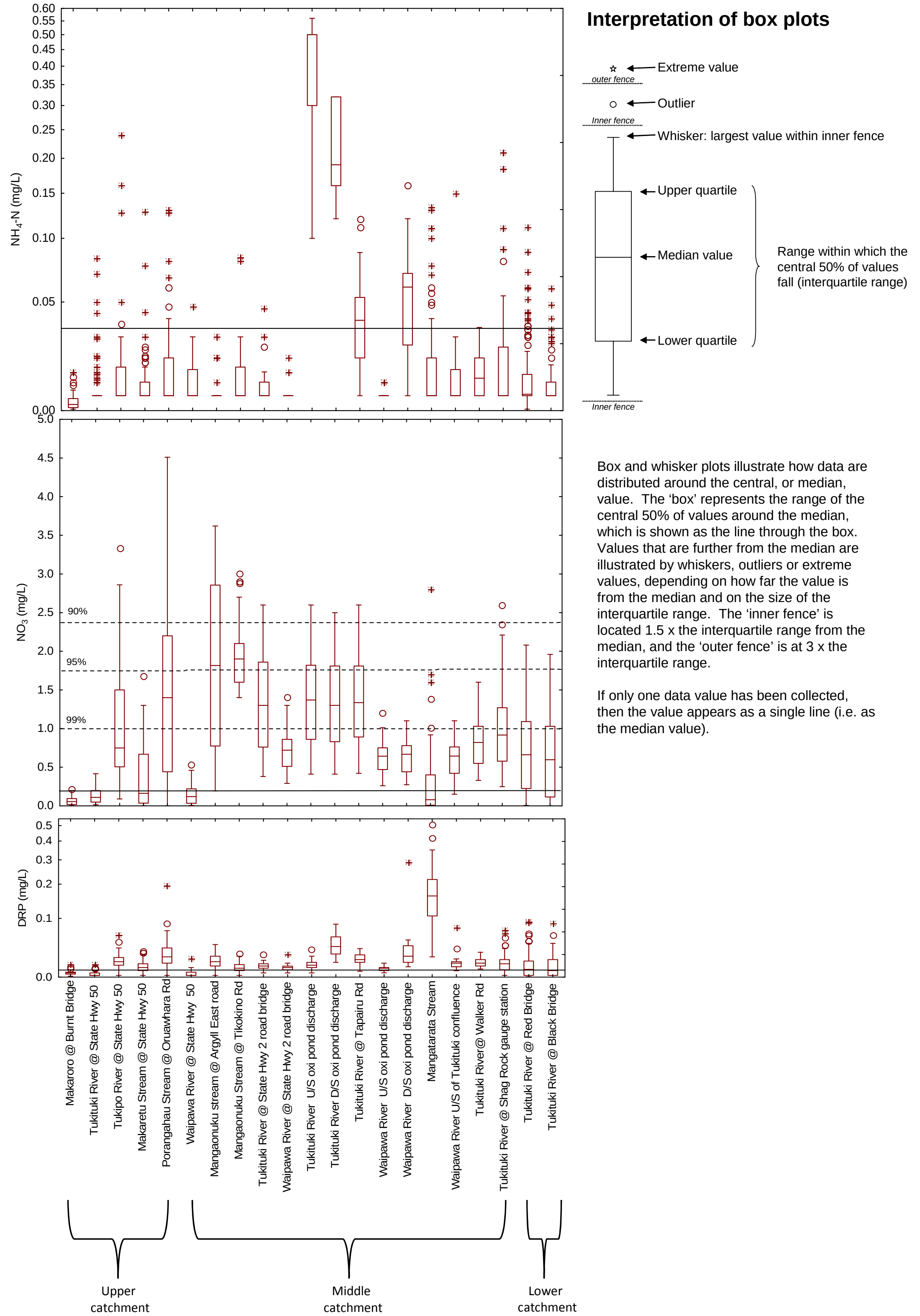

Figure 5. Comparison of nutrient concentrations among sites in the Tukituki catchment between August 2004 and June 2011. The solid lines indicate ANZECC water quality guidelines for each parameter. The dotted lines on the nitrate graph indicate guidelines for 90, 95 and 99% protection against nitrate toxicity. Note: DRP and NH$_4$-N are on a log scale. Data source: HBRC and NIWA.

2.2.3.4. DIN:DRP ratio and N and P limitation of algal growth

Nutrient supply is a controlling factor in the proliferation of aquatic macrophytes and algae in streams and rivers. The availability of either nitrogen (N) or phosphorus (P) can potentially limit macrophyte and algal growth rates.

Nutrient diffusing substrate assays are the best way to determine whether N or P are limiting aquatic plant growth rates, although predicting N versus P limitation is difficult (Francoeur *et al.* 1999; Keck & Lepori 2012). However, ratios of N:P offer one way to estimate if nitrogen or phosphorus are likely to be limiting growth (Biggs 2000b). Sites with N:P ratios less than 7:1 are likely to be N-limited, while sites with N:P ratios greater than 15:1 are likely to be P-limited. Sites with N:P ratios in between these extremes may be co-limited (McDowell *et al*. 2009).

Comparison of median DIN:DRP ratios amongst sites in the Tukituki catchment indicated that all sites except two are likely to be P-limited with median DIN:DRP ratios greater than 15:1. This means that increases in P will result in increases in algal growth rates and biomass, while increases in N are unlikely to increase algal growth. Mangatarata Stream was the only site where DIN:DRP ratios were less than 7:1 (potentially indicating N-limitation). However, this low ratio was primarily driven by the high P concentrations. N concentrations are also high at this site and therefore nutrient limitation is unlikely. Makaroro at Burnt Bridge was the only site where ratios indicated nutrient co-limitation (*i.e.* DIN:DRP ratio between 7:1 and 15:1; Figure 6). Mangaonuku Stream at Tikokino Rd had the highest median ratio of all sites (*i.e.* greater than 150:1), indicating high levels of nitrogen availability and possibly strong phosphorus limitation.

In an intensive collaborative study of multiple sites down the length of the Tukituki River during summer of 2010/11, NIWA (May 2013a) found a downstream decline in the DIN/DRP ratio with phosphorus limitation likely in the upper river and co-limitation or nitrogen limitation likely in the lower reaches (Red Bridge and Black Bridge).

Nutrient diffusing substrate assays have been conducted at 19 sites throughout the Tukituki Catchment, with 6 of these sites being assessed twice (Uytendaal & Ausseil 2013). The results indicated co-limitation of algal growth at some sites (Waipawa at SH50, Makaretu at Speedy Road, Papanui, Mangaonuku at Argyll Road, Tukipo at SH50-winter, Tukituki at Tennant Road, Tukituki at Wildlife Refuge-summer), phosphorus limitation at some sites (Tukituki at River mouth, Tukituki upstream of Black Bridge, Waipawa at SH2, Tukituki at Moore Road-winter, Tukituki at Wildlife Refuge-winter, Tukituki at Walker Road, Porangahau-winter), nitrogen limitation at some sites (Tukipo at SH50-summer), and indeterminate results at other sites (Porangahau-summer, Maharakeke). The results from the nutrient diffusing substrate assays tended to follow the nutrient limitation inferred from N:P nutrient ratios as discussed in detail in Uytendaal & Ausseil (2013).

In summary, ratios of nitrogen to phosphorus in the water indicate that algal growth at most sites in the middle and lower reaches of the Tukituki mainstem is likely to be limited by phosphorus concentrations, rather than nitrogen. Nutrient diffusing substrate assays generally supported these assessments with phosphorus limitation occurring frequently in the middle and lower reaches of the Tukituki, co-limitation only found in the upper catchment above SH50, and N limitation only occurring in the upper Tukipo River (and perhaps Papanui Stream).

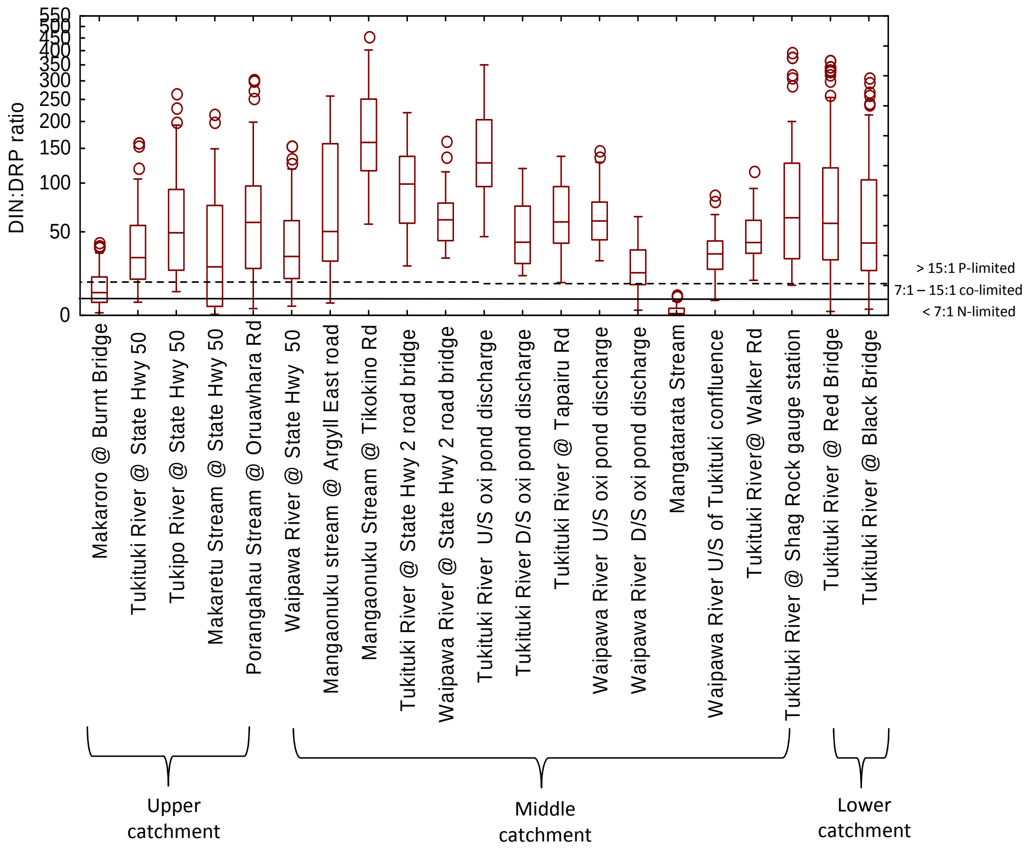

Figure 6. Ratios of the concentration of dissolved inorganic nitrogen (DIN) to dissolved reactive phosphorus (DRP) at each water quality site in the Tukituki River catchment. Ratios above top dashed line (*i.e.* ratios > 15:1) indicate potential P-limitation for plant growth, ratios below lower solid line (*i.e.* ratios < 7:1) indicate potential N-limitation, and ratios between the lines (*i.e.* ratios between 7:1 and 15:1) indicate potential co-limitation. Data source: HBRC and NIWA.

2.2.3.5. Faecal indicator bacteria

Concentrations of faecal indicator bacteria were generally within guidelines across the entire Tukituki catchment. Most sites had a rate of compliance with the MfE (2002) guideline (*i.e.* 550 *E.coli* / 100 mL) in excess of 90% (Ausseil 2008). Exceptions were two tributaries, Porangahau and Mangatarata Streams (82 % and 84 % compliance, respectively) and two sites downstream of oxidation pond discharges (*i.e.* Tukituki at Tapairu Rd and Waipawa downstream of Waipawa oxidation pond) with 82 % and 44% compliance, respectively (Ausseil 2008). Faecal indicator bacteria and nutrients are currently discharged from these ponds into the river. Alternative wastewater treatment options are being considered that will reduce bacteria and nutrient inputs to the river (NIWA May 2013a), with a requirement for Central Hawke's Bay District Council to meet new resource consent discharge limits for their Waipukarau and Waipawa wastewater discharges by 2014. .

Concentrations of faecal indicator bacteria at the Makaroro River at Burnt Bridge were below recommended guidelines (*i.e.* complied with guidelines) at all times and generally lower (*i.e.* better quality) than other sites in the Tukituki catchment (Figure 7).

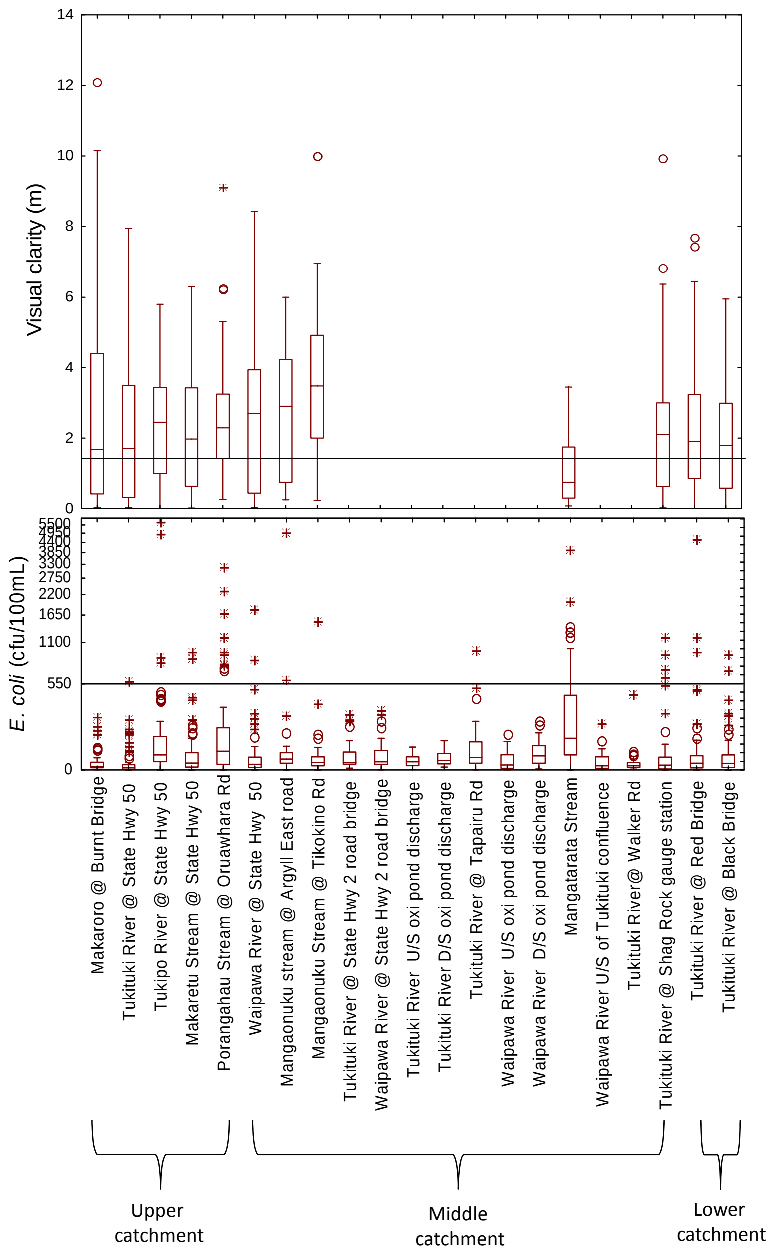

Figure 7. Comparison of median water clarity and faecal indicator bacteria concentration among sites in the Tukituki catchment. The solid lines indicate water quality guidelines for each parameter. Note: *E. coli* is plotted on a log scale.

All the data available from these sites is shown in Figure 7. As would be expected, *E. coli* concentrations are usually elevated during high flows, but swimming and other contact recreation is unlikely to occur at these times. Therefore, the distribution of data at flows less than the median are likely to be more relevant to assessing the suitability of these sites for contact recreation. A plot of the data at flows less than the median is shown in Appendix 27, and indicates a similar pattern among sites with regular exceedance of the guidelines in the Mangatarata Stream and occasional exceedances in the Porangahau Stream and Tukipo River.

2.2.3.6. Water clarity

Median water clarity was generally highest at sites in the middle reaches of the Tukituki catchment (particularly in the Mangaonuku Stream), and lower in the upper and lower Tukituki catchment (Figure 7). However, records still complied with the ANZECC (1992) 1.6 m contact recreational guidelines between two thirds and three quarters of the time, with the exception of one site (*i.e.* Mangatarata Stream, Figure 7).

Median water clarity was better than contact recreational guidelines at the Makaroro at Burnt Bridge site, and was generally similar to most of the other sites throughout the Tukituki catchment. However, occasionally this site had extremely high water clarity measurements (> 12 m) that were higher than ever measured elsewhere in the Tukituki catchment (Figure 7).

Clarity is strongly dependent on flow, and again the distribution of data at flows less than the median are likely to be more relevant to the suitability of these sites for contact recreation than the distribution of the full data set shown in Figure 7. After removing clarity data collected when flows were greater than the median, the pattern of clarity among sites was still very similar (Appendix 27).

2.2.3.7. Water temperature

During a recent collaborative project involving Cawthron, NIWA and HBRC staff, continuous water temperatures were measured at eight sites in the Tukituki catchment over at least four days in mid February 2011, and at 14 sites over four days in mid-February 2012. In general, water temperatures were warmer in 2011 than in 2012 (*i.e.* mean water temperatures at the same sites of 19.8°C and 17.7 °C, respectively). This reflects the general weather conditions and river flows during these summers, with 2011 being a stable, low flow year with low numbers of floods, compared to 2012 which was a wetter summer with regular floods.

In 2011 the highest temperatures was recorded in the Tukituki at Red Bridge (25.2°C) while the lowest temperature was recorded in the Tukituki River upstream of the Waipukurau sewage discharge site (16.2°C). In 2012 the highest temperature was again recorded at the Tukituki at Red Bridge (20.3°C) and the lowest temperatures was recorded in the Waipawa River at SH50 (Figure 8).

The main concerns with water temperature are the effects of high temperatures on aquatic life. Quinn *et al*. (1994) examined the temperature tolerances of 12 types of freshwater invertebrates and found that New Zealand's most common mayfly, *Deleatidium*, was the most sensitive species tested, with 50% of the animals dying (LT_{50}) after an exposure of 23°C for 96 hours. Brown trout will cease feeding once temperatures climb above 19°C and they will begin to die once temperatures climb above 25°C for a sustained period (Elliott 1994). Of the native fish, glass eels have the lowest LT_{50} of 25°C, followed by koaro (27–28°C) (Richardson *et al.* 1994).

The high temperatures observed in 2011 are warm enough to cause stress on sensitive invertebrates and fish, and, as expected, appear to be most severe in the lower catchment. These high temperatures, consistent with many rural waterways in New Zealand, will be a natural feature of the lower Tukituki River during warm summers given the local climate and unshaded nature of the channel. These warm summer temperatures may be at least partially responsible for the lack of sensitive invertebrate species (indicating relatively poor stream health) in the lower catchment (See Section 2.3.2).

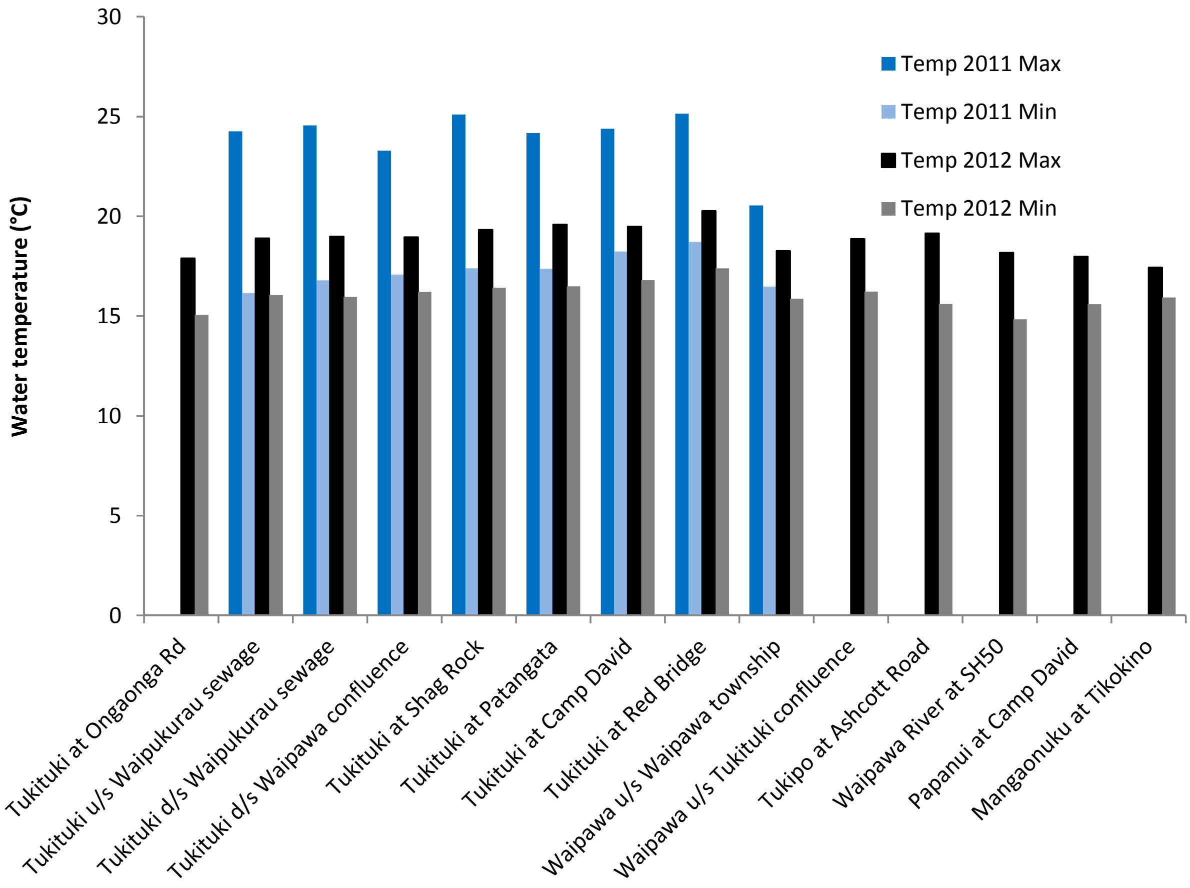

Figure 8. Observed continuous maximum and minimum water temperature (°C) recorded at 15 sites throughout the Tukituki catchment during the summers 2011 and 2012.

2.2.3.8. Dissolved oxygen

In the same collaborative project, continuous dissolved oxygen (DO) levels were also measured at eight sites over at least four days in mid February 2011, and at 14 sites over four days in mid-February 2012. Dissolved oxygen concentrations vary on a daily basis since photosynthesis of algae and other aquatic plants release oxygen into the water during the daytime, whereas during the night photosynthesis stops and oxygen uptake (respiration) by all the river life lowers oxygen concentrations. Low DO concentrations can stress aquatic life. The highest DO levels were recorded in the Tukituki River downstream of the Waipukurau sewage discharge site and at Patangata in 2011 (200 % saturation) and the lowest in the Papanui Stream at Camp David in 2012 (37% saturation; Figure 9). Flows in the spring-fed Papanui and Mangaonuku streams are strongly influenced by groundwater which typically have low DO levels. If these streams are excluded from the analysis then the lowest DO concentrations were seen at the Tukituki at Shag Rock site in 2011 (75 % saturation).

The fact that the highest and lowest DO levels in non-springfed systems were recorded in 2011 can be related to warmer and dryer climatic patterns that were experienced that summer. This resulted in more stable flows, allowing faster algal growth and more build up of periphyton biomass which, in turn, causes more extreme daily DO fluctuations. Regular floods and relatively high flows during 2012, resulted in frequent scouring of algal communities and less extreme daily DO fluctuations (Figure 9).

Dissolved oxygen is fundamental to the survival of aquatic life and the 1992 ANZECC guidelines recommend that DO should be above 80% saturation (ANZECC 1992). The amount of oxygen required by aquatic animals is quite variable and depends on a variety of factors such as species, size, condition and water temperature (Boyd 1990). Some species are more sensitive to low levels of oxygen than others. The DO requirements of trout, for example, are generally higher than for most other freshwater fishes (Dean & Richardson 1999) and minimum oxygen saturation should be at least 80% for free swimming brown trout (Elliott 1994; Mills 1971). There is little information on DO tolerances of aquatic invertebrates in New Zealand, however, some species such as mayflies, stoneflies and caddisflies are expected to be sensitive to low DO, while others such as chironomids are expected to be tolerant of low DO. These inferences are drawn from the fact that mayflies, stoneflies and caddisflies dominate invertebrate communities in high quality, pristine streams that have high DO concentrations, whereas these species are often absent from contaminated streams that may have lower DO (Boothroyd & Stark 2000).

Dissolved oxygen saturation levels at the non spring-fed sites were generally well above or relatively close (minimum 75%) to the 1992 ANZECC guideline and similar to that seen in many other rural waterways throughout New Zealand. Therefore DO concentrations are unlikely to be adversely affecting aquatic communities at these sites. However, minimum DO levels at the sites that are strongly affected by naturally occurring groundwater inputs are well below guideline levels and probably exclude sensitive species from these sites.

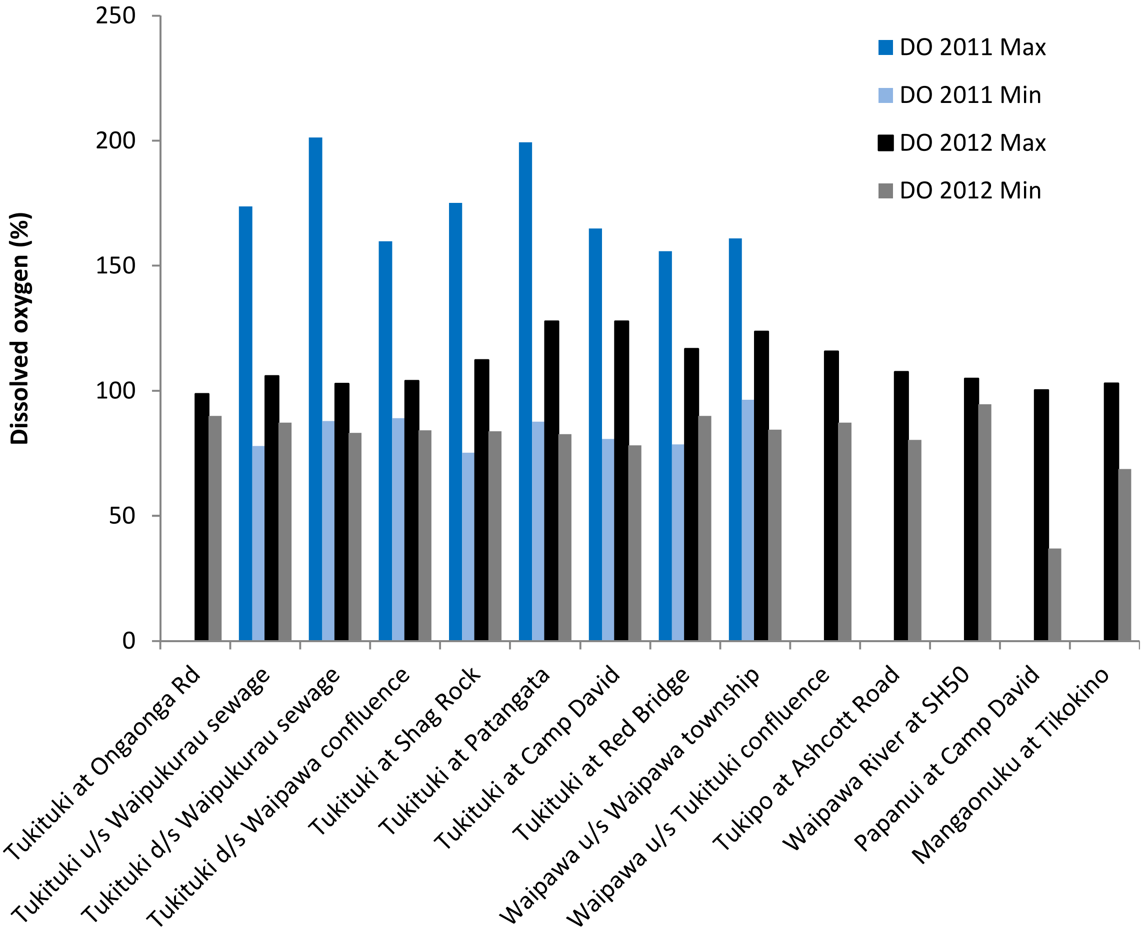

Figure 9. Observed continuous dissolved oxygen (%) concentrations recorded at 15 sites throughout the Tukituki catchment during the summers 2011 and 2012.

2.2.3.9. *Comparison between the Tukituki and Makaroro catchments and national water quality values*

A comparison between the Tukituki catchment and national figures showed that water clarity was better than, or comparable with, national median values (Ausseil 2008). Similarly, the bacteriological water quality was usually better than national median values, except in the Mangatarata Stream.

In the upper catchment (upstream of SH50), nutrient concentrations in the Tukituki and Waipawa rivers were comparable to (DIN), or better than (DRP) national median values for the upland pastoral category. Nutrient concentrations in the Makaretu

Stream were comparable with (DRP) or marginally higher than (DIN) national median values.

In the middle reaches of the Tukituki River (between SH50 and Tukituki at Shag Rock), DRP concentrations were lower than national median values at Tukituki at SH2 and Tukituki at Shag Rock sites, but higher at the Porangahau and Mangatarata sites. DIN concentrations in the middle reaches of the Tukituki River were higher than national median values at all four sites that are sampled. Nutrient concentrations in the lower Tukituki River were marginally lower (DRP) or comparable with (DIN) national figures (Ausseil 2008).

Median water quality values for the Makaroro at Burnt Bridge site were better than national medians for all parameters, including DRP (*i.e.* 0.005 mg / L compared to 0.009 mg / L), DIN (*i.e.* 0.06 mg / L, compared to 0.10 mg / L), *E. coli* (*i.e.* 13.5 cfu / 100 mL, compared to 517 cfu / 100 mL) and water clarity (*i.e.* 1.68 m compared to 1.5 m).

As such, the Tukituki River has similar water quality to many other rivers around New Zealand. The upper reaches, including the Makaroro River, have high water quality, while the middle reaches are somewhat enriched with DIN. Some tributaries such as the Porangahau and Mangatarata are also enriched with DRP. Nutrient enrichment has the potential to increase periphyton growth, which can adversely affect stream health, angling and aesthetic values.

2.2.3.10. Long-term trends in water quality

Water quality can vary widely on a seasonal basis and / or with flow. Long-term variations in water quality at Makaroro at Burnt Bridge and Tukituki at Red Bridge sites were analysed using the seasonal Kendall trend test with flow adjustment where appropriate (Smith *et al.* 1996; Ballantine & Davies-Colley 2009).

Water clarity at Makaroro at Burnt Bridge has significantly increased since 1989 ($P < 0.001$) with a positive trend of 3.03% per year. There were no ecologically meaningful trends identified for any other water quality parameters at this site.

Concentrations of DRP and total phosphorus (TP) have increased significantly at the Tukituki at Red Bridge site since 1989 (2.7 % and 1.65 % increase per year, respectively; Figure 10) because of intensification and / or changes in land use. No other ecologically meaningful trends were identified at this site, however the plot of nitrate nitrogen clearly shows the annual pattern of highest nitrate concentrations in the winter and lowest concentrations in the summer (Figure 10).

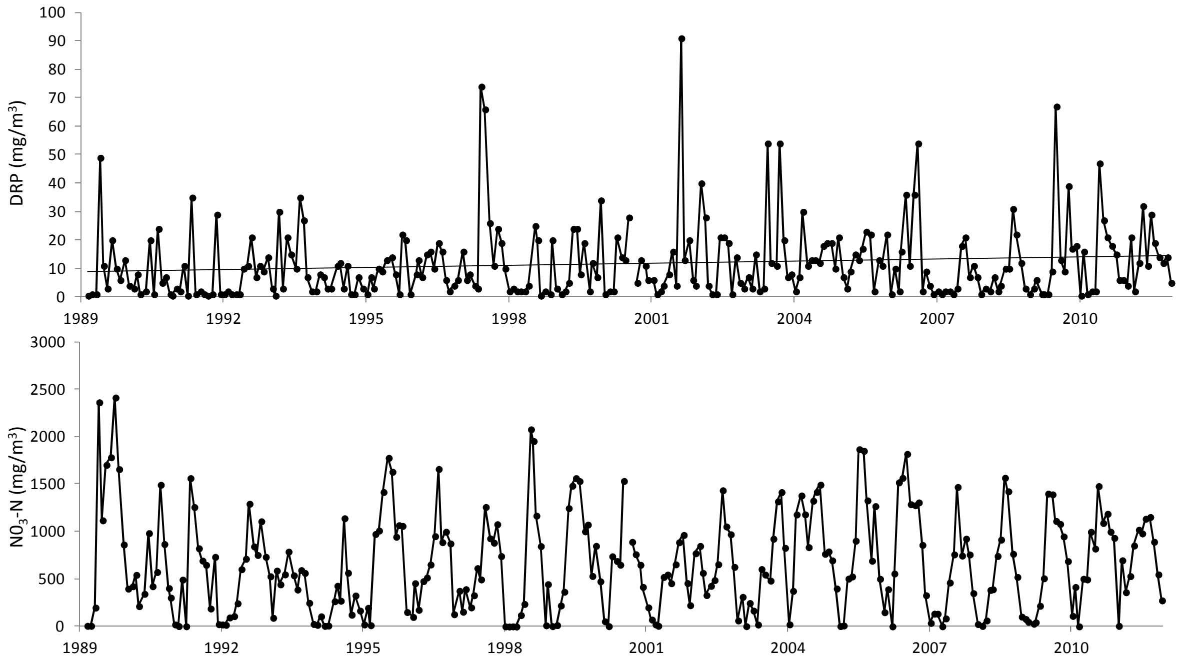

Figure 10. Concentrations of dissolved reactive phosphorus (DRP) and nitrate-nitrite nitrogen (NO_3-N) since 1989 at the Tukituki at Red Bridge site (Data from NIWA).

Using HBRC data Ausseil (2008) reported significant increases in DRP concentration at four sites in the upper catchment above SH50 (and in the Mangaonuku Stream), and also at the Tukituki at Shag Rock site. However, he also reported significant decreases in DRP concentration in the Tukituki at SH2 and Tukituki downstream of the Waipukurau sewage discharge site. DIN concentrations have significantly increased in the Tukipo River at SH50 and the Mangaonuku Stream at Tikokino (Ausseil 2008). There was also evidence of a decline in faecal bacteria concentrations in three of the upper catchment sites above SH50 (Ausseil 2008).

2.3. Biological environment

2.3.1. Periphyton

2.3.1.1. Introduction

Periphyton is a term used to refer to the algae, fungi and bacteria that are attached to the surface of rocks or other substrates (*e.g.* macrophytes, wood). In many river systems periphyton supplies the majority of the energy (food) supporting the food web. While periphyton is an essential part of a stream ecosystem, it may proliferate to nuisance levels under certain conditions and start to impact upon other instream values.

2.3.1.2. Factors controlling periphyton and macrophyte growth in rivers

Periphyton biomass at any point in time reflects the balance of two opposing processes: biomass accrual and biomass loss (Biggs 2000a). The rate of cell division controls the rate of biomass accrual, and is controlled by factors such as nutrients, light and temperature (Biggs 2000a). Meanwhile, the rate of biomass loss is governed by physical disturbance (substrate instability, water velocity and suspended solids) and grazing (by invertebrates) (Biggs 2000a).

Chlorophyll-*a* (chl-*a*), ash-free dry mass (AFDM) and % cover of the river bed are standard measures of periphyton abundance. Chlorophyll-*a* gives an indication of the total biomass of photosynthesising organisms, whereas AFDM is a measure of the total biomass present, and also includes non-photosynthesising microorganisms, as well as dead periphyton, microinvertebrates, and terrestrial organic debris (Biggs & Kilroy 2000).

2.3.1.3. Periphyton in the Tukituki River catchment

HBRC has sampled periphyton biomass quantitatively at 10 sites in the Tukituki catchment. The longest records date back to 2002. Periphyton sampling was initially conducted only once in any given year, and after a stable flow (*i.e.* two to three weeks without any major hydrological disturbance). However, since 2009 monitoring has been more intensive, with sampling conducted on a monthly basis.

As mentioned above, periphyton biomass at individual sites varies considerably over time, primarily in response to flow conditions (Figure 11). In general, and as would be expected, the periphyton biomass observed in the upper Tukituki catchment sites was lower than that recorded in the middle and lower Tukituki catchment. This concurs with the findings of Ausseil (2008) who reported a general upstream to downstream increase in periphyton biomass.

Periphyton guidelines for the protection of recreational and trout fishery values have been breached at almost all of the sites occasionally. However, breaches are more common in the middle and lower parts of the catchment (Figure 11). Breaches of the guidelines are typically associated with extended low flow periods when the combination of low shear stresses, abundant sunlight and high nutrient concentrations promotes substantial accumulations of periphyton biomass.

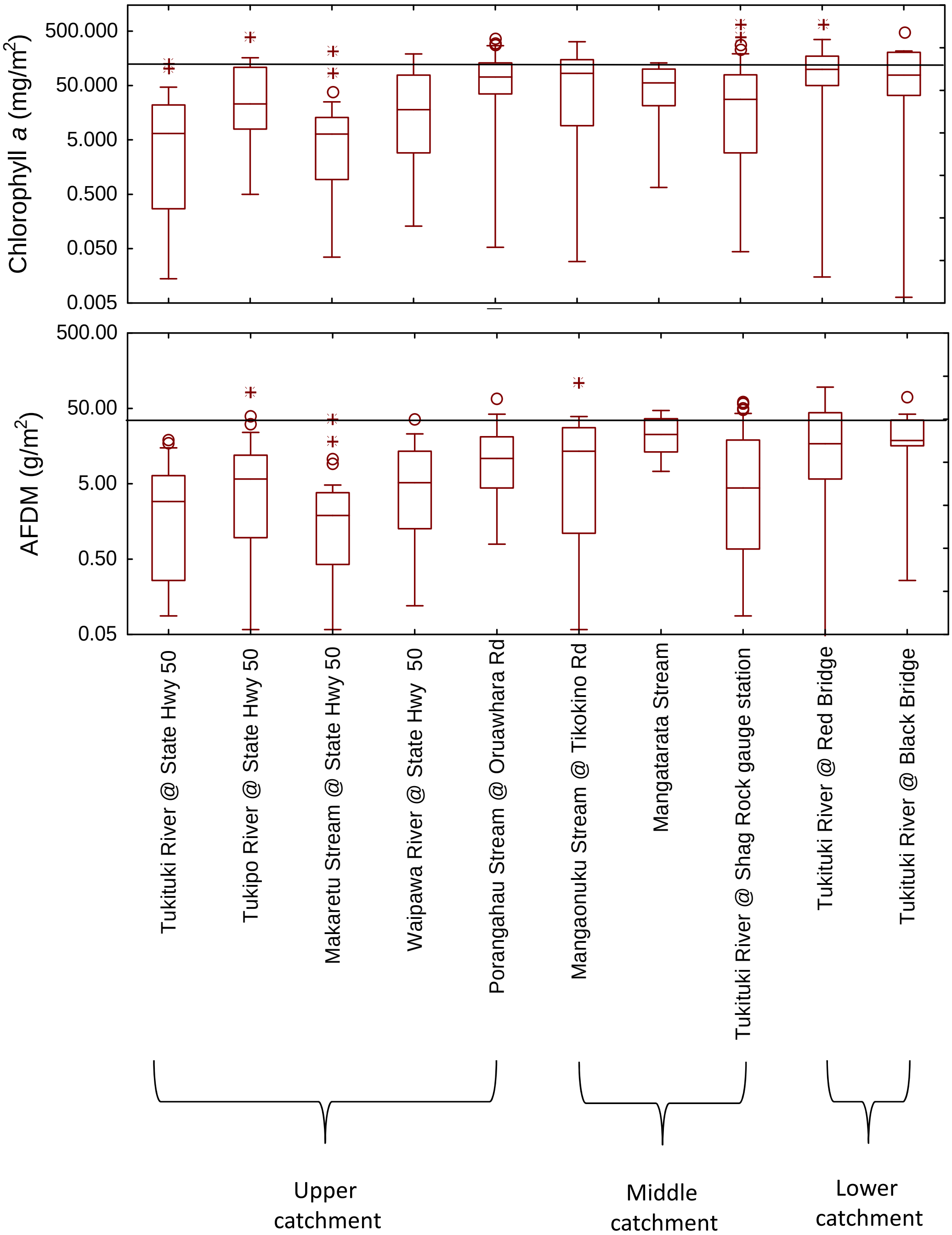

Figure 11. Periphyton biomass measured as chlorophyll-*a* (chl-a) and ash-free dry mass (AFDM) at sites throughout the Tukituki catchment. The red lines represents the periphyton guidelines for the protection of trout habitat and angling (120 mg / m^2 chl-a, 35 g / m^2 AFDM). Data provided by HBRC.

A recent collaborative research project led by NIWA included measurements of periphyton biomass at 14 sites along the Tukituki and Waipawa river mainstems during low flows in the summer of 2011 (NIWA May 2013a). Periphyton biomass was highly spatially variable. The highest biomass of periphyton observed during that survey was downstream of the Waipukurau wastewater treatment plant with chl-*a* values > 400 mg / m^2 at one site. Biomass generally decreased downstream, although periphyton was still abundant in the lower river (NIWA May 2013a).

Periphyton cover has been qualitatively measured at the Makaroro at Burnt Bridge site and the Tukituki at Red Bridge sites on a monthly basis since 1989 as part of the NRWQN. Substantial growths of periphyton are very rare at the Makaroro at Burnt Bridge site with mean and maximum coverage of 0.06 and 7.5%, respectively over the last 10 years. In contrast, periphyton coverage is generally much higher at the Tukituki at Red Bridge site with mean and maximum coverage of 14 and 98%, respectively over the same time period. However, after high flows periphyton can be absent at both sites (*i.e*. minimum cover 0%).

Overall, periphyton accumulations can reach problematic levels at most sites after prolonged periods of low flow. However, the main concerns are in the middle / lower reaches of the catchment, and in some tributaries (Porangahau and Mangaonuku) where periphyton proliferation can be relatively common and may be affecting instream health, angling and aesthetic values.

2.3.2. Macroinvertebrates

2.3.2.1. Introduction

Macroinvertebrates are animals without a backbone that can be seen with the bare eye. Aquatic macroinvertebrates, mostly worms, insects, crustaceans, molluscs and mites, live in and on the streambed. They are an essential food-web link in the transfer of energy from plant matter, fungi and bacteria to the larger animals that live in (*e.g.* invertebrate predators, fish) and around (*e.g.* insectivorous birds) the waterways. Thus, it is important to consider the effects of flow-modification and changes in water quality on macroinvertebrates as anything that affects them is likely to have consequences for other parts of the ecosystem.

Macroinvertebrates are abundant, taxonomically diverse and also exhibit a wide range of feeding behaviours and habitat requirements, which makes different species respond differently to environmental stressors. Therefore, macroinvertebrate community structure is widely used to assess water and habitat quality in streams and rivers. Stream-health indices specific to New Zealand such as the Macroinvertebrate Community Index (MCI) and its semi-quantitative (SQMCI) and quantitative (QMCI) variants are most commonly used in biomonitoring and distill macroinvertebrate community data down to a single number which is indicative of the degree of contamination present. Further indices used instream health reporting are those related to the contaminant-sensitive taxa in the EPT (mayfly, stonefly and caddis fly) insect orders include:

- percent EPT abundance (the percentage of the total number of invertebrates that belong to the EPT group)
- percent EPT taxa
- EPT taxon richness.

2.3.2.2. Available information

Three main sources of data were used in this analysis of macroinvertebrate communities in the Tukituki catchment:

- HBRC has been qualitatively sampling macroinvertebrates on an annual basis as part of their State of the Environment (SOE) monitoring programme. There are currently 11 sites in the Tukituki catchment that are monitored (Figure 12) with varying records available, the longest dating back to 1998.
- NIWA has been collecting quantitative macroinvertebrate samples on an annual basis during summer at two sites in the Tukituki River catchment (Makaroro at Burnt Bridge and Tukituki at Red Bridge) since 1990 as part of the National River Water Quality Network (NRWQN).
- In February 2012 HBRC collected quantitative macroinvertebrate samples at three sites in the Makaroro River and five sites in the Waipawa River using methods similar to that used for the NIWA sampling (Figure 12). This sampling was conducted specifically to provide information on the diversity and density of macroinvertebrates in the reaches potentially most affected by the proposed scheme.
- In January 2013 HBRC collected macroinvertebrate samples at four sites in the Papanui Stream (Figure 12) to help determine the health and values of the stream.

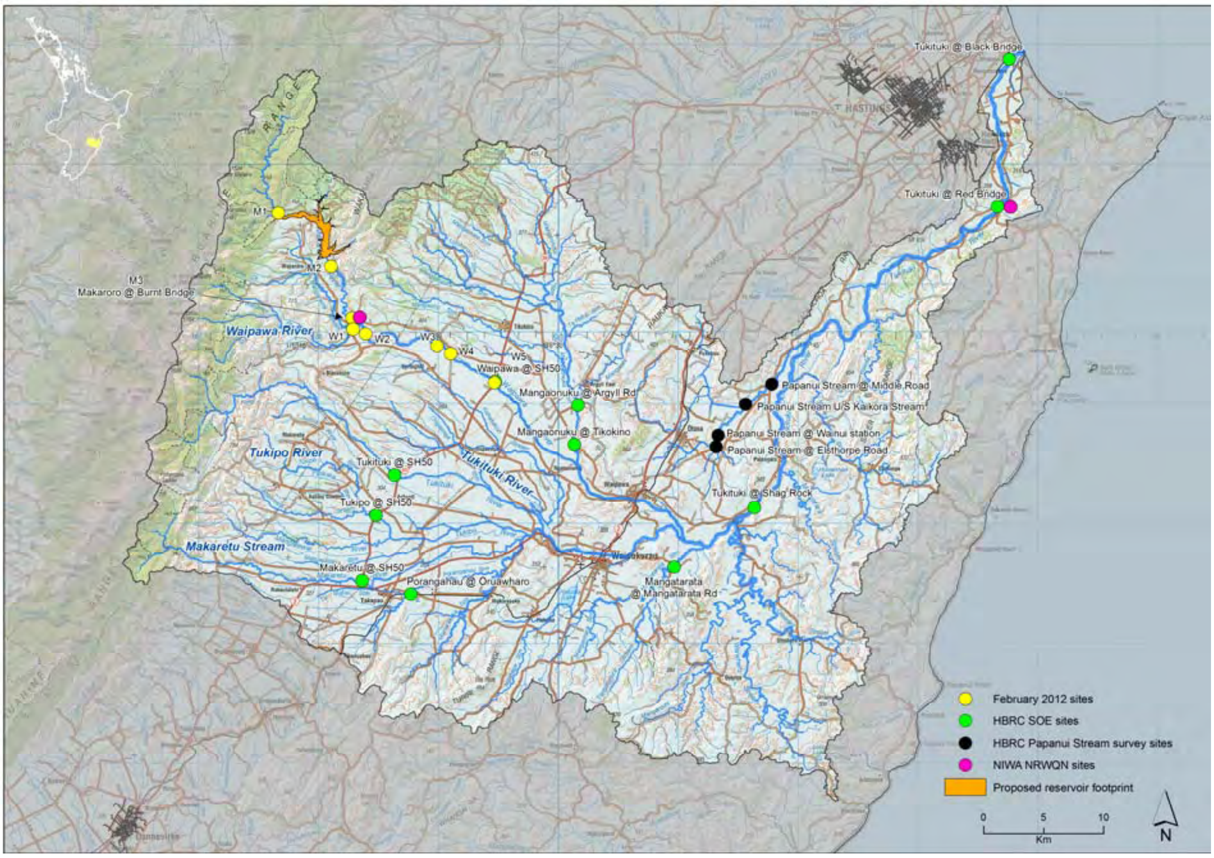

Figure 12. Location of macroinvertebrate sampling sites in the Tukituki catchment.

2.3.2.3. *Macroinvertebrate community composition*

Composition of invertebrate communities in the Tukituki catchment

Using the 20-year record of macroinvertebrate community composition from the Makaroro at Burnt Bridge and Tukituki at Red Bridge sites, the riffle beetle (Elmidae) and common mayfly (*Deleatidium*) account for 10% or greater of the invertebrate community at both sites (Table 8). Differences in community composition are evident between sites with a lower relative abundance of *Deleatidium* and higher relative abundance of the net-spinning caddis (*Aoteapsyche*) and chironomid fly larvae (Orthocladiinae and *Tanytarsus*) at the Tukituki River at Red Bridge site. These latter two taxa are often associated with higher periphyton biomass and warmer water temperatures. None of the invertebrate taxa recorded in the Tukituki catchment are listed by Hitchmough *et al.* (2007) as being threatened or in decline.

Table 8. Relative abundance (%) of the most dominant (> 10 % of the overall community composition) macroinvertebrate taxa in samples collected from the NRWQN sites Makaroro at Burnt Bridge and Tukituki at Red Bridge over a 20-year period.

Insect group	**Taxon name**	**Makaroro River at Burnt Bridge**	**Tukituki River at Red Bridge**
Mayflies	*Deleatidium*	26	10
Caddis flies	*Pycnocentrodes*	12	< 1
	Aoteapsyche	4	17
Beetles	Elmidae, larvae	27	28
True flies	Orthocladiinae	8	10
	Tanytarsini	9	12

The data collected by HBRC in February 2012 at eight sites in the vicinity of the proposed dam found an invertebrate community dominated by *Deleatidium,* mayflies (30-73% of the community) and chironomid fly larvae (3-51% of the community).

Accordingly, the Tukituki Catchment can be considered relatively typical of many New Zealand rivers with a community dominated by mayflies in the headwaters and more contaminant and temperature tolerant species in the lower reaches.

2.3.2.4. Stream health in the Tukituki catchment

MCI

Using data collected between 1998 and 2006, Ausseil (2008) reported a progressive degradation of stream health at four sites from upstream to downstream in the Tukituki mainstem. An analysis of MCI values across all eleven HBRC sites and the Makaroro at Burnt Bridge site using data collected between 2003 and 2011 show a similar pattern of degradation from the upper to lower catchment (Figure 13). It is likely that the low MCI scores at the Tukituki at Black Bridge site are the result of salt water moving up to this site during high tides (Adam Uytendaal, HBRC, pers. comm.). The Makaroro River at Burnt Bridge site had the highest mean MCI value of 121. This was the only site in the Tukituki River catchment where invertebrate communities indicated a water quality status of 'Excellent' (Figure 13).

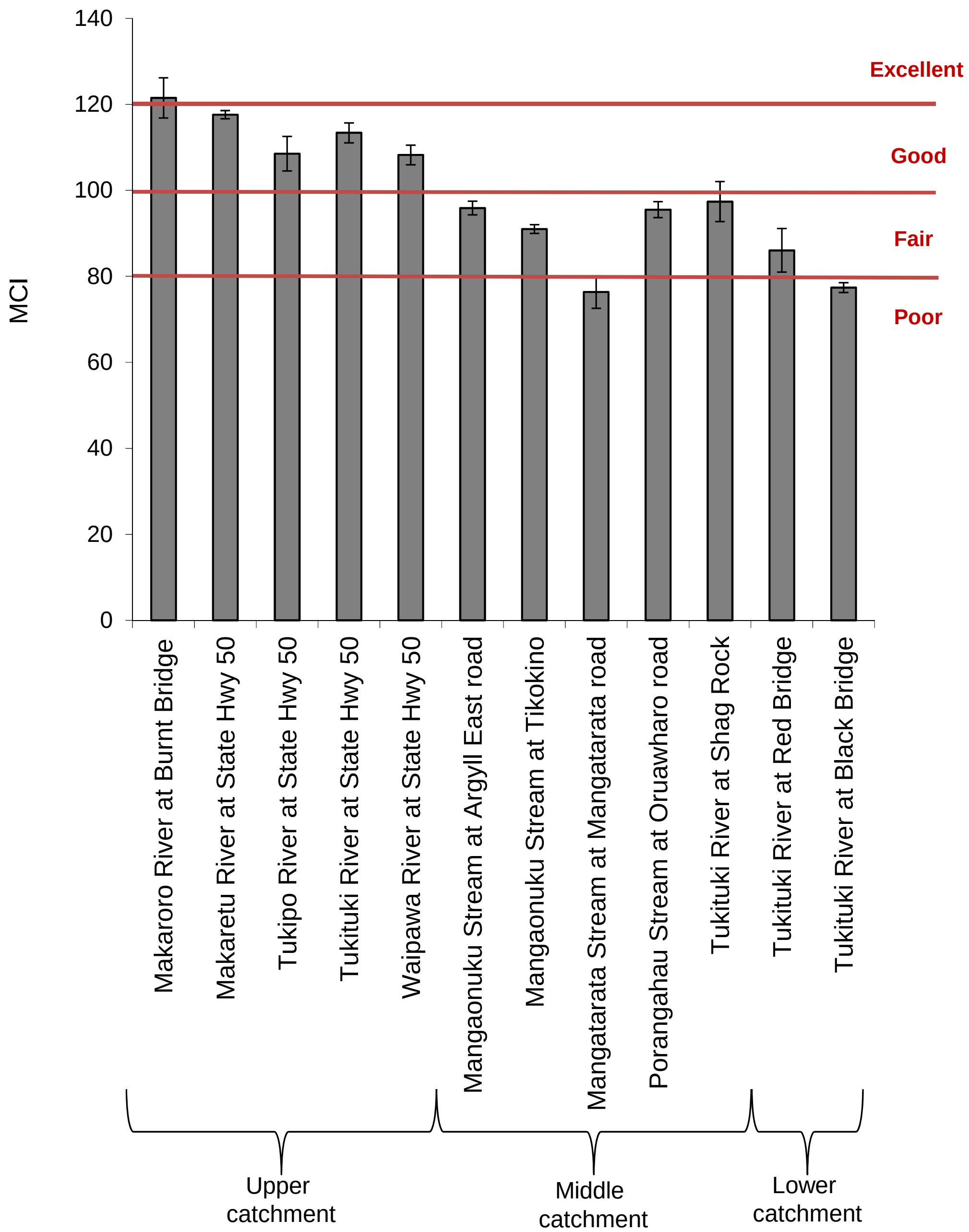

Figure 13. Mean MCI at 11 SOE monitoring sites and one site of the NRWQN (Makaroro River at Burnt Bridge) calculated from annual samples taken between 2003 and 2011. The red lines on the MCI graphs indicate water quality ranges defined by Stark & Maxted (2007). Errors bars are standard errors.

Temporal trends of the MCI were statistically analysed for nine sites of HBRC's SOE monitoring programme over the period from 1998 until 2006 by Ausseil (2008). Results showed significant decreasing trends in MCI indicating a degradation in stream health over time at most of the sites in the upper catchment (Tukituki River at SH50, Tukipo River at SH50 and Makaretu Stream at SH50) and in the middle catchment (Tukituki River at Shag Rock). The two sites in the lower catchment

(Tukituki River at Red Bridge and Tukituki River at Black Bridge) showed no significant temporal trends in MCI values (Ausseil 2008).

MCI values for the eight sites sampled by HBRC in February 2012 ranged from 92 at Sites W4 and W5 to 125 at Site M1 (Table 9). The high score at M1 is consistent with the previous high MCI scores that are typically recorded at the Makaroro at Burnt Bridge site (Figure 13). However, the MCI scores calculated from these samples were surprisingly low at the other sites. For example, W5 has had MCI scores consistently above 110 for the last three years based on HBRC SOE monitoring. There were several large floods in January 2012 and it is likely that the macroinvertebrate communities were still recovering from these floods when the February 2012 samples were collected. Therefore, the February 2012 samples should not be considered representative of the long-term average conditions at these sites.

Table 9. Metrics describing the macroinvertebrate communities at the sites in the vicinity of the proposed dam that were sampled in February 2012. For locations of each site see Figure 12.

Metric	M1	M2	M3	W1	W2	W3	W4	W5
MCI	125.3	115.6	101.4	106.7	110.0	103.1	92.0	92.0
QMCI	7.3	6.4	6.3	7.0	5.6	5.1	4.2	5.9
Number of taxa	19	18	14	21	18	13	10	10
EPT taxa	10	9	6	10	9	7	5	5
Number of individuals (/m^2)	217	324	227	797	579	241	210	530

The sites surveyed in the Papanui Stream (Lynch 2013) showed an impaired macroinvertebrate community with MCI scores below 80, indicating poor stream health and habitat quality.

EPT taxa

Total invertebrate taxon richness did not follow the gradual degradation from the upper to lower Tukituki catchment that was indicated by the MCI. However, because taxa richness does not account for changes in macroinvertebrate community composition it is not commonly used as an indicator of stressor impacts. The richness of taxa in the sensitive EPT orders on the other hand, showed a similar declining trend as the MCI (Figure 14).

EPT taxon richness for all five sites in the upper catchment ranged between 3 and 15, however the Makaroro River had four EPT taxa (*Austroperla cyrene, Megaleptoperla* spp., *Oeconesus* sp., *Pycnocentrella eruensis*) present at least once during the sampling period of 2003 to 2011 that were not found at any other sampled sites.

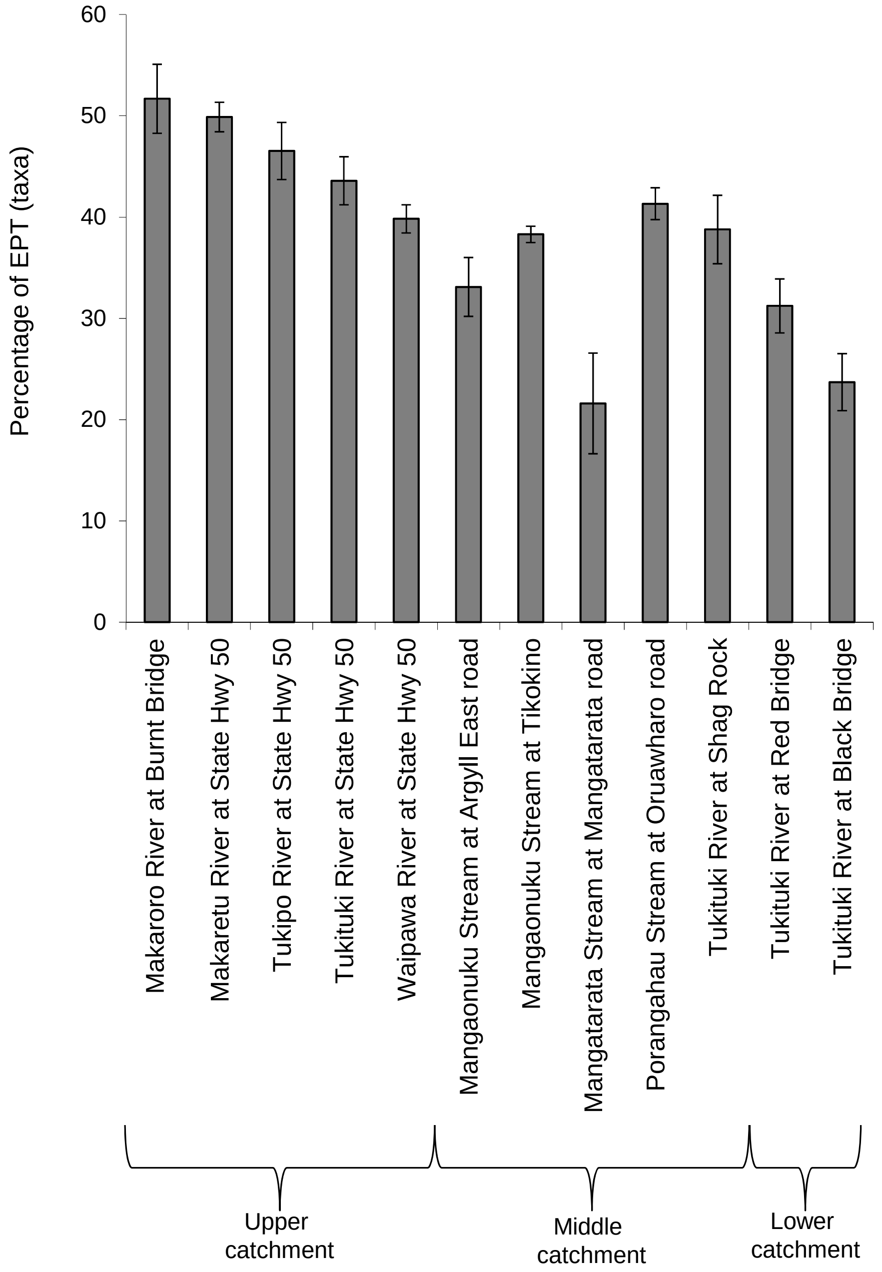

Figure 14. Mean percentage EPT taxon richness at 11 SOE monitoring sites and one site of the NRWQN (Makaroro River at Burnt Bridge) calculated from annual samples taken between 2003 and 2011. Errors bars are standard errors.

EPT taxon richness at the eight sites in the vicinity of the proposed dam that were sampled in February 2012 ranged from 43-54%, which is similar to that observed at the Makaroro at Burnt Bridge site in the past (Figure 14).

In summary, invertebrate communities indicate that stream health is high in the upper reaches of the Tukituki Catchment, but generally indicative of fair health in the middle and lower reaches of the catchment and in tributaries such as the Mangaonuku, Mangatarata and Porangahau Stream. Invertebrate communities at the site of the proposed dam are typical of mountain-fed rivers and similar to what has been sampled previously further downstream at the Makaroro at Burnt Bridge site. Invertebrate communities in the Papanui Stream are indicative of poor health.

2.3.2.5. Macroinvertebrate densities

Total invertebrate densities measured in the Makaroro River at Burnt Bridge site over the last ten years are relatively low compared with the 66 other NRWQN sites, and give it a rank of 52nd place (Figure 15). In contrast, total invertebrate densities at the Tukituki River at Red Bridge site are relatively high (9th place) out of the 66 other NRWQN sites (Figure 15). The total density of macroinvertebrates does not give a good indication of the ecological health of a site or the biomass of invertebrates that is potentially available as a food source to fish and birds because the most abundant macroinvertebrates (*e.g.* chironomid fly larvae) are often very small and relatively tolerant to contaminants. Densities are also strongly affected by antecedent hydrological conditions. The EPT taxa are generally relatively large invertebrates and are commonly found in the diet of fish. Therefore, their density gives a better indication of the potential food resource available for fish, but still doesn't give a good idea of the ecological health of a site because of the strong influence of recent flow conditions. The densities of sensitive EPT organisms at the Makaroro at Burnt Bridge and Tukituki at Red Bridge sites place them 42nd and 24th out of the 66 NRWQN sites, respectively (Figure 15). The relatively low densities in the Makaroro River at Burnt Bridge are generally consistent with that expected in a river system that experiences frequent flushing and bed movement. For example, note the similar EPT densities between the Makaroro at Burnt Bridge and nearby headwater sites such as the Mohaka at Glenfalls, Ngaruroro at Kuripapango (and Chesterhope), Rangitaiki at Murupara, and Rangitikei at Mangaweka (Figure 15).

The density of macroinvertebrates at the eight sites in the vicinity of the proposed dam that were sampled in February 2012 ranged from 210-797 individuals per m^2. These densities are very low compared with that measured at NRWQN sites throughout the country and with the densities generally recorded at the Makaroro at Burnt Bridge site (Figure 15). In fact the lowest density previously recorded at the Makaroro at Burnt Bridge site was 511 / m^2 compared with 212 / m^2 at the same site in February 2012. As mentioned, the macroinvertebrate community at these sites was apparently still recovering from the flooding in January 2012 and these densities should not be considered representative of the long-term average density at these sites.

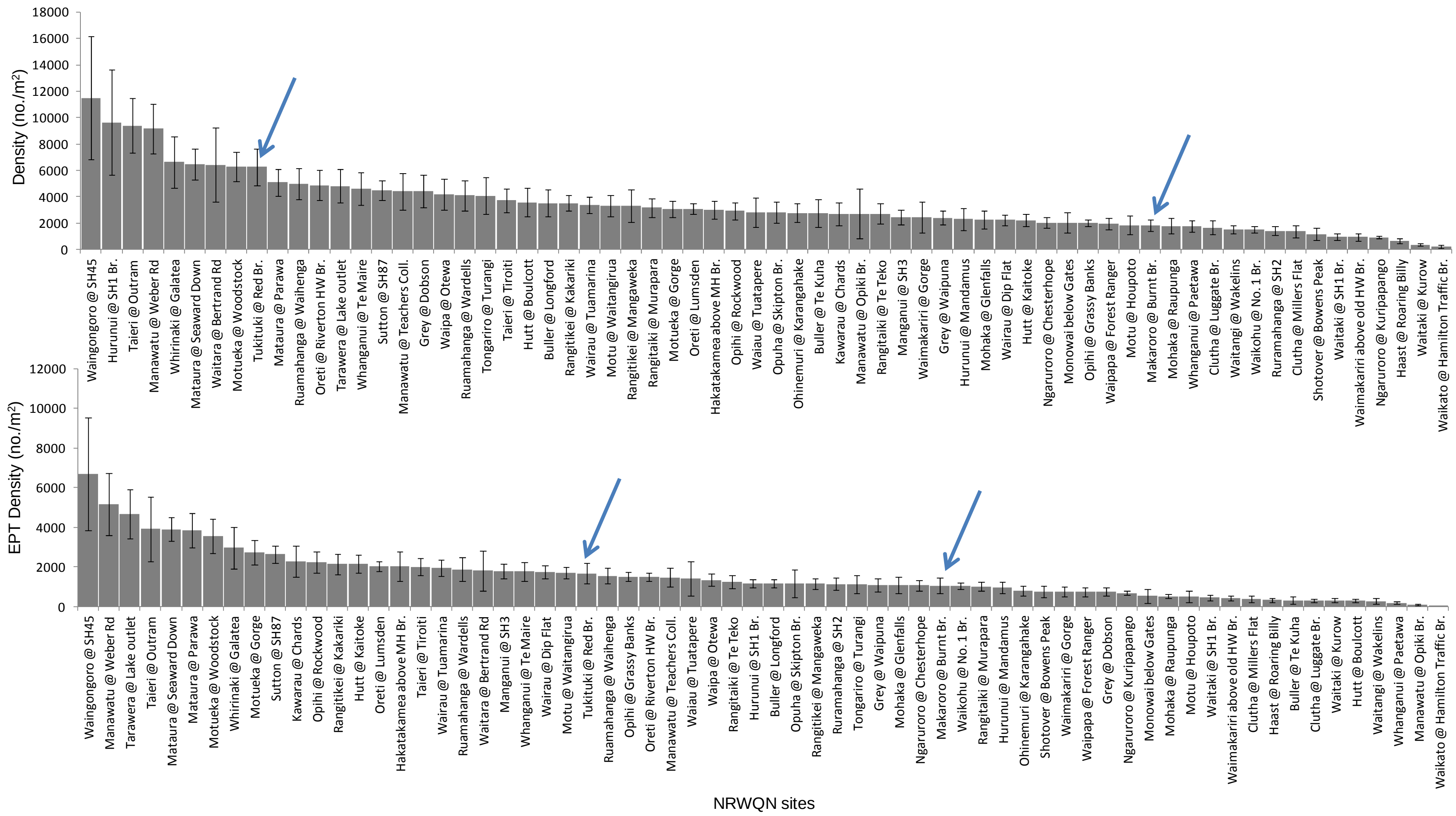

Figure 15. Mean total density and EPT (mayfly, stonefly and caddisfly) density for the 66 NRWQN sites using the latest 10 years of data (2001-2010). Arrows indicate the Tukituki River at Red Bridge and Makaroro River at Burnt Bridge sites. Data supplied by NIWA.

2.3.3. Native fish

2.3.3.1. Introduction

New Zealand has a reasonably small freshwater native fish fauna (comprising only 38 species). This is partly due to the country's geographical isolation from other land masses, but also due to its geological history with periods of extensive marine submergence, ice ages and glaciations, mountain building and intensive volcanic activity (McDowall 2010).

Of the 38 native species, 18 are diadromous (*i.e.* they migrate between the sea and freshwater to complete their life cycle) which means access to and from the sea is generally a prerequisite for these fish species to complete their life cycle. However, five of these species can form landlocked populations where sea migration is abandoned and the usually marine life stages occur in lakes. The other 20 native freshwater fish species are non-migratory, which means they do not undertake any migrations between the sea and freshwater (McDowall 2000). However, non-migratory species may travel reasonable distances within freshwater systems, for instance between lakes and / or different rivers (Rowe & Chisnall 1997; Baker *et al.* 2003).

2.3.3.2. Available information

The distribution of native freshwater fish in the Tukituki catchment was reviewed using three methods:

- Presence / absence data was obtained from the New Zealand Freshwater Fish Database (NZFFD; National Institute of Water & Atmospheric Research (NIWA)). Data was derived for the Tukituki catchment (Catchment number 232.000) between 1965 and 2009 and included all sampling methods and locations, except lakes, ponds and wetlands.
- Distributions were predicted using a spatial database based on Leathwick *et al.* (2008). The model is built around the river network developed originally as the River Environment Classification (REC; Snelder *et al.* 2004) and predicts the probability of presence of each species for all NZ rivers and streams.
- Field sampling in the form of electric fishing was conducted between 25 -27 October 2011 (Makaroro and Waipawa rivers) and on 4 November 2011 (Dutch Creek and immediately downstream of the confluence of Dutch Creek and Makaroro River). During sampling, up to three reaches were fished with a single pass until a minimum of 150 m river length had been fished. Habitat type (*i.e.* pool, riffle, run) and stream width were recorded to enable fish abundance calculations per site. Time taken to sample a site ranged from 1.0 to 2.5 hours.

2.3.3.3. Native fish distribution

Fish distribution was recorded according to which area of the catchment fish species were found, *i.e.* either the entire Tukituki catchment; the Waipawa River upstream of Tukituki confluence or the Makaroro River upstream of Waipawa confluence.

2.3.3.4. Native fish distribution in the entire Tukituki River catchment

There were 478 records entered into the NZFFD between 1965 and 2011 for the wider Tukituki River catchment with particularly high sampling records for 1984 (62 records), 1988 (69 records), 2004 (66 records), 2005 (137 records) and 2006 (43 records).

In total, there were 21 fish species recorded in the Tukituki River catchment, including three estuarine fish species (*i.e.* grey mullet (*Mugil cephalus*), black flounder (*Rhombosolea retiaria*) and yelloweye mullet (*Aldrichetta forsteri*)), three introduced species (*i.e.* goldfish (*Carassius auratus*), brown trout (*Salmo trutta*) and rainbow trout (*Onchorhynchus mykiss*)) and the crustacean koura (*i.e. Paranephrops planifrons*; Table 10). Longfin eel (*Anguilla dieffenbachii*), dwarf galaxias (*Galaxias divergens*) and torrentfish (*Cheimarrichthys fosteri)* were the most recorded native fish species and yelloweye mullet, koaro (*Galaxias brevipinnis*) and lamprey (*Geotria australis*) the least recorded native fish species in the Tukituki catchment (Table 10).

Longfin eel (Appendix 1) and shortfin eel (Appendix 2) were evenly distributed throughout the entire catchment; with longfin eel being more common than shortfin eel.

Inanga and koaro are both migratory galaxiids and members of the 'whitebait' species. Inanga have been recorded at seven sites in the catchment, and even above the Tukipo confluence (Appendix 3). Koaro have only been recorded at two locations in the catchment, although they are predicted to occur in the small headwater streams draining the Ruahine Ranges (Appendix 4). Torrentfish (Appendix 5) was widespread but with relatively few records from the lower part of the catchment.

Bully species were evenly distributed throughout the catchment (Appendices 6-11). Cran's bully (Appendix 6) was the most widespread and commonly recorded, whereas giant bully was the least recorded bully species with only two records entered into the NZFFD, both for the lower Tukituki River (*i.e.* below the Waipawa and Tukituki River confluence; Appendix 7).

There have only been two sightings of lamprey; both in the lower parts of the Tukituki catchment (Appendix 12).

There have been two records entered into the NZFFD for black flounder (Appendix 13), both in the lower part of the catchment, but black flounder have been observed in the Tukituki River just upstream of the Waipawa confluence and in the Kahahakuri Stream (pers. observation, Roger Young, Cawthron Institute).

Common smelt, a species usually found in lowland parts of rivers, was widely distributed throughout the catchment (Appendix 14).

The diversity of native fish found in the Tukituki Catchment is relatively high, but similar to other catchments draining to the east coast of the North Island. Eight of the 18 native fish species found in the catchment are considered to be ‘declining’ according to the latest national threat classification (Allibone *et al.* 2012).

Table 10. Fish species recorded in the Tukituki catchment between 1965 and 2011 and their national threat classification (Allibone *et al.* 2010). Data were derived from the New Zealand Freshwater Fish Database (NIWA) and from 2011 field sampling by Cawthron. *= these species are often found in brackish and estuarine habitats. u / s = upstream.

				Number of entries in NZFFD		
Common name	Scientific name	**Threat classification**	**Migratory**	**Tukituki catchment**	**u / s Waipawa / Tukituki confluence**	**Makaroro catchment**
Longfin eel	*Anguilla dieffenbachii*	Declining	Y	83	40	19
Rainbow trout	*Onchorhynchus mykiss*	Introduced and naturalised	Y	66	31	25
Dwarf Galaxias	*Galaxias divergens*	Declining	N	62	37	24
Torrentfish	*Cheimarrichthys fosteri*	Declining	Y	59	35	22
Common smelt	*Retropinna retropinna*	Not threatened	Y	36	11	5
Cran's bully	*Gobiomorphus basalis*	Not threatened	N	31	15	4
Common bully	*Gobiomorphus cotidianus*	Not threatened	Y	26	5	2
Shortfin eel	*Anguilla australis*	Not threatened	Y	22	9	3
Inanga	*Galaxias maculatus*	Declining	Y	14	-	-
Bluegill bully	*Gobiomorphus hubbsi*	Declining	Y	10	4	3
Brown trout	*Salmo trutta*	Introduced and naturalised	Y	8	7	1
Redfin bully	*Gobiomorphus huttoni*	Declining	Y	6	2	2
Goldfish	*Carassius auratus*	Introduced and naturalised	N	5	-	-
Upland bully	*Gobiomorphus breviceps*	Not threatened	N	4	2	-
Koaro	*Galaxias brevipinnis*	Declining	Y	2	2	-
Yelloweye mullet	*Aldrichetta forsteri*	Not threatened	Y*	2	-	-
Lamprey	*Geotria australis*	Declining	Y	2	-	-
Giant bully	*Gobiomorphus gobioides*	Not threatened	Y	2	-	-
Grey mullet	*Mugil cephalus*	Not threatened	Y*	2	-	-
Black flounder	*Rhombosolea retiaria*	Not threatened	Y*	2	-	-
Koura	*Paranephrops planifrons*	Not threatened	N	41	18	4
Total number of species recorded (incl. koura)				**21**	**14**	**12**

2.3.3.5. Fish distribution in the Waipawa River upstream of the Tukituki confluence

There are 266 freshwater fish records upstream of the confluence of the Waipawa and Tukituki rivers. The streams surveyed included Dutch Creek, Gold Creek, Kahahakuri Stream, Liddles Creek, Makaroro River, Mangamate Stream, Mangamauku Stream, Mangataura Stream, Ongaonga Stream, Triplex Stream, Upokororo Stream and Waipawa River.

The three most recorded fish species in the Waipawa River were longfin eel, which were also found in relatively high densities (Table 11), dwarf galaxias and torrentfish and the least recorded were upland bully (*Gobiomorphus breviceps*), redfin bully (*Gobiomorphus huttoni*) and koaro (Table 10). Although common bully was not found very commonly, they had densities up to 3.3 fish / 100 m^2 at the Makaroro River at Burnt Bridge site (Table 11).

Table 11. Maximum fish densities (per 100 m^2) recorded for the 2011 field sampling in the Waipawa and Makaroro rivers.

Species	**Max density per 100 m^2**	**Site**
Dwarf galaxias	51.4	Makaroro u / s ford, side braid
Rainbow trout	28.0	Makaroro u / s of Gorge, mainstem
Longfin eel	16.5	Waipawa d / s bridge small side arm
Brown trout (juveniles and adults)	5.6	Makaroro u / s ford, side braid
Torrentfish	4.0	Makaroro u / s of Gorge, mainstem
Common bully	3.3	Makaroro u / s Burnt Bridge
Cran's bully	2.4	Dutch Creek
Bluegill bully	1.2	Dutch Creek

Note: u / s = upstream, d / s = downstream.

2.3.3.6. Fish distribution in the Makaroro River upstream of Waipawa confluence

Although field sampling in October 2011 found no new fish species in the Makaroro catchment that hadn't been recorded before, it enabled population densities to be calculated for some fish species in this area (Table 11).

In total, there were 113 records of freshwater fish species between 1965 and 2011 for the Makaroro River upstream of the Waipawa confluence with redfin bully as the least recorded, and torrentfish and dwarf galaxias as the two most recorded native fish species (Table 10).

Although fish were generally widely spread throughout the Makaroro River, dwarf galaxias numbers reached densities up to 51.4 fish per 100 m^2 (Table 11). This species, which is usually solitary and cryptic, was found in shallow side-braids of the

Makaroro River 2 km upstream of the ford near the top of the proposed reservoir (Figure 16). However, they also form higher density populations in discrete areas of suitable habitat such as found in the Makaroro catchment. These findings concur with distribution predictions which indicate a medium to high probability of occurrence for this species in the proposed dam footprint area.

Figure 16. Dwarf galaxias habitat in the upper Makaroro River. Photo: Cawthron Institute

Longfin eel were commonly found in the Makaroro catchment and at the proposed dam site (Appendix 1). The 2011 field sampling found a very large, presumably female, longfin eel (1500 mm) immediately downstream of the proposed dam site. This indicates that there is suitable habitat for this ‘declining’ species in the vicinity of the dam.

In general, bully species had relatively low densities (Table 11) at the proposed dam site. Bluegill and redfin bully are listed as ‘declining’ (Table 10) and although predictions indicated a low probability of occurrence in the vicinity of the proposed dam footprint area, both species were found in Dutch Creek and downstream of the Dutch Creek-Makaroro River confluence (Appendix 8 and Appendix 9, respectively), both areas that would be inundated by the proposed dam. Similarly, Cran’s bully was found downstream of the Dutch Creek-Makaroro River confluence, despite predictions suggesting a low likelihood of occurrence at this site (Appendix 6).

Although common smelt has not been found at the proposed dam site itself, it has been recorded upstream of it and in Mangataura Stream (Appendix 14). Both these areas show low predicted probabilities of occurrence as this species is usually found close to the coast in estuarine environments. Common smelt was not found during the 2011 field sampling.

2.3.4. Trout

2.3.4.1. Distribution and abundance of trout in the Tukituki catchment

Both brown and rainbow trout occur in the Tukituki catchment. Rainbow trout are the dominant species and are widespread throughout the river system (Richardson *et al*. 1984; Appendix 16). Little information exists on the migration patterns of trout in the Tukituki and there are no reliable trout abundance or density estimates because the river is too turbid to effectively drift dive (the standard method used to assess adult trout numbers and distribution) (Hawke's Bay Fish & Game undated). Anecdotally, it is thought that the bulk of the adult rainbow trout population is highly mobile (Maclean 2011). Parts of the mid and lower reaches of the Tukituki and Waipawa can become very low and warm or cease surface flow during mid to late summer. These conditions are currently associated with nuisance algal growths in the river (Ausseil 2008). The warm temperatures and excessive algal growths are likely to temporarily reduce the quality of the trout habitat in these reaches. It is perceived that large numbers of trout move from the low water reaches to the upper catchment and / or lowland tributaries until higher and more variable flows resume in autumn (Hawke's Bay Fish & Game, undated).

Most of the mainstem river and headwater tributaries of the Tukituki catchment are thought to provide suitable spawning habitat (Hawke's Bay Fish & Game undated). Rainbow trout spawning effort may occur extensively throughout the catchment tending to be most prevalent in the headwater streams. After juvenile rainbow trout emerge during spring the majority of juvenile trout are thought to migrate downstream before their second summer to the lower river where they grow to spawning age. Hawke's Bay Fish & Game (undated) has suggested that large areas of potentially suitable spawning habitat in the Tukituki catchment are not used because of an overabundance of potential spawning habitat. However, trout are known to spawn in the upper Makaroro (Maclean 2011) and a recent juvenile rainbow trout survey indicated that the Makaroro River may be an important spawning stream relative to other streams draining hill and lowland areas of the Tukituki catchment (Maclean 2012).

Brown trout are reported to be largely confined to the mid reaches of the Tukituki and Waipawa rivers and are also associated with various tributaries, such as the Mangaonuku Stream (Richardson *et al*. 1984; Appendix 15). They are known to focus spawning effort in the lowland spring creek tributaries (Richardson *et al.* 1984, Maclean 2011).

2.3.4.2. Angling value of the Tukituki River catchment

During the most recent National Angler Survey (NAS: 2007-2008 angling season) the Tukituki River was rated the most popular river in the Hawke's Bay with an estimated 11920 angler days occurring throughout the Tukituki catchment. Within the Hawke's Bay Fish & Game region, 33% of the total estimated angling effort occurred in the Tukituki catchment, making it the region's most heavily fished catchment (Unwin 2009). In addition, a significant proportion of anglers fishing the river are overseas visitors (Unwin 2009). The Tukituki River has been considered as a potentially nationally significant fishery (Deans 2004), although on a national scale, it is estimated to be the 29th most popular fishery out of 848 river and lake fisheries (excluding the Taupo area) included in the most recent NAS (Unwin 2009).

An analysis of angler questionnaires by Richardson *et al.* (1984) suggested that virtually all fishing occurs in the middle and lower reaches. The more recent NAS results confirm that the mid and lower reaches (below the Waipawa confluence) remain the most popular fishing areas in the catchment, attracting 57% of the fishing effort (Unwin 2009). The Waipawa is the largest tributary of the Tukituki River and is a reasonably popular fishery in its own right attracting an estimated 1,286 angler days which corresponds to 11% of the total effort expended in the Tukituki catchment (Unwin 2009).

The Tukituki River also contains a number of lesser hill-draining and lowland spring-fed tributaries which also provide angling opportunities. However, lower angler patronage of these tributaries suggests that they are less important angling destinations than the Tukituki and Waipawa mainstems. When combined, the lesser tributaries attracted a total of 4% of the angling effort in the catchment. On each of the three occasions that the NAS has been conducted the Mangaonuku Stream (a Waipawa tributary) was the most popular lesser-tributary stream in the Tukituki catchment (Unwin 2009).

In general, small tributary rivers are fished early season (October to the end of November) and target aggregations of fish after they have spawned. Some angling effort in these tributaries is also spent late in the season (March to the end of April) and targeting up-stream migrating fish prior to spawning.

Lowland mainstem rivers (like the Tukituki River) can warm to the point where trout feeding rates, and thus angling opportunity, is reduced (See Section 2.2.3). Tributary streams, especially those that are spring-fed or tree-lined, can provide trout with cooler summer temperatures allowing good fishing opportunities during mid to late summer (Hayes & Hill 2005).

2.3.4.3. Angling value of the Makaroro River catchment

The Makaroro River is a significant tributary of the Waipawa River (which in turn is the major tributary of the Tukituki River). Richardson *et al.* (1984) suggests that the Makaroro River is not highly rated as an angling destination relative to the other fisheries in Hawke's Bay because of difficult access and its small size. Maxwell (2010) suggests that "…the Makaroro, although not highly rated as an angling destination, is more stable than the Waipawa and may provide good angling during the later summer months when the Waipawa and Tukituki are suffering from low flows and weed problems". The most recent NAS reports no respondents fishing the Makaroro River (Unwin 2009). However, it must be noted the NAS survey does not purport to accurately estimate angler usage of low ranked rivers (*e.g.* less than 200 angler days per year).

Hawke's Bay Fish & Game supplied the contact details for a local fishing guide and a recreational angler, who both regularly fish the Makaroro River. These anglers supplied the contact details of another local angler who also fishes the river on a regular basis. The three anglers were asked a list of questions about the nature and quality of the Makaroro River fishery (Appendix 18). A very consistent picture of the fishery emerged from interviewing the three anglers.

The summary of responses to the angler questionnaire confirm that this river offers early season fishing (October-November) for post-spawned rainbow trout; with late season angling opportunities in the lower and mid-reaches during April for upstream migrating fish before they spawn. The upper reach above Gold Creek (and above the proposed dam footprint) is the most favoured fishing area. Dutch Creek (an upper Makaroro River tributary) can also provide good fishing in the first week(s) of the season. During spring, fly-anglers sight fish for post-spawned rainbow trout in the 0.75-1.5 kg range using artificial nymphs. Fish are generally in poor to average condition because they are still recovering from spawning. The abundance and the distribution of fish can be highly variable from year to year depending on the timing and magnitude of spring floods. After spawning, medium to large spring floods are perceived to cause the fish to drop out of the Makaroro River to the Waipawa and / or Tukituki rivers. The best fishing usually occurs in the first two weeks of October but in some years good fishing can continue through until the end of November. Catch rates vary from poor to exceptional depending on the strength and timing of the spawning run. During early to mid-summer low numbers of resident fish in the upper Makaroro River (upstream of Gold Creek) can be targeted using large dry flies. After November the rest of the river holds very low numbers of fish and is generally not worth fishing until late season (April) when the upstream spawning migration of rainbow trout repopulates the river.

Very few people fish the river which is one of the attractions of the fishery. Two of the anglers considered the fishery was of average quality when compared to other Hawke's Bay fisheries. However, one angler considered that the river was an exceptional fishery and relatively unique due to its small stream nature, low angler encounter rate, high scenic values, easy access and (sporadically) high catch rates. He suggested that there are few rivers in the region that have all of these attributes. The disparity between different people's opinion of the fishery may be based on the weight that individuals place on scenic value as a component of a fishery's value. All respondents agreed that the scenic value of the river in the gorged sections in the mid and upper reach is exceptional and that catch rates, fish size / condition and other attributes were about average. The anglers' opinions of the proposed scheme ranged from strongly against through to strongly in favour.

During an appraisal of the river (Robin Holmes, pers. observation, October 2011), good adult trout habitat occurs where the river is constrained by a gorge in the middle reach. However, there is no public access to this section and only a few access points via private land down the steep sided gorge to the river bed (although once on the river it is easily wadeable). Therefore, although there may be relatively good trout angling in the middle reach the difficult access means this section of river would receive limited use by anglers. At present the middle reach of the Makaroro River is likely to be an under-utilised angling resource.

The lower Makaroro River is accessible at a Makaroro Road bridge. Fishing up and downstream of this point may provide average fishing (at certain times of the year) relative to other Hawke's Bay rivers. The upper reach of river is accessible at the Makaroro River ford, from here 4WD and tramping tracks continue up to the headwaters of the river. The river from the ford to the upper extent of the proposed dam area is braided, unstable and shallow and provides little adult trout habitat (Robin Holmes, pers. observation, October 2011). Upstream of Gold Creek, where the river is constrained by a narrow steep valley, deep water habitat (*e.g.* > 1 m) is more common (Maclean 2011). This is why anglers targeting the upper river will prefer to fish in this area as deep water is a key component of adult trout holding habitat. The upper reaches of the Makaroro River in the Ruahine Forest Park is a Department of Conservation (DOC) recreational area and a popular hunting destination. It is likely that incidental angling occurs by people who combining fishing with tramping and hunting in the area.

2.4. Summary

The Tukituki River catchment is the third largest catchment in the Hawkes Bay region and drains from the Ruahine Ranges to the Pacific Ocean. Land use in most of the catchment has been modified and developed for agriculture, horticulture and forestry.

Like many other large catchments in New Zealand, water quality is excellent in the upper reaches and generally declines downstream. During low flows, most sites meet guidelines for contact recreation, although there are concerns in some tributaries (*e.g.*

Mangatarata). The mid-reaches of the river are somewhat enriched with dissolved organic nitrogen, and there are some tributaries with relatively high concentrations of dissolved reactive phosphorus (*e.g.* Mangatarata, Porangahau, Papanui). Ratios of nitrogen to phosphorus in the water indicate that algal growth at most sites in the middle and lower reaches of the Tukituki mainstem is likely to be limited by phosphorus concentrations, rather than nitrogen. Nutrient diffusing substrate assays generally supported these assessments with phosphorus limitation occurring frequently in the middle and lower reaches of the Tukituki, co-limitation only found in the upper catchment above SH50, and N limitation only occurring in the upper Tukipo River (and perhaps Papanui Stream). This suggests that increases in phosphorus concentration in the middle and lower reaches of the Tukituki will result in faster algal growth and more algal biomass on the riverbed, whereas increases in nitrogen concentration are not likely to result in such a response. Like many other large unshaded lowland rivers, water temperatures in the lower Tukituki River can be warm enough in summer to stress sensitive aquatic life. Minimum DO levels in some tributaries are strongly affected by naturally occurring groundwater inputs and are well below guideline levels, probably excluding sensitive species from these sites. Over the last 20 years there has been a significant increase in the concentration of phosphorus in the lower reaches of the river.

Periphyton guidelines for the protection of recreational and trout fishery values have been breached at almost all sampling sites occasionally. However, periphyton proliferations are more common in the middle and lower reaches of the catchment, and in some tributaries (*e.g.* Porangahau and Mangaonuku).

Invertebrate communities within the river indicate that health in the upper reaches is excellent, while the middle and lower reaches are generally considered to be in fair health. The Mangatarata and Papanui streams are considered to be in poor health.

The Tukituki Catchment supports a relatively diverse range of native fish. Eight of the 18 native fish species found in the catchment are considered to be ‘declining’ according to the latest national threat classification (Allibone *et al.* 2012).

Both brown and rainbow trout occur in the Tukituki catchment, but rainbow trout are the dominant species and are widespread throughout the river system. During the most recent National Angler Survey the Tukituki River was rated the most popular angling river in the Hawke’s Bay region and arguably could be considered a national significant fishery. A significant proportion of anglers fishing the river are from overseas. The majority of angling takes place in the middle and lower reaches of the catchment, although a small number of anglers target trout in some of the tributaries (*e.g.* Mangaonuku, Makaroro) before or after spawning.

3. ASSESSMENT OF AQUATIC ECOLOGICAL EFFECTS

3.1. Introduction

The assessment of aquatic ecological effects has been focused on the specific features / activities associated with the development and operation of the proposed Ruataniwha Water Storage Scheme (the Scheme). Some of the potential effects will occur over a short period (*e.g.* effects of construction), while other effects (*e.g.* effects of changes to the flow regime) will be ongoing for the duration of the Scheme's operation.

Some of the effects mentioned in this section will be addressed using measures that are already incorporated into the scheme design (*e.g.* the proposed residual flow, fish screens, flushing flows — refer to Section 1.2.2 of this Report — will ensure that the effects of flow change, water abstraction and periphyton growth associated with the scheme will be minimized as much as possible). However, our analysis includes assessments of effects with and without these avoidance and remediation measures. More details on these and additional recommended mitigation are provided in Section 4.

3.2. Assessment of effects of construction

3.2.1. Introduction

Large volumes of rock and alluvial materials totalling in excess of approximately 2.1 million cubic metres will be cut and placed to construct the dam. Details on construction procedures are explained in the Project Description (Tonkin & Taylor May 2013a).

Dam construction procedures include two main physical areas that will require different management practices during construction: 1) within the river or its tributaries and 2) on the river terraces. Both activities will potentially have effects on the downstream aquatic environment; however, activities within the river are expected to have the greatest direct ecological impacts. The most significant ecological effects are those resulting from increased suspended sediments due to river bed disturbance.

Specific activities within the river as outlined in Tonkin & Taylor (May 2013a) include: the construction of coffer dams and diversion of the river through a tunnel, construction of the main dam embankment, grouting of the foundation under the main dam embankment, spillway outlet works and loosening of river gravels from the reach that will be used as filters and concrete aggregate. Apart from these major, short-term disturbances in the river bed, smaller disturbances such as consistent vehicle stream crossings will mobilise sediment, especially with contractors working seven days per week, 24 hours per day (Tonkin & Taylor May 2013a).

3.2.2. Effects on the physical environment

While there are not likely to be major changes to the overall river morphology caused during the construction phase, movement of excavated material will potentially cause changes in the physical environment of the Makaroro River immediately downstream of the construction site (Reach 3).

Along with reduced flow during construction, these changes include the deposition of generally coarser sediment (*e.g.* gravel) at the immediate downstream site, and the deposition of fine sediments further downstream. The terms fine sediment and sedimentation describe sediments less than 2 mm in size, thus encompassing sand (< 2000 to > 62 µm), silt (< 62 to > 4 µm) and clay (< 4 µm). In low energy environments such as reservoirs or backwaters, this can create fine sediment banks along the river bank and changing river morphology in the downstream reaches. Fine sediment deposition on the river bed will cause short-term loss of interstitial space, changing the river bed's porosity and composition. However, fine suspendable material will be moved through the reach with the next flood or will be widely dispersed, so that changes are unlikely to be detectable downstream of the dam following flooding (Doeg & Koehn 1994; Collier 2002). In contrast, gravel can become wedged in the interstices of larger substrate elements, and levels can remain high for an extended period after flushing at more flow protected sites (Collier 2002).

Suspended sediment peaks will decline rapidly when the streambed is not disturbed, although some residual increases due to scour of the trench, erosion of exposed surfaces, and the resuspension of fine material settled in slow velocity areas (*i.e.* pools, behind boulders or instream debris) may occur.

If the working site is adequately stabilised at completion of the diversion channel in Phase 1 of construction, reaches downstream of the dam site will no longer receive large amounts of bed load from areas upstream. This is discussed in detail in Tonkin & Taylor (May 2013a).

Sediment deposited from any coffer dam failure may temporarily alter the morphology of the Makaroro River below the dam until the material is dispersed further downstream by successive bed-defining floods (*i.e.* those with an annual return period). The potential effects of coffer dam failure on water quality are described in Section 3.2.3.1.

Overall, the effects of construction on the physical environment are expected to be relatively localised to the area at, and immediately downstream of, the construction site. The amount of sediment likely to be mobilised during construction is relatively small compared to the natural sediment load of the Makaroro River (160,000–262,000 m^3 / yr, Tonkin & Taylor May 2013b). Fine sediment deposited within the substrate further downstream will be resuspended by floods sourced from the Makaroro and upper Waipawa rivers and not expected to have effects lasting more than a year after construction.

3.2.3. Changes to water quality

Mobilisation of sediment is expected to be the main factor affecting water quality in the Makaroro River downstream of the construction site (Reach 3). Increased concentrations of fine sediment in suspension will affect water clarity and the visual appearance of the river, particularly during low-moderate flows when water clarity would be expected to be high. During high flows, poor water clarity and high concentrations of suspended sediment are typical under status quo conditions and therefore any change will be less obvious (See Section 2.2.3.6). The effects on water clarity will subsequently affect the biological environment (*i.e.* invertebrates, fish and primary producers such as algae).

3.2.3.1. Potential effects of a coffer dam failure

A 10.5 m high temporary coffer dam will be used to divert the Makaroro River around the Makaroro dam construction area over a three month period (Tonkin & Taylor May 2013a). A flood event with a > 1: 2.33 annual exceedence period will overtop the coffer dam. During such an event there is a chance the structure could fail resulting in a large volume of coarse sediment becoming washed downstream with the floodwater (Tonkin and Taylor May 2013a).

The coffer dam will contain approximately 10,000 m^3 of rock fill (coarse gravel). The annual coarse sediment budget of the Makaroro is estimated to be between 80,000–180,000 m^3 / yr (Tonkin & Taylor May 2013b). Under the worst-case scenario, if the coffer dam is breached by a flood and the entire volume of sediment is released this would equate to an additional 5–13% to the annual coarse sediment budget of the Makaroro River.

Coffer dam rock fill material moving down the river during a flood event will abrade the surface of the streambed and smother the benthic habitat in depositional areas. We expect a near 100% reduction in fish and invertebrate communities in the first kilometer of river below the dam. The effect will lessen further downstream as the sediment settles on the streambed. We do not anticipate effects on aquatic biota (beyond the natural background flood effects) below the Makaroro / Waipawa confluence approximately 10 km downstream. In the affected areas, invertebrates can be expected to recolonise the river within 4–7 weeks (Sagar 1983; Scrimgeour & Winterbourn 1989).

Little is known about recolonisation rates for native fish after severe disturbance events. Therefore, it is not possible to accurately predict the how long it will take native fish to repopulate the areas affected by deposition of coffer dam rockfill. Non-migratory fish species (*e.g.* dwarf galaxiids) will be unaffected in the upper catchment above the dam site. The downstream flow of fry from the upstream refuge area will eventually repopulate the affected areas. Migratory species (*e.g.* longfin eels) will move up from lower Waipawa and Tukituki Rivers. We expect native fish populations to take no longer than five years to approach pre-existing levels. Anecdotal reports suggest that there are few year-round resident trout in the reach of river below the proposed Makaroro dam (see Section 2.3.4.3). Therefore, the affected reach is likely to be recolonised after one or two annual runs of spawning fish from the lower catchment with trout that take up residency in pockets of favorable habitat after spawning.

Sediment deposited from a coffer dam failure may temporarily alter the morphology of the Makaroro River below the dam until the material is dispersed further downstream by successive bed-defining floods (*i.e.* those with an annual return period). Carrying capacity for some fish species (particularly trout and eels) may be reduced in the medium term (< 5 years) due to pool infilling. Over the long term, the Makaroro dam will withhold sediment causing the streambed to armor in the reach below the dam (Tonkin & Taylor May 2013b). The post-dam trend of streambed armoring will counter any long-term effects of deposited sediment from a breach of the coffer dam during the construction phase.

3.2.3.2. Effects of irrigation channel underpass (canal siphon) construction

A network of irrigation canals will be constructed to distribute water from the Waipawa irrigation intake structures. Siphons are required where the irrigation canals cross under six major water courses, the Waipawa River, Tukituki River, Kahahahuri Stream (twice) and The Ongaonga Stream (twice). Under significant waterways the pipe will be placed a minimum of 5 m below the streambed to avoid scour (Tonkin and Taylor May 2013a).

The extent and severity of any damage to streams caused by constructing the siphons will depend on the construction methods used. If the stream is diverted around the siphon construction site and the pipe is dug into the streambed there will be localised streambed and bank damage with minimal displacement of sediment downstream. However, digging directly into the streambed without diverting the stream around the site will displace sediments from the streambed and banks causing increased turbidity and sedimentation of areas immediately downstream. The effects of increased turbidity and fine sediment deposition on aquatic biota are explained in Section 3.3.4.

The effects of displaced sediment in the larger rain-fed Tukituki and Waipawa Rivers will be localised and temporary. Bed-defining floods (*i.e.* events with more than a one

year return period) are likely to the reinstate the natural character of the stream channels and disperse any locally deposited sediment from the siphon construction works within one or two years.
Special care should be taken to minimise the release of sediments into spring-fed streams with predominantly unconsolidated gravel-beds. Spring-fed streams with gravel-beds can have high native fish and trout spawning values which are very sensitive to fine sediment deposition. Furthermore, these systems may lack the flood power to mobilise fine sediments deposited as a result of any construction activities. In spring-fed gravel-bed streams (*i.e.* < 20% fine sediment cover) tunneling or diverting the stream around the siphon construction area prior to disturbing the streambed should be considered. However, if the streambed is predominantly fine-sediment (*i.e.* > 20% fine sediment cover) below a potential siphon site then the impact of displaced sediment will be minimal and temporary. In these environments fine sediment deposited from siphon construction activities will not alter the character of the stream benthic habitat. Areas of deposited sediment will be recolonised by invertebrate communities within 4–7 weeks (Sagar 1983; Scrimgeour & Winterbourn 1989).

In summary, the mobilization of fine sediment will be the main factor associated with construction that affects water quality and instream values. These effects on water clarity downstream will be obvious during low-medium flows during the initial stages of construction when work is occurring within the river channel. However, they are expected to be largely avoided if disturbance of the wetted channel can be prevented and other sediment controls, as described in Tonkin & Taylor (May 2013a), are implemented. Any effects on water clarity will reduce rapidly once disturbance of the wetted river channel is completed.

3.2.4. Effects on the biological environment

Increased mobilisation of suspended solids during construction are likely to affect fish and invertebrate communities due to increased turbidity of the stream water and increased siltation of stream beds. The scale of increased mobilisation of suspended solids is hard to assess, but is likely to be relatively small compared with the natural sediment load of the Makaroro River (Tonkin & Taylor May 2013b).

Suspended sediment can affect instream biota either directly (*e.g.* behaviour, abundance, survival) or indirectly (*e.g.* reduction of food sources, alteration of habitat). Direct effects on aquatic biota will generally be limited to the time of construction, however, sediment deposited downstream in low energy areas (*i.e.* backwaters, pools) can cause prolonged effects on the biological environment.

Fine sediment suspension in the water column and deposition on the river bed affects periphyton in these five main ways:

1. Reducing the penetration of light and, as a result, reducing photosynthesis and primary productivity within the stream with resultant impacts on the rest of the food chain (van Nieuwenhuyse & La Perriere 1986; Davies-Colley *et al*. 1992)
2. Reducing the organic content of periphyton cells (Cline *et al*. 1982; Graham 1990)
3. Damaging macrophyte leaves and stems due to abrasion (Lewis 1973)
4. Preventing attachment to the substrate of algal cells
5. Smothering and eliminating periphyton and aquatic macrophytes in extreme instances (Brookes 1986).

Some habitat will be lost, for example, as fine sediments settle into interstitial spaces on the river bed, clogging up and / or burying the loose gravel top layers (*i.e.* hyporheic zone). This zone provides valuable habitat and refuge for many (sub-) surface riverine species, such as macroinvertebrates (*e.g.* EPT taxa) and some native fish species (redfin bully; McEwan 2009).

Fine sediment suspension and deposition affect macroinvertebrates by altering substrate composition and changing the suitability of the substrate for some taxa, by increasing drift due to sediment deposition or substrate instability, by affecting respiration due to the deposition of silt on respiration structures or low oxygen concentrations associated with silt deposits, by affecting feeding activities by impeding filter feeding, by reducing the food value of periphyton and prey density (Wood & Armitage 1997).

For sediment sensitive fish species (*e.g.* salmonids, upland bullies, koaro), high turbidity levels can directly affect fish by inhibiting feeding, reduced growth, reduced resistance to diseases, preventing successful egg and larval development and affecting migratory behaviour. Indirect effects include reducing the abundance of food sources (Alabaster & Lloyd 1982; Bruton 1985; Rowe *et al*. 2000; Richardson & Jowett 2002).

Reduction of visual range also has considerable effects on human perception of recreational water bodies and their ‘fishability’. Although riverbed works are currently planned for the dry period between October and December (Tonkin & Taylor May 2013a), large rainfall events may occur during construction, influencing the amount of fine sediment being washed downstream. Sedimentation effects on biota during dam construction will be most evident immediately downstream of the proposed dam site in the Makaroro River (Reach 3, Figure 2), although it must be remembered that the Makaroro River has a relatively high natural sediment load. The magnitude of effects will be reduced downstream of the confluences of the Makaroro River with the Waipawa and Tukituki rivers as they receive a greater proportion of water from the wider catchments, diluting high sediment levels downstream. However, trout fishery values may still be temporarily reduced in the Waipawa River (Reach 4 and 5), because trout are one of the most sediment sensitive species.

The rate of recovery from any effects on the aquatic biota depends on several factors, such as the duration and severity of disturbance, the survival of organisms in refugia from which recolonisation can take place, and on the timing of construction relative to life-history requirements of, for example, fish species (*e.g.* spawning, migration).

Recovery may be quick following short-duration disturbances (*i.e.* days). However, when an impact is extended over several months or years, as expected for this dam construction, the stream ecology may be more significantly altered over a period of time. This means recovery of the stream ecosystem may take many months or years and may require human intervention to restore the system to a natural state (Wood & Armitage 1997). Studies have shown that it can take between six weeks to a year after construction for macroinvertebrates to recover (Tsui & McCart 1981; Reid & Anderson 1999), and between one month and one year for fish (Schubert *et al*. 1987).

3.2.5. Summary

The main effects of construction will be associated with the disturbance of the river bed and mobilisation of sediment. It is difficult to quantify the likely amount of sediment that will be mobilised during construction, but it is expected to be relatively small compared with the natural sediment load in the Makaroro River. Effects on water quality will reduce rapidly once the working site is adequately stabilised after completion of the diversion channel. However, deposition of mobilised sediment downstream of the proposed dam site may have longer term effects that take six months to 1 year for recovery. The effects will be most marked close to the proposed dam site and have less influence downstream of the Waipawa and Tukituki confluences. Sediment control measures, as outlined in Section 4.1 will be required to reduce mobilisation of sediment as much as possible and these are discussed in Tonkin & Taylor (May 2013a). However, an increase in sediment mobilisation compared with the status quo will be inevitable, but probably a relatively small increase compared with the naturally high sediment load of the Makaroro River.

3.3. Assessment of effects of the dam and reservoir

3.3.1. Introduction

This section of the report focuses on the effects of the placement of a dam and reservoir where there is currently a flowing river.

Potential effects include the trapping of sediment in the reservoir and the associated changes to downstream river morphology, the effects of storage of water in the reservoir on water quality being released from the reservoir, the effects of the dam wall as a barrier for fish passage, and the effects of inundation of flowing water habitat by the proposed reservoir.
The effects of the dam on the flow regime downstream are addressed in Section 3.4.

3.3.2. Effects on downstream river morphology

The dam / reservoir will trap all bedload (large sediment particles that are transported along the river bed) and the majority of suspended sediment (smaller particles transported up in the water column) (Tonkin & Taylor May 2013b). The change in sediment supply downstream from the dam will result in changes to the sediment budget and could cause channel degradation (lowering of the river bed), encroachment of vegetation and changes in mean sediment size in some areas.

Physical changes are not anticipated for the lower Tukituki (Reach 6) and Waipawa (Reach 5 below SH50) rivers as the active channel is managed and gravel extraction and raking occurs.

The Waipawa River above SH50 and below the confluence with the Makaroro (mostly Reach 4) is not as actively managed as it is downstream. The river here receives a surplus of gravel which deposits in the active channel, flood berms and braids. The Waipawa catchment upstream from the Makaroro confluence supplies 45% of the gravel to Reach 4, compared to 55% from the Makaroro (Tonkin & Taylor May 2013b). The likely effect of the dam through this reach is a reduction in the rate of gravel aggradation. Also, the associated reduction in flood flows and flood peaks may allow vegetation to encroach on channel margins possibly causing reductions in channel width and changes in channel form (Tonkin & Taylor May 2013b). This is discussed in more detail in Section 3.4.3.

The Makaroro River below the dam (Reach 3) will be most affected by the loss of sediment supply caused by the dam as this section will lose all of the bedload and the majority of the suspended sediment. The likely effects will be channel degradation and coarsening of bed sediment. There is potential for bank erosion but this is limited given the confines of the gorge lining parts of this reach (Tonkin & Taylor May 2013b).

As mentioned above, changes in the flow regime include a reduction in flood flows. Increased bed armouring is likely to occur as finer sediments are transported and coarser sediments remain (Tonkin & Taylor May 2013b). This armouring will mitigate channel degradation somewhat. Vegetation will encroach on channel margins as in the Waipawa, reducing channel width and form — probably from a braided channel to more meandering in form.

Reduced sediment supply downstream of the dam will result in altered habitat conditions for native fish living in this section of the Makaroro River. The dam is expected to capture all of the bedload and much of the fine sediment which will result in the bed downstream becoming progressively coarser, as the finer sediment fraction is winnowed out over time (Tonkin & Taylor May 2013b). The habitat suitability criteria commonly used in habitat modelling analyses (RHYHABSIM, Jowett 2004) give an indication of whether a coarser bed is likely to have adverse effect on the native fish species recorded from this section of the river (see Appendix 19). Most of these fish generally tend to be associated with the coarser substrate classes (coarse gravel, cobble, boulder, and bedrock) at least as much or more than they are associated with finer substrate classes (fine gravel, sand, silt / mud). The only possible exception is common smelt, which show optimum suitability scores for sand and fine gravel (Jowett & Richardson 2008). However, this species is likely to occur only rarely in the Makaroro River, due to the distance from the sea. On the basis of these habitat suitability criteria it seems unlikely that a reduction in fine substrate would have a direct adverse impact on habitat quality for native fish in this section of the river.

The coarsening of sediment is, however, likely to reduce the availability of suitable spawning gravels (*i.e*. particles between 2–64 mm) for rainbow trout downstream of the dam. This effect will be primarily evident in the reach of the Makaroro down to the confluence with the Waipawa River. Further downstream, fine sediment delivered from the upper Waipawa River should help to maintain sediment size composition more similar to the status quo.

The coarsening and armouring of the bed may also increase the suitability of habitat for nuisance filamentous algae. Large stones are more stable during high flows allowing algae to remain attached. The habitat suitability criteria for long and short filamentous algae reflect this preference for large bed particles (see Appendix 19).

The auxiliary spillway is a 50 m wide unlined excavation in rock on the far left abutment of the dam. It is designed to only begin to operate for floods with a greater than 1-in-200 year annual exceedance period (including estimates of climate change), or a 1 in 450 year return period based on a statistical analysis of historical floods (Tonkin & Taylor May 2013a). This spillway discharges into a heavily forested gully that leads back to the river. Erosion within this gully (and deposition of sediment and vegetation in the river channel downstream) is possible if large spills were to occur over this spillway. Under the maximum design flood (752 m^3/s) the auxiliary spillway is expected to take 167 m^3/s (Tonkin & Taylor May 2013a). However, for floods up to a 1-in-300 year return period, peak spills of less than 3 m^3/s are expected over the auxiliary spillway and these are not anticipated to result in any significant erosion in the gully downstream. On a catchment wide scale, a rainstorm and consequent flood event of this threshold magnitude (300 year flood and greater) is expected to result in mobilisation of massive amounts of debris (sediment and vegetation) under pre-existing conditions, and the potential erosion and vegetation removal caused by auxiliary spillway operation under such extreme hydrological events should be considered in this context. Any sediment and vegetation mobilisation resulting from spillway operation is expected to be insignificant compared to the load of sediment and vegetation transported by the river in such a large event.

3.3.3. Effects on water quality

The quality of water discharged from the reservoir will reflect the water quality in the reservoir at the draw depth. Generally, the longer the residence time, the greater the potential effects of storage on water quality (Young *et al*. 2004). Based on the full volume of 90 × 10^6 m^3 and a proposed mean annual discharge of 6.3 m^3 s^{-1} (Tonkin & Taylor May 2013a), the theoretical mean residence time in the reservoir would be about 164 days. NIWA (May 2013c) modelled reservoir water quality under various scenarios and discussed potential changes to water temperature, dissolved oxygen, nutrients, phytoplankton and sediment. The NIWA findings for the preferred scenario (M1 — single outtake at 405 mRL) are summarised below.

3.3.3.1. Water temperature

Most New Zealand lakes and reservoirs that are deeper than 20-30 m undergo seasonal mixing and are thermally stratified; *i.e*. a less dense warm surface layer ‘floats’ above a colder, more dense bottom layer (Green *et al*. 1987; Davies-Colley 1988).

Stratification usually happens from late spring through summer and much of autumn, while mixing usually happens during winter. The depth of the thermal stratification layer in the reservoir is largely influenced by the level of the outlet. With all water for this proposal being drawn from the 405 mRL outtake valve, the water column in the reservoir would be strongly stratified at the draw depth during summer months and weakly stratified or completely mixed each winter (Figure 17). During summer, the water column above, and up to 5 m below the draw depth will warm up, with surface temperatures reaching up to 22 °C (Figure 17). Water temperatures at the 405 mRL outtake are predicted to reach 16 °C during summer (Figure 17).

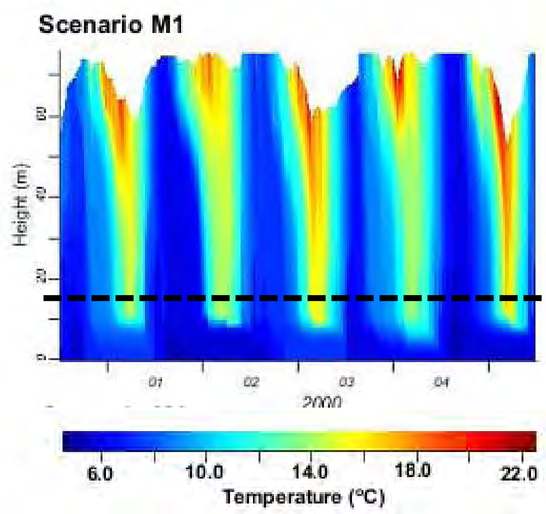

Figure 17. Simulated temperature patterns for scenario M1 for the period 30/06/2000–30/06/2005 (NIWA May 2013c). The level of the outtake valve at 405 mRL is shown by the dotted black line.

Average daily temperatures less than 20 °C are considered to protect even the most sensitive species of fish and invertebrates (Elliott 1994; Quinn *et al*. 1994; Cox & Rutherford 2000). The maximum predicted water temperatures at the draw depth are less than 20 °C and therefore suggest that water temperatures will always be suitable for aquatic life immediately downstream of the dam. Daily water temperature fluctuations in the reservoir are expected to be reduced relative to that in the Makaroro River upstream and thus suppressing the daily temperature cycles in the river immediately below the dam (NIWA May 2013c). Existing knowledge of fish and invertebrate thermal preferences suggests that this dampened daily temperature change would have positive effects, if any, on fish and invertebrate communities downstream of the dam (Hayes *et al*. 2000; Cox & Rutherford 2000).

3.3.3.2. Dissolved oxygen (DO)

Stratification of the water column, as is common in deep reservoirs, causes the separation of surface and bottom waters. Bottom waters commonly experience oxygen depletion, due to the decay of submerged vegetation and organic matter deposited on the lake bed. This is particularly a problem during the first five years after reservoir filling, but can be a longer term concern too (NIWA May 2013c). As mentioned above, the draw depth is a critical factor affecting the degree of stratification and the vertical position of the stratified layer and, therefore, has an effect on both the water quality in the reservoir and on the water discharged downstream.

Modelling of dissolved oxygen concentrations in the reservoir have indicated that water below the draw depth of 405 mRL will become anoxic, but water drawn into the 405 mRL outtake valve will have DO concentrations > 5 g m^{-3} for most of the year, except during late summer / autumn when concentrations may approach anoxic conditions at times (Figure 18).

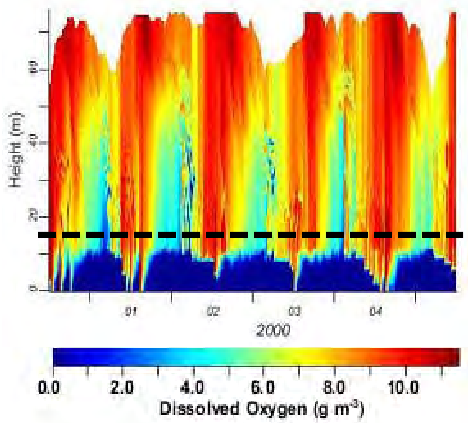

Figure 18. Simulated dissolved oxygen patterns for scenario M1 for the period 30/06/2000–30/06/2005 (NIWA May 2013c). The level of the outtake valve at 405 mRL is shown by the dotted black line.

ANZECC (1992) water quality guidelines for aquatic ecosystem protection recommend DO concentrations to be > 6.5 mg L^{-1}. As mentioned above, water discharged into the Makaroro River from the reservoir during late summer and autumn may be below these recommended guidelines and therefore potentially affect aquatic life such as fish and macroinvertebrates.

The amount of oxygen required by aquatic animals is quite variable and depends on a variety of factors such as species, size, condition and water temperature (Boyd 1990). Some species are more sensitive to low levels of oxygen than others. The DO requirements of salmonids, for example, are generally higher than for most other freshwater fishes (Dean & Richardson 1999) and minimum oxygen saturation should be at least 80 % for free swimming brown trout (Mills 1971; Elliott 1994). There is little information on DO tolerances of aquatic invertebrates in New Zealand, however, some species such as mayflies, stoneflies and caddisflies are expected to be sensitive to low DO, while others such as chironomids are expected to be tolerant of low DO. That said, it is generally accepted that having DO levels that are protective of trout will also result in protection of invertebrates and other species.

NIWA (May 2013c) suggest that an aerator should be installed near the dam wall to generate a circulation current within the reservoir and reduce the likelihood of anoxic water at the outtake valve. The aerator would be turned on if DO concentrations drop below 7 g m^{-3}, meaning that adverse effects of DO on downstream aquatic life would not be expected.

3.3.3.3. Nutrients and phytoplankton

Concentrations of phosphate, total P, ammonium and total N are predicted to be elevated in the anoxic water below the draw depth (NIWA May 2013c). In contrast, concentrations of these nutrients are predicted to be low in the water column above the draw depth throughout the year (Figure 19). During winter mixing the high concentrations of these nutrients in the water from below the draw depth will be rapidly diluted (400 fold) by the large volume of water above the draw depth.

Nitrate-N concentrations are predicted to be elevated in the water column above the draw depth during winter and spring (Figure 19), being consistent with the nitrate concentrations of the inflow water from the Makaroro River (NIWA May 2013c). Below the draw depth, nitrate concentrations were predicted to reduce to zero during summer months due to denitrification in the anoxic dead zone (Figure 19; (NIWA May 2013c).

Phytoplankton biomass (indicated by chl-*a* concentrations) is predicted to rise in the upper water column during spring with near surface chl-*a* concentrations reaching > 7 mg m^{-3}, but falling to < 2 mg m^{-3} by summer (Figure 19). Since phytoplankton are restricted to the upper water column, this phytoplankton biomass is unlikely to be drawn in the water discharged from the reservoir (NIWA May 2013c).

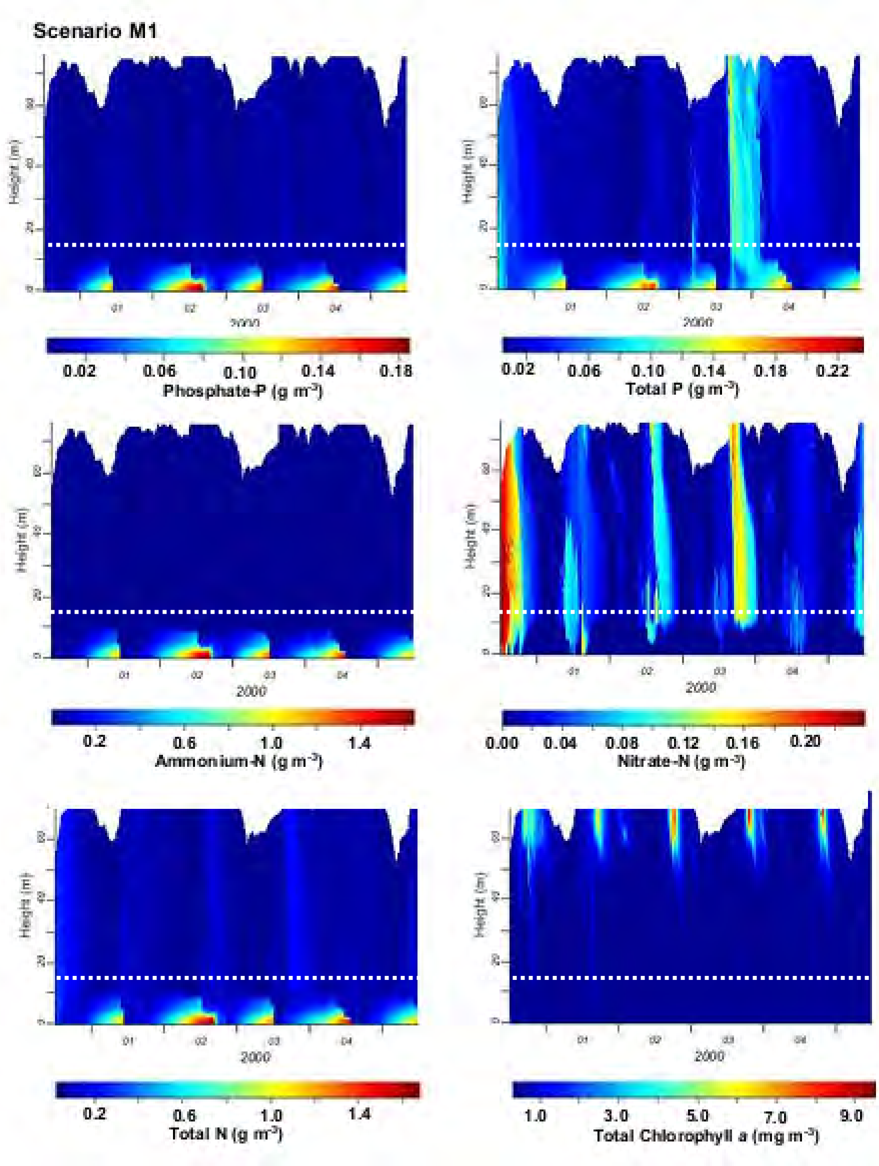

Figure 19. Simulated nutrient concentrations and chlorophyll-a (chl-a) for the period 30/06/2000–30/06/2005 NIWA (May 2013c). The draw depth of 405 mRL is shown by the dotted white line. Note that the colour schemes are different for each plot.

The simulated total nitrogen and chl-*a* concentrations in the reservoir are those typically associated with low productivity, high quality lakes and reservoirs, according to trophic level index (TLI) values defined by Burns *et al*. (2000). The reservoir is likely to have a trophic level classification of low to medium nutrient enriched (*i.e.* oligotrophic to mesotrophic). The concentration of phytoplankton is a key factor controlling water clarity. Therefore, based on this trophic level classification water clarity in the reservoir is expected to be in the range between 7.8–15 m, this is being considered of ‘good’ visual clarity.

NIWA (May 2013c) showed that mean nutrient concentrations predicted for the reservoir were generally lower than that observed at the Makaroro River at Burnt Bridge for the years 2000–2005. Therefore, nutrient availability for periphyton growth immediately downstream of the reservoir is expected to be similar to or lower than the status quo such that no adverse effects are expected.

3.3.3.4. Suspended sediment and water clarity

Very fine sediment from the Makaroro River inflow will remain in suspension and pass along the length of the reservoir and potentially be discharged past the dam (NIWA May 2013c). The current near the outtake valve created by water release from the dam may also result in resuspension of deposited fine sediment near the entrance to the outtake valve and this sediment would also pass downstream (NIWA May 2013c).

However, the majority of the sediment delivered to the reservoir by the Makaroro River will be deposited within the reservoir (Tonkin & Taylor May 2013b), indicating that water clarity downstream of proposed dam will generally be higher than that experienced currently.

Water clarity is also strongly affected by the concentration of phytoplankton in the water. As mentioned in Section 3.3.3.3, predicted concentrations of phytoplankton are expected to be low and thus water clarity expected to be in the range between 7.8–15 m.

3.3.4. Effects on fish passage

3.3.4.1. Native fish

Of the nine native fish species recorded upstream of the proposed dam site in the Makaroro River, seven have a life history that would require free migratory access to and from the sea past the dam (Table 12). In the absence of mitigation, obstruction of this migratory pathway by the dam would be expected to result in a change in the composition of the fish community upstream of the dam.

The seven migratory native species are unlikely to establish self-supporting populations above the dam (although it is possible that common bully and / or koaro could). Consequently, these species would be lost from the fish community above the dam over time if no mitigation measures were put in place. The time over which this is likely to occur would vary between species, depending on their life expectancy, from a few years for the bully species to several decades for longfin eels. Four of these native species have a threat classification of ‘Declining’ under the latest Department of

Conservation threat classification (Allibone *et al.* 2010), while the others are considered, ‘Not threatened’ (Table 10). Dwarf galaxias and Cran’s bully are non-migratory and likely to maintain self-supporting populations upstream of the reservoir.

Table 12. Fish species found upstream of the proposed Makaroro River dam site between 1965 and 2011 (NZFFD, NIWA). * Fish species was not recorded in the NZFFD, but has medium (34-66%) predicted probability of occurrence, + fish species was recorded in the NZFFD, but has low predicted probability of occurrence.

Common name	Scientific name	Migratory
Longfin eel	*Anguilla dieffenbachii*	Y
Torrentfish	*Cheimarrichthys fosteri*	Y
Dwarf galaxias	*Galaxias divergens*	N
Koaro	*Galaxias brevipinnis*	Y*
Cran’s bully	*Gobiomorphus basalis*	N
Common bully	*Gobiomorphus cotidianus*	Y
Bluegill bully	*Gobiomorphus hubbsi*	Y
Redfin bully	*Gobiomorphus huttoni*	Y
Rainbow trout	*Onchorhynchus mykiss*	Y
Common smelt	*Retropinna retropinna*	Y^{+}

The downstream migration of eels may also be obstructed by the dam. Eels migrate downstream as large adults in autumn (April-May in particular) as part of a spawning migration to the subtropical Pacific Ocean. Since the reservoir will generally have been drawn down during the summer irrigation season, the water level is often likely to be below the spillway crest during this migration period. Consequently, the only way out of the reservoir would be through the outtake valve. However, the intake for this may be difficult for migrant eels to find, if it is located back from the face of the dam. But more importantly, downstream passage through this release would involve passing through the turbines of the powerstation. Turbine passage survival rates for large migrant eels are generally low (Larnier & Travade 2002, Boubée *et al.* 2001). Due to the long life span of longfin eels (25-100+ years), the issue of obstruction of downstream eel migration may continue for the lifetime of the dam (though probably affecting relatively low numbers from year to year), regardless of whether the upstream migration obstruction is mitigated (see Section 4.3).

The downstream migration phase of the other migrant native fish species recorded from above the proposed dam site occurs as tiny larvae, which can be expected to have high turbine passage survival rates (Coutant & Whitney 2000). Consequently, successful downstream passage for these species may still be possible if larvae are carried by water discharged through either the spillway or the power station.

All of the seven migratory native fish species that are potentially affected by the proposed dam are found elsewhere in the catchment (Appendices 1, 4, 5, 8, 9, 10, 14). While the loss of the seven migratory species within the Makaroro River upstream of the proposed dam would restrict the geographic range of these species within the wider Tukituki catchment, the loss of the upper Makaroro River populations of these species is not expected to result in a significant increase to the threat of extinction of these species from elsewhere in the catchment. The length of river channel upstream of the proposed dam represents only 3.7% of the total river channel length in the Tukituki Catchment. Nevertheless habitat loss for any species that is considered to be declining is not desirable. This issue was discussed in a workshop with the Mana Whenua working party and a range of mitigation options were discussed. As discussed in detail in Section 4.3, we recommend that an upstream and downstream trap and transfer operation in conjunction with habitat restoration be adopted as part of the operation of the proposed Scheme to mitigate these effects.

3.3.4.2. Trout

The proposed dam will prevent the upstream migration of rainbow trout from the adult habitat in the Waipawa and Tukituki rivers to the spawning and juvenile rearing areas in the upper Makaroro River. In particular is the potential reduction of spawning area and activity in the Makaroro which could impact on juvenile trout recruitment for the locally and regionally significant Tukituki fishery downstream.

Maclean (2012) undertook a spawning survey of the upper Makaroro and other tributary streams in the Tukituki catchment. This study attempted to compare the potential contribution of juvenile trout recruitment from the Makaroro with other potential spawning streams in the catchment. Ten streams with different catchment characteristics were surveyed. Rainbow trout fry densities in the upper Makaroro were at least twice that of any other stream included in the survey and more than 10 times that of eight of the 12 survey areas. In addition Dutch Creek (an upper Makaroro tributary above the proposed dam location) had the third highest fry densities of the 12 areas surveyed (Maclean 2012). Even the highest fry densities (1.3 fish / m^2), however, were low compared with that observed in fully utilised spawning streams elsewhere (up to 6-7 fish / m^2, Hayes 1988)

While this indicates that the Makaroro may be an important spawning area relative to other hill draining and lowland streams in the Tukituki catchment, results from the juvenile rainbow trout survey must be interpreted with caution (Maclean 2012). The juvenile fry survey had limited spatial coverage and only included one year (there may be considerable variation in spawning activity in a stream from year to year). In addition, ‘suitable’ fry habitat was deliberately chosen from within each stream to sample. Because it was not possible to quantify the area of suitable fry habitat in each stream the results give little indication as to the relative total production of juvenile fry from the Makaroro. Suitable juvenile habitat was common at some of the survey sites (*e.g.* Dutch Creek, upper Waipawa), whereas it was difficult to find at other sites (*e.g.* Makaroro, upper Tukituki) (Maclean 2012). Moreover, the survey results are at odds with an adult spawning survey in the upper Makaroro conducted by Maclean (2011), which found relatively low densities of adult spawning fish.

A self-supporting rainbow trout population is likely to establish in the reservoir upstream of the dam and juveniles from this population could contribute to the fishery downstream if they can migrate downstream past the dam, while the proposed reservoir could be expected to provide good rearing habitat for juvenile trout. A recent review of the mortality rates associated with spillways and turbines was undertaken for the formerly proposed Mokihinui hydro scheme. The proposed Mokihinui dam was of a similar size (80 m) to the proposed Makaroro Dam (85 m). Therefore, the modelled predictions for juvenile trout survival are generally applicable to the Makaroro Dam. Using two literature derived models (Travade *et al.* 1998; Larinier 2002; Larinier *et al.* 2002) the survival rate of downstream migrating juvenile trout was predicted to be range from 75-90% for 5-10 cm juvenile trout passing through the turbines (Hayes 2008). Higher survival rates are expected for smaller fish or if the fish are diverted away from the turbines. Therefore, and noting the potential for increased recruitment in the lake environment, it is likely that juvenile trout reared in the upper Makaroro and Dutch Creek and within the reservoir will continue to contribute to the Waipawa and Tukituki fisheries with any adverse effects being difficult to separate from natural variability.

3.3.5. Effects of inundation by the reservoir

Filling of the proposed reservoir will result in approximately 7 km of flowing water habitats in the footprint of the reservoir being replaced with still water habitat. This includes the flowing water habitat in the Makaroro River and in tributaries such as Dutch Creek. Some of the native fish species recorded from this location are also commonly found in still water habitats (*e.g.* longfin eels, common smelt, common bullies). These species will be able to use the newly formed lake-like habitat of the reservoir and will continue to be able to do so if trap and transfer, or other mitigation approaches, are used to transfer these fish past the dam (see Section 4.3). However, other species (*e.g.* torrentfish, bluegill bully, redfin bully, Cran's bully, and dwarf galaxias) are unlikely to use the still-water habitat in the reservoir, and for these species the inundation of streams in this area will represent a loss of habitat. Many of the invertebrate species found in the Makaroro River are also unlikely to use the still water habitat in the reservoir, but will be replaced by lake-dwelling invertebrates. Rainbow trout are commonly found in still-water habitats and will use the habitat provided within the reservoir, but the spawning habitat in the Makaroro River and Dutch Creek that is inundated by the reservoir will be lost.

While any loss of habitat is not desirable, the length of flowing water habitat inundated by the reservoir is relatively small compared with the length of flowing water habitat throughout the Tukituki Catchment. The loss of this habitat is not expected to result in a significant increase to the threat of localised extinction for any species.

3.3.5.1. Reservoir productivity and fishery quality

A reservoir of approximately 372 ha will be created by the proposed dam. It is likely that rainbow trout from the upper Makaroro River and inundated reach will establish a fishery in the reservoir.

The productivity of a lake is largely dependent on the extent and stability of shallow areas (littoral zone) around the lake margin. Fluctuating lake levels reduce the potential diversity and biomass of macrophytes and invertebrates (which form the basis of trout production in lakes) in the reservoir margins (Stark 1993; James *et al.* 1998). However, if a lake is sufficiently clear for light to penetrate beyond its operating range, then it will retain some productive stable (permanently wetted) littoral habitat for feeding trout. This is illustrated by the very clear Lakes Wanaka and Hawea producing similar quality fisheries despite Hawea having level changes seven times greater than Lake Wanaka. By contrast, Lakes Tekapo and Ohau are turbid and their frequently fluctuating levels are less than optimal for their trout populations (Livingston *et al*. 1986; James & Graynoth 2002).

The average visual clarity of the Makaroro River is 2.5 m (calculated from monthly black disk measurements since 1989 from Burnt Bridge). This value may indicate the average clarity of the proposed reservoir, although it is likely an underestimate due to sediment deposition and a resultant increase in clarity. A general rule of thumb is that the euphotic zone of a lake (the layer that will receive enough sunlight to support plant growth) can be estimated by multiplying the secchi disk depth readings by three to four times (Stewart 1976). Assuming conservatively, that black disc clarity measurements from the river are equivalent to likely secchi disc readings in the proposed reservoir, this gives an estimate of 7-10 m as the limit of the euphotic zone in the proposed reservoir. The lake level is predicted to vary by 10-20 m during wet and average years, respectively and up to 30 m in a dry year (95th exceedance percentile) (Tonkin & Taylor May 2013a). Consequently, it is unlikely that any permanently productive littoral zone supporting semi to permanent macrophyte beds will establish in the reservoir.

Generally, large invertebrate taxa which could support a productive reservoir fishery are associated with stable weed beds (Stark 1993; James *et al*. 1998). In the absence of weed beds, the benthic food web in the reservoir is likely to be based on fast growing algae species which can be expected to support a seasonally variable and sparse invertebrate community dominated by chironomids and snails. These invertebrates groups are generally small and are considered to be poor quality food for adult trout relative to generally larger mayfly and caddis taxa in rivers, or damselfly and dragonfly larvae that are associated with weed beds in lakes (de Crespin de Billy *et al.* 2002; Shearer & Hayes 2003; Shearer *et al.* 2003). Significant populations of

native fish are considered to be unlikely to establish in the reservoir. Therefore, given that the Makaroro Reservoir is likely to have ‘poor quality’ adult trout food resources the fishery is expected to be, at best, of average quality relative to other lake fisheries in New Zealand.
The Cobb Reservoir in Tasman District is a similar size and shape to the proposed reservoir on the Makaroro River and also has a large operation range (12 m). A fishery for small rainbow trout (0.5-1.5 kg) exists in the Cobb Reservoir despite the large operating range, medium water clarity, and depauperate aquatic plant and invertebrate communities (Young *et al.* 2000). The fishery attracts 200-400 angler visits each year (Unwin 2009). Furthermore, the flood and drought refuge created by the Cobb Reservoir has created a fishery for brown and rainbow trout in the upper Cobb River. Both these fisheries were non-existent before the presence of the dam (Young *et al*. 2000). The fishery in the proposed reservoir and upstream on the Makaroro River may be somewhat comparable in nature to that provided by the Cobb Reservoir and upper Cobb River. Therefore, it would be quite different to the existing fishery provided by the upper Makaroro River (as described in Section 2.3.4) in that it would support a full season (or even year round) fishery for small rainbow (and perhaps brown) trout, rather than the current early and late season fishery for post- or pre-spawning rainbow trout of average size. The relative value of these fisheries will depend on the preferences, method and experience of individual anglers. Experienced anglers may prefer the current river fishery, while more inexperienced anglers may prefer the angling opportunities provided by the reservoir.

3.3.5.2. Will the trout population in the reservoir provide recruitment for the downstream fishery?

Approximately 7 km of potential spawning habitat for rainbow trout will be inundated by the proposed reservoir. However, significant areas (approximately 20 kilometres) of potential spawning habitat will remain unmodified upstream of the reservoir. The utility of this spawning area to supply recruitment for the downstream fisheries will depend on the number of trout that can live in the reservoir, the positive effect of the lake on juvenile trout survival, and the likely mortality of juvenile trout passing downstream through the turbines or over the spillway.

Maclean (2011) used density information from other New Zealand rivers to provide a general estimate that the existing spawning run in the upper Makaroro River was less than 200 trout. It is likely that the 372 ha reservoir would support more than 200 fish; despite the fact that it is likely to be a relatively poor habitat for adult trout, compared with a number of other lakes and reservoirs in New Zealand. Based on acoustic surveys undertaken by NIWA in the southern hydro lakes in 2007-2008 (Benmore, Tekapo, *etc.*) trout densities can vary between 12 and four fish per hectare in hydro lakes recognised as ‘good’ fisheries. In contrast, trout densities in Lake Pukaki (which would be considered ‘poor’ in terms of lake trout fisheries in the country) are estimated as being approximately 0.6 trout per hectare (James & Graynoth 2002).

Our assessment, based on the modelled reservoir water quality report by NIWA (May 2013c) (*i.e*. taking into account the degree of flow fluctuation, the potential stratification and upper temperature limits), is that the fishery of the proposed Ruataniwha reservoir should sit close to the lower quartile of the range between Lake Benmore and Lake Pukaki. This would place trout densities at approximately 3 fish per hectare in the proposed reservoir. This gives a very approximate population estimate of about 1100 trout (3* the reservoir area of 372 ha when full).

Modelling provides an alternative means to estimate the future size of the fishery. Downing *et al.* (1990) created an empirical model to estimate salmonid production in lakes based on total phosphorus (TP) and mean annual temperature. We used the predicted average TP levels in the reservoir (from NIWA May 2013c) and mean river temperatures from the NRWQN Makaroro at Burnt Bridge record for the model. This model predicts that there would be 2.68 kg of trout produced in the reservoir per hectare per year. Downing & Plante (1992) showed that there is a relationship of almost 1:1 between salmonid productivity and standing crop in oligo / mesotrophic lakes (without fishing pressure). If we assume that the average size of adult trout in the reservoir is close to 1 kg then it could support a population of around 1000 trout (2.68 * the reservoir area of 372 ha when full).

Another model from Downing *et al.* (1990) predicts salmonid production based on limnetic phytoplankton food resources. A nominal value of phytoplankton production derived from Wetzel (2001) of 100 mg C / m^2 / day for oligo / mesotrophic lakes gave a predicted salmonid production value of 5.5 kg of trout per hectare per year. This would place the total population in the reservoir at approximately 2000 adult trout (5.5 * the reservoir area of 372 ha when full).

These very coarse estimates suggest that the Ruataniwha reservoir could support between 1000- 2000 adult trout in the lake during wet / average years. This does not take into account the effects of dry years when the carrying capacity of the lake would be reduced by the lower lake level / volume.

The reservoir will provide a refuge from flood flows which will allow juvenile trout to persist in the upper river when they would otherwise be vulnerable to flood induced displacement and mortality (Young *et al.* 2010; Hayes *et al.* 2010). The dam will also provide juvenile rearing habitat. Small food items such as chironomids, which are likely to form the food production base in the reservoir, can be an adequate food source for juvenile trout. Therefore, juvenile trout (< 10 cm) will not be food limited in the reservoir to the same extent as adult trout.

Given that there is expected to be a relatively large population of adult rainbow trout in the reservoir, relatively high juvenile survival rates within the reservoir and relatively high survival of juvenile trout passing over the spillway or through the turbines, we expect that the trout population upstream of the dam will provide a significant source of recruits for the trout population in the Waipawa and Tukituki rivers downstream. Similar situations are found elsewhere in New Zealand. For example, the current sea-run chinook salmon fishery in the Clutha River is thought to be almost entirely based on the supply of progeny from landlocked salmon that live in Lakes Wanaka and Wakatipu, and perhaps Hawea (Rasmus Gabrielsson, Cawthron Institute, pers. comm.). These juvenile salmon must pass downstream through the Clyde and Roxburgh dams before heading out to the ocean.

3.3.6. Summary

The placement of a dam and reservoir where there is currently a flowing river will have a variety of effects on the aquatic ecosystem.

The majority of the sediment transported down the upper Makaroro River will be trapped within the reservoir resulting in a reduction in sediment supply and bed aggradation downstream of the dam. The channel is likely to narrow due to vegetation encroachment and change from a braided to a single-channel river. The bed is also likely to coarsen and become armoured as fine sediments are washed downstream and not replaced. The reduction in bed aggradation and the likely associated reduction in habitat disturbance associated with gravel removal from the channel is likely to have a net benefit to the aquatic ecosystem. The coarsening of the bed is also likely to have a net benefit for many species of native fish which prefer coarse substrates and the hiding spaces among them that they provide. However, bed coarsening and armouring will potentially reduce the availability of suitable spawning gravels for rainbow trout from downstream of the dam to the confluence of the Waipawa River. Bed coarsening and armouring will also potentially increase habitat suitability for nuisance filamentous algae.

Changes in water quality associated with storage of water within the reservoir are expected to be relatively minor. Any issues with anoxia in the bottom waters of the reservoir will be able to be addressed using an aeration system. Thermal buffering means that the water released from the lower levels of the reservoir will have a lower daily fluctuation in temperature than occurs currently in the river. Seasonal changes in temperature are also expected to be dampened. These changes will only persist for a few kilometres downstream of the dam but are expected to be a net benefit to the aquatic ecosystem. Based on predictions relating to the proposed design and operation of the dam and outlet levels, we anticipate that there will be no problems with levels of dissolved oxygen, nutrients and sediment released downstream from the reservoir.

Movement of fish, both upstream and downstream, past the dam will be affected by the presence of the dam. The seven migratory native species currently present, or likely to be present, in the vicinity of the dam are unlikely to establish self-supporting populations above the dam (although it is possible that common bully and / or koaro could). Consequently, these species will only be retained in the fish community above the dam over time, if fish passage is provided (See Section 4.3). Dwarf galaxias and Cran's bully are non-migratory and likely to maintain self-supporting populations upstream of the reservoir. Spawning migrations of rainbow trout from the Waipawa and Tukituki rivers upstream to the upper Makaroro River will also be blocked by the dam.

The creation of a 372 ha reservoir will result in a loss of approximately 7 km of flowing water habitats. Some of the native fish species currently found in the river habitat are also commonly found in still water habitats and will be able to use the newly formed lake-like habitat of the reservoir. However, other species (*e.g.* torrentfish, bluegill bully, redfin bully, Cran's bully, and dwarf galaxias) are unlikely to use the still-water habitat in the reservoir, and for these species the inundation of streams in this area will represent in a loss of habitat. Many of the invertebrate species found in the Makaroro River are also unlikely to use the still water habitat in the reservoir, although invertebrates that prefer still waters will replace them to some extent. Rainbow trout are commonly found in still-water habitats and will use the habitat provided within the reservoir, but the spawning habitat in the Makaroro River and Dutch Creek that is inundated by the reservoir will be lost.

The reservoir is predicted to have relatively large fluctuations in water level on an annual basis, therefore restricting the development of productive aquatic plants communities along the reservoir margins. Fish communities in the reservoir will probably be dependent on production of opportunistic invertebrates like chironomids, which will provide a reasonable food resource for small and juvenile fish, but unlikely to support an abundant population of large trout.

A trout population of between 1000-2000 adult fish is predicted to develop in the reservoir and juvenile trout production may be enhanced compared with the status quo as a result of the reservoir. It is very likely that some of these juvenile trout will pass downstream through the turbines or over the spillway and make a substantial contribution to the fishery in the Waipawa and Tukituki rivers. However, whether overall trout numbers will be enhanced or will decline (relative to the *status quo*) can not be definitively determined at this time.

3.4. Assessment of effects of flow regulation

3.4.1. Introduction

The proposed Scheme aims to capture flows during the autumn, winter and spring period and provide enhanced flows that can be used for irrigation of the Ruataniwha

Plains during the summer. Therefore, changes to the flow regime downstream of the proposed dam are inevitably substantial.

This section of the report characterises the changes in the hydrological regime and associated changes in river morphology, water quality, and the quality of habitat for periphyton, invertebrates and fish. The effects of the fluctuating flows associated with changes in irrigation demand in the summer, and fluctuating flows associated with hydro-peaking in the winter, are also assessed.

The hydrological effects of the Scheme differ among the various reaches of the catchment. Accordingly, the analysis examines the Makaroro River downstream of the proposed dam (Reach 3, Figure 2), the Waipawa River from the confluence with the Makaroro River downstream to the proposed irrigation intake (Reach 4, Figure 2), the Waipawa River immediately downstream from the irrigation intake (top of Reach 5, Figure 2), the Waipawa River at RDS (bottom of Reach 5, Figure 2), and the Tukituki River at Red Bridge (Reach 6).

The analyses presented in this section are relatively complex, given the numerous ways that changes in the flow regime can affect river ecosystems. For a summary of the analyses see Section 3.4.7.

3.4.2. Hydrological effects

The flow regime associated with the proposed dam was modelled by Tonkin & Taylor. Four separate datasets were produced and used in this assessment. The first uses flow data supplied by David Leong (Tonkin & Taylor, 28 March 2012) and applies to Reach 3 only. The data series, titled 'Tapairu Road based Makaroro inflows — Original Synthetic Makaroro at Burnt Bridge', was derived from the extended Makaroro River flow record as described in Section 2.2.1. It can be considered as representing naturalised and status quo conditions because there is no abstraction in this part of the catchment. Analyses carried out using this dataset are presented in this section and compare the effects of the proposed flow regime, referred to as '**Proposed**'; to the natural flow regime, referred to as '**No dam'**.

The second dataset, named 'RWS flow regime change — alternate Waipawa RDS based fully synthetic Makaroro flow, 12 June 2012', was supplied by Rob Waldron (HBRC). This data was applied to sites in Reaches 4 and 5, upstream and downstream of the irrigation intake (though not including the Waipawa RDS site). The site downstream from the irrigation intake is at the upper-most part of Reach 5. Once again the **'No dam'** datasets used for these reaches represent naturalised and status quo conditions, while the proposed flow regime is referred to as **'Proposed'**.

The third dataset, described in HBRC Science (May 2013a), was modelled for Reaches 5 and 6 to take account of current abstraction in the lower reaches of the catchment. It contains modelled flow data for the Waipawa RDS and Tukituki Red Bridge sites under five abstraction scenarios:

1. 'Natural state' no water abstraction or water storage scheme in place. This will be referred to as '**Naturalised'** or '**Scenario 1'**. For ease of reference, it is also referred to as '**No Dam'** in Table 13.
2. Current consented water abstraction continuing into the future. This will be referred to as **'Status quo'**, '**Abstraction only'** or **'Scenario 2'.** The effects of the proposed Scheme are determined by comparison with this scenario.
3. Water storage in place in 2017 and all current consented water abstraction discontinued. This will be referred to as '**Dam only'** or '**Scenario 3**'.
4. Water storage in place in 2017 and all current consented water abstraction continued. This will be referred to as '**Dam and abstraction'** or '**Scenario 4'**.
5. Water storage in place in 2017 and all current consented surface water or surface-depleting groundwater abstraction discontinued (all deep groundwater takes continue at their current rate). This will be referred to as **'Scenario 5'**. Scenario 5 represents one possible level of Scheme uptake by irrigators in the catchment and is between the extremes of uptake by current irrigators that are represented by Scenarios 3 and 4.

Scenario 2 represents the current 'existing environment' for the assessment of effects under the Resource Management Act 1991 and is the comparative reference point used in this analysis.

The modelled flow scenarios do not include the four flushing flows of up to 30 m^3/s that will be released from the dam for a duration of 9 hours on each occasion.

It is important to note that the Makaroro flow series supplied by Tonkin & Taylor were for flows at the base of the proposed dam. These were derived from modelled flows at the Makaroro Burnt Bridge site, being factored by 0.952 to account for the smaller catchment size. This accounts for the difference in flow statistics between Tables 3 / 4 and Table 13.

Additional scenarios exploring different levels of Scheme uptake by current groundwater irrigators and exploring the outcomes of different environmental low flow supplementation strategies have also been modelled and are described in detail in Aquanet (May 2013).

The majority of our assessments presented below are based on the original 4 flow scenarios. However, the effects of all the different scenarios on habitat availability for the most flow demanding fish (adult rainbow trout and torrentfish) and food producing habitat are given in Section 3.4.5.5 below.

The Aquanet (May 2013) analysis modelled flow in the Lower Tukituki using a selection of low flow thresholds to supplement ‘natural’ low flows experienced in summer. The thresholds include the current and proposed regulatory minimum flows (‘Cur MF’ and ‘Prop MF’ respectively), the current 7-day Mean Annual Low Flow (‘MALF’), and the Q_{99}, Q_{98}, Q_{97}, Q_{96} and Q_{95} flows.

Given the higher prevalence of environmental issues during summer and the higher recreational use during this period, the analysis was conducted on the basis of low flow supplementation during two periods: December to April and December to February (inclusive) (Aquanet May 2013).

3.4.2.1. *Change to mean and median flow statistics*

Changes to the flow statistics of selected sites under the different flow scenarios are presented in Table 13 and Figures 20-23.

Mean annual flow in the Makaroro River below the dam (Reach 3) does not change under the proposed flow regime. However, monthly median flows (Figure 20) are significantly different. Median flows in January and February are more than five times higher under the proposed flow regime than for the natural regime, whereas the opposite is true in June when median flows are four times higher under a natural regime.

Similarly, mean annual flow in the Waipawa River between the Makaroro confluence and the irrigation intake (Reach 4) does not change under the proposed flow regime when compared to status quo. However, median monthly flows are higher under the proposed flow regime, particularly in summer when water is released from the dam to supply flow to the irrigation network (Figure 21). Median annual flow is 27% higher under the proposed flow regime (Table 13) and median monthly flow between November and February is two to three times the natural / status quo median flow for this time of year.

The combined effect of the proposed flow regime below the dam and abstraction of water from the Waipawa at the irrigation intake, results in a 19% decrease in the mean annual flow and a 30% decrease in median flow immediately downstream from the intake (the upper limit of Reach 5) compared with the status quo (Table 13). Monthly median flow under the proposed flow regime stays below that of the status quo monthly median flow throughout the year (Figure 21).

At the Waipawa RDS site, further downstream in Reach 5, modelled flows for Scenario 4 (Dam and abstraction) indicate that mean annual flow will be about 16% lower than that of the status quo (Scenario 2), while median annual flow will be 25% lower than for status quo (Table 13; Figure 22). Modelled flows with the dam only

(Scenario 3) gave similar results to Scenario 4, however all mean and medians were slightly higher (Table 13).

In the lower Tukituki River (Reach 6), modelled flows at the Tukituki at Red Bridge site indicate that the dam and irrigation (Scenario 4) will reduce mean and median flows by 5% and 9%, respectively, compared with the status quo (Scenario 2) (Table 13). Median monthly flows for the different scenarios are relatively similar from July to September (Figure 23). Modelled flows for the dam only (Scenario 3) indicate a 3% and 5% drop in mean and median annual flow, respectively compared with the status quo (Table 13).

Comparing flow statistics of the 52 different flow scenarios modelled for flow optimisation in Reach 6 (Appendix 20) to those of the status quo (Scenario 2) shows that there is more than 90% retention of mean and median flow under all of the modelled scenarios. This is also the situation for Waipawa below the irrigation intake (Aquanet May 2013).

Table 13. Flow statistics for selected sites with and without the flow regime associated with the proposed dam (From HBRC Science May 2013a). u / s = upstream, d / s = downstream.

Flow statistic	**Makaroro downstream from dam Reach 3**		**Makaroro / Waipawa confluence Reach 4**		**Waipawa u / s of irrigation intake Reach 4**		**Waipawa d / s of irrigation intake Reach 5**	**Waipawa at RDS Reach 5**				**Tukituki at Red Bridge Reach 6**			
	No Dam	Proposed	No Dam	Proposed	No Dam	Proposed	Proposed	Naturalised No Dam Scenario 1	Abstraction only Scenario 2	Dam only Scenario 3	Dam and abstraction Scenario 4	Naturalised No Dam Scenario 1	Abstraction only Scenario 2	Dam only Scenario 3	Dam and abstraction Scenario 4
Mean annual flow (m^3/s)	6.3	6.3	11.4	11.5	11.9	12	9.6	14.9	14.6	12.5	12.3	44.1	43.2	41.7	40.9
Median annual flow (m^3/s)	3.5	3.3	7.0	8.9	7.3	9.3	5.1	8.7	8.4	6.6	6.3	21.5	20.6	19.5	18.7
MALF (Instantaneous)	1.14	1.2	2.7	2.89	2.82	3.02	2.79	2.61	2.34	2.56	2.28	5.44	4.5	5.36	4.51
MALF (7-day)									2.67	2.79	2.52		5.32	6.06	5.21

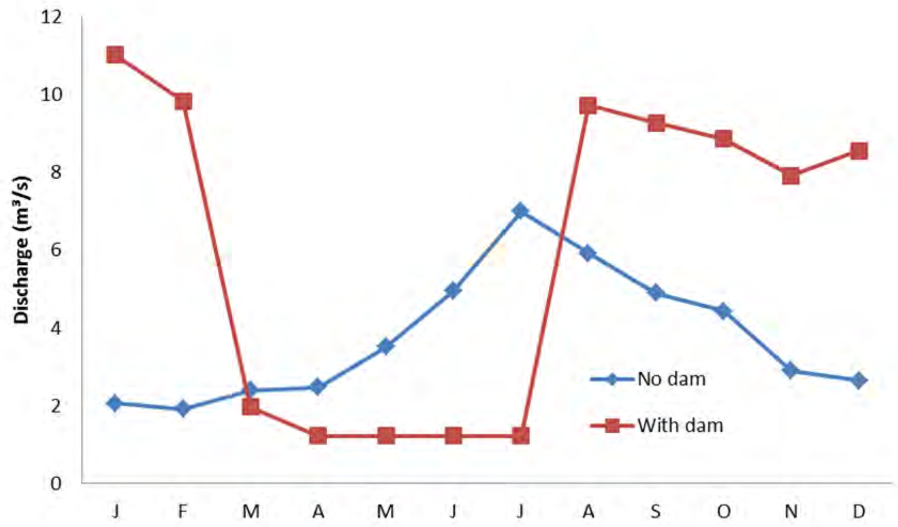

Figure 20. Monthly median flow: Makaroro below dam (Reach 3) (1972–2010)

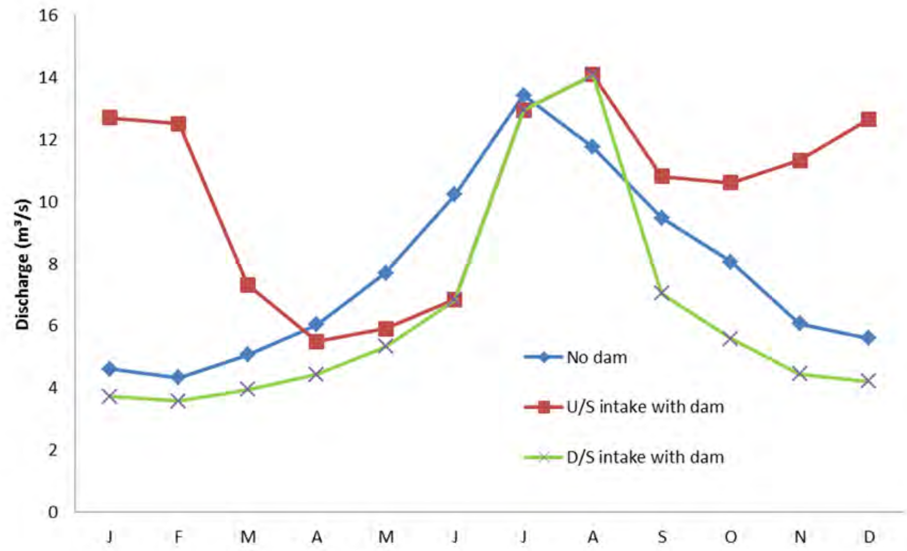

Figure 21. Monthly median flow: Waipawa upstream and downstream of the irrigation intake (Reaches 4 and 5) (1972–2010).

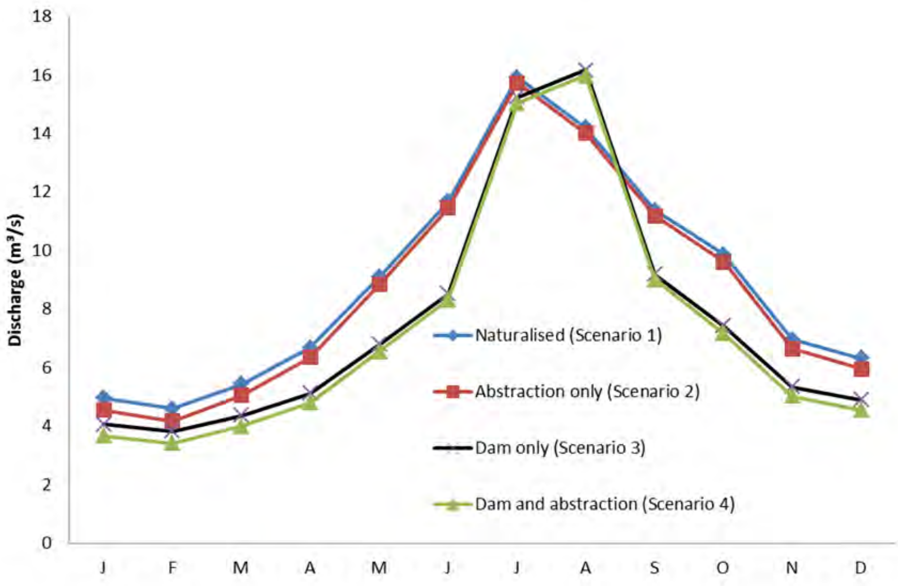

Figure 22. Monthly median flow: Waipawa at RDS (Reach 5) (1972–2008).

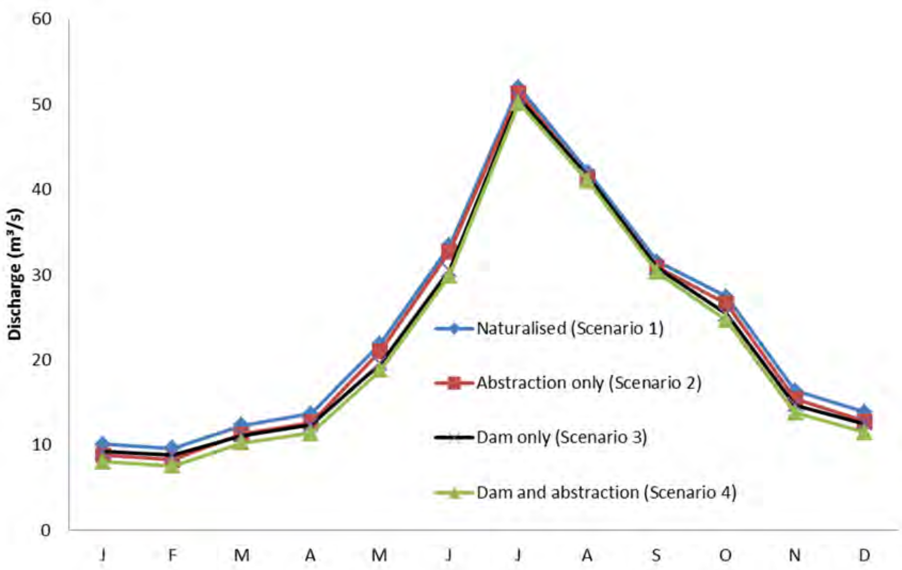

Figure 23. Monthly median flow: Tukituki at Red Bridge (Reach 6) (1972–2008).

3.4.2.2. Low flows

Mean annual low flow (MALF) for each of the reaches under different proposed flows are compared with status quo flows in Table 14. All sites show either no significant change or a slightly higher MALF under the proposed flow regime. However, there are significant improvements in extreme low flows (*e.g.* Q_{99}, the flow exceeded 99% of the time) associated with the scheme (HBRC Science May 2013a). For example, the Q_{99}

flows at the Waipawa at RDS and Tukituki at Red Bridge sites are expected to increase by 5% & 14%, respectively under the Scenario 3 flow regime compared to the status quo, and by 13% & 7%, respectively compared to the status quo under the Scenario 4 flow regime (HBRC Science May 2013a). Similarly, the number of days less than the proposed minimum flow is predicted to reduce from 23 days to 14 days at the Waipawa at RDS site and from 22 days to 10 days at the Tukituki at Red Bridge site under Scenario 3 flow regime. However, under the Scenario 4 flow regime the number of days less than the proposed minimum flow would increase from 23 to 31 days at the Waipawa at RDS site and from 22 to 26 days at the Tukituki at Red Bridge site (HBRC Science May 2013a).

Table 14. Mean annual low flow (MALF) (1972-2010) for the proposed flow regimes at selected sites (as a % of the status quo MALF). u / s = upstream, d / s = downstream.

Site / scenario		**MALF retained (%)**
Makaroro below dam[1]		105
Makaroro / Waipawa confluence[1]		107
Waipawa u / s irrigation intake[1]		107
Waipawa d / s irrigation intake[1]		99
Waipawa RDS[2]	Scenario 3	109
	Scenario 4	98
Tukituki Red Bridge[2]	Scenario 3	119
	Scenario 4	100

Notes:
[1] Compares status quo and proposed regimes.
[2] Compares status quo (Scenario 2) with Scenarios 3 and 4.

Table 15 summarises changes to the 1-day MALF for the 52 different flow scenarios modelled for flow optimisation in Reach 6 in relation to the 1-day MALF of the status quo (Scenario 2). Full results are displayed in Appendix 20, including the modelled values for the 7-day MALF. The 7-day MALF could not be included in Table 15 because the status quo was calculated using a 1-day MALF (Table 13).

The colour coding used in Table 15 and subsequent tables is intended to help the reader gauge the scale of change brought about as a result of changes to the flow regime. The colours do not represent critical values.

There is an increase in MALF of up to 46% under the modelled scenarios (*i.e.* up to 146% retention). Whilst all of the MALFs are predicted to rise to some extent. Increases are most pronounced when using Q_{90} – Q_{94} thresholds under Scenario 3 (Dec-April) (Table 15).

Table 15. Predicted 1-day Mean Annual Low Flow (MALF) retention for the 52 different scenarios modelled for Tukituki at Red Bridge (Reach 6), as compared to that of the status quo (Scenario 2). Rows titled 'Prop MF' and 'Cur MF' represent modelled scenarios using the current and proposed minimum flows, respectively, 'MALF' uses the current 7-day MALF, and Q_{99}, Q_{98}, Q_{97}, Q_{96} and Q_{95} are flow exceedence percentiles (Aquanet May 2013)

	Scenario 3 Dec–Feb Top Up (%)	Scenario 3 Dec–April Top Up (%)	Scenario 4 Dec–Feb Top Up (%)	Scenario 4 Dec–April Top Up (%)
>Prop MF	123	124	109	113
MALF	129	134	113	124
Cur MF	120	120	101	101
Q99	121	121	104	105
Q98	122	123	107	111
Q97	124	126	109	115
Q96	126	128	111	118
Q95	127	131	112	121
Q94	129	134	113	124
Q93	130	137	114	127
Q92	131	140	115	130
Q91	132	143	116	132
Q90	133	146	117	135

Key: retention (as a % of status quo)				
100-110%	110-120%	120-130%	130-140%	>140%

This analysis uses a status quo 1-day MALF value of 4.5 m³ / s as the basis for comparison (from Table 13).

To assess the seasonal effects of the proposed flow regime on Reaches 3-6, the mean monthly low flow was calculated for all sites. These have been plotted in Figures 24–27. For ease of comparison, mean monthly low flows under the proposed flow scenarios are compared with status quo flows (% retention) and summarised in Table 16.

During summer, monthly minimum flows in the Makaroro and Waipawa rivers upstream of the irrigation intake (Reaches 3 and 4) are higher than status quo flows as a result of irrigation flow releases. However, monthly minimum flows in the Waipawa River downstream of the irrigation intake during summer are lower than for status quo because the irrigation releases and some extra water are abstracted into the irrigation network (Table 16). The reductions in flows at the Waipawa at RDS are most marked for Scenario 4, which includes the dam and groundwater takes. The changes in flow for the Tukituki at Red Bridge are less marked but with a similar summer reduction in monthly minimum flows under Scenario 4, but an increase in summer monthly minimum flows for Scenario 3 resulting from the switch from groundwater takes to dam supply under this scenario.

During autumn, winter and spring monthly minimum flows in the Makaroro and Waipawa rivers are reduced compared to status quo because the dam is being refilled during these periods (Table 16).

The changes in mean monthly low flows resulting from the Scheme are most dramatic close to the dam and attenuate downstream (Table 16).

Changes to the mean monthly low flow for the 52 different flow scenarios modelled for flow optimisation in Reach 6 can be found in Appendix 21. There were few significant changes (>110% or <90% retention) from April to December under all modelled scenarios. The most significant increase in mean monthly low flow was during January and February using Q_{90} – Q_{94} thresholds, particularly under the Scenario 3 regimes, where MALF was up to 30% higher than MALF at the status quo.

Table 16. Mean monthly low flow for the proposed flow regimes at selected sites (as a % of status quo mean monthly low flow). u / s = upstream, d / s = downstream.

Month	Makaroro below dam[1]	Waipawa u / s irrigation intake[1]	Waipawa d / s irrigation intake[1]	Waipawa RDS[2]		Tukituki Red Bridge[2]	
				Scenario 3	Scenario 4	Scenario 3	Scenario 4
J	114	122	87	97	86	109	94
F	124	133	90	99	88	112	95
M	70	102	88	97	87	106	94
A	66	87	82	89	82	103	92
M	53	82	82	87	82	96	91
J	37	72	72	78	75	93	90
J	61	77	77	82	80	96	94
A	39	71	71	78	76	94	91
S	44	77	74	79	77	94	91
O	51	83	74	80	76	96	92
N	56	103	82	88	81	99	91
D	86	109	83	90	82	105	93
Year	60	89	79	85	80	98	92

Flow loss					Key	Flow gain		
< 40%	40-50%	50-60%	60-70%	70-80%	90-110%	110-120%	130-140%	> 140%

Notes:
[1] Compares status quo and proposed regime.
[2] Compares status quo to Scenarios 3 and 4.

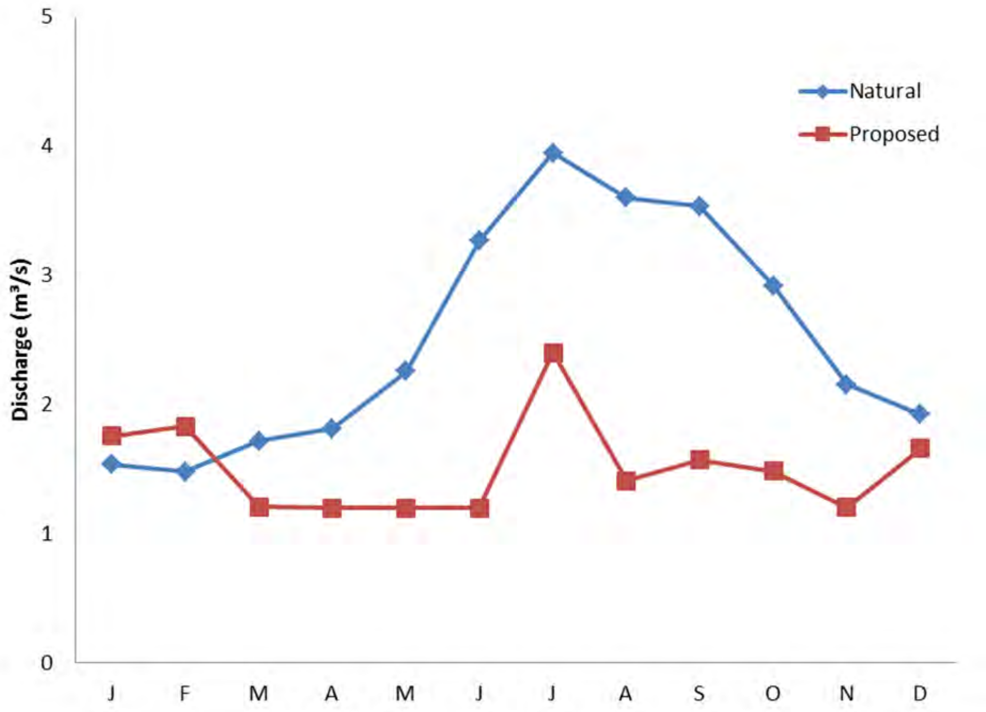

Figure 24. Mean monthly low flow: Makaroro below dam (Reach 3) (1972–2010).

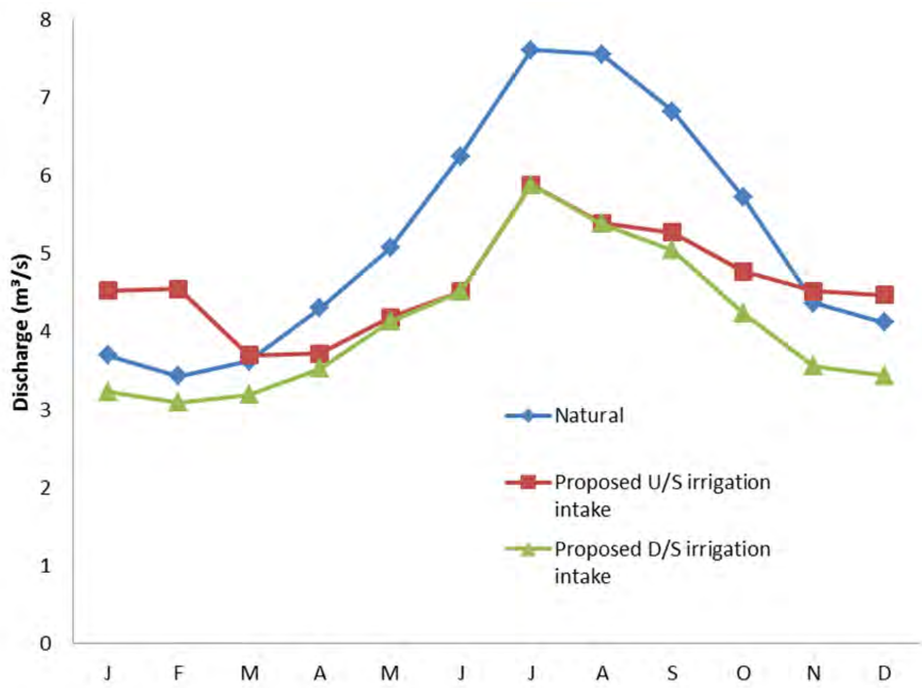

Figure 25. Mean monthly low flow: Waipawa upstream and downstream of irrigation intake (Reaches 4 and 5 respectively) (1972–2010).

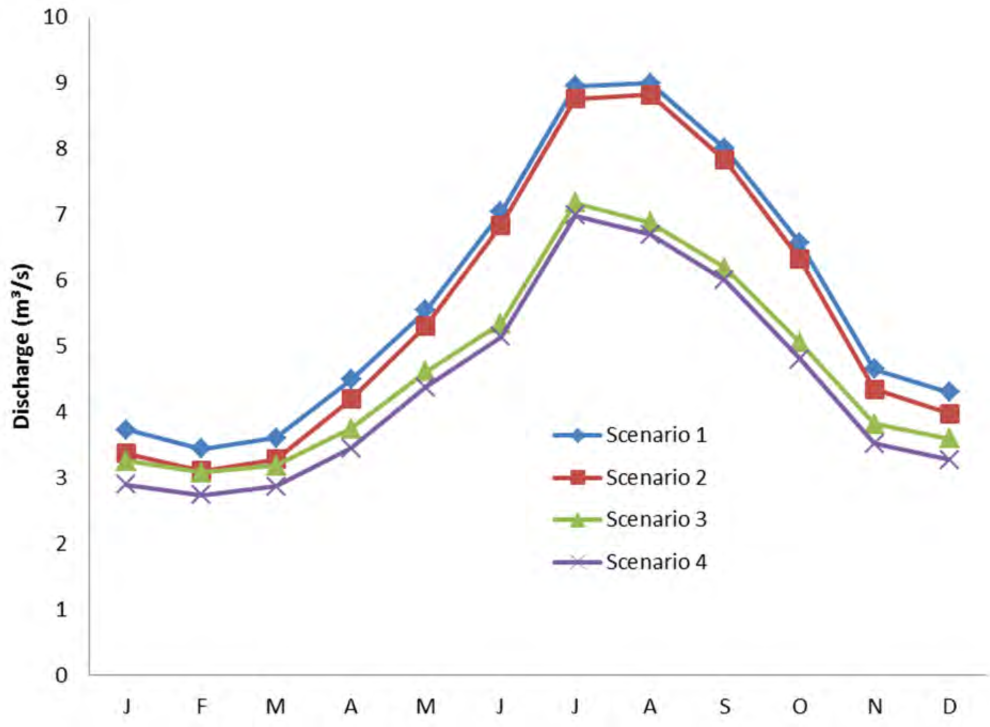

Figure 26. Mean monthly low flow: Waipawa at RDS (Reach 5) (1972–2008).

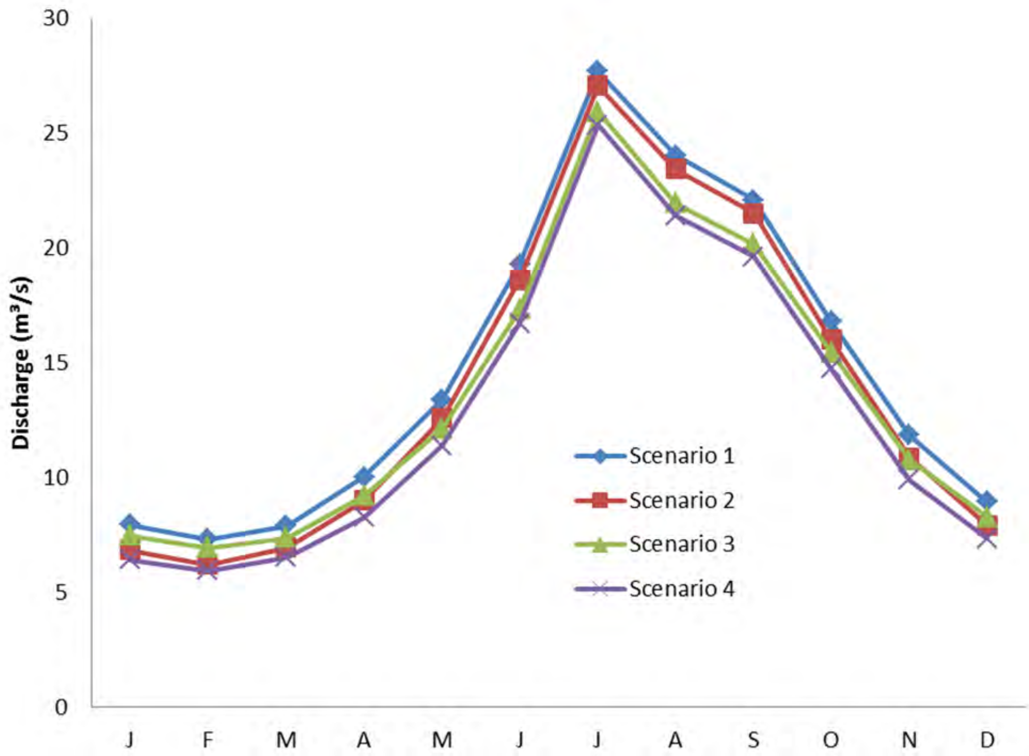

Figure 27. Mean monthly low flow: Tukituki at Red Bridge (Reach 6) (1972–2008).

3.4.2.3. Changes to flushing flow frequency

During prolonged periods of stable low flow, periphyton and fine sediments can accumulate to excessive levels in the streambed, adversely affecting water quality, invertebrates and aesthetic values. Flushing flow capable of removing these accumulations of periphyton and sediment are important for maintaining the health of the river ecosystem.

Clausen & Biggs (1997) developed the concept of FRE3 flushing flows based on research showing a strong negative relationship between periphyton (measured using chl-*a* concentration) and the frequency of floods > 3 times the median flow. This provided a rule of thumb that can be used to determine the appropriate size of periphyton flushing flows. For example, the post-scheme median flow of the Makaroro River downstream of the dam is predicted to be 3.3 m^3/s (Table 13); so this rule of thumb would suggest a flushing flow of 3 x 3.3 m^3/s = 10.0 m^3/s.

To better understand the effect that the proposed flow regime will have on the frequency of FRE3 flows in each reach, a variety of average annual statistics were extracted from the data (Table 17). Studies on the accumulation of periphyton in New Zealand rivers have found that in the absence of adequate flushing flows, accrual of aquatic algae potentially increases exponentially to reach ‘nuisance’ levels after a period of around six weeks, if there are abundant nutrients and sunlight available (Scrimgeour & Winterbourn 1989; Biggs & Stokseth 1996). Hence the mean annual 6 week period with no FRE3 flow was calculated under the natural and proposed flow regime.

Analyses of the relationship between periphyton biomass and flow fluctuations in the Tukituki River indicate that flows twice the median are sufficient to clear some of the ‘fluffy’ brown periphyton and detritus that can accumulate along the edges of the river at times (Adam Uytendaal, HBRC, pers. comm.). Therefore, FRE2 flushing flow statistics were also calculated (Table 18).

It should be remembered that a flow of three times the median flow is not a threshold flow — some periphyton and sediment flushing will still occur at lower flows, and more effective flushing will potentially occur at higher flows (See Appendix 28).

The analysis was limited by the fact that it used mean daily flow records and not instantaneous or maximum daily flow records. However, the analysis still provides an insight into the impact of the dam on flushing flows. For each reach and flow scenario, comparisons were made using the appropriate FRE3 / FRE2 defined by the modelled flow record (*i.e*. relevant to the dataset being analysed, not always the natural FRE3 / FR2). It is also important to note that the four annual flushing flows that are incorporated into the Scheme design are not incorporated into this hydrological analysis. A detailed discussion of the potential benefits of the flushing flows incorporated into the Scheme design is provided in Section 4.5.

Makaroro downstream of the dam

In the Makaroro River there will be almost twice as many flows at both three times the median flow (FRE3) and two times the median flow (FRE2) under the proposed flow regime (Tables 17 and 18). There will also be a 40% reduction in the average number of times each year that six consecutive weeks pass by without a FRE2 or FRE3 flow. In other words, there will be more flushing flows spaced more evenly throughout the year.

The longest period over which there were no FRE2 or FRE3 flushing flows will be slightly less under the proposed flow regime.

At first glance this result seems anomalous considering that natural flushes will generally be trapped within the reservoir and the frequency of flooding in this reach drops as a result of the Scheme (Tonkin & Taylor 2011a). The reason for this apparent anomaly relates to the size of the proposed irrigation release flows which just exceed the FRE3 threshold (10 m^3/s). Therefore, if the FRE3 threshold is strictly used to define a flushing flow (*e.g.* Table 17) then every time an irrigation flow is released this is sufficient to serve as a flushing flow.

Table 17. Changes to FRE3 flushing flow statistics under the proposed flow regime for Reach 3 and 4 and downstream of the irrigation intake.

	Makaroro at dam site		**Waipawa upstream of irrigation**		**Waipawa downstream of irrigation**	
	No Dam	**Proposed**	**No Dam**	**Proposed**	**No Dam**	**Proposed**
Median flow	3.5	3.3	7.3	9.3	7.3	5.1
Magnitude of FRE3 flow (three times the median flow) (m^3/s)	10.5	10.0	21.9	28.0	21.9	15.3
Mean annual frequency of FRE3 days	49	92	39	18	39	64
Mean annual frequency of six week periods with no FRE3 flow	2.4	1.4	2.4	2.1	2.4	2.2
Longest period with no FRE3 flows (days)	262	218	301	404	301	287

Table 18. Changes to FRE2 flushing flow statistics under the proposed flow regime for Reach 3 and 4 and downstream of the irrigation intake.

	Makaroro		Waipawa upstream of irrigation		Waipawa downstream of irrigation	
	No Dam	Proposed	No Dam	Proposed	No Dam	Proposed
Median flow	3.5	3.3	7.3	9.3	7.3	5.1
Magnitude of FRE2 flow (two times the median flow) (m^3/s)	7.0	6.6	14.6	18.7	14.6	10.2
Mean annual frequency of FRE2 days	81	158	75	41	75	93
Mean annual frequency of six week periods with no FRE2 flow	2	0.9	2.3	2.4	2.3	1.9
Longest period with no FRE2 flows (days)	259	200	258	307	243	243

Waipawa upstream of the irrigation take

The FRE3 analysis indicates that under the proposed flow regime there will be approximately half the number of days each year where flows exceed three times the median flow in the Waipawa (Reach 4)(Table 17). It is also predicted that the longest period between FRE3 flows will be significantly longer, but the annual frequency of extended low flow (6 week) periods stays about the same.

This result is conceptually consistent with the fact that most natural flushes will be captured by the dam. The change in the flushing flow regime in the Waipawa River upstream of the irrigation intake will increase the risk of periphyton accumulations compared to status quo conditions, although nutrient concentrations upstream of the intake are not likely to be high and the four annual flushing flows incorporated into the scheme design will effectively remove any periphyton accumulations that do occur in this reach.

Waipawa downstream of the irrigation intake

The median flow under the proposed flow regime downstream of the irrigation intake is significantly lower than for both the status quo flow regime at this site and the proposed flow regime upstream of the intake (Table 17). Correspondingly, a flushing flow of three times the median flow at this site is approximately half of that upstream of the intake. As a result, there is a 20% increase in the mean annual frequency of flushing flows through this reach compared with the status quo. Statistics describing the duration between flushing flows are essentially the same as the status quo flow regime (Table 17).

Therefore, in contrast to upstream of the irrigation intake the change in the flushing flow regime in the Waipawa River downstream of the irrigation intake will reduce the risk of periphyton accumulations compared to status quo conditions. However, a reduction in larger flood flows in this reach is expected as a result of the Scheme (Tonkin & Taylor 2011a). The four annual flushing flows that have been incorporated into the scheme design will also enable flushing of periphyton accumulations in this reach.

Tukituki at Red Bridge

In the Tukituki River at Red Bridge (Reach 6), there will be 7% more days each year with flows at or greater than three times the median flow (FRE3) under Scenario 4 than under status quo conditions (Scenario 2) (Table 19). There is no significant change to the average number of times each year that six consecutive weeks pass by without a FRE3 flow, nor is there a difference in the longest period over which there were no flows of three times the median or more.

Changes in the flow regime of the lower Tukituki River are therefore not expected to cause an increase in periphyton accumulations. The flushing flows that have been incorporated into the Scheme design therefore provide a clear environmental benefit over the status quo and will help to meet the objectives of the proposed Tukituki Plan Change 6.

Table 19. Changes to FRE3 and FRE2 flushing flow statistics under the Scenarios 1 to 4 for Reach 6.

	Tukituki Red Bridge			
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Median annual flow	21.5	20.6	19.5	18.7
Magnitude of FRE3 flow (three times the median flow) (m^3/s)	64.6	61.9	58.4	56
Magnitude of FRE2 flow (two times the median flow) (m^3/s)	43	41.3	38.9	37.3
Mean annual FRE3 days	53	55	56	59
Mean annual FRE2 days	86	89	92	95
Mean Annual six week periods with no FRE3	2.1	2.2	2.0	2.0
Mean Annual six week periods with no FRE2	2.1	2.1	2.1	2.1
Longest period with no FRE3 flows (days)	298	298	298	298
Longest period with no FRE2 flows (days)	258	257	257	254

3.4.3. Effects of hydrological changes on the physical environment

3.4.3.1. Changes to river bed substrate

As described in Section 3.3.2, the dam will trap all bed load and the majority of suspended sediment delivered by the upper Makaroro River. The reduction in sediment supply will be most evident in the Makaroro River (Reach 3), as the Waipawa River will still receive sediment from the Waipawa catchment.

Also mentioned in Section 3.3.2 was the likely effect of a reduction in flood flows with the proposed flow regime. In that regard, Tonkin & Taylor (2011a) estimated the mean annual flood in the Makaroro River will be reduced by more than 47%.

The combined effect of the loss of sediment supply and a reduced flood magnitude / frequency is likely to be increased armouring and entrenchment of the bed through this reach (Tonkin & Taylor May 2013b). It is anticipated that finer sediments will be transported downstream whilst coarser sediments remain, changing the substrate composition in the Makaroro downstream of the dam, although this change will occur slowly and take several years.

River morphology in reaches below the Makaroro / Waipawa confluence is not expected to be changed to the same extent as the Makaroro itself, being immediately downstream of the dam.

The exact implications of the changes in substrate composition on instream habitat throughout Reach 3 are difficult to quantify precisely, but habitat suitability criteria (Appendix 19) provide a good indication. Bed sediment found near the head of the proposed reservoir had a median grain size of 16 mm, with a 10th and 90th percentile of 1.6 mm and 88 mm respectively (Tonkin & Taylor May 2013b). It was noted that the gorge at the dam site constituted a higher proportion of larger rocks. Williams (1985) found that the median grain size in the armour layer was 65 mm. If the proposed flow regime induces coarsening and increased armouring of the bed as suggested by Tonkin & Taylor (May 2013b), then the median grain size is expected to increase from 16 mm to something closer to the 65 mm found by Williams (1985).

Based on habitat suitability criteria for selected species (as shown in Appendix 19), species whose habitat is likely to be positively affected by this shift in substrate composition include the net-spinning caddisfly (*Aoteapsyche*), mayfly (*Deleatidium*) free living caddisflies (Hydrobiosidae), chironomids (Orthocladiinae), diatoms and algae, longfin and shortfin eels, torrentfish, redfin bully, bluegill bully and common bully.

Species that are more likely to be adversely affected by the shift in substrate composition include spawning rainbow trout, adult rainbow trout (> 20cm), Cran’s bully, dwarf galaxias, smelt, and riffle beetles (Elmidae). Although dwarf galaxias are considered to be in decline (Table 10), they are found widely throughout the catchment (Appendix 17) and the reach of the Makaroro River downstream of the dam is not considered to represent a population 'hotspot'. Cran's bully are similarly widespread throughout the Tukituki catchment and elsewhere, thus limiting the localised effects downstream of the dam.

Compared to other fish, spawning rainbow trout have a narrow range of preferred substrate size (Appendix 19). Therefore changes in substrate size associated with the dam and proposed flow regime are likely to have detrimental effects on the availability of suitable spawning gravels. These effects are discussed further in Section 3.4.7 and recommended approaches for mitigation are identified in Section 4.5.

3.4.3.2. Changes to water velocity and depth

Instream habitat modelling was used to assess the change in water velocity and depth with variations in flow. More details on the methods used are presented in Section 3.4.5 below. This section does not account for changes due to daily flow fluctuations caused by winter hydro-peaking and summer irrigation supply flows. This is covered in detail in Section 3.4.6.

Water velocities and depths will increase with increasing discharge as quantified in Figures 28-30. Under the proposed flow regime, median flow in the Makaroro (Reach 3) will decrease slightly from 3.5 m^3/s to 3.3 m^3/s. This results in no significant change in water depth and velocity.

In the Waipawa, Reach 4, median flow will increase from 7.0 m^3/s to 8.9 m^3/s. This corresponds to a 12% increase in velocity and a 5% increase in depth. Below the irrigation intake (Reach 5), median flow decreases from 7.3 m^3/s to 5.1 m^3/s, corresponding to a 16% decrease in velocity and 10% decrease in depth. Habitat data was not available for the Waipawa at RDS site, so no habitat modelling was possible.

There would be minimal changes to median flows at the Tukituki at Red Bridge site, and so there would be no significant change in water depth and velocity under the proposed flow regime.

The extent to which changes in these physical variables affect specific organisms is dependent on the physical habitat requirements of those organisms. The predicted effects on specific taxa are modelled and discussed in the following sections.

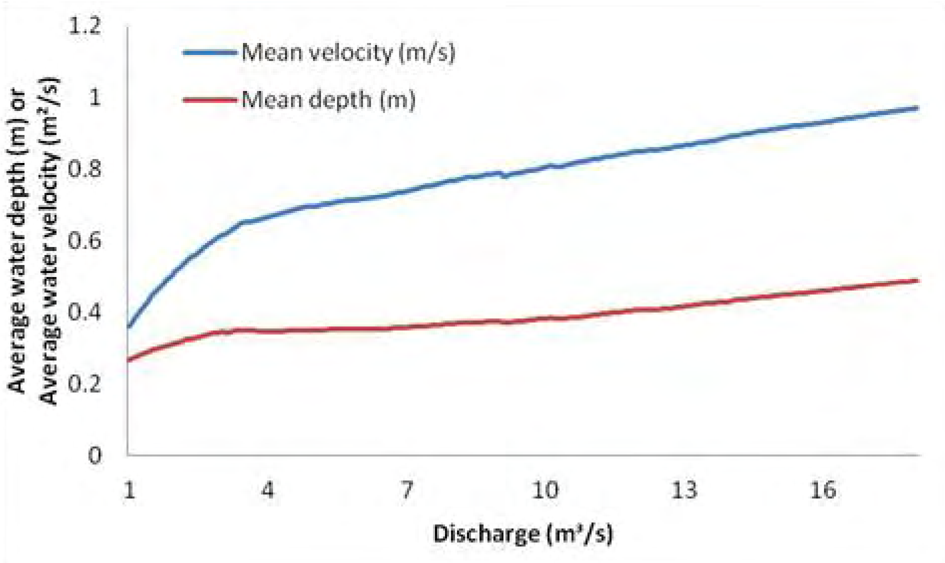

Figure 28. Change in average depth and velocity for the Makaroro River with flow (Reach 3). Data derived from IFIM instream habitat modelling.

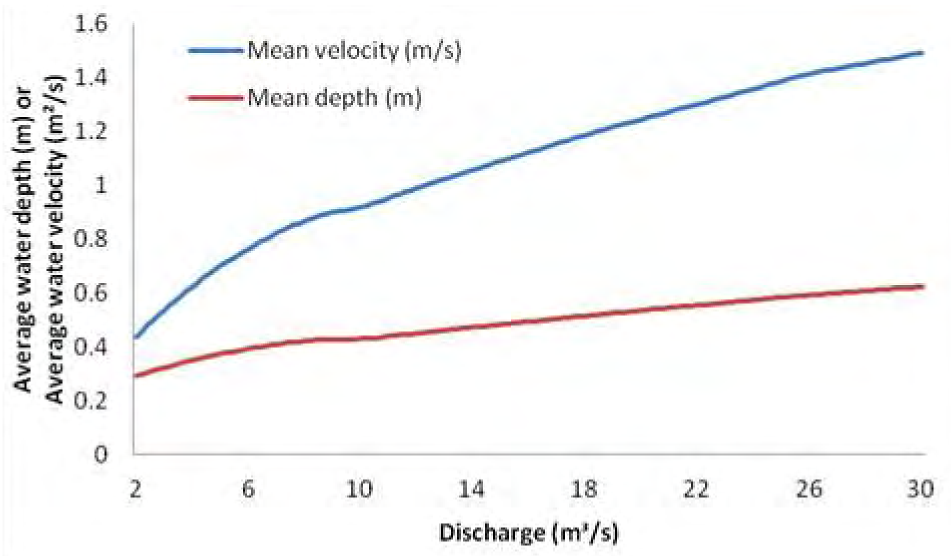

Figure 29. Change in average depth and velocity for the Waipawa River (Reach 4) with flow. Data derived from Johnson (2011).

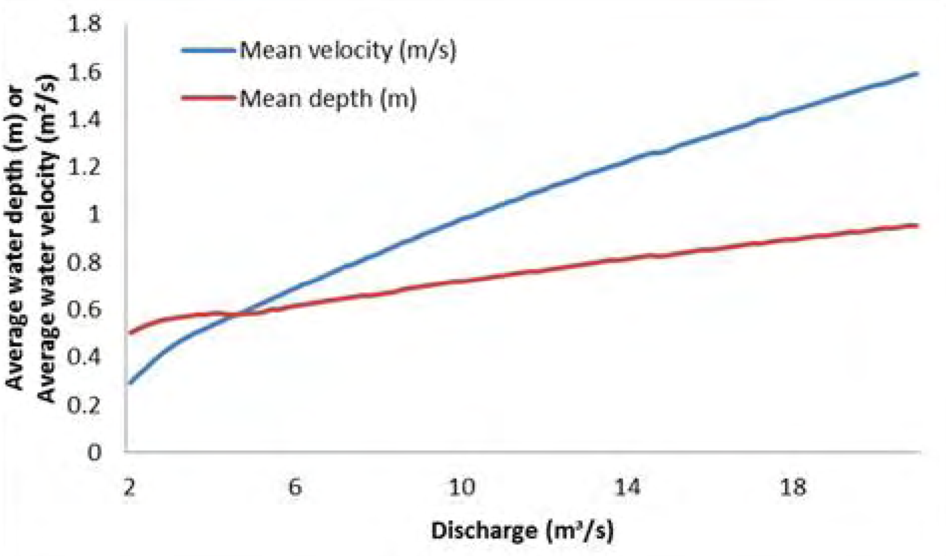

Figure 30. Change in average depth and velocity for the Lower Tukituki River (Reach 6) with flow. Data derived from Johnson (2011).

3.4.4. Effects of hydrological changes on water quality

3.4.4.1. Water temperature

During low flows, the magnitude of daily temperature fluctuations will be higher, because a smaller volume of water with shallower average depth tends to warm and cool more rapidly. However, studies elsewhere indicate that water temperatures are not particularly sensitive to changes in flow — and noticeable effects are only expected at extremely low flows (Theurer *et al*. 1984). The effects of shading (or lack of) and changes to inputs of cool groundwater would be expected to have a much greater impact on the thermal regime of the river.

In the Makaroro River downstream of the dam (Reach 3) and Waipawa River upstream of the irrigation intake (Reach 4) summer flows will generally be higher than they are currently and therefore daily temperature fluctuations are expected to be reduced slightly compared to the status quo. More importantly, water released from the bottom of the dam will generally be considerably cooler (up to 7°C in the summer, NIWA May 2013c) and have smaller daily fluctuations than is occurring currently (Section 3.3.3; NIWA May 2013c) — again decreasing the likelihood of temperature thresholds being exceeded in these reaches of the catchment. Therefore any effects of the proposed scheme on water temperatures in these reaches are expected to be small and beneficial to temperature sensitive species in the ecosystem.

Downstream of the irrigation intake, flows are reduced compared with natural flows, although the reduction is relatively small in summer (Figure 21) when the effects of temperature are of relevance. Using the temperature modelling module within

RHYHABSIM and the habitat survey data for this reach, this reduction in flow is predicted to result in no change to mean temperatures and no more than a 0.5°C increase in maximum water temperature through this reach (Figure 31).

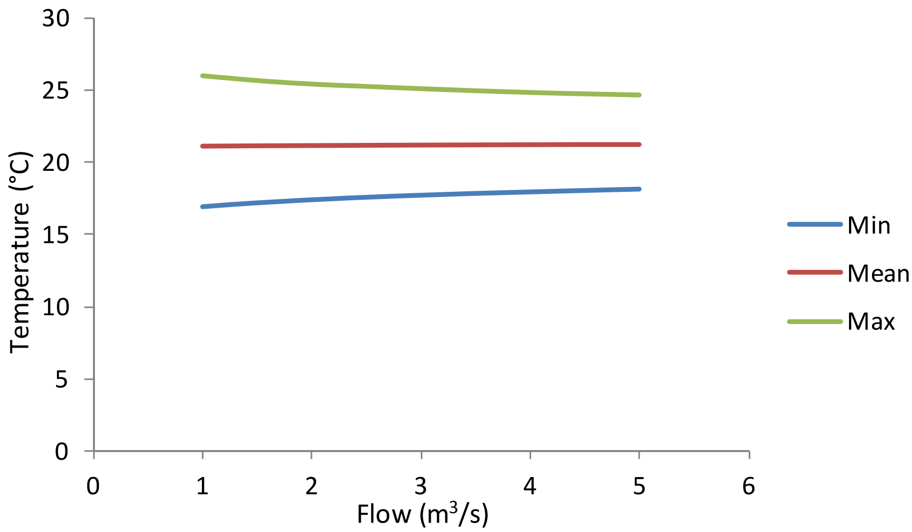

Figure 31. Predicted mean, minimum and maximum water temperatures associated with changes in flow in the Waipawa downstream of the irrigation intake.

Further downstream, the inputs of flow from the Mangaonuku and Tukituki rivers will further reduce any effect of flow change on water temperature, to the extent that such changes will be barely noticeable. In HBRC Science (May 2013a) the prediction is that a reduction in groundwater takes (compared to the current level of abstraction) would result in an increase in inputs of groundwater to streams and rivers. The groundwater is expected to be cooler than the surface water in summer, which would be beneficial for temperature sensitive species. The scale of benefits are expected to be proportional to the amount of increased groundwater flows, itself dependent on the proportion of current groundwater takes that are switched over to water supply from the Scheme. Scenario 3 is predicted to return spring flows to very close to natural groundwater conditions.

3.4.4.2. Dilution of contaminants

The change in the ability to dilute contaminants will largely reflect the relative change in flow resulting from the Scheme.

Water quality in Reaches 3 and 4 is currently good and is not expected to change markedly as a result of the Scheme. Any inputs of contaminants along these reaches will be diluted to a greater extent in the summer when flows will be elevated by the Scheme, and less diluted during autumn / winter when flows are lower than the status quo. However, the inputs through this reach are expected to be small and therefore the effects of reduced nutrient dilution during late autumn and winter on the aquatic ecosystem in this reach are expected to be minor.

In the Waipawa River downstream of the irrigation intake, flows will be lower than status quo conditions throughout the year, therefore the capacity to dilute contaminants will be continually reduced. The reduction in median monthly flow ranges from 0.6 m^3/s in August and September to 2.8 m^3/s in June (Figure 21), which equates to a 5-32% decrease in median monthly flow.

Further downstream in the Waipawa River at RDS median monthly flows are predicted to be reduced in all months except July and August. Flow changes associated with the Scheme range from a 16% increase in monthly median to a 28% decrease.

At the Tukituki at Red Bridge site the effects of the proposed Scheme on flows are reduced with predicted monthly medians under Scenario 4 between 1-11% lower than the status quo with an associated reduction in capacity to dilute contaminants. However, monthly minimum flows are predicted to be higher during summer and early autumn with the proposed scheme (Table 16), so should result in an increased capacity for contaminant dilution during this critical period.

The changes in contaminant concentrations resulting from changes in land use associated with the Scheme have been modelled in detail by NIWA (May 2013a). The effects of these changes are addressed in Section 3.6. However, this modelling does not address the changes in dilution capacity mentioned above.

3.4.5. Effects of hydrological changes on the biological environment

3.4.5.1. Methodology

Instream habitat modelling

The flow related habitat requirements of instream communities (*e.g.* periphyton, macroinvertebrates and fish) in the Makaroro and Waipawa rivers were assessed by hydraulic-habitat modelling. The computer program, RHYHABSIM Version 5.0 (developed by I Jowett, formerly of NIWA) was used for this purpose, complemented with additional analysis and modelling to summarise effects of the proposed flow regime. This approach was consistent with the Instream Flow Incremental Methodology (IFIM).

The IFIM is a decision-support framework, which provides a process for assessing environmental flows and water allocation effects on instream values (Bovee *et al*. 1998). Hydraulic-habitat modelling is used to simulate the relationship between habitat and flow for various instream values based on physical habitat suitability criteria (*i.e.* suitable depth, water velocity and substrate curves). RHYHABSIM can also be used to simulate the relationship between bed flushing and flow and the effects of fluctuating flows (*e.g*. hydropeaking) on habitat. For a full description of hydraulic and habitat modelling and how it is applied in New Zealand see Jowett *et al.* (2008). Hydraulic-habitat modelling entails measuring water depths and velocities and substrate composition across several representative stream cross-sections at a given flow (referred to as the survey flow). Points on the banks, above water level, along the cross-sections are also surveyed to allow model predictions to be made at flows higher than the survey flow. Additional measurements of water level for each cross-section, relative to flow, are taken on subsequent visits to allow calibration of a hydraulic model for predicting how depths, velocities and the area of different substrate types covered by the stream will vary with discharge in the surveyed reach.

Modelled depths, velocities and substrate types can then be compared with habitat suitability criteria (HSC) describing the suitability of different depths, velocities and substrate sizes as habitat for given species of interest. These criteria take the form of habitat suitability curves, which have been developed by observing the depths and velocities used by various species, both in New Zealand and overseas. Comparison of the HSC with the modelled physical characteristics of the study stream provides a prediction of the availability of habitat in the stream. Modelled depths and velocities can also be used to assess the impact of a proposed fluctuating flow regime. HSC for selected species are shown in Appendix 19.

Modelled habitat availability is expressed as the index, weighted usable area (WUA), which is calculated as the sum of the area weighted products of the combined habitat suitability scores (*i.e.* depth x velocity x substrate suitability) for the measurement points on the cross-sections. WUA is a dimensionless index providing an indication of the relative quantity and quality of available habitat predicted at a given flow.

It is important to realise that these metrics provide only a relative measure of how predicted habitat changes with flow. Therefore, when interpreting the WUA x flow curves that are the output of modelling, it is the shape of the curves (*e.g.* the flows at which the optimum WUA and major changes in slope occur) that are of interest, rather than the magnitude (or height) of the WUA x flow curves. These outputs provide an indication of how habitat availability is predicted to change with flow. WUA serves as a currency which stakeholders can use for interpreting effects of flow change on instream habitat and for negotiating flow decisions.

Flow requirements for instream habitat in the Waipawa (Reaches 4 and 5) and Lower Tukituki (Reach 6) were assessed by Johnson (2011) using habitat data collected in 2004 and 2005. This data was re-modelled by Cawthron to enable a more detailed assessment of habitat availability.

No hydraulic-habitat modelling surveys have been undertaken on the Waipawa River between the Mangaonuku confluence and the Tukituki confluence (Reach 5). The

Mangaonuku contributes a significant proportion of the flow recorded at the Waipawa RDS site. The survey data from Johnson (2011) is therefore not considered representative of the habitat in the Waipawa River downstream from the Mangaonuku confluence. To accurately assess habitat at the RDS site further habitat measurements and IFIM analysis would be required.

Habitat surveys in the Makaroro River were conducted by Cawthron in November 2011. Habitat mapping was carried out in two reaches of the Makaroro River (Figure 32), both below the foot of the proposed dam. In the upper reach the channel was more confined, while the lower reach tended to be wider and more open. Within each reach cross sections were selected by Cawthron staff on 2nd and 3rd November 2011, and subsequent calibration measurements and cross-section surveys were carried out by HBRC hydrology staff over the following six weeks. Cross-sections were positioned in an attempt to encompass the full range of variability represented by each habitat type in each reach (Table 20). Calibration data were collected at a range of flows between 2.153 m^3/s and 4.187 m^3/s in the upper reach and between 1.957 m^3/s and 5.127 m^3/s in the lower reach.

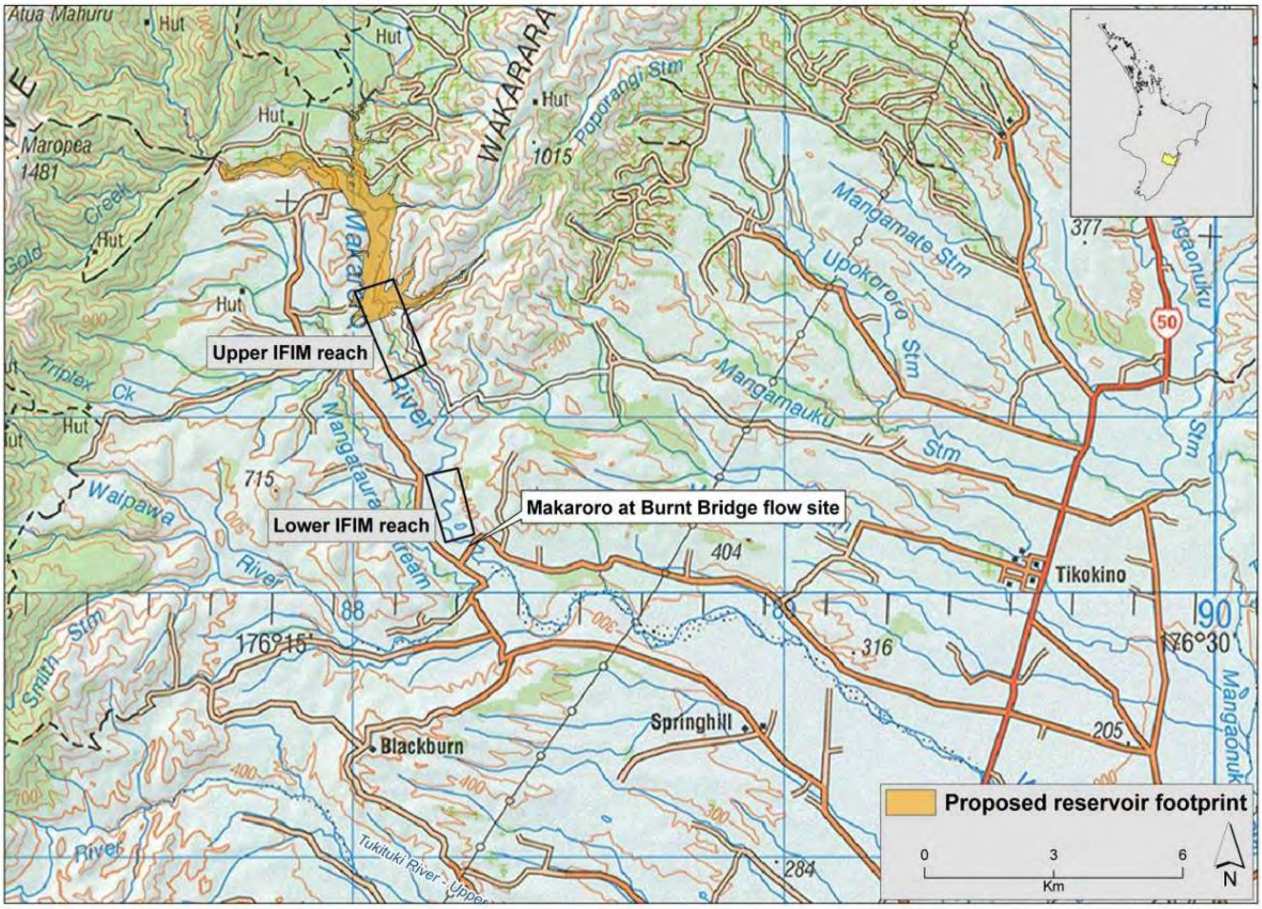

Figure 32. The Makaroro and Waipawa rivers, showing the reaches where the IFIM habitat analyses were based and the location of the flow recorder, Makaroro at Burnt Bridge.

Table 20. Summary of habitat mapping and cross-section allocation in the Makaroro IFIM reaches.

Reach	Habitat type	Percentage of total length (%)	Number of cross-sections
Upper	Shallow Run	55	4
	Riffle	25	6
	Pool / Deep Run	20	3
Lower	Shallow Run	54	5
	Riffle	44	4
	Pool / Deep Run	2	3

Predicted changes in physical habitat with flow were modelled for periphyton, selected species of macroinvertebrate, and all fish species recorded or considered likely to be present in the Makaroro River (Table 12). The two reaches were combined for modelling since there was found to be little difference in flow between reaches during the calibration data collection (consistently less than 10% difference). Together they are representative of the distribution of habitat types in the Makaroro River below the proposed dam site.

Ecologically relevant flow statistics

Hydraulic-habitat modelling produces continuous relationships between flow and habitat. In order to compare alternative flow regimes in terms of how well they maintain habitat it is helpful to interpret the habitat — flow relationships with respect to ecologically relevant flow statistics.

The mean annual low flow (MALF) is ecologically relevant to annual spawning fish because it defines the minimum space available each year. Jowett (1992) found that trout abundance in New Zealand rivers was correlated with the quality of adult trout habitat (indexed by adult trout combined habitat suitability index (CSI)) at the mean annual low flow (MALF). He also found that the quality of benthic invertebrate habitat (indexed by 'food producing' CSI) at the median flow, was strongly correlated with trout abundance. The correlation was even stronger with aquatic invertebrate biomass.

The MALF is also relevant to native fish species with generation cycles longer than one year, at least in small rivers where the amount of suitable habitat declines at flows less than MALF. Research in the Waipara River, where native fish habitat is limited at low flow, showed that the detrimental effect on fish numbers increased with the magnitude and duration of low flow (Jowett *et al*. 2008). Research on the Onekaka River in Golden Bay also showed that, when habitat availability was reduced by flow reduction, abundance of native fish species responded in accord with predicted changes in habitat availability in both direction and magnitude (Jowett *et al.* 2008).

Aquatic macroinvertebrates have much faster colonisation times than annual spawning, and multi-aged fishes. Denuded habitat is recolonised by invertebrates drifting from refugia and by winged adults laying eggs and some taxa have more than one generation per year. Benthic invertebrate communities have been found to recolonise river braids within 30 days after drying — probably mainly by drift of colonists from permanently flowing braids upstream. Recovery takes longer after large floods. Due to relatively fast rates of recolonisation by invertebrates, the median flow is an ecologically relevant flow statistic when assessing the effects of flow regime change on benthic invertebrate habitat.

Provision for seasonal flow variation may also allow for seasonally varying food requirements of fish and birds and nesting requirements of the latter. Fish have higher food requirements in summer because their metabolic and consumption rates are higher at warmer water temperatures. If space and or food is limiting, then flows higher than the MALF ought to give some respite from limiting conditions, especially feeding conditions, at the MALF. This is the rationale for also assessing fish habitat, but particularly benthic invertebrate habitat with respect to monthly flow statistics. This sometimes referred to as '**Seasonal habitat retention analysis'**. Sometimes monthly median (50^{th} percentile) flows are used, but other percentiles can also be used for referencing habitat (*e.g*. the 90^{th} and 10^{th} percentile flows for the month).

Habitat retention levels

The effects of a proposed flow regime are assessed by expressing the habitat retained at the ecologically relevant flow statistic as a percentage of that retained at a reference flow (*e.g*. the 'natural flow' or the 'status quo flow'). This, of itself, does not define the significance of the change, and determining acceptable levels of habitat retention requires expert judgement to be applied. If a significant instream value is very high then the level of habitat retention would be expected to also be high in order to manage the risk that a reduction in habitat might pose to the maintenance of that value. The inverse also applies. This approach is consistent with the Minitry for the Environment's Flow Guidelines (MfE 1998).

Some account should also be given to whether the fish (or invertebrate) populations are likely to be space or food limited. If habitat is limiting then a predicted reduction in habitat is assumed to correspond to reduction in abundance. However, this will not be the case if other factors unrelated to flow depress the population below their theoretical carrying capacity.

Seasonal habitat retention analysis — habitat retention during dry, wet and average months

As described above, seasonal habitat retention analysis is a means of summarising the continuous habitat — flow relationship predicted by RHYHABSIM so that the effects of the proposed flow regime can be assessed on the basis of habitat retention at relevant monthly (or seasonal) flow statistics (*e.g*. flow percentiles). Seasonal habitat retention analysis was undertaken for periphyton, macroinvertebrates and fish for Reaches 3, 4, 5, and 6 and the monthly habitat retention results expressed in tabular form. The analysis involved comparing the amount of habitat at status quo in each month with the amount of habitat under the proposed regime and calculating the percent of habitat retained as:

$$\%\,Habitat\ retention = 100\ \times \frac{WUA(i)\ with\ the\ proposed\ flow\ regime}{WUA(i)\ with\ natural\ flow}$$

(Where WUA(i) is the weighted usable area for the month (i.e. January to December))

This comparison was made for wet, dry and average months. The summary flow statistic for the dry month was the flow that was exceeded for 90% of the time in that month across the entire flow record (*i.e*., the 10th percentile). We used the median flow for the month (50th percentile) to represent typical flow conditions (the median having the advantage over the mean because it is not heavily influenced by high flows of short duration). The flow statistic for a wet month was the flow exceeded 10% of the time in that month (*i.e*. the 90th percentile). This percentile approach is the same method used in Jowett (2012) to assess the environmental effects of a proposed hydro-scheme on the Waiau River in North Canterbury.

When flows exceeded the long-term median flow (*e.g.* 3.5 m^3/s in the Makaroro River), WUA was set to the WUA for the median flow. This was because high flows do not persist for long enough for there to be an ecological effect on the margins of the the channel that are inundated by flows greater than median. In wet months, monthly median flows were often greater than the long-term median flow for the flow regime scenarios. When this occurred habitat retention was considered to be 100%.

Benthic Invertebrate Habitat Time series Simulation (BITHABSIM)

In respect of benthic macroinvertebrates, a shortcoming of traditional hydraulic-habitat modelling complemented with seasonal habitat retention analysis is that it does not account for flood disturbance resetting invertebrate abundance. If frequent flood disturbance suppresses abundance at low levels then macroinvertebrates will not be habitat limited and so seasonal habitat retention analysis may overestimate effects of flow alteration. The BITHABSIM model was recently developed to address this shortcoming. The model uses the WUA, bed disturbance (deep flushing), and wetted width output of RHYHABSIM. It adds value to the predictions of RHYHABSIM by imbuing more biological realism into the habitat index WUA.

BITHABSIM takes into account: 1) changes in habitat suitability that occur in response to variation in flow, 2) the disturbance effects of high flow and drying events that are expected to reduce invertebrate densities, and 3) the recovery (or accrual) rates and times of benthic invertebrate populations following such events.

BITHABSIM calculates changes in an index of productive invertebrate habitat over a flow regime (hydrograph) (Olsen *et al.* 2011a). The index is termed WUA2 (based on WUA) and is calculated on daily maximum or daily average flow. WUA can be considered an index of ‘potential’ invertebrate habitat, whereas WUA2 is an index of the realisable invertebrate habitat. The inclusion of disturbance and post-disturbance recovery should increase the ecological realism of the modelled responses of macroinvertebrates to hydrological alteration.

The key inputs to BITHABSIM comprise:

- A WUA-discharge relationship for an invertebrate taxon, *Deleatidium* (the common New Zealand mayfly) in this application
- A sediment flushing — discharge relationship (applied to the median flow channel in this application)
- A relationship describing the invertebrate colonisation (*i.e.* accrual) rate — expressed as the proportion of the population colonised versus time;
- A wetted width — discharge relationship
- Initial proportion of the population colonised
- Hydrographs for representative locations (Reaches 3-5 under both the natural, status quo and proposed flow regimes in this application).

BITHABSIM is applied to a representative hydrograph (usually annual hydrograph). In this sense it is different from seasonal habitat retention analysis which can take account of the entire flow record (*i.e*., by assessing habitat with respect to flow percentiles that represent dry, typical and wet conditions). For BITHABSIM analysis, representative dry, typical and wet annual hydrographs were selected using a percentile analysis based on mean annual flows. From the percentile rankings, the years closest to the 10th (dry), 50th (median) and 90th (wet) percentiles were considered. Before being selected, the hydrographs were visually assessed to make sure there was a reasonably even spread of flows across the year (*i.e*. that mean flow in the year was not highly skewed by very few, or a single large flow event). The following representative annual hydrographs were selected: 1976 (wet year), typical year (1996), dry year (1990).

Cawthron Institute used the above approach in an assessment of environmental effects of Meridian’s proposed irrigation / hydroelectric power generation scheme on the Waiau River (Olsen *et. al.* 2011b). Tonkin and Taylor also used this approach in a hydrological assessment of a similar scheme near Lake Coleridge (Tonkin & Taylor 2011b).

The BITHABSIM analysis in the Makaroro and Waipawa rivers was confined to the median flow channel on the assumption that channel margins wetted at higher flow do not remain wet for long enough to contribute significantly to annual benthic production.

In the absence of maximum daily flow data, BITHABSIM was run using mean daily flow. Maximum daily flow data better captures the essential flood disturbance maxima, and is advantageous since the duration of flood peaks are much shorter than the duration of low flow minima. Therefore, our results are likely to underestimate bed disturbance and the reduction in WUA that occurs during high flows.

The relationship between recolonisation by *Deleatidium* and time was represented by a logistic curve, with the intrinsic rate of increase (*r*) = 0.022. This value is the mean estimated from four braided New Zealand rivers (Ashley, Rangitata, Rakaia, Waimakariri) for which *r* has been calculated for *Deleatidium* from post-flood accrual time series (Olsen *et al.* 2011a).

BITHABSIM results (daily WUA2 predictions) were summarized by monthly averages and compared between modelling scenarios following the habitat retention approach (*i.e*., percent WUA2 retention by the proposed flow regime referenced to the status quo flow).

3.4.5.2. Effects of hydrological changes on periphyton

Introduction

The periphyton biomass observed at a location at a point in time reflects the balance of two opposing natural processes; biomass accrual and biomass loss (Biggs 2000b). The rate of cell division controls the rate of biomass accrual, and is controlled by factors such as nutrients, light and temperature (Biggs 2000b). Meanwhile, the rate of biomass loss is governed by physical disturbance (substrate instability, water velocity and suspended solids) and grazing (by invertebrates) (Biggs 2000b). This section of the report focuses only on how changes in flow regime may affect periphyton growth. Increases in habitat availability for short, and particularly long filamentous algae are considered ecologically undesirable, while changes in habitat availability for diatoms are considered to be neither desirable nor undesirable. The effects of potential changes in land use and the operation of the sewage discharges on water quality and periphyton growth are arguably more important than the effects of hydrological change on periphyton habitat suitability and are covered in Section 3.6.

Altered flows affect periphyton by changing habitat quality, through changes in water depth (which affects the amount of light reaching the riverbed), water velocity (which affects the accrual rate, oxygen and nutrient delivery) and may change water quality (through reduced dilution of nutrient inputs). When considering such effects, the primary concerns are the percentage of the bed covered and the local biomass of periphyton, rather than total reach biomass. Thus, analyses used to assess the effects of altered flows on periphyton consider the habitat suitability index (HSI, an index of habitat quality), rather than WUA. Weighted useable area provides an indication of a whole-reach effect because it is affected by changes in habitat quantity (wetted area) and quality. This complicates interpretation for periphyton taxa because increases in WUA could result from changes in wetted area, habitat quality, or a combination of both. Changes as a result of changes in wetted area are of little concern as long as there is no increase in habitat quality that may lead to high periphyton biomass. HSI on the other hand is the WUA divided by the wetted area and can be seen as an index of changes in periphyton on a per unit area basis (*e.g.* per m^2).

Long filamentous algae can be unsightly, have detrimental effects on recreational values (by being slippery, snagging fishing gear) and can affect habitat quality for macroinvertebrates. Therefore, increases in habitat availability for filamentous algae needs to be considered. In comparison, diatoms (with the exception of *Didymo*) are less apparent visually, are unlikely to snag fishing gear and are generally considered to be more favourable for macroinvertebrates. However, diatoms may still make rock surfaces slippery, which may affect recreational enjoyment. Therefore, changes in habitat availability for diatoms are considered to be neither positive nor negative.

The analyses presented below assess likely changes to periphyton habitat with the proposed changes in flow. It is important to note that nutrient concentration and the flushing flow regime are also key determinants in the frequency, duration and peak biomass of proliferations of long and short filamentous algae and a reduction in diatoms. These are addressed in Sections 3.6 (nutrients) and 3.4.6 (flushing flows). Nonetheless, an assessment of the change in available habitat is required. Habitat suitability curves for short and long filamentous algae, as well as diatoms can be found in Appendix 19.

Makaroro River (Reach 3): The effect of the proposed flow regime on periphyton
In the Makaroro River, average habitat quality for filamentous algae is predicted to decrease with increased flow (Figure 33). There is a slight increase in HSI for long filamentous algae which is likely due to the increase in wetted area. Discharges higher than about the proposed median flow (3.3 m^3/s) provide habitat across 17% to 35% of the bed surface.

Predicted habitat retention for periphyton groups in the Makaroro (Reach 3) under the proposed flow regime during dry, wet and average months is summarised in Table 21. Predicted increases in habitat availability for long filamentous algae were most evident between March and December (up to 156%) but were decreased at other times, notably during the summer. Habitat increase was greatest during average and dry months, but primarily in the wetter, colder months when algal proliferation is not generally likely to be significant.

Overall, the proposed flow regime would increase the habitat availability for nuisance periphyton growth in the Makaroro River downstream of the dam.

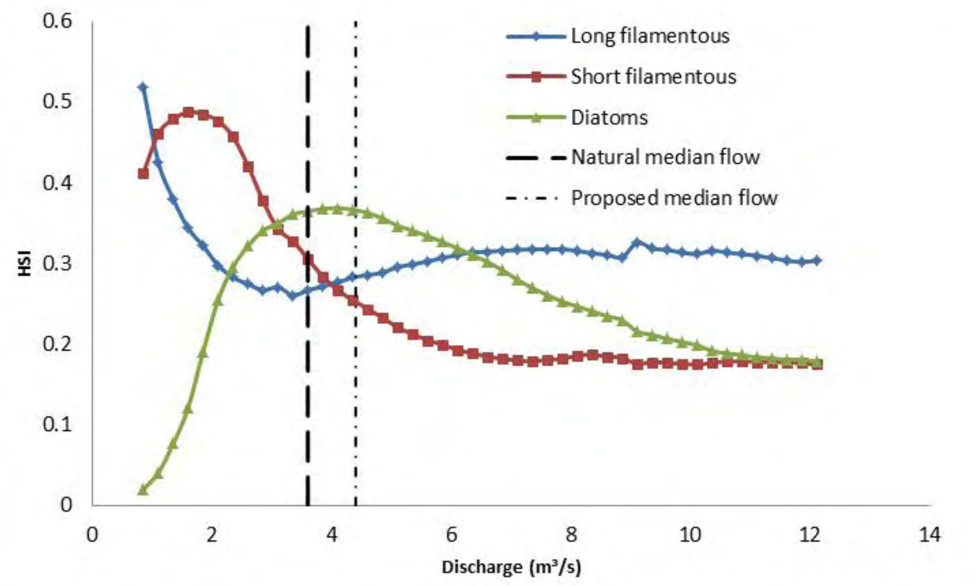

Figure 33. Flow dependant proportion of habitat availability (HSI) for periphyton in the Makaroro River (Reach 3). Note that the proposed median flow and MALF shown are those from Table 13.

Table 21. Habitat retention in the Makaroro River (Reach 3) for periphyton groups under the proposed flow regime expressed as a percentage of habitat available at status quo flows for dry months, wet months and average months.

Month	Long filamentous			Short filamentous			Diatoms		
	Dry	Wet	Average	Dry	Wet	Average	Dry	Wet	Average
J	100	100	86	100	100	66	100	100	156
F	96	100	84	101	100	65	129	100	176
M	100	100	111	100	100	105	100	100	71
A	106	100	146	98	100	103	77	100	18
M	123	100	155	95	100	148	36	100	15
J	146	100	155	103	100	148	18	100	15
J	156	100	155	131	100	148	15	100	15
A	155	100	100	143	100	100	15	100	100
S	151	100	100	115	100	100	16	100	100
O	146	100	100	103	100	100	18	100	100
N	130	100	100	96	100	85	26	100	105
D	119	100	96	95	100	75	43	100	113

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	140-150% retention	> 150% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention	40-50% retention

Waipawa River upstream of irrigation intake (Reach 4): The effect of the proposed flow regime on periphyton

In the Waipawa River upstream from the irrigation take (Reach 4), average habitat quality for filamentous algae is predicted to be highest at flows lower than the proposed MALF, while the average habitat quality for diatoms is predicted to be highest at around 5.5 m^3/s (Figure 34). Flows above the proposed median flow (9.3 m^3/s) provide habitat across approximately 15% to 25% of the bed surface.

Predicted habitat retention for periphyton groups in the Waipawa (Reach 4) under the proposed flow regime during dry, wet and average months is summarised in Table 22. Predicted increases in mean habitat were limited mostly to short filamentous algae between June and September. Habitat increases are more likely to occur during dry months (Table 22).

Overall, the proposed flow regime would have a minimal effect on periphyton growth in the Waipawa River upstream of the irrigation intake resulting in a neutral effect for this reach.

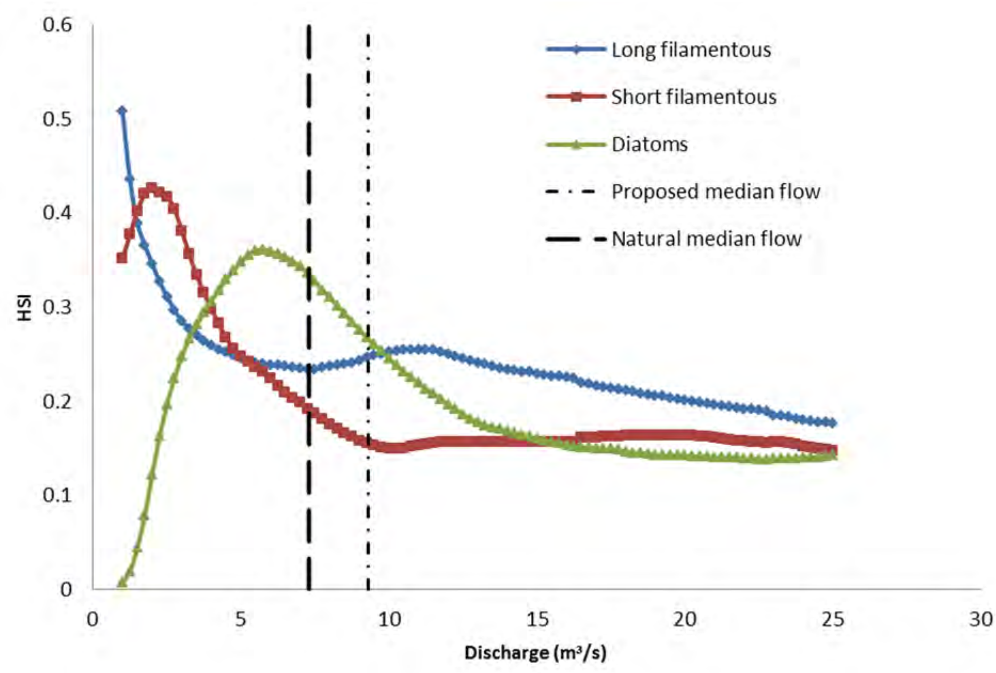

Figure 34. Flow dependant proportion of habitat availability (HSI) for periphyton in the Waipawa River u / s from the irrigation intake (Reach 4). Note that the proposed median flow and MALF shown are those from Table 13.

Table 22. Habitat retention in the Waipawa River u / s from the irrigation take (Reach 4) for periphyton groups under the proposed flow regime expressed as a percentage of habitat available at status quo flows for a dry months, wet months, and average months.

	Long filamentous			Short filamentous			Diatoms		
Month	**Dry**	**Wet**	**Average**	**Dry**	**Wet**	**Average**	**Dry**	**Wet**	**Average**
J	92	100	94	78	100	75	116	100	103
F	95	100	93	88	100	71	107	100	107
M	100	100	96	97	100	80	98	100	99
A	98	100	101	95	100	106	105	100	100
M	102	100	102	105	100	115	96	100	105
J	105	100	100	121	100	102	88	100	101
J	105	100	100	122	100	100	94	100	100
A	105	100	100	125	100	100	97	100	100
S	105	100	100	111	100	100	93	100	100
O	99	100	100	98	100	100	101	100	100
N	97	100	99	90	100	88	108	100	96
D	94	100	98	83	100	84	115	100	95

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	140-150% retention	> 150% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention	40-50% retention

Waipawa River downstream of irrigation intake (Reach 5): The effect of the proposed flow regime on periphyton

In the Waipawa River downstream from the irrigation intake (Reach 5), average habitat quality for filamentous algae is predicted to be highest at flows lower than the proposed MALF, while the average habitat quality for diatoms is predicted to be highest at around 5.5 m^3/s, which is close to the proposed median flow (5.1 m^3/s) (Figure 35). Flows above the proposed median flow provide habitat across approximately 15% to 35% of the bed surface.

Predicted habitat retention for periphyton groups in the Waipawa below the irrigation intake (upper part of Reach 5) under the proposed flow regime during dry, wet and average years is summarised in Table 23. Similar to upstream of the intake, predicted increases in mean habitat were limited mostly to short filamentous algae, but the increase was largely year round and most prevalent in average to dry years.

Overall, the proposed flow regime would result in relatively small changes in the habitat availability for short filamentous algae in the Waipawa River downstream of the intake.

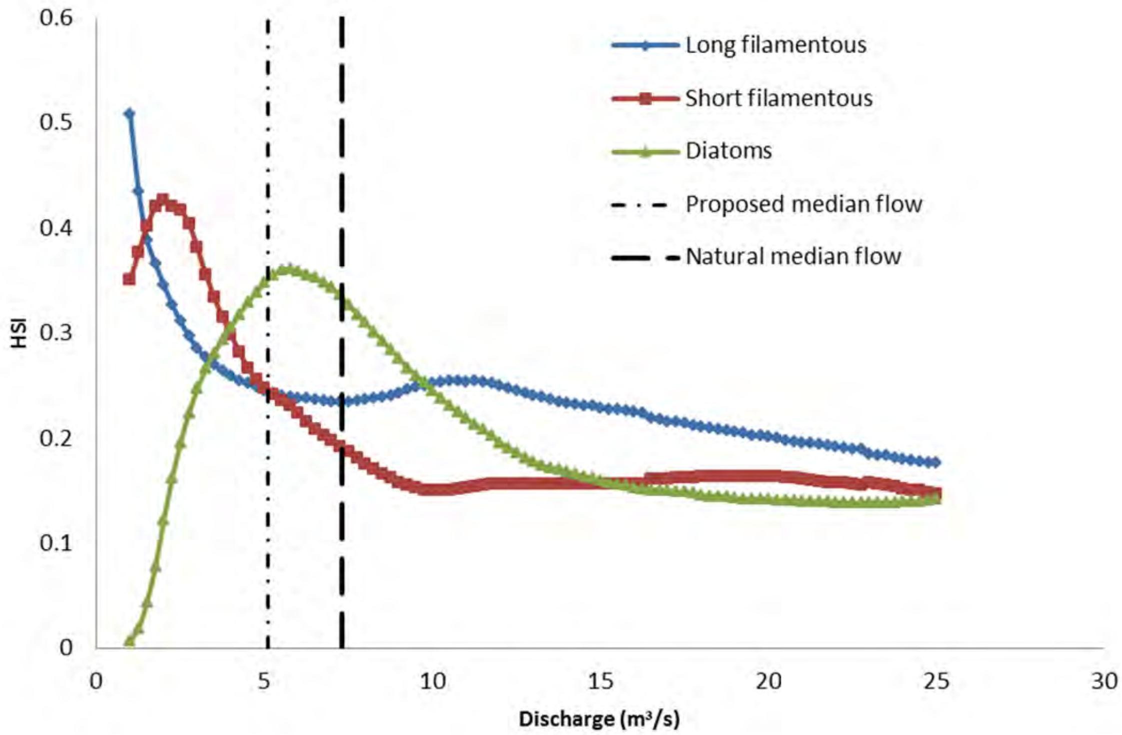

Figure 35. Flow dependant proportion of habitat availability (HSI) for periphyton in the Waipawa River downstream of the irrigation intake (Reach 5). Note that the proposed median flow and MALF shown are those from Table 13.

Table 23. Habitat retention in the Waipawa River downstream from the irrigation take (Reach 5) for periphyton groups under the proposed flow regime expressed as a percentage of habitat available at status quo flows for dry months, wet months, and average months.

	Long filamentous			Short filamentous			Diatoms		
Month	**Dry**	**Wet**	**Average**	**Dry**	**Wet**	**Average**	**Dry**	**Wet**	**Average**
J	100	100	106	100	100	121	100	100	87
F	100	100	106	100	100	120	100	100	88
M	100	100	107	100	100	123	100	100	86
A	97	100	106	94	100	122	111	100	90
M	104	100	103	110	100	122	92	100	104
J	106	100	100	124	100	102	86	100	101
J	105	100	100	122	100	100	94	100	100
A	105	100	100	125	100	100	97	100	100
S	107	100	100	121	100	100	88	100	100
O	106	100	102	121	100	119	87	100	105
N	106	100	106	115	100	122	89	100	90
D	103	100	107	108	100	121	93	100	88

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	140-150% retention	> 150% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention	40-50% retention

Lower Tukituki River (Reach 6): The effect of the proposed flow regime on periphyton

In the Lower Tukituki River at Red Bridge (Reach 6), average habitat quality for filamentous algae is predicted to be highest at flows close to the proposed MALF, while the average habitat quality for diatoms is predicted to be highest at around 38 m^3/s (Figure 36). Flows at the proposed median flow (18.7 m^3/s) provide habitat across approximately 22% of the bed surface.

Seasonal habitat retention for periphyton groups in the Tukituki River (Reach 6) under the proposed flow regime during dry, wet and average months was modelled using Scenarios 1 to 4. When compared to the status quo (Scenario 2), the proposed flow regimes under Scenarios 3 and 4 produce very small changes (Appendix 22).

Overall, the proposed flow regime will have no discernible effect on the habitat availability for nuisance periphyton growth in the lower Tukituki River.

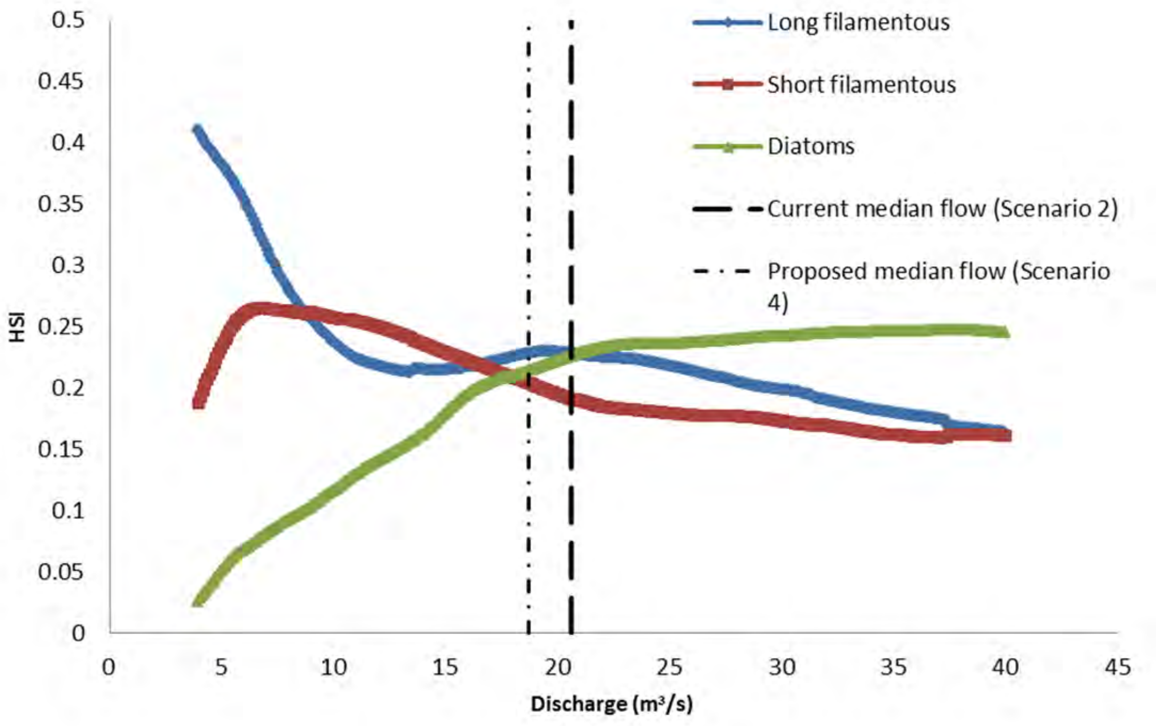

Figure 36. Flow dependant proportion of habitat availability (HSI) for periphyton in the Lower Tukituki River (Reach 6).

3.4.5.3. Effects of hydrological changes on macroinvertebrates

Introduction

This section presents the effects of the proposed flow regime on invertebrates relative to the natural flow regime. Effects were assessed using two methods: seasonal habitat retention analysis and BITHABSIM, as described in Section 3.4.5.1. To recap, seasonal habitat retention analysis summarises the continuous habitat — flow relationship predicted by RHYHABSIM so that the effects of the proposed flow regime can be assessed on the basis of habitat retention at relevant monthly (or seasonal) flow statistics (*e.g.* flow percentiles). A shortcoming of seasonal habitat analysis for invertebrates is that it does not account for flow disturbance resetting invertebrate abundance to lower levels. This means that it may overestimate the adverse effects of run-of-the-river abstraction and under estimate the positive effects of storage. BITHABSIM addresses this shortcoming and so we present the results of both seasonal habitat retention analysis and BITHABSIM analysis expressed in the same form (*i.e.* percentage of the habitat index retained by the proposed flow regime relative to the status quo).

Seasonal habitat retention and BITHABSIM targets the effect of flow alteration on invertebrate productivity. The latter is important for providing food resource for fish and river birds. Food production is most important for fish in summer as food intake and metabolic energy demands are greatest then owing to higher water temperature. Food requirements for river birds are important in spring for maintaining nesting adults and their fledglings. Our indices of invertebrate productivity are WUA for *Deleatidium* and food producing habitat in the case of seasonal habitat retention analysis, and WUA2 for *Deleatidium* in the case of BITHABIM analysis. *Deleatidium* was selected as a representative species because they are the most common invertebrate in the benthos and drift of many New Zealand rivers. Habitat suitability curves for *Deleatidium* and food producing habitat can be found in Appendix 19.

Makaroro River (Reach 3): The effect of the proposed flow regime for water storage on macroinvertebrates

Instream habitat modelling for this reach indicates that *Deleatidium* habitat (WUA) increases steadily with flow across the modelled flow range (1 to 12 m^3/s) (Figure 37) Within the modelled flow range, food producing habitat peaks at about 2.5 m^3/s, and declines most steeply below 2 m^3/s. The proposed median flow differed little from the natural median flow and so the difference in habitat between them is small (1.5%); a small decrease for *Deleatidium* and a small increase for food producing habitat. This is considered to be within the 'margin of error' and for all practical purposes, both scenarios are the same.

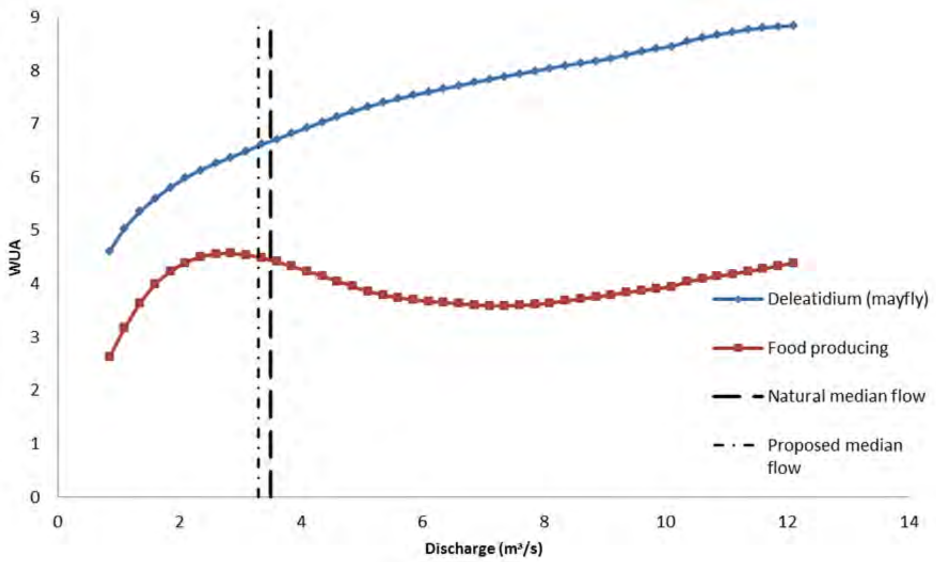

Figure 37. Relationship between weighted useable area (WUA) and flow for Deleatidium (mayfly), and ‘food producing’ habitat in the Makaroro River (Reach 3) based on instream habitat modelling. Note: natural median flow = status quo flow in this reach.

Predictions for seasonal flow retention analysis and BITHABSIM are presented in Tables 23 and 24. Predictions from the two analyses differ primarily because BITHABSIM accounts for the effect of high flow resetting invertebrate abundance to low levels followed by recovery over time. When flood frequency and magnitude is reduced, invertebrate abundance will be sustained at higher levels.

The seasonal habitat analysis, indicates that the greatest *Deleatidium* and food producing habitat losses under the proposed flow regime occur in winter / spring in dry years (*Deleatidium*: 79-89%; Food producing: 74-79%) and late autumn / early winter in median years (*Deleatidium*: 78-84%; Food producing: 74-76%) (Table 24). More than 90% of *Deleatidium* and food producing habitat is maintained for the remainder of the dry and median years, and throughout the wet year.

Results from the BITHABSIM analysis (Table 25) are variable depending on the month. Greatest habitat losses occur over summer / autumn for the dry years. Substantial habitat gains are predicted for mid-winter in dry years. The reverse is predicted for wet and median years *i.e*. gains in summer / autumn and losses in winter/spring. The predicted moderate to substantial invertebrate habitat losses during summer in dry years (62-67% habitat retention, Table 25) may adversely affect fish. Similarly, there is predicted to be a moderate invertebrate habitat loss in the spring bird nesting period during median years (78-85% habitat retention, Table 25).

The difference in predictions of the seasonal habitat and BITHABSIM analyses are to be expected in a hydrologically and physically unstable river such as the Makaroro.

Habitat limitation is expected to be strongest in physically benign (low disturbance) systems, where macroinvertebrate numbers can increase unimpeded by periodic disturbance events until they are eventually limited by food or space (*i.e.* they reach their carrying capacity). In contrast, in highly disturbed systems, losses associated with high flows will keep macroinvertebrate numbers well below the carrying capacity. In such circumstances, a reduction in the availability of habitat tends not to lead to habitat limitation, since the population is being depressed by high flow events.

As mentioned above, BITHABSIM predicts that greatest *Deleatidium* habitat losses will occur in summer in dry years. As mentioned earlier invertebrate habitat losses in summer are more important for fish than in winter. In dry years the seasonal habitat analysis suggests moderate *Deleatidium* habitat losses (79% to 89% habitat retention, Table 24) in winter / spring (July to November) due to the proposed flow regime. By contrast, BITHABSIM predicts substantial habitat gains in mid-winter (204% and 321% habitat retention, Table 25). This difference arises because of the effects of storage on flood flows which BITHABSIM is able to account for (*i.e.* large floods can be captured to fill the reservoir thereby mitigating the losses that would have otherwise occurred).

In comparison, the seasonal habitat analysis suggests high *Deleatidium* habitat retention (98%-103%) during summer in a dry year, whereas BITHABSIM modelling suggests only 62% to 79% habitat retention (Tables 23 and 24). This difference arises for the same reason discussed above. However, in this case it is the operation of the reservoir that results in high flows that depress realisable habitat (WUA2) rather than the natural flow regime. During this period high flows will be released from the reservoir for irrigators. These pulses of flow decrease WUA, which tends to reset WUA2 to lower levels from which it then must recover. These aspects of the high flow releases are confined to the Makaroro because its channel is more confined than the Waipawa.

Our experience to date with testing BITHABSIM indicates that it is probably overestimating the adverse effects of high flows on realisable habitat for *Deleatidium.* That is, the aforementioned dry year habitat gains in winter / spring and habitat losses in summer are probably overestimated by BITHABSIM. Nevertheless we are confident that the general principle is correct (*i.e*. that reduction in the frequency of high flow events has a positive effect on realisable habitat).

Another factor that will tend to mitigate the adverse effects of the high flow releases for irrigation is the predicted coarsening of bed substrates (as discussed in Section 3.3.2). The increased bed armouring will provide better refuge for *Deleatidium*, and would be expected to allow them to tolerate higher velocities. More importantly, the macroinvertebrate community composition will change, with *Aoteapsyche* (net-spinning caddis fly) comprising a much higher proportion of the community. *Aoteapsyche* can tolerate and prefer higher water velocities than *Deleatidium* (Jowett *et al.* 1991), and so would be more able to cope with the higher flows predicted over the summer period. On the other hand the channel will evolve following damming, becoming narrower and deeper over the long-term so water velocities associated with irrigation releases will be higher than currently predicted. Nonetheless, the armouring is predicted to substantially mitigate the effects of high flow releases for irrigation on invertebrate habitat.

Table 24. Habitat retention in the Makaroro River (Reach 3) for macroinvertebrates under the proposed flow regime expressed as a percentage of habitat available (WUA) at status quo flows for dry months, wet months, and median months based on seasonal habitat retention analysis.

	Deleatidium, mayfly			**Food producing (Waters 1976)**		
Month	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**
J	100	100	113	100	100	103
F	103	100	114	106	100	104
M	100	100	96	100	100	95
A	98	100	84	95	100	74
M	91	100	78	82	100	76
J	84	100	78	74	100	76
J	80	100	78	74	100	76
A	79	100	100	75	100	100
S	82	100	100	74	100	100
O	84	100	100	74	100	100
N	89	100	104	79	100	97
D	92	100	107	84	100	97

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Table 25. Habitat retention in the Makaroro River (Reach 3) for Deleatidium under the proposed flow regime expressed as a percentage of realisable habitat available (WUA2) at status quo flows for a dry year (1990), a wet year (1976), and a median year (1996) based on BITHABSIM analysis.

	***Deleatidium*, mayfly (Jowett *et. al.* 1991)**		
Month	**Dry**	**Wet**	**Median**
J	62	197	99
F	64	187	134
M	71	105	117
A	79	146	214
M	83	146	159
J	98	129	132
J	321	107	88
A	204	96	85
S	93	90	82
O	100	88	79
N	91	86	78
D	67	83	70

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Waipawa River upstream of irrigation intake (Reach 4): The effect of the proposed flow regime for water storage on macroinvertebrates

Instream habitat modelling for the Waipawa River above the irrigation intake indicates that *Deleatidium* habitat (WUA) peaks at about 6 m^3/s and declines most steeply below 5 m^3/s (Figure 38). Within the modelled flow range, food producing habitat peaks at about 3 m^3/s. The proposed median flow is 2 m^3/s higher than the natural median flow (7.3 m^3/s) and this change is associated with reductions in both *Deleatidium* and food producing habitat — particularly the latter.

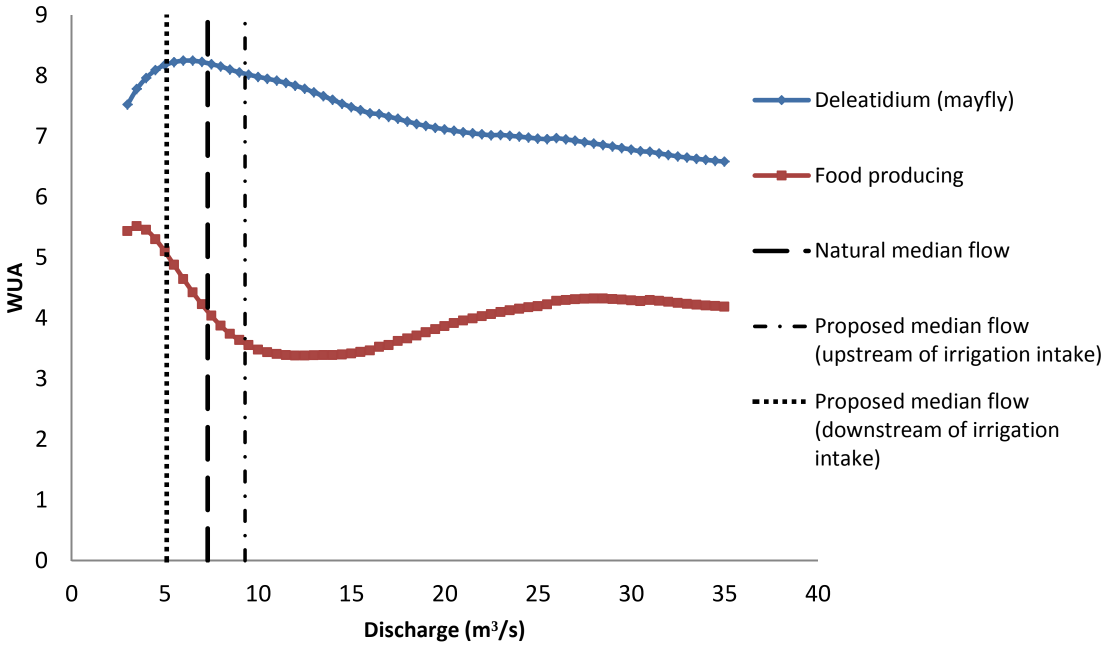

Figure 38. Relationship between weighted useable area (WUA) and flow for Deleatidium (mayfly), and 'food producing' habitat in the Waipawa River u / s (Reach 4) and d / s of irrigation take (Reach 5) based on the instream habitat model of Johnson (2011). Note: natural median flow = status quo flow in this reach.

The seasonal habitat retention analysis suggests there will be minimal effects on *Deleatidium* habitat throughout the year during dry, wet and median years (Table 26). Small to moderate food producing habitat losses are predicted in summer in median years (up to 21%).

BITHABSIM predicts that there will be moderate habitat loss in mid-summer in dry years (69-83%), and small habitat losses in spring for median years. Habitat gains occur in other months. In wet years, habitat gains are predicted in almost all months. (Table 27). The loss in *Deleatidium* habitat in mid-summer in dry years could adversely affect fish. On the other hand, the substantial habitat gains through most of the year offset by only small losses in spring suggest a largely positive effect of the scheme in median and wet years.

Table 26. Habitat retention in the Waipawa River u / s from the irrigation intake (Reach 4) for macroinvertebrates under the proposed flow regime expressed as a percentage of habitat available (WUA) at status quo flows for dry months, wet months, and median months based on seasonal habitat retention analysis.

	***Deleatidium*, mayfly**			**Food producing**		
Month	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**
J	104	100	101	92	100	80
F	102	100	102	94	100	79
M	100	100	101	95	100	83
A	101	100	100	101	100	106
M	99	100	100	100	100	111
J	97	100	100	105	100	102
J	98	100	100	117	100	100
A	99	100	100	119	100	100
S	99	100	100	108	100	100
O	100	100	100	99	100	100
N	102	100	100	97	100	91
D	104	100	100	98	100	87

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Table 27. Habitat retention in the Waipawa River u / s from the irrigation intake (Reach 4) for Deleatidium under the proposed flow regime expressed as a percentage of realisable habitat available (WUA2) at status quo flows for a dry year (1990), a wet year (1976), and a median year (1996) based on BITHABSIM analysis.

Month	***Deleatidium*, mayfly (Jowett et. al. 1991)** Dry	Wet	Median
J	69	262	233
F	74	200	253
M	94	143	176
A	105	175	228
M	125	154	181
J	147	148	163
J	302	163	124
A	185	160	102
S	110	126	99
O	111	103	92
N	103	99	92
D	83	103	97

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Waipawa River downstream of irrigation intake (Reach 5): The effect of the proposed flow regime on macroinvertebrates

The proposed median flow for the Waipawa River below the irrigation intake is 2.2 m^3/s lower than the natural median flow (7.3 m^3/s) and this change is associated with no overall change in *Deleatidium* habitat and an increase of 13% food producing habitat (Figure 39).

Overall there were minimal adverse effects predicted from the seasonal habitat analysis for *Deleatidium* and food producing habitat, and gains in some months for the dry and median years (Table 28).

BITHABSIM predicts that there will be small to moderate habitat losses (84-94% habitat retention) in spring for wet years, and moderate to small habitat losses in late winter / early spring (79-97% habitat retention) for median years (Table 29). Habitat gains occur in other months. In dry years, habitat gains are predicted in almost all months (Table 29). The loss in *Deleatidium* habitat in spring in wet years occurs because flows are already higher then optimal in wet years and the releases from the reservoir will increase flows further. On the other hand, habitat gains through most of the year offset by mainly small losses in spring suggest a largely positive effect of the scheme in dry and wet years.

Table 28. Habitat retention in the Waipawa River d / s from the irrigation intake (Reach 5) for macroinvertebrates under the proposed flow regime expressed as a percentage of habitat available (WUA) at status quo flows for dry months, wet months, and median months based on seasonal habitat retention analysis.

	Deleatidium (mayfly)			Food producing		
Month	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**
J	100	100	97	100	100	105
F	100	100	97	100	100	103
M	100	100	97	100	100	107
A	103	100	98	105	100	115
M	98	100	100	99	100	118
J	97	100	100	105	100	102
J	98	100	100	117	100	100
A	99	100	100	119	100	100
S	98	100	100	111	100	100
O	97	100	100	105	100	115
N	97	100	98	100	100	115
D	98	100	98	99	100	111

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Table 29. Habitat retention in the Waipawa River d / s from the irrigation intake (Reach 5) for Deleatidium under the proposed flow regime expressed as a percentage of realisable habitat available (WUA2) at status quo flows for a dry year (1990), a wet year (1976), and a median year (1996) based on BITHABSIM analysis.

Month	***Deleatidium*, mayfly (Jowett *et. al.* 1991)**		
	Dry	**Wet**	**Median**
J	101	227	184
F	109	157	190
M	121	138	152
A	125	139	168
M	133	120	138
J	143	123	123
J	217	118	79
A	131	118	85
S	99	92	92
O	95	84	97
N	105	94	103
D	101	100	114

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Lower Tukituki River (Reach 6): The effect of the proposed flow regime for water storage on macroinvertebrates

The relationship between *Deleatidium* and food producing habitat with flow followed an asymptotic pattern, with habitat decreasing most steeply with flow reduction below 7 and 12 m^3/s, respectively (Figure 39). The proposed median flow (under Scenario 4) is 1.9 m^3/s lower than the Scenario 2 median flow (20.6 m^3/s) and this change is associated with a very small reduction in both *Deleatidium* and food producing habitat (1.5 and 1%, respectively).

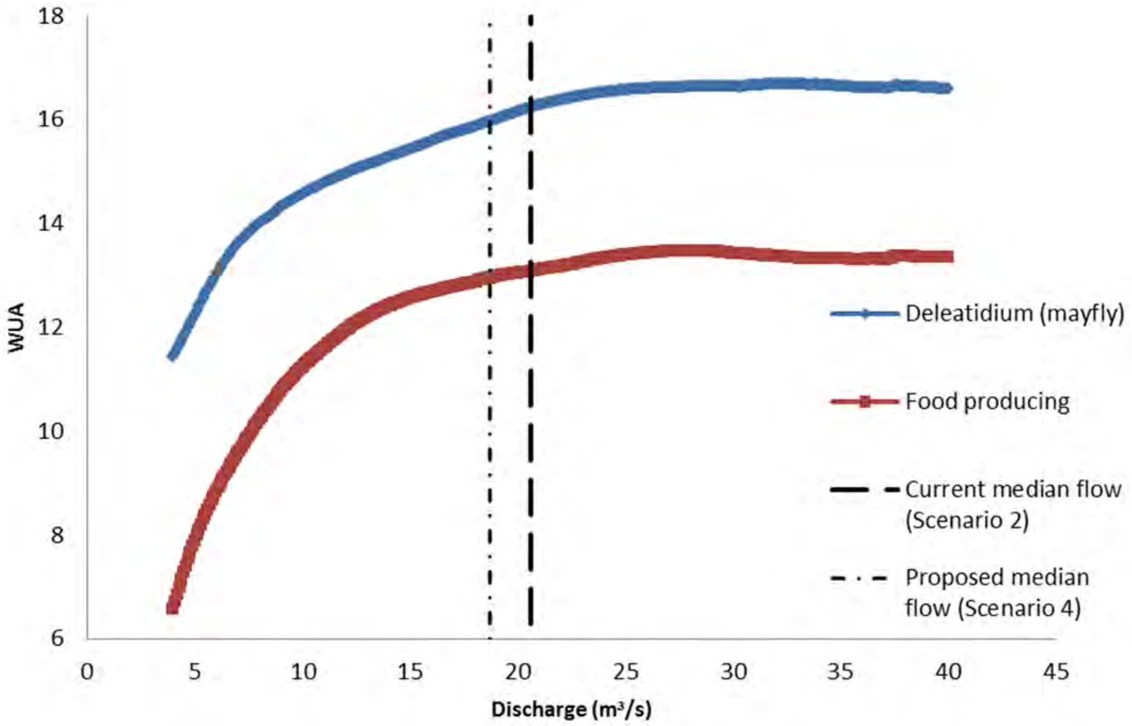

Figure 39. Relationship between weighted useable area (WUA) and flow for Deleatidium (mayfly), and 'food producing' habitat in the Lower Tukituki River (Reach 6) based on the instream habitat model of Johnson (2011). Note: Scenario 2 = status quo flow in this reach.

Seasonal habitat retention analysis for the lower Tukituki indicates minimal effects of Scenario 4 relative to the status quo (*i.e.* Scenario 2) on *Deleatidium* and food-producing habitat (Appendix 23).

Given these predictions, the further attenuation of the flow effects downstream of tributary inflow, and the fact that seasonal habitat retention analysis is environmentally conservative, BITHABSIM modelling was not undertaken on the lower Tukituki River (Reach 6).

Summary: Effects of the proposed flow regime on macroinvertebrates

While there will be changes to the composition of invertebrate communities in the Makaroro, the predicted habitat losses will not affect the viability of populations below the dam down into the Tukituki system, noting also that the effects of bed armouring will tend to increase invertebrate habitat.

Moderate to substantial habitat losses under BITHABSIM modelling during summer in dry years for the Makaroro River (Reach 3) and the Waipawa River upstream of the intake (Reach 4) could adversely affect fish. Moderate *Deleatidium* habitat losses also occur in spring during median years in the Makaroro River (Reach 3), this being the times when river birds are nesting. On the other hand, there are some positive effects of the scheme. The proposed flow regime resulted in mainly habitat gains in median and wet years in the Waipawa River upstream of the intake (Reach 4), and dry and wet years in the Waipawa River downstream of the intake (Reach 5). Generally, the adverse effects predicted in the Makaroro below the dam are attenuated below the Makaroro — Waipawa confluence such that effects are minimal by Reach 6 (Tukituki).

Overall, taking account for the gains and losses and the relative lengths of the respective river segments, habitat effects on productivity of invertebrate populations will be at or about neutral. This analysis does not take into account the effects of short term flow fluctuations, which are considered separately in Section 3.4.6.

3.4.5.4. Effects of hydrological changes on native and introduced fish

Introduction

The assessments presented in this section are based on the results of habitat modelling for fish known to be present in each of the relevant reaches, as described in Section 3.4.5.1. Habitat suitability curves for these species can be found in Appendix 19.

Makaroro River (Reach 3): The effect of the proposed flow regime on native and introduced fish species

Eel habitat (WUA) is predicted to increase as flows drop below about the natural median flow (3.5 m^3/s) (Figure 40). This increase in habitat with reducing flows is mainly the result of improved average habitat quality, whereas the increase in habitat (WUA) as flows rise above the median flow is mainly the result of an increase in wetted area providing a greater area of habitat.

A similar pattern of habitat response was evident for most other native fish species (Figure 41), with torrentfish and bluegill bullies being the notable exceptions. The habitat responses of these two fast-water specialist native fish were more similar to those of rainbow trout (Figure 42). For these species both habitat quality and quantity were predicted to increase to an optimum before declining at higher flows.

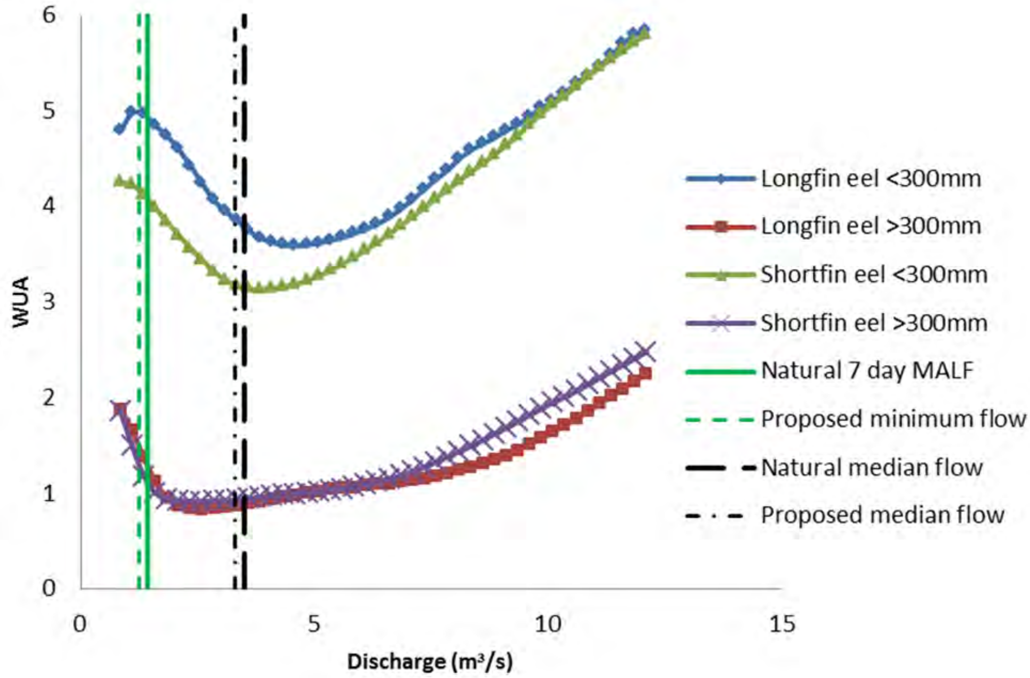

Figure 40. Weighted useable area (WUA) for longfin and shortfin eel.

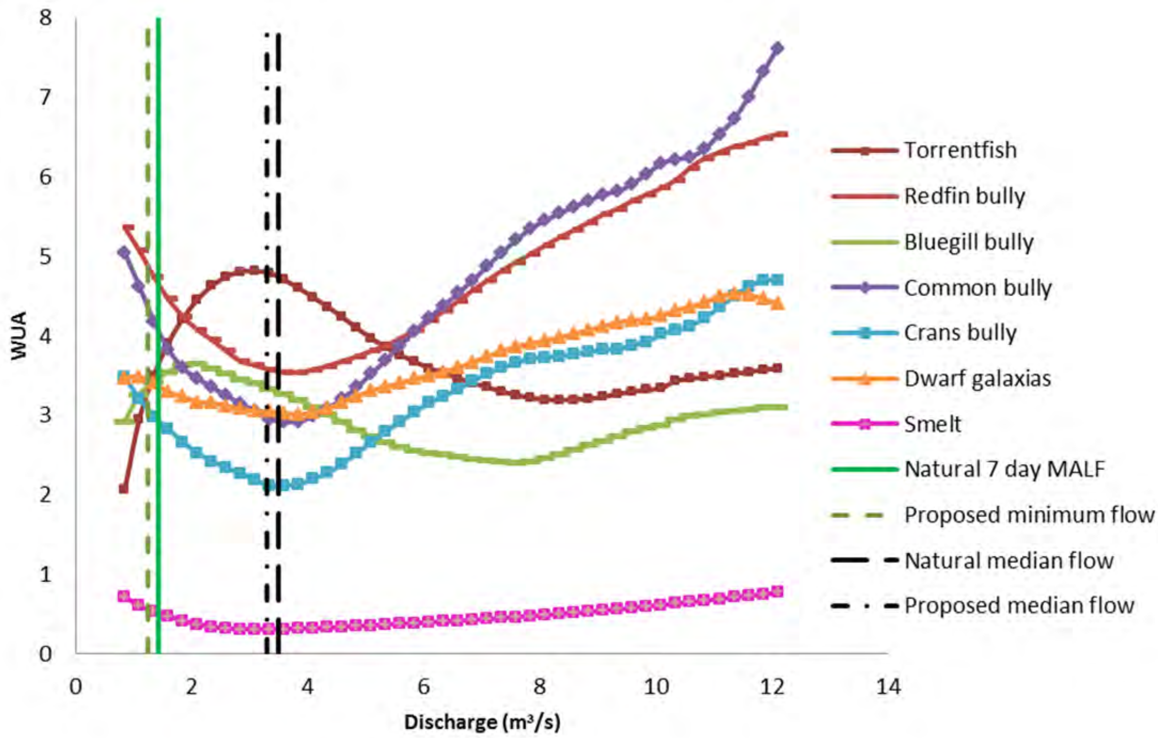

Figure 41. Weighted useable area (WUA) for other native fish species.

The two species with the highest flow requirements to provide optimum physical habitat were rainbow trout (> 20 cm) and torrentfish (Figure 42). For both of these species the flow providing optimum habitat (WUA) was predicted to be about 3-4 m^3/s, and WUA was predicted to decline relatively steeply with reductions in flow below the MALF.

The MALF is recognised as being an ecologically relevant flow statistic, and habitat availability at the MALF is thought to act as a bottleneck to trout populations (and other long lived freshwater fish) because it is indicative of the annual average minimum living space available to these populations. Setting of minimum flows that retain a proportion (usually 90%) of the habitat (WUA) at the MALF for valued species with high flow requirements has become a commonly used approach in recent years in New Zealand rivers. An assumption is made that setting minimum flows to retain habitat for critical species with high flow requirements will also provide for those species with lower flow requirements. This approach has been applied elsewhere in New Zealand and also specifically in the Tukituki catchment (Johnson 2011).

Based on the predicted habitat response curves for rainbow trout (> 20 cm) and torrentfish (Figure 42), the flow required to provide 90% habitat retention relative to that at the MALF would be 1.22 m^3/s and 1.25 m^3/s, respectively. Therefore, setting the minimum flow at 1.25 m^3/s would be expected to provide adequate instream habitat for freshwater fish in the Makaroro River. For comparison, the interim minimum flow used in the assessments and modelling in the feasibility studies was 1.23 m^3/s. We consider that the difference between 1.23 and 1.25 m^3/s is essentially negligible and recommend that 1.23 m^3/s at the base of the dam is adopted as the minimum flow.

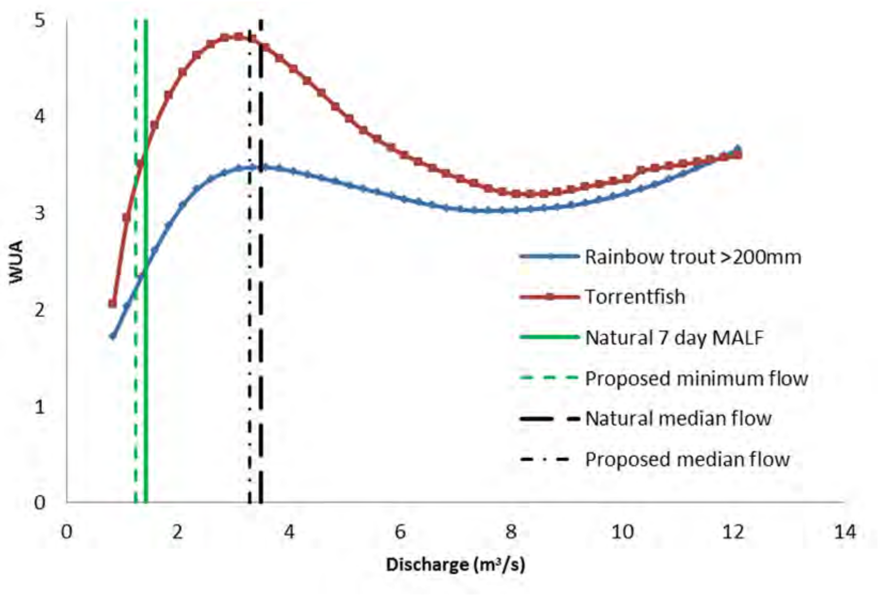

Figure 42. Weighted useable area (WUA) for adult rainbow trout and torrentfish.

The results of the seasonal habitat retention analysis for this reach (Table 30) show that up to 33% of torrentfish habitat (WUA) and up to 38% of rainbow trout habitat (WUA) would be lost as a result of the proposed flow regime. This reduction in habitat will be most prevalent in dry years between May and December, peaking in June or July. Although these habitat losses represent the average amount of habitat potentially available to fish, they do not necessarily translate to fish numbers. Reductions in habitat in the winter spring months, as indicated here, will have less effect than a similar reduction in summer because cool water temperatures mean that the food intake and metabolic energy demands of these fish over winter are lower than they are in summer.

Table 30. Habitat retention in the Makaroro River (Reach 3) for selected fish under the proposed flow regime expressed as a percentage of habitat available at status quo flows for dry months, wet months, and median months based on a seasonal habitat retention analysis.

	Rainbow trout (> 20 cm) (Hawke's Bay Provisional)			Torrentfish (Jowett & Richardson 2008)			Bluegill bully (Jowett & Richardson 2008)		
Month	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**
J	100	100	116	100	100	109	100	100	90
F	106	100	119	109	100	111	102	100	90
M	100	100	91	100	100	93	100	100	101
A	95	100	66	94	100	69	98	100	93
M	79	100	62	79	100	67	93	100	101
J	66	100	62	69	100	67	93	100	101
J	63	100	62	66	100	67	98	100	101
A	62	100	100	67	100	100	100	100	100
S	64	100	100	67	100	100	95	100	100
O	66	100	100	69	100	100	93	100	100
N	74	100	101	75	100	99	92	100	96
D	82	100	104	82	100	100	94	100	93

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Waipawa River upstream of irrigation intake (Reach 4): The effect of the proposed flow regime on native and introduced fish species

Flow requirements regarding habitat retention for the most flow demanding fish species in the Waipawa River were assessed by Johnson (2011). In summary, flows above 2.3 m^3/s, 2.4 m^3/s, and 2.5 m^3/s would need to be maintained for 90% habitat retention for torrentfish, rainbow trout and longfin eel, respectively. Further details can be viewed in Johnson (2011).

The results of the seasonal habitat retention analysis for this reach (Table 31) show that up to 27% of torrentfish WUA and up to 14% of rainbow trout WUA will be lost under the proposed flow regime. This is predicted to occur over the summer period, between November and March. The greatest losses occur during dry to median months. The opposite is true for the longfin eel, where the greatest habitat loss occurs over winter (up to 19% loss of WUA). Despite the reduction in habitat available for rainbow trout during the summer period, it is relatively small and close to the 90% habitat retention guidelines that have been proposed in the Tukituki Plan Change process. The habitat reduction for torrentfish over summer is also slightly greater than the 90% habitat retention guidelines during median summer conditions, but is neutral or enhanced in all other flow scenarios and times of year. Overall, habitat losses predicted for rainbow trout (> 20 cm), and longfin eels are relatively minor, but moderate habitat losses predicted over the summer period in a median year may adversely affect torrentfish.

Table 31. Habitat retention in the Waipawa River u / s from the irrigation intake (Reach 4) for selected fish under the proposed flow regime expressed as a percentage of habitat available at status quo flows for dry months, wet months, and median months based on a seasonal habitat retention analysis.

	Torrentfish (Jowett & Richardson 2008)			Rainbow trout (> 20 cm) (Hawke's Bay Provisional)			Longfin eel (> 300 mm) (Jowett & Richardson 2008)		
Month	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**
J	89	100	75	98	100	87	104	100	128
F	93	100	73	97	100	86	107	100	129
M	94	100	79	96	100	88	110	100	125
A	101	100	108	102	100	104	97	100	93
M	100	100	113	99	100	108	102	100	88
J	108	100	102	101	100	101	101	100	98
J	124	100	100	109	100	100	84	100	100
A	127	100	100	112	100	100	81	100	100
S	112	100	100	104	100	100	93	100	100
O	99	100	100	100	100	100	100	100	100
N	96	100	89	100	100	93	99	100	112
D	96	100	84	102	100	90	95	100	119

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Waipawa River downstream of irrigation intake (Reach 5): The effect of the proposed flow regime on native and introduced fish species

As discussed earlier, flow requirements regarding habitat retention for the most flow demanding fish species in the Waipawa River were assessed by Johnson (2011). In summary, flows above 2.3 m^3/s, 2.4 m^3/s, and 2.5 m^3/s would need to be maintained for 90% habitat retention for torrentfish, rainbow trout and longfin eel, respectively. Further details can be viewed in Johnson (2011). The proposed instantaneous MALF and median flow for this reach is 2.79 m^3/s and 5.1 m^3/s respectively.

The results of the seasonal habitat retention analysis for this reach (Table 32) show that torrentfish and rainbow trout gain habitat, while longfin eel (> 300 mm) WUA is slightly reduced (up to 81% retention of habitat at natural flows). Overall, the effect of the proposed flow regime downstream of the irrigation intake on torrentfish, trout and longfin eel habitat is considered to be minor.

Table 32. Habitat retention in the Waipawa River d / s from the irrigation intake (Reach 5) for selected fish under the proposed flow regime expressed as a percentage of habitat available at status quo flows for dry months, wet months, and median months based on a seasonal habitat retention analysis.

	Torrentfish (Jowett & Richardson 2008)			Rainbow trout (> 20 cm) (Hawke's Bay Provisional)			Longfin eel (> 300 mm) (Jowett & Richardson 2008)		
Month	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**	**Dry**	**Wet**	**Median**
J	100	100	108	100	100	100	100	100	102
F	100	100	105	100	100	99	100	100	104
M	100	100	112	100	100	102	100	100	98
A	106	100	122	107	100	108	88	100	87
M	100	100	123	98	100	112	105	100	83
J	109	100	102	100	100	101	101	100	98
J	124	100	100	109	100	100	84	100	100
A	127	100	100	112	100	100	81	100	100
S	116	100	100	105	100	100	92	100	100
O	108	100	119	100	100	111	102	100	84
N	101	100	122	98	100	108	105	100	87
D	99	100	116	98	100	105	105	100	92

Key:

Habitat gain	100-110% retention	110-120% retention	120-130% retention	130-140% retention	> 140% retention
Habitat loss	90-100% retention	80-90% retention	70-80% retention	60-70% retention	50-60% retention

Lower Tukituki River (Reach 6): The effect of the proposed flow regime on selected fish species

Flow requirements regarding habitat retention for the most flow demanding fish species in the Lower Tukituki River were also assessed by Johnson (2011). In summary, flows above 5.3 m^3/s and 5.8 m^3/s would need to be maintained for 90% habitat retention for adult rainbow trout and torrentfish, respectively and have been proposed as possible minimum flows (Table 7). Further details can be viewed in Johnson (2011). The proposed instantaneous MALF and median flow for this reach as calculated under Scenario 4 of the proposed regime was 4.51 m^3/s and 18.7 m^3/s, respectively. Therefore, it appears that under Scenario 4 the proposed minimum flow (5.2 m^3/s) will not always be met. Under Scenario 3 the instantaneous MALF is slightly higher at 5.36 m^3/s and close to the proposed minimum flow, while the median flow is 19.5 m^3/s.

The results of the monthly habitat retention analysis for this reach (Appendix 24) indicate no significant habitat loss occurs under Scenarios 3 and 4.

As for the Waipawa downstream of the intake, the effect of the proposed flow regime in the lower Tukituki on fish habitat is considered to be minor.

Summary: The effect of the proposed flow regime on native and introduced fish species

Overall the predicted habitat losses for native and introduced fish are not expected to affect the viability of populations below the dam down into the Tukituki system.

In the Makaroro River (Reach 3), predicted moderate / substantial habitat (productivity) losses from autumn through to early summer in dry years and autumn / winter in median years may adversely affect rainbow trout (> 20 cm) and torrentfish. In general, adverse effects predicted in the Makaroro below the dam are attenuated downstream, such that in the Waipawa upstream of the irrigation intake only minor habitat losses are predicted for rainbow trout and torrentfish, and further downstream there are mainly habitat gains. Habitat retention for longfin eels remained relatively unchanged in the Makaroro and Waipawa upstream of the intake.

Overall, taking account for the gains and losses and the relative lengths of the respective river segments habitat effects on fish species will probably be close to neutral. This analysis does not take into account the effects of short term flow fluctuations, which are considered in Section 3.4.6.

3.4.5.5. Flow optimisation modelling for Reach 6

As discussed earlier, Aquanet (May 2013) suggests that fish populations, particularly trout, would benefit from low flow supplementation in most years. This section provides a detailed analysis of this by calculating the change in physical habitat for a given species under each of the 52 scenarios. This assumes that trout are habitat limited in this reach, and so does not take account of disturbance events or the effects of short term flow fluctuations.

The results of flow optimisation modelling for the 52 different scenarios presented in Section 3.4.2 indicate there will be no significant effect on mean/median flows compared to that of the status quo (Scenario 2) (*i.e.* more than 90% retention in all cases). 1-day MALFs are predicted to increase by up to 46% under the modelled scenarios (*i.e.* up to 146% retention of the status quo MALF). Increases are most pronounced when using flow thresholds of Q_{90}, Q_{91}, Q_{92}, Q_{93}, and Q_{94} under Scenario 3 (Dec-April) (Table 15). Mean monthly low flows increase by up to 30% in January and February, whereas there is no significant increase in other months.

Habitat data collected from the lower Tukituki River (Johnson 2011) was combined with habitat suitability criteria for adult rainbow trout (Hawkes Bay Provisional), torrentfish (Jowett and Richardson 2008), and food producing habitat (Waters 1976) to calculate the change in habitat availability (WUA) with flow (Figure 43).

Habitat availability at the MALF for each of these species was calculated for each of the 52 flow optimisation scenarios and compared to habitat available at the status quo, to give habitat retention.

Results (Figures 44-46) show that the greatest habitat gains (up to 140% retention) are likely to occur under Scenario 3 (Dec – April) using Q_{90}, Q_{91}, Q_{92}, Q_{93}, Q_{94}, or the current MALF as the threshold flow. The least gain was observed when using the current minimum flow as the threshold flow.

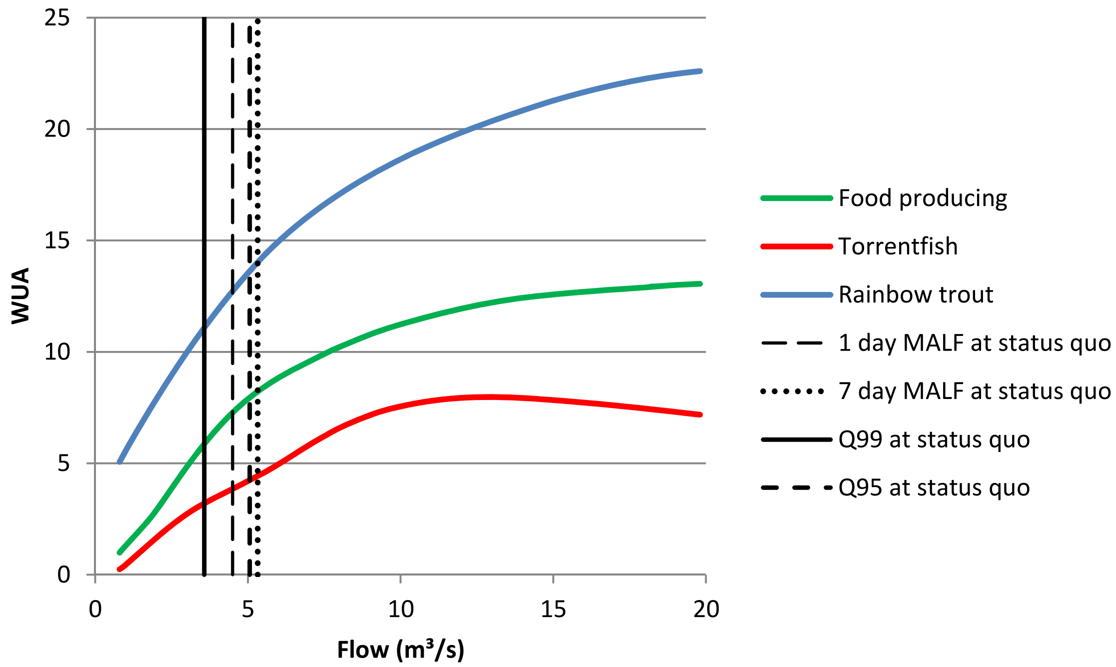

Figure 43. WUA for adult rainbow trout, torrentfish and food producing habitat in the Lower Tukituki River.

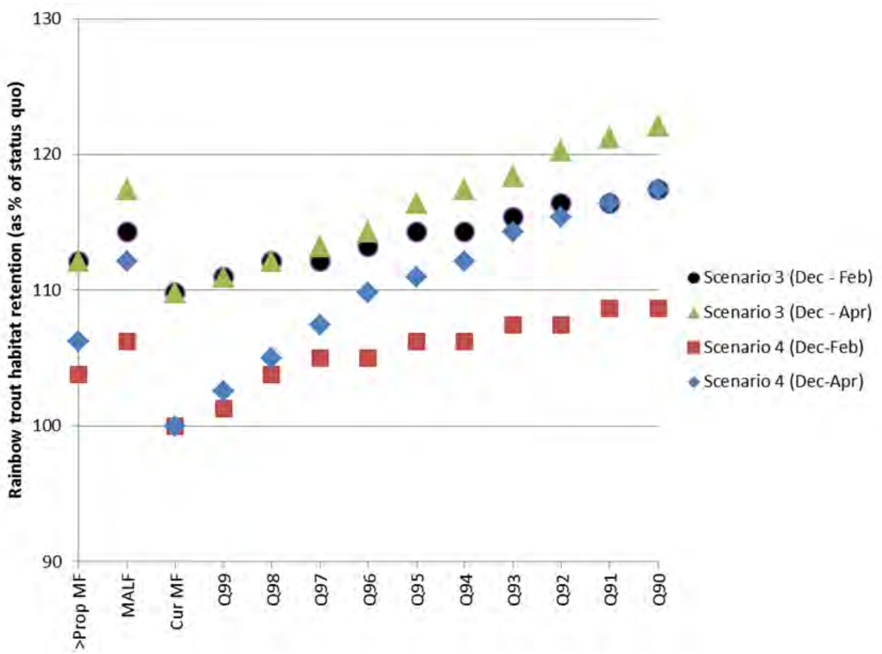

Figure 44. Habitat retention at the 1-day MALF for adult rainbow trout habitat under the flow optimisation scenarios modelled by Aquanet (May 2013) (as a % of that available under the status quo, Scenario 2). Variables named 'Cur MF' and 'Prop MF' represent the current and proposed minimum flows; 'MALF' represents the current 7-day Mean Annual Low Flow; and Q_{99}–Q_{90} are exceedence percentile flows.

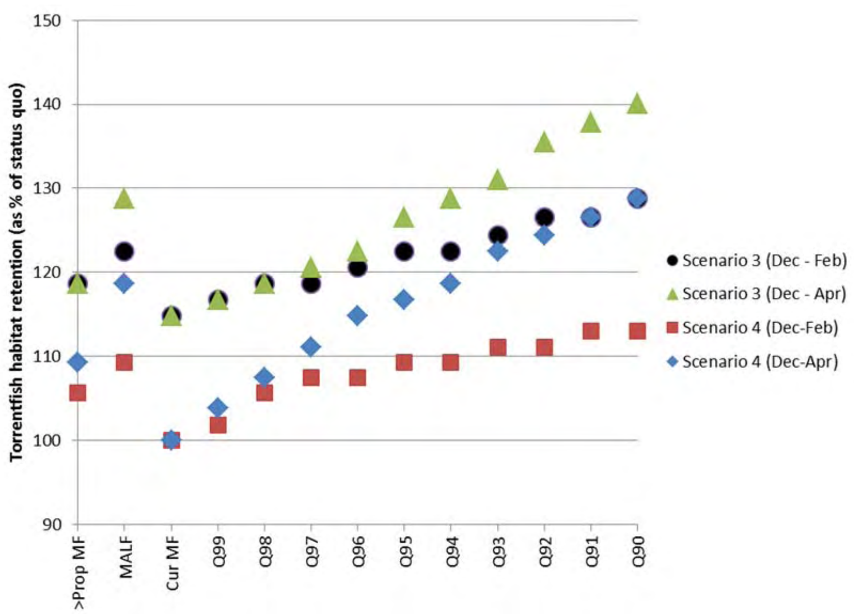

Figure 45. Habitat retention at the 1-day MALF for torrentfish habitat under the flow optimisation scenarios modelled by Aquanet (May 2013) (as a % of that available under the status quo, Scenario 2). Variables named 'Cur MF' and 'Prop MF' represent the current and proposed minimum flows; 'MALF' represents the current 7-day Mean Annual Low Flow; and Q_{99}–Q_{90} are exceedence percentile flows.

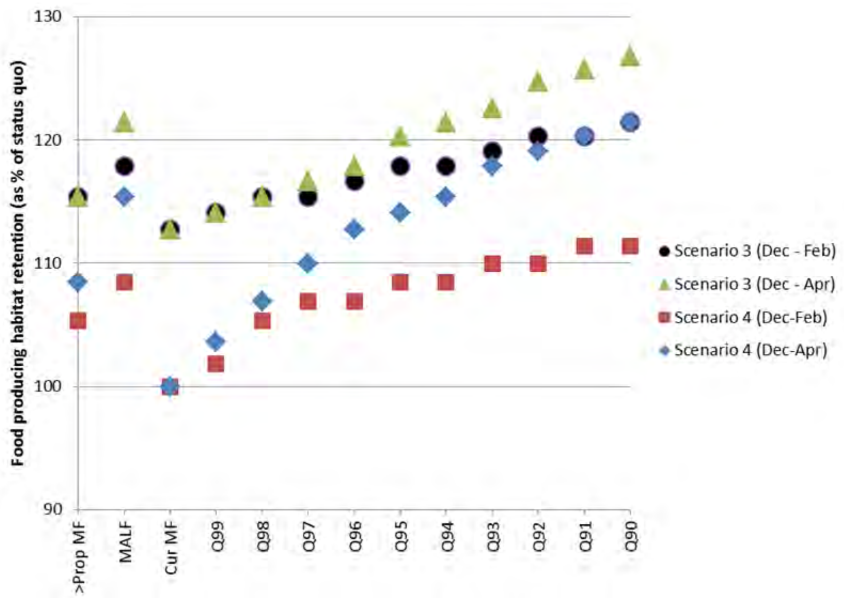

Figure 46. Habitat retention at the 1-day MALF for food producing habitat under the flow optimisation scenarios modelled by Aquanet (May 2013) (as a % of that available under the status quo, Scenario 2). Variables named 'Cur MF' and 'Prop MF' represent the current and proposed minimum flows; 'MALF' represents the current 7-day Mean Annual Low Flow; and Q_{99}–Q_{90} are exceedence percentile flows.

In summary, supplementation of low flows potentially would result in habitat gains for some flow demanding species of up to 40% compared with the status quo. The amount of habitat gain is proportional to the degree of low flow supplementation, with the largest habitat gains associate with a scenario where flows are not allowed to drop below the Q_{90} and under Scenario 3 where all current consented abstractions are moved to water supply from the Scheme. Supplementation of maintain flows greater than the minimum flow proposed in the Tukituki Plan Change 6 would result in a 5-20% increase in habitat availability compared to the status quo, depending on the irrigation Scenario and species examined.

3.4.6. Effects of fluctuating flows

3.4.6.1. Introduction

Fluctuations in flow create a varial zone that is wetted and dried as water levels rise and fall (Jowett *et al*. 2008). Depending on their timing, frequency, duration and magnitude, fluctuating flows can have adverse short and long term effects on resident fish and invertebrates (Young *et al.* 2011). Repeated fluctuating flows have negative consequences for the river ecosystem and should not be confused with flushing flows which are released infrequently to address nuisance accumulations of periphyton and have positive effects on river ecosystems. A varial zone that is wetted and dried at more frequent intervals than weekly is likely to be unproductive and can be regarded as providing no meaningful aquatic habitat.

During summer, the proposed flow regime features diurnal variations of discharge from the proposed minimum flow (1.23 m^3/s) up to 11.125 m^3/s. This will occur in Reaches 3 and 4, between the dam site and the irrigation take. During winter, flow fluctuations are also being considered as a means to meet peaks in electricity demand (*i.e*. hydro-peaking). Diurnal variations of discharge range from the proposed minimum flow (1.23 m^3/s) up to 9.73 m^3/s. This will affect Reaches 3, 4, 5 and 6. This section presents modelling predictions estimating the effects of flow fluctuation on habitat. These effects are additional to the effects of the proposed flow regime (discussed in Sections 3.4.5.2, 3.4.5.3 and 3.5.4.4), and are not comparable to the natural flow regime. Effects were simulated incrementally over a range of flow fluctuation scenarios, up to the maximum proposed fluctuations noted above.

The effects of the proposed flow fluctuations were predicted using the same hydraulic model used for habitat modelling (RHYHABSIM). The concept underlying this analysis is that some aquatic species may become established at locations that provide suitable habitat at base flow. However, if the flows change, and the location no longer provides suitable habitat, then that location would not be considered suitable under a fluctuating flow regime (Jowett 2004). At each simulated flow, the WUA tally includes only suitable habitat from those locations that overlap in space with the suitable locations that were available at base flow.

This analysis assumes that the species is unable to move to other suitable habitats. Consequently, it is only really applicable to species or life-stages with relatively low mobility, such as benthic invertebrates or spawning habitat/egg incubation habitat for fish. Highly mobile species, like most fishes, are likely to move to find more favourable habitat as flows vary and so are unlikely to be directly affected by flow fluctuation. Although the possibility of stranding does exist, especially for smaller fish in channels with broad shallow sloping cross-sectional profile, the main effect on fish may actually come via changes in densities of their invertebrate food resources.

Modelling estimates the minimum habitat available over the high and low flow cycle of flow fluctuation, and calculates habitat retention relative to an ecologically relevant base flow. An ecologically relevant baseflow was selected by considering both the season (*i.e*. when flow fluctuations are likely to be present in the flow regime) and the species / life stage requirements.

Proposed 'winter' flow fluctuations occur most frequently between June and September, but are also present in other months. Effects of 'winter' fluctuating flows were assessed for rainbow trout spawning habitat (including egg incubation), which is most vulnerable between August and December. Eggs are susceptible to desiccation by dewatering of the channel margins (at the low flow part of the fluctuation flow cycle), and trout may be deterred from spawning by high water velocities in mid-channel (at the high flow part of the cycle). Hence the mean monthly minimum flow between August and December was selected as the ecologically relevant base flow for ‘winter’ flow fluctuations. The habitat at this flow represents the minimum spawning habitat that remains wetted under the proposed regime.

Proposed ‘summer’ flow fluctuations occur most frequently between November and March. Food and energy requirements for fish peak during the summer; hence this is the critical season to assess habitat retention for macroinvertebrates, since they are the major food resource for fish in New Zealand rivers. Given the relatively short life cycle of macroinvertebrates (compared to annual spawning fish), the summer median flow is ecologically relevant for them (*i.e*. 50th percentile flow between November and February).

The modelled outputs display habitat retention (%) vs. the proportion of flow fluctuation indicated in the proposed flow regime. Habitat retention indicates how much WUA is still suitable with flow fluctuation compared to the WUA at the base flow. The modelled outputs display the range of habitat retention with increased flow fluctuation, up to the maximum as described above (11.125 m^3/s in summer and 9.73 m^3/s in winter).

Note that the modelled outputs can be considered worst-case scenarios since the natural flow fluctuations about the base flow are not incorporated into this analysis and therefore the predicted effects are an overestimate. In addition, the actual fluctuations at sites distant from the proposed dam will be less than those modelled because of the attenuation of flow peaks with distance downstream from the dam. This latter effect is discussed in more detail in relation to flushing flows in Section 4.4.1.

3.4.6.2. *Makaroro River (Reach 3): The effect of flow fluctuations on fish and invertebrates*

Winter flow fluctuation (hydro-peaking)

During winter, the proposed flow regime features daily flow fluctuations between the proposed minimum flow (1.23 m^3/s) and the hydro-peaking flow (9.73 m^3/s). Hence the maximum winter hydro-peaking flow range (for this and all reaches during winter) is 8.5 m^3/s (*i.e*. 9.73 minus 1.23). The model uses a base flow of 1.5 m^3/s, which represents the base flow during a typical dry winter (as described above).

Habitat retention for spawning trout is predicted to be strongly negatively affected by flow fluctuations (Figure 47). Given the full flow fluctuation of 8.5 m^3/s, spawning habitat would be reduced by 98%. Even if flow fluctuations were reduced by as much as 70% of that proposed (*i.e*. down to 2.55 m^3/s), 80% of the river’s trout spawning habitat would be lost.
This is important because trout attempting to swim up the Makaroro River to their traditional spawning sites higher in the catchment will not be able to get past the dam. These trout will then attempt to find a suitable spawning site below the base of the

dam, where spawning trout are predicted to be most negatively affected by fluctuating flows.

Fluctuating flows have the potential to significantly affect spawning success in the Makaroro River below the dam. Artificial flow fluctuation can temporarily dewater trout redds. Salmonid eggs can survive for weeks in dewatered gravel (Stober *et al*. 1982, Reiser & White 1983, Becker & Neitzel 1985, Neitzel *et al*. 1985) if they remain moist and are not subject to freezing or high temperatures. Thus dewatering is not necessarily lethal to eggs. However, the alevins (yolk sac fry still within the gravel) are more sensitive to dewatering. They rely on gills to respire so dewatering is lethal to them. They may however, survive in subsurface flow if the water table does not withdraw below their level in the redd (Stober *et al*. 1982).

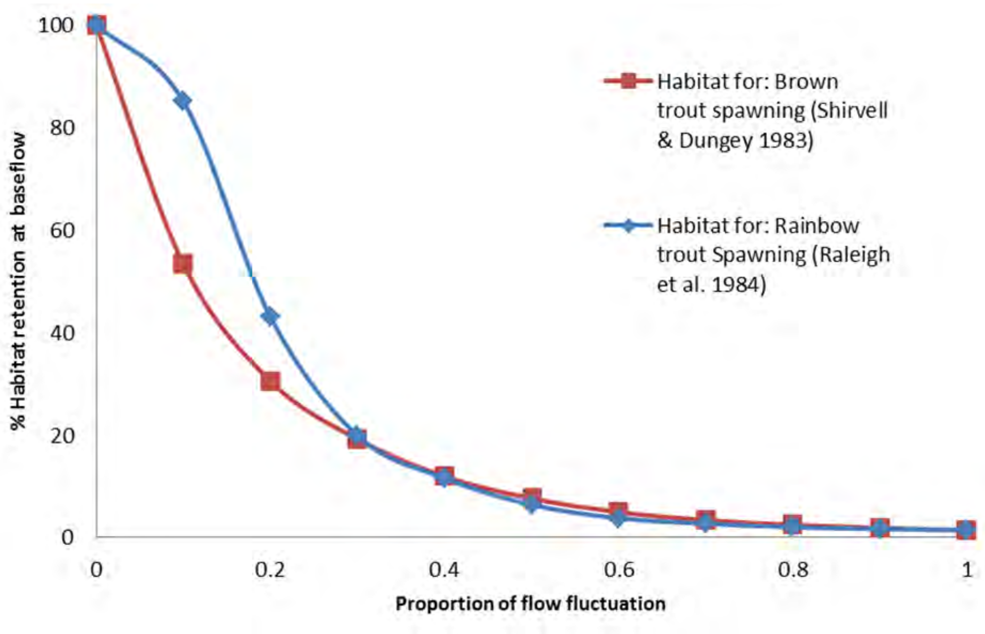

Figure 47. Predicted change in habitat retention for trout spawning caused by winter hydro-peaking in the Makaroro River (Reach 3), relative to that available at a base flow of 1.5 m^3/s.

Summer flow fluctuation

Summer flow fluctuations are likely to have a strong influence on instream habitat for macroinvertebrates in Reaches 3 and 4. Trout spawning in the Tukituki catchment only occurs in winter, so spawning habitat is not considered here.

During summer, the proposed flow regime features daily flow fluctuations between the proposed minimum flow (1.23 m^3/s) and the maximum irrigation flow (11.135 m^3/s). Hence the maximum summer-time fluctuating flow range (for Reaches 3 and 4) is 9.9 m^3/s (*i.e*. 11.135 minus 1.23). The model uses a base flow of 9.3 m^3/s, which represents a typical summer baseflow (the long term median as described above).

Habitat retention for common benthic invertebrate taxa in the Makaroro River with summer flow fluctuations is shown in Figure 48. Note this output accounts for habitat retention on either side of the baseflow.

Given the full flow fluctuation of 9.9 m^3/s, 42% to 65% of the habitat available at baseflow is retained (depending on the species). If the magnitude of flow fluctuations were reduced by half, then between 68% and 82% would be retained; and if fluctuations were reduced by 80% (*i.e*. fluctuations of only 2 m^3/s) there would be relatively little change in WUA for all but one species.

Deleatidium habitat in Reach 3 is predicted to be reduced to about 42% of the optimum with full flow fluctuation. Overall, there is likely to be a reduction of the invertebrate food base available to fish feeding in this reach caused by summer flow fluctuations.

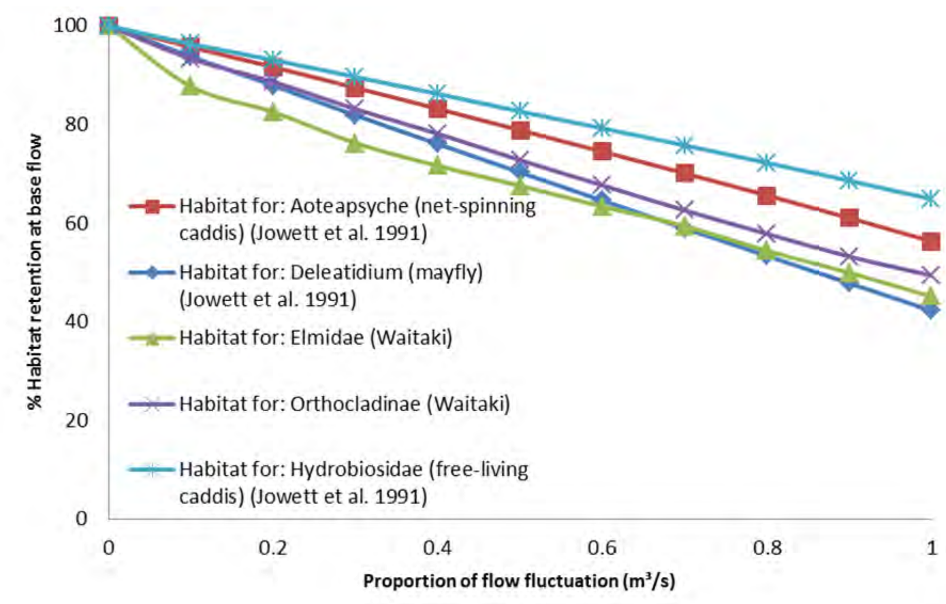

Figure 48. Predicted change in habitat retention for common invertebrate species caused by summer flow fluctuations in the Makaroro River (Reach 3), relative to that available at a baseflow of 9.3 m^3/s.

3.4.6.3. Waipawa River upstream of irrigation intake (Reach 4): The effect of flow fluctuations on fish and invertebrates

Winter flow fluctuation (hydro-peaking)

For the Waipawa River upstream from the irrigation intake (Reach 4), hydro-peaking is likely to have a strong influence on instream habitat for species of life stages with relatively low mobility.

Flow fluctuations were modelled as described for the Makaroro, using habitat data from Johnson (2011). The modelled outputs from these flow fluctuations can be considered conservative, since the actual fluctuations will be less given the attenuation of flow change with distance from the dam. The model uses a base flow of 4.9 m^3/s, which represents the base flow during a typical dry winter.

As in the Makaroro, trout spawning habitat was predicted to be strongly negatively affected by flow fluctuations (Figure 49). Given the full flow fluctuation of 8.5 m^3/s, spawning habitat would be reduced by 97%. If flow fluctuations were reduced by half, about 26% of the rainbow trout spawning habitat available at base flow would be retained.

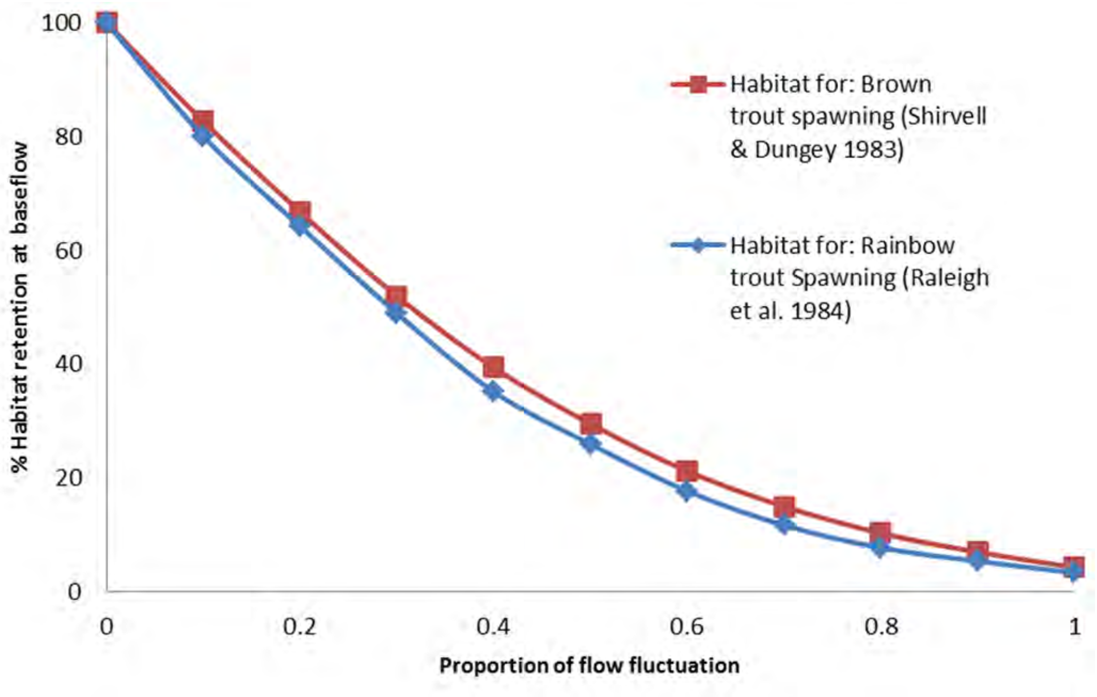

Figure 49. Predicted change in habitat retention for spawning trout in the Waipawa (u / s irrigation intake) with winter hydro-peaking using a baseflow of 4.9 m^3/s.

Summer flow fluctuation

As with the Makaroro, Reach 4 of the Waipawa will experience summertime flow fluctuations of up to 9.9 m^3/s. The model uses a base flow of 12.3 m^3/s, which represents a typical summer baseflow.

Habitat retention for common benthic invertebrate taxa in the Waipawa River upstream of the irrigation intake with summer flow fluctuations is shown in Figure 50. Note this output accounts for habitat retention on either side of the baseflow.

Given the full flow fluctuation of 9.9 m^3/s, 59% to 80% of the habitat available at baseflow is retained (depending on the species). If the magnitude of flow fluctuations were reduced by half, then between 79% and 90% would be retained; and if fluctuations were reduced by about 30% there would be relatively little change in WUA for all species.

Deleatidium habitat is predicted to reduce to about 59% of the optimum with full flow fluctuation. Overall, there is likely to be a reduction of the invertebrate food base available to fish feeding in this reach caused by summer flow fluctuations.

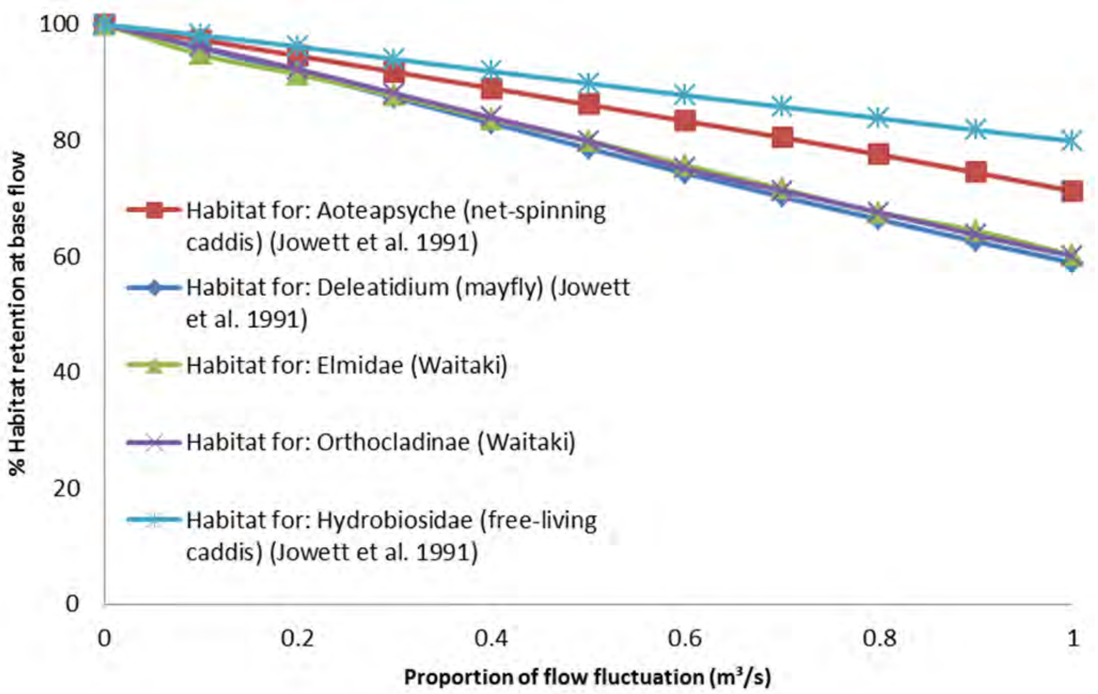

Figure 50. Predicted change in habitat retention for common invertebrate species in the Waipawa (u/s irrigation intake) with summer flow fluctuation, using a baseflow of 12.3 m^3/s.

3.4.6.4. Waipawa downstream of the irrigation intake (Reach 5): The effect of flow fluctuations on fish and invertebrates

Flow fluctuations were modelled as described for the Makaroro, using habitat data from Johnson (2011). This analysis is only relevant for Reach 5 between the irrigation intake and the confluence of the Mangaonuku Stream (*i.e*. the upper half of Reach 5). This is because site measurements by Johnson (2011) were located in the vicinity of the irrigation intake and modelling habitat below this confluence is not possible due to the fact that there will be a significant change in flow and a likely change in substrate / habitat composition further downstream.

Since the irrigation supply flows will be diverted to the irrigation intake, Reach 5 will not be affected by summer fluctuating flows as in Reaches 3 and 4. However, winter hydro-peaking flows will continue down through Reaches 5 and 6, so are assessed here. As with the Waipawa Reach 4 analysis, modelled outputs can be considered conservative since the actual fluctuations will be less than those modelled because of the attenuation of flow with distance from the dam.

Winter flow fluctuation (hydro-peaking)

The predicted impact of a hydro-peaking regime on habitat retention for spawning trout in the Waipawa River downstream of the irrigation take is shown in Figure 51. The model uses a base flow of 4.3 m^3/s, which represents the base flow during a typical dry winter.

As in the Makaroro, trout spawning habitat was predicted to be strongly negatively affected by flow fluctuations (Figure 51). Given the full flow fluctuation of 8.5 m^3/s, spawning habitat would be reduced by 97%. If flow fluctuations were reduced by half, about 21% of the rainbow trout spawning habitat available at base flow would be retained.

Whilst significant, maintaining trout spawning WUA in this reach is not as significant as in the Makaroro because fish that are ready to spawn are likely to recognise that suitable spawning sites are not available, so may choose to continue swimming upstream into either the Makaroro or upper Waipawa.

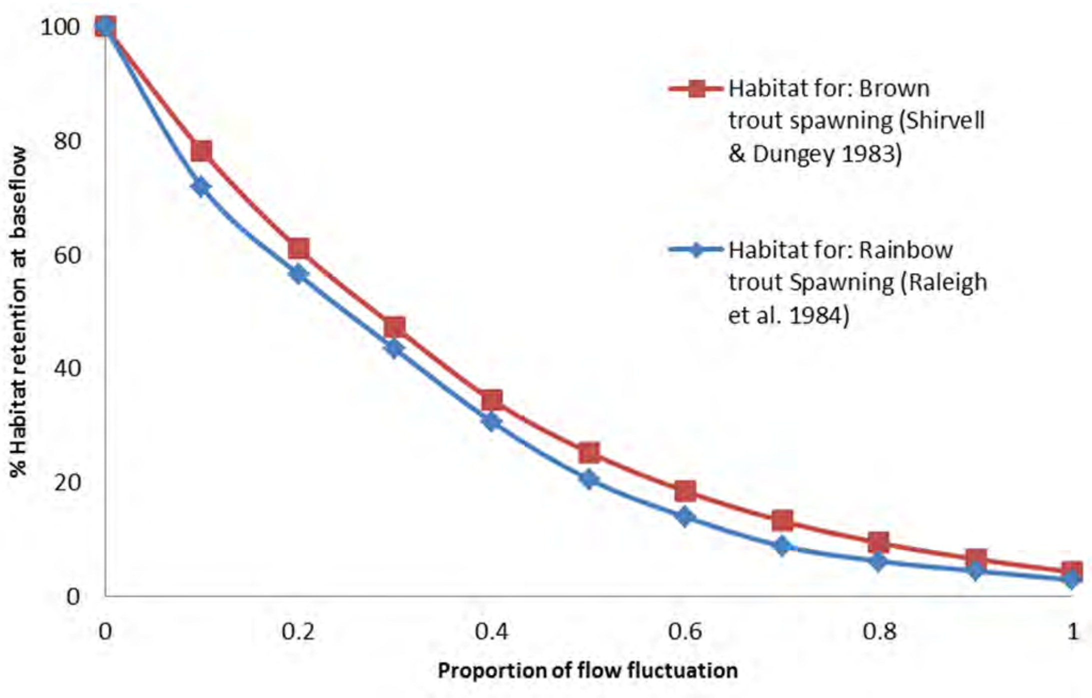

Figure 51. Predicted change in weighted useable area (WUA) for spawning trout in the Waipawa (d / s irrigation intake) with winter hydro-peaking using a baseflow of 4.3 m^3/s.

3.4.6.5. Lower Tukituki River (Reach 6): The effect of flow fluctuations on fish and invertebrates

Winter flow fluctuation (hydro-peaking)

As with Reach 5, summer flow fluctuations are not anticipated in this reach, but it is likely that winter flow fluctuations caused by hydro-peaking will reach the Tukituki River. The extent to which fluctuations attenuate downstream from the dam is considered in more detail in Section 4.4.1, but flow changes will be relatively small relative to baseflow in the lower catchment. The effects of the flow fluctuations were modelled using habitat data from Johnson (2011).

The model uses a base flow of 14.6 m^3/s (*i.e.* the mean monthly minimum flow for August– December under Scenario 4), which represents the base flow during a typical dry winter.

Trout spawning habitat in the Lower Tukituki was predicted to be moderately negatively affected by flow fluctuations (Figure 52). There is a gradual loss of habitat across the modelled range, culminating in the retention of 40% of the optimum at the maximum extent of fluctuation. With a flow fluctuation of half of the proposed magnitude, 85% of the trout spawning habitat available at base flow would be retained.

Maintaining trout spawning WUA in this reach is not as significant as in the Makaroro because it is unlikely that spawning is important in the lower reaches of the Tukituki River.

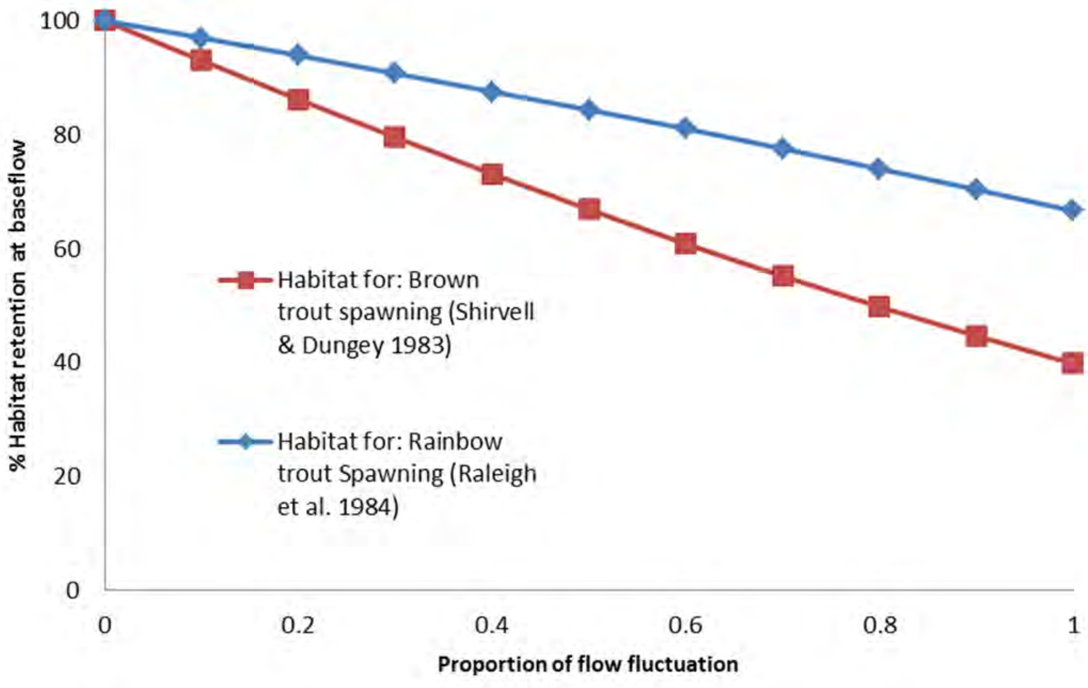

Figure 52. Predicted change in weighted useable area (WUA) for spawning trout in the Lower Tukituki River with winter hydro-peaking, using a baseflow of 14.6 m^3/s.

3.4.6.6. Fish stranding

Another potential issue with fluctuating flows below the dam is fish stranding as flow declines when generation or irrigation demand ceases. The likelihood of fish stranding depends on:

1. The size and mobility of fish, with smaller fish being more likely to be stranded, due to weaker swimming ability; mobility is also reduced at cold temperature.
2. The shape of the streambed, in particular whether there are areas where isolated pools may form temporarily as flow reduces, which may subsequently dry, stranding fish remaining in them.
3. The rate at which flow changes.

A fish stranding study undertaken for Meridian Energy on the lower Waitaki River found some evidence of stranding, particularly of bullies, as well as eels and juvenile salmonids, with a ramping rate of 5.5 cm/hr (Strickland *et al*. 2002). However, this was in a broad, braided channel with plenty of scope for isolated pools and side channels to strand fish. In the Makaroro River there are few areas where isolated pools are likely to be formed by rapid dewatering because the river is largely a single channel with a narrow flood plain. Therefore, although there are fish in the river that may be susceptible to stranding the channel morphology risk factors are not considered to be high. Below the confluence of the Waipawa River, the channel opens out and becomes more braided. At this point the risk of stranding could be higher; however, the daily flow fluctuations will be moderated by downstream attenuation of the flows and the flow contribution of the unregulated upper Waipawa River. We consider it unlikely that fish stranding would occur to an extent sufficient to cause a detectable reduction in fish densities.

3.4.7. Summary

The proposed Scheme will result in substantial changes to the flow regime downstream of the dam. In the reach between the dam and the irrigation intake there will be higher flows in the summer irrigation period and lower flows in late autumn and winter. Mean annual low flows will be either unchanged or slightly higher under the proposed flow regimes. However, there are predicted improvements in extreme low flows with the scheme in place and reductions in the number of days less than the proposed minimum flow under flow Scenario 3 where the scheme is in place and all current consents are discontinued. Flood frequency will be reduced particularly during late autumn and winter when floods will be captured within the refilling reservoir. Downstream of the irrigation intake there will be a general reduction in median flows throughout the year as a result of the Scheme. The changes in flow are most marked in the Makaroro and Waipawa rivers. In the Tukituki River the effects are buffered by flow inputs from the Upper Tukituki River and other tributaries.

The alteration to the flow regime will potentially affect water temperatures and the dilution of contaminants, such as nutrients, sediment and faecal bacteria entering the river. The effects on water temperature are considered to be minor, with lower temperatures than would occur naturally predicted upstream of the irrigation intake resulting from buffered temperatures in the reservoir and the higher summer flows. Downstream of the intake, daily fluctuations in water temperature will be slightly greater as a result of the reduction in median flows. However, this change is predicted to result in no more than a 0.5°C increase in maximum water temperatures, so the effects on the aquatic ecosystem are expected to be minor.

The higher summer flows downstream of the dam will result in an increase in dilution of any contaminants entering the river upstream of the irrigation intake. However, contaminant inputs are not high in this reach and are not expected in increase significantly as a result of the Scheme. Downstream of the irrigation intake the 5-32% reduction in median flows will reduce the dilution of contaminants entering the river with associated increases in contaminant concentrations. The scale of this increase in contaminant concentrations is difficult to assess, since it will depend on the background contaminant concentrations, the load of contaminants coming into the river and the change in flow. The likely change in land use and increase in contaminant inputs from the Ruataniwha Plains will compound the effect of decreased dilution. This issue is discussed further in Section 3.6 and in NIWA (May 2013a).

The change in the flow regime in the Makaroro River will provide better hydrological conditions for the growth of undesirable long and short filamentous algae on the river bed and reduce habitat suitability for desirable diatoms. Further downstream and below the irrigation intake the changes in flow regime on habitat suitability for different components of the periphyton community are mixed, with increases in suitability in some months and decreases or no change in other months. Changes in nutrient concentrations and flushing flow frequency are likely to be more important in controlling periphyton biomass than general hydrological conditions.

Adverse effects on invertebrates downstream of the dam are attenuated with distance downstream, such that in the Waipawa upstream of the irrigation intake overall there are habitat gains. Downstream of the intake, habitat gains are also predicted for summer / autumn. Summer is the most important period for food production for fish. The habitat losses predicted for late winter/spring downstream of the intake are considered to be less important for fish but may have some relevance to nesting river birds. Overall, the effects are attenuated further downstream of the Tukituki confluence.

The effects of changes in the flow regime on native fish and trout depend on the habitat preferences of particular species and/or life stages. The winter decreases in flow in the Makaroro River are associated with reductions in habitat suitability for flow demanding species like torrentfish and rainbow trout, whereas habitat suitability for less flow demanding species like longfin eel is predicted to increase during winter. A similar pattern occurs further downstream with summer losses and winter gains for some species and the reverse for other species. The effects are generally reduced further down the catchment as the changes in the flow regime are buffered by inputs from other tributaries. Winter losses in habitat are considered to be less important than summer losses, because the metabolic energy demands of fish are reduced because of the cool water temperatures.

Supplementation of low flows could potentially be used to increase habitat availability for flow demanding species. However, large amounts of flow supplementation are predicted to be required to provide more than a 10% increase in habitat availability in the lower Tukituki River.

Regular fluctuations in flow resulting from short-term changes in irrigation demand during the summer and hydro-peaking in the winter will have negative effects on habitat suitability for species with limited mobility such as most invertebrates, and also on areas considered suitable for trout spawning. Areas that are suitable at the high end of the flow fluctuations may dry out or become too shallow during the low flow part of the fluctuating cycle, while areas that are suitable at the low end of the fluctuating cycle may become too deep and fast at the high end of the cycle. The predicted reductions in habitat suitability associated with these fluctuating flows are large (up to 100% for trout spawning habitat, and generally around 50% for invertebrates). However, these predictions do not take into account the effects of natural flow fluctuations and therefore are an overestimate of habitat reductions. Additionally, the flow fluctuations will attenuate downstream so the effects are expected to be minimal in the lower catchment.

Reduced invertebrate productivity as a result of flow fluctuations downstream of the proposed dam may mean that trout need to feed more of the time to meet their daily energy requirements and their scope for growth may be reduced. Furthermore, because there will be less productive area due to flow fluctuations, the density of drifting invertebrates at high flows may be diluted, which would decrease the foraging efficiency of drift feeding trout and exacerbate any effect of food reduction. Therefore, although the hydraulic conditions suitable for drift feeding trout may still exist, food delivery and intake is likely to be reduced, leading to a potential reduction in carrying capacity.

The degree to which fish abundance and/or growth rate may be affected by this reduction in invertebrate habitat is uncertain, because it depends on whether fish are currently food limited. But given that the predicted reduction in invertebrate habitat is potentially large (around 50% for *Deleatidium* which represents a riverine trout's main food source), this may have some effect on food intake by fish -- with a consequent effect on growth rates and/or survival.

When the reduction of suitable spawning habitat below the dam is considered in combination with the loss of spawning habitat in the inundated reach and the uncertainty regarding the benefits to be derived from the juvenile trout that will pass downstream, it is difficult to accurately predict the scale and significance of the Scheme on recruitment of juvenile rainbow trout. There have been suggestions that there are large areas of potentially suitable spawning habitat in the Tukituki catchment that are not used because of an overabundance of potential spawning habitat (Hawke's Bay Fish & Game undated). However, Maclean (2012) found that the Makaroro River may be an important spawning stream relative to other streams draining hill and lowland areas of the Tukituki catchment. Even if there is abundant spawning habitat, the potential reduction in recruitment from the Makaroro and Waipawa mainstem means the wider Tukituki trout population may be less resilient. However, given the high spatial and temporal variability that is typical of trout populations, any effect on abundance in the wider catchment is unlikely to be detectable. Nevertheless, retention and enhancement of key spawning and rearing habitats is considered to be very important and we recommend that these areas are identified and protected through stock exclusion (fencing), replanting and ongoing riparian maintenance.

3.5. Effects of the irrigation intake structures

3.5.1. Introduction

This section considers the effects of the upper intake structure that is used to take water from the Waipawa River into the irrigation head-race and the lower intake structure that is proposed to take water from the Waipawa River into the old Waipawa riverbed for irrigation supply to Zone M (Tonkin & Taylor May 2013a). The effects of the water take itself on the downstream flow regime are addressed in Section 3.4.

Many of the issues associated with the proposed upper intake are also relevant for the proposed lower intake structure. However, we consider that fish exclusion at the lower intake structure is not such as important issue, since water from the lower intake will be released to a natural waterbody — the old Waipawa River/Papanui Stream. Indeed, there may be benefits to the ecology of the old Waipawa River/ Papanui Stream if recruitment of fish from the Waipawa River is provided by the lower intake.

3.5.2. Effects on the physical environment

A side braid will be created at the upper irrigation intake and maintained to ensure that water is continually flowing past (and through) a rock-fill infiltration bund. However, more broad-scale changes in river morphology as a result of the irrigation intake are unlikely (Tonkin & Taylor May 2013b).

Similarly, in-river works will be required from time to time during the operation of the scheme at the lower intake to maintain the river channel (flow and level) at the intake location, and manage the deposition of coarse sediment in the vicinity of the intake (Tonkin & Taylor May 2013a).

3.5.3. Effects on fish passage and entrainment

There are seven native fish species, as well as two introduced salmonids, whose migratory life history and recorded distribution within the catchment require them to swim past the proposed upper intake from the Waipawa River (Table 33). Though not recorded from upstream of the upper intake, koaro are another native migratory species that is highly likely to occur in the upper catchment. In addition, fish will move about the river independently of these major life phase migrations and fish residing in the vicinity of the intake will also have the potential to be entrained into the canal. As well as the migratory fish mentioned above, there are two non-migratory species (Cran's bully and dwarf galaxias) that are likely to reside in the vicinity of the intake. Consequently, it is recommended that the intake have screening to reduce or avoid entrainment of fish into the irrigation canal system.

Table 33. Fish species found in the vicinity of the proposed upper irrigation intake between 1965 and 2011 (NZFFD, NIWA). * species has not been found, but high probability of occurrence.

Common name	Scientific name	Migratory	Found in vicinity of proposed upper irrigation intake
Longfin eel	*Anguilla dieffenbachii*	Y	Y
Shortfin eel	*Anguilla australis*	Y	Y
Torrentfish	*Cheimarrichthys fosteri*	Y	Y
Koaro	*Galaxias brevipinnis*	Y	N*
Dwarf Galaxias	*Galaxias divergens*	N	Y
Cran's bully	*Gobiomorphus basalis*	N	Y
Bluegill bully	*Gobiomorphus hubbsi*	Y	Y
Redfin bully	*Gobiomorphus huttoni*	Y	Y
Common bully	*Gobiomorphus cotidianus*	Y	Y
Common smelt	*Retropinna retropinna*	Y	Y
Brown trout	*Salmo trutta*	Y	Y
Rainbow trout	*Onchorhynchus mykiss*	Y	Y

In the absence of screens a commonly applied assumption is that entrainment is directly proportional to the volume of water taken. Based on a minimum flow of 2.5 m^3/s and a maximum abstraction of 11.1 m^3/s, this suggests that up to 82 % (*i.e.* 11.1/13.6) of fish passing the upper intake may be entrained under maximum abstraction conditions without fish screens. Fish entrained through the upper intake would effectively be lost to the river system. Although some species may be able to reside within the canal system, it is unlikely to provide favourable habitat, particularly due to seasonal variability in water levels.

We have discussed the need for a fish screen at the upper intake with Tonkin & Taylor during the design of the intake structure. NIWA have prepared a report on good practice guidelines for fish screening for a working group including Environment Canterbury, Fish & Game NZ, Irrigation NZ, and the Department of Conservation (Jamieson *et al.* 2007). Although the guidelines suggested in that report were developed with a focus on the Canterbury area for intakes of up to 10 m^3/s, the principles are also useful for other regions and for larger takes. As discussed in that report, key factors in screen design include: location, approach velocity (velocity component through the screen), sweep velocity (velocity component parallel to the screen), fish bypass design (both at the screen and connectivity back to the mainstem), screening materials, and operation and maintenance.

Several of the native fish species known to occur in the catchment and likely to come into contact with the intake are listed on the Department of Conservation’s threat classification listings as ‘Declining’. Of these, dwarf galaxias is the species with the smallest adults. Consequently, screen design criteria aimed at excluding dwarf galaxias adults would also provide protection for the adults of other species. Such design criteria would also provide a similar level of protection for longfin eel elvers (the upstream migrating juvenile lifestage), another species listed as ‘Declining’. The juvenile life stages of dwarf galaxias and other native fish known to occur in the catchment are so tiny that exclusion with physical screens is infeasible. However, given the naturally high rates of mortality for larval fish, entrainment of some of these small fish into the scheme is unlikely to have any more than a minor effect on the populations of these fish in the wider catchment.

The Waipawa River is a major tributary of the Tukituki River, which is one of the most highly used trout fisheries in the region. Fish screen design criteria that exclude dwarf galaxias adults would also provide similar level of protection for trout fry and would also obviously protect larger size classes of trout.

The project description design includes fish screening at the upper intake (Tonkin & Taylor May 2013a). The proposed fish screen solution involves a rock fill infiltration bund (rather than a more traditional mesh screen) and is very similar to, and draws on Tonkin & Taylor experience with a similar structure on the south bank of the Rangitata River in Canterbury. This intake abstracts a larger flow and Environment Canterbury granted consent for this intake on the basis that the proposed arrangement met the intent of the NIWA guidelines (*i.e*. rock fill and filter pack equivalent to 2 mm bar clearance or 3 mm mesh aperture). Assuming that the filter pack used in the rock fill bund is sufficiently small to result in screening that is equivalent to a 3 mm mesh, then the effects on fish entrainment should be largely avoided. However, since there have been no specific assessments of the efficacy of rockfill bunds as fish screens, we recommend that a monitoring programme is conducted to ensure that it is working as expected.

As mentioned above, we consider that fish exclusion at the lower intake structure is not such as important issue, since water from the lower intake will be released to a natural waterbody — the old Waipawa River/Papanui Stream and there may be benefits to the ecology of the old Waipawa River/ Papanui Stream if recruitment of fish from the Waipawa River is provided by the lower intake. The project description design also mentions fish screening at the lower intake (Tonkin & Taylor May 2013a) and some level of fish screening, particularly of adult trout is appropriate. However, we consider that it may be beneficial to have a lower specification fish screen at the lower intake that will allow recruitment of adult and juvenile native fish to the Papanui Stream.

However, fish screens will be required on the individual takes from the Papanui Stream to ensure that fish are not entrained into the Zone M secondary distribution system. We understand that design of the Zone M secondary distribution system will be incorporated into the detailed design stage. The intakes to the secondary distribution system should be designed to meet the good practice guidelines for fish screening (Jamieson *et al.* 2007).

3.5.4. Summary

The upper irrigation intake structure will be used to take water from the Waipawa River into the irrigation head race. The lower intake structure will be used to divert water to the old Waipawa river/Papanui Stream. A side braid will be created at the irrigation intake and maintained to ensure that water is continually flowing past (and through) the rock-fill infiltration bund at the upper intake, and in-river works will be required to maintain the river channel in the vicinity of the lower intake. However, the intakes are not expected to create broad-scale changes in river morphology.

The main issue with the upper irrigation intake structure is the potential entrainment of fish into the canal system. Without a fish screen up to 82% of fish passing the intake could theoretically be entrained. A rockfill infiltration bund is currently proposed to act as a fish screen at the proposed upper intake. The efficacy of this bund as a screen will be dependent on the size of the packing fill used to construct the bund. To be effective the fill needs to emulate 3 mm mesh openings in a metal screen. Tonkin & Taylor have confirmed that the packing fill will meet this intent and therefore the effects on fish entrainment should be largely avoided. Nevertheless, since there have been no specific assessments of the efficacy of rockfill bunds as fish screens, we recommend that a monitoring programme is conducted to ensure that it is working as expected.

Fish exclusion at the lower intake structure is not such as important issue, since water from the lower intake will be released to a natural waterbody — the old Waipawa River/Papanui Stream and there may be benefits to the ecology of the old Waipawa River/ Papanui Stream if recruitment of fish from the Waipawa River is provided by the lower intake. A lower specification fish screen that will exclude adult trout but allow recruitment of adult and juvenile native fish to the Papanui Stream is appropriate for the proposed lower intake. However, fish screens will be required on the individual takes from the Papanui Stream to ensure that fish are not entrained into the Zone M distribution system.

Based on the designs included in the Project Description (Tonkin & Taylor May 2013a) the effects of the irrigation intakes are expected to be minimal, although we recommend that a monitoring programmes is conducted on the upper intake to ensure that it is working as expected.

3.6. Assessment of effects of additional irrigation water in Tukituki tributaries

3.6.1. Introduction

The Ruataniwha irrigation water distribution network will include a section of the Waipawa River adjacent to the Waipawa Township and two lesser tributaries of the Tukituki River, the Kahahakuri Stream and the Old Waipawa River Channel/Papanui Stream. These waterways will be used to transport irrigation water sourced from the Makaroro dam to farms in the lower Tukituki plains and the proposed irrigation zone M (Figure 1). This section assesses the effects of these additional flow releases as described in Tonkin & Taylor (May 2013) on the aquatic ecology of the Waipawa River (adjacent to the Waipawa township), the Kahahakuri Stream and the Old Waipawa River channel/Papanui Steam.

3.6.2. Effects of additional water in the Waipawa River at Waipawa Township

It is proposed that up to 3 m^3/s from the secondary water distribution network will be discharged into the Mangaonuku Stream at the confluence with the Waipawa River (Tonkin & Taylor May 2013a), but will only influence a very short section of the Mangaonuku Stream. This water will be abstracted at the lower intake approximately 11 km downstream near the Old Waipawa River Channel to be distributed into irrigation Zone M (Figure 1). During peak irrigation demand 1.82 m^3/s will be abstracted to supply Zone M irrigation and the proposed Papanui Stream minimum flow. A lesser amount of up to 0.92 m^3/s will bypass the lower intake to supply farmers on the Lower Tukituki with water during irrigation ban periods (Tonkin & Taylor May 2013a). Irrigation bans typically occur for up to two weeks at a time during mid to late summer.

Depending on which of the future scenarios is considered the Waipawa at RDS will have a MALF of between 2.51 and 2.79 m^3/s, a median flow of between 6.39 and 6.59 m^3/s and a mean annual flood flow of 408 m^3/s (Tonkin & Taylor May 2013a). An additional 3 m^3/s will be accommodated by the existing channel without changing the river's morphology. Moderately increased flow rates in this reach during the irrigation season (summer low flow periods) is likely to have little or no effect on river biota depending on the duration that the increased flows are maintained. Macroinvertebrates take over two weeks to colonise newly inundated habitat (Sagar 1983, Scrimgeour & Winterbourn MJ 1989). Therefore, if irrigation flows are maintained for two weeks or more there will be a response from the invertebrate community. The Johnson (2011) IFIM analysis undertaken in the Waipawa is only relevant in the upper half of Reach 5 because site measurements were located in the vicinity of the upstream irrigation intake. However, despite the fact that there are some changes in river morphology between the upper and lower halves of Reach 5, predictions of changes in habitat availability at the upper end of Reach 5 can be used to guide what affect the proposed flow releases will have on the Waipawa at RDS.

A sustained flow increase of 3 m^3/s may have weakly positive effects on food producing habitat at flows close to the proposed MALF and weakly negative effects at flows close to the median flow (Figure 38). Fish will be relatively unaffected as they are able to move to find more favorable habitat during periods of moderately increased flows. There is a risk that fish may strand in side braids or shallow margins during periods when irrigation releases are stopped. Monitoring of the incidence of fish stranding in this reach of the Waipawa River should be conducted to determine the significance of this issue. Ramping rates on the shut-down of irrigation releases could potentially be applied if this issue was found to be significant.

3.6.3. Effects of additional water in the Kahahakuri Stream

The Kahahakuri is a spring-fed stream. The upper catchment has a base flow of between 0.2 – 0.3 m^3/s with flow increasing to approximately 1 m^3/s where it meets the Tukituki River near Waipukurau township. The stream is approximately 12 km long and flows through the proposed irrigation Zone B (Figure 1). A site visit was conducted on the 21 December 2012 during base flow conditions. Single pass electric-fishing was undertaken at two sites using a Smith Root electric-fishing machine over a 50 m stretch of stream. Water quality measurements were taken using a YSI water quality meter.

At the upper site (immediately upstream of Fairfield Road) all water quality parameters measured (temperature, conductivity and dissolved oxygen) were within acceptable limits for aquatic life according to ANZECC 2000 guidelines. The streambed was characterised by macrophyte beds and large areas of fine clay/silt sediments with lesser areas of gravels imbedded in a fine sediment matrix. Slow run was the predominant habitat type with some areas of fast run. Eels (both longfin and shortfin) and koura were abundant. However, with the exception of a single black flounder (*Rhombosolea retiaria*) no other fish species were found.

At the lower site (approximately 500 m upstream of the confluence with the Tukituki River) the streambed was characterised by fine sands and fine gravels with extensive macrophyte beds. The habitat included slow runs, fast runs and pools in roughly equal proportions. Eels were abundant and koura were present. Along the shallow margins shoals of dwarf galaxiid fry were identified. Adult rainbow trout were observed in association with the deeper pools. No juvenile trout were found at either the upstream or downstream sites.

It is proposed that the Kahahakuri Stream is used to transport 0.35 m^3/s of water to supply irrigation takes in the Tukituki River upstream of the Waipawa confluence. These flow releases will only occur during periods of water restrictions. In a typical year water restrictions can occur for up to two weeks at a time during mid to late summer.

Given the small and temporary nature of the proposed flow augmentation to the Kahahakuri Stream we anticipate the flow releases will have negligible effects on the aquatic ecosystem. The Kahahakuri is generally deep and steep-sided. An additional 0.35 m^3/s will result in minor changes to the average wetted width and velocity. An initial assessment (Thomas Wilding, HBRC, pers. comm.) indicated that a 0.35 m^3/s increase to the current median flow of 0.43 m^3/s would result in:

- an increase in mean depth from 500 mm to 600 mm
- an increase in mean velocity from 0.14 m/s to 0.24 m/s
- an increase in mean wetted width from 4.09 m to 4.23 m.

During summer low flows (when flow releases will occur) the additional 0.35 m^3/s will be contained within the channel formed by winter base flows. Therefore, there will be no risk of significant bank erosion as a result of the higher flow rate.

3.6.4. Effects of additional water in the Papanui Stream

The Waipawa River used to follow what is now referred to as the Old Waipawa River Bed and joined the Tukituki River approximately 25 km downstream of the current confluence of the Waipawa and Tukituki rivers. The Bishop's Stopbank was constructed more than one hundred years ago to divert the Waipawa River into the Tukituki River at the present location to facilitate land development adjacent to the former Waipawa river bed (Tonkin & Taylor May 2013a). The Old Waipawa river channel currently starts approximately 4 km downstream of the Waipawa township and feeds the Papanui Stream with ground water and surface water (during high flows). Hereafter, the Old Waipawa River Channel will be referred to as the Papanui Stream.

Available information on the Papanui Stream is summarised in Lynch (2013). Cawthron staff visited two locations in the Papanui Stream on the 21 December 2012. Water quality measurements were taken using a YSI water quality meter. The Papanui Stream is spring-fed and characterised by pools and still-water ponding areas with abundant macrophytes. Some pools are connected by shallow riffles/trickles. Ephemeral reaches occur throughout the stream. The substrate is dominated by fine sediment with sparse patches of cobbles and gravel. Filamentous algae and macrophyte beds are a dominant feature of the stream.

Dissolved oxygen was below tolerance levels for sensitive aquatic organisms at the upstream site (Table 34). The daily DO minima could be expected to be lower than the value recorded during the site visit at 14:00 hours because DO levels typically reach there minimum at dawn (ANZECC 2000). In contrast, the lower site at Elsthorpe Road had water quality parameters within the tolerance limits for most aquatic species although the recorded water temperature of 21.6°C would stress sensitive fish such as salmonids (Table 34).

Table 34. Physical water quality parameters measured at two sites in the Papanui Stream.

Site	Temp	Conductivity	DO %	DO mg/l
Todd Road	16.3	237	48.4	4.66
Elsthorpe Road	21.6	232	130	11.48

No electric fishing was conducted at either site. However, large feral goldfish and a trout were observed in a pool below Elsthorpe Road. We expect that koura, eels and other fish typical of spring creeks in the Ruataniwha Plains will be present in reaches of the Papanui Stream that have persistent flow and high DO, although results from sampling presented in Lynch (2013) indicate that the Papanui Stream is in a heavily degraded state and extremely low DO levels have been recorded at the Middle Road monitoring site.

It is proposed that the Papanui Stream is used to transport up to 1.77 m^3/s to supply irrigation Zone M (Figure 1) and a permanent minimum flow of 0.05 m^3/s. This is a large volume of water relative to the residual flow in the Papanui Stream and will alter the existing ecosystem from a small ephemeral swamp/spring creek network to a medium-sized temporary river during the irrigation season. The irrigation water is not likely to provide any additional habitat for fish because flow rates will be highly variable. However, it is proposed that a two stage channel is constructed with an approximately 7 m channel for irrigation water and a subsidiary 2 m channel for the proposed residual flow of 0.05 m^3/s (EMS May 2013a; Tonkin & Taylor May 2013a; HBRIC May 2013f). This channel design, along with riparian fencing and planting and if/where possible restoration, and re-connection with the stream channel, of riparian wetlands, is likely to increase the capacity of the Papanui stream to support native fish populations.

3.6.5. Summary

The additional water released into the Waipawa River and Kahahakuri Stream is expected to have minimal effects on the ecology of these systems because the flow releases are small relative to the range of flows that will naturally occur in these systems and will be easily accommodated by the river channel. There is a risk that fish may strand in side braids or shallow margins of the Waipawa River during periods when irrigation releases are stopped. We recommend that monitoring of the incidence of fish stranding in this reach of the Waipawa River is conducted to determine the significance of this issue.

The Papanui Stream is currently in a degraded state. The additional water released into the stream, along with a re-design of the channel, riparian fencing and planting is likely to improve the health of the stream and increase the capacity of the Papanui stream to support native fish populations.

3.7. Assessment of effects of land use change

3.7.1. Introduction

Changes to land use within (and potentially outside) the irrigation zones are expected as a result of the proposed Scheme. A potential future land use scenario within the irrigated zones (Figure 1) has been developed by Macfarlane Rural Business Ltd (2012) and comprises:

- Little change to sheep and beef extensive farming and mixed livestock farming (constant at 14,175 ha)
- A decrease in mixed/dairy support (5,730 ha to 4,671 ha)
- A decrease in area associated with stock finishing (9,128 ha to 1,800 ha)
- An increase in arable and mixed arable land use (8,100 ha to 9,355 ha)
- Dairy farming increasing from 4,167 ha to 9,175 ha
- An increase in both orchards and vineyards (700 ha to 2,825 ha).

Changes in land use of this magnitude have the potential to affect nutrient losses from the land, and thus nutrient loads and concentrations in the waterways within the Tukituki catchment (Parkyn & Wilcock 2004). There could also be increases in inputs of sediment and faecal bacteria to waterways as a result of the predicted land use changes. Changes to stock type and stocking intensity may also cause changes to the amount of physical damage occurring to instream habitat and the riparian margins of streams flowing through the irrigated areas if stock are not excluded from waterways

(Parkyn & Wilcock 2004). We recommend that stock exclusion, fencing and planting of the riparian areas surrounding waterways draining the Ruataniwha Plain are conducted as part of the restoration and enhancement packages associated with the Scheme (See Section 4.6 for more discussion).

Models (TRIM2_CATCHMENT; TRIM2_STREAM) have been developed to predict the effects of the potential future land use scenario on nutrient losses, instream nutrient loads and periphyton biomass for the entire Tukituki Catchment (NIWA May 2013a, b). Like all models, the TRIM models have inherent uncertainties which means that there is uncertainty about the absolute values of nitrate concentration and periphyton biomass predicted by the model. However, the main aim of the TRIM modeling is to identify the possibility of 'hot spots' in some tributaries where phosphorus concentrations may increase or where nitrate concentrations approach limits set for the protection of sensitive species. Management actions can then be targeted to these areas with further investigation and, if this risk is confirmed, to put in place additional mitigation to avoid adverse effects.

3.7.2. Changes to water quality

Based on a worst case scenario with no on-farm mitigation, total nitrogen and total phosphorus inputs to streams across the entire Tukituki Catchment are predicted to increase by 32% and 6%, respectively, as a result of land use intensification associated with the Scheme (NIWA May 2013a). However, within the irrigation command area the percentage increases are higher: 81% and 41% for TN and TP respectively (NIWA May 2013a).

It is our understanding that the Scheme is intended to be phosphorus neutral compared with a 2013 baseline. If streams are fenced and optimal soil phosphorus levels are maintained throughout the irrigation command area, then it is predicted that the RWSS will be within 1% of phosphorus-neutral for the catchment as a whole (NIWA May 2013a). However, the combined phosphorus losses from the irrigation command area are estimated to be 7% above pre-irrigation levels, with five sub-catchments being above, and others at or below, pre-irrigation phosphorus inflows (NIWA May 2013a). No monitoring data exist to compare with model predictions in most of the smaller streams – predictions should therefore be treated with caution. Nevertheless, predictions highlight where potential 'hot spots' of high nutrient, and potentially high periphyton biomass, are likely to occur. Additional mitigation measures may need to be put in place within these five sub-catchments if the RWSS is to be uniformly phosphorus-neutral. There are a number of options available to reduce phosphorus loss from farms, some of which are not are captured within OVERSEER (McDowell and Nash 2012).

Mitigation efforts focused on reducing inputs of phosphorus should be similarly effective for reducing inputs of sediment and faecal bacteria to waterways on the Ruataniwha Plains.

The reductions in phosphorus inputs from the waste water treatment plants at Waipukurau and Waipawa will reduce phosphorus concentrations in the lower Tukituki River.

3.7.3. Effects on the biological environment

The majority of evidence that is available for the middle and lower Tukituki catchment indicates that periphyton growth is likely to be phosphorus limited (see Section 2.2.3.4), meaning that additional phosphorus would cause an increase in periphyton growth rates and biomass, but additional nitrogen would not result in the same effect (see also NIWA May 2013a; Uytendaal & Ausseil 2013).

This information could be used to suggest that management efforts should concentrate only on phosphorus management. However, there are some risks involved with focusing management on a single limiting nutrient and relaxing controls on the other nutrient, since nutrient limitation can switch between nitrogen and phosphorus over time, downstream waterways may have a different limiting nutrient, and if proposed controls on the single nutrient are unsuccessful then higher concentrations of the other nutrient may exacerbate effects (Wilcock *et al.* 2007). There is also growing evidence that potentially toxic cyanobacteria (*Phormidium*) blooms may be stimulated by high nitrogen concentrations (Wood & Young 2012). These risks have been considered in detail in two expert workshops convened by HBRC (see workshop reports which are included as appendices in Uytendaal & Ausseil 2013). The concensus view of the expert panels was that based on the available evidence periphyton growth in the lower Waipawa and Tukituki rivers is primarily P-limited. The group of experts also agreed that it is very unlikely that attempting to reduce DIN inputs to the upper and middle catchment's rivers would be an effective way to reduce, or contribute to reducing, periphyton growth in the mainstems of the lower Tukituki and Waipawa Rivers. The consensus view of the group was that an increase in DIN concentration in the lower Tukituki River (relative to the current situation) will probably not cause an increase in periphyton biomass, provided DRP is maintained below appropriate target concentrations.

In relation to benthic cyanobacteria, the expert group recognized the potential for a change in species composition towards a community favouring mat-forming algae such as *Phormidium*, because *Phormidium* may have the ability to use sediment-bound P. The opportunity exists to test this hypothesis in the lower Tukituki River post-2014 (i.e. following upgrade of the oxidation pond discharges) - monitoring of the river to assess this issue is strongly recommended. However, the major benefits to river condition associated with reduction of P inputs to the system are likely to far outweigh the risk of increasing *Phormidium* growth, which is unproven in the Tukituki. The potential increase in risk of *Phormidium* growth (if any) would be associated with a reduction in phosphorus, not an increase in nitrogen.

With on-farm mitigation measures in place, no increase in periphyton biomass is predicted in the Tukituki River at SH2 and only a minor increase is predicted at Red Bridge, consistent with the minor (1%) predicted increase in phosphorus concentration (NIWA May 2013a) Reduced inputs of phosphorus from the Waipukurau/Waipawa waste water treatment plants are predicted to result in significant reductions in annual average periphyton biomass, and less frequent periods of high biomass. Nevertheless, during periods of prolonged low flow, periphyton biomass will continue to reach high levels (NIWA May 2013a). The proposed flushing flows associated with the Scheme are expected to provide additional reduction in the incidence of high periphyton biomass by interrupting the periods of biomass accumulation during prolonged summer low flows.

High concentrations of nitrate nitrogen can be toxic to aquatic life affecting growth rates, development and, at extremely high concentrations, mortality. To avoid problems associated with nitrate toxicity, annual median concentration limits have been recommended for inclusion in the Tukituki Plan Change 6 for the lower Tukituki River (Table 35; Uytendaal & Ausseil 2013). Winter peaks and summer lows in nitrate nitrogen concentration are observed in the Tukituki catchment (see Section 2.2.3.10). Therefore, 95th percentile limits to address the risk of seasonal peaks in nitrate concentration have also been recommended for inclusion in the Tukituki Plan Change 6 (Table 35; Uytendaal & Ausseil 2013).

Due to the substantial contribution of nitrate-rich groundwater to river flows at the outlet of the Ruataniwha Basin, concentrations of nitrate in the Tukituki River are at their highest at this point (Uytendaal & Ausseil 2013). For the 827 stream segments throughout the whole Tukituki Catchment that was modelled, NIWA (May 2013a) predicted that there were 50 breaches of the annual median nitrate concentration limit and 52 breaches of the 95th percentile nitrate concentration limit in the year that was simulated (2010). All these breaches occur in the Kahahakuri, OngaOnga, Porangahau, Papanui and Pukehou (a tributary of the Papanui) catchments. The Porangahau Stream is affected by the land disposal of effluent from the Silver Fern Farms meat works. The Pukehou and Papanui Streams are affected by the WWTP discharge from Otane. The Kahahakuri and OngaOnga streams are affected by N losses from farmland.

Table 35. Framework for managing nitrate toxicity risk for aquatic species (from Hickey 2013a).

Guideline type	Application to	Annual average mg NO_3-N/L (NOEC)	95th percentile mg NO_3-N/L (TEC) (proposed)
Acute	Very localised point source discharge	20	30
Chronic– high conservation value systems (99% protection)	Pristine environments with high biodiversity and conservation values	1.0	1.5
Chronic– slightly to moderately disturbed systems (95% protection)	Environments which are subjected to a range of disturbances from human activity	2.4	3.5
Chronic– disturbed systems (90% protection)	Specific environments which: (i) either have measurable degradation; or (ii) which receive seasonally high elevated background concentrations for significant periods of the year (1-3 months).	3.8	5.6
Chronic– highly disturbed systems (80 % protection)	Specific environments which: (i) either has measurable degradation; or (ii) which receive seasonally high elevated background concentrations for significant periods of the year (1-3 months).	6.9	9.8

The NIWA (May 2013a) prediction of hot-spots of high nitrate concentration in groundwater-fed streams on the Ruataniwha Plains is consistent with the data available. Recent monitoring data collected by HBRC shows that winter nitrate concentrations at most sites in the Ruataniwha Plains are below levels of concern, but at some sites concentrations are close to (and in 2 cases may exceed) the nitrate toxicity concentration limits that have been recommended in the proposed Tukituki Plan Change 6 (Figure 53; Uytendaal & Ausseil 2013). High nitrate concentrations in this range may result in an increased risk of minor effects on growth rates, development and reproduction of some aquatic organisms (Hickey 2013b). It is recommended that this issue will require close monitoring and management to avoid increasing the risk of toxic effects on aquatic life at sites with high groundwater influence. Nitrogen mitigation may be required in some sub-catchments to avoid exceeding the proposed nitrate concentration limits. In the earlier TRIM1 study

(Rutherford *et al.* 2012) it was shown that nitrogen mitigation scenarios had the potential to reduce the increase in nitrogen losses associated with the implementation of the Scheme. Without mitigation, the N loads were predicted to increase by 295 T/year (22% compared with current land use); with mitigation, the N load increase was predicted to be cut back to 160 T/year (12% overall increase). Nitrogen reductions of this scale may be sufficient to ensure that toxicity limits are not exceeded in some sub-catchments, although further modelling is required to confirm this. If cost-effective nitrogen mitigation measures are unable to ensure that toxicity limits are not exceeded then it may be necessary to restrict the types of agriculture that will be permitted in some, sensitive, sub-catchments.

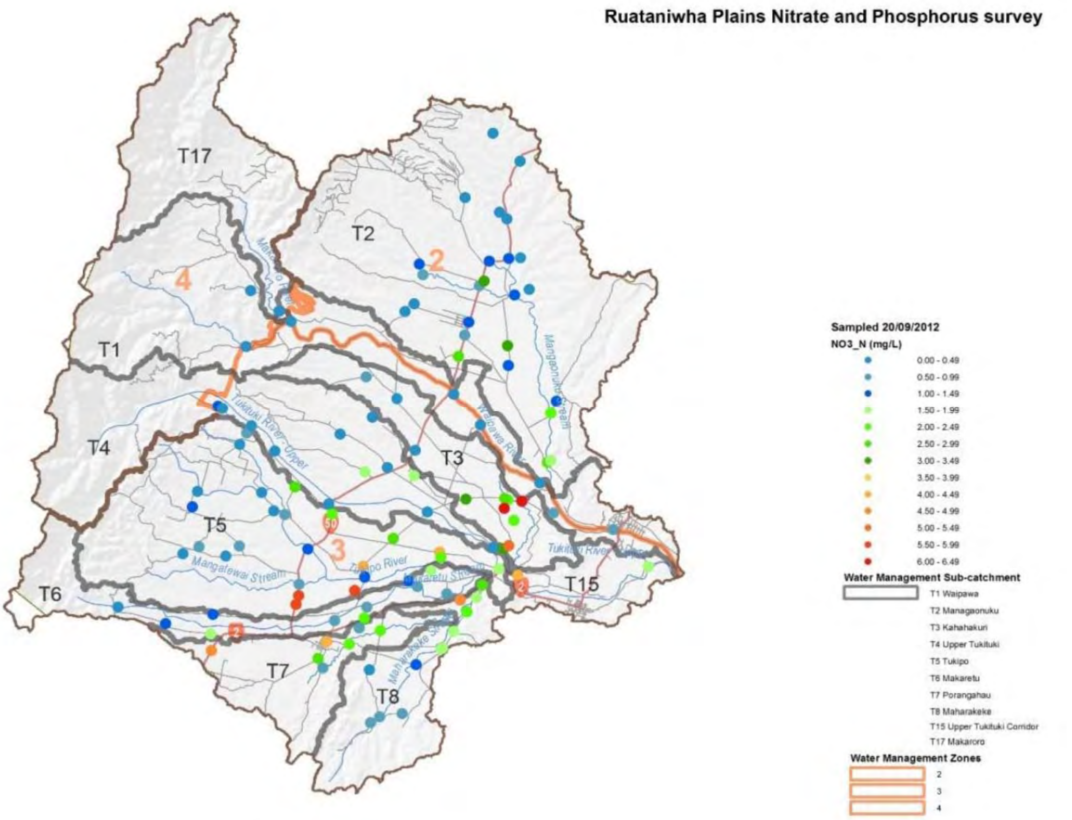

Figure 53. Nitrate-N results from spot sampling of sites throughout the Ruataniwha Plains in September 2012 (from Uytendaal & Ausseil 2013).

3.7.4. Summary

Changes to land use are expected as a result of the Scheme. Changes to stock type and stocking intensity may increase the amount of physical damage occurring to instream habitat and the riparian margins of streams flowing through the irrigated areas if stock are not excluded from waterways. We recommend that stock exclusion, fencing and planting of the riparian areas surrounding waterways draining the Ruataniwha Plain are conducted as part of the implementation phase of the Scheme.

The Scheme is aiming to be phosphorus neutral, with no increases in phosphorus loss from any properties as a result of the Scheme. Phosphorus control mechanisms and the stock exclusion rule proposed in the Tukituki Plan Change 6 will also potentially be effective for limiting the inputs of sediment and faecal bacteria to waterways in areas of the catchment outside the proposed irrigation areas.

Periphyton biomass currently exceeds guidelines for the protection of benthic biodiversity, trout habitat and angling on a relatively regular basis so adverse effects of periphyton proliferation on invertebrates and fish and recreational river values are already occurring. Prior to construction of the Scheme the discharges of sewage from Waipukurau and Waipawa will be significantly reduced due to the requirements of their consent conditions. This reduction in phosphorus load to the river is expected to reduce periphyton biomasses.

Land use changes associated with the Scheme are predicted to increase total nitrogen and total phosphorus inputs by 32% and 6% at the whole-catchment scale, respectively, if no mitigation measures are implemented (NIWA May 2013a). Within the irrigation command area, the percentage increases are higher: 81% and 41% for TN and TP respectively. If streams are fenced and optimal soil phosphorus levels are maintained throughout the irrigation command area, then it is predicted that the RWSS will be within 1% of phosphorus-neutral for the catchment as a whole. However, the combined phosphorus losses from the irrigation command area are estimated to be 7% above pre-irrigation levels. Additional mitigation measures may need to be put in place within these five sub-catchments if the RWSS is to be uniformly phosphorus-neutral.

High concentrations of nitrate nitrogen can be toxic to aquatic life. Land use changes associated with the Scheme are predicted to increase nitrate concentrations significantly in tributaries draining the irrigation command areas and fencing will result in only minimal reductions in nitrate losses. It is predicted that nitrate concentrations will exceed the limits set in the proposed Tukituki Plan Change in five of the tributaries – three affected by point source waste discharges and intensive farming, and the remainder only affected by intensive farming. To address this issue additional monitoring will be required and particular attention will need to be given to sites that are predicted to be close to or beyond the proposed limit. Management actions aimed at reducing nitrogen leaching will be required in any areas where modelling indicates a high likelihood of the proposed nitrate concentration limits being exceeded.

4. RECOMMENDED APPROACHES FOR AVOIDING, REMEDYING OR MITIGATING ADVERSE EFFECTS

As mentioned in Section 1.2.2 and at the start of Section 3, some of the effects that have been identified will be avoided or remedied using measures that are already incorporated into the scheme design (*e.g.* a minimum residual flow at the base of the dam, flushing flows released from the dam to remove periphyton, an aerator installed near the upstream face of the dam to address any issues with anoxia in the bottom waters of the reservoir, a rockfill bund at the upper irrigation intake which will act as a fish screen).

This section of the report provides further discussion of approaches that will be used to avoid or remedy potential effects of the Scheme and makes recommendations on appropriate mitigation measures to minimize identified significant effects on aquatic ecology which have not been able to be avoided or remedied in the proposed Scheme design.

4.1. Mitigating effects of the construction phase

To minimise construction effects on water quality, river bed works should ideally be conducted during the drier period of the year where water levels are low and sediment suspension is minimal, or during seasons where the impact on primary production is minimised, *i.e.* autumn or winter (Wood & Armitage 1997). Fine sediment discharge during construction (due to sedimentation and erosion) should be appropriately managed in accordance with standards and widely used techniques. For example, the mitigation methods to reduce the amount of sediment laden runoff that enters the Makaroro River are described in the draft Construction Environmental Management Plan (Appendix C, Tonkin & Taylor May 2013a) and include specific measures such as the construction of a temporary coffer dam, sediment retention ponds, mulching, silt fences and hay bales.

4.1.1. Temporary coffer dam

The amount of work carried out in the river whilst the river is flowing will be minimised by diverting the flow into a temporary coffer dam during dam construction. The coffer dam will be constructed upstream of the main dam embankment and the river diverted through a cutting and diversion tunnel through the terrace on the right bank. Once built, this will enable the main dam to be constructed in the river without mobilising sediment. Moreover, stabilised construction entrances will be used at the site access locations to prevent silt from leaving the site. Roads will incorporate vee drains and possibly rock dams to reduce erosion and trap sediment. It is envisaged that water collecting in the bottom of either large excavations, or during tunnelling will need to be decanted to sediment retention ponds before discharged back into the river.

4.1.2. Sediment retention ponds

Sediment retention ponds (Figure 54) will be constructed according to the Hawke's Bay Regional Council — Waterway Design Guidelines (Shaver 2009). These ponds enable dewatering at a rate that allows suspended sediment to settle out to protect the downstream Makaroro River from excessive sedimentation and water quality degradation. To achieve this objective, the sediment retention ponds must be maintained until the disturbed area is fully protected against erosion by permanent stabilisation.

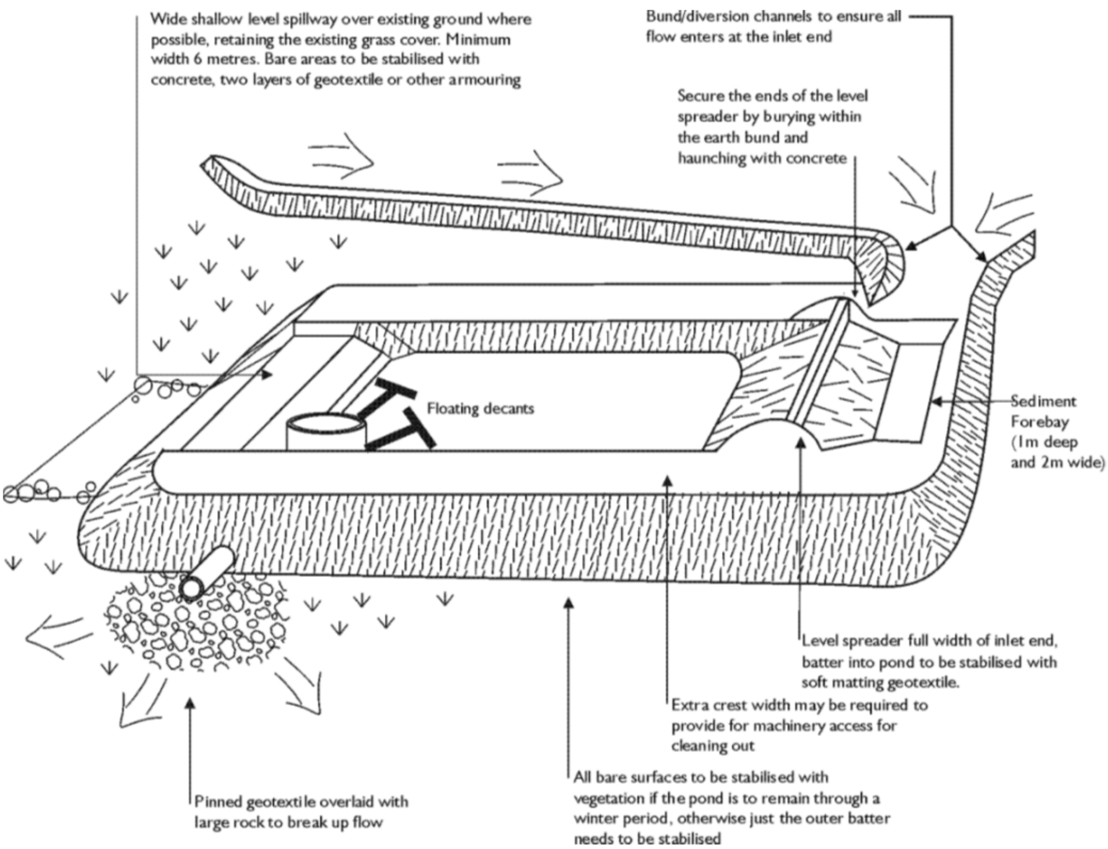

Figure 54. Schematic of a sediment retention pond (Shaver 2009).

4.1.3. Mulching

Mulching of unprotected open surfaces involves the application of a straw or hay layer to protect the soil surface from erosive forces, such as raindrop impacts and/or overland flow (Shaver 2009).

4.1.4. Silt fences

Geotextile fabric silt fences are commonly constructed across the downslope end of the proposed works as a temporary barrier to intercept sediment laden runoff into the waterway and reduce its velocity.

4.1.5. Hay/straw bales

Hay/straw bale barriers do not filter sediment, but are temporary barriers to intercept or direct sediment laden runoff from small areas to a sediment retention pond so that deposition of transported sediment can occur. They deteriorate easily and should therefore only be used for short term needs of less than one month duration.

As construction progresses, it is recommended that the position of the above discussed erosion control measures changes, so that adequate protection at the highest impact site is guaranteed.

4.1.6. Summary

If the mitigation methods described in the draft Construction Environmental Management Plan (Appendix C, Tonkin & Taylor May 2013a) are implemented during the construction of the Scheme, the effects of construction on sediment mobilisation will be reduced as much as possible. Weather conditions and river flows will influence the effectiveness of the mitigation measures, but even if a worst case scenario were to occur resulting in the failure of the coffer dam, the amount of sediment mobilised is relatively small compared with the natural sediment load down the Makaroro River. Fine sediment deposited within the substrate further downstream will be resuspended by floods sourced from the Makaroro and upper Waipawa rivers and not expected to have effects lasting more than a year after construction.

4.2. Reservoir water quality — outlet towers and aeration

To ensure all year round high discharge water quality into the Makaroro River downstream reaches, water quality within the reservoir needs to be managed before, during and after dam establishment. This includes future proofing the reservoir from catchment activities that would adversely affect the water quality at some future date, and monitoring and the management of anoxic bottom waters in the reservoir.

The proposed arrangement of outlet towers with the lower outlet primarily used to discharge water from the reservoir should limit the extent of the anoxic zone in the reservoir (NIWA May 2013c).

If issues occur with low dissolved oxygen concentrations in the bottom waters, oxygen concentrations in the reservoir can be managed using an aeration bar located across the deepest section of the reservoir upstream of the dam wall (NIWA May 2013c). If timed correctly, aeration generates a circulation current that allows the reservoir water to absorb oxygen from the air before moving to the bottom of the reservoir, transporting oxygen rich water into the bottom waters of the reservoir. NIWA (May 2013c) predicted that a single aerator installed near the dam wall is likely to be able to keep the whole reservoir mixed and maintain a high level of aeration throughout the reservoir water column.

However, starting the aeration process after thermal stratification occurs can result in mixing of nutrient enriched water from the bottom waters into the top-most layers where it can stimulate phytoplankton growth in the reservoir. Aeration after stratification has developed is also likely to disturb nutrient enriched bottom waters which will then be discharged through the outlet valve, increasing nutrient concentrations, and potentially stimulating periphyton growth, in the downstream reaches. NIWA (May 2013c) have suggested a detailed dissolved oxygen and temperature monitoring regime for the reservoir water column that is linked with the operation of the aerator. If DO concentrations in the reservoir water column drop below 7 g/m^3 then the aerator should be turned on (NIWA May 2013c). This is an appropriate trigger for activating the aerator.

Overall, if an aeration system is installed in the reservoir and provided that the main draw depth for water is kept as deep as possible then water quality in the reservoir and released downstream will be good.

4.3. Fish passage

The proposed dam will present an obstruction to upstream fish migration in the Makaroro River. Unless measures are taken to assist fish passage over the dam, these migratory native fish will ultimately be lost from the fish community upstream. The dam will also represent an obstruction to downstream passage of eels.

4.3.1. Fish passage options considered

There are several fish passage mitigation options available, and while there is no perfect solution, the relative suitability of each option depends on the management objective (or goal) identified, as well as the characteristics of the dam. Table 36 provides a comparison of four fish passage mitigation options, with a qualitative assessment of their relative ranking with respect to five criteria. Definitions of these criteria are:

- Upstream and downstream passage: whether the mitigation option directly mitigates for obstruction to both upstream and downstream passage
- Construction and operational feasibility: The feasibility of implementing the mitigation measure given the physical characteristics of the site, uncertainty with

being able to locate, and attract and/or catch migrating fish in sufficient numbers, and the difficulty of maintaining ongoing passage as a long-term mitigation measure. This column was completed with input from Cawthron and Tonkin & Taylor staff.

- Cultural acceptability: the acceptability of the mitigation option for local iwi. Cultural acceptability was determined by one of the members of the Mana Whenua working party (Des Ratima) who used a cultural health indicators framework to assess acceptability of each passage option in terms of mauri, mahinga kai, kaitiakitanga and ki uta ki tai concepts. Scores between 1 and 5 were given for each of these components. For more details on the cultural acceptability assessment see Appendix 25.
- Effectiveness: the likelihood of successfully meeting the management objective.
- Cost: a qualitative assessment of the long-term design, construction and operational costs associated with each mitigation option.

The relative rankings in Table 36 are based on a broad management objective of maintaining the existing fish community composition upstream of the dam (*i.e.* providing mitigation for all of the potentially relevant fish species occurring upstream of the proposed dam site). According to the NZ Freshwater fisheries database and our own sampling (see Section 2.3.3), species that have been found upstream of the proposed dam include: longfin eel, torrentfish, dwarf galaxias, Cran's bully, common bully, bluegill bully, redfin bully and common smelt. Shortfin eels have not been recorded upstream of the dam, and the suitability of habitat declines for them upstream of the dam, but they have been found further down the Makaroro. Koaro have not been recorded in the Makaroro Catchment, but fish distribution models indicate that they have a relatively high probability of occurrence in the headwaters of the Makaroro. Cran's bully and dwarf galaxias are non-migratory so will probably establish self-supporting populations upstream of the dam. It is possible that common bully and koaro may also establish self-supporting populations upstream of the dam. Other species would be lost from the fish community upstream of the dam over time if no mitigation measures are put in place.

The construction and operational feasibility and the effectiveness of the upstream trap and transfer option improve if the objective of the mitigation is focused solely on strong migrant species with good climbing abilities, (*e.g.* eels and koaro). An example of this type of management objective could be, to provide for the long-term maintenance of a longfin eel population upstream of the dam and cultural harvest of longfin eels for local iwi.

In the paragraphs below each of the options shown in Table 36 are discussed. This discussion of the pros and cons of each option should help provide clarification of the rationale behind the qualitative rankings.

Table 36. Relative assessment of fish passage mitigation options with respect to five criteria (defined in the text). Note the rankings are comparable within each criterion only, *i.e.* they are not comparable between columns. For the cultural acceptability score, M,M,K,K refers to individual scores for the mauri, mahinga kai, kaitiakitanga and ki uta ki tai components of the overall score.

Mitigation options	**Upstream and downstream passage**	**Construction and operational feasibility**	**Cultural acceptability** M,M,K,K 1 poor, 5 good	**Effectiveness**	**Cost**
Do nothing	No	High	1,2,2,1 **6/20**	Zero	NIL
Off-set mitigation elsewhere in the catchment	No	Medium-High	1,2,2,1 **6/20**	Low	Medium
Engineered fish pass up dam face	No, upstream only	Medium	1,2,2,1 **6/20**	Low	Medium-high initial cost. Low operational cost
Trap and transfer programme – upstream passage only	No, upstream only	Low-Medium	1,2,2,1 **6/20**	Low-Medium	Medium-low initial cost, but ongoing cost.
Trap and transfer programme – upstream and downstream	Yes	Low-Medium	1,3,3,1 **8/20**	Low-Medium	Medium-High low initial cost, but larger ongoing cost.
By-pass canal to head of reservoir	Unlikely	Low	1,3,3,3 **10/20**	Low	Very high

Do nothing

Although the option of doing nothing has an evident cost saving advantage, it also has the obvious flaw of offering no mitigation of the adverse effect identified. Therefore, this option is not considered further here.

Off-site mitigation

Restoration and enhancement of fish habitat elsewhere in the catchment or region could be undertaken to offset the impacts on the migratory fish community above the proposed dam. Five major mitigation projects have been proposed in the mitigation report (HBRIC May 2013f). These projects focus on:

A. restoration and enhancement of habitat around the reservoir and in the catchment upstream of the dam
B. enhancement of a halo of riparian zone around the Waipawa and Makaroro rivers

C. threatened species habitat enhancement projects both in the affected area and throughout Hawke's Bay
D. enhancement and mitigation of phosphorus loading in spring-fed and priority streams on the Ruataniwha Plains
E. restoration of the Old Waipawa River bed / Papanui Stream.

Provision of fish passage is included as part of Project C. However, it is important to recognize that these options are not mutually exclusive, and any of them could be undertaken along with provision of a fish passage option at the dam.

Engineered fish pass up the dam face

A fish pass is essentially an artificial channel that provides access past an obstruction for fish using their own propulsion. A wide variety of fish passes have been designed and built worldwide, although the majority of designs have focused on strong swimming and jumping salmonid species. These typically consist of a stairway of resting pools separated by weirs, often with some form of orifice to allow fish to swim through, rather than jump over the successive weirs. While this approach has been proven for salmonids on moderate sized dams, passage success tends to decline with increasing dam height. A practical maximum height for pool and weir type fish passes has been suggested to be in the range of 30-35 m (Glova 2000). Furthermore, pool and weir type fish passes typically tend to be less successful at providing passage for many non-salmonid species.

Fish passes specifically designed for eels have also been built both in New Zealand and overseas, with some success. For example, a fish pass targeting elvers comprising a PVC pipe approximately 300 m long with water continuously trickling down it (initially installed with brush liners to give the elvers purchase, but then up-graded to a gravel lining) has been used to allow passage of eel elvers over the 65 m high Patea Dam.

More recently, there has been a move toward nature-like fish passes (Santos *et al.* 2005), which attempt to mimic a natural stream channel. This type of fish pass channel has been shown to be effective overseas, particularly when catering for several different species (Jungwirth 1998; Larinier 2002), although this tends to be reliant on the pass being of sufficiently low gradient. Another potential advantage is that they may provide some habitat within the pass. While this approach has been fairly well demonstrated for low obstacles, we are not aware of any proven examples on high dams either in New Zealand or overseas.

Three main benefits of a functional fish pass are consistency of availability (*i.e.* fish can use it whenever they need to), possibly catering for multiple species, and relatively low operating costs (compared to the ongoing costs of trap and transfer operations, see below). However, the initial construction costs can be relatively high and (depending on the target species) the requirement to maintain relatively low gradient can result in very long fish passes, particularly as dam height increases.

The efficacy of fish passes tends to decline as dam size increases, at least in part because the energy expenditure of fish attempting to use the pass increases with its height. The time required to negotiate a fish pass also increases with its length, and fish are often exposed to elevated water temperature, predation risk, and the risk of desiccation while in the fish pass, and expend a lot of energy on the climb. Given the height of the proposed dam (~85 m) any type of engineered fish pass is likely to work for only the strongest climbing migrant species (*e.g.* eels and koaro).

A key difficulty with implementing a fish pass in this situation is that the water level behind the dam is expected to fluctuate over a broad range. Summer and autumn are the period of most upstream migration for New Zealand native fish. For much of the time, particularly over summer and autumn, the water level behind the dam will be below the crest. Hence, water required to flow down a fish pass would have to be pumped to the top of the dam and a mechanism to conduct fish from the top of the pass down to the reservoir water level would have to be devised (possibly a sluice, although this would require more water pumped up).

Fish locks are an alternative to fish passes based on the concept of canal locks. Fish enter a chamber at the bottom, the entrance is then closed and the chamber is filled with water until the water level matches that of the reservoir above and the fish can swim out. This approach is untested for New Zealand native species (although it is unlikely to be successful for many of our benthic oriented species, which may not be inclined to swim up the shaft of the lock to the outlet (Glova 2000)). Furthermore, this approach would encounter the same key problem with fluctuating reservoir levels as discussed above, and would require substantially more water pumped to the top in order to fill a chamber to the height of the dam.

Trap and transfer

Given the height of the proposed dam (~85 m) a manual 'trap and transfer' operation is likely to be the only practical option for providing fish passage. This involves fish being trapped, by attracting them (using an attraction flow) in a holding box, for later manual (or automatic) transfer upstream. This approach has been successfully operated for young eels (elvers) at several hydro dams throughout New Zealand (*e.g.* Karapiro Dam, Patea Dam, Matahina Dam, Manapouri Lake Control).

A key advantage of trap and transfer operations at high dams is the relatively low energy expenditure required on behalf of the fish. This may have contributed to substantially higher numbers of elvers gaining access past the Patea Dam by trap and transfer compared with a PVC pipe elver pass, mentioned above. During a trial trap and transfer operation in early 2000 approximately 455 000 elvers were successfully moved over the dam, while only 27 000 elvers passed through the fish pass over the same six week period (Boubée *et al.* 2003). An active trap and transfer operation has now replaced the pipe elver pass (Ryder Consulting 2011).

Trap and transfer operations can also provide passage for other migratory species if they can be successfully trapped at the base of the dam. Several other species of native fish are caught as “bycatch” in trap and transfer operations primarily targeting elvers. For example, native fish “bycatch” including koaro, banded kokopu, inanga, koura, smelt, torrentish, common bully and redfin bully have been recorded at the elver trap at the Patea Dam (Bonnett 2011). Between December 2004 and March 2005, a total of 640 fish other than eels were caught, and between November 2005 and March 2006 a total of 2,513 fish other than eels were caught. It is likely that the ability of other native fish species to enter a trap and transfer facility could be enhanced by altering the trap entrance conditions (*e.g.* changing the slope and substrate on the entrance ramp, or experimenting with a submerged orifice trap entrance).

The release point for the trapped fish is also a consideration. Ideally, fish should be transferred from the river below the dam to the river upstream of the dam. Otherwise, released fish may become ‘lost’ in the reservoir and/or eaten by predators. This is a further advantage of trap and transfer over a fish pass in this situation, where any fish that did manage to climb the pass would then also need to negotiate the reservoir before reaching riverine habitat upstream.

While the initial set up costs of a trap and transfer operation are likely to be substantially lower than a fish pass on a dam of the height proposed, a trap and transfer facility requires continuing maintenance and operation, since the effects of the dam on fish passage are on-going. However, upstream migrations tend to have reasonably strong seasonality. Consequently, the trap and transfer need not operate year round after an initial evaluative period. This evaluation period would need to be several years long in order to account for likely high inter-annual variability in numbers of migrants reaching the dam. We recommend that a seasonal operating regime for the trap and transfer facility is developed following monitoring over the first few years of operation. The monitoring would involve counts of the numbers and species of fish caught in the trap. At that time, optimised seasonally-based operational parameters could be confirmed. If reasonable numbers of fish are not caught, then consideration needs to be given to whether the trap arrangement needs to be modified, or if the numbers of migrating fish are insufficient to justify the effort involved. We also recommend monitoring of the age-structure of the eel population and the composition of the broader fish community before and after the construction of the scheme to determine if the trap and transfer programme is resulting in successful recruitment to the population and what amendments may be required.

Among the disadvantages of trap and transfer are delay of migration and predation risk while fish are held in the trap prior to transfer. The longer that fish are held in a trap prior to transfer the more likely they are to suffer detrimental effects (*e.g.* predation by larger eels also held in the trap). As a result, the trap infrastructure has to be in place, be maintained, and be monitored on an almost continuous basis throughout the season that it is in use. Another potential disadvantage is that handling and agitation during transport and manual transfer and release into receiving tributaries have the potential to cause stress, injury or even mortality. However, even with these disadvantages trap and transfer would provide substantial mitigation of the potential adverse impact of fish passage obstruction.

Trap and transfer also offers the opportunity to readily monitor the numbers of fish transferred, and also potentially control the species of fish transferred. Controls on transporting smelt upstream of the Patea Dam are included in the trap and transfer conditions on that dam (Ryder Consulting 2011a).

We anticipate there may be some cultural aspects associated with moving fish upstream of the dam. Therefore, discussions with local iwi seeking their involvement in the programme are advised.

Assuming access is provided past the dam for koaro and eels, some consideration then needs to be given to providing for their return access downstream. Koaro require downstream access after spawning in autumn when their larvae passively migrate downstream during a fresh. This is also the case for most other diadromous native fish species (those with a marine stage in their lifecycle), although the timing of their downstream passage varies. Consequently, they will be naturally entrained, either via flow augmentation releases or spilling. The majority of downstream movement will occur during freshes, when the dam may be spilling and larvae will be carried downstream in the spillway flow. Alternatively, those koaro larvae that are not carried past the dam may remain and rear in the reservoir. Natural mortality of koaro larvae as they are shunted downstream is unknown. However, Coutant &Whitney (2000) report that survival of planktonic fish larvae through the extreme conditions associated with hydro-power turbines is high. On this basis survival is also likely to be high for larval fish passing downstream in the spillway flow, and there is likely to be little advantage to downstream trap and transfer of koaro in attempting to provide an alternative downstream pathway.

Eels present a different problem because they migrate downstream as mature (and often very large) adults. There are likely to be few options for enhancing downstream migration of adult eels other than releasing flows over the spillway during autumn freshes when the strongest likelihood of these fish seeking downstream access will occur (Boubee *et al.* 2001, 2003; Richkus & Dixon 2003). Installation of a bypass pipe may also be effective, but only when it is the only option for fish to bypass the impoundment (Boubee & Williams 2006). Allowing release of water through the spillway (or bypass pipe) rather than the intake may allow fish, particularly eels, a better chance of locating the spillway or bypass pipe exit (Watene & Boubee 2005;

Watene *et al.* 2003). However, many natural autumn high flows will be 'captured' within the reservoir as water levels recover following flow augmentation over the summer. The wide range of reservoir levels also makes the design and operation of a bypass pipe difficult. Also, spilling at the appropriate time of year is not likely to occur during dry years. Reservoir populations of eels are often restricted to downstream migration during years when there are sufficient flows to bring about spillway flow and allow access out.

The primary spillway is designed with a hydraulic jump basin with chute blocks and a dentated end sill to slow the water (dissipate energy) at the bottom of the spillway (Tonkin & Taylor May 2013a). Energy dissipation does not rely on the water 'hitting' the projections within the basin, but rather on a hydraulic jump (area of raised water level) which forms within the basin. The projections are designed to encourage formation of the jump within the basin and to shorten the length of the channel that is exposed to very turbulent and high velocity currents. In effect the flow would 'ride' over the projections in the basin. Therefore, eels and other fish entrained in the spill flow would be expected to also ride over the energy dissipation projections rather than hitting them and incurring injuries. Flow would be shallow and fast as it enters the basin near the chute blocks but much deeper and slower as it leaves the downstream end of the basin. Spillflow in this spillway design is not flipped up and thrown downstream, as is the case in a 'flip bucket' energy dissipator. Survival of any eels passing over the primary spillway is expected to be high.

As a contingency for successive dry years that produce no spilling during autumn, the only feasible option to facilitate downstream migration would be to trap migrants and manually transfer them downstream over the dam wall. This approach is currently used by Meridian to enable downstream passage of large eels in the Waitaki catchment. The best location for trapping downstream migrants is probably at the head of the reservoir where migrant eels sourced from the upper Makaroro Catchment will move downstream with river flows. Peak downstream movements normally occur in autumn, at night, during rainfall/high flow events (>35 mm rain in 24 hours) and during new moon (Richkus & Dixon 2003). Once again, the downstream trap and transfer programme would benefit from review after monitoring over the first few years of operation to determine when/where adult eels seeking downstream passage can be caught and if the numbers of eels involved justifies the effort.

By-pass canal to head of the reservoir

At an early meeting DOC staff queried the possibility of incorporating a by-pass canal from the base of the dam right up to the head of the reservoir where the river flows in – *i.e.* essentially a very long fish pass of > 5km. At a follow-up meeting (8^{th} Feb 2013) with the Mana Whenua working party (which DOC also attended) this option was discussed, but the low feasibility of this option was recognized by all present and therefore should not be considered as a serious option. Nevertheless, this option has been included in Table 36 and received the highest score for cultural acceptability.

4.3.2. Recommended fish pass options

Based upon the ratings and scores in Table 36, we consider that the upstream and downstream trap and transfer option is the most feasible and effective way of mitigating the effect of fish passage blockage by the proposed dam. However, it is recognised that the effectiveness of the trap and transfer is only low-medium if the objective is to maintain the full range of fish species currently found upstream of the dam. A higher level of effectiveness is expected for the strongest migrants (*e.g.* longfin eels).

Off-site mitigation is also planned as part of the scheme implementation (Section 4.5), so there should also be some off-site benefits to at least some of the fish species that will be affected by the dam.

4.3.3. Screening of the reservoir outlet for large eels

The probability of fish injury or mortality during turbine passage increases with fish length (Larinier & Travde 2002). While survival rates for small fish and larvae passing downstream through the turbines of the proposed hydro-electric scheme are likely to be high, the same is not true for large migratory eels. In the absence of a physical screen or other barrier, large migratory eels that pass through the outlet and turbine are unlikely to survive.

A behavioural study of downstream migrating eels approaching a reservoir wall indicates that the initial migration down the reservoir is near the surface (top 5 m), but once the eels approach the dam and find their pathway blocked they dive repeatedly to seek an outlet (Watene *et al.* 2003).

A variety of barrier types have been trialled internationally to deter eels from being entrained in the outlet and include behavioural (e.g. light, electricity, sound, water jets, bubbles) and physical screens (e.g. angled bar racks, louvers and screens) (Richkus & Dixon 2003). Light arrays, physical screens and sound barriers have shown some promise in laboratory conditions or for relatively small projects. However, their efficacy under ‘natural’ conditions cannot currently be predicted (Richkus & Dixon 2003). The major problem with physical screens is ensuring that the approach velocity is low enough so eels can manoeuvre away from the screen and avoid becoming entrained through the screen into the intake, or impinged on the screen surface. Maintenance of a screen with a sufficiently small aperture size to physically exclude eels is also expected to be a major undertaking, and especially if the outlet is at considerable depth, as is the case in the proposed dam design (Ryder Consulting 2011b).

Given the uncertainty in efficacy of any screening options, we recommend that the downstream trap and transfer programme is the primary mechanism for mitigating the effect of obstruction to downstream passage. It may be possible to incorporate a bypass pipe within the outlet design that could be used to release the minimum flow downstream of the dam (and bypass the turbines) during autumn when downstream passage of migrant eels is most likely. Discussions are ongoing with the Mana Whenua working party on the fish passage issue (EMS May 2013b). We recommend that the design of a bypass pipe be considered should the working party decide that this is a significant issue from a cultural perspective. The Project Description (Tonkin & Taylor May 2013a) identifies areas of future optimization of the Scheme that could be considered in the detailed design phase, including the intake/outlet structure. We recommend that consideration of a bypass pipe on the intake be conducted during this phase.

Overall, the proposed trap and transfer programme is expected to be effective at maintaining a longfin eel population upstream of the proposed reservoir and allow downstream movement of migrant eels so they can complete their life cycle. The effectiveness of the programme for other fish species is less certain, and will depend on how many fish can be trapped downstream of the proposed dam.

4.4. Flushing flows

As mentioned earlier, the Scheme design has incorporated the need for four flushing flows to be released from the dam per year to remove nuisance accumulations of periphyton. Based on our initial advice, flushing flows of approximately 3 times the median flow as calculated at the toe of the dam were included in the project feasibility assessments. Further work on the effectiveness of different sized flushing flows (Appendix 28) has confirmed that flows around three times the median flow (*i.e.* ~10 m^3/s) should be appropriate for flushing periphyton in the reach of the Makaroro River downstream of the dam. However, the effectiveness of a flushing flow of this size will decrease downstream as the channel widens and as the flushing flow is attenuated.

Mitigating the adverse effects of reductions in flushing flow frequency in the Makaroro River could be achieved by releasing approximately **10 m^3/s** at times when the Makaroro has been at or near the minimum flow for a prolonged period (in the order of 6 weeks). However, an alternative approach may be needed for times when the Makaroro flow has been released at or close to the irrigation demand/design generation flow (approx 11 m^3/s) for a prolonged period (more than six weeks) and periphyton growth becomes a concern. Under these conditions the ‘base flow’ is already close to 10 m^3/s and releasing 10 m^3/s is not likely to flush periphyton that has accumulated at this flow. Release of higher flows (up to 30 m^3/s) would enable very effective flushing in this reach in the unlikely event of periphyton accumulation. An alternative option would be to decrease flows down to near the minimum flow for several days so that periphyton along the river margins is exposed to the sunlight and air (and winter frosts) and dies.

For the Waipawa River a flushing flow of 20 m^3/s is considered to be sufficient to flush periphyton accumulations resulting from the reduction in flushing flow frequency and/or the increase in nutrient concentrations resulting from land use change (Appendix 28). A flow of 30 m^3/s can potentially be released from the dam and would result in effective flushing in the Waipawa River even if flows from the upper Waipawa were low. Alternatively, a smaller release in conjunction with a natural fresh in the upper Waipawa would also result in flows of at least 20 m^3/s in the Waipawa River downstream of the confluence with the Makaroro River. Any flushing flow would of course have to bypass the irrigation intake to result in periphyton flushing further downstream.

In the Tukituki River, a flow of around 50 m^3/s is predicted to be required for effective flushing of surface sediment (Appendix 28). Analysis of long-term National River Network Monitoring data (maintained by NIWA) shows that excessive filamentous algae growths (*i.e.* in excess of the 30% cover proposed Plan Change 6 target) were regularly observed in the lower Tukituki River at Red Bridge (58 out of 286 monthly observations made over the 1989 to 2012 period), but only rarely (three times) when the flow at the time of the observation was above 23 m^3/s and never when the flow was above 34 m^3/s (Aquanet May 2013).

Periphyton removal by flow events is of course determined not only by the flow on the day the observation is made, but also by the flow history in the 2 to 3 weeks period preceding the observation, and it is probable that some observations of low periphyton biomass made at a certain daily flow were actually driven by higher flow events in the days or weeks preceding the observation. Nonetheless, the fact that nuisance periphyton growths are frequent at that site, but were never observed at flows above 34 m^3/s and only three times at flows over 23 m^3/s, over a period of 23 years of monthly monitoring provides a strong indication that river flows in the 23 to 34 m^3/s range are likely to provide significant periphyton removal benefits.

The Proposed Tukituki Plan Change 6 defines in-river dissolved reactive phosphorus (DRP) targets, in order to achieve in-river periphyton biomass and cover targets. The Plan Change 6 DRP targets will be defined taking into account an accrual period (*i.e.* the time between two flushing flows) of up to 30 days. This means that Plan Change 6's DRP concentration targets were defined at a level considered sufficiently low to control periphyton growth below periphyton biomass target levels for up to 30 days, but exceedences of the periphyton targets may occur when the accrual period (*i.e.* the period of low flows) extends beyond 30 day.

Based on this, it is recommended that flushing flows from the RWSS dam should, as much as possible, be released in order to 'interrupt' periphyton accrual periods of 30 days or more, particularly during the key summer recreational use and periphyton growth period (Aquanet May 2013).

4.4.1. Attenuation of flushing flows downstream

A key question to be considered regarding the potential for dam releases to flush downstream reaches is the degree of attenuation of the flow peak as it moves downstream. For example, would a three hour release of the maximum possible discharge (*i.e.* 30 m^3/s) at the dam result in a similar increase in peak discharge at Red Bridge, or would this flow release be rapidly attenuated downstream and result in a much smaller increase in flow (but spread over a longer period)?

To address this issue, HBRC (Craig Goodier) used a hydraulic model of the Tukituki catchment (MIKE11) to determine the factors potentially affecting attenuation of flow down the catchment and the likely degree of attenuation down the catchment. The results of this modelling are reported in detail in Aquanet (May 2013) and indicate that flushing flows are likely to be only moderately attenuated, and a flow release of 30 m^3/s for nine hours over a base flow of approximately 5 m^3/s in the Tukituki River is predicted to result in flows of 35 m^3/s in the Tukituki River at Shagrock (where flow is predicted to remain above 23 m^3/s for nine consecutive hours) and just under 30 m^3/s at Red Bridge even under low base flow conditions. Alternatively, a flow release of 25 m^3/s for a duration of 11 hours (corresponding to approximately the same water volume as 30 m^3/s for nine hours) over low base flow conditions is predicted to result in a peak flow of 30 m^3/s at Shagrock (where the flow is predicted to remain above 23 m^3/s for 10 consecutive hours) and 27 m^3/s at Red bridge (where it remains above 23 m^3/s for 7 consecutive hours). These flows are well within the 23 to 34 m^3/s range where considerable periphyton flushing is expected.

4.4.2. Piggy-backing releases of flushing flows on natural flushes

Aquanet (May 2013) also reported on the results of GoldSim modelling where the operation of the storage dam to harvest, store and release river flows to meet irrigation demand and an environmental flow regime was simulated. In the model, up to four flushing flows were released during the period from December to March in order to interrupt accrual periods of 30 days or more, whilst allowing piggy-backing onto natural flows which are greater than 15 m^3/s but less than 50 m^3/s when accrual periods exceed 20 day. If no ‘piggy-back’ release of flushing flows occur before the accrual reaches 30 days then a flushing flow is automatically released on the 30th day of accrual.

The GoldSim modelling indicated that over the 36 year record, these flushing flow operating rules resulted in the release of four flushing flows every year except in 1995-1996 when only 3 flushing flows were required (Aquanet May 2013).

The peak flow of each flushing flow at Red Bridge was calculated by combining the flow release from the dam as modelled by GoldSim, the flow on that day at Red Bridge and the attenuation factors obtained using the Mike11 model mentioned above. Over the 36 year record, the average and median peak flows at Red Bridge resulting from flushing flow releases from the reservoir were 37.6 m^3/s and 36.3 m^3/s, respectively. The minimum peak flow was 27.1 m^3/s, and 25% of flows exceeded 46.5 m^3/s. The maximum peak flows were capped at 50 m^3/s in the model.

4.4.3. Summary

Releases of flushing flows from the reservoir as proposed in the initial feasibility assessments (four releases of 10.5 m^3/s each) would have enabled significant flushing of any periphyton accumulations in the Makaroro and Waipawa rivers, but would have been insufficient to provide appreciable periphyton removal in the lower Tukituki corridor. Four flushing flows of up to 30 m^3/s for nine hours are now proposed to be released to ‘interrupt’ periphyton accrual periods of 30 days or more, particularly during the key summer recreational use and periphyton growth period, as described in the Project Description (Tonkin &Taylor, May 2013a). These are expected to result in significant periphyton removal during periods of excessive periphyton accumulation in the lower Tukituki River, although complete removal of the accumulated biomass is unlikely. ‘Piggy-backing’ these flushing flow releases on natural flushes would further increase the periphyton flushing efficiency of these flushing flows in the lower Tukituki River. These flushing flows are expected to be a very useful tool for managing any periphyton accumulations in the Tukituki River and instrumental in helping meet the periphyton objectives in the proposed Tukituki Plan Change 6.

4.5. Ruataniwha Plains Spring-fed stream enhancement and Phosphorus mitigation

The potential effects of land use change and the uncertainty associated with the effect of the Scheme on juvenile trout recruitment are likely to be most effectively addressed by a contribution to the enhancement or special protection of the spring-fed streams that drain the lower Ruataniwha Plains (*e.g.* tributaries of the lower Mangaonuku, Kahahakuri, Waipawamate, Black Stream, Maharakeke, Tukipo and presumably many unnamed ones). Based on anecdotal reports and the recent assessment of juveniles in the lower Mangaonuku Stream (Maclean 2012), these areas are probably also key locations for spawning and juvenile trout rearing. These streams will also offer good habitat for eels and some other native fish species.

Fencing and riparian planting along these streams would provide improvements to trout spawning, juvenile trout recruitment, native fish habitat, and other wildlife and thus help mitigate the potential effects on trout spawning/native fish habitat in the Makaroro and Waipawa rivers, and also contribute to reducing N & P inputs that will be associated with the changes in land use on the Ruataniwha Plains.

If water users move from groundwater takes to dam storage then flows in the smaller spring fed streams would be expected to increase and become more permanent (HBRC Science May 2013a), again increasing the habitat value of these systems.

One potential concern with focussing mitigation efforts on these spring-fed streams is the existing and potential nitrate concentrations in these systems, which may reach levels that are potentially toxic for some aquatic life (Table 35). To determine the extent of this issue, HBRC undertook an extensive survey of the nutrient status of surface waters draining the Ruataniwha Plains on 20th September 2012 and 1st November 2012 (Uytendaal & Ausseil 2013). The results indicated that winter nitrate concentrations at most sites are below levels of concern, but at some sites concentrations are close to (and in 2 cases may exceed) nitrate toxicity concentration limits that have been recommended in the proposed Tukituki Plan Change 6 (Figure 53; Uytendaal & Ausseil 2013). Changes in land use are predicted to increase nitrate concentrations in these streams and without mitigation result in some exceedances of nitrate toxicity limits (NIWA May 2013a). Nitrate concentrations in this range may result in an increased risk of minor effects on growth rates, development and reproduction of some aquatic organisms (Hickey 2013b). It is recommended that this issue will require close monitoring and management to avoid increasing the risk of toxic effects on aquatic life at sites with high groundwater influence. Particular attention will need to be given to sites that are, or are predicted to become as a result of intensified land use, close to or beyond the proposed limit, and management actions aimed at reducing nitrogen leaching will be required in any areas that are over the limit.

4.6. Summary of recommended mitigation options

A number of initiatives have been recommended to address potential adverse effects of the Scheme on aquatic ecology. These include:

- An upstream and downstream trap and transfer programme that will enable migratory native fish to access habitat upstream of the proposed dam.
- Pre- and post-construction monitoring of the age-structure of the eel population upstream of the dam to ensure that the trap and transfer programme is enabling successful recruitment.
- Post-construction monitoring of the efficacy of the rockfill infiltration bund at the upper irrigation intake as a fish screen.

We recommend that these initiatives could be implemented alongside five broad restoration and enhancement packages that are described in detail in HBRIC (2013f). These include:

4.6.1. Ruataniwha Reservoir Restoration Buffer and Catchment Enhancement Zone:

This is as advocated in the terrestrial ecology effects assessment. In terms of aquatic ecology the key objectives of this package would be to protect and enhance the aquatic habitat within the upper Makaroro River above the dam and other reservoir tributaries such as Dutch Creek. This package would also help to limit inputs of nutrients and sediment to the proposed reservoir and maintain reservoir water quality.

4.6.2. Ruataniwha Riparian Enhancement Zone (River Halo Project):

This is also as advocated in the terrestrial ecology effects assessment. The focus of this package should be on protection of riparian habitats alongside the Makaroro and Waipawa rivers that are affected by flow fluctuations resulting from the Scheme.

4.6.3. Ruataniwha Threatened Species Habitat Enhancement

This initiative focusses on fostering habitat protection/enhancement for bats throughout Hawke's Bay, terrestrial predator trapping to enhance biodiversity values within the upper Makaroro Catchment and downstream to the upper intake structure, and the upstream and downstream trap and transfer programme for native fish, as mentioned above.

4.6.4. Ruataniwha Plains Spring-fed Stream Enhancement and Priority subcatchment Phosphorus Mitigation:

The objectives for this package are to protect and enhance the spring-fed streams and other waterways that drain the lower Ruataniwha Plains (*e.g.* tributaries of the lower Mangaonuku, Kahahakuri, Waipawamate, Black Stream, Maharakeke, Tukipo and presumably many unnamed ones). These streams provide good habitat for eels and some other native fish species and also appear to be important locations for spawning and juvenile trout rearing. The package would involve support for landowners with fencing, replanting and ongoing riparian maintenance and legal protection and fencing of any existing wetlands. The proposed stock exclusion rule in the Tukituki Plan Change 6 will also help to restrict inputs of phosphorus, sediment and faecal bacteria to waterways in the Ruataniwha Plains and the wider Tukituki Catchment. We recommend that sites on several waterways in the lower Ruataniwha Plains are added to the HBRC state of the environment monitoring programme to determine the effectiveness of this package and closely monitor any issues that arise with high nitrate concentrations.

4.6.5. Old Waipawa River Bed / Papanui Stream Restoration

The objective of this package is to rehabilitate and enhance water quality and stream habitat in the bed of the old Waipawa River / Papanui Stream subsequent to any works required to meet Zone M irrigation requirements. This will involve funding to contribute to fencing, planting and wetland creation along the riparian margins of the stream.

5. SUMMARY

The Ruataniwha Water Storage Scheme has been developed with the intention of avoiding potential effects on the aquatic ecosystem as much as possible. Nevertheless, there are some residual effects that are impossible to avoid including:

- disturbance of the riverbed during construction
- inundation of flowing water habitat by the reservoir
- obstruction of fish passage
- changes to the flow regime
- changes in water quality associated with land use change.

We have recommended a variety of approaches to reduce and mitigate these effects. Sediment retention measures during the construction process will be important, while trap and transfer of native fish over the dam will help to reduce the obstruction of fish passage. Flowing water habitat will be lost when it is inundated by the reservoir. However, the reservoir will provide habitat for some species and the proposed reservoir restoration buffer and catchment enhancement zone will help to mitigate the lost habitat. The changes to the flow regime are relatively large, especially in the reach between the dam and irrigation intake. However, the river will still provide some habitat for all the species currently present and the proposed minimum flow, in conjunction with the residual flow releases from the dam, will mean that extreme low flows are higher than they are currently. The flushing flow releases that have been incorporated into the design of the Scheme will enable effective control of any nuisance periphyton accumulations that occur in the Makaroro and Waipawa rivers and also significant control of periphyton accumulations in the lower Tukituki River.

The changes in land use associated with the proposed Scheme will have to be managed carefully. As part of the Ruataniwha Plains spring-fed stream enhancement and phosphorus mitigation package we recommend that stock exclusion from waterways draining the Ruataniwha Plains, as proposed in the Tukituki Plan Change 6, should be an important component of the implementation of the Scheme, so that damage to instream and riparian habitats is avoided and habitat is enhanced.

Periphyton growth is currently excessive in parts of the catchment, particularly in the lower Tukituki corridor. We also recommend that the load of phosphorus, from the area influenced by the Scheme, should be carefully managed to avoid increases,and concur with the proposal for the Scheme to be progressed on a phosphorus neutral basis. Mitigation measures in addition to stock exclusion and phosphorus fertiliser management will likely be required in some areas to ensure that no increases in phosphorus losses occur as a result of the RWSS. Provided the “phosphorus neutral” status can be achieved in all sub-catchments, the provision of augmented flushing flows, as now proposed, should contribute to reducing periphyton growth in the lower Waipawa and Tukituki rivers.

The losses of nitrate nitrogen from the land areas influenced by the Scheme will also have to be carefully managed to avoid exceeding the proposed instream limits, particularly in areas where the current instream concentrations are close to the limits. Two sites out of 130 were currently found to have one-off nitrate concentrations exceeding the proposed instream nitrate-N concentration limits. We recommend these exceedences be confirmed or otherwise by additional monitoring, and if confirmed recommend that nitrogen losses from the land area influencing these sites be actively managed to reduce instream concentrations to below the proposed instream concentration limits. Similarly, land use change will have to be carefully managed, and water quality closely monitored in subcatchments where modelling indicates possible exceedances of the proposed N toxicity limits. Limit exceedances are possible in some sub-catchments with strong groundwater influence such as the Kahahakuri, OngaOnga, Porangahau, Tukipo and Papanui. The scenarios reported by NIWA (May 2013a) did not include N mitigation, but it appears that careful monitoring and management of N losses from land use within the irrigation command area will be required in sub-catchments where in-stream nitrate concentrations are, or are predicted to become, close to or in excess of, the proposed limits

At a whole-catchment scale, modelling indicates that with stock exclusion and optimal use of phosphorus fertiliser the Scheme can be developed on a near phosphorus-neutral basis overall. However, it appears likely that careful monitoring and additional P loss mitigation measures will be required to avoid increases in phosphorus concentrations in some sub-catchments within the irrigation command area..

Provided the RWS can be developed on a phosphorus-neutral basis in all sub-catchments and without causing the proposed nitrate concentrations limits to be exceeded, and if all the other mitigation and rehabilitation efforts are in place, the Scheme will have relatively minor effects on the aquatic ecosystem and the Tukituki will continue to support the current wide range of values.

6. ACKNOWLEDGEMENTS

We thank Olivier Ausseil, Stephen Daysh, Graeme Hansen, Adam Uytendaal, Thomas Wilding, Trevor Robinson, Sandy Haidekker, Rob Waldron, Iain Maxwell, John Hayes, David Leong and Des Ratima for assistance with data gathering, advice and comments on this report. We also thank the Makaroro River anglers who were willing to be interviewed about their opinions on the river.

7. REFERENCES

Alabaster JS, Lloyd R 1982. Water quality criteria for freshwater fish. 2nd ed. London, Food and Agriculture Organisation. 456 p.

Allibone R, David B, Hitchmough R, Jellyman D, Ling N, Ravenscroft P, Waters J 2010. Conservation status of New Zealand freshwater fish, 2009. New Zealand Journal of Marine & Freshwater Research 44 (4): 271-287.

ANZECC 1992. Australian water quality guidelines for fresh and marine waters. Australian & New Zealand Environment & Conservation Council.

Ausseil O 2008. Water Quality in the Tukituki catchment: State, trends and contaminant loads. Report prepared for Hawke's Bay Regional Council. 96 p.

Aquanet May 2013. Ruataniwha Water Storage Scheme Environmental Flow Optimisation. Report prepared for Hawke's Bay Regional Investment Company Ltd.

Baker CF, Jowett IG, Allibone RM 2003. Habitat use by non-migratory Otago galaxiids and implications for water management. Prepared for Department of Conservation. 5-34 p.

Ballantine DJ, Davies-Colley RJ 2009. Water quality trends at National River Water Quality Network sites for 1989-2007. Prepared for Ministry of the Environment. National Institute of Water & Atmospheric Research. Client Report HAM2009-026. 21 p.

Becker CD, Neitzel DA 1985. Assessment of intergravel conditions influencing egg and alevin survival during salmonid redd dewatering. Environmental Biology of Fishes 12 (1): 33-46.

Benson M 2010. Ruataniwha Plains Water Storage Feasibility Study Demand for Irrigation Water. 45pp p.

Biggs BJF 2000a. New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams. Prepared for Ministry for the Environment. 1-122 p.

Biggs BJF 2000b. Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. Journal of North American Benthological Society 19: 17-31.

Biggs BJF, Kilroy C 2000. Stream Periphyton Monitoring Manual. 226 p.

Biggs BJF, Stokseth S 1996. Hydraulic habitat suitability for periphyton in rivers. Regulated Rivers: Research and Management 12: 251-261.

Bonnett ML 2011. Statement of evidence of Martin Lee Bonnett for Meridian Energy Ltd, before the Environment Court, in the matter of Appeals pursuant to Section 120 of the Resource Management Act 1991, with regard to resource consents for the Mokihinui Hydro Project.

Boothroyd I, Stark JD 2000. Use of invertebrates in monitoring. In: Collier KJ, Winterbourn MJ ed. New Zealand Stream invertebrates: ecology and implications for management. New Zealand Limnological Society, Christchurch. Pp 344-373.

Boubée J, Haro A 2003. Downstream Migration and Passage Technologies for Diadromous Fishes in the United States and New Zealand: Tales From Two Hemispheres. Downstream Movement of Fish in the Murray-Darling Basin – Canberra Workshop,June 2003. Available from http://www.mdbc.gov.au/__data/page/509/Jacques_Boubee_&_Alex_Haro.pdf Accessed 1 November 2006.

Boubée J, Williams EK, 2006. Downstream passage of silver eels at a small hydroelectric facility. Fisheries Management and Ecology 13: 165-176.

Boubée J, Mitchell CP, Chisnall, BL, West DW, Bowman E, Haro A 2001. Factors regulating the downstream migration of mature eels (*Anguilla* spp.) at Aniwhenua Dam, Bay of Plenty, New Zealand. New Zealand Journal of Marine and Freshwater Research 35: 121-134.

Boubée J, Chisnall B, Watene E, Williams EK, Roper D, Haro A 2003. Enhancement and management of eel fisheries affected by hydroelectric dams in New Zealand. Pages 191-205. In Dixon DA ed. Biology, Management and Protection of Catadromous Eels. American Fisheries Society, Bethesda, Maryland, USA..

Boyd CE 1990. Water quality in ponds for aquaculture. Prepared for Alabama Agricultural Experiment Station, Auburn University.

Brookes A 1986. Response of aquatic vegetation to sedimentation downstream from river channelisation works in England and Wales. Biological Conservation 38: 351-367.

Bruton MN 1985. The effects of suspensoids on fish. Hydrobiologia 125: 221-241.

Burns N, Bryers G, Bowman E 2000. Protocol for monitoring the trophic status of New Zealand lakes and reservoirs. Prepared for NZ Ministry for the Environment. Lakes Consulting Ltd. 190 p.

Charteris SC 2006. Native fish requirements for water intakes in Canterbury. Department of Conservation, Christchurch. 52 p.

Clausen B, Biggs B 1997. Relationships between benthic biota and hydrological indices in New Zealand streams. Freshwater Biology 38: 327-342.

Cline LD, Short RA, Ward JV 1982. The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream. Hydrobiologia 96: 149-159.

Collier KJ 2002. Effects of flow regulation and sediment flushing on instream habitat and benthic invertebrates in a New Zealand river influenced by a volcanic eruption. River Research and Applications 18 (3): 213-226.

Coutant CC, Whitney RR 2000. Fish behaviour in relation to passage through hydropower turbines: a review. Transactions of the American Fisheries Society 129: 351-380.

Cox TJ, Rutherford JC 2000. Predicting the effects of time-varying temperatures on stream invertebrate mortality. New Zealand Journal of Marine & Freshwater Research 34: 209-215.

Davies-Colley RJ 1988. Mixing depths in New Zealand lakes. New Zealand Journal of Marine & Freshwater Research 22: 517-527.

Davies-Colley RJ, Hiskey CW, Quinn JM, Ryan PA 1992. Effects of clay discharges on streams 1. Optical properties and epilithon. Hydrobiologia 248: 215-234.

de Crespin de Billy VD, Dumont B, Lagarrigue T, Baran P, Statzner B 2002. Invertebrate accessibility and vulnerability in the analysis of brown trout (*Salmo trutta* L.) summer habitat suitability. River Research and Applications 18: 533-553.

Dean TL, Richardson J 1999. Responses of seven species of native freshwater fish and a shrimp to low levels of dissolved oxygen. New Zealand Journal of Marine & Freshwater Research 33: 99-106.

Deans N 2004. Sports Fisheries of National Importance. Nelson Fish and Game Council, Miscellaneous document. 19p.

Doeg TJ, Koehn JD 1994. Effects of draining and desilting a small weir on downstream fish and macroinvertebrates. Regulated Rivers: Research and Management 9: 263-277.

Downing JA, Plante C 1992. Production of fish populations in lakes. Canadian Journal of Fisheries and Aquatic Sciences 50: 110-120.

Downing JA, Plante C, Lalonde S 1990. Fish production correlated with primary productivity, not the morphoedaphic index. Canadian Journal of Fisheries and Aquatic Sciences 47: 1929-1936.

DWA 2005. Fish protection technologies and downstream fishways. Dimensioning, design, effectiveness inspection. German Association for Water, Wastewater and Waste. 226 p.

Elliott JM 1994. Quantitative ecology and the brown trout. Oxford Series in Ecology and Evolution. University Press. Oxford. 286.

EMS May 2013a. Ruataniwha Water Storage Scheme Zone M Primary Distribution Concept Review and Assessment. Environmental Management Services Ltd.

EMS May 2013b. Mana Whenua working party report. Environmental Management Services Ltd.

Francoeur SN, Biggs BJF, Smith RA, Lowe RL 1999. Nutrient limitation of algal biomass accrual in streams: seasonal patterns and a comparison of methods. Journal of North American Benthological Society 18: 242-260.

Glova G 2000. A literature review and assessment of fish passage at high dams. NIWA Client Report CHC00/100. 25p.

Graham AA 1990. Siltation of stone-surface periphyton in rivers by clay-sized particles from low concentrations in suspension. Hydrobiologia 199: 107-115.

Grant 1982. Coarse sediment yields from the upper Waipawa River basin, Ruahine Range. Journal of Hydrology 21: 81-97.

Green JD, Viner AB, Lowe DJ 1987. The effect of climate on lake mixing patterns and temperatures. In: Viner, A.B. (Editor), Inland waters of New Zealand, pp 65-95. Department of Scientific and Industrial Research, Wellington.

Hawke's Bay Fish & Game New Zealand undated. The Tukituki River inventory. Internal Technical Report. 47 p.

Hayes J, Hill L 2005. The Artful Science of Trout Fishing. Canterbury University Press.

Hayes JW 1988. Mortality and growth of juvenile brown and rainbow trout in a lake inlet nursery stream, New Zealand. New Zealand Journal of Marine and Freshwater Research 22: 40-47.

Hayes JW 2008. Statement of Evidence prepared for Meridian Energy Ltd. In the matter of: An application by Meridian Energy Limited for Resource Consents for the Mokihinui Hydro Project. pp 69.

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

Hayes JW, Olsen DA, Hay J 2010. The influence of natural variation in discharge on juvenile brown trout population dynamics in a nursery tributary of the Motueka River, New Zealand. New Zealand Journal of Marine & Freshwater Research 44: 247-269.

Hayes JW, Stark JD, Shearer KA 2000. Development and test of a whole-lifetime foraging and bioenergetics growth model for drift-feeding brown trout. Transactions of the American Fisheries Society 129: 315-332.

HBRC 2013. Proposed Change 5 to the Hawke's Bay Regional Resource Management Plan – Land and Freshwater Management. HBRC Plan Number 4396.

HBRC Science May 2013a. Ruataniwha Water Storage Scheme – Tukituki River Catchment. Assessment of potential effects on groundwater and surface water resources. BHBRC Plan No. 4469. Hawke's Bay Regional Council. 52 p + appendices.

HBRIC 2013f. Ruataniwha Water Storage Scheme: Proposed Integrated Mitigation and Offset Approach. Report prepared for Hawke’s Bay Regional Investment Company Ltd.

Hickey CW 2013a. Updating nitrate toxicity effects on freshwater aquatic species. NIWA Client Report. Prepared for Ministry for Business, Innovation and Employment.

Hickey CW 2013b. Site specific nitrate guidelines for Hawke’s Bay. Prepared for Hawke’s Bay Regional Council. NIWA client report no. HAM2012-127.

Hitchmough R, Bull L, Cromarty P 2007. New Zealand Threat Classification System lists — 2005. Prepared for Department of Conservation. 1-194 p.

James GD, Graynoth E 2002. Influence of fluctuating lake levels and water clarity on trout populations in littoral zones of New Zealand alpine lakes. New Zealand Journal of Marine & Freshwater Research 36: 39-52.

James MR, Weatherhead M, Stanger C, Graynoth E 1998. Macroinvertebrate distribution in the littoral zone of Lake Coleridge, South Island, New Zealand — effects of habitat stability, wind exposure, and macrophytes. New Zealand Journal of Marine & Freshwater Research 32: 287-305.

Jamieson D, Bonnett ML, Jellyman D, Unwin M 2007. Fish screening: good practice guidelines for Canterbury. NIWA Client Report: CHC 2007-092. Prepared for Fish Screen Working Party: Environment Canterbury, Fish & Game New Zealand, Irrigation New Zealand, Department of Conservation. 70 p.

Jellyman DJ 2008. Statement of evidence of Donald John Jellyman on behalf of Meridian Energy Limited, in the matter of the Resource Management Act 1991 and in the matter of an application by Meridian Energy Limited for resource consents for the Mokihinui Hydro Project.

Jellyman DJ, Todd PR 1982. New Zealand freshwater eels: their biology and fishery. Fisheries Research Division Information Leaflet 11. Ministry of Agriculture and Fisheries, Wellington, New Zealand. 19 p.

Johnson K 2011. Tukituki Catchment Instream Flow Assessments. Prepared for Hawkes Bay Regional Council. EMT 10/36.

Jowett IG 1992. Models of the abundance of large brown trout in New Zealand rivers. North American Journal of Fisheries Management 12: 417-432.

Jowett IG 2004. RHYHABSIM River Hydraulics and Habitat Simulation (Software Manual).

Jowett IG 2012. Instream habitat in the Waiau River and assessment of effects of the Amuri Hydro Project. Prepared for Meridian Energy. 65 p.

Jowett IG, Hayes JW, Duncan MJ 2008. A guide to instream habitat methods and analysis. NIWA Science and Technology Series No. 54.11.

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

Jowett IG, Richardson J, Biggs BJF, Hickey CW, Quinn JM 1991. Microhabitat preferences of benthic invertebrates and the development of generalised *Deleatidium* spp. habitat suitability curves, applied to four New Zealand rivers. New Zealand Journal of Marine & Freshwater Research 25: 187-200.

Jungwirth M, 1998. Bypass channels at weirs as appropriate aids for fish migration in rhithral rivers. Regulated Rivers: Research & Management 12: 483-492.

Keck F, Lepori F 2012. Can we predict nutrient limitation in streams and rivers? Freshwater Biology 57: 1410-1421.

Kessels & Associates Ltd May 2013. Ruataniwha Water Storage Scheme. Terrestrial Ecology Study. Assessment of Ecological Effects.

Kozyniak K 2012. Ruataniwha Basin, Central Hawke's Bay Rainfall Pattern Analysis 1990–2009. Hawkes Bay Regional Council. 15 p.

Larinier M 2002. Biological factors to be taken into account in the design of fishways, the concept of obstructions to upstream migration. Bulletin Français de la Pêche et de la Pisciculture 364: 28-38.

Larinier M, Travade F, Porcher JP 2002. Fishways: biological basis, design criteria and monitoring. Bulletin Français de la Pêche et de la Pisciculture 364 suppl.: 208.

Leathwick J, Julian K, Elith J, Rowe D 2008. Predicting the Distributions of Freshwater Fish Species for all New Zealand's Rivers and Streams. Cawthron Report No. NIWA Client Report: HAM2008-005. 56 p.

Lessard JL, Arscott D, Booker DJ, Hicks MD, Larned ST, Snelder TH, Suren AM in review. Dam design can impede adaptive management of environmental flows: a case study from the Opuha Dam, New Zealand. Environmental Management.

Lewis K 1973. The effect of suspended coal particles on the life forms of the aquatic moss *Eurhynchium riparioides* (Hedw.). I. The gametophyte plant. Freshwater Biology 3: 251-257.

Livingston M, Biggs B, Gifford J 1986. Inventory of New Zealand Lakes, Part II South Island. 193 p.

Lynch B 2013. Papanui Catchment: an environmental characterisation. HBRC Plan No. 4372. Hawkes Bay Regional Council.

Macfarlane Rural Business Ltd. 2012. Ruataniwha Water Storage Project: Review of farm profitability. 66 p. plus appendices.

Maclean G 2011. Assessment of rainbow trout spawning in the upper Makaroro River.

Maclean G 2012. Survey of juvenile rainbow trout in the Upper Tukituki catchment.

McDowall R 2000. The Reed Field Guide to New Zealand Freshwater Fishes. Reed Publishing (NZ) Ltd, Auckland. 224 p.

McDowall RM 2010. New Zealand Freshwater Fishes: an Historical and Ecological Biogeography. Springer, Dordrecht. 449 p.

McDowell RW, Nash D 2012. A review of the cost-effectiveness and suitability of mitigation strategies to prevent phosphorus loss from dairy farms in New Zealand and Australia. Journal of Environmental Quality 41:680–693.

McDowell RW, Larned ST, Houlbroke DJ 2009. Nitrogen and phosphorus in New Zealand streams and rivers: Control and impact of eutrophication and the influence of land management. New Zealand Journal of Marine & Freshwater Research 43: 985-995.

McEwan AJ 2009. Fine scale spatial behaviour of indigenous riverine fish in a small New Zealand stream. Master of Science. Massey University, Palmerston North, New Zealand. pp 95.

MfE 1998. Flow guidelines for instream values. Ministry for the Environment

Mills D 1971. Salmon and trout: a resource, its ecology, conservation and management. Oliver and Boyd, Edinburgh.

Ministry for the Environment 2002. The New Zealand Land Cover Database (LCDB) 2.

Ministry for the Environment and Ministry of Health 2003. Microbial Water Quality Guidelines for Marine and Freshwater Recreational Areas. In Microbial Water Quality Guidelines for Marine and Freshwater Recreational Areas.

Mitchell CP 1989. Swimming performances of native freshwater fishes. New Zealand Journal of Marine and Freshwater Research 23: 181-187.

Mitchell CP 2003. Review of Auckland Regional Council intake structure standards. Report prepared for Auckland Regional Council by Charles Mitchell & Associates. 32 p.

National Institute of Water & Atmospheric Research 2011. New Zealand Freshwater Fish Database. Retrieved 6 May, 2011 from http://www.niwa.co.nz/our-services/databases/freshwater-fish-database

Neitzel DA, Becker CD, Abernathy CS 1985. Proceedings of the Symposium on Small Hydropower and Fisheries, May 1-3, 1985, Aurora, Colorado. F. Olson, R White and RH. Hamre, Editors. American Fisheries Society.

Newsome P, Wilde R, 2008. Land Resource Information System Spatial Data Layers: Data Dictionary. Landcare Research.

NIWA May 2013a. Effects of land use on streams – Phase 2 modelling studies in the Tukituki River, Hawke’s Bay. NIWA Client Report. Prepared for Hawkes Bay Regional Investment Company Ltd. 87 p.

NIWA May 2013b. Effects of land use on nutrients – Phase 2 modelling studies in the Tukituki River, Hawke's Bay. NIWA Client Report. Prepared for Hawkes Bay Regional Investment Company Ltd. 69 p. plus appendices.

NIWA May 2013c.Ruataniwha Plains Water Storage Project. Characterisation of Reservoir Water Quality. Prepared for Hawkes Bay Regional Investment Company Ltd. NIWA Client Report No: HAM2011-136.

Olsen D, Hayes J, Booker D, Barter P 2011a. Benthic Invertebrate Time Series Habitat Simulation Model. Prepared for Ministry of Science and Innovation. Cawthron Report No. 1482.

Olsen D, Maxwell I, Holmes R, Hay J, Allen C, Doehring K, Hayes J, Young R 2011b. Assessment of the Amuri Hydro Project on the Waiau River, North Canterbury. Prepared for Meridian Energy. Cawthron Report No. 2011. 129 p.

Parkyn S, Wilcock R 2004. Impacts of agricultural land use. Pp. 34.1- 34.16. In Harding, J.S.; Mosely, M.P.; Pearson, C; Sorrell, B. (eds.) Freshwaters of New Zealand. New Zealand Hydrological Society and New Zealand Limnological Society.

Plante C, Downing JA 1993. Relationship of salmonine production to lake trophic status and temperature. Canadian Journal of Fisheries and Aquatic Sciences 50: 1324-1328.

Quinn JM, Steele GL, Hickey CW, Vickers ML 1994. Upper thermal tolerances of twelve New Zealand stream invertebrate species. New Zealand Journal of Marine & Freshwater Research 28: 391-397.

Raleigh RF, Zuckerman LD, Nelson PC 1986. Habitat suitability index models and instream flow suitability curves: brown trout, revised. Prepared for U.S. Fish and Wildlife Service.

Reid SM, Anderson PG 1999. Effects of sediment released during open-cut pipeline water crossings. Canadian Water Resources Journal 24: 235-251.

Reiser DW, White RG 1983. Effects of complete redd dewatering on salmonid egg hatching success and development of juveniles. Transactions of the American Fisheries Society 112: 532-540.

Renwick JA 2013. Climate change and its implications for the Ruataniwha Water Storage Scheme. Report prepared for HBRIC. 33 p.

Richardson J, Boubee JAT, West DW 1994. Thermal tolerance and preference of some native New Zealand freshwater fish. No. 4. 399-407 p.

Richardson J, Jowett IG 2002. Effects of sediment on fish communities in East Cape streams, North Island, New Zealand. New Zealand Journal of Marine & Freshwater Research 36: 431-442.

Richardson J, Unwin M, Teirney L 1984. The relative value of Hawke's Bay rivers to New Zealand anglers. Ministry of Agriculture and Fisheries. Fisheries Research Division. 69 p.

Richkus WA, Dixon DA 2003. Review of research and technologies on passage and protection of downstream migrating catadromous eels at hydroelectric facilities. Pages 377-388. In Dixon DA ed. Biology, Management and Protection of Catadromous Eels. American Fisheries Society, Bethesda, Maryland, USA.

Rowe DK, Chisnall BL 1997. Distribution and conservation status of the dwarf inanga *Galaxia gracilis* (Teleostei: Galaxiidae) and endemic fish of Northland dune lakes. Journal of the Royal Society of New Zealand 27: 223-233.

Rowe D, Hicks M, Richardson J 2000. Reduced abundance of banded kokopu (*Galaxias fasciatus*) and other native fish in turbid rivers of the North Island of New Zealand. New Zealand Journal of Marine & Freshwater Research 34: 547-556.

Rutherford K 2012. Modelling the effects of land use on nutrients entering the Tukituki River, Hawke's Bay. NIWA Client Report No: HAM2012-077. Prepared for Hawke's Bay Regional Council. 122 p.

Ryder Consulting Ltd 2011a. Patea Dam Upstream Native Fish Trap & Transfer Protocol. Report prepared for TrustPower.

Ryder Consulting Ltd 2011b. Review of downstream eel migration options – updated to reflect consent conditions. Report prepared for TrustPower.

Sagar PM 1983. Invertebrate recolonisation of previously dry channels in the Rakaia River. New Zealand Journal of Marine and Freshwater Research 17: 377–386.

Santos JM, Ferreira MT, Godinho FN, Bochechas J, 2005. Efficacy of a nature-like bypass channel in a Portuguese lowland river. Journal of Applied Ichthyology 21: 381 -388.

Schubert JP, Vinikour WS, Gartman DK 1987. Comparison of impacts on macroinvertebrates and fish gas pipeline installation by wet-ditching and plowing. In: 4th Symposium on Environmental Concerns in Right-of-Way Management, Indianapolis, Indiana.

Scrimgeour G, Winterbourn M 1989. Effects of floods on epilithon and benthic macroinvertebrate populations in an unstable New Zealand river. Hydrobiologia 171: 33-44.

Shaver E 2009. Hawke's Bay Regional Council. Waterway Design Guidelines.

Shearer KA, Hayes J 2003. Review of the Environmental Effects of Agriculture on Salmonids. Prepared for Cawthron Institute. Cawthron Report. 21 p.

Shearer KA, Stark JD, Hayes JW, Young RG 2003. Relationships between drifting and benthic invertebrates in three New Zealand rivers: implications for drift-feeding fish. New Zealand Journal of Marine & Freshwater Research 37: 809-820.

Shirvell CS, Dungey RG 1983. Microhabitats chosen by brown trout for feeding and spawning in rivers. Transactions of the American Fisheries Society 112: 355-367.

Smith D, Maasdam R 1994. New Zealand's National River Water Quality Network. 1.Design and physico-chemical characterisation. New Zealand Journal of Marine & Freshwater Research 28: 19-35.

Smith DG, McBride GB, Bryers GG, Wisse J, Mink DFJ 1996. Trends in New Zealand's National River Water Quality Network. New Zealand Journal of Marine & Freshwater Research 30: 485-500.

Snelder TH, Biggs BJF, Weatherhead MA 2004. New Zealand river environment classification user guide. Prepared for Ministry for the Environment. 1-145 p.

Stark JD 1993. A survey of macroinvertebrate communities in seventeen South Island lakes. Prepared for Cawthron Institute.

Stark JD, Maxted JR 2007. A biotic index for New Zealand’s soft-bottomed streams. New Zealand Journal of Marine & Freshwater Research 41: 43-61.

Stewart KM 1976. Oxygen Deficits, Clarity, and Eutrophication in some Madison Lakes Internationale Revue der gesamten Hydrobiologie und Hydrographie 61: 563-579.

Stober QJ, Crumley SC, Fast DE, Killebrew ES, Woodin RM, Engman G, Tutmark G 1982. Effects of hydroelectric discharge fluctuation on salmon and steelhead in the Skagit River, Washington. Prepared for Washington State Department of Fisheries and Washington State Department of Game.

Strickland RR, Hayes JW, Boubee J 2002. Project Aqua: environmental study — fish stranding. Prepared for Meridian Energy. 1-41 p.

Theurer FD, Voos KA, Miller WJ 1984. Instream Water Temperature Model. Instream Flow Inf. Pap. 16. U.S. Fish and Wildl. Serv. FWS/OBS-84/15. v.p.

Thompson CS 1987. The climate and weather of Hawkes Bay. New Zealand Meteorological Service, Wellington.

Tonkin & Taylor Ltd 2011a. Ruataniwha Water Storage Project: Technical Feasibility Study — Initial Project Description. 240 p.

Tonkin & Taylor Ltd 2011b. Lake Coleridge Project: Hydrology Assessment. Trustpower Ltd. T&T Ref: 27234.

Tonkin & Taylor Ltd May 2013a. Ruataniwha Plains Water Storage Scheme: Project Description. Prepared for Hawke's Bay Regional Investment Company Ltd. 106 p. + appendices.

Tonkin & Taylor Ltd May 2013b. Ruataniwha Water Storage Scheme Sedimentation Assessment. Prepared for Hawke's Bay Regional Investment Company Ltd. 80 p. + appendices.

Tsui PTP, McCart PJ 1981. Effects of stream-crossing by a pipeline on the benthic macroinvertebrate communities of a small mountain stream. Hydrobiologia 79: 271-276.

Unwin M 2009. Angler usage of lake and river fisheries managed by Fish and Game New Zealand: results from the 2007/08 National Angling Survey. Prepared for Fish and Game New Zealand. NIWA client report CHC2009-046.

Uytendaal A, Ausseil O 2013. Tukituki Catchment: Recommended Water Quality Limits and Targets for the Tukituki Plan Change 6. Resource Management Group Technical Report. EMT 13/04. HBRC Plan No. 4463. Hawke's Bay Regional Council.

Watene EM, Boubée JAT 2005. Selective opening of hydroelectric dam spillway gates for downstream migrant eels in New Zealand. Fisheries Management and Ecology 12: 69-75.

Watene EM, Boubée JAT, Haro A 2003. Downstream movement of mature eels in a hydroelectric reservoir in New Zealand. Pages 295-305. In Dixon DA ed. Biology, Management and Protection of Catadromous Eels. American Fisheries Society, Bethesda, Maryland, USA.

Waters BF 1976. A method for evaluating the effects of different streamflows on salmonid habitat. In Proceedings of the Symposium and Specialty Conference on Instream Flow Needs. American Fisheries Society, Bathesda, MD. USA. pp 254-266.

Wetzel RG 2001. Limnology: Lake and River Ecosystems. Acedemic Press.

Wilcock R, Biggs B, Death R, Hickey C, Larned S, Quinn J 2007. Limiting nutrients for controlling undesirable periphyton growth. Prepared for Horizons Regional Council. NIWA Client Report HAM2007-006. 38 p.

Williams G 1985. Upper Tukituki Catchment Control Scheme–Investigations and proposed scheme. Prepared for Hawkes Bay Catchment Board.

Wood PJ, Armitage PD 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21: 203-217.

Wood SA, Young RG 2012. Review of Benthic Cyanobacteria Monitoring Programme 2012. Prepared for Horizon Regional Council. Cawthron Report No. 2217. 30 p. plus appendices.

Young P, Chech J, Thompson L 2011. Hydropower-related pulsed-flow impacts on stream fishes: a brief overview, conceptual model, knowledge gaps, and research needs. Reviews in fish biology and fisheries 21: 713-731.

Young R, Harding J, Smart G, Mosley P, Pearson C, Sorrell B 2004. Impacts of hydro-dams, irrigation schemes and river control works. In: ed. Freshwaters of New Zealand. New Zealand Hydrological Society, Christchurch. Pp 37.1-37.16.

Young RG, Wilkinson J, Hay J, Hayes JW 2010. Movement and Mortality of Adult Brown Trout in the Motupiko River, New Zealand: Effects of Water Temperature, Flow, and Flooding. Transactions of the American Fisheries Society 139: 137-146.

Young RG, Harding JS, Strickland RR, Shearer KA, Hayes JW 2000. Cobb Power Scheme resource consent renewal 2000/2001: Water Quality, Aquatic Habitat and Fisheries. Prepared for TransAlta New Zealand Ltd. Cawthron Report No. 554. 131 p plus appendices.

Young RG, Allen C, Shearer KA, Doehring K, Berkett N, Holmes R, Hay J 2012. Ruataniwha Water Storage Project – Aquatic Ecology Assessment of Effects. Prepared for Hawke’s Bay Regional Council. Cawthron Report No. 2086. 170 p. plus appendices.