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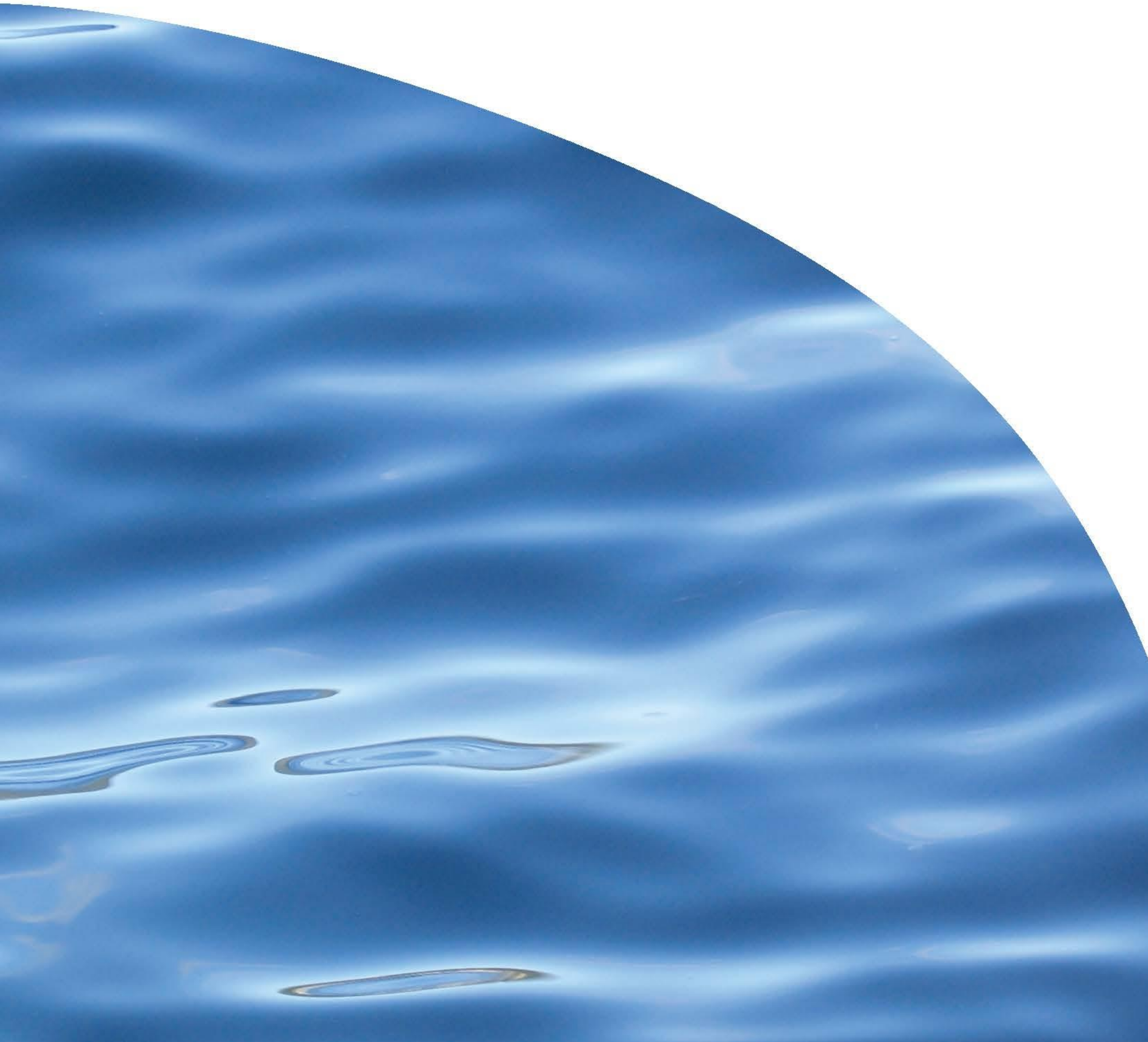
MAITAI RIVER MUNICIPAL SUPPLY AQUATIC ECOLOGY – SUMMARY OF ENVIRONMENTAL EFFECTS—UPDATED REPORT



MAITAI RIVER MUNICIPAL SUPPLY AQUATIC ECOLOGY – SUMMARY OF ENVIRONMENTAL EFFECTS—UPDATED REPORT

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EXECUTIVE SUMMARY

Nelson City Council (NCC) has operated a municipal water supply scheme on the Maitai River since 1989. The Maitai municipal supply infrastructure consists of a 30 m high dam that obstructs the North Branch of the Maitai River immediately upstream of its confluence with the Maitai River South Branch. A reservoir of approximately 32 hectares (at full capacity) has a maximum depth of 29 m and a total volume of 4.3 Mm^3. Water from the Maitai Reservoir is fed to the downstream Maitai River via a valve tower that can feed water from multiple depths (6 m, 15 m, 24 m at full reservoir capacity) through a backfeed pipeline to the Maitai South Branch weir, with an associated river inlet water-take at the weir. Water can also enter the Maitai River via a dam spillway which operates when inflows exceed the operational water take. This typically spills water over most of the year except during dry summer periods.

Operation of the system varies depending on river flow conditions; in brief, when the Maitai River is clear, water for Nelson City is abstracted at an intake on the South Branch. This water is replaced by a discharge from the Maitai Reservoir backfeed. When the river is turbid, such as in flood conditions, the Nelson City supply is fed directly from the reservoir. In this manner, Nelson City is supplied with the best quality water available at any given time.

Nelson City Council hold six water consents relating to the operation of the Maitai Dam, which are due to expire in 2017 (Appendix 1). These water consents provide for the abstraction of water from the Maitai South Branch for urban water supply, and the discharge of water from the Maitai Reservoir into the Maitai River.

Summary of existing operational effects on the environment

Maitai Reservoir

The Maitai Reservoir can be characterised as a low productivity system. However, because the reservoir is deep it thermally stratifies[1] between October and April, and this contributes to deoxygenation in its bottom waters. Anoxic bottom waters, which typically persist between February and April, render the reservoir susceptible to internal recycling of trace metals and dissolved nutrients (phosphorus and nitrogen) from reservoir sediments. High dissolved iron and manganese concentrations in bottom waters were evident in monitoring data, and concentration ranges for dissolved iron could pose a toxicity risk to organisms within and downstream of the reservoir. Nutrient concentrations were moderate. The prevalence of high dissolved metal concentrations is likely to continue without management intervention. Anoxic conditions that persist over the summer stratified period result in the breach of several water quality standards cited in the Nelson Resource Management Plan (NRMP), including dissolved oxygen saturation, trace metal toxicants, and mean daily temperature.

[1] Water heats up at the surface and stays cold at the bottom. This stops any mixing of the temperature layers.

Water levels in the reservoir are operated over a reasonably narrow range and are anticipated to maintain healthy ecological conditions in the lake-edge community, which extends to around 6 m depth.

Biota in the reservoir such as phytoplankton[2], zooplankton[3], macrophytes[4] and macroinvertebrates[5] are characteristic of low productivity systems. Fish populations consist of four species: common bullies, upland bullies, longfin eels, and brown trout. Anoxic conditions in the bottom waters limit fish to the shallow portions of the reservoir. The heavily-skewed size class structure of longfin eels towards large (> 600 mm) adult individuals indicates that limited recruitment is occurring from juveniles migrating upstream to the Maitai Reservoir.

Maitai river flows

The effects of the construction of the Maitai Reservoir and associated operation of the reservoir were examined in relation to their effects on flows in the downstream Maitai River by using long-term records from flow recorders at the Maitai Forks and Maitai Avon Terrace, as well as previously-derived flow regression functions.

Augmentation of summer flows by the reservoir substantially decreased the duration of low flows caused by abstraction. Abstraction of Maitai S. Branch water for the municipal supply scheme prior to the dam being constructed reduced the 95 percentile low flow by 52% compared with naturalised flows. Low flows since the Maitai Reservoir has been in operation have improved this reduction to only a 9% decrease relative to naturalised flows.

The Maitai Reservoir has a moderate effect on low to median flows, with the median and 7-day mean annual low flow (7-day MALF) approximately 18% and 12% lower at the Forks recorder site than the naturalised flow regime. Further downstream, the relative change in median and 7-day MALF at Avon Terrace was smaller at approximately 8% and 10%, respectively. Seasonal analyses of mean monthly median flow at Maitai Forks showed the greatest reductions in flows from the reservoir occur over summer.

The Maitai Reservoir is thought to have a small impact on flow variability, with the frequency of larger flow events (three or more times the median flow) for the river at Forks in the order of one fewer event per year.

While there is no significant long term historical trend in rainfall for the Nelson–Tasman region, current climate change projections estimate an increase of 5–6% by 2090, with more frequent periods of very heavy rainfall. Variability due to the influence of the El Niño-Southern Oscillation and the Inter-decadal Pacific Oscillation are predicted, on average, to fluctuate rainfall by up to 20% and 15%, respectively.

[2] Tiny plants suspended in the water
[3] Tiny animals suspended in the water
[4] Aquatic plants
[5] Aquatic insects and molluscs

Flow-related fish habitat

Changes to the flow regime have the potential to reduce habitat available for instream life during periods of moderate to low flow. This has been assessed in the Maitai River using in-stream physical habitat modelling (Hay & Allen 2014). Reduction in flow below the natural MALF is likely to lead to a reduction in the amount and average quality of habitat for most species of native fish and brown trout recorded from the Maitai River. Habitat for invertebrates, which these fish feed on, is also reduced by flow reduction. Prospective minimum flows were derived from the habitat modelling results based on maintaining habitat of 'critical value', with the rationale that by providing sufficient flow to sustain the most flow-sensitive species, other significant values will also be sustained.

In the Maitai, torrentfish habitat is the most flow-demanding, with minimum flows of 228-235 L/s (at the Maitai Forks), depending on the level of habitat retention applied. Torrentfish is a fast water specialist, so its habitat is sensitive to flow. Torrentfish is also listed as 'Declining' in the DOC threat classification, and the fish was traditionally caught by Māori and is still considered taonga by some. These characteristics make torrentfish an obvious candidate to act as a critical value for minimum flow setting.

These prospective minimum flows based on torrentfish habitat retention are higher than the existing summertime minimum flow[6] at the Maitai Forks (175 L/s[7]). However, in practice abstraction is managed so that flow is usually above this cited minimum. For this reason the measured 7-day MALF at the Maitai Forks is 220 L/s, and is quite close to the recommended minimum flows for torrentfish.

River water quality

Temperature— Water temperature affects all aspects of freshwater ecosystems, from its influence on the solubility of oxygen through to regulating metabolic rates and growth of most aquatic organisms. Several consent conditions are in place to mitigate local water temperature changes potentially arising from the discharge of water from the Maitai Reservoir into the Maitai South Branch via the backfeed. Monitoring data show that these temperature consent conditions are complied with most of the time. Nonetheless, river water temperature also tends to increase immediately downstream of the spillway discharge pool, and during summer can be in a range likely to induce thermal stress for some sensitive aquatic organisms and in excess of mean daily temperatures standards cited in the NRMP. However, the potential influence of the reservoir on water temperature is likely to attenuate rapidly, and is unlikely to have much influence on water temperature in the mid to lower river.

Dissolved oxygen (DO) levels greater than 6 mg/L (or 80% saturation) are considered sufficient to support sensitive fish or macroinvertebrate communities. During summer, thermal stratification in the reservoir can result in severely reduced oxygen levels in its bottom waters. Water from the lake bottom is commonly discharged into the Maitai River via

[6] As was the ~300 L/s minimum flow recommended by Hayes (2003).

[7] Stipulated by Consent No. RM025151/2 as the summertime minimum flow at the Maitai Forks recorder site (1 November to 30 April).

the backfeed. However DO levels 100 m below the backfeed discharge point have, to date, always exceeded 6 mg/L, even during summer, indicating rapid oxygenation in the river downstream of the backfeed.

The Maitai Reservoir is situated in a geological region that contains naturally high levels of trace metals such as nickel, chromium, iron and manganese. In the absence of the reservoir, the rain events that mobilise these metals would also flush them out to sea in floods, but the reservoir has the effect of trapping, storing and slowly releasing these metals into the Maitai River in a more toxic dissolved form. High concentrations of these heavy metals can be toxic to aquatic life. During summer, the reservoir sometimes discharges water high in iron and manganese, which oxidise to form precipitates when this water is released into the South Branch. Manganese and iron concentrations have generally been at or below consented limits, and very rarely exceed values cited in the NRMP for trace metal toxicants. However, dissolved iron levels can in some cases exceed concentrations identified for protection of aquatic life. The influence of other trace metals (nickel, chromium) has also been elevated below the backfeed discharge, although there is currently no monitoring of these elements.

Turbidity (a measure of water clarity) often increases in the Maitai River below the backfeed discharge, mostly related to dissolved materials in the reservoir discharge precipitating when entering an oxygen–rich environment. High turbidity can affect ecosystem functioning (e.g. poor visibility for fish). Current consent requirements demand that there is to be a change of less than 10 turbidity units (NTU) at a site 100 m below the backfeed discharge, which has always been met in consent monitoring. Only occasionally do increases in turbidity from the backfeed and spillway result in turbidity breaching NRMP standards for the Maitai South Branch and mainstem of 3 NTU.

Nutrients and periphyton

Nutrients (nitrogen and phosphorus) are potentially limiting elements for the growth of river periphyton. Monitoring of nutrients in the Maitai River downstream of the reservoir backfeed is not required under current consent conditions. However, Allen et al. (2014) found evidence of elevated nutrient concentrations downstream of the reservoir backfeed. This is mostly related to higher nitrogen concentrations in the North Branch and the reservoir, with the reservoir acting as a storage pool for nutrients that are then released more gradually to the river. Elevated nitrogen from the backfeed could contribute to the greater coverage by periphyton. This is mostly filamentous algae, and not the potentially-toxic cyanobacteria, *Phormidium* that affects the lower reaches of the Maitai River. Increased nuisance periphyton cover downstream of the backfeed frequently results in regular breaches of filamentous green algae cover above standards cited in the NRMP (i.e., 30% cover maximum).

Macroinvertebrates

Aquatic macroinvertebrates are large (> 0.5 mm in length) invertebrates such as insects, snails and worms that live in the riverbed. Macroinvertebrates play an important role in maintaining periphyton communities (through grazing), and as a food source for fish and some birds species. Macroinvertebrates are commonly used in assessments of ecological health of rivers.

Based on a range of macroinvertebrate community indices commonly used for assessing water quality, biomonitoring upstream and downstream of the backfeed indicates that the reservoir appears to be having a negative impact on stream biota immediately downstream of the backfeed discharge. This included downstream declining trends in the Macroinvertebrate Community Index (MCI); Semi-Quantitative Macroinvertebrate Community Index (SQMCI); and the proportion of Ephemeroptera, Plecoptera and Trichoptera (%EPT abundance) over the course of 18 years of consent monitoring. These changes are most likely associated with changes in the periphyton communities, which in turn are influenced by nutrients and possibly trace metals present in the discharge of anoxic water from the bottom of the reservoir, especially during mid to late summer. Indices downstream of the backfeed discharge were below water quality standards identified for Class B waters in the NRMP. On the basis of the continued declining trend in macroinvertebrate community health downstream the backfeed and its breaching of Class B standards this effect is considered to be more than minor.

Fish communities

Fourteen species of native fish have been identified in the Maitai River as well as the introduced brown trout. Of these fish, eight have been recorded in the upper catchment around the reservoir. With the exception of longfin eels, data are deficient to undertake a trend analysis on the native fish populations.

Prior to the 1990s the mid-lower Maitai River is reported to have supported a popular and productive trout fishery. Currently the river is not a popular fishery. Electric fishing and drift dive surveys indicate a sustained decline in the trout population over the past two decades. At present it is unclear as to the reasons for the population decline.

The popular mixed-species whitebait fishery in the tidal reach of the Maitai River is likely to be predominantly based on juvenile īnanga which are a low-land river species. Therefore, there is little potential for the reservoir (in the upper catchment) to influence this value. However, the NCC initiative to improve access for kōaro to habitat upstream of the reservoir may have a modest positive impact on the fishery.

Tuna (eels) are valued for biodiversity reasons as well the customary and recreational fisheries they provide. However, there is little available information on the use or productivity of the tuna fishery in the Maitai River. Based on electric fishing records at one site, juvenile eel numbers appear to have been in decline since 2002. This decline occurs in parallel with a decline in trout numbers. At present it is unclear as to the reasons for the apparent decline in the juvenile eel population.

Fish passage

The Maitai Dam and South Branch weir are both partial barriers to fish passage, particularly for fish moving upstream. A large proportion of New Zealand's native fish species require access to and from the sea to complete their life cycles. The location of the Maitai Dam and South Branch weir in the upper catchment means they are likely an impediment only to relatively strong migrants, such as redfin bully, longfin eel and kōaro and trout, which penetrate that far upstream from the coast.

With the exception of redfin bully, all of these species have been recorded upstream of both the Maitai Reservoir and the South Branch weir, although the population densities above these structures are probably reduced to some extent relative to what may have existed naturally.

Nelson City Council has recently undertaken remedial work to improve fish passage opportunities at both the Maitai Dam spillway and the South Branch weir (Hay et al*.* 2015). These alterations have mainly focused on assisting native species with a relatively strong ability to climb obstacles, such as longfin eel and kōaro. Monitoring following the remedial work indicates that eel elvers[8] are successfully climbing these structures. However, exposure to predation remains an issue for these fish as they are concentrated to predictable points to climb these structures.

Options to mitigate effects of operations on the environment

A range of options were considered for mitigating the effects of the operations of the Maitai Municipal water supply on the Maitai River. Five key mitigation options were considered to be most relevant for minimising effects of the scheme's operations.

1. **Backfeed management:** Management of the reservoir outflows through implementing a 50% DO minimum for backfeed waters could also act to reduce the output of dissolved iron and manganese to the Maitai River. This could be considered as an alternative strategy to aeration, but could result in slight warming of the river during late summer, although this is thought to be minor. However some consideration of consent temperature conditions would have to be made for this option although it is anticipated temperature effects of operating the backfeed off upper valve levels would be minor.

2. **Reservoir aeration:** Reversal of issues associated with deoxygenation (e.g. dissolved metals) would require intervention by increasing DO in the Maitai Reservoir bottom over the summer stratified period. Typically this is done through hypolimnetic aeration or aeration mixing. There are documented cases for reservoirs in New Zealand and internationally which would provide useful background knowledge. Aeration mixing would improve both the water quality for water backfed to the Maitai River, and result in a catchment-wide restoration outcome. Nelson City Council has funded a detailed

[8] juvenile eels

investigation into the technical design and costs of such a system, with two viable options identified.

3. **River flows:** Consideration is suggested around increasing the minimum flow in the Maitai River below the dam, to maintain in-stream values closer to natural levels. Increasing the minimum flow to about the magnitude of the current MALF would substantially increase the level of habitat retention for torrentfish (to 59% of naturalised MALF) and other fish species. Alternatively, the existing practise of maintaining flows above the minimum flow level as much as possible could be continued and perhaps formalised in some way, particularly during years in which water storage in the reservoir appears to be available for this use.

   The feasibility of providing additional flushing flow releases from the Maitai Dam during prolonged periods of low flow, to flush fine sediment and periphyton[9] accumulations from the riverbed was considered. Flow releases of up to 3.5 m^3/s from the Maitai Reservoir have the potential to increase the flushing effectiveness in the upper river by topping up floods in the 1.5–3 m^3/s range; these events occur regularly in most summers. However, they are likely to be less effective in the lower reaches because of the infrequency of natural flow events large enough (> 14 m^3/s) to flush the river. Therefore it is unlikely that flow releases from the dam will have much impact on cyanobacterial blooms that occur predominantly in the mid-lower river. Consideration would also need to be made around water-use efficiency, as any water used for flushing-flow releases decreases the amount of stored water in the Maitai Reservoir that are available to augment minimum flows.

4. **Fish passage:** Improvement in fish passage for eels and kōaro over the weir and spillway has partially been completed through installing a spat rope over the length of the spillway face, and a pump to keep the face wetted during periods when the reservoir levels are below the spillway crest. This appears to be facilitating better passage, albeit only low numbers of elvers have been observed to date. These improvements could result in greater fish abundances in the reservoir and North Branch tributary. The backfeed weir modifications also appear to facilitate enabling eels to pass the structure, with some minor adjustments needed to minimise fish becoming stranded near the backfeed attractant flow. Given the relatively low numbers observed successfully ascending the spillway, we recommend manual trap and transfer operations be continued to move juvenile fish past the dam. This should also facilitate movement of a wider range of species (kōaro, redfin bullies) past the dam.

5. **Fishery enhancement**: The Maitai River brown trout population has declined over the past two decades and no longer supports a productive fishery. It is unclear what (if any) impact the Maitai Reservoir has had on the fishery - although it is possible that changes in invertebrate communities, observed for some distance below the backfeed discharge, have reduced the quality of the invertebrate food base for trout. The biannual release of 100 ‘takeable’ sized brown trout (i.e. > 500 g) in the mid-catchment could adequately

[9] Slime and algae

mitigate for the declining value of the Maitai River fishery. The increased predation pressure on native fish populations, as a result of hatchery releases in the mid-catchment, could be offset by trout removal in the Maitai Reservoir and North Branch upstream of the dam which is impassable by trout. This action would also support native fish passage improvement initiatives in the Maitai North Branch.

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GLOSSARY

Term	Definition
Aeration	The addition of atmospheric air to a waterbody, often for the purpose of increasing the dissolved oxygen content of the waterbody
Allochthonous	Material that is imported into an ecosystem from somewhere else.
Autochthonous	Material originating within an ecosystem.
Anoxic	Sea water, fresh water or groundwater that is devoid of dissolved oxygen.
Deoxygenation	Reduction in dissolved oxygen content of water over saturated conditions
Destratification	The act of mixing a waterbody that is stratified to allow complete mixing of the waterbody. This is usually done to allow the waterbody to aerate by enabling deep waters to aerate at the surface of the waterbody.
Epilimnion or epilimnetic	The top-most layer in a thermally stratified lake, occurring above the deeper hypolimnion. It is warmer and typically has a higher pH and higher dissolved oxygen concentration than the hypolimnion.
Flushing flow	Flows of sufficient magnitude that they mobilise fine sediment layers on the river bed and often scour attached periphyton from large cobbles and boulders.
Hypolimnion or hypolimnetic	The lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant.
Macroinvertebrate	The invertebrate community living on the bottom of the waterbody (river or lake) that are large enough to be retained in sampling apparatus, usually with a sample mesh-size of 0.5 mm.
Macrophyte	Aquatic plants that grow on the bottom of waterbodies, typically attached to the bed with rooted or rhizomes, and large enough to be seen by visual assessment.
MALF	Mean annual low flow, typically expressed as the lowest flows per annum over a seven-day measurement interval (7-d MALF)
Metalimnion	See Thermocline
Periphyton	The microbial community growing on the river-bed, typically comprised of algae, bacteria, and fungi.
Oxic	Containing oxygen; with oxygen; oxygenated.
Phytoplankton	Microalgae and bacteria that grow suspended in the water column of lakes and large slow-moving rivers
Stratification	The presence of a density gradient (usually associated with temperature) over depth in the water column that acts to prevent mixing between depth layers (see Thermocline)
Thermocline	Thermocline (sometimes metalimnion in lakes) is a thin but distinct layer in a large body of fluid (e.g. water, such as an ocean or lake, or air, such as an atmosphere) in which temperature changes more rapidly with depth than it does in the layers above or below.
Trace Metals	The occurrence of (and often its associated concentration) heavy metals elements that are rare in the environment (e.g., copper, iron, cadmium, zinc) in the waterbody or associated bed sediments
Zooplankton	Small animals that grow suspended in the water column of lakes and slow moving rivers, typically comprised of small crustaceans, amphipods and rotifers.

Term	**Definition**
Trophic classifications	**Oligotrophic** An oligotrophic lake is a lake with low primary productivity, the result of low nutrient content. These lakes have low algal production, and consequently, often have very clear waters, with high drinking-water quality. The bottom waters of such lakes typically have ample oxygen. Therefore, such lakes often support many fish species, like lake trout, which require cold, well-oxygenated waters. The oxygen content is likely to be higher in deep lakes, owing to their larger hypolimnetic volume. **Mesotrophic** Mesotrophic lakes are lakes with an intermediate level of productivity. These lakes are commonly clear water lakes and ponds with beds of submerged aquatic plants and medium levels of nutrients. **Eutrophic** A eutrophic body of water, commonly a lake or pond, has high biological productivity. Due to excessive nutrients, especially nitrogen and phosphorus, these water bodies are able to support an abundance of aquatic plants. Usually the water body will be dominated either by aquatic plants or algae. When aquatic plants dominate, the water tends to be clear; when algae dominate, the water tends to be darker. The algae engage in photosynthesis that supplies oxygen to the fish and biota that inhabit these waters. Occasionally an excessive algae bloom will occur and can ultimately result in fish death due to respiration by algae and bottom-living bacteria. The process of eutrophication can occur naturally and by human impact on the environment. **Hypereutrophic** Hypereutrophic lakes are very nutrient-rich lakes characterised by frequent and severe nuisance algal blooms and low transparency. Hypereutrophic lakes have a visibility depth of less than 1 m; they have greater than 40 micrograms/litre total chlorophyll and greater than 100 micrograms/litre phosphorus. The excessive algal blooms can also significantly reduce oxygen levels and prevent life from functioning at lower depths, creating dead zones beneath the surface. **Dystrophic** Dystrophic lakes typically contain brown-stained water due to high concentrations of humic materials. They are often, but not always, strongly acidic and of relatively low productivity.

1. INTRODUCTION

1.1. Background

Nelson City Council (NCC) operates a municipal water supply on the Maitai River, which was commissioned in 1989. Stark and Hayes (1996) describe the system in detail. In brief, when the Maitai River is clear, water for Nelson City is abstracted at an intake on the South Branch. This water is replaced by a discharge from the Maitai Reservoir (referred to as the 'backfeed') which enters the South Branch at the foot of the intake weir. When the river is turbid, such as in flood conditions, the Nelson City supply is fed directly from the North Branch reservoir. In this manner, Nelson City is supplied with the best quality water available at any given time.

Nelson City Council hold six water consents relating to the operation of the Maitai Reservoir and associated infrastructure, which are due to expire in 2017 (Appendix 1). These water consents provide for the abstraction of water from the Maitai South Branch for urban water supply, and the discharge of water from the North Branch Reservoir into the Maitai River.

1.1.1. Description of the Maitai Dam Scheme

The Maitai municipal supply infrastructure consists of a 30 m high, sloped earthworks dam that obstructs the North Branch of the Maitai River immediately upstream of its confluence with the Maitai River South Branch (2540845E, 5990420N) (Figure 1). This creates the Maitai Reservoir which approximately 32 hectares in area (at full capacity), has a maximum depth of 30 m, and a total volume of 4.3 Mm^3 (Payne 2007). Water from the Maitai Reservoir is fed to the downstream Maitai River in three ways:

1. via a 130 m long sloping spillway which overflows surface waters of the reservoir when water levels exceed the spillway height of 173.75 metres above mean sea level (masl).
2. via a backfeed line that can feed reservoir water at a maximum rate of 400 L/s just downstream of the Maitai River South Branch backfeed weir (NZTM coordinates E1630699 N5427956)
3. a cone valve located at the base of the dam that feeds water to a channel adjacent to the dam spillway at a maximum rate of 3500 L/s.

Sourcing of water to the backfeed occurs via a valve tower located near the dam wall (2541055E, 5990235N), which has three valve inlets at reservoir depths of 6 m (inlet 1), 15 m (inlet 2), and 26 m (inlet 3) when the reservoir is at its full capacity. An additional scour valve inlet is located on the concrete skirting of the valve tower base at approximately 27 m water depth. The placement of valves at these varying depths allows for selective off-takes of water from the reservoir to the backfeed in order to meet the backfeed discharge temperature consent requirements, as well as for sourcing of water from various levels of the reservoir for the water treatment plant.

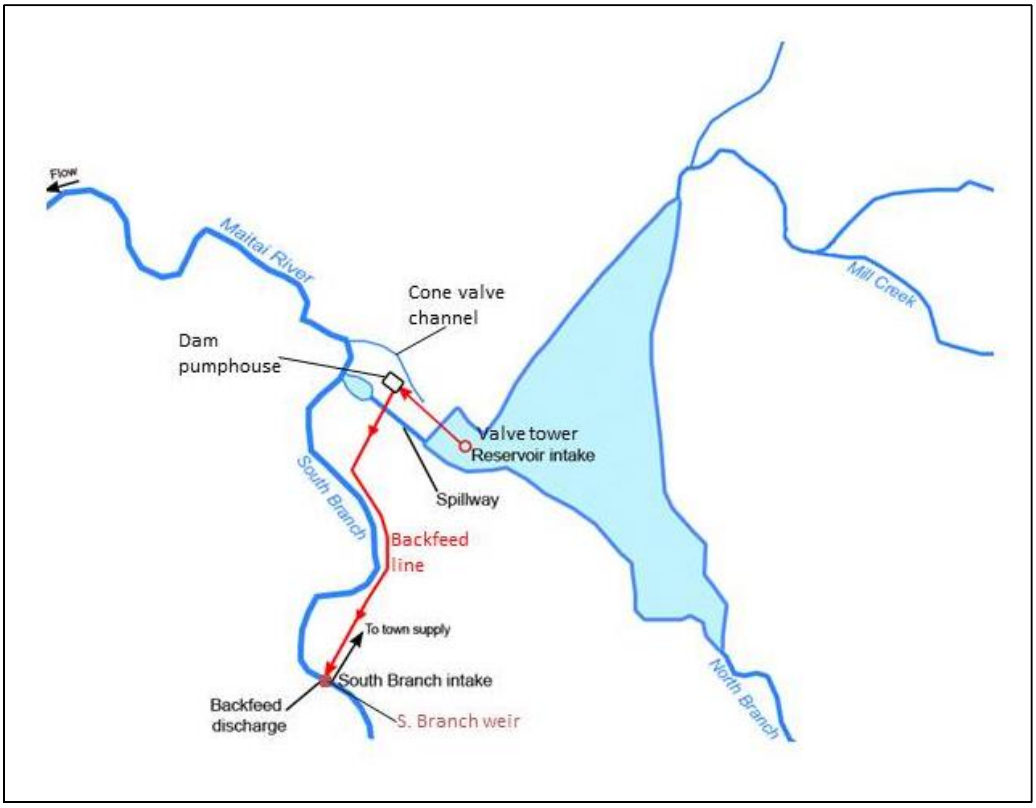


Figure 1. Map of the Maitai municipal water supply scheme.

1.1.2. Operation of the Maitai Water Supply scheme

Most of the time Nelson City is supplied with water directly from the South Branch of the Maitai River, abstracted at the intake weir. This is termed the 'South Branch Supply'. This water is replaced by water from the reservoir (the 'Backfeed') discharged at a maximum rate of 400 L/s at the foot of the weir. On occasions when the South Branch is too dirty to feed the city supply, reservoir water ('Dam Supply') is fed into the water supply system[10].

Compliance with flow and temperature requirements is achieved using a computerised warning and alarm system. The computer compares the water temperature of the South Branch upstream of the intake with the temperature recorded by a sensor in a manhole at Site B (1.1 km downstream of the intake). A warning (including a record of the backfeed, South Branch and Site B temperatures) is

[10] Note that water for the Nelson Municipal Supply is also taken from the Roding River supply in addition to the Maitai River.

printed on the log if the difference reaches or exceeds 2.5°C. An alarm sounds, at the dam and at the Caretaker's residence. The Maitai Caretaker responds to the warnings or alarms and manipulates the flows to ensure compliance. This normally can be achieved by changing the backfeed from inlet 3 (at around 26 m depth in the lake), to either inlet 2 (at 15 m) or inlet 1 (at 6 m) depending on the temperature of the lake water at the time.

Minimum flow conditions on Water Right 820540 apply at the Forks, which is the confluence of the South Branch and the old North Branch (now the reservoir). Condition 5 on this right reads:

> The following minimum flows shall be maintained in the river immediately below the forks:-
> (i) From 1 May to 31 October, 300 L/s
> (ii) From 1 November to 30 April, 175 L/s

At a hearing held in September 1992, following a severe drought in winter that year, the winter flow condition (i.e. (i) above) was amended to:-

> From 1 May to 31 October the flow in the South Branch shall be measured at the existing water level recording station:
>
> a. When the South Branch mean daily flow exceeds 140 L/s- the minimum flow at the forks shall be 300 L/s.
> b. When the South Branch mean daily flow is less than or equal to 140 L/s the minimum flow at the forks shall be 225 L/s. This minimum flow shall remain effective until the South Branch mean daily flow exceeds 140 L/s and the water level in the Maitai Reservoir exceeds the level shown on the graph below. [N.B. Graph not shown in this report.]
> c. When the South Branch mean daily flow is less than or equal to 130 L/s the minimum flow at the forks shall be 190 L/s. This minimum flow shall only remain effective until the South Branch mean daily flow exceeds 130 L/s.

The above amended flow conditions were subject to a monitoring condition which stated that ecological monitoring be undertaken by Cawthron Institute within the period 31 August 1992 to 31 August 1994. This monitoring was never completed because it required winter drought conditions similar to those found in 1992, and these have not occurred since that time.

Normally the South Branch supply is abstracted from the river at the intake via valve CV4, which is linked to the valve controlling the backfeed (CV5) so that the water abstracted from the river is replaced by the same volume of lake water to maintain the flow in the river at its natural level. Sometimes, to achieve compliance with minimum flows at the forks, the backfeed needs to discharge more water into the river than is abstracted. This is achieved manually by adjusting the offset on valve CV5. The flow at the forks includes any spillway discharge from the reservoir.

In addition to temperature and flow warnings and alarms, the computerised log records summaries of total daily flows (‘Dam Supply’, South Branch’, ‘City Supply’, ‘Backfeed’) and the Reservoir level (masl).

1.1.3. Compliance with water consent flow, temperature and water quality requirements

A computerised monitoring system records the following variables once every 15 minutes (i.e. 96 times in 24 hours):

- date
- time
- South Branch supply flow (L/s)
- backfeed flow (L/s)
- dam supply flow (L/s)
- South Branch temperature (°C)
- backfeed temperature (°C)
- Forks weir height (mm)
- lake level (masl).

Dissolved oxygen (DO), iron (Fe) and manganese (Mn) concentrations and turbidity have been measured in the South Branch 100 m downstream of the intake weir since 1987 (turbidity and DO) and 1989 (Fe and Mn). Sampling was carried out at the ‘Maitai River at Forks’ site prior to March 1998, but since then has been carried out at Site B. Routine monthly monitoring of water temperature, DO, Fe, Mn and turbidity is also carried out in the Maitai River above the intake and in the Maitai Reservoir by NCC.

Annual monitoring of reservoir source-water for more than a hundred nutrients, organic pesticide, and trace metal contaminants is conducted for the purpose of assessing the compliance of the Maitai Reservoir and South Branch water sources against national standards for municipal drinking water supply criteria (Appendix 2). Whilst this information is not typically used for ecological assessment purposes, it provides supporting information that the Maitai River and South Branch tributary have excellent water quality, with very low concentrations (mostly undetectable) of dissolved contaminants in water.

1.1.4. Bi-annual ecological monitoring of the receiving environment

Biological monitoring of the Maitai River is required by NCC's Water Consent 831560 for the Maitai Reservoir. A programme of 6-monthly monitoring was established after an intensive one year study undertaken during 1989 (Stark 1990), to assess the potential impact of an alteration to the temperature conditions of the Consent, and to assess long-term impacts of the Maitai Reservoir water supply scheme.

The monitoring (comprising electric fishing, duplicate quantitative macroinvertebrate sampling and field measurement of pH, temperature, DO and conductivity) is normally undertaken twice per year (May and November) at Site B, and reporting is provided annually. Sampling methods follow those given by Stark (1990).

1.1.5. Recent additional studies

In recent years NCC has commissioned several projects to fill information gaps highlighted by results from monitoring and relevant to consent renewal including:

- a review on Mn toxicity (Holmes 2010)
- options for improving water quality in the Maitai Reservoir and Maitai River South Branch (Holmes & Kelly 2012)
- surveys of habitats and aquatic biota in the Maitai Reservoir and North Branch of the Maitai River (Kelly & Shearer 2013)
- establishing the longitudinal extent of the Maitai Reservoir backfeed influence on the Maitai River ecology (Allen et al*.* 2013, 2014)
- an investigation into water and sediment quality in the reservoir (Kelly 2014)
- fish passage remediation options for the Maitai Dam and South Branch Weir (Doehring & Hay 2014)
- a review of minimum flows and flushing flow releases from the Maitai Dam for controlling periphyton and fine sediment accumulation in the Maitai River (Hay& Allen2014).
- an investigation of the fish passage remediation efficacy for the Maitai South Branch weir (Hay et al. 2015)
- an investigation modifying backfeed operations to minimise the discharge of anoxic water and implications for water temperature in the Maitai River South Branch (Hay & Allen 2015).
- options for aeration or destratification in the Maitai Reservoir to rectify bottom water anoxia (Kelly 2015)
- an investigation into the fish passage remediation efficacy for the Maitai Dam spillway (Hay, ongoing)
- monitoring of Maitai River ecological health in relation to modified backfeed operations (Kelly, ongoing).
- Maitai trout population drift dive assessment (Holmes; conducted in 2016).

Findings from these further investigations is summarised or re-presented in the respective sections of this assessment of ecological effects (AEE) for the operations of the Maitai Dam.

1.2. Purpose and structure of report

The purpose of this report is twofold.

The first purpose (covered under Section 2 of the report) is to provide a summary of the existing ecological information surrounding the operation of the Maitai Reservoir to underpin an aquatic assessment of environmental effects (AEE) to support NCCs re-consenting application. We build on a comprehensive review of the state of the Maitai River undertaken by Crowe et al. (2004), by updating and integrating information that has been collected since that report was commissioned, including information highlighted in the previous section (Section 1.1.5).

The second purpose (covered under Section 3 of the report) is to provide consideration of scenarios of proposed Maitai Reservoir operations and associated mitigation options, including expected outcomes in terms of water quality and ecological parameters. This section of the report discusses the results and management implications of recent ecological research work undertaken by Cawthron at NCC's request. These include:

1. Maitai Reservoir backfeed operational strategy
2. Maitai Reservoir aeration or destratification
3. Maitai River minimum flow augmentation and flushing flow releases
4. Maitai Dam fish passage remediation
5. Maitai River trout fisheries enhancement.

The report scope is focussed on the influence of the Maitai Reservoir operations on the Maitai River system. It does not include a review on other land use activities that also affect the river (e.g. forestry and urban influences). Although the reservoir is considered in relation to the cumulative effect it may have along with other land use activities on river ecology.

2. SUMMARY OF EXISTING ENVIRONMENT

2.1. Overview of the Maitai River catchment

The Maitai River catchment covers 9,140 ha and can be broadly divided into three main sub-catchments based on land use: 'Upper', 'Middle' and 'Lower' (Figure 2). Various sites within these three sub-catchments have been used in the past for monitoring stream health in the Maitai River and its tributaries. For the purposes of this report the main tributaries are included within these three sub-catchments (e.g. Groom Creek–middle; Sharlands Creek–middle; and The Brook–lower; Figure 2).

2.1.1. Land use

Different types of land use are known to be associated with specific impacts on river ecosystems. By considering land use (and changes in land use) within the Maitai River catchment a picture of what pressures are likely to be influencing ecological parameters can be constructed. In Sections 2 and 3 these land-use pressures are considered alongside historical river health indicators to qualitatively and quantitatively identify impacts.

Land use has been described in the Ministry for the Environment's 'Land Cover Database' (LCDB), which assesses land use using satellite information collected in 1996/97, 2001/02, and 2007/08. These are commonly referred to as the LCDB1, LCDB2 and LCDB3 databases (respectively), and give a reliable assessment of changes in land use over this period. The LCDB3 was released in 2012, and represents the most up-to-date land-use information available.

Figure 2 displays current land use in each of the three sub-catchments. Land use in the upper Maitai sub-catchment that comprises drainage to the Maitai Reservoir is dominated by native forest (95%), with small amounts on exotic forest cover localised around the Maitai Reservoir. The middle Maitai sub-catchment is dominated by exotic forest (54%) and native forest (39%), with a small area of pastoral / agricultural land use (4%). The lower Maitai sub-catchment (which includes the Brook) is dominated by native forest (60%), exotic forest (15%), urban / built up areas (14%), and pastoral / agricultural land use (8%). In all three sub-catchments there has been no substantial change in land use since 1996.

2.1.2. Modelled prediction of river health caused by Maitai catchment pressures

The 'Freshwater Environments of New Zealand Geo-database' (FENZ) 'River Pressure' dataset can be used to predict the effect of spatial variations in human pressure on the health of the Maitai River. Model inputs include: satellite-based estimates of land cover, information on the distributions of mines and reservoirs, estimates of the extent of impervious cover based on topographic map data, modelled nitrogen inputs to rivers and streams, and the estimated distributions of introduced fish. Estimates of river health are combined into a single index, values for which vary from 0 (totally degraded) to 1 (pristine).

Figure 2 displays the FENZ predictions of human pressure on river health in the Maitai catchment. In general, waterways situated in native forest are predicted to have the highest estimates of river health (0.6–1). River health is predicted to decrease with distance downstream as various anthropogenic pressures come into effect, driven mainly by the dominate sub-catchment land use. This is particularly evident in areas dominated by plantation forestry. Streams in the North Branch of the upper Maitai sub-catchment are predicted to be under greater pressure than those in the South Branch, which reflects the influence of the Maitai Reservoir on fish passage (Figure 2).

Pressure from surface water allocation in the Maitai catchment is considered negligible, with minimal abstraction (< 5 L/s) apart from the Nelson Municipal Supply scheme according to a GIS database that describes the extent of surface water allocation in New Zealand in 2011 (Clapcott 2011).

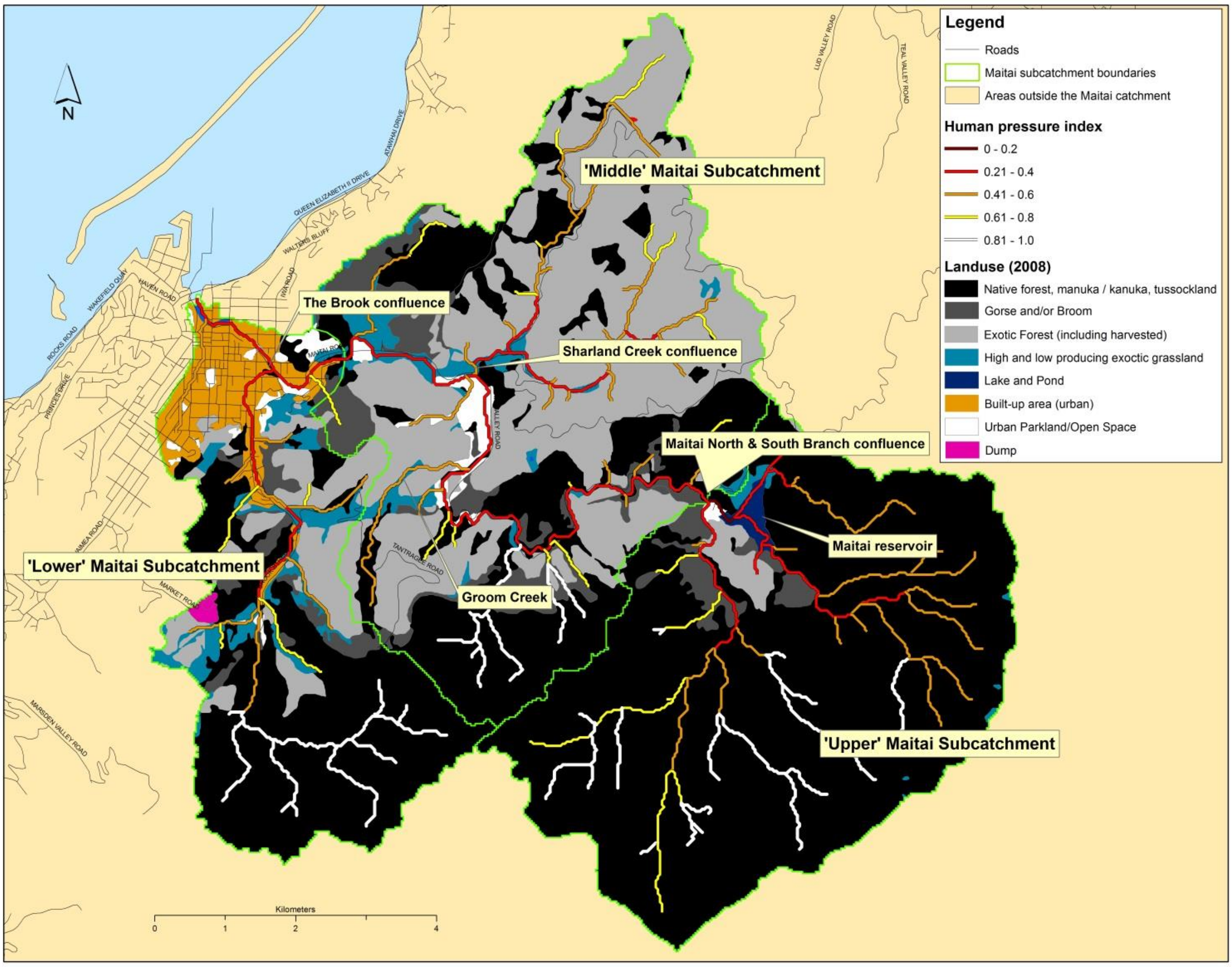


Figure 2. Land use in the Maitai River catchment: 'Upper', 'Middle' and 'Lower' sub-catchments (green boundaries) are stratified according to land-use type. Land-use influences the human pressure index for river health, where '0-0.2' is degraded (due to greater pressure) and '0.81-1' is pristine (Source: LCDB3, Ministry for the Environment 2012; and the FENZ geo-database 2010).

2.1.3. Influence of Maitai reservoir in context of other catchment pressures

Crowe et al. (2004) provided a comprehensive review on the influence of catchment pressures on the Maitai River including pre- and post-reservoir data. Since then a review undertaken by Allen et al. (2013) has found that nutrients from the backfeed discharge may contribute to cumulative impacts within the catchment (Figure 2, Table 1). However, they suggest that the impact of the Maitai Reservoir on the mid and lower Maitai River was likely to be comparatively minor when considered in the context of the magnitude and extent of other pressures facing the catchment. These other pressure included plantation forestry in mid-reaches of the river and, in the lower reaches urbanisation (particularly stormwater runoff).

Allen et al. (2013) highlighted three issues arising from the Maitai Reservoir that may affect the wider Maitai River catchment. These were:

- concentrations of naturally occurring heavy metals (Mn, Fe, nickel and chromium) were higher in the upper Maitai River than in the mid-catchment, with a low to moderate risk that this issue may be exacerbated by the discharge of anoxic water from the Maitai Reservoir;
- the Maitai Reservoir spillway was the most significant fish passage obstacle within the Maitai River, restricting access for native fish (particularly longfin eel and kōaro) and trout to habitat in the Maitai Reservoir and North Branch; and
- water chemistry below the Maitai Reservoir's backfeed discharge was being altered, especially during periods when anoxic reservoir water is discharged. Subtle changes in water chemistry can alter algal communities, potentially providing favourable conditions for undesirable species (e.g. toxic cyanobacteria).

These issues are discussed further under the relevant sections in this report.

Table 1. Possible impacts of catchment activities on river ecology within the Maitai River catchment.

Catchment activity	Examples	Possible negative impact
Maitai Reservoir water storage and water supply management	Abstraction / water storage	• Reduced habitat for invertebrates which will cause a reduction in food supply for fish, and hence a possible reduction in the condition and/or size of fish populations. (Hayes 2003).
	Discharge of water from Maitai Reservoir	• Water discharged into the Maitai River from the Maitai Reservoir over the summer months can be anoxic, and may alter water chemistry downstream and contain contaminants such as Mn, nickel and chromium. • There has been a decline in water quality and an increase in algal growth directly below the Maitai Reservoir backfeed discharge. • Whilst Mn, nickel and chromium are naturally occurring, the current Maitai Reservoir operating regime may increase their concentration at the point of discharge into the Maitai River. • Micronutrients present in the Maitai Reservoir (e.g. Mn and Fe) may be causing increased algal growth below the backfeed discharge.
	Reduced fish passage	• The Maitai Reservoir spillway may impede access for diadromous fish to areas upstream, specifically longfin eels and kōaro. • The backfeed discharge acts as an attractant flow for migratory species, but is ultimately a dead end. Fish gathered in the pool adjacent to the discharge may be more susceptible to predation by birds.
Plantation forestry	Harvesting operations and earthworks related to plantation forestry	• Increased sedimentation and reduced water clarity (loss of fish habitat and spawning habitat; loss of invertebrate habitat; reduction in quality and quantity of food for fish and invertebrates). • Increased nutrient loading in streams during harvest may cause increased growth of algae and may also stimulate cyanobacterial growth.
Agriculture and stock grazing	Stock access to channel or riparian area	• Decreased water quality (bacterial contamination, nutrient and chemical inputs, sedimentation from bank erosion (see above). • Limited spatial impacts only relevant to the mid-lower Maitai sub-catchment (8% of land use).
Barriers to fish passage	Maitai Dam, Almond Tree ford, Packers Creek ford, concrete fords and culverts	• Maitai River mainstem: no significant barriers downstream from the Maitai Reservoir, other than occasional temporary blockage of fords. • The lower Brook: reduced passage for trout and native fish (NCC addresses this in the 'Long Term Plan' (2012-2025).

Table 1, continued

Catchment activity	**Examples**	• **Possible negative impact**
Urbanisation	Storm water discharge and urban pollution	• Urban stormwater outfalls deposit a variety of contaminants into the river in the lower reaches (nutrients, bacteria, heavy metals, oil, grease and fuel compounds from roads). • Regularly high concentrations of faecal indicator bacteria in the lower Maitai is a 'chronic problem' for recreational water quality in the lower river (Sinton 2007).
	Channelisation and flood protection works	• Reduced fish habitat and fish passage. • Reduced cover for fish and increased water velocity (floods are more likely to impact fish populations). • Probably also reduced habitat for invertebrates with resulting reduction in feeding opportunity for fish.
Recreation	Swimming, walking, picnicking, camping angling *etc.*	• Decreased water quality (bacterial contamination). • Pollution via the decay of litter such as plastic bags / bottles, food waste etc.

2.2. Maitai Reservoir

The Maitai Reservoir, located immediately upstream of the junction of the Maitai North and South Branch confluence, is approximately 32 hectares in area. It has a maximum depth of 30 m near the dam, a mean depth of 7.6 m, and a total volume of 4.3 Mm^3 (Payne 2007). The inundation area of the valley was largely cleared of vegetation before flooding, and the substrate of the reservoir margins are predominantly sandy with more rocky areas towards the dam face (Figure 3). The margins of the reservoir are bushclad with either exotic forest or native forest with the exception of the south margin of the reservoir where the dam is located (Figure 4).

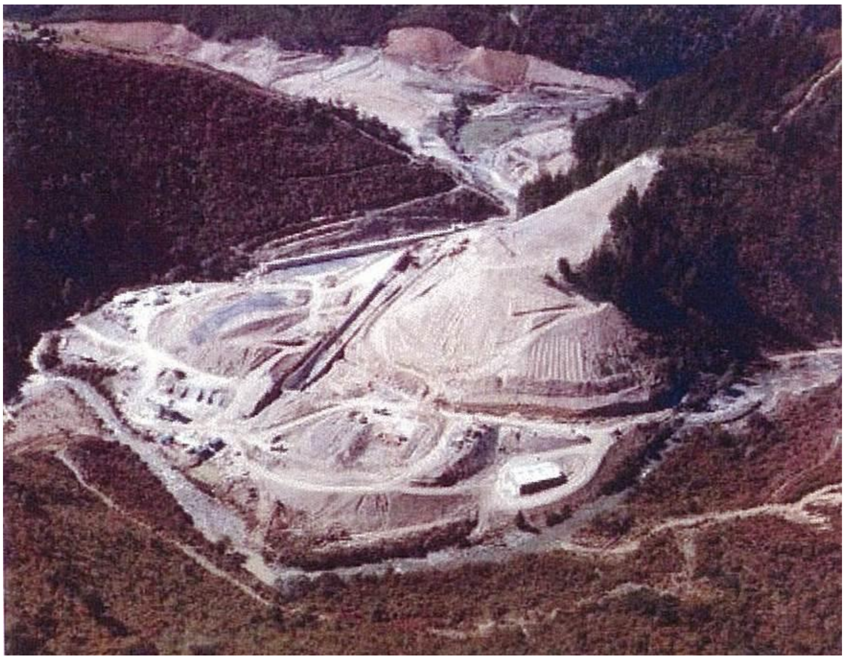


Figure 3. Maitai Dam prior to infilling in 1985. Photo taken from the TheProw.org.nz. (http/www.theprow.org.nz/assets/enterprise/ maitai-dam-1985.jpg).

Figure 4. The Maitai Reservoir, 3 April 2013. Photo from the north-west arm shoreline sampling site looking towards the dam.

The reservoir basin forms a T-shape with two shallower arms connecting along its northern and southern extents fed by two inflowing tributaries, the Maitai River North Branch and Mill Creek (Figure 5). A depth gradient exists along an east to west axis of the reservoir, with the deepest portion of the basin (approximately 30 m) occurring near the dam face at the western margin.

As with many natural lakes that occur in flooded river valleys (e.g. landslide lakes), the margins of the reservoir are relatively steep, and therefore there are limited areas of the reservoir that have suitable substrata and light for rooted aquatic plants to form littoral habitat[11].

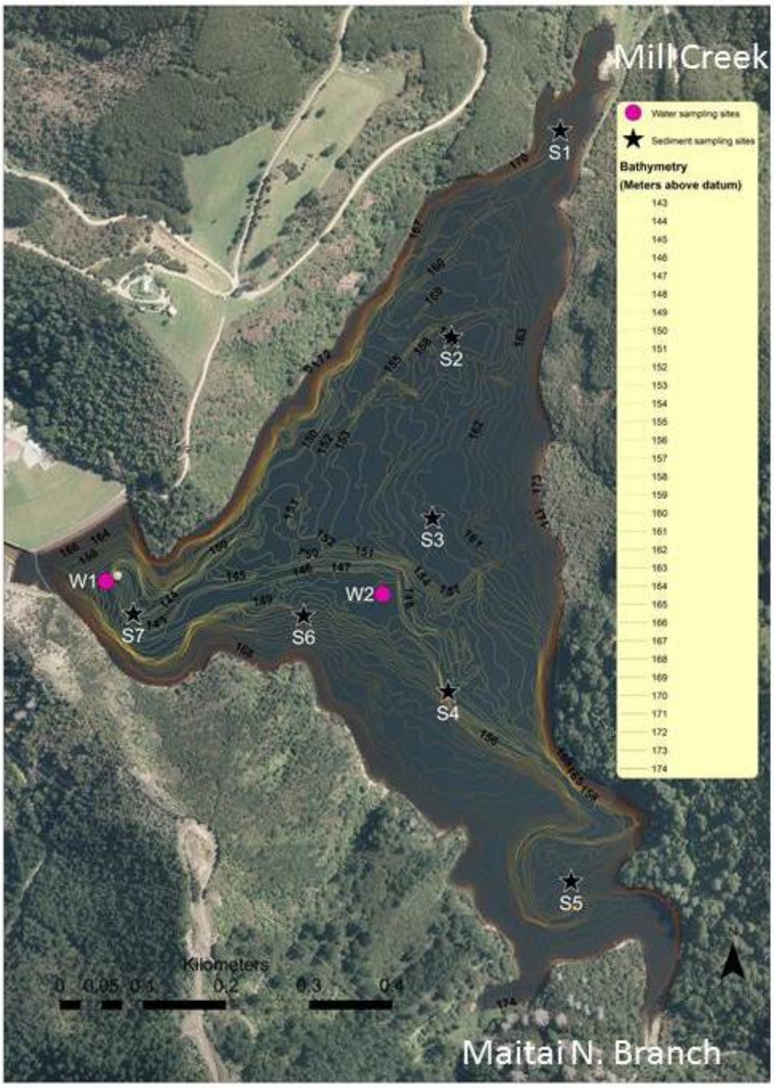


Figure 5. Maitai Reservoir bathymetry showing the locations of water quality (W1 and W2) and sediment quality (S1 to S7) monitoring sites during the 2013–2014 Cawthron study. Bathymetry data digitised from Payne (2007).

[11] Littoral habitats are shoreline margins of waterbodies that have sufficient light (typically greater than 1% of surface irradiance) where photosynthesis by bottom-growing plants (macrophytes and algae) occurs.

2.2.1. Historical monitoring

Since its construction, there has been a consistent pattern of mid to late summer thermal stratification in the Maitai Reservoir. Stratification is the process by which lakes and reservoirs develop separate layers: the epilimnion (surface layer), thermocline (maximum temperature / density gradient) and hypolimnion (bottom layer). Monthly monitoring of DO at the valve tower off-take levels (water depths of 6 m, 15 m and 26 m) indicate anoxic conditions can occur in the bottom waters (hypolimnion) once they become isolated from mixing with surface waters after the onset of stratification in spring. Typically, from January until turnover (break-up of stratification) in April–May, water in the hypolimnion below the thermocline can be reduced in DO, and can become anoxic towards the end of the stratification cycle in March through to May.

Annual consent monitoring has reported that water with elevated Mn and Fe concentrations is discharged into the Maitai River from the Maitai Reservoir as part of the operation of the Nelson City water supply scheme (e.g. Olsen 2007a; Olsen 2007b; Holmes 2010). Both Mn and Fe can be solubilised (re-enter the water) from lake sediments during anoxic conditions in the hypolimnia of lakes (McQueen & Lean 1986). However, it is also possible that Mn is entering the lake via the metal-rich geology of the upper North Branch catchment of the Maitai River (Holmes 2010). Increased levels of Mn (and Fe) in the Maitai Reservoir's discharge have only a moderate risk of direct or chronic toxicity to the river's aquatic life based on ANZECC guidelines (ANZECC 2000). There is concern though that the Mn and Fe (and potentially other metals such as chromium and nickel) may be encouraging the dominance of (potentially toxic) cyanobacteria over diatom-based communities in the Maitai River.

Historical monitoring in the Maitai Reservoir has focused solely on collecting water quality data. This has included some documentation of thermal stratification and deoxygenation cycles in the reservoir (e.g. Holmes 2009b, Olsen 2010), and was largely driven by issues around anoxic conditions in the reservoir hypolimnion. There has been limited sampling undertaken to examine nutrient concentrations and the potential for internal nutrient cycling during periods of anoxia in the hypolimnion in the reservoir (McQueen & Lean 1986). Therefore, there is limited understanding of whether nutrient concentrations in water being transferred from the backfeed into the South Branch have an effect on periphyton proliferations below the backfeed discharge. Stark (1998a) did some detailed analyses, relating spring nutrient concentrations in the Maitai Reservoir, to possible summer chlorophyll–*a* (chl-*a*) concentrations. This investigation was limited to a short (two month) sampling period, and it appears that hypolimnetic anoxia has intensified since this time. Thus these earlier findings may have limited applicability to current water quality conditions.

More detailed analyses of metal concentrations in reservoir water transferred through the backfeed were conducted by Holmes (2010). This was undertaken in response to a consent condition breach in May 2006, where high Mn concentration levels (1.7 g/m^3), were in breach of the consented limit of 1 g/m^3. A further breach occurred again in May 2007 with levels at 1.2 g/m^3 in the Maitai South Branch below the discharge (Wilkinson & Olsen 2007). This and other Maitai Reservoir consent monitoring reports indicated that the Reservoir can at times discharge high concentrations of Mn and Fe (Holmes 2010).

2.2.2. Water level fluctuations

Water levels are recorded continuously as part of monitoring conditions, and analysed annually as part of consent monitoring reporting. Water levels in the Maitai Reservoir are maintained between the spillway height of 173.75 m and potentially as low as 167.75 m. There are a range of water use restriction measures within this range to prevent significant draw-down of reservoir water levels. Measures around water use restrictions are listed in points A-F below and displayed on the hydrograph of Figure 6.

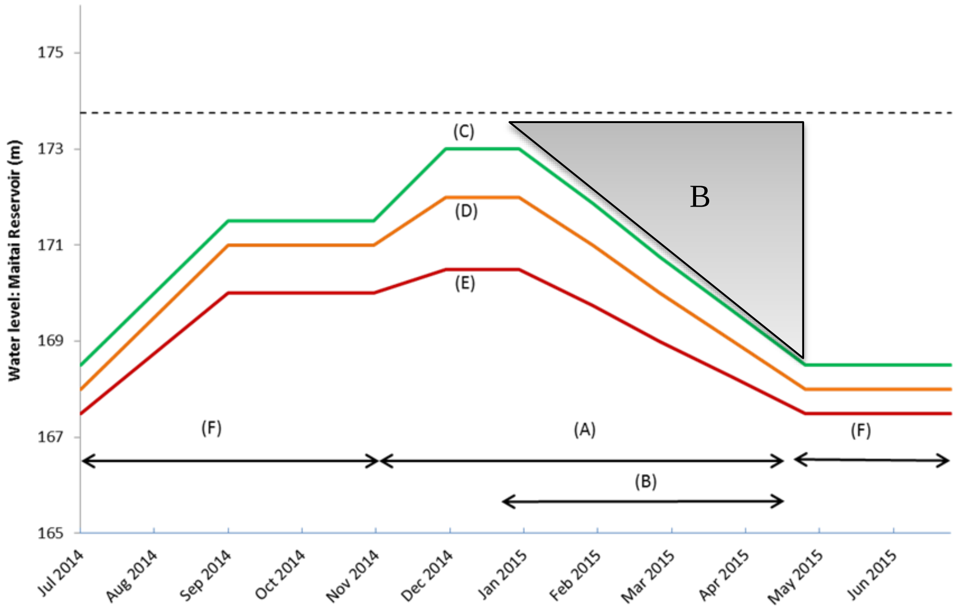


Figure 6. Maitai Reservoir water level conditions for 1 July–30 June (2014-15) showing water usage rules for operation of the water supply system. See the text below for a description of the lines and letters on the graph.

Letters (A) to (F) on the graph (Figure 6) represent:

(A) The period when the summer minimum flow conditions apply.

(B) During the period 1 January–1 May, when the water level is in this range (grey shaded triangle), water will be released from the Maitai Reservoir into the Maitai

River (via the 'backfeed') as required by the 'surplus water' requirement of Consent No. RM025151/2 (previously Water Right No. 820540).

(C) When the water level is in this range, sprinkler restrictions will be put in place. As a minimum restriction, odd-numbered properties would be able to water on odd-numbered days and even-numbered properties on even-numbered days. Advertising will be run to remind the public of these restrictions. Flushing of mains will be reduced.

(D) When the water level is in this range, a sprinkler ban will be put in place. The only exception will be high-value areas such as bowling greens, golf course greens, cricket pitches and high profile public gardens. Advertising will be run to remind the public of this ban.

(E) When the water level is in this range, housing restrictions will be introduced. Depending on the severity of the situation these measures could include:

- a complete ban on residential housing
- restrictions on industrial and commercial use of water (e.g. close down automatic car washes, stop washing cars in sale yards)
- approaches to major industries to explain the severity of the situation and request co-operation through minimal water use
- increased advertising on water use and restrictions
- establishment of a 'Hot Line' for residents to report non-compliance with water restrictions
- water mains only flushed in response to water quality complaints.

(F) The period when the winter minimum flow conditions apply. If during the period 1 May to 30 October the minimum flow is reduced in accordance with a variation to Water Right 820540, the response shall be the same as for item (E).

Although water-use restriction measures are in place to limit the extent of reservoir level fluctuations, in practice these restrictions have rarely been imposed in recent years because actual levels have consistently remained above restriction levels (Figure 7). Between 2004 and 2015, reservoir levels remained reasonably close to the spillway height with a mean annual minimum reservoir level of 172.35, or 1.4 m below spillway height. Only in very dry years were reservoir levels lowered significantly more than 1.5 m, which typically only occurred during the late summer season period. The lowest reservoir level over the 10 year period was approximately 3.5 m below the spillway height in April 2006. At the time the present biological surveys were conducted (April 2013), the Reservoir was drawn down approximately 1.25 m to the lowest level it had been since April 2010.

The extent of water level fluctuations is not considered large in comparison to other reservoirs in New Zealand. Extreme examples where storage reservoirs are used for hydroelectric generation have much greater operating ranges (e.g. 22.3 m for Lake Hawea, and 13.8 m for Lake Pukaki; James et al. 2002). Moreover, the frequency of draw-downs in the Maitai Reservoir was typically only once per annum in comparison to frequent (sometimes daily) fluctuations in other hydroelectric and irrigation storage reservoirs. Therefore patterns observed in the Maitai Reservoir are more likely to reflect patterns of water level fluctuations observed in many New Zealand natural lakes, where water level fluctuations are more moderate.

The extent to which reservoir level fluctuations are likely to affect the ecology and biological communities in the system can depend on several factors (James et al*.* 2002). This would include the extent of wave mixing around the margins of the lake and its potential to enhance shoreline erosion, particularly around high water levels. However, the small overall area (32 ha) and small fetch[12] (1 km) of the Maitai Reservoir as well as the protected high-sided nature of its valley would act to minimise any wind-induced waves. Thus it is unlikely that shoreline erosion would be an issue, and no obvious signs of shoreline erosion are evident.

Water clarity is an important factor in determining the extent (or depth) to which aquatic plants and their associated animal communities (macroinvertebrates and fish) can colonise the lake along its shoreline edges, termed the littoral zone (Kelly & McDowall 2004). This is an important zone for productivity and diversity of lake biota, and has strong linkages to fisheries in most lakes (James et al*.* 1998; Kelly & McDowall 2004). Lakes that have either low water clarity, or very high water level fluctuations (or a combination of both) tend to be poorly suited for colonisation by most biota (particularly plants), because the depths that remain permanently wetted are too deep for light to penetrate during some portions of the year (James et al*.* 2002). This is particularly evident for lakes such as Lake Pukaki which has a euphotic depth of less than 1 m, but a dam operating range of over 13 m. Thus most of its shoreline is comprised of substrates not colonised by plants and has limited invertebrate populations (Weatherhead & James 2001).

In the case of the Maitai Reservoir, although data measuring water clarity is limited as discussed in the next section, the data suggest that light penetration is sufficient to allow aquatic plants to grow to depths of up to 6.1 m. Thus, the annual Maitai Reservoir level fluctuations of on average 1.4 m would still enable the more permanently wetted depths between 1.4 and 6.1 m to be conducive for colonisation by littoral plants and animals. James et al*.* (2002) in an analysis of water level fluctuations nationally, suggested that lakes with water level fluctuations of less than 3 m tend to have diverse and healthy aquatic plant communities. Thus water level fluctuations in the Maitai Reservoir appear to provide an environment conducive to colonisation by a healthy littoral shoreline community.

[12] Fetch- The distance across a waterbody for wind-waves to be generated on the reservoir surface

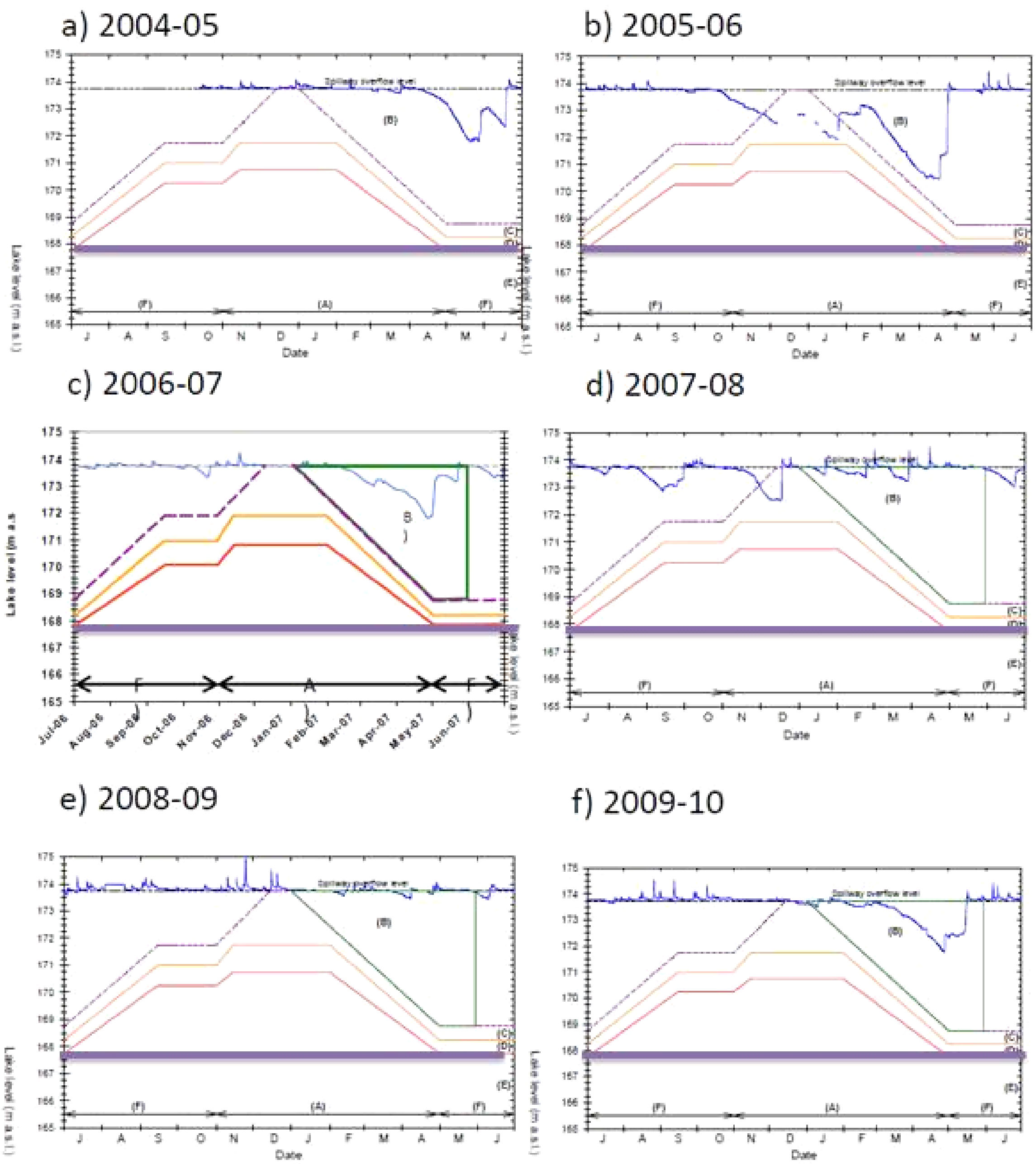


Figure 7. Water level fluctuations (blue line) in the Maitai Reservoir between July 2004 and June 2015. Sourced from Kelly and Shearer (2013), and biomonitoring reports. Note the thick purple line at 167.75 represents the Upper-inlet valve level.

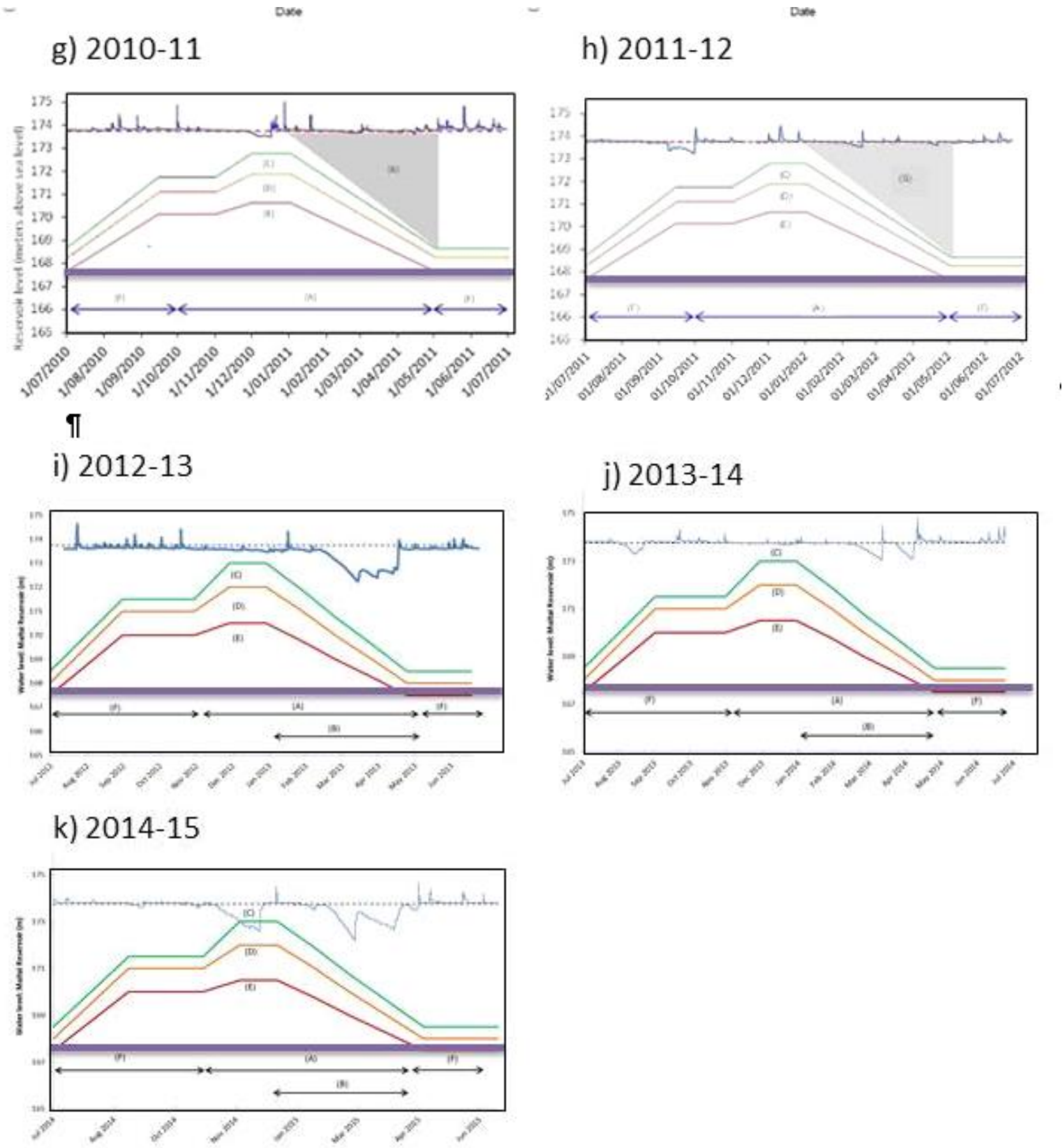


Figure 7, continued

2.2.3. Reservoir water quality

Water quality in the Maitai Reservoir has been discussed in several reports that have evaluated consent condition monitoring data collected between 2004 and 2012 (e.g. Olsen & Stark 2007; Holmes 2009b; Holmes 2012; Holmes & Kelly 2012). Subsequently, more detailed investigations have been conducted to understand processes driving water quality dynamics in the reservoir (Kelly 2014), exploring possible ways in which water quality could be improved (Kelly 2015), and evaluating how management of the reservoir backfeed sourcing could be adapted to improve water quality conditions in the Maitai South Branch downstream of the backfeed (Kelly 2014; Hay & Allen 2015).

The following subsections detail the findings of these detailed investigations on the Maitai Reservoir water quality (Kelly 2014, 2015).

Thermal stratification

Based on 2 years of temperature data collected using a thermistor chain deployed at the valve tower between 2013-2015 (Kelly 2014, 2015), thermal stratification of the Maitai Reservoir initiated in September and progressively became stronger through to February (Figure 8). The thermocline initially formed around 6 m depth (i.e., the upper valve level), and progressively deepened to between 10 m–16 m by late summer (March). When stratification was most pronounced (in February), there was nearly a 10°C difference in water temperature between the epilimnion and hypolimnion. In 2013-14, a flood on 16 March (66 m^3/s at Maitai Forks flow station; Figure 8), destabilised the thermocline by cooling the upper 8 m of the water column, deepening the thermocline slightly to 16 m. This resulted in the upper epilimnion being notably cooler, and likely contributed to destabilising of stratification. The Maitai Reservoir then completely mixed (turned over) during a subsequent flood on 16 April 2014 (79 m^3/s at Maitai Forks flow station). Turnover occurred rapidly, and following two days of mixing (i.e. by 18 April 2014), the Maitai Reservoir was nearly isothermal.

The timing of turnover in 2014 was approximately three weeks earlier than the previous year which occurred on 5 May 2013 (Kelly & Shearer 2013). Monitoring conducted in 2014–2015 used a chain of eight continuous data recorders between 3 and 26 m depth and showed a similar progression of the thermocline (between October and May). Reservoir turnover was timed similarly to 2014, initiating around 19 April 2015 (Kelly 2015).

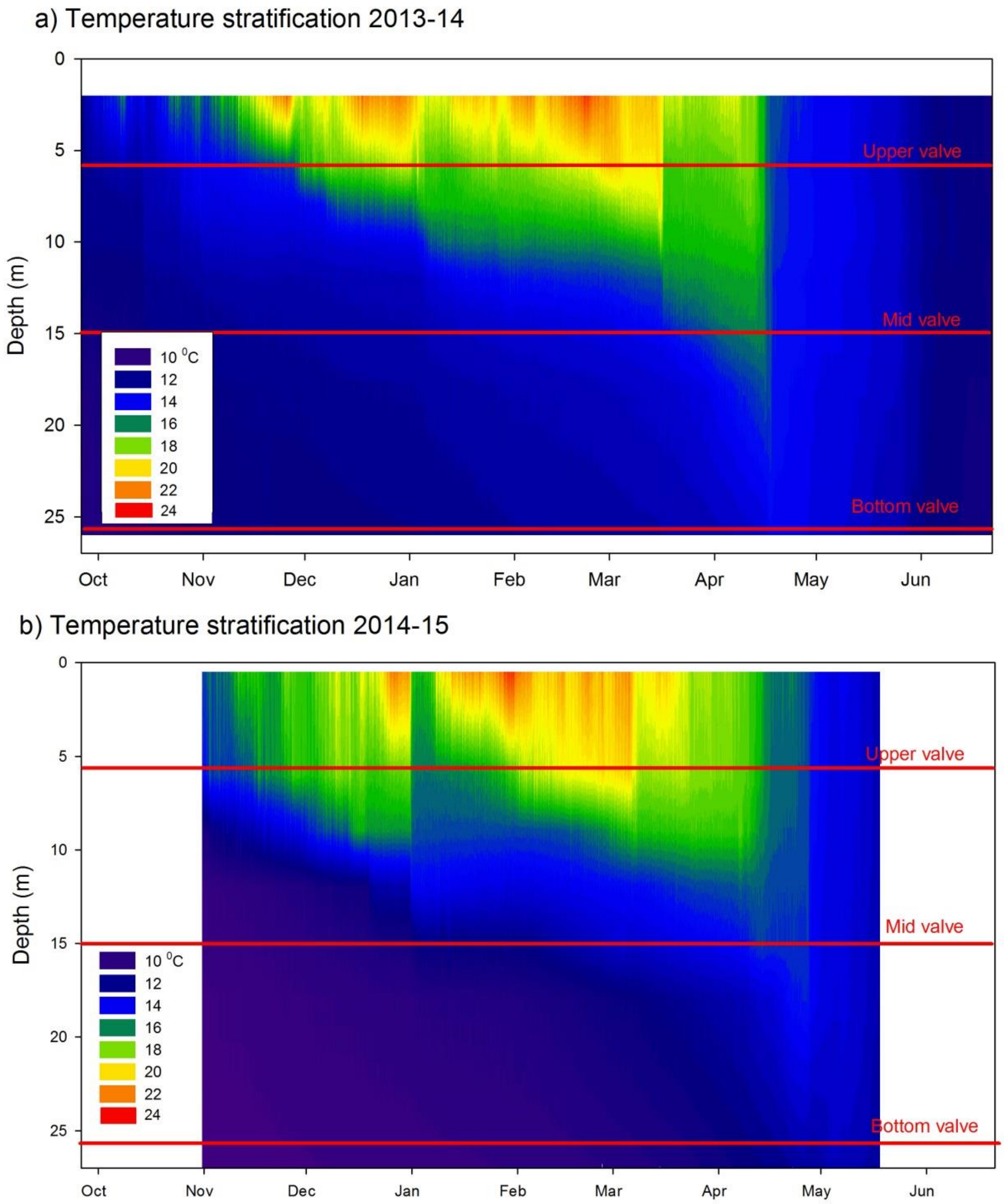


Figure 8. Contour plot of temperature stratification in the Maitai Reservoir from thermistor chain data at the valve-tower over the thermal stratified period between September 2013 and July 2015.

The Nelson Resource Management Plan (NRMP) cites water temperature standards for Class C waterbodies (‘moderate condition’ applicable to the Reservoir) not to exceed daily mean temperatures of 22 °C or have maximum temperatures in excess of 27 °C (Appendix 3 and Appendix 4). Because lakes are relatively more stable in their thermal variation over daily cycles (save the top 1 m of the water column), the mean daily temperature standard is likely to be most appropriate to consider for the

Maitai Reservoir. Mean daily temperatures in the Reservoir between 2-6 m depth can at times exceed the mean daily standard of 22 °C, particularly during the February-March late-summer period. Below 6 m water depth, temperatures remain cooler with mid and bottom-water temperatures in the range of 10–16 °C over most of the year. Therefore it is expected that a cool water refuge exists below these warm surface waters. However, as discussed in the next section, because deoxygenated water persists up to the depth of the thermocline in summer (to around 6 m), in February-March these cool-water refuge areas are likely to be compromised by having dissolved oxygen levels below what sensitive species can tolerate. Salmonids have a chronic stress below 80% saturation and acute stress occurs around 50% (Hay et al. 2007). DO saturation around these mid-water depths is likely to be close to this acute threshold. Therefore the interaction between thermal stratification and deoxygenation in the reservoir mean that portions of the reservoir that are suitable to aquatic sensitive aquatic life from a dissolved oxygen perspective (i.e., > 80% DO saturation), are likely to be affected by water temperatures in excess of the temperatures in the NRMP standards cited for this waterbody.

The NMRP cites that improvements in water quality over its existing water classification should be targeted where ever practicable; in this case standards cited for Class B waters being the aspirational target. The NRMP cites water temperature standards for Class B waterbodies (‘very good condition’) not to exceed daily mean temperatures of 20°C or have maximum temperatures in excess of 24°C. Over the mid-summer period, mean water temperature conditions cooler than 20°C occur below depths of 6 m, which as discussed previously are typically below depths at which DO ranges that are considered conducive to aquatic life (< 50% DO saturation). Therefore improvements in DO conditions in the reservoir would need to occur for these cooler habitats to be available to temperature sensitive species.

Dissolved oxygen

Continuous monitoring of DO levels in the reservoir over a two year period (2013-2015) indicated declining DO saturation in bottom water over the summer period when the reservoir remained thermally stratified. In 2013-14, at the start of the monitoring period (September 2013), DO was between 80% and 100% saturation over the whole water column (Figure 9). Saturation levels then progressively declined below the thermocline depth over the spring-summer period, but remained at near-saturated levels between the surface and 6 m depth (shallow valve inlet) over the course of monitoring. The decline in DO corresponded to the depth of thermocline, occurring mainly between 6 m and 14 m. The decline then became relatively more stable through the hypolimnion to the reservoir bottom. The magnitude of the DO decline progressively decreased over time, until the reservoir turned over in late April. However, deepening of the thermocline over summer resulted in DO depletion being extended to progressively greater depths over time. This meant that in February the water column below 7 m was < 50% DO saturated, but the reduced oxygen layer was confined to below 12 m in early April (see paragraph below). This has implications in regards to what water layers (valve depths) could potentially be sourced for backfeed, in order to minimise the impacts of the release of deoxygenated water. Patterns of DO declines with depth were very similar over both years of reservoir monitoring, indicating DO decline rates were consistent between years (further discussed below).

Significant floods that occurred over the monitoring period (e.g. 16 March 2014) resulted in some entrainment of DO into the upper hypolimnion. This is likely to have contributed to the deepening of the anoxic layer as floodwaters entrained cooler oxygenated water to the upper layers of hypolimnion. However, it was insufficient to have completely re-oxygenated the reservoir and further deoxygenation occurred following the stabilisation of inflows. A subsequent significant flood event on 16 April 2014 facilitated the turnover of the reservoir. This is not typical, as turnover is usually driven by air temperatures cooling surface waters and, in many New Zealand South Island lakes, may not occur until mid to late May. The hypolimnion in the Maitai Reservoir was rapidly re-aerated and exceeded 7 g O_2/m^3 within one day of turnover.

Seasonal profiles of DO using a lake profiling sonde were conducted in 2013-14 and indicated that deoxygenation patterns were similar between the sites at the valve tower and the mid-reservoir. This suggests that tributary inflows, valve-tower inlet sourcing, and morphometric differences do not appear to greatly influence deoxygenation patterns over the main basin of the reservoir. Although we did not profile shallower locations closer to the inflow locations, it would appear that most of the deeper regions have similar patterns of stratification and deoxygenation.

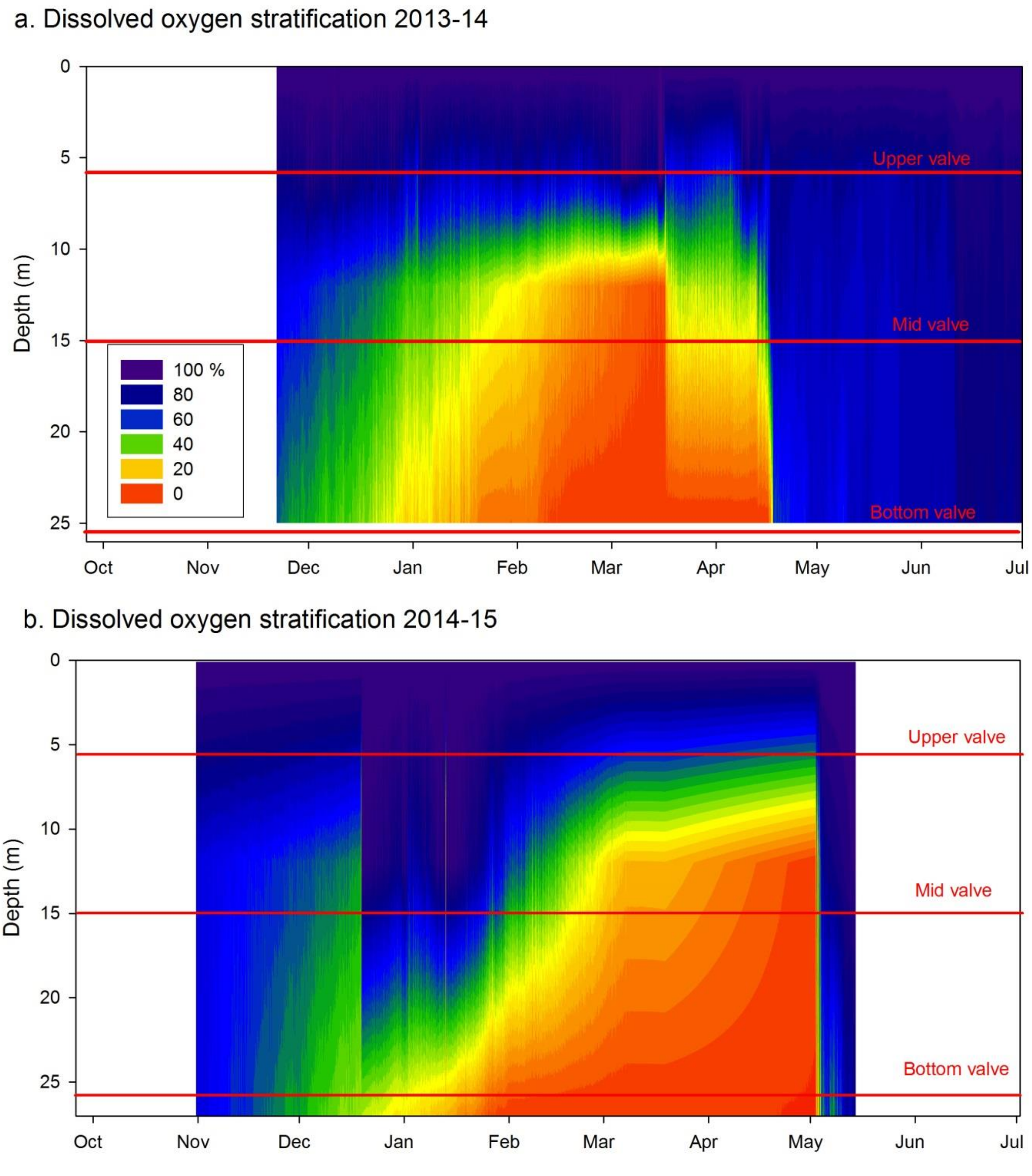


Figure 9. Contour plot of dissolved oxygen (expressed as percent saturation) in the Maitai Reservoir from thermistor chain data at the valve-tower over the thermal stratified period between September 2013 and July 2015.

Continuous measurements of hypolimnetic DO over two years of monitoring (i.e. using a thermistor chain sensor at 25 m) indicated DO declines were linear between September and January, with anoxia occurring near the end of February 2014 (Figure 10). The rate of oxygen depletion, or the hypolimnetic volumetric oxygen depletion rate (HVOD; Burns 1995), was 0.177 g $O_2/m^3/d$. This had a strong model fit with an r^2

of 0.949. A similar HVOD was also reported for eutrophic Lake Hayes in Central Otago (HVOD of 0.2 g $O_2/m^3/d$; Burns & Rutherford 1998). Eutrophic lakes in the North Island, such as Lake Rotorua, can have HVOD values higher than 1 g $O_2/m^3/d$ (Vant 1987; Burger et al. 2007).

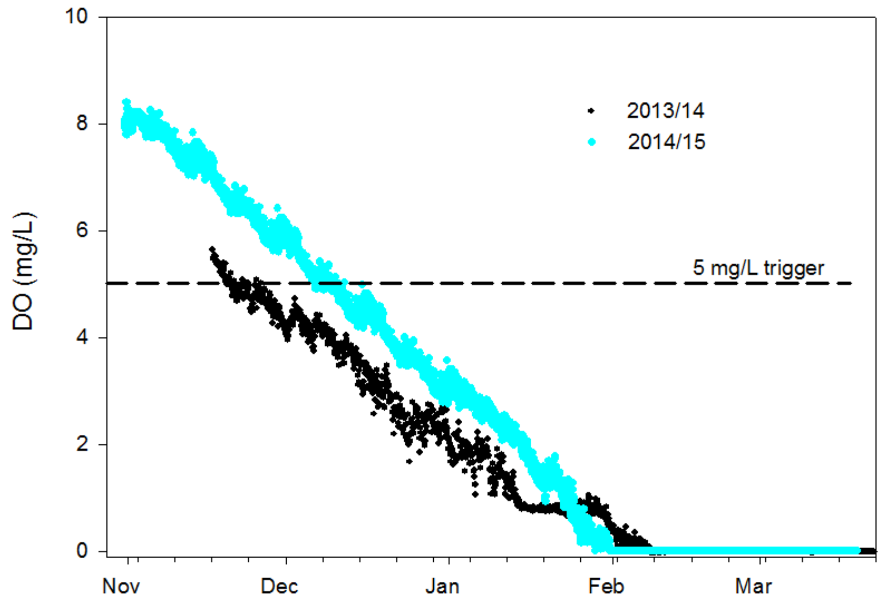


Figure 10. Seasonal trend in dissolved oxygen (DO) at 25 m depth at the reservoir valve tower over two years of monitoring during the summer stratified period between November 2013 and May 2015.

The NRMP cites DO standards for lakes and reservoirs for both Class C (existing Reservoir Class) and Class B (aspirational target standard) waters to be in the range of 90-110% saturation. The ranges of DO observed in the Maitai Reservoir are consistently lower than these standards below 6 m of water depth over most of the thermally stratified period. Depletion of DO to below 90% saturation is not unusual for bottom waters of lakes and reservoirs in the Upper South Island and other regions (Verburg 2010). However, the severity of the DO declines in the Maitai Reservoir in mid and bottom-waters clearly demonstrate conditions persist for extended periods well below these standards. As discussed in the previous section, because deoxygenated conditions persists over the depths where cool water could provide refugia for temperature-sensitive species (e.g., most fish) during summer, these conditions are likely to degrade habitat values below those cited by the NRMP for this waterbody.

Reservoir nutrients and trophic status

There are obvious seasonal patterns in nutrient status of the reservoir (Figure 11). Dissolved inorganic nitrogen (DIN) was high in winter and spring in surface waters (i.e. 0 m–10 m integrated samples). It then declined over summer months, presumably as phytoplankton uptake of nutrients increased. Total nitrogen (TN) and total phosphorus (TP) both tended to be high in mid-summer, likely related to the particulate organic N and P contained in phytoplankton. Algal biomass, as measured by chl-*a* concentration, was greatest over summer. Secchi[13] depth ranged between 5.1 m and 2.2 m, and was on average 4.0 m. The effect of the floods was evident in patterns of nutrient and Secchi data, with high TP and TN concentrations and low Secchi depth post-flood. There was evidence of large amounts of sediment and floating detritus in the reservoir (author's observations) on this sampling date and the flood had notably extended the river delta at the North Branch inflow. Seasonal nutrient patterns were highly similar between sites, suggesting relatively low variation over the reservoir basin caused by inflows or mixing processes.

Concentration ranges of nutrients and chl-*a* suggest the Maitai Reservoir to be in an intermediate nutrient status, or mesotrophic state (Table 2). Trophic level index (TLI), which integrates TN, TP, chl-*a* and Secchi depth (Burns et al. 2000), was on average 3.1 and ranged between 2.8 and 3.5 over the monitoring period. This index is a relatively important environmental indicator to consider. It provides an indication of the amount of organic material (e.g. phytoplankton), which settles to the hypolimnion and is linked with oxygen-consuming processes in bottom waters (e.g. respiration, decomposition). For drinking water supplies, it also provides a likely indicator of algal production that could be linked with cyanobacteria and / or taste and odour compounds contained in algae. The nutrient status of the reservoir would be considered low to intermediate risk of algal or cyanobacteria blooms based on these TLI parameters.

[13] Secchi disk is a measure of the water clarity of a reservoir using a black and white coloured disk lowered through the water column to the point disappearance (i.e., visual clarity).

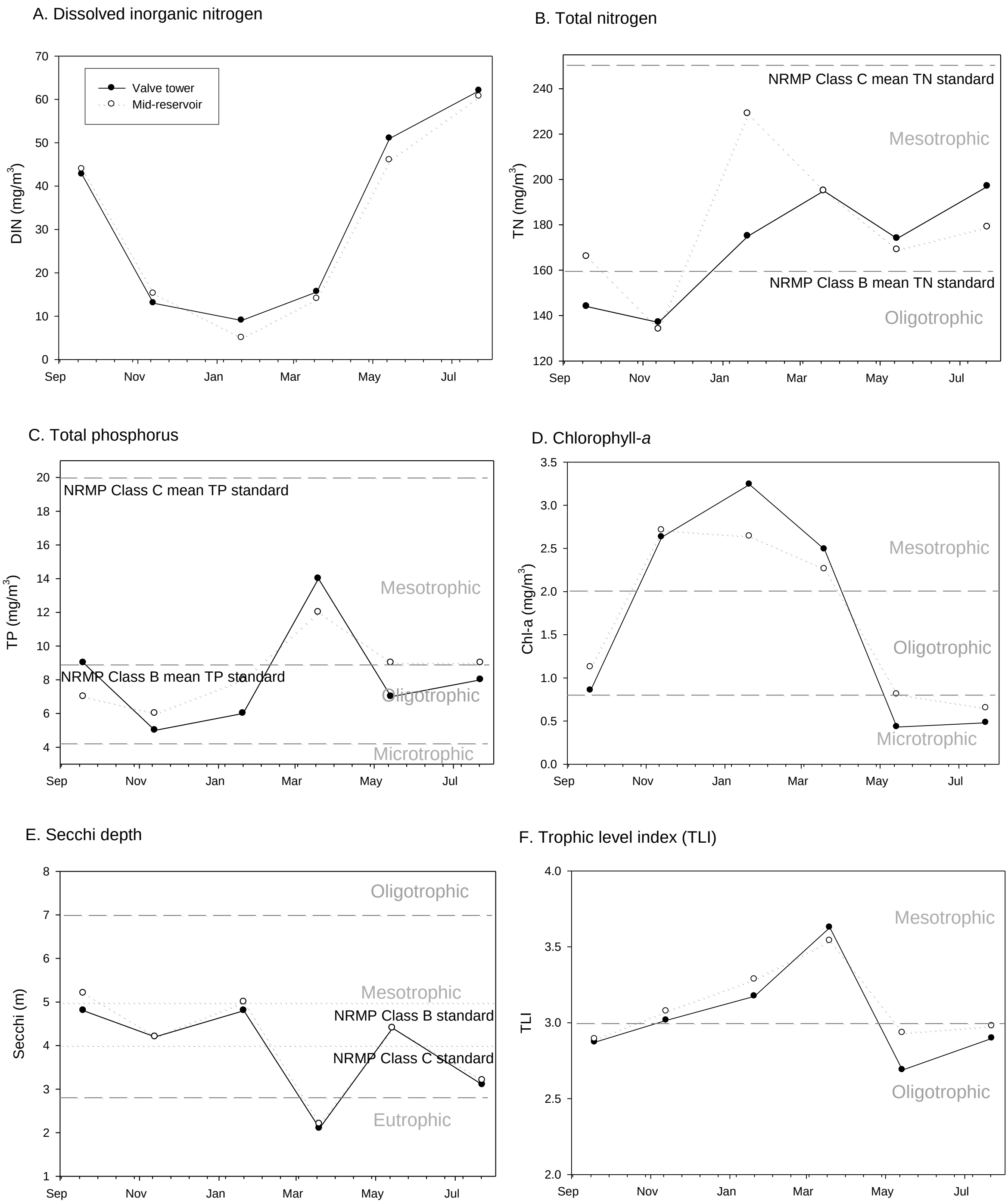


Figure 11. Bi-monthly nutrient concentrations (A-C), chlorophyll-*a* (D), Secchi disk depth (E), and trophic level index (TLI; F) at two sites in the Maitai Reservoir over the 2013–2014 monitoring period.

Table 2. Ranges of total nitrogen (TN), total phosphorus (TP), and chlorophyll-*a* (chl-*a*) concentrations and Secchi disk depth for trophic level states of New Zealand lakes according to Burns et al*.* (2000).

Trophic state	**TLI**	**Chl-*a* (mg/m^3)**	**TN (mg/m^3)**	**TP (mg/m^3)**	**Secchi (m)**	**Algal and cyanobacteria bloom risk**
Ultra-microtrophic	0–1	0.13–0. 33	16–34	0.8–1.8	25–33	Very low
Microtrophic	1–2	0. 33–0. 8	34–73	1.8–4.1	15–25	Very low
Oligotrophic	2–3	0. 8–2	73–157	4.1–9	7–15	Low
Mesotrophic	3–4	2–5	157–337	9–20	2.8–7	Intermediate
Eutrophic	4–5	5–12	337–725	20–43	1.1–2.8	High
Supertophic	5–6	12–31	725–1,558	43–96	0.4–1.1	Very high
Hypertrophic	6+	> 31	> 1,558	> 96	< 0.4	Very high

From depth-specific nutrient samples collected in 2013-14 (Kelly 2014), comparison of nutrients between epilimnetic (0 m–10 m) and hypolimnetic (20 m) depths suggests relatively small differences over depth (Figure 12). On an annual basis, there were no significant differences in DIN between surface and bottom waters (T-test, P = 0.25), although DIN tended to be higher in the hypolimnion during summer (November–March). Similarly, there were also no significant differences in TP concentration between surface and bottom waters (T-test, P = 0.39), but TP tended to be higher in the surface waters in summer. These seasonal depth-related differences in DIN and TP were likely related to phytoplankton nutrient uptake in the epilimnion during the summer peak growing season. This would explain the observed nutrient depletion in surface layers relative to the hypolimnion.

Other water chemistry parameters (Figure 12) that might indicate increased organic nutrients from decomposing vegetation, such as total dissolved nitrogen (TDN) and dissolved organic carbon (DOC) were also at similar concentration ranges within epilimnetic and hypolimnetic depths. This is a very important finding, as it indicates that internal nutrient recycling within the reservoir is likely to be a relatively minor factor affecting water quality.

Coloured dissolved organic carbon concentrations (DOC) were moderate, and ranged between 3–4 mg/L. This results in a moderate humic staining (tea colouration) of the reservoir waters which has implications for using the water for municipal water sourcing because alkaline dosing (using hydrated lime) is required before water can be fed to the reticulation system. A large proportion of the DOC and other nutrients (TN and TP) are brought into the reservoir during high flow periods, which are subsequently stored and released to the river via the backfeed during normal flows. As such the reservoir acts as a storage pool for nutrients, mostly stored during winter and spring high flows, which are then slowly released into the river over summer when low flows in the Maitai are augmented by release from the reservoir backfeed. This has implications for the seasonality of nutrient loads from the North Branch tributary to the Maitai River downstream of the dam, with higher summer loads than would have occurred prior to the construction of the Maitai Reservoir. However, the river does benefit from having greater minimum flows due to augmentation over this summer low flow period which is beneficial outcomes for instream biota (discussed in Section 2.4)

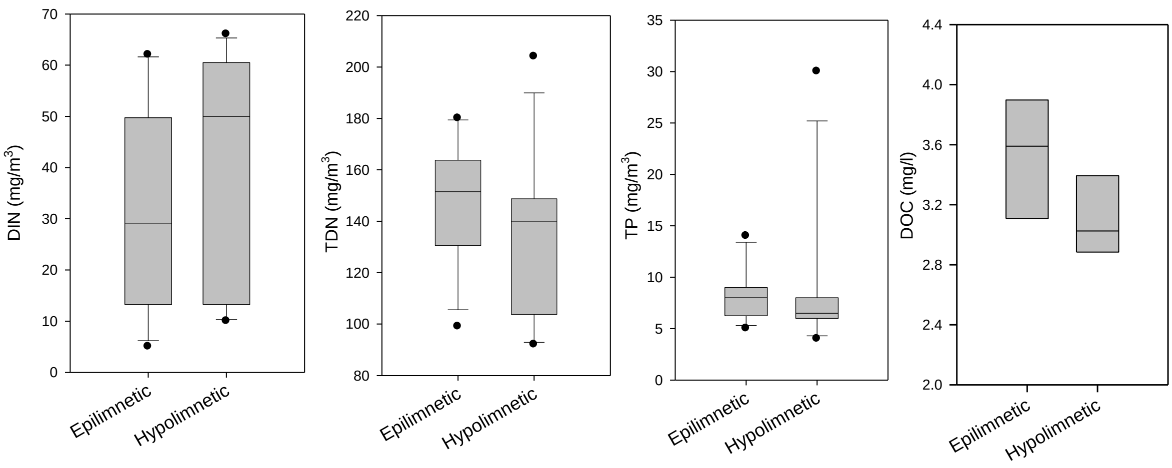


Figure 12. Box and whisker plots of bimonthly measures of dissolved inorganic nitrogen (DIN), total dissolved nitrogen (TDN), total phosphorus (TP), and dissolved organic carbon (DOC) in epilimnetic (0-10 m depth) and hypolimnetic (23m depth) waters in the Maitai Reservoir (site W1- valve tower). Note that boxes correspond to quartile data ranges with median shown as a line, with bars at 5th and 95th percentiles of the data range.

For lakes that undergo periods of bottom water anoxia, there are enhanced risks associated with recycling of accumulated sedimentary nutrients (e.g. accumulating detritus and phytoplankton settlement) back into the water column during periods of low DO. The processes, also referred to as 'internal loading', can greatly increase annual loads of P in conjunction with external sources in some lakes (e.g. Howard-Williams & Kelly 2003; Gibbs 2011). These internal nutrient cycling processes are greatly enhanced by anoxic conditions near the sediment water interface, which change redox processes and release particulate-bound P and ammonium into the water column (e.g. Vant 1987; Burger et al. 2007).

Based on seasonal nutrient patterns in the Maitai Reservoir at surface and hypolimnetic depths, there appeared to be minimal internal nutrient loading from reservoir sediments during deoxygenated periods, which persisted over several months in 2013–2014. The data shows only modest increases in hypolimnetic DIN and no difference in TP between the epilimnion and hypolimnion (Figure 12). The moderately higher hypolimnetic DIN compared with surface waters could have arisen partly from storage of nutrients in the hypolimnion from winter and spring inflows when river concentrations of DIN are greater (due to low periphyton uptake). Dissolved inorganic nitrogen was predominantly comprised of ammonium-N during summer periods, but concentrations were not at levels considered harmful to aquatic life (ANZECC 2000).

The NRMP cites mean annual water nutrient standards applicable to C Class waters for TN and TP of 250 and 20 mg/m^3, respectively. Limited data have been collected for the Maitai Reservoir to evaluate if the reservoir meets such standards, but based on the bi-monthly monitoring of surface waters over 2013–2014, both the TN and TP standards were met (mean of 8.33 mg TP/m^3 and 174.5 mg TN/m^3). These concentrations would also suggest that the Reservoir is close to meeting the aspirational Class B standards for TN and TP of 160 and 9 mg/m^3, respectively, although the TN standard was slightly exceeded.

The NRMP cites a visual clarity minimum standard for Class C waters of 4 m Secchi depth. Clarity conditions in the Maitai Reservoir did breach these standards on occasion, largely related to elevated humic organic materials contained in inflows during high flow periods, but on an average basis reservoir clarity was close to this standard (2013–2014 mean Secchi of 4.0 m). The reservoir is unlikely to ever achieve the aspirational B Class standard of 5 m Secchi depth because humic organic materials derived from the beech forest catchment are likely to be the main driver of clarity in the reservoir, and this is mainly influenced by vegetation cover and hydrology of the upper North Branch catchment.

Both nutrients and clarity indicate that nutrient status of the reservoir is moderately higher than the oligotrophic (or better) standard cited for Class B reservoir waters. Both TN and Secchi are affected to an extent by concentrations of dissolved humic material that contain organic nitrogen (increasing TN) and colouring the water thereby reducing Secchi depth. Therefore, although conditions in the reservoir at times (particularly following floods) breach the TN and clarity standards, this was likely partly mediated by beech catchment inputs to the reservoir. Overall the nutrient status and clarity of the reservoir are indicative of good water quality for its drinking water supply and ecosystem health values.

Bi-monthly monitoring of nutrient status in the Maitai Reservoir by NCC has commenced as of October 2015 as part of the NPS-Freshwater reporting requirements and is expected to enable in the future a more robust assessment of the nutrient status of the reservoir in relation to the NRMP standards.

Reservoir trace metals

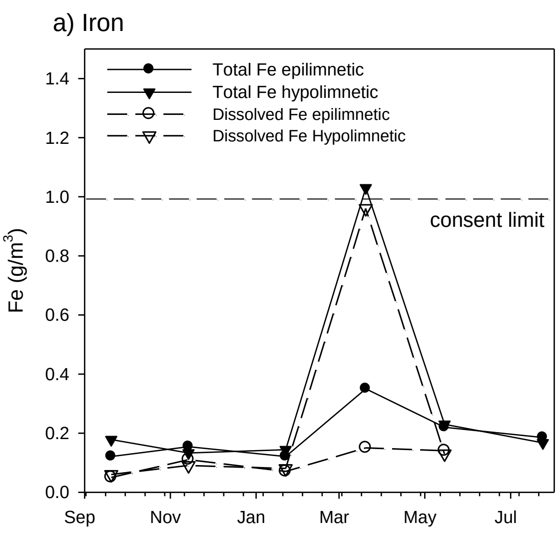
Concentrations of Fe were relatively low in epilimnetic (0 m–10 m) waters of the reservoir over most of the monitoring period (Figure 13). Dissolved Fe was mainly around 0.1 g/m^3 (median 0.11 g/m^3), but there was a moderate peak of up to 0.35 g/m^3 in March. Median epilimnetic concentrations were below concentrations that have been reported for other New Zealand waters (0.12 mg/m^3; Daughney 2003).

A similar seasonal pattern was evident for Fe concentrations in the hypolimnion as surface waters; however, the summer peak was more pronounced with dissolved Fe concentrations of being 0.96 g/m^3 in March. This concentration was marginally less than the 1 g Fe/m^3 consent limit for the reservoir backfeed. The release of lake sediment-bound toxicants such as Fe and Mn during anoxic periods has previously been thought to result in elevated concentrations of these trace metals in backfeed waters (Holmes 2010). Dissolved oxygen was anoxic from the bottom to approximately 15 m depth at the time of the peak concentrations in March 2014, indicating conditions were favourable for Fe solubilisation. There are presently no trigger values cited in ANZECC (2000) for concentrations of dissolved Fe due to insufficient data related to toxicity. A Canadian trigger value of 0.35 g/m^3 has been published for dissolved Fe related to protection of aquatic life in British Columbia rivers (Phippen et al*.* 2008). This takes into account acute and chronic toxicity studies that identified sensitivity of various aquatic species (e.g. mayflies, mussels, and juvenile trout) ranging between 0.21–0.4 g dissolved Fe/m^3 (Warnick & Bell 1969; Milam & Farris 1998; Linton et al. 2007). The occurrence of dissolved Fe concentrations in the Maitai Reservoir hypolimnion, well in excess of these levels, suggest there could be associated toxicity effects on aquatic life within the reservoir and downstream of the backfeed during peak anoxic periods. Oxidised Fe is deposited on river substrates downstream of the backfeed (see Section 2.5.4).

It is expected the range of dissolved Fe observed in the reservoir hypolimnion over this study could have toxic effects on aquatic life within the Reservoir and downstream of the backfeed. A preliminary examination of toxicity triggers for dissolved Fe would suggest concentrations in excess of 0.35 g dissolved Fe/m^3 could affect aquatic life. This is based on toxicity studies from North America on a range of freshwater species (Phippen et al*.* 2008). Toxicity of Fe is mediated to an extent by pH (Vuori 1995), and the more alkaline pH of the Reservoir associated with the limestone geology could potentially enhance these toxic effects (Kelly & Shearer 2013).

Concentrations of Mn showed similar patterns as for Fe. Dissolved Mn in the hypolimnion peaked at concentrations of 0.47 g/m^3 during March. This did not exceed the consented limit of 1 g/m^3 for the Maitai Reservoir backfeed. Historically, dissolved Mn concentrations measured in the backfeed have been up to 1.2 g/m^3. Concentrations of Mn in the epilimnion were consistently lower, with a maximum concentration of 0.032 g/m^3. The ANZECC (2000) guideline for Mn concentration in freshwaters for the protection of aquatic life is 1.2 g/m^3. Therefore concentrations observed during this monitoring period were lower than half of this ecosystem health benchmark (ANZECC 2000). Generally, toxicity thresholds are well in excess of the consent limit of 1 g/m^3 of dissolved Mn (Holmes 2010). Consequently toxicity to aquatic life associated with Mn concentrations in the reservoir hypolimnion is expected to be unlikely.

The NRMP cites water standards for toxicants for both Class C and B waters equivalent to the 95% level of protection for aquatic life. On this basis, concentrations of Mn observed in reservoir waters are unlikely to exceed these levels of 1.9 g/m^3. ANZECC (2000) does not cite 95% levels of protection of aquatic life for Fe, and therefore interpreting reservoir concentrations of dissolved Fe relative to the NRMP water standards is not possible. However, based on preliminary examination of toxicity triggers for dissolved Fe from overseas literature (Phippen et al*.* 2008), it is possible that toxicity effects of dissolved Fe on sensitive species may occur in the reservoir bottom waters. It should be noted, however, that these periods of high Fe concentrations occur simultaneously with anoxia, and therefore chronic metal toxicity is likely to be of minor concern relative to the acutely toxic conditions associated with anoxia. The outflow of reservoir waters containing high concentrations of dissolved Fe to the Maitai South Branch (via the backflow) is likely to be of greater concern in a management context, and is addressed in subsequent sections on river water quality (see Section 2.5.4).



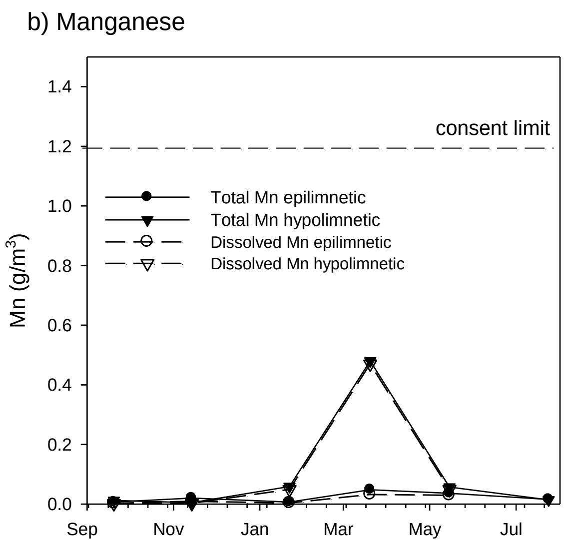


Figure 13. Bi-monthly concentrations of total and dissolved iron and manganese in the epilimnion (0 m–9 m) and hypolimnion (20 m) at the Maitai Reservoir valve-tower (Site W1) over the 2013–2014 monitoring period.

2.2.4. Reservoir sediment quality

Sediment quality in the Maitai Reservoir was assessed on two occasions (2013 and 2016) to understand

- biological oxygen demand (BOD) of reservoir sediments contributing to reservoir DO depletion (Kelly 2014),
- oxidation reduction characteristics (redox) that could contribute to nutrient release during reservoir anoxic periods (Kelly 2014), and
- solubilisation of trace metals bound to sediment particulate matter (2016).

Sediment characteristics varied at seven sites in the Maitai Reservoir covering the main basin and shallower river-delta areas of the two inflow tributaries (Table 3). Water depth at the sites varied between 5 m (near the west inflow) and 24 m (valve tower site). Redox potential in surface sediments (0 cm–10 cm) was negative at all sites, ranging between -312 and -402 mV. These highly negative redox values indicate that sediment surface layers are anoxic over most of the reservoir bottom, and are not localised to portions of the reservoir.
Oxygen demand of sediments, measured as total biological oxygen demand ($tBOD_5$), provides a surrogate measure of oxygen consumption in sediments. The $tBOD_5$ in reservoir sediments varied between 200 mg O_2/kg and 540 mg O_2/kg. The highest $tBOD_5$ rates occurred in deeper portions of the valve tower basin, at Site S7 and closer to the North Branch confluence at Site S4. Sediment at Site S5 was more sandy (high bulk density, low organic content) and had a corresponding low $tBOD_5$ rate (< 200 mgO_2/kg sediment). This site may be influenced by riverine sediment sources from the North Branch inflow, and may be too shallow to allow fine organic material to settle.

Nutrient content of sediments were similar across the seven sites, with the exception of Site S5, which had both low N and P content (Table 3). This was likely related to the low organic content of sediment at Site S5. Sediment P content ranged between 32 mg/100 g and 79 mg/100 g sediment and was greatest at site S2. Sediment P content was relatively low by comparison to other medium-sized South Island lakes such as Lakes Johnson and Hayes (M. Schallenberg, University of Otago; unpublished data), which had mean sediment P content of 120 mgP/100 ml and 101 mgP/100 ml, respectively.

Experiments conducted to examine the potential for the release of P from sediment under anoxic hypolimnetic conditions found that the rates varied considerably between sites (Figure 14; data from M. Schallenberg, University of Otago). Sediment from most of the Maitai Reservoir sites showed evidence of some P release under anoxia, although sites S5 and S7 had negative rates, which indicated no P release. The occurrence of negligible extractable P in sediments at some sites, suggests either that: all extractable P has previously been solubilised, and / or limited extractable P occurs in the sediment. Highly negative redox conditions at Site S7 may already have contributed to extractable P being solubilised, because anoxic bottom-water conditions were starting to occur in the valve tower basin around the time of sediment coring in September. At Site S5 there appears to be very low overall P content in the sandy sediments.

Table 3. Sediment chemistry at seven sites in the Maitai Reservoir on 29 October 2013, and from trace metal sampling conducted in 25 January 2016.

Sediment parameters	**Units**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Temperature	°C	15.2	12.4	10.7	10.5	14.8	10.6	10.2
Depth	m	5.1	15.5	21	23	5.2	20.5	24
Redox	mV	-402	-369	-312	-379	-368	-381	-395
Bulk density	g dry wt/ml	0.262	0.096	0.153	0.208	0.599	0.298	0.107
Organic matter	g /100g dry wt	15.8	11.9	8.8	12.4	6.8	11.3	11.5
Total nitrogen	g/100g dry wt	0.44	0.32	0.3	0.32	0.1	0.27	0.29
Total phosphorus	mg/100g dry wt	73	79	65	70	32	68	64
Phosphorus release rate	µg/g dry wt/d	0.065	0.007	0.042	0.048	-0.147	0.242	-0.005
Total BOD ($tBOD_5$)	mg O_2/kg	270	380	320	500	< 200	300	540

Estimated sediment P release rates were lower than observed in other South Island lakes analysed as part of a wider study. Rates for Lake Johnson were five times greater, and those for Lake Hayes were around double those estimated for the Maitai Reservoir (Figure 14). Hypertrophic Lake Ellesmere, included for additional comparison, also had much greater P release rates than the Maitai Reservoir sediment. Both Lakes Hayes and Johnson are moderately eutrophic, with sediment organic material likely to be comprised mostly of phytoplankton. Such lakes are likely to be higher in sediment P content than the Maitai Reservoir. The Maitai Reservoir has a lower phytoplankton biomass, and is likely comprised of allochthonous catchment material such as beech forest leaf litter (Kritzberg et al. 2004). Leaf litter often contains relatively low levels of nutrients (N and P) that are taken up by the tree prior to senescing and falling. Much of the Maitai Reservoir basin was cleared of vegetation prior to infilling. However, it is possible that some organic material associated with the remaining terrestrial forest (e.g. roots, tree stumps) have been slowly decomposing, thereby increasing oxygen demand in the lake bottom. These materials are also likely to be low in nutrient content and therefore may not contribute significantly to internal loads. Overall, the relatively low P release rates for the Maitai Reservoir sediments supports the observations of only moderate increases in hypolimnetic TP concentrations during anoxic periods in the Maitai Reservoir.

Analysis of cation chemistry during the sediment P-release experiments under anoxic conditions indicate considerable increases in the concentration of calcium (as carbonate) and sulphur (as sulphate) when sediments become anoxic. This suggests that much of the sedimentary Fe and Mn in reservoir sediments are likely to be bound to sulphate and carbonate complexes rather than phosphate, which are then preferentially solubilised under negative redox conditions. This assists in understanding why P (as phosphate) is not released in significant quantities during hypolimnetic anoxia, despite obvious increases in Fe and Mn occurring in anoxic waters. Large portions of the reservoir drainage area upstream consists of limestone geology associated with the Dunn Mountain mineral belt. This is likely to contribute these cation-bound metal precipitates to the reservoir sediments.

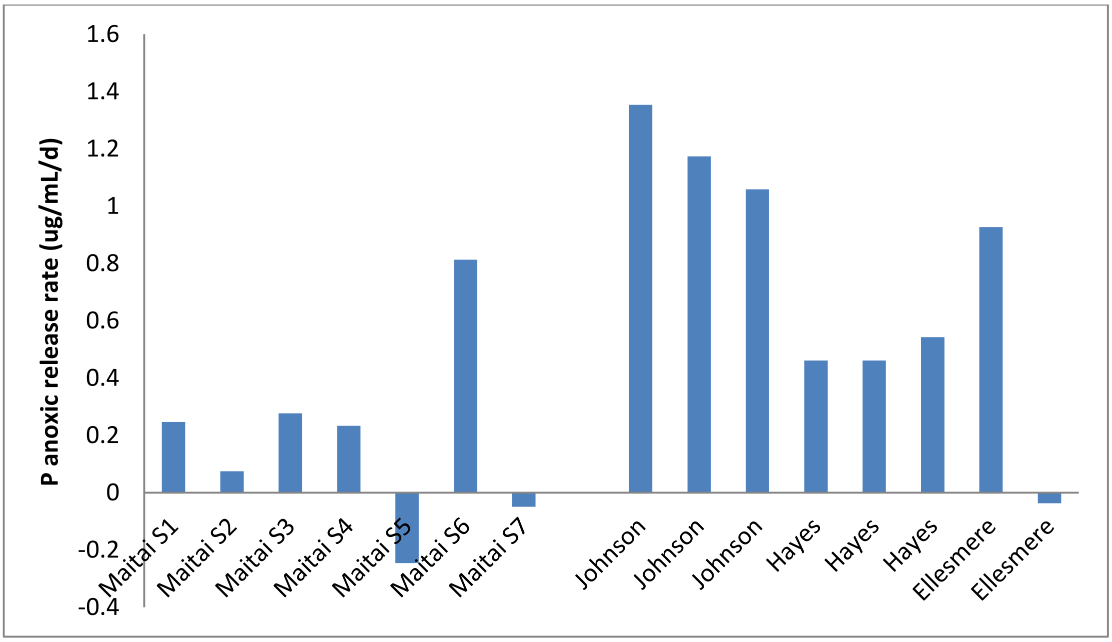


Figure 14. Phosphorus release rates from lake surface sediments in the Maitai Reservoir incubated under anoxic conditions. Comparison data from Lakes Hayes, Johnson, and Ellesmere are also included. Unpublished data from M. Schallenberg, University of Otago.

Sediment trace metals

Sediment trace metals were sampled in the Maitai Reservoir and two inflow tributaries (in January 2016) to assess the degree to which the metal-rich geology of the upper catchment influences reservoir sediments (Table 4). As has previously been reported for the Maitai River (Sneddon & Elvines 2012; Allen et al. 2014), sediments in the Maitai Reservoir contained high concentrations of chromium (Cr) and nickel (Ni). Concentrations of both these trace metals exceeded ANZECC (2000) high trigger concentrations for the protection of aquatic life. It is largely unknown the extent to which these two metals may affect reservoir biota, but the species composition of benthic macroinvertebrates in reservoir sediments are lower in diversity and abundance than observed in other coastal lakes in the region (discussed in Section 2.2.7).

The North Branch tributary inflow also had high concentrations of chromium and zinc in river sediments, and is presumed to be the source of high metals in reservoir sediments. Mill Creek, which drains a smaller catchment area outside of the Dunn Mountain mineral belt had much lower trace metal concentrations, and did not exceed the ANZECC (2000) trigger values.

Annual monitoring of a range of trace metals (including those identified in Table 5) is conducted annually for reservoir source water, and high concentrations of trace metals, with the exception of iron and manganese which are solubilised during anoxic periods, have not be measured (Alex Miller, Nelson City Council, personal communication 22 December 2015).

Table 4. Trace metal concentrations in sediments at seven sites in the Maitai Reservoir sites and two inflows (near reservoir confluence) sampled on 16 January 2016. Also shown are the ANZECC (2000) low and high triggers concentration values for the protection of aquatic life.

Site	Total Arsenic mg/kg	Total Cadmium mg/kg	Total Chromium mg/kg	Total Copper mg/kg	Total Lead mg/kg	Total Mercury mg/kg	Total Nickel mg/kg	Total Zinc mg/kg
S1	3	0.34	97	34	11.6	0.1	136**	90
S2	4	0.2	460**	49	12.1	0.15	570**	103
S3	3	0.16	480**	49	12	< 0.10	560**	96
S4	3	0.15	550**	44	8.4	0.1	690**	83
S5	< 2	0.12	690**	45	5.1	< 0.10	960**	86
S6	3	0.17	570**	51	10.3	0.11	720**	97
S7	4	0.17	490**	47	11.3	0.14	640**	107
N. Branch	< 2	< 0.10	670**	34	3	< 0.10	930**	61
Mill Ck.	5	0.2	22	27	10.1	< 0.10	18	71
ANZECC Low/High Triggers	20/70	1.5/10	80/370	65/270	50/220	0.15/1	21/52	200/410

* breaches low ANZECC ISQG trigger for aquatic life
** breaches high ANZECC ISQG trigger for aquatic life

The NRMP cites standards for sediment-bound toxicants for both Class C and B waters equivalent to the ANZECC (2000) low trigger values (see Table 4). Concentrations of both Cr and Ni exceeded these NRMP standards at all reservoir sites sampled, as well as at the North Branch inflow. The pattern of high Cr and Ni in sediments is prevalent throughout portions of the Maitai catchment affected by drainage from the Dun Mountains mineral rich areas (Sneddon & Elvines 2012; Kelly & Shearer 2012; Allen et al. 2014). Therefore it is unlikely that sedimentary-bound Cr and Ni would ever meet these standards cited in the NRMP, and presently are well in excess of the ANZECC (2000) high trigger values in both the reservoir and Maitai River. This is unrelated to operations of the reservoir, although persistent anoxic conditions in reservoir bottom waters could exacerbate the toxicity effects of trace metal by enhancing concentrations of dissolved metals which are far more toxic.

2.2.5. Maitai Reservoir phytoplankton and zooplankton

Only limited investigation has been conducted into phytoplankton communities of the Maitai Reservoir, which is generally recognised to be of low phytoplankton productivity (Stark 2000). Of greatest concern to drinking water, contact recreation and food gathering is that some species or strains of cyanobacteria produce highly potent neurotoxins, hepatotoxins or dermatotoxins ('cyanotoxins'). Commencing in around the year 2000, there has been an apparent rapid increase in the incidence of potentially toxic cyanobacterial blooms in New Zealand (e.g. Wood et al*.* 2006). Eutrophication due to increasing nutrient inputs appears to be a major driver of increasing dominance of cyanobacteria in lakes (e.g. lowland lakes in Waikato). Hamilton et al*.* 2010 and Paul et al*.* 2012 demonstrated a positive correlation between cyanobacterial densities in lakes and the percentage of a lake's catchment that is in pasture. Regional and district councils in New Zealand have statutory obligations to protect the health and wellbeing of their constituent populations. When cyanobacteria biovolumes in a lake exceed defined threshold levels (MfE 2009), the lake (or the area within a lake where the threshold biovolume exceedance occurs) may be closed to contact recreation. Similarly, alternate drinking water supplies or specific additional treatment may be required when thresholds of potentially toxic cyanobacteria in drinking water are exceeded (Kouzminov et al*.* 2007).

Phytoplankton species and biomass can be highly dynamic in lakes, changing over daily or weekly time scales (e.g. Marshall & Peters 1989). Therefore, caution should be taken when interpreting phytoplankton data from one-off samplings.
The phytoplankton community in the Maitai Reservoir were assessed to obtain a snapshot of the density and composition of the community (Kelly & Shearer 2013). The dominant taxon detected in the Maitai Reservoir in April 2013 was a colonial cyanobacteria species of the genus *Cyanodictyon* (Table 5). This genus, for which 11 species have been reported, is not known to have toxic or flavour tainting properties. At the intake tower site, another cyanobacteria species, *Aphanocapsa* sp., was also relatively abundant at 890 cells/ml. Some strains of this cyanobacteria genus have been linked with cyanotoxin production (microcystin), although this would not mean that cyanotoxin risk is necessarily an issue in the Maitai Reservoir. Toxin production

can depend on a range of properties including the particular species, strain, and its density (Wood et al. 2012). *Aphanocapsa* is a very small celled species (approximately 1 µm diameter) thus although counts were elevated (Table 5), the total biovolume was low (Wood et al. 2012). As a precautionary measure phytoplankton samples were further tested for any known toxin producing genes using molecular techniques. No genes involved in toxin production were detected indicating very low likelihood for cyanotoxin risk (pers. comm. Susie Wood, Cawthron Institute, 11 June 2013).

The majority of other taxa that were abundant in the Maitai Reservoir included species characteristic of oligotrophic New Zealand lakes, including colonial green algal taxa (*Sphaerocystis*, *Oocystis*, *Monorahidium*), *Cryptomonas*, and a number of diatom taxa (*Nitzschia*, *Cyclotella*). The dinoflagellate *Certatium*, which can cause flavour tainting if present in high numbers, was present in very low abundances (< 4 cells/ml). Overall the composition of phytoplankton in the Maitai Reservoir was quite typical of oligotrophic lakes. The presence of *Aphanocapsa* sp. would likely only be of concern if obvious blooms were to form, and this is unlikely in an oligotrophic system such as Maitai Reservoir. Should significant internal nutrient flux of nutrients (particularly phosphorus) occur in the reservoir during times of hypolimnetic anoxia, this could facilitate greater biomass of phytoplankton in spring following the winter mixing period. Further monitoring of chlorophyll-*a* concentrations over the seasonal mixing cycle could be pursued to better understand these dynamics.

Table 5. Mean cell counts of phytoplankton by order of abundance from sampling through the mixed layer (0-5 m) in the Maitai Reservoir on 4 April 2013.

Species	Group	Mid-lake (cells/ml)	Tower (cells/ml)
Cyanodictyon sp.	Cyanobacteria	2000	6900
Aphanocapsa sp. *	Cyanobacteria	0	890
Sphaerocystis sp.	Chlorophyta	810	0
Monoraphidium sp.	Chlorophyta	110	130
Oocystis sp.	Chlorophyta	88	330
Cryptomonas sp.	Cryptophyta	65	77
Small unicells *(< 5 µm)*	Assorted	64	0
Peridinium sp.	Dinoflagellates	63	6
Small flagellates *(< 5 µm)*	Assorted	23	10
Crucigeniella sp.	Chlorophyta	21	0
Elakatothrix sp.	Chlorophyta	9	4
Cyclotella sp.**	Diatoms	8	2
Ceratium sp.	Dinoflagellates	4	2
Encyonema sp.	Diatoms	3	0
Coelastrum sp.	Chlorophyta	1	0
Gomphonema sp.	Diatoms	1	0
Navicula sp.	Diatoms	1	0
Nitzchia sp.	Diatoms	0	12

* Potential toxin forming species ** Potential taste/odour species

Abundances of zooplankton species were also assessed on one occasion, to characterise the composition of the community (Kelly & Shearer 2013). Metazooplankton (zooplankton > 150 µm) in the reservoir was comprised of four native zooplankton taxa, with the dominants being two crustacean species, *Daphnia carinata* and *Ceriodaphnia dubia* (Table 6). Exotic species of *Daphnia*, predominantly the North American *Daphnia pulex,* are spreading through lakes in New Zealand (Duggan et al*.* 2012). Reservoirs are often sites for incursion by invasive species because they offer a new lentic habitat that is largely devoid of lake species when they are formed and thus are colonised over time lake species (Henriques 1987). Because many exotic species are often highly adapted for spread, they often out-compete native fauna in colonising new sites. The presence of an entirely native zooplankton community in the Maitai Reservoir is thus encouraging. Larger-bodied daphnid taxa such as *Daphnia carinata* are known to be effective phytoplankton grazers (Burns & Schallenberg 2001). Thus the presence of this species could indicate that zooplankton would be effective at reducing phytoplankton should springtime phytoplankton production increase following the winter mixed period.

As with phytoplankton, zooplankton community dynamics are highly temporally dynamic. Thus one-off sampling events are difficult to interpret in terms of their influence on the ecology lake system (Table 6). This April 2013 sampling has provided a snapshot picture to document the presence of zooplankton in the reservoir, dominant species, and any potential invasive species.

The NRMP does not cite any standards associated with toxic cyanobacteria or other phytoplankton or zooplankton species.

Table 6. Mean zooplankton densities in the Maitai Reservoir over the 0–10 m mixed layer collected 4 April 2013.

Group	Taxa	Mean density (m^{-3})
Crustacea	*Daphnia carinata*	2.99
	Ceriodaphnia dubia	1.17
	Larval un-ID Crustacea	0.15
Copepoda	*Boeckella triarticulata*	0.16
	Microcyclops sp.	0.29
	Nauplii	0.24

2.2.6. *Maitai Reservoir aquatic macrophytes*

Aquatic macrophytes play many important roles in the ecology of lakes and reservoirs (Kelly & McDowall 2004). They provide habitat for zooplankton, invertebrates and fish, by providing a refuge to these animals from predators (Kelly & Hawes 2005). They can also provide food source to aquatic birds. Aquatic macrophytes and the microscopic algae that grow on them absorb nutrients from the water, competing against phytoplankton for nutrient resources. However, aquatic macrophytes can also become nuisance organisms if their growth and proliferation becomes excessive, as has occurred when certain exotic macrophytes have colonised shallow lakes in New Zealand (Howard-Williams et al*.* 1987). Reservoirs are often sites of exotic plant invasions due to conditions of greater water level fluctuations favouring tall exotic weeds, and because reservoirs are often very accessible they attract recreational boating access.

Two species have been observed to be present in the Maitai Reservoir, including the emergent species, *Typha orientalis* and the submerged species *Potamogeton cheesemanii* (Table 7). They both occurred along several areas of the reservoir's margin. The lack of prevalence by submerged macrophyte species was noted by Kelly and Shearer (2013), but subsequently some areas of the reservoir have been noted to be colonised by pondweeds (i.e., *P. cheesemanii*). However, low abundances and very low diversity of macrophytes in the Reservoir was noted to be unexpected (Kelly & Shearer 2013), as the reservoir has now been present for over two decades. Therefore colonisation would be expected to occur over such a timeframe (Henriques 1987; Closs et al*.* 2004). Other lakes in the Nelson-Tasman region such as the Kaihoka lakes and Lake Otuhie have diverse aquatic macrophyte communities, and this will be enhancing their ecological functioning, uptake of soluble nutrients and provide habitat for fish. Reasons behind the lack of macrophytes in the Maitai Reservoir are unknown. It is unlikely that the magnitude and frequency of water level fluctuations is a major factor in preventing macrophytes from growing between the depth of normal draw-down levels to the light extinction depth, or between 1.5–6 m (discussed in previous Section 2.2.2). It is possible colonist sources of aquatic macrophytes to the reservoir have been lacking, as there are no macrophytes present in upstream inflow streams that are steep and 'bouldery', and the reservoir has minimal access for boating or recreation which would also reduce the potential for introducing aquatic plant fragments, seeds, and spores. The only remaining transfer vectors would be aquatic birds (Champion & Clayton 2000; Closs et al*.* 2004). Importantly, this lack of colonist sources minimises risk of introduced aquatic weeds that could negatively impact the reservoir for its intended water uses and its ecological functioning.

Table 7. Aquatic macrophytes observed in the Maitai Reservoir in April 2013, and plants reported in historical surveys of three other lakes in the region; the Kaihoka lakes and Lake Otuhie.

Survey	Maitai Reservoir	Kaihoka Lake 1	Kaihoka Lake 2	Lake Otuhie
Cawthron April 2013-June 2015	*Typha orientalis* *Potamogeton cheesemanii*			
Drake et al. (2009) and R. Wells (pers. comm.) — sampled in July 1997.		*Typha orientalis* *Lilaeopsis* sp. *Glossostigma submersum* *Nitella pseudoflabellata* *Nitella hookeri*	*Typha orientalis* *Glossostigma submersum* *Lilaeopsis* sp. *"pratia-like species"* *Chara* sp. *Nitella* sp.	*Jointed wire rush* *Flax (emergent)* *Eliocharis* sp. *(emergent)* *Typha orientalis (emergent)* *Lilaeopsis* sp.

2.2.7. Maitai Reservoir macroinvertebrate communities

The macroinvertebrate communities of lakes comprise a diverse array of insect and other invertebrate fauna (Stark 1993a; Kelly & McDowall 2004; Drake et al. 2010; Ball et al. 2009). They provide an important portion of species diversity in lakes, and represent an important intermediary in the aquatic food web for fish (Kelly & Hawes 2005). Generally, the diversity of littoral zone macroinvertebrates remains quite stable throughout the year (Talbot & Ward 1987; Kelly & McDowall 2004). However, macroinvertebrate diversity has been shown to relate to nutrient status of lakes, but the relationship was non-linear with the main response occurring at the super-eutrophic end of the nutrient gradient (Timms 1982). Weatherhead and James (2001) also showed that littoral invertebrates were strongly influenced by physical gradients of depth and exposure. Kelly and Hawes (2005) demonstrated community composition of macroinvertebrates was related to invasive macrophytes.

Macroinvertebrates in the Maitai Reservoir were assessed on a single occasion in 2013 (Kelly & Shearer 2013), and compared against macroinvertebrate community attributes collected from 20 small South Island coastal lakes (Drake et al. 2010). Macroinvertebrates in the Maitai Reservoir were comprised of a moderately diverse range of taxa, with 14 taxa observed over the three sites (Table 8). Numerically, the community was dominated by molluscs including *Potamopyrgus* and unidentified species of fingernail clams, which together comprised 76% of the total invertebrate abundance. Both of these taxonomic groups could potentially have colonised the reservoir from the upstream river, as both occur in the rivers and were found in the North Branch. There were several lentic specialist taxa, including insects from the orders Odonata (dragonflies/damselflies), Trichoptera (caddis flies) and Diptera (flies, mainly chironomids). All of these insect species have flying adult stages, and thus would likely have colonised the reservoir from small ponds or wetlands in the area.

Comparatively speaking, the Maitai Reservoir had intermediate (between 30-75th percentile) invertebrate scores for invertebrate metrics which quantify the richness, diversity, and evenness of the invertebrate community in comparison to other South Island small lakes (Table 9). However, natural lakes in the Tasman region such as Kaihoka Lake and Lake Otuhie generally have more abundant and diverse invertebrate communities than the Maitai Reservoir. This could be related to two factors; the greater range of habitats within these natural lakes that had rich aquatic plant communities and the Maitai Reservoir could very well still be in the process of being colonised by new species because it is relatively young (25 years old) in comparison to other natural lakes (that would have formed centuries ago during the process of dune migrations and stream blockages along the Tasman coast; see Leathwick et al*.* 2010).

Table 8. Mean density of macroinvertebrates (and standard errors) at littoral sites (n=3) in the Maitai Reservoir on 4 April 2013.

Group	Taxa	Mean density (m^{-2})	SE of Density
Crustacea	Chydoridae	43.6	43.6
	Cyclopoida	82.8	42.9
	Ostracoda	7969	990
Diptera	Ceratopogonidae	34.9	23.1
	Chironominae	1825	1214
	Chironomus sp. "a"	222.2	125.6
	Cryptochironomus	662.3	457.2
	Tanypodinae	710.2	253.3
Mollusca	*Gyraulus*	17.4	17.4
	Potamopyrgus	15089	6851
	Sphaeriidae	4662	4389
Nematoda	Nematoda	169.9	94.6
Odonata	*Procordulia grayi*	17.4	17.4
	Xanthocnemis	8.7	8.7
Oligochaeta	Oligochaeta	6827	1753
Trichoptera	*Oecetis unicolor*	719.0	399.6
	Triplectides cephalotes	113.3	74.5
	Total density	39176	14818

An MDS ordination plot that graphically represents the similarity of the macroinvertebrate community composition of 18 South Island lakes in relation to each other is shown in Figure 15. From this cluster analysis, it can be seen that lakes with similar physico-chemical properties in terms of nutrient status, presence of macrophytes, and tannin staining form distinctive groupings of lakes. The Maitai Reservoir clusters together with a group of lakes that are characterised by low nutrients, but have low dominance by aquatic macrophytes mostly linked with dissolved tannin staining of their waters. Lakes that were most similar in their invertebrate community composition to the Maitai Reservoir included Lake Otuhie (Tasman), Lake Wilkie (Catlins) and the Māori lakes (South Westland). Overall the macroinvertebrate community of the Maitai Reservoir was of an intermediate diversity and abundance, with a combination of aquatic generalist (species that can inhabit both rivers and lakes) and lentic specialist species present in the Maitai Reservoir.

Although standards for macroinvertebrate community metrics have been cited in the NRMP for rivers and streams, there are no equivalent macroinvertebrate metrics for lakes and reservoirs. Hence, macroinvertebrate communities are only interpreted relative to other lakes in the region to provide insight as to the relative health of the community. On this basis the reservoir is considered to have an intermediate macroinvertebrate community relative to these other lakes.

Table 9. Macroinvertebrate metrics for the Maitai Reservoir, three other lakes in the region, and a percentile rank of the Maitai Reservoir against 18 South Island (SI) small lakes from Drake et al. (2009).

Variable	Maitai Reservoir	Kaihoka 1	Kaihoka 2	Otuhie	Maitai Rank 18 SI lakes (%)
Species richness	17	26	28	28	33.3
Total density (m^{-2})	39176	122014	95051	52918	39.9
Shannon diversity	1.71	1.78	2.02	2.10	73.3
Pielou evenness	0.60	0.55	0.61	0.63	60

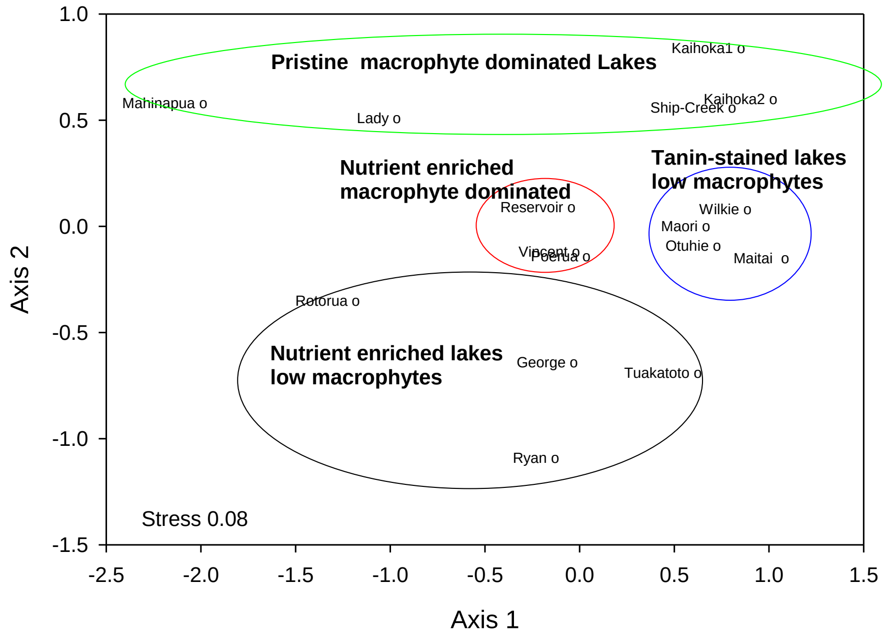


Figure 15. Multi-dimensional scaling ordination plot of the Bray-Curtis similarity of macroinvertebrate community from 18 South Island small lakes. Also shown are ellipses around clusters of lakes with hypothesised environmental habitat parameters characterising each cluster.

2.2.8. Maitai Reservoir fish community

Fish are essential components of lakes and reservoirs, affecting the food web structure (e.g., zooplankton composition), and water quality (bioturbation, zooplankton grazing of phytoplankton; Jeppesen et al. 1997; Jeppesen et al. 2000). Measurements of fish assemblage composition and abundance have been incorporated into the assessment of aquatic health indices of rivers (Karr et al. 1986; Joy & Death 2003) and attempts have been made to apply similar systems to lakes (Jeppesen et al. 2003). However, the high variability in lake morphology, bottom type and sampling efficiency (US EPA 1998) renders the monitoring of lake fish communities costly. The sampling effort required to obtain representative samples of fish assemblages in lakes is high because thorough surveys usually necessitate using a combination of sampling methods, such as gillnetting, seining, trawling and electrofishing (Wanzenböck et al. 2002).

Fish populations were surveyed on a single occasion to provide knowledge on the species inhabiting the Maitai Reservoir, their relative dominance, and main habitats utilised. These data are compared against fisheries survey data collected in the same manner (same fishing effort and season) from 18 small lowland lakes on the South Island (Drake et al. 2009). Four species were present in the Maitai Reservoir: longfin eel, upland bully, common bully, and brown trout. Common bully was the most numerically dominant in the reservoir, followed by upland bully, and longfin eel (Table

10). In terms of biomass, longfin eels were the largest component. Trout were not caught as part of this survey but have been reported in the reservoir from gillnet surveys (pers. comm. M. Rutledge, Department of Conservation). Catches in minnow traps, which extended through the littoral zone between 0 and 25 m, suggested fish were very rare or absent beyond 5 m depth in the reservoir. The greatest catches were from traps closest to lake shore margins in depths less than 0.3 m (Figure 16).

Table 10. Fish species and catch per unit effort (CPUE) from overnight fish surveys in the Maitai Reservoir in April 2013, and those from three Tasman district lakes in 2009 (Kaihoka lakes and Lake Otuhie). Also shown is the percentile rank of the Maitai Reservoir fish metrics in relation to 18 South Island small lowland lakes (Drake et al. 2010).

Variable	**Maitai Reservoir**	**Kaihoka1**	**Kaihoka2**	**Lake Otuhie**	**Rank 18 SI lakes (%)**
Fish richness (N)	4	2	1	4	14
Species	Common bully Upland bully Longfin eel Brown trout	Banded kokopu Longfin eel	Banded kokopu	Common bully Īnanga Longfin eel Shortfin eel	n/a
CPUE (fish/trap or net)	18.8	1.75	29.1	27.5	50
#Exotic fish sp.	1	0	0	0	50

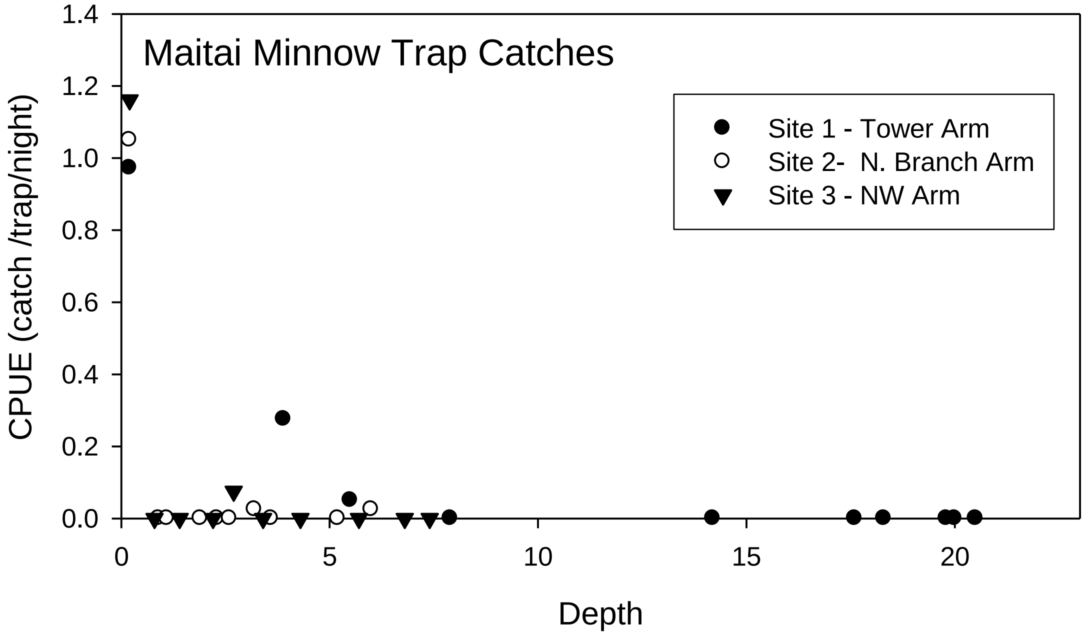


Figure 16. Overnight catch per unit effort (CPUE) of common and upland bullies in gee-minnow traps situated at varying depths in the Maitai Reservoir on 3-4 April 2013.

The fish community richness and overall catch abundances were intermediate to low in comparison to other South Island lakes (Drake et al. 2009). A possible reason for the lack of fish at deeper depths is the anoxic conditions below the thermocline. The fact that no exotic fish other than brown trout were detected in the Maitai Reservoir is a positive aspect for this reservoir. Many lakes in the 18-lake South Island dataset had populations of other exotic species such as European perch and goldfish. The lack of access to the Maitai Reservoir has probably minimised this risk. Populations of kōaro have been observed the North Branch of the Maitai River during subsequent spotlight monitoring (see Section 2.8.1); however these were not detected in the reservoir despite kōaro known to inhabit lakes (Kelly & McDowall 2004). Juvenile kōaro, which drift downstream following their emergence from eggs, could colonise the Maitai Reservoir but none were detected using the methods employed.

Most of the freshwater fish fauna present in rivers of the South Island northern regions are obligate migrants. Obligate migrants periodically utilise inland freshwater habitats (McDowall 2006) and coastal and estuarine resources at certain times and / or at particular periods of their life cycle. Some species complete essential portions of their lifecycles (e.g. reproduction) well inland while others achieve this far away at sea (e.g. eels). Species habitat preferences and climbing ability usually determine the distance inland they travel. Some species such as kōaro and longfin eels can migrate more than 100 km inland while others such as giant bully, smelt and īnanga are rarely found beyond the lower reaches of rivers or streams.

Some fish species (longfin eel, probably kōaro) presently residing in the reservoir are diadromous, however these populations likely have been derived from populations upstream of the Matai Reservoir. In particular, it was evident from the size structure of the eel population that limited recruitment by juvenile upstream migrants has occurred (Figure 17). No longfin eels of less than 600 mm fork length were observed in the Maitai Reservoir, however, several longfin eels in the 180-400 mm size class have subsequently been recorded from the North Branch in spotlight and electric fishing surveys. In contrast, the dataset for all other South Island lakes showed a much more normally distributed size distribution. Therefore, although there has been some transfer of longfin eels of various size classes upstream of the Maitai Reservoir via trap and transfer (see Section 2.8.2), these transfer efforts have been limited and may not have targeted juvenile elvers migrating upstream, and thus it has not maintained a normal age / size population structure. In the case of kōaro, no adults were detected in the Maitai Reservoir, possibly indicating that the species has also not been unable to obtain access to the reservoir, and only low densities of large adult fish were observed in the North Branch tributary.

The size of the dam wall (155 m log spillway) and slope of the dam face would not entirely rule out that fish with good climbing ability, as longfin eel and kōaro possess, could bypass the structure during times when flow was overtopping the spillway. Flows over the dam are quite regular, and this has been further regulated by the installation of a pump-system to maintain flow over the spillway surface during the summer migration period. However, the distance of climb and relatively recent modifications to the spillway indicate that the dam face surface has previously prevented these species from climbing over the dam. Fish passage options, which could potentially consist of further modifications to the dam face, or more extensive trap and transfer are most likely required to enable sufficient native fish passage into the Maitai Reservoir and North Branch tributary to maintain these populations. These points are discussed in greater detail in the fish passage section of the assessment (Section 2.8.2).

No standards for fish communities or passage have been cited in the NRMP, however both are relevant to aquatic habitat standards prescribed for Class B waters (no standards are cited from Class C waters), which indicate habitat should not be impaired. Based on comparison of fish community abundance and composition relative to other lakes in the region, the reservoir is considered to have a poor fish community health relative to other lakes. The limited passage of diadromous species into the reservoir, and poor water quality conditions caused by low DO in cold-water refuge habitats are thought to be the two main contributors to this result.

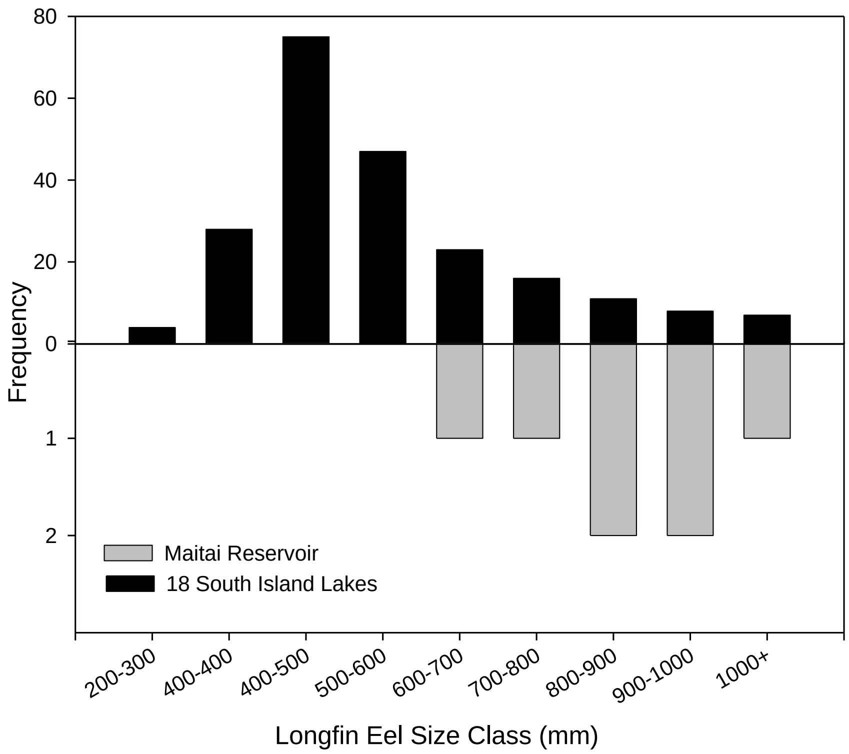


Figure 17. Size distribution histogram of longfin eels in the Maitai Reservoir (grey bars) compared against the size distribution of longfin eels caught in a pooled dataset from 18 lakes on the South Island (South Island lake data from Drake et al. 2009).

2.2.9. Summary of key findings

Summary – Reservoir water quality and water level fluctuations

- Water levels in the Maitai Reservoir are operated over a reasonably narrow range by comparison to operations of most reservoirs (mean drawdown 1.4 m between 2004 and 2013), and are anticipated to maintain healthy ecological conditions in the lake-edge littoral community, which extends to the euphotic depth of around 6 m.
- Water quality in the Maitai Reservoir is characterised as a low-intermediate level of productivity (mesotrophic score of 2.0), and water clarity was moderate (Secchi of 4.0 m) by comparison to other small South Island lakes. The pH in the reservoir is slightly alkaline (pH 8), and likely influenced by limestone geology of several rock formations (principally Dun Mountain, Stephen's argillite) in its catchment. NRMP water quality standards for clarity can at times be exceeded, mostly as a result of high humic organic materials derived from the beech forest catchment inflowing to the reservoir during floods.
- Based on monitoring data for 2013-2015, thermal stratification in the Maitai Reservoir over spring / summer contributes to deoxygenation in its hypolimnion, which was near-anoxic between 10 and 25 m depth. The progression of the thermocline and deoxygenation was highly consistent over two years for which continuous monitoring of reservoir DO and temperature data were available. This is consistent with patterns of low DO in bottom waters of deep lakes observed in other lakes in the region, however it does present ecological issues associated with the supply of backfeed water to the Maitai South Branch during stratified periods. Anoxic conditions in the reservoir breach the 90-110% DO NRMP standards for lakes and reservoirs. More importantly, these depleted DO conditions overlap all cool-water habitats that could provide thermal refugia for sensitive species in summer when surface waters (the only remaining oxic zone) can exceed the NRMP 22°C mean daily temperature standard.
- Highly reducing conditions in deep reservoir sediments result in solubilisation of trace metals into the bottom waters of the reservoir, principally dissolved Fe and Mn. These concentrations can occasionally exceed consent conditions for water discharged from the backfeed, as well as NRMP standards for contaminants, and result in the export of soluble metals into the Maitai South Branch downstream of the backfeed. It is more difficult to interpret the significance of high levels of dissolved Fe in the reservoir and backfeed waters because no ANZECC guidelines are cited, but based on North American criteria it suggests that concentrations exceed levels to protect sensitive aquatic life. However, it is expected that oxidation and precipitation of metals occurs rapidly in the river.
- Results from Maitai Reservoir monitoring and laboratory experiments indicate that only limited solubilisation of particulate bound P and N in reservoir

sediments occurs under anoxic conditions. Redox conditions appear to favour sulphur and calcium reduction pathways over phosphate reduction. This means that internal loading of nutrients is not of great concern for water quality in the reservoir and backfeed water outflowing to the Maitai River.

- Phytoplankton and zooplankton communities present in the Maitai Reservoir are mostly characteristic of low productivity systems, dominated by small-celled cyanobacteria, colonial greens and diatoms. The zooplankton community was comprised predominantly of the native daphnids *Daphnia carinata* and *Ceriodaphnia dubia*. These species would be effective phytoplankton grazers and could promote good water quality in the reservoir should phytoplankton increase in spring following the winter mixed period.
- Submerged macrophyte species were of low abundance and diversity in the reservoir, despite suitable substrata and a moderate reservoir water-level operating regime. Possibly a lack of localised colonist sources along with the reservoir's isolated access have meant that only limited macrophyte species have colonised the system. The absence of macrophytes does result in poorer quality habitats for aquatic biota, but would minimise its use by aquatic waterfowl that could contribute to faecal bacteria loads unfavourable to the human drinking water uses of the water.
- The macroinvertebrate community in the reservoir was of intermediate abundance and relatively low diversity by comparison to other South Island lakes, most likely related to the limited diversity of habitats and lack of submerged macrophytes. Unlike for rivers, no NRMP standards are cited for macroinvertebrates in lakes and reservoirs.
- Fish populations consisted of four species, numerically dominated by common bullies, followed by upland bullies and longfin eels. Kōaro were found in the river and juveniles may inhabit the reservoir, but were not detected during this survey, possibly due to the autumn timing. Brown trout are also known to be present in the reservoir but were not observed in the present survey principally due to survey methods used (fyke nets, gee-minnow traps).
- Near-anoxic conditions in the hypolimnion likely limited fish to the shallow portions of the Maitai Reservoir, and no fish were caught below 5 m depth during a survey in 2013. The heavily-skewed size class structure of longfin eels towards large (>600 mm) adult individuals indicates that limited or possibly no recruitment is occurring to the reservoir from downstream juvenile migrants.
- Upstream fish passage appears to be an issue for longfin eels and kōaro populations accessing the Maitai Reservoir and North Branch. Landlocked lake populations of this species can occur, but any kōaro in the North Branch would historically have been from a sea-run population. Kōaro can live quite long periods with individuals of 16+ years found in this region. Thus the finding of only few very large individual kōaro in the North Branch suggests

uncertainty regarding whether migrants are regularly bypassing the dam face to access the upper catchment.

- No standards for fish communities or fish passage have been cited in the NRMP, but both are relevant to aquatic habitat standards prescribed for Class B waters, which indicate habitat should not be impaired. Relative to other lakes in the region the reservoir is considered to have a poor fish community health. The limited passage of diadromous species into the reservoir, and poor water quality conditions caused by low DO in cold-water refuge habitats are thought to be the two main contributors to this result.

2.3. Hydrology of the Maitai River and influence of the Maitai Reservoir

The flow regime with regard to water abstraction in the Maitai catchment can be divided into three periods: pre-dam natural flow (prior to 1963); pre-dam with abstraction (1963-1987); and post dam with abstraction (since 1987).

Water abstraction for town supply began in the Maitai catchment in about 1963 when a pipeline was constructed to take water directly from an intake grating on the Maitai River South Branch. With no storage available it is likely that water was taken as and when required, consequently having a substantial effect on stream flows and ecology. Hewitt and Kemp (2004) estimated that the (summer) median and low flow (95 percentile) pre-dam abstracted flows were reduced by 13% and 52%, respectively, compared with pre-dam natural flows.

Construction of the Maitai Reservoir was completed in 1987, providing surety of supply for Nelson during extended summer dry spells. The abstraction regime associated with the dam substantially reduced the impact of abstraction on low flows, with (summer) median and low flow (95 percentile) estimated to be reduced by 18% and 9%, respectively, compared with natural flows (Hewitt and Kemp 2004).

2.3.1. Abstraction and backfeed operations

Operational usage of Maitai River-water and subsequent return of Maitai Reservoir water to the Maitai South Branch via the backfeed were examined over the past five years of operations between 2010 and 2015 (Table 11). Abstraction rates of water from the Maitai River varied considerably, depending on water demand by the treatment plant as well as seasonal availability of water in the Maitai River. Abstraction rates ranged between 0 and 585.6 L/s, which on a mean annual basis equated to between 73.2 and 90.8 L/s over the 5-year period.

Mean daily flow rates of water discharged from the backfeed ranged from 0 to 328.6 L/s over the same period between 2010 and 2015 (Table 11). On an average annual basis this equated to between 105.5 and 123.9 L/s of water discharged via the backfeed, approximately 30% greater than water abstracted from the river for its municipal supply. There were obvious increases in the proportional composition of backfeed water in the river below the weir during low flow periods, which predominantly occurred over the summertime period (Figure 18). During low flows (< 250 L/s), water discharged from the backfeed often comprised greater than 90% of the total river flow downstream of the backfeed weir. This flow would be further augmented with flows from the Maitai Reservoir spillway should it be operating at the time of low flows, however this was often not the case.

Overall, operations of the Maitai Reservoir augmented flows in the Maitai River below the South Branch weir backfeed discharge, with backfeed water comprising a large proportion of total Maitai River flows during low flow periods. These were most likely to occur in summer, but occasional winter low flow periods have occurred (e.g., Stark & Hayes 1996).

Table 11. Annual flow statistics over the five most recent operating years (and 5-year average) for the rates of abstraction of Maitai River South Branch water, rates of return flows via the backfeed discharge to the Maitai South Branch, and river flows recorded at the Maitai Forks recording site.

Flow Statistic	2010-11	2011-12	2012-13	2013-14	2014-15	5-year average
South Branch Extraction rate (L/s)						
Mean	90.8	73.2	84.1	88.2	88.9	85.0
Min.	0.0	0.0	0.0	0.0	0.0	0.0
Max.	306.8	499.9	310.9	585.8	306.6	401.9
Backfeed Flow (L/s)						
Mean	122.6	105.5	116.2	118.7	123.9	117.4
Min.	0.0	0.0	0.0	0.0	0.0	0.0
Max.	328.6	313.7	318.7	314.9	317.2	328.6
Flow at Maitai Forks recorder (L/s)						
Mean	1229	1607	1814	1276	953	1375.9
Min.	168.0	243.4	188.5	175.5	160.2	160.2
Max.	50968	90805	429783	476774	75769	429783

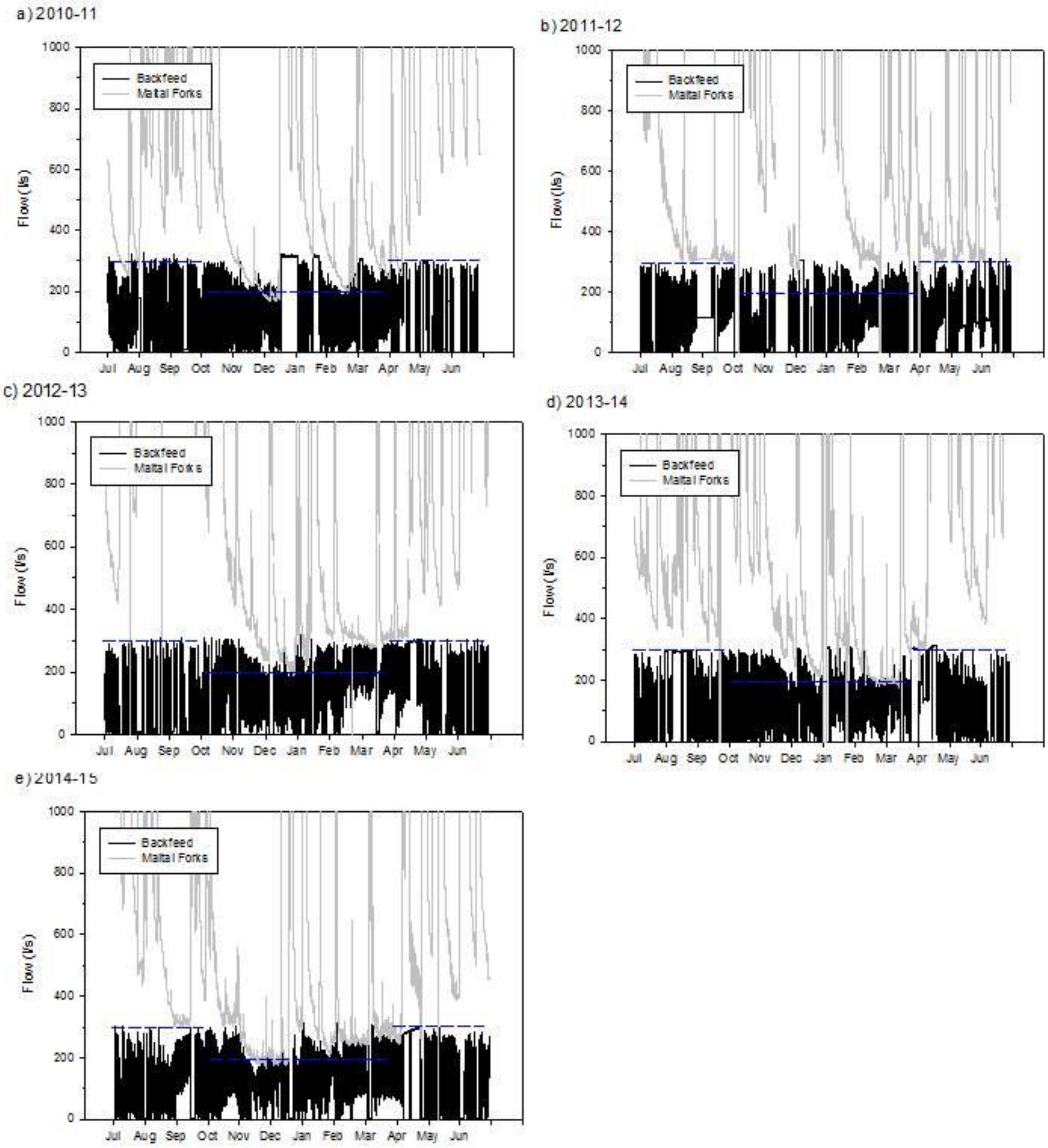


Figure 18. Flows from the Maitai River backfeed to the Maitai River at the South Branch weir and flows in the Maitai River at the Forks recorder site for the five most recent operating years of the Maitai municipal water supply. Data supplied by Nelson City Council and Tasman District Council.

2.3.2. Flow records

The hydrological analyses presented in the following sections used flow statistics based primarily on flow data from the ‘Maitai at Forks’ hydrometric monitoring site

(Figure 19), provided by Tasman District Council (TDC)[14]. This site is located a short distance downstream of the reservoir spillway and backfeed, providing a reliable point of reference for flows affected by the Maitai Reservoir. Data from two separate sites ('Maitai at Forks' (1997-2015) and 'Maitai at Forks Weir' (1990-1998)) were combined[15] to provide a record spanning 23 full hydrological years (August–July). The catchment area for Maitai at Forks is 35.7km^2.

[14] This site is owned by Nelson City Council

[15] These flow sites are located approximately 100 m apart, with no significant tributaries in between.

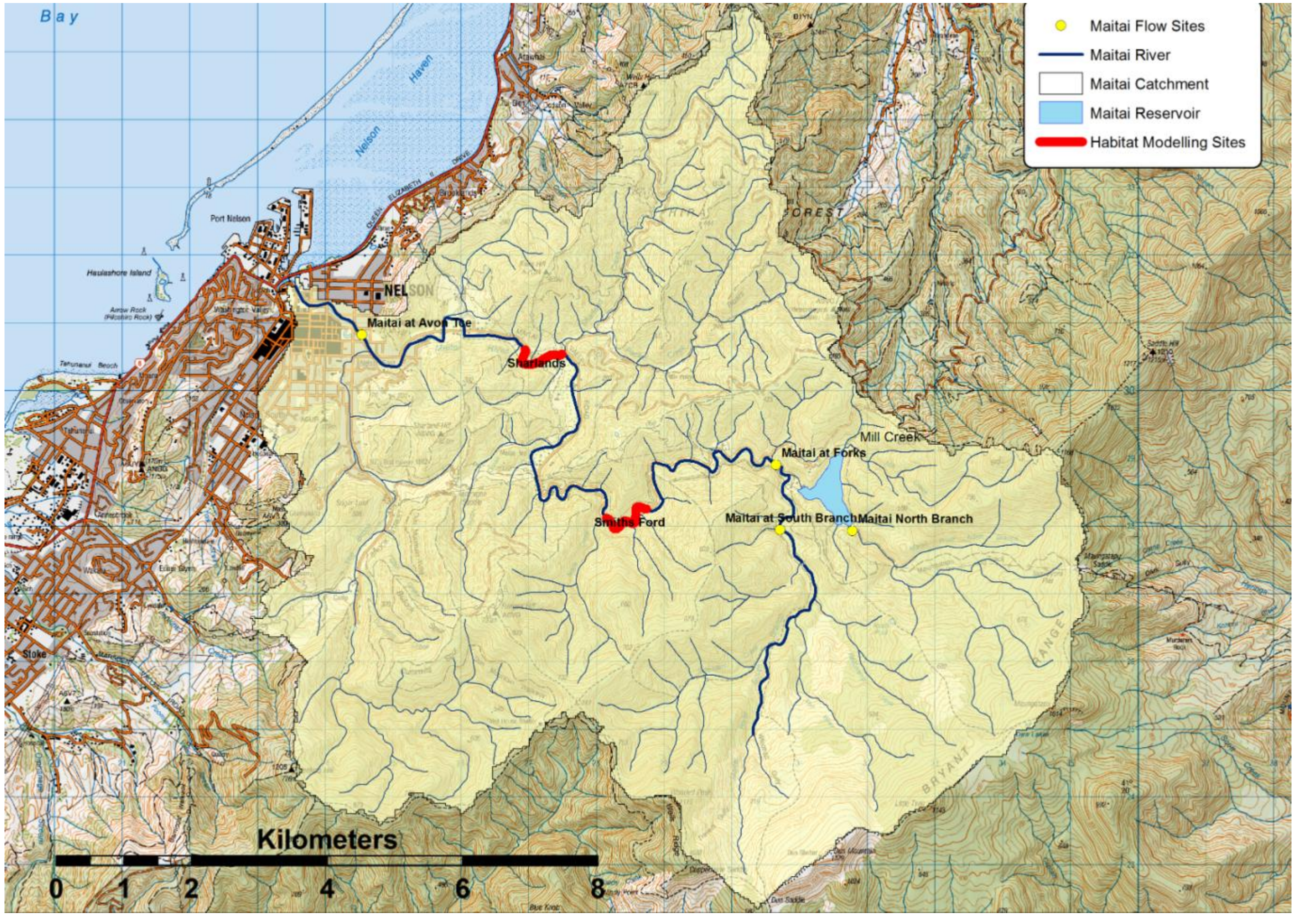


Figure 19. Maitai River study reaches for modelling hydraulic habitat availability for fish and invertebrate species under varying river flows.

Data from TDC's site 'Maitai at Avon Terrace' (2008-2015) (approximately 14.5 km downstream from the Reservoir spillway; Figure 18) were used to assess flows further down the catchment. The river at this point, located downstream from major tributaries including Sharlands Creek and The Brook, has a catchment area of 85 km^2.

Flow statistics for two more sites (Maitai at Smith's Ford and Maitai at Sharlands Creek reach) were synthesised (using Maitai at Forks data) because of their relevance to habitat modelling presented in Section 3 (Figure 18).

2.3.3. Flow statistics

Hewitt and Kemp (2004) undertook a thorough hydrological analysis of the Maitai River as part of a broader investigation into the health of the Maitai River (Crowe et al. 2004). The report described methods for calculating naturalised flow statistics for the above-mentioned flow records.

In summary, steps undertaken to generate flow statistics that were used in the analyses presented in this report included:

- Calculating the 'Status quo' mean, median and 7-day mean annual low flow (7-day MALF) for Maitai Forks from TDC flow data using a hydrological year August–July (combined records for 'Maitai at Forks Weir' (1990-1998) and 'Maitai at Forks' (1997–present) recorder sites.
- Calculating the 'Naturalised' mean, median and 7-day MALF for Maitai Forks (i.e. flows that would have occurred had the dam not been present) using the following three steps.
    1. Calculating these same statistics for 'Maitai at South Branch' hydrometric monitoring site (Figure 19) (1995 - 2015), using data provided by Tasman District Council (TDC).
    2. Calculating these same statistics for the Maitai River North Branch (i.e. the branch that is captured in the Maitai Reservoir) using the relationship provided by Hewitt and Kemp (2004): North Branch = 0.6892 × South - 21.693.
    3. Summing the North and South Branch flows to give the 'Naturalised' mean, median and 7-day MALF for Maitai Forks.
- Calculating the Status quo and Naturalised flow statistics for Smith's Ford using the flow relationship provided by Hewitt and Kemp (2004): Flow at Smith's Ford = Flow at Maitai Forks / 0.9946.
- Calculating the Status quo and Naturalised flow statistics for Maitai below Sharlands Creek using the flow relationship provided by Hayes (2003): Flow at Sharlands Creek reach = Flow at Smith's Ford × 1.65.
    - Calculating the Status quo flow statistics for the 'Maitai at Avon Terrace' hydrometric monitoring site (2008-2015), using data provided by Tasman District Council (TDC).

- Naturalised flow statistics for Maitai at Avon Terrace were calculated by adding the difference of Maitai at Forks Status quo vs Maitai at Forks naturalised flow statistics (using same period that Avon Terrace Status quo data availability: 2008-2015) to the equivalent values from Maitai at Avon Terrace Status quo. This was the best method available, despite assumptions that there is no change in specific discharge, rainfall intensity and losses to groundwater lower in the catchment. Naturalised mean, median and 7-day MALF values were cross checked with equivalent values that were submitted to NCC by Envirolink in 2004 to inform water allocation for the Nelson Resource Management Plan (NRMP).

It should be noted that the method used to calculate naturalised flow statistics is likely to underestimate medium to high flows. The method, first used by Hewitt and Kemp (2004), relies solely on adding modelled North Branch (Figure 19) flows to those recorded in the South Branch. This does not account for flow contributions from other tributaries to the reservoir, which collectively account for approximately 1/3 of the catchment area feeding into the Maitai Reservoir (Hay & Allen 2014). While this omission is unlikely to have had a material impact on the low flow statistics used in this report (i.e. naturalised 7-day MALF) due to very low base-flows from these minor tributaries, it is likely to have caused the influence of the dam during high flow flushing events to be underestimated.

2.3.4. Median, mean and low flows – observed and naturalised

Flow statistics (Table 12) calculated using Maitai at Forks Status quo data (1995-2015)[16] show a moderate reduction from naturalised flow for the median and 7-day mean annual low flow (7-day MALF) of approximately 18% and 12%, respectively. Mean flow is unaffected due to the influence of large floods, which are not captured by the dam.

The relative change in flow statistics for Smith's Ford and the Sharlands Creek (Instream Flow Incremental Methodology- IFIM reaches are identical to those of Maitai Forks, since these records were synthesised from Maitai Forks data.

The relative change in median and 7-day MALF for Maitai at Avon Terrace (2008-2015) also shows a moderate reduction in flow of approximately 8% and 10% of naturalised flows. The naturalised mean, median and 7-day MALF calculated here were within 5% of the equivalent values submitted to NCC by Envirolink Ltd in 2004 to inform water allocation for the NRMP (see Appendix 5).

[16] Only Maitai Forks status quo data since 1995 was used to compare with Maitai Forks naturalised statistics, because the naturalised record was derived from South Branch flows (1995-2015).

Table 12. Status quo and Naturalised monthly flow regime for Maitai at Forks, Smith's Ford and Avon Terrace. N = naturalised, SQ = status quo.

	Maitai at Forks (N)	Maitai at Forks (SQ)	Smith's Ford reach (N)	Smith's Ford reach (SQ)	Sharland Creek reach (N)	Sharland Creek reach (SQ)	Maitai at Avon Terrace (N)	Maitai at Avon Terrace (SQ)
Mean	1406	1412	1413	1420	2332	2342	2778	2799
Median	641	523	644	526	1063	1063	1171	1081
7-day MALF	250	220	251	221	415	365	440	395
Record	1995-2015						2008-2015	

2.3.5. Seasonal flow regimes

Mean monthly median and low flows are influenced by the Maitai Reservoir at both the Maitai at Forks and Maitai at Avon Terrace sites, though the effects are most visible for Maitai at Forks (Figure 20, Figure 21 and Table 13). Mean monthly mean flows for both sites are largely unaffected.

An easy method of visualising the magnitude of average flow reduction or increase is to calculate flow retention, where the status quo value is divided by the naturalised value and expressed as a percentage (Status quo / Naturalised ×100%). A flow retention value of < 10% change (i.e. 90-110% flow retention) can be considered to be insignificant, since the margin of error for a flow gauging (and therefore all flow data) is 8%. 'Traffic light' style colours have been used to visualise flow retention around naturalised values, thereby highlighting both monthly and seasonal effects.

Mean monthly median flows for Maitai at Forks (Table 13) showed the greatest reductions, with flow retention ranging from 77% to 94% of Naturalised flows (i.e. a reduction of 23% to 6%). These flows are most affected through summer, autumn and winter, with minimal difference occurring though late winter and spring.

Mean monthly low flows for Maitai at Forks are moderately reduced during late autumn and summer months (November 74% to January 88% flow retention) but substantially increased during wetter months (May 160%, August 142% and September 124%).

During the dry season (November–March), mean monthly median flows for Maitai at Avon Terrace are slightly affected (86–87% flow retention), and mean monthly low flows are moderately affected (75%–84% flow retention). There is little effect at other times of the year at this site.

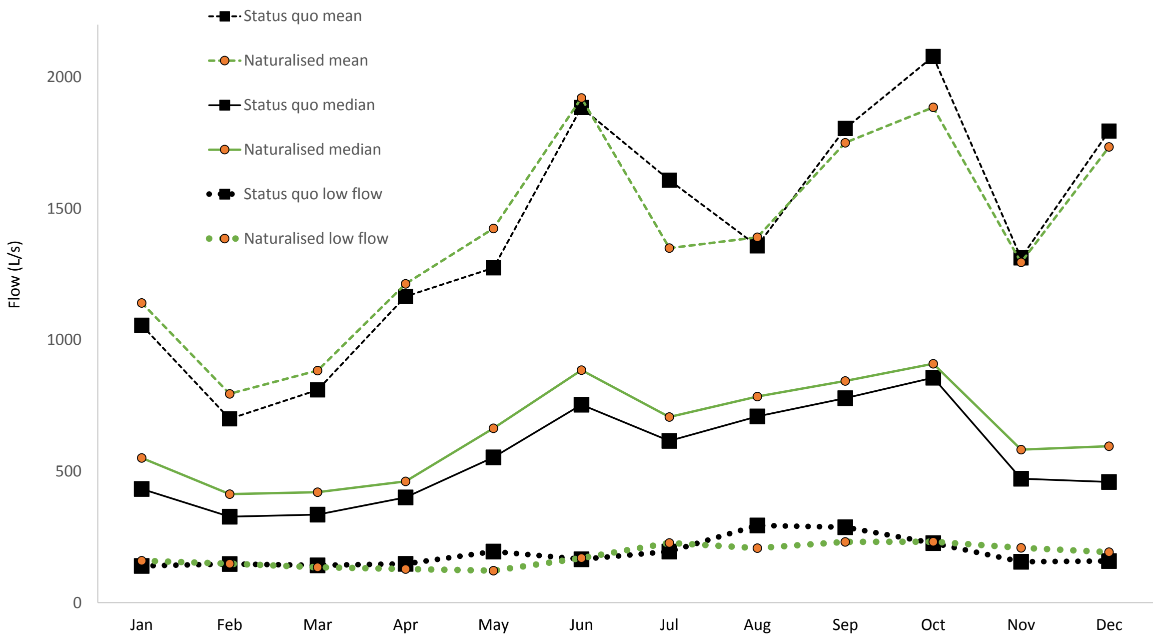


Figure 20. Monthly mean, median and low flows for Maitai at Forks, Status quo versus Naturalised (1990 to 2015).

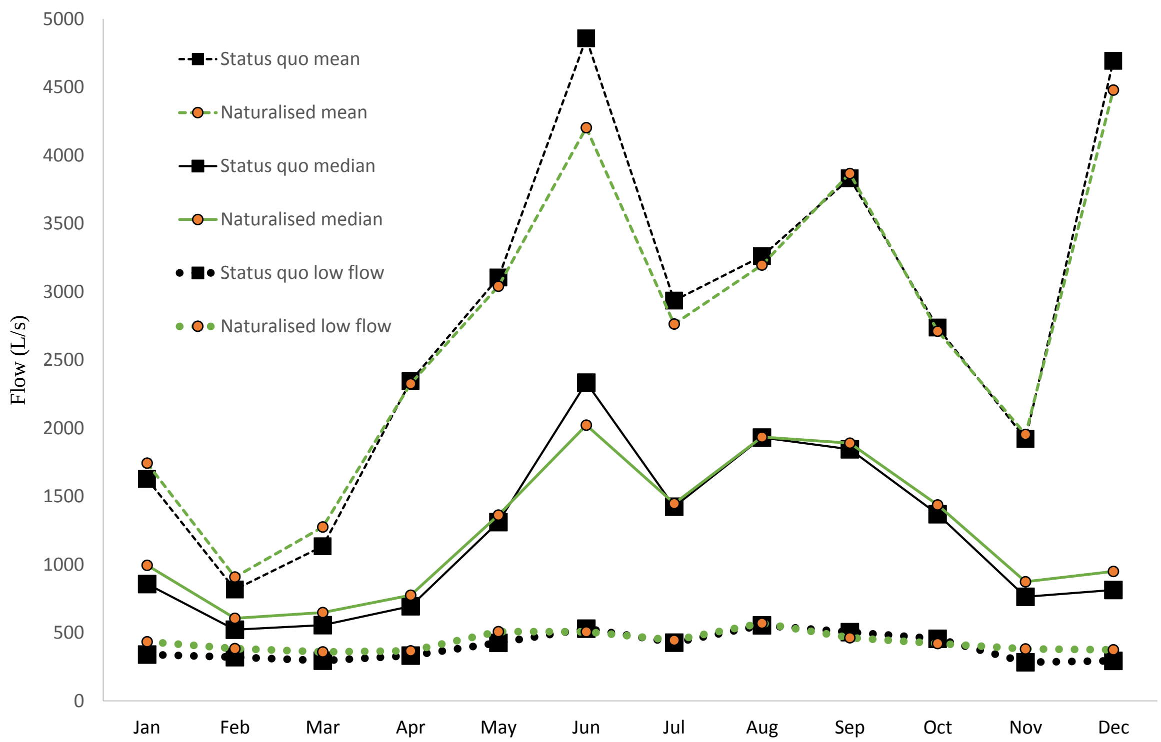


Figure 21. Monthly mean, median and low flows for Maitai at Avon Terrace, Status quo versus Naturalised (2008 to 2015).

Table 13. Mean monthly flow retention (Status quo / Naturalised × 100%) for Maitai at Forks (1995-2015) and Maitai at Avon Terrace (2008-2015).

Month	Monthly low flow		Monthly median flow		Monthly mean flow	
	Maitai at Forks	Avon Terrace	Maitai at Forks	Avon Terrace	Maitai at Forks	Avon Terrace
Jan	88	78	79	86	93	93
Feb	99	84	79	86	88	90
Mar	105	82	80	86	92	89
Apr	116	90	87	90	96	101
May	160	84	83	96	89	102
Jun	98	105	85	115	98	116
Jul	86	96	87	98	119	106
Aug	142	97	90	100	98	102
Sep	124	109	92	98	103	99
Oct	98	108	94	95	110	101
Nov	74	75	81	87	101	98
Dec	82	78	77	86	103	105

XX	Less than 10% change in flow
XX	11-20% flow reduction
XX	21-30% flow reduction
XX	11-20% flow increase
XX	Greater than 20% flow increase

2.3.6. Flushing flows

The FRE3 is a flow statistic that has been widely used by river managers in New Zealand to assess the frequency of freshes[17], since Clausen and Biggs (1997) found that it was a useful flow index for predicting periphyton biomass in New Zealand streams. It represents the average annual frequency of flows that are greater than three times the median flow. 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. Clausen & Biggs (1997) found that periphyton biomass decreased with increasing FRE3, whereas invertebrate density peaked at values of FRE3 of 10–15 floods per year. 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.

The reservoir scheme is predicted to have a small impact on the FRE3 for Maitai at Forks, in the order of one fewer event per year (Table 14). As described above however, the methodology used in this analysis is likely to underestimate the influence of the Maitai Reservoir. Subsequent analyses of flushing flow requirements indicate that substantially higher flows than 3x median are likely to be required to achieve

[17] Moderate high flow events that help cleanse the streambed of accumulated sediment and algae.

flushing of periphyton and fine sediment in the Maitai River (discussed in Section 2.4.3).

Flushing flow statistics were not calculated for Maitai at Avon Terrace because of the relatively short monitoring period (2008-2015). It is highly likely, however, that the effect of the reservoir will ameliorate slightly with distance downstream, as was the case for other annual flow statistics (Table 13).

Table 14. Flushing flow analysis for Maitai River at Forks (based on naturalised and status quo flows)

	Maitai at Forks (Naturalised) (1995-2015)	Maitai at Forks (Status quo) (1995-2015)
Magnitude of FRE3 flow	1999 L/s	1570 L/s
Mean annual frequency of FRE3 flows	12.4	11.4
Min/max frequency of FRE3 flows	Min. 8 Max. 20	Min. 7 Max. 17

2.3.7. Inter-annual variation and climate change predictions

Wratt et al. (2008) describe recent climate history in the Nelson–Tasman region. To date, there has been significant year-to-year variability in Tasman's rainfall, with no significant long term trend. Air temperature increased by 0.73 ± 0.15 °C between 1908 and 2006, which is in line with the national average. Wratt et al. (2008) also provide a summary of major inter-annual climate drivers and provide regional-scale predictions for climate change as predicted by the chapter on Australia and New Zealand in IPCC's Fourth Assessment report (Hennessey et al. 2007).

2.3.8. El-Niño Southern Oscillation

The El Niño-Southern Oscillation (ENSO) is a natural phenomenon that causes fluctuating climate patterns over the Pacific Ocean. El Niño events occur irregularly, about 3 to 7 years apart, typically becoming established around April or May and persisting for about a year thereafter. La Niña events are essentially the opposite of El Niño, facilitating quite different climatic effects.

The general pattern during El Niño events is for New Zealand to experience stronger than normal southwesterly airflow, lower than average seasonal temperatures, and drier than normal conditions in the northeast of the country. During La Niña conditions New Zealand generally experiences more northeasterly flows, higher temperatures, and wetter than normal conditions in the north and east of the North Island (Wratt et al. 2008)

For the Tasman area, Wratt et al. (2008) predict that on average, summer rainfall will be 5-15% less than normal during El Niño periods and 15–20% more than normal during La Niña periods. There is no scientific consensus on whether the frequency and intensity of El Niño and La Niña phases will be affected by climate change, or whether the relatively high frequency of El Niños observed over the last two decades is related to the rise in global temperatures this century[18].

2.3.9. Inter-decadal Pacific Oscillation

The Inter-decadal Pacific Oscillation (IPO) is a natural fluctuation associated with decadal climate variability over parts of the Pacific Ocean. It also influences some aspects of climate over parts of Australia and New Zealand (Salinger et al. 2001). Periods of positive IPO tend to be a little drier than average for Tasman Bay (10-15%), including the Maitai River catchment (Wratt et al. 2008).

2.3.10. Climate change predictions

According to the Ministry for the Environment[19], by 2090 rainfall in Nelson is predicted to increase by 6% in summer and winter, 5% in autumn, with little change predicted for spring. Very heavy rainfall events are likely to become more frequent throughout the Nelson-Tasman region. For example, in Richmond heavy rainfall events are likely to occur twice as often by 2090. Temperatures in Nelson are likely to be around 0.9 ˚C warmer by 2040 and 2.0 ˚C warmer by 2090, compared to 1990.

[18] https://www.niwa.co.nz/climate/information-and-resources/elnino

[19] http://www.mfe.govt.nz/climate-change/how-climate-change-affects-nz/how-might-climate-change-affect-my-region/nelson-and

2.3.11. Summary of key findings

Summary – Hydrology

- Analyses of flow statistics by Hewitt and Kemp (2004) showed a substantial decrease in the duration of low flows caused by abstraction since the construction of the Maitai Reservoir. The pre-dam abstracted flow regime was estimated to reduce the 95 percentile low flow by 52%, relative to naturalised flows, compared to a post reservoir (status quo) reduction of 9%.
- Updated flow statistics for the Maitai River at Maitai Forks show that the Maitai Reservoir has a moderate effect on low to median flows, with the median and 7-day mean annual low flow (7-day MALF) approximately 18% and 12% less than the naturalised flow regime. Mean flow is unaffected due to the influence of large floods, which are not captured by the dam. The relative change in median and 7-day MALF for the Maitai River at Avon Terrace shows a smaller reduction of approximately 8% and 10%, respectively, of naturalised flows.
- Seasonal analyses of mean monthly median flow at Maitai Forks show a reduction of between 23% and 6% compared to the naturalised flow, with the largest reductions occurring during summer (23 to 21%). Mean monthly low flows for Maitai at Forks are moderately reduced during late autumn and summer months (November 26% to February 1%) but substantially increased during wetter months (May 60% increase, August 42% increase and September 24% increase).
- Seasonal analyses of mean monthly median flow for Maitai at Avon Terrace show that the Maitai Reservoir has a small effect over the summer months (14% to 13% reduction from naturalised flows), and a moderate effect on mean monthly low flows at this time of year (25% to 16% reduction). There is little effect at other times of the year at this site.
- The Maitai Reservoir is predicted to have a small impact on the frequency of flushing flows three or more times the median flow for Maitai at Forks: in the order of one fewer event per year. However the methodology used in this analysis is likely to slightly underestimate the influence of the reservoir.
- While there is no significant long term historical trend in rainfall for the Nelson-Tasman region, currents climate change projections estimate an increase in rainfall of 5–6% by 2090, with more frequent periods of very heavy rainfall. Variability due to the influence of the El Niño-Southern Oscillation and the Inter-decadal Pacific Oscillation are predicted, on average, to reduce rainfall by up to 20% and 15%, respectively.

2.4. Flow regime

Operation of water abstraction from the Maitai Reservoir and the South Branch weir are governed by minimum flow requirements stipulated by Consent No. RM025151/2. There is a summertime minimum flow at the Maitai Forks recorder site of 175 L/s

(1 November to 30 April) and a graduated minimum flow for the winter of between 130-300 L/s, depending on the South Branch flow at the time. However, in practice abstraction is managed so that flow is usually above the minimum, as evidenced by the 7-day MALF at the Maitai Forks being greater than the minimum flow.

The reservoir and associated abstraction regime mainly influence flows in the low to median flow range, as discussed above, with the median flow in the upper catchment being reduced by about 18% and the mean annual low flow (7 day) reduced by 12%. These changes to the flow regime have the potential to reduce habitat available for instream life during periods of moderate to low flow. The influence of these flow regime changes on the quantity and quality of available habitat in the Maitai River has been assessed using instream physical habitat modelling (Hayes 2003; Hay & Allen 2014).

In-stream physical habitat modelling first uses hydraulic modelling to predict how depths and water velocities (and the area of different substrate types covered by the stream) vary with discharge. Then it compares these predictions with habitat suitability criteria (HSC), describing the suitability of these habitat variables for given species of interest. These HSCs have been developed by observing the water depths and velocities used by various species, both in New Zealand and overseas. Comparison of given HSC with the modelled physical characteristics of the study stream provides a prediction of the availability of habitat for the species or life stage of interest. Habitat modelling is undertaken over a range of flows to predict how habitat availability will change with flow, providing a basis for decision making regarding allocation of water resources.

In the Maitai River habitat modelling was undertaken for two reaches in the vicinity of Smith's Ford and Sharlands Creek, respectively. Field data collection and calibration of the model were carried out by Hayes (2003), and these models were used in an updated analysis by Hay and Allen (2014). The updated analysis presented by Hay and Allen (2014) was carried out to take account of updated HSC and a new approach to interpreting in-stream habitat modelling outputs in conjunction with ecologically relevant flow statistics (notably the mean annual low flow (MALF)) in making flow decisions (Jowett & Hayes 2004). The model predictions of habitat availability discussed below are for the two reaches combined, with all flows in the figures and tables referenced to the flow at Smith's Ford. This same approach was taken by Hayes (2003) and Hay and Allen (2014). The habitat modelling analysis reported by Hay and Allen (2014) was rerun for this report using System for Environmental Flow Analysis (SEFA; Version 1.2[20]) for the sake of consistency with a recent analysis undertaken for the Roding River (Holmes et al. 2015). The key difference is the name given to the habitat metric calculated by the software. The metric formally known as weighted useable area (WUA) is now called area weighted

[20] System for Environmental Flow Analysis; I Jowett, B Milhous, T Payne, JM Diez Hernández; www.sefa.co.nz

suitability (AWS). It is still calculated in the same way, but the name area weighted suitability is considered to more accurately reflect the calculation process.

The selection of species to include in habitat modelling was based on the species recorded from the Maitai River catchment, based on data summarised by Doehring and Hay (2014).

2.4.1. Interpretation of habitat modelling predictions

Research in New Zealand indicates that MALF and median flows are ecologically relevant flow statistics influencing trout carrying capacity and stream productivity (Jowett 1990, 1992). Habitat availability at the MALF is indicative of the average annual minimum living space for adult trout. Trout populations can be expected to be limited by annually occurring events because they reproduce only once per year and so are relatively slow to recover from abundance-limiting events. 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 (Jowett et al. 2008). By contrast, aquatic invertebrates (which trout and native fish feed on) can recover much more rapidly from abundance-limiting events (e.g. flood disturbance). New Zealand aquatic macroinvertebrates generally have asynchronous lifecycles (i.e. a range of different life stages are likely to be present at any given time), and may also have multiple cohorts per year so their populations bounce back quickly (in the order of weeks to months) from disturbance from floods and droughts. For this reason the median flow or monthly median flows can be viewed as providing an approximation of the typical habitat conditions experienced, and that can be utilised by benthic invertebrates (Jowett 1992). If the minimum flow restricts habitat for any species, there is potential for a detrimental effect on that population, particularly if abstraction draws flow below the MALF for extended periods of time (weeks to months).

These insights formed the basis for an approach to interpreting the output of habitat modelling in conjunction with ecologically relevant flow statistics (notably the MALF) in flow decisions. This approach has been adopted by several regional councils around New Zealand since it was suggested by Hayes and Jowett (2004). It involves deriving prospective minimum flows to retain a given proportion of the habitat available at the natural MALF, or the habitat optimum if that occurs at a lower flow. The minimum flow is then set to maintain the habitat of the 'critical value', with the rationale that 'by providing sufficient flow to sustain the most flow sensitive, important value (species, life stage, or recreational activity), the other significant values will also be sustained' (Jowett & Hayes 2004, p. 8). The level of habitat retention is varied according to the in-stream values, with levels of 70-90% of the habitat at the natural MALF commonly being applied.

This approach was used to derive prospective minimum flows for the Maitai River from the habitat–flow relationships predicted by habitat modelling (Hay & Allen 2014).

2.4.2. Modelled changes in habitat for the Maitai River

In-stream physical habitat modelling suggests that any reduction in flow below the natural MALF is likely to lead to a reduction in the amount and average quality of habitat for most species of native fish (Figure 22) recorded from the Maitai River, as well as feeding habitat for brown trout (Figure 23). Invertebrate habitat (represented by *Deleatidium* mayfly (Jowett et al. 1991) and Waters (1976) generic invertebrate habitat criteria for producing food for fish) is also predicted to decline with flow reductions over the flow range modelled (Figure 23), implying reductions in flow are also likely to result in reduced food availability for fish. These results were generally similar to those previously presented by Hayes (2003). He noted that predicted habitat availability declined for most species modelled below 0.3 m^3/s, and that habitat for invertebrates was already well below optimum at this flow.

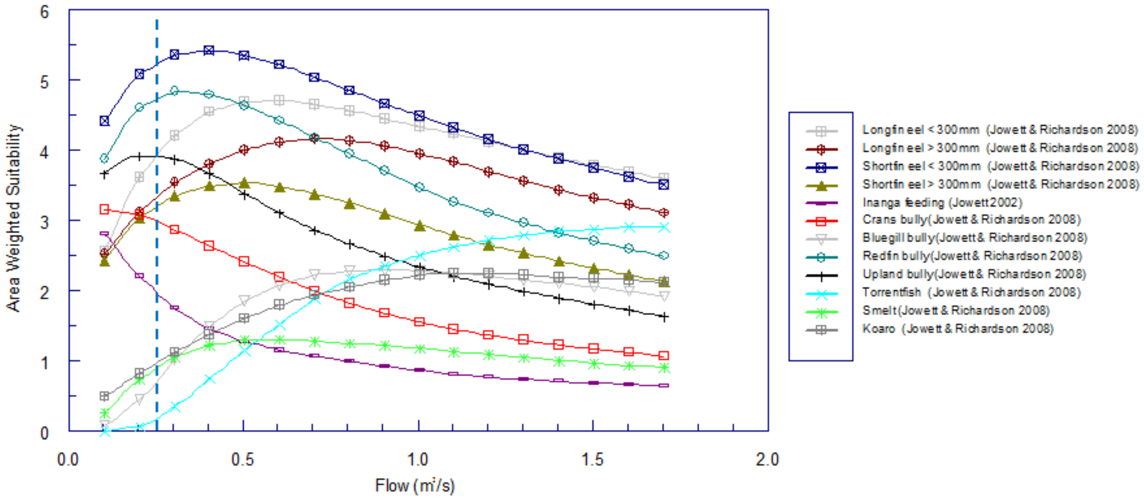


Figure 22. Predicted habitat availability (area weighted suitability; AWS) versus flow for native fish in the Maitai River, Smith's Ford and Sharlands Creek modelled reaches combined. Blue dashed lines denote naturalised 7-day mean annual low flow. From Hay & Allen (2104).

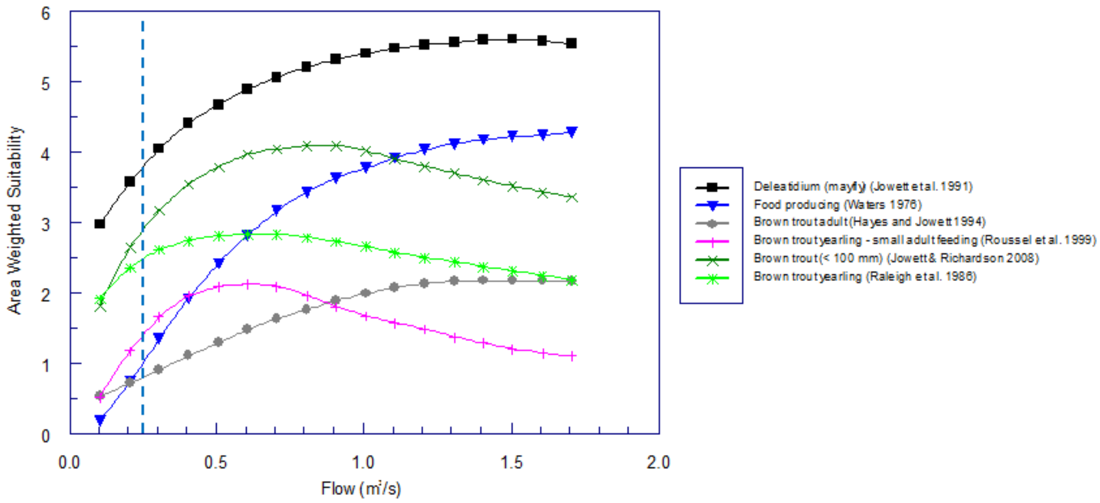


Figure 23. Predicted habitat availability (area weighted suitability; AWS) versus flow for trout and macroinvertebrates in the Maitai River, Smith's Ford and Sharlands Creek modelled reaches combined. Blue dashed lines denote naturalised 7-day mean annual low flow. From Hay & Allen (2104).

Table 15 shows prospective minimum flows based on each of the species modelled, with those of three candidate critical value species highlighted. Of these the torrentfish habitat retention is the most flow demanding, with prospective minimum flows of ~0.228-0.235 m^3/s, depending on the habitat retention level applied. As a fast water specialist, torrentfish is a candidate critical value species because its habitat is relatively sensitive to flow reductions, and torrentfish is listed as 'Declining' in the latest Department of Conservation threat classification listings (Goodman et al. 2014). They were traditionally caught by Māori and are still considered to be a taonga by some.

Table 15. Flows at predicted area weighted suitability (AWS) optima for all species and life-stages modelled in the Maitai River, and flows predicted to retain 70% and 80% of AWS at the naturalised mean annual low flow (MALF) or the flow at the AWS optimum (whichever is lowest) for each species and life-stage. All flows referenced to the Maitai Forks flow recorder site. Potential minimum flows based on the three most flow-demanding prospective critical value species are highlighted in bold.

MALF (m^3/s)*	Species-specific Habitat Suitability Criteria	Flow at WUA Optimum (m^3/s)	Flow that retains 80% of AWS at MALF or the AWS optimum flow (m^3/s)	Flow that retains 70% of AWS at MALF or the AWS optimum flow (m^3/s)
0.250	Brown trout adult (Hayes and Jowett 1994)	1.500	0.164	0.122
	Brown trout yearling - small adult feeding (Roussel et al. 1999)	0.600	**0.193**	**0.172**
	Brown trout (< 100 mm) (Jowett & Richardson 2008)	0.800	0.161	0.127
	Brown trout yearling (Raleigh et al 1986)	0.600	0.117	< 0.100
	Longfin eel < 300mm (Jowett & Richardson 2008)	0.600	0.153	0.116
	Longfin eel > 300mm (Jowett & Richardson 2008)	0.700	0.124	< 0.100
	Shortfin eel < 300mm (Jowett & Richardson 2008)	0.400	< 0.100	< 0.100
	Shortfin eel > 300mm (Jowett & Richardson 2008)	0.500	0.120	< 0.100
	Īnanga feeding (Jowett 2002)	0.100	< 0.100	< 0.100
	Common bully (Jowett & Richardson 2008)	0.100	< 0.100	< 0.100
	Bluegill bully (Jowett & Richardson 2008)	0.900	**0.224**	**0.212**
	Redfin bully (Jowett & Richardson 2008)	0.300	< 0.100	< 0.100
	Upland bully (Jowett & Richardson 2008)	0.200	< 0.100	< 0.100
	Torrentfish (Jowett & Richardson 2008)	1.700	**0.235**	**0.228**
	Smelt (Jowett & Richardson 2008)	0.600	0.195	0.176
	Kōaro (Jowett & Richardson 2008)	1.100	0.185	0.156

As with the minimum flow recommended by Hayes (2003; circa 0.3 m^3/s), the prospective minimum flows based on torrentfish habitat retention in Table 15 are higher than the existing summertime minimum flow at the Maitai Forks (0.175 m^3/s). However, in practice abstraction is managed so that flow is usually above the minimum, as mentioned above. For this reason the 7-day MALF at the Maitai Forks is greater than the minimum flow. The existing 7-day MALF (0.220 m^3/s at the Maitai Forks) is quite close to the prospective minimum flows presented in Table 15.

The existing summertime minimum flow at the Maitai Forks recorder site (0.175 m^3/s) is approximately 70% of the naturalised MALF at this site. Table 16 shows the percentage of habitat at the naturalised MALF retained at this minimum flow for the species modelled in the Maitai River. For the majority of species modelled > 70% of the habitat predicted at the MALF is retained at the minimum flow. However, for torrentfish and bluegill bully only 20% and 48%, respectively, of the habitat at the

MALF is retained at the minimum flow. This represents a large reduction in habitat compared with precedents of habitat retention usually applied in minimum flow setting in other regions. This restriction of habitat could be interpreted as a significant reduction in life-supporting capacity of the river, and may be a contributing factor to the apparently low density of these species in the Maitai River.

Table 16. Percentage of habitat (area weighted suitability; AWS) at the naturalised 7 day mean annual low flow (7 day MALF) retained by the existing summertime minimum flow (0.175 m^3/s), and by existing (abstracted) 7 day MALF.

Species-specific Habitat Suitability Criteria	Percent of naturalised MALF habitat (AWS) retained by existing minimum flow	Percent of naturalised MALF habitat (AWS) retained by existing MALF
Brown trout adult (Hayes & Jowett 1994)	83	93
Brown trout yearling - small adult feeding (Roussel et al. 1999)	71	90
Brown trout (< 100 mm) (Jowett & Richardson 2008)	84	95
Brown trout yearling (Raleigh et al. 1986)	91	97
Longfin eel < 300mm (Jowett & Richardson 2008)	86	96
Longfin eel > 300mm (Jowett & Richardson 2008)	89	96
Shortfin eel < 300mm (Jowett & Richardson 2008)	94	98
Shortfin eel > 300mm (Jowett & Richardson 2008)	90	97
Īnanga feeding (Jowett 2002)	119	107
Common bully (Jowett & Richardson 2008)	104	102
Bluegill bully (Jowett & Richardson 2008)	48	77
Redfin bully (Jowett & Richardson 2008)	94	99
Upland bully (Jowett & Richardson 2008)	99	100
Torrentfish (Jowett & Richardson 2008)	22	59
Smelt (Jowett & Richardson 2008)	69	90
Kōaro (Jowett & Richardson 2008)	76	91

While a minimum flow should provide sufficient habitat to maintain aquatic life through relatively short periods of low flow, higher flows in the low to median flow range maintain more wetted habitat to support invertebrate production and also maintain higher delivery rates of drifting invertebrate food items to drift-feeding fish. Maintaining feeding opportunity for trout was part of the rationale for a higher minimum flow suggested by Hayes (2003). Over the last 15 years Cawthron has been involved in the development of a suite of models that predict how changes in flow affect invertebrate drift and energetics of drift-feeding trout (Hayes et al. 2015). Recent advances in the application of this modelling approach suggest that drift-feeding fish may be more sensitive to flow reductions around the MALF to median flow range than was previously recognised. Both water velocity and the concentration of drifting invertebrates decline with flow reduction. The two factors combine to reduce the rate of invertebrates passing through the cross-sectional foraging area of a drift-feeding fish. While habitat availability for adult trout in larger rivers is often predicted to peak at flows in the low to median flow range, net rate of energy intake for drift-feeding trout is predicted to continue to increase across this flow range. The net rate of energy intake is a fitness metric that translates to growth and potential abundance. These findings suggest that allocation of water in the mid-to-low flow range (in the order of about 0.5 × the median to the MALF) has the potential to adversely affect feeding opportunity, growth, and ultimately, carrying capacity of drift-feeding trout. These findings are also likely to apply to drift-feeding fish including native species such as smelt, īnanga, dwarf galaxias, kōaro).

Table 17 shows an alternative approach for considering the influence of abstraction on habitat retention levels. Habitat retention is based instead on monthly median flows for key flow sensitive species and their invertebrate food sources. This alternative approach illustrates seasonal variation in habitat retention for key species, rather than habitat retention only at minimum flows. For most species more than 70% of habitat predicted at the naturalised monthly median flows is retained under the existing abstraction regime. The exception is torrentfish habitat, for which the most significant habitat reductions occur during February and March. This comparison is based on the existing abstraction regime and it should be noted that if the flow was regularly drawn down to the minimum flow the levels of habitat retention would be lower.

On the basis of the discussion above, Hay and Allen (2014) suggested that it would be worthwhile considering increasing the minimum flow in the Maitai River below the dam, from the perspective of maintaining in-stream values closer to natural levels.

Table 17. The influence of the Maitai Dam and the associated abstraction regime on physical instream habitat retention levels (status quo versus naturalised) based on monthly median flows, for critical flow demanding fish species and their invertebrate food source.

Month	*Deleatidium* (mayfly) (Jowett et al. 1991)	Food producing (Waters 1976)	Brown trout yearling - small adult feeding (Roussel et al. 1999)	Bluegill bully (Jowett & Richardson 2008)	Kōaro (Jowett & Richardson 2008)	Torrentfish (Jowett & Richardson 2008)	Key:	
Jul	97	91	102	95	93	83		>140% retention
Aug	98	94	105	98	96	90		130-140% retention
Sep	99	96	105	99	97	94		120-130% retention
Oct	99	97	105	100	98	96		110-120% retention
Nov	95	83	97	86	88	71		90-110% retention
Dec	93	79	96	82	85	65		80-90% retention
Jan	94	79	95	82	86	66		70-80% retention
Feb	93	76	88	75	85	58		60-70% retention
Mar	94	77	89	76	85	59		50-60% retention
Apr	96	86	96	87	91	75		40-50% retention
May	96	87	101	91	90	77		30-40% retention
Jun	97	92	111	98	94	88		<30% retention

2.4.3. Floods and freshes

High flow events also fulfil ecologically relevant roles. Large floods, the size of the annual flood or larger, are important for maintaining the channel form (thus influencing habitat available at other flows) and clearing terrestrial vegetation from the flood fairway. These are likely to be in the order of the mean annual maximum flow, with flows of more than about ten times the mean flow or 40% of the mean annual maximum flow beginning to move a substantial portion of the river bed (Clausen & Plew 2004). Moderate size floods (freshes), about 3–6 times the median flow (Biggs & Close 1989; Clausen & Biggs 1997), are also important for regularly flushing periphyton and fine sediment from the river bed. Maintaining the quality of benthic invertebrate habitat is the main ecological benefit of this process.

As discussed above (Section 2.3), the magnitude and frequency of large channel forming floods are not materially influenced by the dam. The average annual frequency of moderate freshes, in the order of 3 times the median flow is reduced slightly by the dam, since the magnitude of small freshes can be reduced if the reservoir has been drawn down before they occur.

However, flushing flow analysis, along with observations of cyanobacteria and periphyton coverage in the lower Maitai, suggest that effective flushing of periphyton and fine sediment from the mid to lower reaches of the river actually requires substantially higher flows than three times the median flow (Hay & Allen 2014). Flows in the order of 17 m^3/s were predicted to be required to effectively flush 50% of the base flow stream bed in the reach immediately downstream of Sharlands Creek, and higher flows would be required further downstream. Nevertheless, it is unlikely that the frequency of high flow events of this magnitude has been substantially reduced by the operation of the dam, i.e. it is likely that events of this magnitude still occur at close to their natural frequency.

On this basis, it is unlikely that flow regime changes associated with the Maitai Reservoir have influenced the prevalence of algal proliferation in the Maitai catchment (see Section 2.6 for further discussion of periphyton).

2.4.4. Summary of key findings

Summary – Flow regime and habitat suitability

- Water abstraction from the Maitai Reservoir and the South Branch weir are governed by minimum flow requirements. There is a summertime minimum flow at the Maitai Forks recorder site of 175 L/s (1 November to 30 April) and a graduated minimum flow for the winter of between 130-300 L/s, depending on the South Branch flow at the time. However, in practice abstraction is managed so that flow is usually above the minimum.
- The abstraction regime influences mainly flows in the low to median flow range, with the median flow in the upper catchment being reduced by about 18% and the MALF (7 day) being reduced by 12%. These changes to the flow regime have the potential to reduce habitat available for instream life during periods of moderate to low flow. This has been assessed in the Maitai River using in-stream physical habitat modelling (Hay & Allen 2014; Hayes 2003).
- This habitat modelling suggests that any reduction in flow below the natural MALF is likely to lead to a reduction in the amount and average quality of habitat for most species of native fish recorded from the Maitai River, as well as feeding habitat for brown trout. Habitat for invertebrates, which these fish feed on, is also reduced by decreases in flow.
- Prospective minimum flows were derived from the habitat modelling results using an approach that has been adopted by several regional councils around New Zealand since it was suggested by Hayes and Jowett (2004). It involves deriving prospective minimum flows to retain a given proportion of the habitat available at the natural MALF, or the habitat optimum if that occurs at a lower flow. The minimum flow is set to maintain the habitat of the 'critical value', with the rationale that 'by providing sufficient flow to sustain the most flow sensitive, important value (species, life stage, or recreational activity), the other significant values will also be sustained' (Jowett & Hayes 2004, p. 8). The level of habitat retention is varied according to the in-stream values, with levels of 70–90% of the habitat at the natural MALF commonly being applied.
- In the Maitai, torrentfish habitat is the most flow-demanding, with prospective minimum flows, based on the approach described above, of circa 228-235 L/s (at the Maitai Forks) depending on the habitat retention level applied. As a fast water specialist, torrentfish is a candidate critical value species because its habitat is relatively sensitive to flow reductions. Torrentfish are listed as 'Declining' in the latest Department of Conservation threat classification listings (Goodman et al. 2014), and they were traditionally caught by Māori and are still considered to be a taonga by some.

- These prospective minimum flows based on torrentfish habitat retention are higher than the existing summertime minimum flow at the Maitai Forks (175 L/s), which is predicted to retain only 20% of the torrentfish habitat at the MALF. This is a large reduction in habitat compared with precedents of habitat retention usually applied in minimum flow setting in other regions. This restriction of habitat could be interpreted as a significant reduction in life-supporting capacity of the river, and may be a contributing factor to the apparently low density of this, and other fish species, in the Maitai River.
- However, in practice abstraction is managed so that flow is usually above the minimum, as mentioned above. For this reason the 7-day MALF at the Maitai Forks is greater than the minimum flow. The existing 7-day MALF (220 L/s at the Maitai Forks) is actually quite close to the prospective minimum flows presented for torrentfish.
- High flow events also fulfil ecologically relevant roles, including channel form maintenance and flushing accumulations of periphyton and fine sediment.
- The magnitude and frequency of large channel forming floods are not materially influenced by the dam.
- The frequency of effective flushing events has not been substantially reduced by the operation of the reservoir. Therefore, flow regime changes associated with the Maitai Reservoir are not likely to have influenced the prevalence of algal proliferation in the Maitai catchment.

2.5. River water quality

2.5.1. Background

The composition and chemical features of river water strongly influence its suitability for aquatic life and use by humans (Davies-Colley & Wilcock 2004). Subtle changes in water chemistry can alter the functioning of an ecosystem, for example, an increase in nutrients may increase periphyton accrual rates, which will affect invertebrate communities and subsequently the food base for fish.

As mentioned earlier in the report, water taken from the Maitai River for municipal supply is replaced with water from the reservoir via a backfeed located just below the intake structure. The replacement water for the Maitai River is often drawn from the reservoir hypolimnion (inlet 3 or scour). One of the main concerns with water being drawn from below the thermocline near the lake bottom is that, during summer periods the deeper reservoir water can be more depleted in DO and contain greater concentrations of dissolved nutrients and trace metals (see Section 2.2.3 concerning reservoir water quality).

Low DO concentrations (i.e. < 50% saturation) in the deepest part of the reservoir can result in solubilisation of metals from lake-bottom sediments, and result in higher concentrations of dissolved Fe and Mn (along with other metals, depending on availability), as these metals are released from sediments as soluble and more toxic forms under anoxic conditions (Wetzel 1983; Kelly 2014). Water quality at different lake depths is monitored monthly in the reservoir, including at inlet 3. Water quality in the Maitai River is also monitored on a monthly basis (at sites 100 m above and 100 m below the reservoir backfeed discharge) to check the replacement water drawn from the reservoir is not adversely altering the downstream water chemistry. In the consent conditions, particular focus is given to:

- Temperature
- DO concentrations
- Fe concentrations
- Mn concentrations
- Turbidity.

In this section of the report, each of these parameters is discussed. Water quality monitoring results prior to 2003 were reported on and discussed by Crowe et al. (2004). Their findings were that consent conditions relating to the Maitai River water quality monitoring in relation to the backfeed discharge had always been met. For this reason, we present results in this section of the report that focus on the last 15 years (i.e. from 2000-2015).

2.5.2. Temperature

Water temperature affects all aspects of freshwater ecosystems, from its influence on the solubility of oxygen through to regulating metabolic rates (and therefore the growth and activity) of most aquatic organisms (Davies-Colley et al. 2013). The majority of aquatic organisms are cold-blooded, meaning that their internal temperature follows that of the environment (with some lag). Consequently, they are highly susceptible to changes in ambient river water temperatures caused by discharges. Therefore, it is critical to correctly manage water temperatures for the protection of aquatic species. Avoiding excessive elevation of temperature is the key management concern, because lethal temperatures for many species are only slightly above their optimal temperatures for growth (perhaps as little at 5 °C above; Davies-Colley et al. 2013) and are close to the temperature range commonly experienced in New Zealand streams during summer. While temperature reductions below optimal conditions tend to produce a gradual decline in growth and activity rates, temperatures above the growth optimum become increasingly stressful comparatively rapidly, because of effects on cellular function, with enzymes becoming denatured (Davies-Colley et al. 2013).

Water temperature varies naturally on daily and seasonal cycles, largely driven by solar inputs. Water flowing downstream will increase or decrease in temperature until the incoming radiation equals the heat lost from the river through radiation and evaporation. The temperature at which incoming energy equals the outgoing energy, resulting in no further increase in water temperature, is known as the equilibrium temperature. However, temperature can also be influenced by discharges of water into a system that are either warmer (e.g. industrial cooling water, or surface water from thermally stratified reservoirs) or cooler (e.g. bottom release from reservoirs, or groundwater) than ambient conditions in the river.

Olsen et al. (2011) recently reviewed the thermal requirements of native freshwater biota and this review subsequently helped inform thermal criteria recommended for the National Objectives Framework (NOF; Davies-Colley et al. 2013). Maintaining river water temperatures below about 19 °C is likely to largely avoid adverse effects on sensitive native fish and invertebrate species (Olsen et al. 2011), as well as brown trout (Hay et al. 2006). Maintaining water temperatures below the low 20's °C is likely to incur some thermal stress on sensitive species, while temperatures over about 25 °C are likely to result in some degree of stress for a range of species and may result in the loss of particularly sensitive fish and invertebrate species from the local community. These thresholds align with the water temperature limits recommended for the NOF by Davies-Colley et al. (2013). Their recommendations for the upper bounds of A, B and C band stream sites for 'Eastern Dry' regions (including Nelson) were ≤ 19 °C, ≤ 21 °C and ≤ 25 °C, respectively [21]. These bands were intended to result in:

A band. No thermal stress on any aquatic organism present at matched reference (near-pristine) sites.

B band. Minor thermal stress on occasion (clear days in summer) on particularly sensitive organisms such as certain insects and fish.

C band. Some thermal stress on occasion, with elimination of certain sensitive insects and absence of certain sensitive fish.

In the Maitai River the water temperature generally increases longitudinally in the main stem, and in summer often enters the stressful range for several native fish, invertebrates, and trout, particularly in the mid to lower river (Crowe et al. 2004, Wilkinson 2007). Crowe et al. (2004) reported that upper lethal temperatures for sensitive native fish and mayflies were exceeded occasionally during summer in the lower reaches, and probably also in the mid reaches, of the mainstem. Wilkinson (2007) confirmed that summer water temperature in the mid to lower reaches of the Maitai River frequently exceeds 19 °C. However, he concluded that water temperature at a given site was more a function of local conditions around that site (e.g. shading, water depth, channel aspect, topography and river bed reflectivity), rather than

[21] These temperature thresholds were intended to be assessed against the summer period measurement of the Cox-Rutherford Index (the average of the daily mean and maximum temperature), averaged over the five hottest days from a continuous temperature record.

upstream water temperature. On this basis, the reservoir and its operation are unlikely to influence water temperature in the mid to lower river. Results of temperature modelling also suggest that the influence of the backfeed discharge on water temperature tends to attenuate relatively rapidly downstream (Hay & Allen 2015).

To mitigate local water temperature changes discharge of water from the dam into the Maitai South Branch, via the backfeed, is governed by the following water temperature consent conditions[22]:

a. When the water temperature prevailing immediately above the intake is between 8 °C and 18 °C inclusive, the discharge shall not change the temperature of the river water by more than 3 °C.
b. When the water temperature prevailing immediately above the intake is greater than 18 °C, the discharge shall not reduce the temperature of the river water below 15 °C.
c. When the water temperature prevailing immediately above the intake is less than 8 °C, the discharge shall not increase the temperature of the river water above 11 °C.
d. When Conditions (b) and (c) are in force, the discharge shall only be turned off at an even rate over a minimum period of two hours.
e. At no time shall the discharge increase the temperature of the river above 20 °C or reduce it below 6 °C.

Compliance is assessed based on data in a 15-minute time-step for sites located in the South Branch upstream and approximately 100 m downstream of the backfeed discharge point. In addition, the water quality standards stipulated in the NRMP state that human activities shall not increase the mean daily water temperature in the South Branch to above 18 °C or the daily maximum above 20 °C. The equivalent levels for the rest of the catchment are a mean daily water temperature of 20 °C and a daily maximum of 24 °C.

Monitoring data show that the temperature consent conditions are complied with for the majority of the time (Holmes 2012; Allen 2014; Newton 2015). There are generally several breaches in most years, but these are mostly of quite short duration (less than 1 hour) and the frequency and duration of these breaches appears to have reduced over time. Since 2006 the vast majority of consent condition breaches have involved excessive cooling (rather than warming), particularly reducing temperatures below 6 °C during winter, with less frequent temperature reductions of greater than 3 °C during summer.

[22] Consent number 960396, Condition 8.

Even though operation of the backfeed discharge complies with temperature-related conditions most of the time, river water temperature increases rapidly downstream during warm settled periods (Wilkinson 2007, Hay & Allen 2015). Daily maximum temperatures from immediately upstream of the spillway discharge pool may be in the order of 1.5–2.0 °C warmer than those 100 m downstream of the backfeed discharge, and can exceed 20 °C during periods of settled fine weather in summer (Hay & Allen 2015). However, these higher temperatures are not caused by the backfeed discharge. The NMRP daily temperature maximum criterion of 27 °C (Class C) or 24°C (Class B waters) was not breached according to continuous monitoring conducted over two summers from 2014–2016 (Hay & Allen 2015, Cawthron unpublished data).

River water temperature also tends to increase immediately downstream of the spillway discharge pool caused by the discharge of warm reservoir surface-waters. This was clearly evident in longitudinal profiles of average daily temperatures recorded through this reach (Hay & Allen 2015). This warming influence occurred even when the spillway was not operating (presumably because warm surface water from the plunge pool below the spillway is entrained into the river flow), although it was more pronounced when the spillway was operating. As a consequence of this rapid longitudinal warming, temperatures observed downstream of the Maitai Forks flow recorder site, particularly during summer, can be in a range likely to induce thermal stress in a variety of aquatic organisms, with the likely elimination of some sensitive species. While the spillway discharge has the potential to cause river water temperatures to increase, this is never likely to exceed the NRMP 24°C mean daily water temperature nor the 27°C daily maximum criteria (due to human activities) cited for Class C waters. However on occasion water temperatures can exceed the NRMP Class B standard for maximum daily water temperature and 24°C when the spillway is operating over mid-summer (e.g., February 2016—Cawthron unpublished data). It is not known the frequency to which this occurs. On the basis of existing data, Class B temperature maxima were not breached downstream of the spillway during the summer of 2014–2015 (spillway not operating), but did over a short week-long period in February 2016.

Although water temperature data from prior to the reservoir construction are very sparse, they indicate that water temperatures did sometimes enter the stress range for sensitive aquatic organisms during that period, at least in the lower reaches of the river. However, there are insufficient data to assess whether the operation of the dam has altered the frequency, duration, or magnitude of high water temperatures in the Maitai River.

2.5.3. Dissolved oxygen

Dissolved oxygen is important for the functioning of many aquatic organisms and represents the balance between oxygen-consuming (e.g. respiration) and oxygen-releasing processes (e.g. photosynthesis). Dissolved oxygen can vary widely over a 24 hour period, especially in systems where there is significant nutrient enrichment. The lowest levels of DO are normally at dawn just before photosynthesis resumes. Dissolved oxygen levels less than 6 mg/L (or 80% saturation) generally are considered insufficient to support sensitive fish (such as trout) or macroinvertebrate (mayflies, stoneflies and most caddis flies) communities (Hay et al. 1996).

The mainstem of the Maitai River is well oxygenated, with saturation levels commonly over 90–130% (Crowe et al. 2004). Historically, DO measurements have always been high in the upper reaches of the Maitai River (Crowe et al. 2004). However, water drawn from the base of the Maitai Reservoir and discharged into the Maitai South Branch via the backfeed can have very low DO levels during summer, and is likely to affect DO in river water over a short distance downstream. The prevalence of high DO levels at monitoring sites downstream of the backfeed (100 m downstream) even during low reservoir DO (Figure 24) suggest sufficient aeration occurs over the discharge weir to re-oxygenate the water within a short distance. Biannual DO spot measurements taken since 1980 at Site B (approximately 800 m downstream of the backfeed) consistently exceed ANZECC (1992) guidelines for the protection of aquatic life (i.e. > 80% saturation).

Consent requirements are that DO in the Maitai River 100 m downstream of the South Branch intake weir should remain above 6 mg/L (ANZECC 1992). Dissolved oxygen concentrations in the Maitai River 100 m downstream of the intake remained high throughout 2000-2015 (6.5–16.5 mg/L, mean 11.0 mg/L), exceeding the limit of 6 mg/L on all occasions that measurements were taken (Figure 24). Dissolved oxygen levels were slightly higher in the cooler months than over summer.

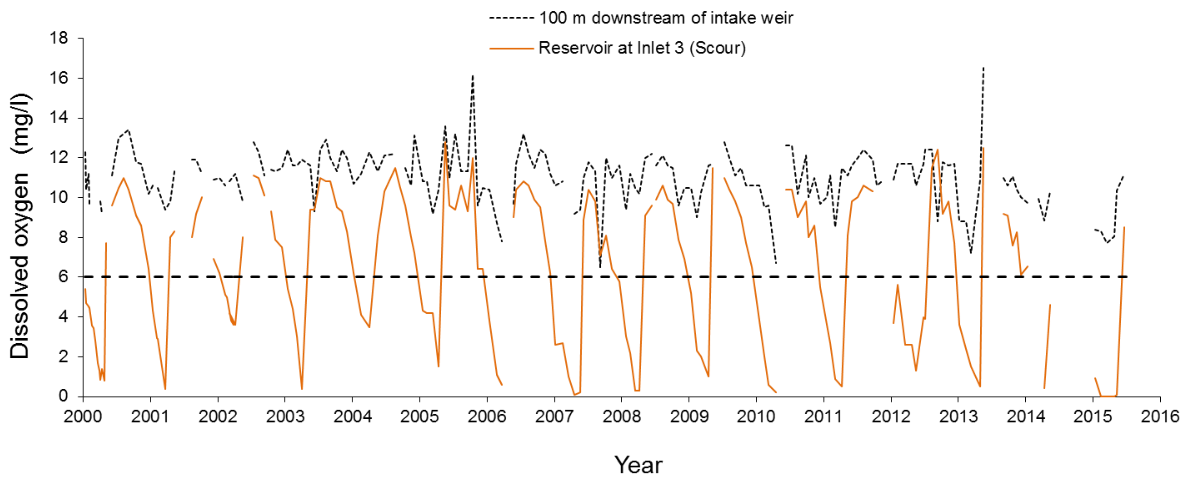


Figure 24. Dissolved oxygen (mg/L) from the bottom intake in the reservoir (Inlet 3) and in the Maitai River 100 m downstream of the intake weir (2000-present). The horizontal dashed line indicates the consented limit for the river (6 mg/L).

The NRMP cites a DO minima standard of 90% saturation during daytime periods for Class C waters. However, because consent monitoring conditions specified DO triggers in terms of parts per thousand (i.e., mg/L), data have not been recorded in terms of % saturation to allow an assessment relative to the NRMP standard, which would require temperature and barometric pressure at the time of monitoring to accurately calculate these values. The NRMP standard is very restrictive, and it is highly probable that the Maitai South Branch would not meet such standards based on spot measurements taken at the time of bi-annual biomonitoring in March (Cawthron unpublished data), as well as from continuous DO monitoring (loggers) conducted to assess river metabolism rates (Cawthron/Project Mahitahi work in January-March 2015). Such a relatively high DO is unrealistic because freshwaters naturally fluctuate in DO over the day-cycle with levels of photosynthetic production, and instrument error of 3-4% saturation could be expected. Therefore we would view this NRMP standard as unrealistic and unachievable. Conditions 100 m downstream of the backfeed weir would, however, meet the 80% standard cited in ANZECC (2000) which would provide a reasonable level of protection for aquatic life. It is possible that downstream of the backfeed that the NRMP DO standard for Class B waters, which cites a daily mean of between 98–105%, may more likely be met. Although there are limited data that has been collected over a daylight cycle (12 hr period) to inform the evaluation of such a standard, and presently consent monitoring is conducted by means of spot measurements.

2.5.4. Trace metals

The Upper Maitai catchment is situated in a geological region that contains naturally high levels of trace metals such as Mn, Fe, Ni, and Cr. Consent conditions for the operation of the Maitai Reservoir require monthly spot monitoring of only Fe and Mn concentrations. Iron and Mn have been measured up- and downstream of the backfeed and in the Maitai Reservoir since 1989 as part of NCC's compliance monitoring.

Routine monitoring and surveys of dissolved metal concentrations in the Reservoir show that metal (Fe and Mn) levels are elevated in the hypolimnion during stratification in the warmer months (Kelly 2014). However, concentrations of Fe and Mn in the reservoir at inlet 3 (Scour) are usually close to or below the consent limits of 1 mg/L.

Iron

Iron is an essential trace element for plants and animals, but at high concentrations it can be toxic to aquatic life. No New Zealand freshwater guideline is currently available for Fe. Acute toxicity to aquatic insects has been reported at Fe concentrations ranging from 0.32 g/m^3 to 16 g/m^3 (Warnick & Bell 1969). Current ANZECC and ARMCANZ (2000) guidelines advise the Canadian guideline of 0.3 g/m^3 (CCREM 1987) be used as an interim indicative working level for freshwaters.

In the presence of oxygen, Fe is often found as colloidal suspensions of ferric hydroxide, which may remain suspended in water or settle and harden (CCREM 1987). Suspended flocs can cause problems with turbidity, decreased light penetration and smothering of benthic organisms (CCREM 1987, ANZECC 1992). Nelson City Council's consent stipulates the concentration of total Fe should not exceed 1 g/m^3 100 m below the Maitai River intake weir (Appendix 1).

The Crowe et al. (2004) Maitai River review showed Fe concentration in the river was commonly at or below laboratory detection levels. At the monitoring site 100 m below the Maitai River intake weir the 1 g/m^3 limit specified in the NCC consent had not been exceeded at any time prior to the 2004 review. However, Fe levels regularly exceed the Canadian freshwater guideline for iron of 0.3 g/m^3.

Since the Crowe et al*.* review Fe concentrations downstream of the intake weir have remained below the consented limit of 1 g/m^3 total Fe (Figure 25). However, during the 2009-2010 survey, Olsen (2010) reported Fe concentrations that were very close to the limit (14 April 2010: 0.927 g/m^3; 6 May 2010, 0.958 g/m^3).

Iron levels in the reservoir are generally higher than in the river (Figure 25). This indicates the metal is quickly diffuses or precipitates out on entering the river via the backfeed. On several monitoring occasions since the Crowe et al. (2004) report, Fe precipitates have been visibly noticeable on the streambed around and immediately below the backfeed discharge (Figure 26).

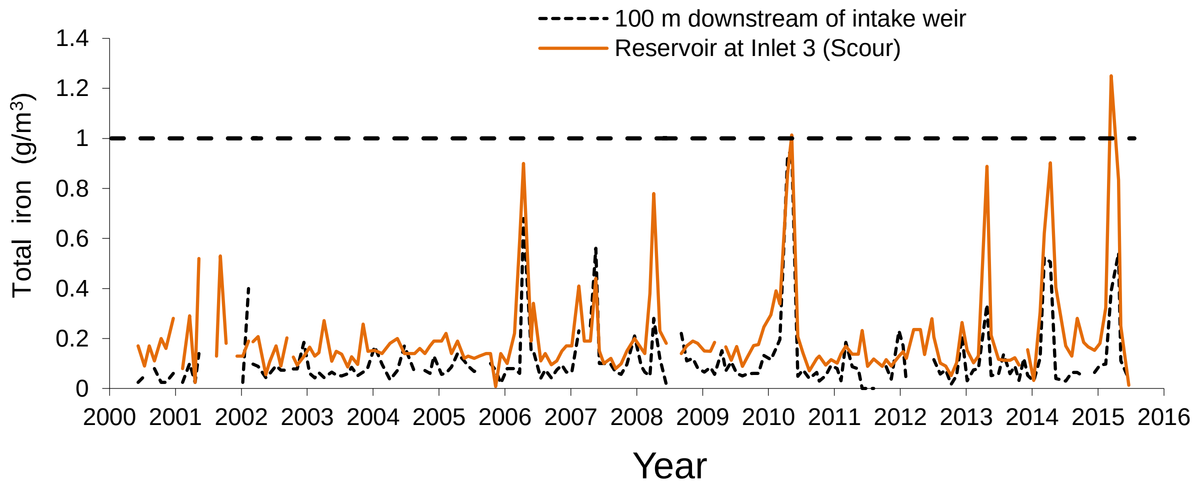


Figure 25. Iron concentrations from the bottom intake in the reservoir (inlet 3) and in the Maitai River 100 m downstream of the intake weir (2000–present). The horizontal dashed line indicates the consented iron limit for the river (1g/m^3).

Figure 26 Picture of oxidised iron deposits on river substrate downstream of the backfeed discharge in the Maitai River South Branch in April 2014 (Photo by P. Fisher, Nelson City Council).

The NRMP cites water standards for toxicants equivalent to the 95% level of protection for aquatic life for both Class C and B waters. ANZECC (2000) does not cite dissolved Fe levels of protection of aquatic life due to insufficient data, and therefore interpreting reservoir concentrations of dissolved Fe relative to the NRMP water standards is not possible. Based on preliminary examination of toxicity triggers for dissolved Fe from overseas literature (0.35 g/m^3, Phippen et al. 2008), it is possible that toxicity effects of dissolved Fe on sensitive species may occur in the South Branch, but most toxicity is probably confined to the portion of the South Branch between the backfeed weir and the monitoring location 100 m downstream. After this point most Fe would precipitate into particulate metals and have low toxicity to biota.

Manganese

Manganese, like Fe, is also an essential trace element for plants and animals, but at high concentrations it can be toxic to aquatic life. Current NRMP guidelines stipulate a trigger value of 1.9 g/m^3 for manganese to achieve protection of 95% of species (ANZECC & ARMCANZ 2000) for both Class C and B waters. Nelson City Council's consent stipulates the concentration of total manganese should not exceed 1 g/m^3 100 m below the Maitai River intake weir, and is more restrictive than this NRMP standard (Appendix 1).

Manganese is present in natural waters in suspended form (similar to Fe) although soluble forms may persist at low pH or low DO. Its toxicity is low compared to other trace metals and toxicity decreases significantly with increasing hardness (Reimer 1999, Stubblefield et al. 1997). The water hardness in Maitai Reservoir and South Branch of the Maitai River was measured (as mg of calcium carbonate per litre of water) on six occasions in late 1998 and ranged from 52–63 g/m^3 in the reservoir, and 52–72 g/m^3 in the South Branch. Based on these ranges in water hardness, Reimer (1999) proposes freshwater aquatic life guidelines of 0.8 g/m^3 for chronic exposure, and 1.1 g/m^3 for acute (< 96 h) exposure. These values are slightly more conservative than those recommended in the ANZECC guidelines, but are consistent with the 1 g/m^3 limit specified in the consent.

The Crowe et al. (2004) Maitai River review showed concentrations for Mn were commonly at or below laboratory detection levels. At the monitoring site 100 m below the Maitai River intake weir the 1 g/m^3 limit specified in the NCC consent had not been exceeded at any time prior to the review.

Since that review, the same consented limit for Mn has been breached on two occasions; April 2006 and May 2007 (Olsen 2007b; Wilkinson & Olsen 2007; Figure 27). The highest concentration recorded from the reservoir in recent years was 1.7 g/m^3 recorded in May 2006. Monitoring reports by Olsen (2007b) and Wilkinson & Olsen (2007) expressed concern over the possible ecological effects of elevated Mn concentrations in the South Branch, and recommended more frequent monitoring of Mn concentrations during autumn.

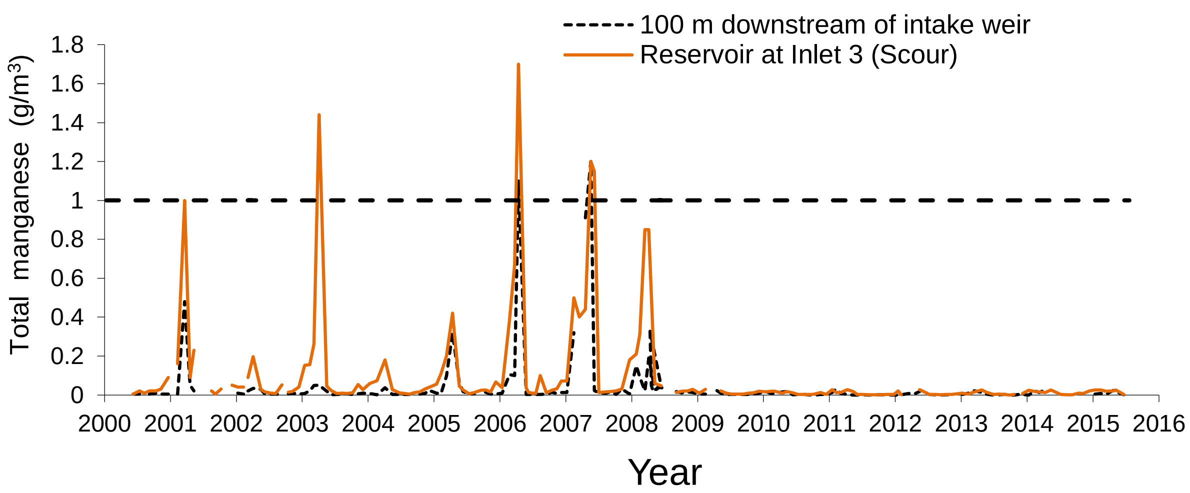


Figure 27. Manganese (bottom) concentrations from the bottom intake in the reservoir (inlet 3) and in the Maitai River 100 m downstream of the intake weir (2000–present). The horizontal dashed line indicates the consented manganese limit for the river (1 g/m^3).

Olsen (2007b) noted that on the 12 April 2006 sampling occasion (when the NCC water chemistry sampling showed that the Mn concentration condition in the consent was breached), the concentration of Mn at the other two intakes in the reservoir (inlets 1 and 2) was much lower (0.016 and 0.044 g/m^3, respectively) than at inlet 3. Thus, it is possible that this breach could have been avoided had the water being discharged into the South Branch of the Maitai River been sourced from one of these two higher intakes. Olsen (2007b) also suggested that given the results of the analysis of the relationship between DO concentration and Mn concentration in Maitai Reservoir, in future it may be possible to avoid breaching Mn consent limits by sourcing water to be discharged to the South Branch from inlet 2 when oxygen concentrations drop below 0.5 g/m^3, which is most likely to occur between late March and early May, shortly before turnover of the reservoir. However, Olsen (2007b) also noted that it must be kept in mind that the Mn concentration is only one part of the consent conditions, and that the discharge of the warmer water from inlets 1 or 2 may have led to a breach of the temperature conditions.

In view of the breaches in Mn the Council commissioned a literature review on the effects of manganese in aquatic ecosystems (Holmes 2010). The main findings from the report in relation to manganese were:

- levels of Mn discharged into the Maitai River (< 1.2 g/m^3 during peak discharges) indicate only a moderate chance of direct or chronic toxicity to the river's aquatic life
- moderately-increased levels of Mn (and possibly Fe) in the reservoir's discharge may be encouraging the dominance of (potentially toxic) cyanobacterial communities over diatom-based communities in the Maitai River.

Holmes (2010) went further to recommend:

- Full chemical analysis of the backfeed discharge should be conducted once a month over the course of a year and additional samples should be taken specifically during discharges of anoxic water from the hypolimnion (generally February–May). Analysis of water from the North Branch above the Maitai Reservoir and the South Branch above the discharge site will help determine the natural background levels of potential contaminants (Kelly & Shearer 2013).
- More intensive surveys of the algal communities above and below the discharge and a chemical analysis of algal cells may help determine if chemical constituents present in the discharge are contributing to undesirable algal growths.
- A desk-top analysis of historical discharge volumes and biomonitoring records may identify if a correlation exists between the scheme's operating regime and the declining trend in macroinvertebrate community indices (which commenced around 2001–2002; Olsen 2010). This could be used to inform how the scheme can be operated in the future to minimise its ecological impact.

- If a problem with metal contamination is identified, modelling of physical and chemical profiles within the Maitai Reservoir under different operating regimes would allow assessment of mitigation options, where any investigation of changes in the scheme's operation would have to consider both the long-term water-quality of the reservoir and the ecological consequences in the river.

The NRMP cites water standards for toxicants equivalent to the 95% level of protection for aquatic life. On this basis, concentrations of Mn observed in the river are unlikely to exceed these levels of 1.9 g/m^3, and have not been reported to do so based on spot monitoring of backfeed waters (Holmes 2010). There have been no incidents of Mn exceeding the 1.9 g/m^3 at the South Branch monitoring site 100 m downstream of the backfeed weir.

Interestingly, since mid-2008, Mn levels in the reservoir and subsequently the river have been, and remained very low, with no breaches of the consent limits (Figure 27). Although encouraging from an ecological effects perspective, at this point it is unclear as to why peak Mn levels have been low in recent years yet high during the three years prior to 2007. Furthermore, the low values observed during recent routine monitoring appears inconsistent with results recorded from detailed investigations into cycling of contaminants within the reservoir, which found dissolved Mn concentrations of up to 0.5 g/m^3 in the reservoir bottom waters (Kelly 2014, also see Section 2.2.3).

Other metals – sediment analyses

There is a possibility that other metals, present in the metal-rich geology of the Dunn Mountain area in the upper North Branch catchment, occur in the reservoir discharge at environmentally significant levels. Sediment analysis is more likely to detect a long-term accumulation of heavy metals than water quality samples collected at single points in time.

Nickel and chromium have been found in high concentrations in sediment in the upper Maitai River to at least six kilometres below the Maitai Reservoir, with reduced concentrations further downstream (Sneddon & Elvines 2012; Allen et al. 2014). Whilst nickel and chromium toxicity was not covered in the report, concentrations were well above those recommended in ANZECC (2000) guidelines for freshwater quality[23]. As discussed previously for the reservoir (see Section 2.2.4), sediment concentrations of nickel and chromium in the South Branch downstream and upstream of the Maitai Reservoir both exceeded NRMP standards for sediment toxicants, which were in line with ANZECC (2000) low-trigger values. As with, Mn and Fe, anoxic conditions in the reservoir could be contributing to this problem by speciating metals from the Maitai Reservoir sediments and discharging them via the

[23] Nickel concentrations measured 250 mg/kg, *c.f.* Australia and New Zealand Environment and Conservation Council — Interim Sediment Quality Guideline-Low Trigger Value (ANZECC ISQG-Low) recommendation of 80 mg/kg; Chromium concentrations measured 540 mg/kg, *c.f.* 'ANZECC ISQG-Low' recommendation of 21 mg/kg and 'ANZECC ISQG-High' recommendation of 52 mg/kg.

backfeed. Alternatively, these metals may have been deposited in the catchment purely though natural erosion processes. Allen et al*.* (2014) determined that while the discharge from the Maitai reservoir had potential to increase concentrations further, they were most likely minimal.

Iron and Mn concentrations in sediment sample collected in February 2014 during a longitudinal survey were elevated directly below the discharge compared to an upstream control site and a site in the North Branch of the river (Allen et al. 2014). This possibly indicates the water supply scheme is increasing Mn concentrations sediments in the Maitai River (South Branch). However, while Fe concentration quickly reduced to levels similar to upstream, the reduction in Mn concentration was less marked, such that levels at the lowermost site were higher than the upstream control and North Branch sites (Figure 28).

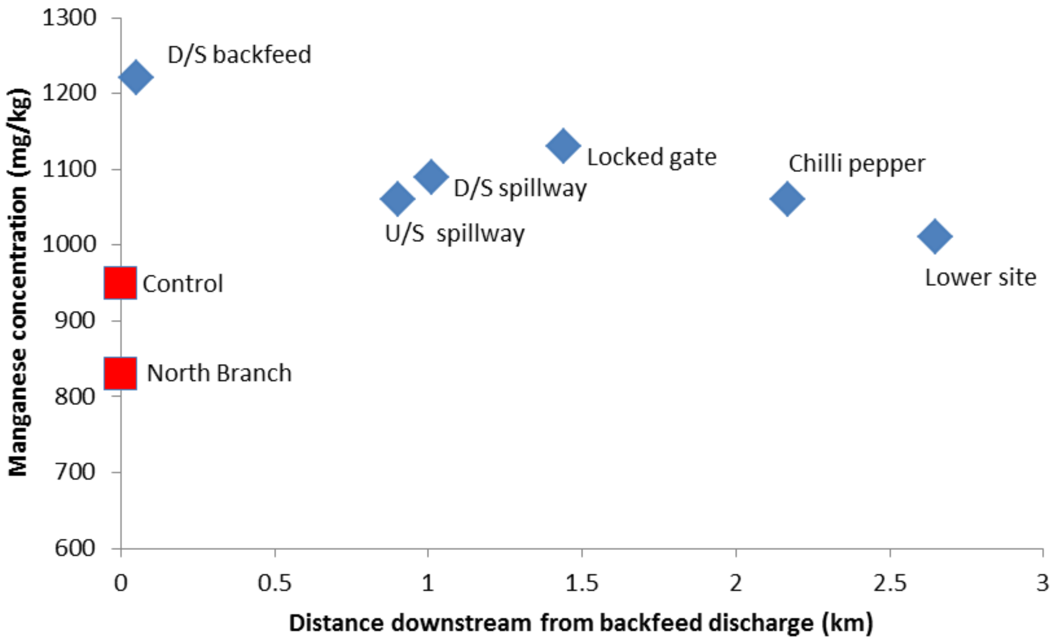


Figure 28. Manganese concentrations at the two sites upstream of the Maitai Reservoir (red squares) were low in comparison to the six sites downstream of the backfeed discharge (blue diamonds). Taken from Allen et al*.* (2014).

2.5.5. Water clarity

Crowe et al*.* (2004) reported the turbidity increased and black disk water clarity measurements decreased with increasing distance down the mainstem of the Maitai River. A study undertaken by Stark & Hayes (1996) found that although the reservoir backfeed discharge may cause a significant reduction in water clarity (using the black disk method) and a change in colour in the river downstream, the ecological significance of any change was likely to be minor and confined to the South Branch.

They found the water clarity effect was attenuated somewhat with increasing distance downstream, however, when the backfeed was off, water clarity decreased more gradually with distance downstream (i.e., there was no sharp drop in clarity below the backfeed).

The current consents pertaining to the reservoir operations require that turbidity (NTU) below the intake weir shall not increase by more than 10 NTU compared with the turbidity in the South Branch upstream of the weir—except in extreme cases when the reservoir is highly turbid (Appendix 1). The change in NTU between the South Branch upstream and 100 m downstream of the intake weir did not exceed this condition on any occasion from 2000–2015 based on monthly sampling (Figure 29).

Turbidity has been measured upstream (control site) and at two sites downstream of the backfeed and in the Maitai reservoir since 1989 as part of NCC's compliance monitoring. The two downstream sites are 100 m downstream of the intake weir, and downstream of the Forks.

The quality of the Maitai River at the Forks is influenced by the spillway discharge from the Maitai Reservoir, over which NCC has no control. Water quality at 100 m downstream of the intake weir, however, is directly affected by the manner in which NCC manipulates the South Branch intake and the backfeed discharge. When the reservoir spillway is not discharging, there is little difference in the turbidity of the river 100 m downstream of the weir and at the Forks (Figure 29). However, when the reservoir spillway is operating, turbidity at the Forks can be much higher than it is upstream of the spillway discharge (e.g. at Site B or 800 m downstream of the intake weir).

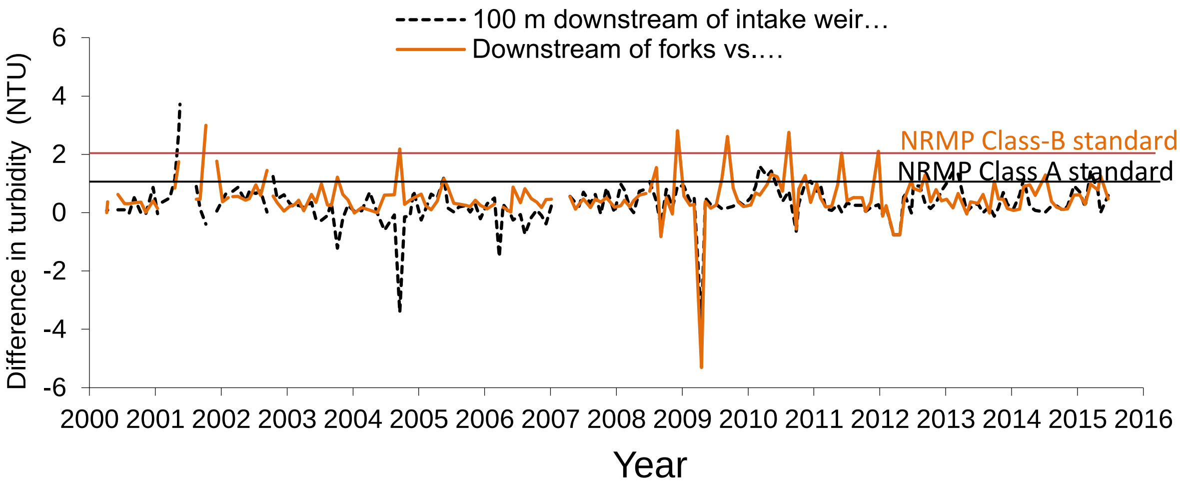


Figure 29. Change in turbidity downstream of the Maitai South Branch intake weir from 2000-15. Values are downstream turbidity minus upstream turbidity (2000-present). The consent limit is a 10 NTU difference.

Water quality data collected from the Forks have been useful in assessing the overall impact of the water supply scheme on the Maitai River. Even if the timing and magnitude of spillway discharges are not controlled directly by NCC, the quality of the water is a result of the presence of the reservoir, and, to some extent, the manner in which NCC operates the intakes.

The NRMP cites a water standard for turbidity in the Maitai of 3 NTU for Class C waters (existing conditions) and 2 NTU for Class B waters, considered to be the aspirational target for the Maitai downstream of the Reservoir. There were no occasions over the last 15 years' monitoring where the Class C standard was breached due to the backfeed or spillway, and therefore it is presumed that this Class C standard is largely always met. Downstream of the forks, there were seven occasions over the past 15 years of monitoring where the reservoir spilling (combined with backfeed) increased turbidity to more than 2 NTU and caused a breach of the Class B standard, but on a mean or median basis (as stipulated in the NRMP) this Class B standard is achieved. Both could be viewed as infrequent and possibly related to localised flow conditions from the North Branch.

The NRMP also cites a standard for water clarity in Class C waters of 2.5 m (black disk) and a 4 m clarity for Class B waters. Because consent conditions are specified in terms of turbidity (a measure of suspensoids in the water), monitoring has been focused around this parameter and has not included black disk monitoring. Hence interpreting the influence of the reservoir in terms of meeting the NRMP clarity targets downstream of the backfeed weir and spillway is more difficult. As discussed in regards to reservoir Secchi disk monitoring, the occurrence of coloured humic materials derived from beech forest catchment drainage reduces water transparency in the reservoir to around 4 m Secchi depth. On this basis we might expect that the NRMP Class C standard of 2.5 m is likely to be met downstream of the dam. However, the Class B clarity standard of 4 m may not be met below the backfeed, as considerable water in the South Branch (up to 80%) can be derived from the backfeed during low flows. Precipitation of soluble metals under oxic conditions in the river increases turbidity and light scattering, and inputs of dissolved humic organic material from the reservoir reduce water transparency. It is anticipated the main influence on clarity downstream of the reservoir are effects related to storage of coloured waters that are imported into the reservoir during high flows and then slowly released over normal flow periods. This ultimately acts to change the clarity in the river over much longer periods than would normally have occurred without the presence of the dam.

2.5.6. Nutrients

Nutrients (nitrogen and phosphorus) are key elements for the growth of river algae (see Section 2.6 Periphyton). Instream nutrient concentrations are commonly compared with guideline concentrations of dissolved inorganic nitrogen (DIN, of which nitrate-N is the major component) and dissolved reactive phosphorus (DRP) in order to assess whether concentrations are likely to prevent development of 'nuisance' biomasses of periphyton (defined as biomasses that are likely to impact on instream values such as aesthetics, recreation, benthic biodiversity, trout habitat and angling; Biggs 2000). The NRMP also cites standards for DIN and DRP for Class C rivers of 295 and 26 mg/m^3, respectively, and for Class B (Maitai mainstem) rivers of 120 and 9 mg/m^3, respectively.

Historically, nitrate-N concentrations in the upper reaches of the Maitai River have been low and below guideline values for periphyton biomass after an 'average' summer accrual period of 15 days (0.295 g/m^3), although spot concentrations frequently exceeded levels that could allow a nuisance periphyton biomass to develop after a 30 or 40 day accrual period (0.075 g/m3 and 0.034 g/m3, respectively) (Crowe et al*.* 2004).

Monitoring of nutrients in the Maitai River downstream of the reservoir backfeed is not required under current consent conditions. However, proliferations of periphyton in recent years and increasing incidences of the potentially toxic cyanobacteria *Phormidium* in the lower river have highlighted a need to understand how the Maitai Reservoir backfeed discharge affects nutrient concentrations in the Maitai South Branch.

A study by Allen et al*.* (2014) showed that dissolved and total nutrient concentrations in the Maitai River were relatively low at eight sites surveyed up and downstream of the reservoir backfeed (Table 18). Concentrations of Total Phosphorus (TP) and Total Nitrogen (TN) suggested the river ranges between microtrophic and oligotrophic, meaning that nutrients are relatively low throughout the study area (Allen et al. 2014). On this occasion all sites met the NRMP Class B standards cited for DIN and DRP.

However, Allen et al. (2014) noted that nutrients are usually present in their lowest concentrations during late summer (i.e. when their samples were taken). They also noted some evidence of elevated nutrient concentrations (nitrogen and phosphorus) downstream of the reservoir backfeed. The nutrient dataset collected during the Allen et al. (2014) study was too small to test for any statistical differences. However, their observations were generally supported by patterns observed in a parallel dataset collected during a separate study assessing the abundance *Phormidium* in the Maitai River (Wood et al*.* 2015a). DIN and DRP concentrations in the Maitai Reservoir are also normally lower than the cited NRMP Class B standards (Kelly 2014).

Table 18. Water chemistry of samples taken from the eight study sites in the upper Maitai River (Allen et al. 2014). ANZECC (2000) water quality guidelines are also provided for New Zealand upland waters as well as NRMP nutrient standards for Class A and Class B rivers.

	Dissolved reactive phosphorus (DRP) mg/m^3	**Ammonium Nitrogen** (NH4-N) mg/m^3	**Nitrite+ Nitrate-N** (NO3-N) mg/m^3	**Dissolved Inorganic Nitrogen** (TDN) mg/m^3	**Total Nitrogen** (TN) mg/m^3	**Dissolved organic carbon** (DOC) g/m^3	**Total Phosphorus** (TP) mg/m^3	**Dissolved organic Nitrogen** (DON) mg/m^3
Control	2	2	4	6	29	0.9	2	21
North Branch	< 1	2	**31**	33	56	1.1	1	19
D/S Backfeed	< 1	9	6	15	90	2.1	4	53
U/S Spillway	< 1	3	< 1	4	65	2.2	3	49
D/S Spillway	< 1	2	1	3	69	2.1	3	51
Locked Gate	< 1	1	1	2	69	2.2	3	55
Chilli Pepper Flat	< 1	1	2	3	76	2.2	3	54
Lower Site	< 1	2	1	3	79	2.0	2	55
ANZECC (2000) trigger values	< 10[a]	< 320[b]	< 17[b]	No guideline	< 295 [a]	No guideline	< 26 [a]	No guideline
NRMP Class A	8			80				
NRMP Class B	9			120				

[a] Trigger levels for slightly disturbed systems – upland river (Table 3.3.10 of the ANZECC (2000) water quality guidelines)

[b] Toxicants trigger value for 99% protection of freshwater ecosystem (Table 3.4.1 of the ANZECC (2000) water quality guidelines)

In the context of aquatic ecosystem health, nutrient concentrations in the Allen et al. (2014) and Wood et al. (2015) surveys were within acceptable ANZECC (2000) limits for aquatic life and NRMP standards. However, DIN in the South Branch below the backfeed does exceed levels upstream of the weir, and could still contribute to the greater coverage by periphyton observed downstream of the backfeed (Allen et al. 2014). The presence of the upstream reservoir is likely to modify the timing of nutrient releases downstream of the backfeed.

Interestingly, Allen et al. (2014) found samples from the North Branch site contained significantly higher concentrations of nitrate-N and DIN than at and upstream from the South Branch control site, a site upstream of the spillway, and Site B. There were slightly greater ammonium-N concentrations in the South Branch downstream of the backfeed, but this was not statistically significant. However, it should be noted that the limited amount of data available gave low statistical power for between-site comparisons (Allen et al. 2014).

2.5.7. Summary of key findings

Summary –River water quality	
Temperature	• Monitoring data show that Maitai South Branch temperature consent conditions are complied with for the majority of the time, with only occasional exceedances. • River water temperature also tends to increase immediately downstream of the spillway discharge pool, and during summer can be in a range likely to induce thermal stress in some sensitive species. • River water temperatures meet the NRMP temperature standards cited for Class C waters downstream of the dam. The spillway discharge has the potential to cause river water temperatures to exceed the 24 °C daily maximum Class B standard, but it is not known how frequently this occurs. Temperature criteria were breached for only one week's duration between 2014 and 2016 summer monitoring downstream of the spillway, but spillway operation was infrequent over the summer of 2014/15 due to dry conditions. • The influence of the dam and its operation on water temperature is attenuated quite rapidly, and unlikely affect water temperature in the mid to lower river.
Dissolved Oxygen	• The impact of the reservoir on DO levels in the Maitai River is minimal and confined to the river immediately downstream of the backfeed weir. • Dissolved oxygen levels at and below the backfeed discharge point have, to date, met consent requirements (i.e. exceeded a limit of 6 mg/L) on all sampling occasion, even during summer stratification in the Reservoir when water in the bottom of the dam is near or at 0 mg/L. • The NRMP DO minimum standard of 90% saturation (Class C) is at times not met downstream of the dam based on the limited monitoring data available, however this is likely to also be the case upstream of the dam, and this criterion is likely to be too restrictive for the Maitai River.
Iron and manganese	• Iron and Mn concentration below the backfeed discharges are generally at or below consented limits. • However, Mn concentrations have exceeded consented levels three (almost four) times during the term of the current consent. However this is unlikely to result in breaches of the Mn standards under the NRMP of 1.9 g/m^3. • Fe concentrations can exceed concentrations reported overseas for the protection of sensitive aquatic life, but no Fe

	criteria are cited by ANZECC for New Zealand freshwaters. • During summer, the anoxia in the bottom waters of the reservoir can elevate stored concentrations of Fe and Mn, which oxidise to form precipitates when this water is released into the South Branch.
Turbidity	• The impact of the reservoir on turbidity in the Maitai River is minor. • Turbidity at and below the backfeed discharge point have, to date, met consent requirements (i.e. a change of less than 10 NTU). • NRMP Class C turbidity standards of 3 NTU are always met downstream of the reservoir, and only on a small number of occasions (fewer than 7 times) were the NRMP Class B standards of 2 NTU exceeded related to the reservoir discharge.
Nutrients	• Recommendation that nutrients be monitored given recent concerns over proliferations of periphyton, and Phormidium in the Maitai River. • Enriched DIN concentrations in the reservoir can at times elevate DIN downstream of the backfeed, however NRMP Class B standards for DIN and DRP (9 mg DRP/m^3 80 mg DIN/m^3) were met in all cases based on limited monitoring data available.

2.6. Periphyton communities

2.6.1. Background

Periphyton growth and rate of growth (accrual) is mainly dictated by light, temperature and nutrients and the flow regime (Biggs & Kilroy 2004). With sufficient light, the nutrient nitrogen and phosphorus can be a major factor in controlling periphyton growth (Biggs & Kilroy 2004). Low to moderate levels of periphyton are important for the functioning of rivers (i.e. they provide the food base for invertebrates that are food for fish and birds). However, proliferation of periphyton in rivers can have a number of in and out of stream effects including:

- Loss of aesthetic appeal
- Decomposition exacerbating daily lows in oxygen and acidity (pH)
- Change in composition of invertebrate communities with follow-on effects in terms of energy flow further up the food chain (see Section 2.7 Macroinvertebrates)
- Hazards to animal and potentially human health (e.g. cyanobacterial blooms releasing toxins).

Nuisance periphyton growths have been a feature of the Maitai River since at least the 1980s (Crowe et al. 2004) and possibly earlier (pers. comm. Paul Sheldon, Tasman District Council). These growths are usually associated with low-flow conditions. Based on available data it is not possible to determine if the incidence of nuisance algal growths has increased over time. However, increased algal growths have been noted downstream of the Maitai Reservoir backfeed discharge (Allen et al. 2013; Allen 2014; Newton 2015).

Proliferations of *Phormidium* have become an emerging issue in the Maitai River. Following the death of a dog due to ingestion of toxic *Phormidium* mats in the Maitai River in 2009, NCC now monitors cyanobacteria coverage at three sites in the 'middle' Maitai River catchment (Wood & Bridge 2014; Wood et al*.* 2015a). High *Phormidium* cover has not been recorded over the three years of monitoring in the upper reaches of the Maitai near the reservoir, with *Phormidium* predominantly confined to the mid and lower reaches of the river (Wood et al*.* 2015a). There have been several further reports of dog deaths since 2009, and a possible case of human poisoning in 2016. Nelson City Council erects information and warning signs seasonally (spring-summer-autumn) in the middle and lower Maitai as a precautionary measure.

Monitoring of periphyton coverage or biomass (chlorophyll-*a* and ash-free dry mass) in the Maitai River is not required under the current Maitai Reservoir consents. However, periphyton can be an indicator of nutrient enrichment. Periphyton is also an important link in the food chain as food for aquatic invertebrates, which are in turn preyed on by fish. Knowledge of periphyton coverage in a river can be an important feature explaining changes in aquatic invertebrate community structure and abundance. For these reasons, visual estimates of periphyton cover at the two biomonitoring sites (control and Site B) were incorporated into the bi-annual monitoring programme in 2010 (Olsen 2010).

2.6.2. Periphyton coverage in Maitai River below water intake/ backfeed discharge

Higher periphyton coverage below the backfeed discharge (at Site B) than at the upstream 'Control site' has been noted or recorded on several occasions (Holmes 2009a, 2009b; Olsen 2010; Holmes 2012; Holmes & Kelly 2012). Holmes (2012) noted that given that the two sites have a similar flow history this indicates that the backfeed may be encouraging algal growth downstream.

The NRMP cites periphyton standards for Class B and C rivers not exceeding 60% cover of the riverbed by medium brown mats, and 30% cover by green filaments longer than 2 cm. Based on recent consent monitoring information on periphyton cover (Olsen 2010; Holmes 2012; Allen & Holmes 2013; Allen 2014, Newton 2015), coverage 800 m downstream of the backfeed weir has on several occasions exceeded these NRMP standards. More often this has been in terms of cover by green filamentous algae in excess of 30% cover. It is probable that this is attributable to the backfeed discharge because cover at the control site immediately upstream of the backfeed weir has not exceeded either of these periphyton cover standards on any occasion. As discussed in previous sections (section 2.5.6), increased DIN in reservoir water backfed to the river (particularly bottom waters) is likely linked with these periphyton growth responses. Wood et al. (2015) found DIN to be one of the most important factors explaining cyanobacteria periphyton proliferations in the Maitai River over its extent.

Allen et al. (2014) investigated the longitudinal extent of periphyton changes in the Maitai South Branch below the backfeed weir and found visually obvious increases in the periphyton downstream of the backfeed discharge, and these changes prevailed over the 2.6 km downstream river section (Figure 30). Coverage of thin brown algae was significantly lower at all individual downstream sites compared to the Control and North Branch sites, and coverage of medium brown and green filamentous algae was significantly higher. Periphyton scores decreased significantly with increasing distance downstream[24] of the backfeed discharge due to increased cover of medium thickness brown mats and green filamentous algae (Figure 31).

Allen et al. (2014) also found average periphyton scores at all sites below the backfeed discharge to be significantly lower than those at both the Control and North Branch sites (a low score indicating greater cover by medium mats and filaments). Periphyton scores for two control sites were characteristic[25] of a stream with 'Very good' water quality, which changed to 'Good' water quality at site below the backfeed discharge and finally 'Moderate' water quality (Allen et al. 2014).

[24] The Allen et al (2014) study sample sites were located above and immediately below the backfeed discharge, in the Maitai North Branch (above the dam) and at five sites progressively downstream from the backfeed over a distance of 2.6 km. Beyond that, non-reservoir related activities also influence the levels of nutrients entering the Maitai River such as exotic forestry in the mid-reaches, and increasing urbanisation through the lower reaches.

[25] According to Biggs & Kilroy (2000)

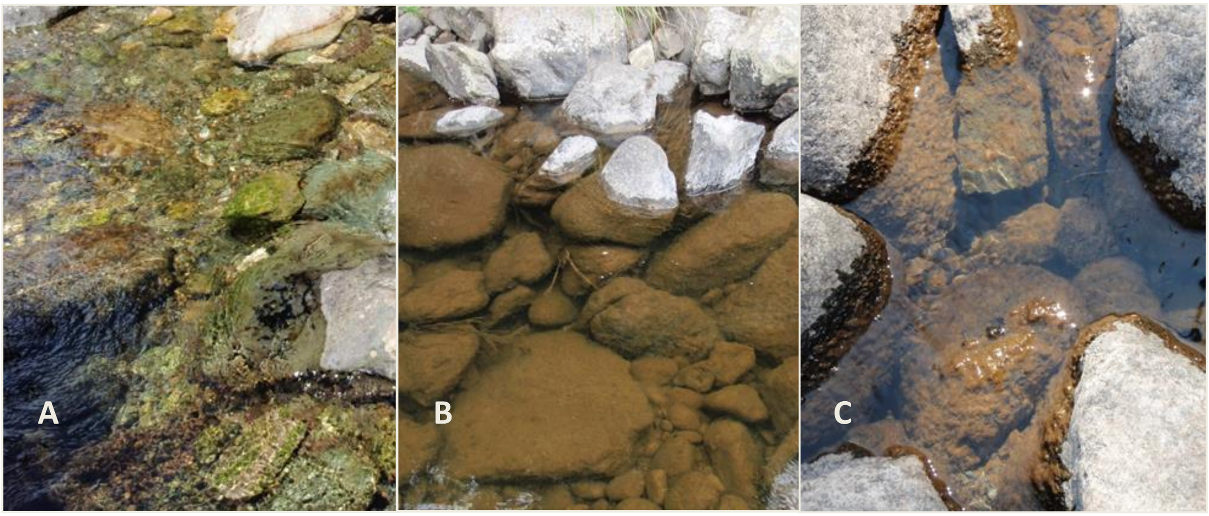


Figure 30. Example of periphyton communities present in the Maitai River South Branch showing: (A) thin brown algae at the Maitai North Branch site; (B) medium brown algae at the downstream of the Spillway site; (C) thick brown algae at the Lower Site located 2.5 km downstream of the backfeed (photo reproduced from Allen et al. 2014).

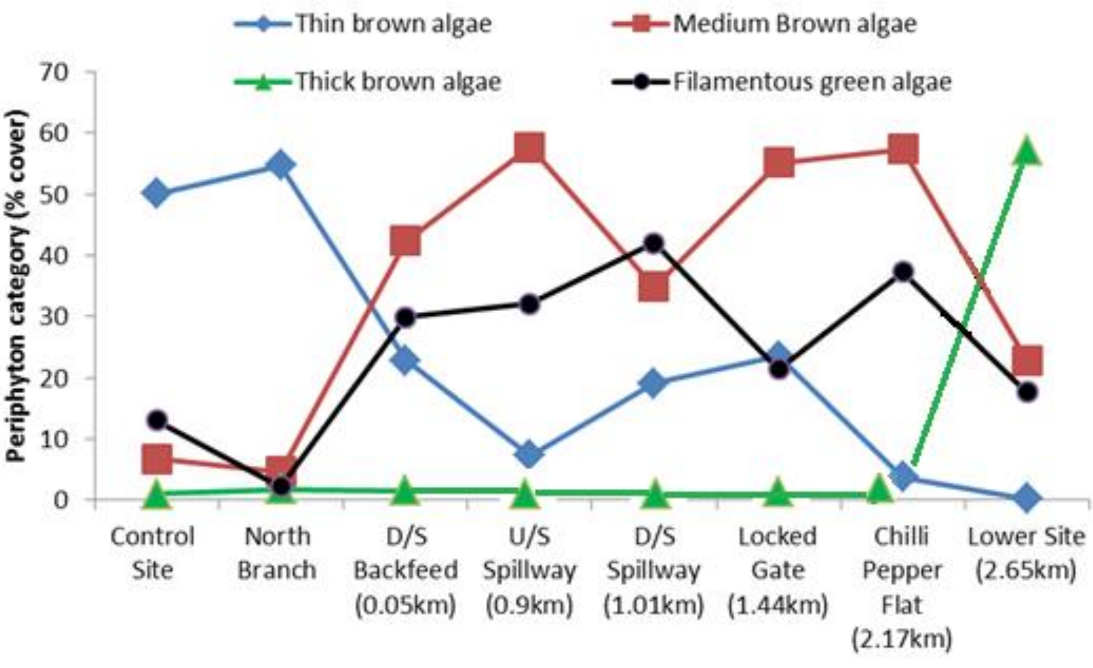


Figure 31. Change in dominant periphyton groups below the backfeed discharge. Coverage of thin and medium brown algae was significantly different (95% confidence) than that found at the Control and North Branch sites (figure after Allen et al. 2014).

A linear regression showed a significant longitudinal decline in overall periphyton score with distance downstream, declining at a rate of 0.67 periphyton score points per km (Figure 32). This was predominantly a result of increasing coverage by medium and thick brown mats and lower coverage by thin brown algae with distance downstream. However, it should be noted that this was based on a single sampling event in late summer, and therefore should be interpreted with caution because periphyton communities are known to vary markedly over time.

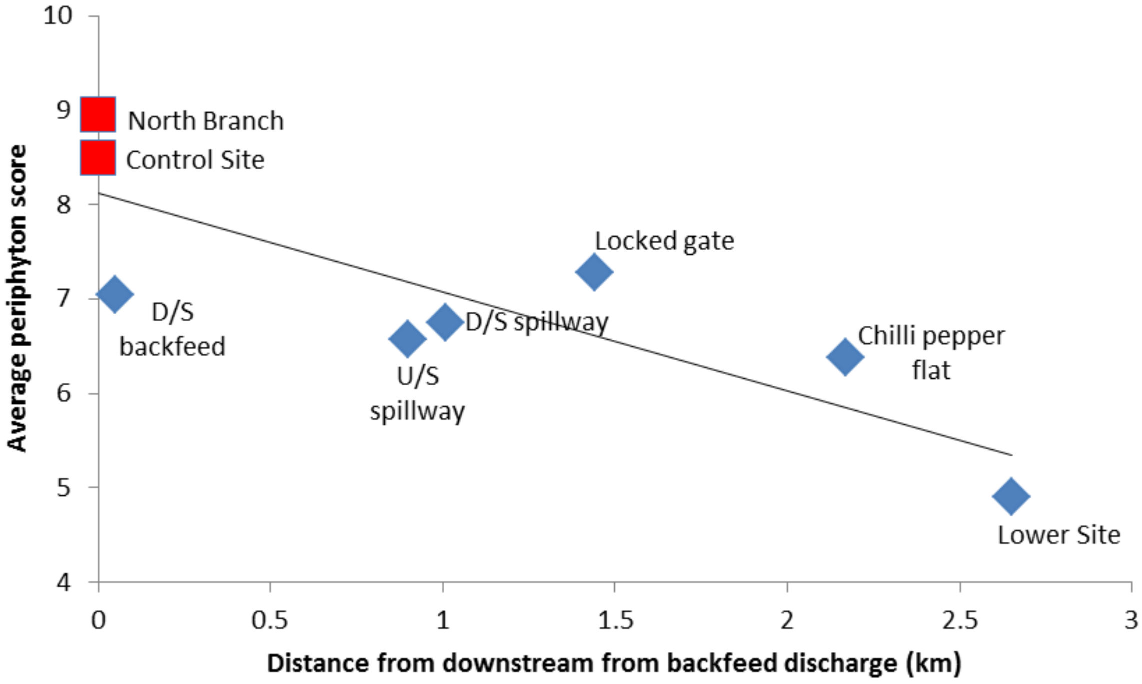


Figure 32. Average periphyton score at sampling sites, showing distance downstream from the backfeed discharge. There is a statistically significant downstream decline (p = 0.026).

Overall, there was a marked change in the periphyton community immediately downstream of the backfeed followed by a continued decline (of indicative water quality) with distance downstream over the 2.6 km of river length surveyed. Input of greater concentrations of DIN from the reservoir backfeed could potentially contribute to these changes. It is unknown if other trace metal concentrations changes (e.g. Mn, Fe) downstream of the backfeed could affect periphyton communities.

Metals such as iron and copper are important in cellular processes for algae and cyanobacteria (Harland et al. 2013[26]). Studies have shown how important periphyton biofilms can be in the sorption[27] of heavy metals, and may account for the progressive reduction in Fe concentration with distance downstream of the reservoir backfeed coupled with increasing periphyton biomass in the Allen et al. (2014) report. Manganese has been shown to have a negative effect on the biomasses of biofilm

[26] Harland et al. (2013) found that when the Fe concentrations were 800 and 4000 g/L, *Phormidium autumnale* cultures did not firmly attach to the substratum. At either 40 or 4000 g/L Fe, growth was suppressed.
[27] Sorption is the act of binding contaminants, usually to organic molecules. In some instances metal contaminants are then used for light harvest pigmentation in photosynthetic apparatus

diatoms and cyanobacteria (Kamjunke et al. 2015). However, it is generally unknown the extent to which trace metal additions from the backfeed affect periphyton in the Maitai, and further work would be necessary under experimental conditions to verify this. Improvements in water quality in the reservoir could reduce concentrations of metals transferred to the river in backfeed discharges, potentially reducing effects on periphyton and other associated biota.

2.6.3. Periphyton growth and flow regime

Variation in river flow, floods in particular, are important for regulating the growth of periphyton. When river flows are low for a long periods of time (e.g. during a summer drought), periphyton can proliferate to nuisance levels and in extreme cases has been known to can cause severe daily fluctuations in dissolved oxygen levels and pH (Biggs et al. 1989; Biggs 2000).

There has been no significant change to the frequency of small floods (4–10 m^3/s), compared to both natural flows pre-reservoir abstraction regime (Hewitt & Kemp 2004). Therefore the reservoir is not a likely factor to be affecting periphyton growth as a result of altered hydrological state in the river.

Discharge from the backfeed both replaces South Branch water abstracted for the domestic supply and augments minimum flows to at least 175 L/s during summer low flows. The reservoir could be used to augment flushing flows in summer via the backfeed. Hay and Allen (2014) suggested such augmentation could be effective in flushing the river and reducing periphyton proliferations in the upper portion of the river. Flow releases of 3.5 m^3/s (i.e., the maximum capacity of the backfeed) supplementary to natural freshes events exceeding 6 m^3/s were predicted to be effective for this purpose. However, flow events exceeding 17 m^3/s are predicted to be required for periphyton removal in the mid-lower river, and these events are relatively rare during summer months. Therefore it is unlikely flow releases from the dam could be effective at controlling periphyton in the mid and lower reaches of the Maitai River, noting that these are the areas in which *Phormidium* blooms predominantly occur. Consideration would also need to be made around water-use efficiency, as with any water used for flushing-flow releases, decreasing amounts of stored water in the Maitai Reservoir are available to augment minimum flows.

Another issue around the augmentation of flows or consideration of flow releases for improving periphyton conditions is that currently replacement water is being taken from the bottom of the reservoir, which can have increase in concentrations of nitrogen and trace metals during summer months. Therefore consideration of additional flow releases from the backfeed would best be done in conjunction with improving water quality in reservoir backfeed water.

2.6.4. Periphyton and nutrients

Linking periphyton biomass to stream nutrient concentrations is difficult, and rather than a single, guideline concentration for each nutrient, a range of concentrations is given that relates to different numbers of 'days of accrual' (i.e. days of stable flow). For example, if 20 days of accrual occur, the concentration of DIN needs to be less than 0.295 g/m^3 (and DRP concentration, < 0.026 g/m^3) to prevent development of nuisance periphyton biomasses (Biggs 2000). In contrast, if 100 days of accrual occur, the maximum concentration of DIN that will prevent nuisance periphyton growth is reduced to 0.010 g/m^3 (*c.f.* DRP concentration < 0.001 g/m^3). This means that rivers prone to frequent freshes can have higher nutrient concentrations than more stable rivers without exceeding periphyton biomass guidelines for instream values. However, if a typically flood-prone river with DIN or DRP concentrations of around 0.295 g/m^3 or 0.026 g/m^3, respectively, experiences a stable period of flow (e.g. during a drought), nuisance periphyton growths are likely to occur.

In the Maitai River, the mean number of 'days of accrual' over the summer period (1 October to 30 April) is 15 days (see Crowe et al*.* 2004, Section 4.7.8). This means that in order to limit periphyton growth to acceptable levels over 15 days, DIN needs to be less than 0.295 g/m^3 or DRP needs to be less than 0.026 g/m^3, depending on which nutrient is limiting growth. Since the shortest accrual period that the 'New Zealand Periphyton Guideline' (Biggs 2000) lists as limiting nutrient concentrations is 20 days, these are conservative estimates of the nutrient concentrations required to promote nuisance periphyton growth over a 15 day period.

The presence of the upstream reservoir is likely to modify the timing of nutrient releases downstream of the backfeed. As mentioned earlier, nitrogen in particular is at higher concentrations in the North Branch (and the reservoir). This would be released into the Maitai River at a moderately constant rate over the summer period from the backfeed when nutrients are normally very low in the South Branch. In turn, this could help sustain the greater periphyton cover observed below the backfeed over the summer, over a longer period. Seston[28] outflowing from the reservoir is likely to contain significant quantities of TN and TP bound-up in phytoplankton, which could account for the greater TN and TP concentrations observed downstream of the backfeed and spillway (Allen et al*.* 2014). Elevated DIN could contribute to the greater coverage by periphyton downstream of the backfeed in comparison to upstream sites as observed during recent biomonitoring occasions (e.g. 2012–2014).

Allen et al. (2013) raised the possibility that micronutrients present in the Maitai Reservoir (e.g*.* Mn and Fe) may also be causing increased algae growth below the backfeed discharge. However, validation of this theory would require an investigative study to measure the concentrations of heavy metals in periphyton mats.

[28] Seston- particulate organic material, usually phytoplankton, outflowing from lakes and reservoirs

2.6.5. Cyanobacteria

Over the past five years blooms of the benthic mat-forming cyanobacterium *Phormidium* have become an annual occurrence in the Maitai River, particularly around the river's mid and lower reaches. Under favourable conditions *Phormidium* forms expansive black/brown leathery mats that can cover large areas of the river substrate. *Phormidium* can produce natural neurotoxins, known as anatoxins. Anatoxins are powerful neuromuscular-blocking agents and pose a health threat to humans and animals when consumed or when there is contact with contaminated water.

As mentioned earlier, NCC currently monitors *Phormidium* coverage at three sites in the 'middle' Maitai River catchment between October and April. Although it arguably the mid-lower reaches where the greatest concern for animal and public health lies, *Phormidium* growths have been noted immediately downstream of the Maitai Reservoir (and at the control site) at lower coverage extents. During biomonitoring surveys higher coverage of *Phormidium* has been noted downstream (Site B) of the backfeed than at the upstream (control site) in some years of monitoring (Holmes 2012; Olsen 2010; Holmes & Kelly 2012). However, high coverage of *Phormidium* did not occur in the upper portion of the river based on monthly monitoring over a two-year period (Wood et al*.* 2015a).

Recent studies suggest that *Phormidium* blooms generally occur in rivers with stable flows, low DRP (< 0.01 mg L^{-1}), and slightly elevated DIN (> 0.02 mg L^{-1}; Heath et al. 2015, Wood et al*.* 2014). A possible link between fine sediment and *Phormidium* blooms has also been identified. The thick and cohesive growth form of *Phormidium* is unlike other river periphyton and allows water to be trapped in the mucilaginous matrix. Well-developed *Phormidium* mats often have a fine layer of sediment at the substrate and mat interface. Wood et al. (2015b) showed that biogeochemical conditions inside natural *Phormidium* mats can be very different to the outside water column, including the development of high pH (> 9) during the day (due to photosynthetic depletion of bicarbonate) and low oxygen (< 4 mg/L) concentrations at night (due to respiration). Such conditions are conducive to the release of DRP loosely bound to sediments trapped in the mat matrix, and this may be an additional source of DRP and one of the reasons why *Phormidium* can reach high biomass when water-column DRP is low. Wood et al. (2015b) used sediment traps to investigate whether there was a relationship between increased sedimentation rates and the prevalence of *Phormidium* mats in the Maitai River. Deposition of fine sediment (< 63 µm, the dominant sediment size observed within *Phormidium* mats) was higher at sites with proliferations. Sequential extraction of phosphorus from trapped sediment found that biological available phosphorus concentrations were higher at sites with proliferations (Wood et al. 2015a), highlighting the importance of fine sediment. The presence of the Maitai Reservoir is likely to attenuate fine sediment additions to the Maitai mainstem from the North Branch. In this manner it is likely to improve downstream river conditions associated with the accumulation of fine sediments, which are known to be sourced in higher quantity from lower tributaries (the Brook, Sharlands Creek, Groom Creek; Wood et al. 2015a).

During the summers of 2013 to 2014, and 2014 to 2015, Wood et al. (2015a) conducted weekly monitoring of *Phormidium* and other algae, and a range of physico-chemical parameters was undertaken at three sites that experience *Phormidium* blooms in the lower Maitai River. Monthly monitoring of the same variables was undertaken at four sites in the upper river that either do not, or only very occasionally, experience *Phormidium* blooms. Sediment traps were used to investigate sedimentation rates, and sequential extraction of phosphorus to quantify biologically available phosphorus in the sediment at various sites along the river. River gauging and nutrient analysis data was collected to enable a preliminary (summer low flow) estimate of nutrient loads from key tributaries (Wood et al*.* 2015a).

Analysis of data from the lower Maitai river sites during periods with and without blooms, identified that water column DIN was significantly higher during blooms. With the exception of the North Branch, the upper sites generally had lower DIN concentrations, and Wood et al*.* (2015a) suggested this may explain why blooms very rarely form at these sites relative to lower down in the catchment.

In rivers with *Phormidium* blooms, the frequency of flushing flows is usually the most important factor whether a bloom will occur (i.e. flows that cause removal of *Phormidium* through elevated velocity shear stresses, abrasion or grinding by mobilised substrata). A three times median flow is generally considered a flushing flow sufficient for the control of periphyton below nuisance levels (Clausen & Biggs 1997) although work by Wood et al*.* (2014) indicated a higher flow may be required to detach *Phormidium* mats in some Manawatu Rivers. Nevertheless, in contrast to many of the rivers in New Zealand, Wood et al. (2015a) found prolonged periods of stable low flow, at least over the summer months, did not favour *Phormidium* blooms in the Maitai River.

From a relatively limited number of samples that Wood et al. (2015a) analysed for elemental compositions there was a suggestion that sites with higher sodium, strontium and potassium may be more prone to experiencing *Phormidium* blooms. They noted that the importance of these variables and other factors such as temperature, day length and competition with other algae, require further investigation.

2.6.6. Summary

Summary – Periphyton

- In recent years, higher periphyton coverage and biomass has been noted downstream of the reservoir discharge than upstream during the summer months when river flows are low and stable. This indicates that the backfeed discharge may be encouraging algal growth downstream, since flow does not differ between the up and downstream sampling sites.
- Coverage of periphyton at the biomonitoring site located 800 m downstream of the backfeed discharge indicate that standards identified in the NRMP are regularly exceeded during summer, most often for filamentous green algal cover exceeding 30%, and occasionally for medium brown mats exceeding 60% cover. No exceedances of these standards have occurred at the upstream control site suggesting the backfeed discharge to be the main cause of this greater coverage by nuisance periphyton.
- The backfeed may be encouraging the growth of algae by increasing nutrients (principally DIN), altering the nitrogen to phosphate ratio, or introducing micronutrients (Fe and Mn) to the South Branch
- Periphyton accrual rates in the river may be augmented though release of nutrients (micronutrients) from the bottom of the reservoir.

2.7. Macroinvertebrate communities

2.7.1. Background

Aquatic macroinvertebrates describes large (> 0.5 mm in length) invertebrates such as insects, snails and worms that live in the riverbed. Macroinvertebrates play an important role in maintaining periphyton communities (through grazing), and as a food source for fish and some birds species. Macroinvertebrates are commonly used in assessments of the environmental change in rivers as they are easy to sample and identify. As most macroinvertebrates have a life span of over a year, and do not move great distances, they will often be better indicators of change in environmental condition at a site than spot water quality measurements or fish surveys.

Common environmental assessments using macroinvertebrates include looking at the number and types (and sometimes size) of animals that are present, and whether the macroinvertebrate community structure has changed at a location as a result of an impact (e.g., Stark 1993b). Changes in macroinvertebrate communities can have important implications for the food chain. If the number of macroinvertebrates that graze on periphyton is too low, there is potential for periphyton to grow in biomass to nuisance levels. For fish that preferentially feed on macroinvertebrates drifting in the water column (such a trout and kōaro) a macroinvertebrate community dominated by invertebrates that are prone to drifting in the water column is important.

A range of macroinvertebrate community indices are commonly used for assessing river health (Stark 1993b; Stark 1998b; Stark et al. 2001). These include % EPT[29] taxa; Macroinvertebrate Community Index (MCI); Semi-Quantitative Macroinvertebrate Community Index (SQMCI); and Quantitative Macroinvertebrate Community Index (QMCI). These indices, based on the relative occurrence of pollution sensitive and pollution tolerant species, provide values that indicate the level of nutrient enrichment and fine-sediment deposition at a sampling location (with higher values indicating more pristine environmental conditions, and lower values more degraded conditions). The indices are described in more detail in Appendix 6.

2.7.2. Macroinvertebrate communities in the Maitai River catchment

Macroinvertebrate community health indices in the Maitai River decline with increasing distance downstream (Crowe et al. 2004; NCC 2010). The progressive decline in macroinvertebrate communities from high to low quality assemblages has been linked to the land use activities, principally forestry (mid-reaches including Sharlands and Groom creeks) and urbanisation (lower reaches including The Brook) (Allen et al. 2013). Poor quality invertebrate community assemblages in the Maitai River have often been associated with prolonged periods of high benthic algal biomass (Crowe et al. 2004; Wood et al. 2015a).

2.7.3. Change in macroinvertebrate communities over time (consent monitoring)

Biological monitoring of the Maitai River is required by Nelson City Council's Water Consent 831560 for the Maitai water supply reservoir (Appendix 1). As part of this monitoring requirement, macroinvertebrate communities have been sampled since the early 1980s. The monitoring includes the collection of duplicate quantitative macroinvertebrate samples, normally undertaken on two occasions per year (May and November), at Site B. Analyses carried out to assess the long-term changes in macroinvertebrate communities below the Reservoir found a statistically significant decreasing trend in invertebrate community health indices between 1989 and 2012. This indicates that water quality has decreased below the Maitai Reservoir (Newton 2015). Statistical evidence of the declining trend did not emerge until after 2003 (Figure 33, compare Stark 2003, 2004 with Olsen 2007b[30]). Following the identification of a declining trend in macroinvertebrate health indices, in 2007 NCC included a control site, located 100 m upstream of the backfeed weir, in the biomonitoring programme (Holmes 2009a). The addition of this site was to provide insight into whether the apparent declining health of the macroinvertebrate community below the intake and backfeed is influenced by the operation of the scheme, or as a result of some other factor.

[29] EPT refers to the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis flies). The presence of these taxa is usually an indication of good stream health.
[30] No biomonitoring undertaken in the 2004-5 monitoring period (Olsen 2007a)

Six biotic indices have been calculated on each occasion to assess community response to the backfeed discharge, including taxonomic richness, density, %EPT taxa, % EPT abundance, MCI and QMCI (see Appendix 6 for descriptions). As no one index can provide a complete picture of how an environmental change is affecting an invertebrate community, it is important to use a range of complementary indices and metrics (Hayes 2014).

Taxonomic richness and density are the two broadest metrics used to measure the state of an invertebrate community. High taxonomic richness indicates a diverse habitat that is able to support a range of different species. Highly diverse ecosystems may be desirable because they can be more resilient to environmental disturbance and support a broader range of ecosystem functions (Elmqvist et al. 2003). Density changes over time can be highly variable and strongly influenced by preceding flow events (floods and droughts). However, sudden changes in density between sites immediately up and downstream of a discharge (and in the absence of any flow-varying factor) can indicate an environmental impact. Taxa richness and density have been variable in the Maitai River at Site B since monitoring began in early 1989 (Figure 33). There have only been a few times when taxonomic richness and densities at Site B have deviated markedly from the Control Site, with Site B values often being lower on these occasions.

Macroinvertebrate Community Indices calculated from samples taken from the upstream control site (monitored since 2008) show no declining trend and consistently indicate pristine water and/or habitat quality (Figure 33). However, significant negative trends have been observed for %EPT abundance, MCI and QMCI scores at Site B over the period of sampling, suggesting that water quality has declined[31] (Figure 33). The control site and Site B (800 m below the backfeed) have similar physical characteristics and hydrological histories. Therefore, in the absence of any other contributing factors, the decline in stream–health indicators below the backfeed is likely to be caused by the discharge of poor quality reservoir water.

Holmes (2009a) observed that the decreasing trends in some of the invertebrate metrics were consistent with those expected due to nutrient enrichment. Indeed, following long periods of stable flow, algal mat percentage cover, which is also an indicator of increased concentrations of nutrients, appears to be higher at Site B than at the control site (see Olsen 2010). Holmes (2009a) suggested the nutrient enrichment could result from the release of sediment-bound phosphorus during periods of low oxygen concentration in the deeper waters of the reservoir, which is then discharged to the South Branch via the backfeed, however subsequent work has found low P release rates from reservoir sediments (Kelly 2014; see section 2.2.4).

[31] The apparent decrease in water quality, macroinvertebrate data from below the reservoir indicate that water quality has gone from ‘Excellent’ (clean water) to is ‘Good’ (‘possible mild pollution’), as interpreted by guidelines suggested by Stark and Maxted (2007) (see Table A4.1, Appendix 4).

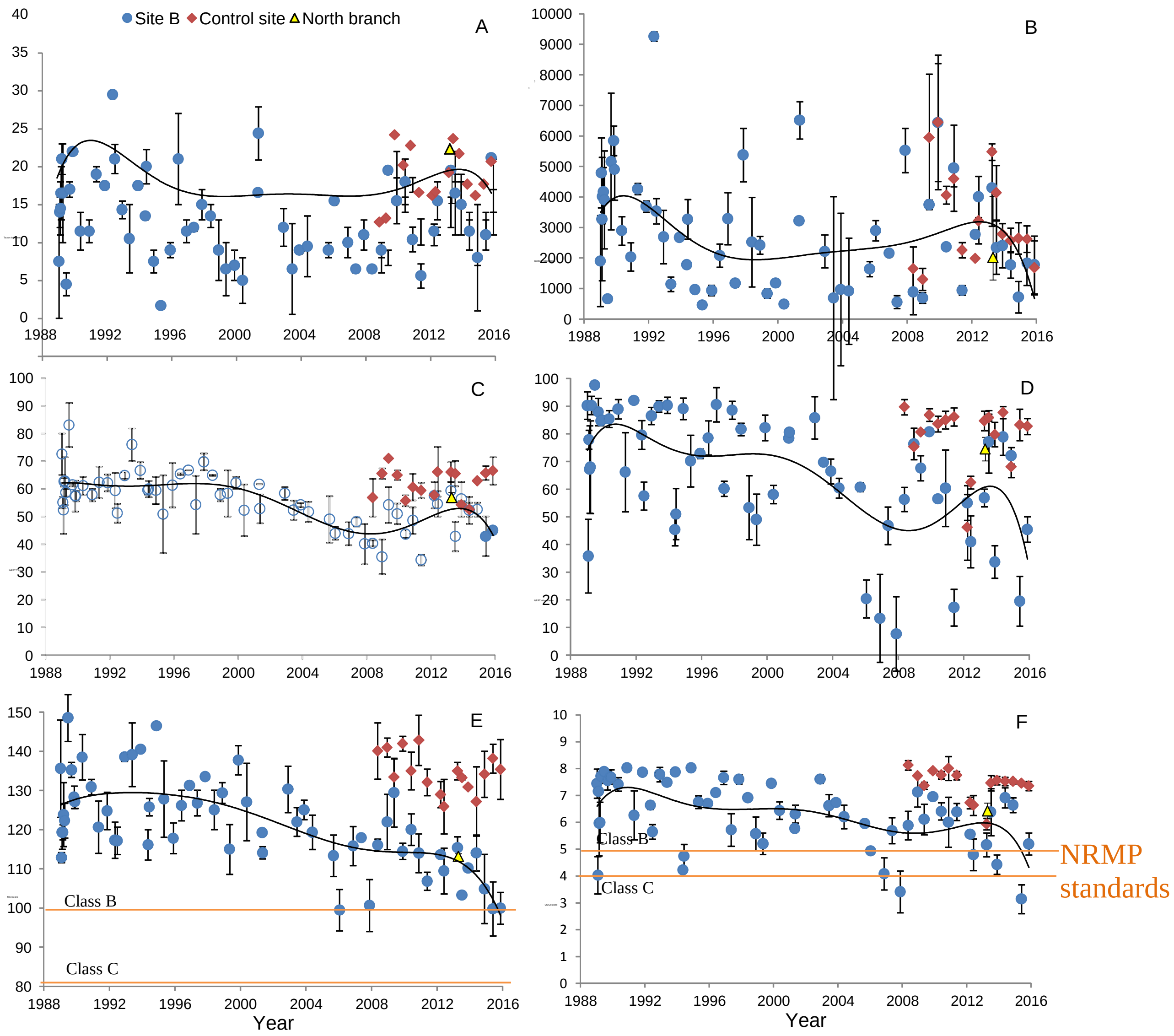


Figure 33. (A) Taxa richness, (B) mean macroinvertebrate densities, (C) %EPT taxa, (D) %EPT abundance (E) Macroinvertebrate Community Index (MCI) scores and (F) Quantitative MCI (QMCI) scores for: Site B in the Maitai River (blue circles) for 60 occasions between 1989 and 2015; the Control Site (upstream of intake = red diamonds) on 16 occasions between 2008 and 2015 and for the North Branch upstream of the Maitai Reservoir on one occasion in 2013 (yellow triangle). Fitted lines (black) are polynomial curves (order 6) fitted to Site B data only. Error bars represent standard errors of the mean. Also shown with an orange line are the NRMP standards for the MCI and QMCI indices.

The NRMP cites water quality standards for macroinvertebrate community metrics in Class C rivers (Maitai downstream of the Reservoir) as a minimum MCI of 80 and a QMCI of 4. The degradation in QMCI that has occurred at the downstream biomonitoring site between 2004 and 2015 indicates that macroinvertebrate metric score on occasion no longer meet these targets. Macroinvertebrate community metrics for Class B waters are cited in the NRMP as a minimum MCI of 100 and QMCI of 5. The declines in invertebrate community health downstream of the dam indicate that neither of these targets were met based on recent (2014–2015) monitoring data. Also apparent from the long term monitoring record is that the upstream control site regularly exceeds the NRMP Class A targets of 120 MCI and 6 QMCI, indicating the backfeed discharge has had a significant effect on the decline in benthic invertebrate community health observed below the backfeed weir.

Allen et al. (2014) and Newton (2015) cautioned that a considerable portion of the decline in MCI and QMCI observed at Site B in comparison to the Control Site will be due to a community shift towards a lake outlet community typology. The MCI and QMCI were developed for use on stony streams, not lake-outlet streams. Typical lake outlet communities score poorly when assessed with MCI and QMCI invertebrate metrics. Since the reservoir's formation, over 25 years ago, it has been changing its thermal and stratification characteristics to the stage that currently defines it. The macroinvertebrate results in the early years of sampling suggest communities downstream of the backfeed discharge were generally in good health up until around 2004 (see Figure 33 E & F). It is unclear why invertebrate community indices have been in decline since 2004. It may be a result of declining water quality in the reservoir or a change in the management regime of the backfeed discharge.

2.7.4. Spatial change in macroinvertebrate communities

A study undertaken by Allen et al. (2014) assessed the longitudinal change in macroinvertebrate community above and below the reservoir backfeed discharge. They found mean scores for %EPT taxa were in all cases lower for sites below the backfeed discharge, though the differences were not always statistically significant.

Mean MCI scores for the Control and North Branch sites are indicative of 'Excellent'[32] water quality, while scores from sites downstream from the backfeed discharge are indicative of 'Fair' (Downstream of Spillway) or 'Good' water quality. Mean QMCI scores for the Control and North Branch sites are indicative of 'Excellent' water quality, while scores from sites downstream from the backfeed discharge are indicative of 'Poor' (Lower Site) or 'Fair' water quality (Figure 33).

The longitudinal decline in QMCI scores with distance downstream from the Backfeed was significant (at the 95% confidence interval). The change in QMCI observed below the backfeed discharge is moderate in gradient, declining at a rate of approximately 0.39 per km. According to Stark and Maxted (2007), this can be interpreted as indicative of water quality that declines from 'Probable moderate pollution' immediately below the backfeed discharge to 'Probable severe pollution' at the Lower Site (Figure 34).

[32] See Appendix 6 for explanation of biotic indices and the water quality classes "Excellent', 'Good' 'Fair' and 'Poor' (Table A4.1)

However, Allen et al. (2014) suggested it was highly unlikely that this rate of decline continues downstream. While QMCI scores from polluted sites will vary over time, the QMCI value calculated from NCC's 2013 State of Environment monitoring for Maitai at Groom Road (8.9 km downstream from the backfeed discharge) was 4.3. This is one category higher than that found at the Lower Site, but is still indicative of 'probable moderate pollution' according to Stark and Maxted (2007).

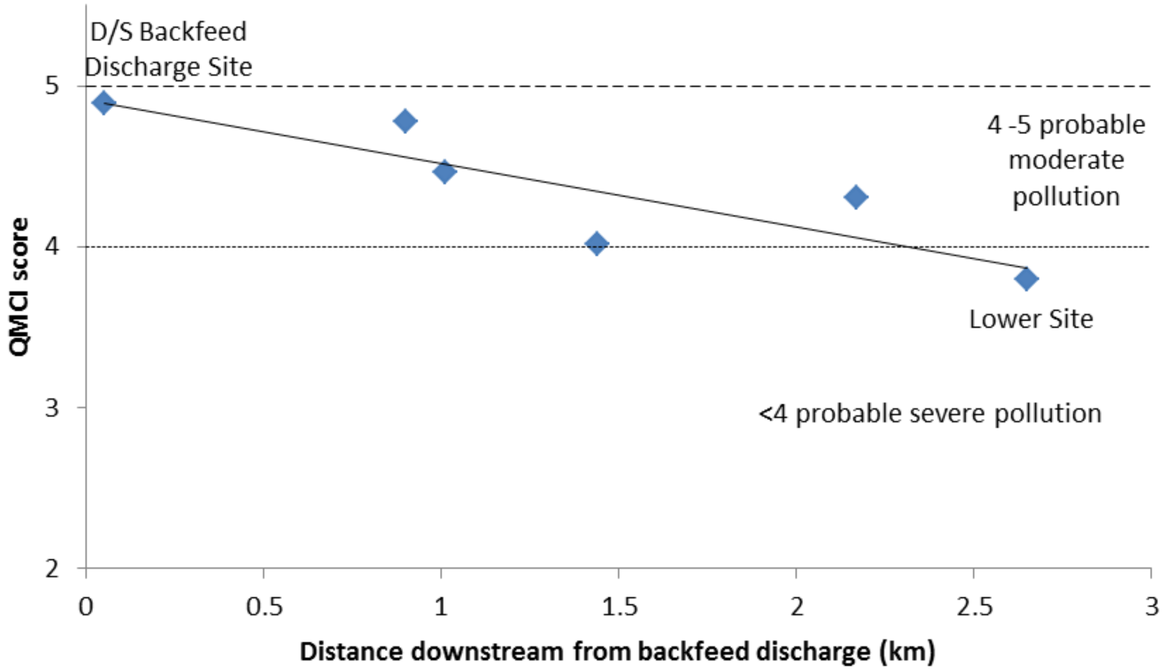


Figure 34. The significant decline in quantitative macroinvertebrate community index (QMCI) scores downstream from the backfeed discharge to Lower Site (February 2014) indicates moderate to severe pollution.

2.7.5. Summary of key findings

Summary – Macroinvertebrates

- Based on a range of commonly used macroinvertebrate community indices used for assessing river health, the presence of the current operation regime of the backfeed appears to be having a negative impact on stream biota downstream of the reservoir over time and spatially (Newton 2015).
- Degradation in both MCI and QMCI metrics downstream of the backfeed between 2004 and 2015 indicate that the macroinvertebrate indices no longer meet NRMP minimum standards for Class C or Class B rivers. Consistent high invertebrate metric scores upstream of the backfeed suggest that the backfeed discharge has likely had a significant effect on the decline in benthic invertebrate community health downstream. These changes appear to continue further downstream and progressively worsen in the lower river with

other tributary inputs.

- Changes around the backfeed are most likely associated with changes in the periphyton communities, which in turn are influenced by nutrients present in the discharge of anoxic water from the bottom of the reservoir, especially during mid to late summer.
- On the basis of the continued declining trend in macroinvertebrate community health downstream the backfeed and its breaching of Class B standards this effect is considered to be more than minor.

2.8. Fish populations and passage

2.8.1. Fish distribution and populations in catchment

The Maitai catchment probably supported an unmodified native fish community until at least 1870 (Crowe et al. 2004). Between 1965 and 2015, fourteen species of native fish have been identified in the Maitai River as well as the introduced brown trout (Table 19). Of these, eight fish species have been recorded from the upper catchment[33], in the vicinity of the Maitai Reservoir (Table 19; Figure 35). It is usual for the diversity of the fish community to decline with altitude and distance from the sea (Leathwick et al. 2005). This is because the majority of New Zealand's freshwater fish have a marine phase in their life-cycles and therefore must migrate back upstream from the sea to populate riverine habitat. Species differing in their ability and propensity to penetrate upstream from the sea, though instream structures such as culverts, fords and weirs can also influence this (see the next section on fish passage).

[33] For the purposes of this section the upper catchment has been defined as the waterways upstream of a point 1.6 km downstream of the Maitai Dam.

Table 19. Fish species found in the Maitai River catchment, indicating locations where each species has been recorded in the upper catchment (i.e. the main stem of the Maitai River 1.6 km downstream of the dam, the North and South branches and the Maitai Reservoir). Data sources include: New Zealand Freshwater Fish Database (NZFFD); Crowe et al. 2004; Doehring & Hay 2014. The latest New Zealand conservation status is also shown (Grainger et al. 2013; Goodman et al. 2014).

Common name	Scientific name	Conservation status	Locations where recorded within the upper Maitai catchment
Longfin eel	*Anguilla dieffenbachii*	At Risk - Declining	Main Stem
			South Branch
			North Branch
			Reservoir
Shortfin eel	*Anguilla australis*	Not Threatened	Main Stem
			North Branch
Kōaro	*Galaxias brevipinnis*	At Risk - Declining	South Branch
			North Branch
Brown trout	*Salmo trutta*	Introduced and Naturalised	Main Stem
			South Branch
			North Branch
			Reservoir
Upland bully	*Gobiomorphus breviceps*	Not Threatened	Main Stem
			South Branch
			North Branch
			Reservoir
Redfin bully	*Gobiomorphus huttoni*	At Risk - Declining	Main Stem
			South Branch
			Reservoir
Common bully	*Gobiomorphus cotidianus*	Not Threatened	South Branch
			Reservoir
Bluegill bully	*Gobiomorphus hubbsi*	At Risk - Declining	South Branch
Īnanga	*Galaxias maculatus*	At Risk - Declining	Not recorded from upper catchment
Torrentfish	*Cheimarrichthys fosteri*	At Risk - Declining	Not recorded from upper catchment
Banded kokopu	*Galaxias fasciatus*	Not Threatened	Not recorded from upper catchment
Giant bully	*Gobiomorphus gobioides*	Not Threatened	Not recorded from upper catchment
Common smelt	*Retropinna retropinna*	Not Threatened	Not recorded from upper catchment
Estuarine triplefin	*Grahamina sp.*	Not Threatened	Not recorded from upper catchment
Yellow eyed mullet	*Aldrichetta forsteri*	Not Threatened	Not recorded from upper catchment

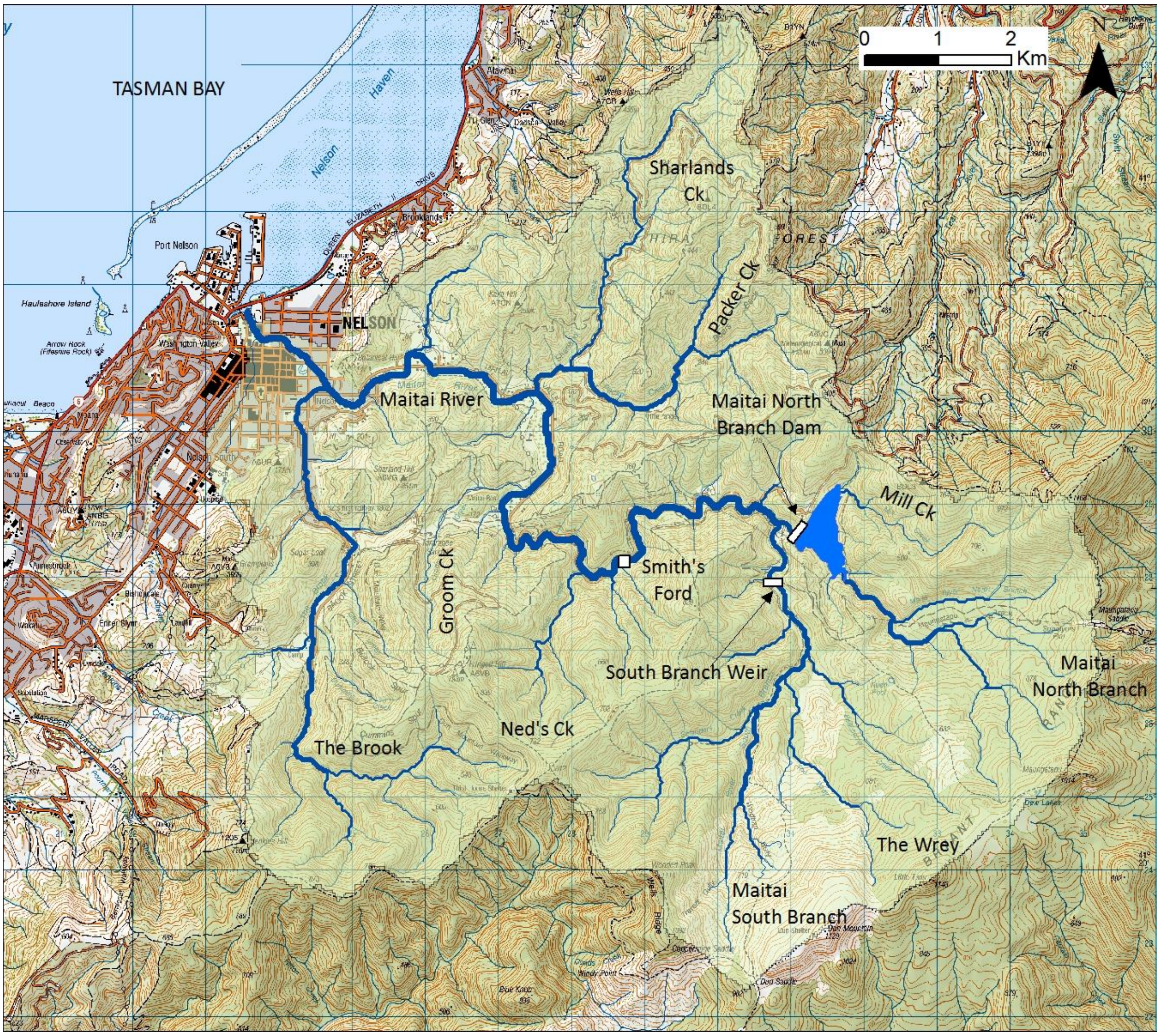


Figure 35. The Maitai River catchment, showing the Maitai Reservoir, South Branch weir, as well as major tributaries.

Of the native fish recorded from the Maitai catchment (Table 19), six are listed as at risk, declining in the latest New Zealand threat classification (Goodman et al. 2014). Four of the seven native fish species recorded from the upper catchment have this threat status (Table 19).

Data on fish distributions within the Maitai catchment are relatively scarce, and spatially and temporally patchy. Consequently, there is insufficient information to detect temporal patterns in the population dynamics of most species. Recent fish distribution survey effort by NCC and Cawthron has focused on extending the coverage of tributaries, including the upper North and South branches of the Maitai River, and The Wrey (a tributary of the South Branch) in the upper catchment, as well as Ned’s, Groom, Packer and Sharlands creeks, in the mid-lower catchment. In addition, a survey of fish inhabiting the Maitai Reservoir has been undertaken (Kelly &

Shearer 2013) with four species found: common bullies, upland bullies, longfin eels and brown trout (see Section 2.2.8).

Prior to reservoir construction the following fish species had been found in the Maitai River above the Forks: longfin eel, upland bullies, redfin bullies, bluegill bullies and kōaro (Table 19). Since the construction of the dam neither redfin or bluegill bullies has been recorded upstream of the reservoir or the South Branch weir, suggesting that these two species may have been excluded from the upper catchment due to these potential barriers to fish passage (see Section 2.8.2). Only a single bluefin bully has been recorded in the upper catchment of the Maitai River, from the South Branch, suggesting that this species may have been rare in this area. By contrast, redfin bullies have been seen downstream of the South Branch weir in the mainstem in recent surveys (e.g. Hay et al. 2015). Longfin eels, upland bullies, kōaro and trout have all been recorded upstream of the Maitai Dam and the South Branch in surveys conducted over the last three years (Kelly and Shearer 2013; Doehring and Hay 2014; Hay et al. 2015), suggesting that these species are able to pass these structures or, with the exception of longfin eels, have established locally recruiting populations upstream of these potential barriers. It is possible that the fish populations upstream of these potential passage barriers exist at lower densities than before to their construction. However, there are not sufficient data to confirm whether this is the case.

Consent monitoring data for fish in relation to the Maitai Reservoir operations

Single-pass electric fishing is part of the biological monitoring of the Maitai River required by Nelson City Council's Water Consent 831560 for the Maitai water supply reservoir at Site B (Appendix 1). A site 100 m upstream of the South Branch weir has also been included in the monitoring programme since 2007 (Holmes 2009a).

Many fish species migrate throughout a catchment and thus the population at any point in the river may be influenced by pressures elsewhere (e.g. urban stressors in the lower river). Therefore, when viewed in isolation the electric fishing monitoring data are of limited use in assessing point discharges of the backfeed. Nevertheless, when fish data are considered in combination with other metrics of stream health (such as invertebrate health indices) they can add weight to evidence.

Based on the fish biomonitoring data, juvenile trout and longfin eel populations show apparent declining trends at Site B over the monitoring period. This is discussed further in the fisheries section below in Section 2.8.3. There are no clear temporal patterns evident for the populations of the other fish species that have been encountered during the biomonitoring period.

2.8.2. Fish passage

The Maitai Dam and South Branch weir are both partial barriers to fish passage, particularly for fish moving upstream (Doehring & Hay 2014; Hay et al. 2015). A large proportion of New Zealand's native fish species require access to and from the sea to complete their life cycles and some introduced sport fish (e.g. trout and salmon), commonly migrate upstream as adults, seeking spawning habitat or cooler water temperatures during summer. Resident fishes in rivers (both native and introduced) often move between parts of a catchment during their life. Consequently, structures that obstruct fish movement, either up or downstream may impede access to habitat or disrupt the life cycles of migratory fishes.

The influence of fish passage barriers depends on their location within a catchment. Those closer to the sea are likely to impact a broader range of species, while those in upper catchments will influence only those species that would normally penetrate further inland. Nelson City Council is working toward addressing two recognised fish passage barriers in the mid to lower Maitai catchment and the fords at Almond Tree Flat (Jo Martin, Project Maitai Coordinator, Nelson City Council, Personal communication 24 February 2016). This will leave the Maitai Dam and the South Branch weir as the only remaining major fish passage barriers in the mainstem of the Maitai River. However, the location of these structures in the upper catchment means they are likely an impediment only to relatively strong migrants, such as redfin bully, longfin eel and kōaro and trout (Doehring & Hay 2014), or to non-migratory fish resident in the vicinity, such as upland bully. With the exception of redfin bully, all of these species have been recorded upstream of both the Maitai Dam and the South Branch weir, although the population densities above these structures are probably reduced to some extent relative to what may have existed naturally. The eel population in the Maitai Reservoir appears to have skewed size distribution suggestive of poor recruitment (Kelly & Shearer 2013).

Nelson City Council have recently undertaken remedial work to improve fish passage opportunities at both the Maitai Dam spillway and the South Branch weir (Hay et al. 2015), following recommendations from Doehring and Hay (2014). These alterations have mainly focused on assisting longfin eel and kōaro which have relatively strong ability to climb obstacles. The juveniles of both these species are adept climbers, using surface tension to cling to and scale quite steep obstacles (even vertical), provided there is a wetted surface. Juvenile eels and / or kōaro had been observed attempting to climb both the Maitai Reservoir spillway and the South Branch weir prior to the fish passage remediation work (Doehring & Hay 2014). The recent alterations to these structures were aimed at providing continuous wetted surfaces, removing sharp corners / transitions (which are difficult to negotiate for fish relying on surface tension), and proving resting opportunities during the climb.

Downstream passage is not likely to present much of an issue. Most downstream migration tends to occur during high flows, when elevated discharge should help carry migrants over both structures.

Maitai Reservoir spillway

The Maitai Reservoir spillway presents a more significant obstacle to fish passage than the South Branch weir, largely due to its height. The spillway is approximately 30 m high and 151 m long.

Fish passage remediation work undertaken at the Maitai Dam spillway during autumn 2015 included (Figure 36):

- Installation of a pump to deliver water from the reservoir to the spillway crest, at times when the reservoir water level is too low for spilling to occur, to ensure continuous flow down the spillway during summer migration periods. Ideally pumped water would be sourced from the cool mid-reservoir intake level to reduce the possibility of thermal stress for fish attempting to climb the spillway.
- Plugging the drainage outlets in the flip bucket with bungs to maintain the pool that usually forms in this bucket when spilling occurs.
- Installation of mussel spat ropes down the length of the spillway and downstream of the flip-bucket, adjacent to the true left spillway wall, to provide additional cover, as well as resting and climbing opportunities for migratory fish.
- Installation of a short ramp from the lip of the flip-bucket to the spillway apron below to allow climbing fish to avoid the steep transition into the flip-bucket.

Figure 36. Fish passage remediation works undertaken in late March 2015 on the Maitai Reservoir spillway: (a) pump delivering water to the spillway crest (reservoir water level >1 m below the crest), (b) paired spat ropes fixed along the true right edge of the spillway from above the crest to the spillway and continuous flow provided by pump in previous image, (c) close up of paired spat ropes where the spillway enters the flip-bucket, (d) synthetic turf lined ramp at downstream end of flip-bucket, (e) paired spat rope continues below flip-bucket ramp into plunge pool below spillway.

Monitoring of fish passage at the Maitai Reservoir during January and February 2016 found that elvers were attempting to climb the spillway, with some observed to successfully reach the reservoir, albeit in relatively low numbers (Appendix 7). The remediation modifications carried out during autumn 2015 have undoubtedly improved the situation for elvers attempting to climb the spillway. Before the installation of the pumped water supply, and bungs in the flip-bucket drains, the spillway was often dry for long periods during summer. For example, during the summer migration season (December to March inclusive) of 2014/15 the reservoir was below the spillway level for all but approximately one month (between 21 December 2014 and 20 January 2015). Consequently, there was no opportunity for fish passage during the rest of the migration season. By contrast, there is now continuous wetted passage route up the spillway, which is consistently available throughout the summer migration season.

Monitoring also revealed that the spat rope was being used for cover by resting elvers, particularly in the flip-bucket pool, but also on the spillway (Appendix 7). The resting cover habitat provided by the spat ropes may well assist elvers avoid predation and thermal stress when caught out on the spillway during the day. Fortunately the true right of the spillway remains shaded by the side wall most of the day even during summer, reducing the potential thermal stress for migrants. However, video footage from the spillway crest showed that the sun did reach the true right edge of the spillway from about 16:00 during late January. The spat rope was also observed being used to assist climbing by a few elvers, though the majority of climbing occurred in the wetted splash zone on the spillway, away from the spat ropes.

Based on observed climbing speeds on the Maitai Reservoir spillway and at the South Branch it is likely that passage over the spillway may take elvers several days to complete (Appendix 7). The speed of climbing generally appeared to become slower with distance up the spillway, with longer resting periods. Climbing the ~151m long spillway is predicted to take in the order of 30-115 hours, probably spread over several nights, given that climbing activity is mainly nocturnal.

Given the observed climbing speeds and the numbers of elvers attempting to climb the spillway during surveys in January and February 2016, it is likely that only a few elvers would successfully complete the climb on any given night. Based on these observations something in the order of 480 elvers might be expected to reach the reservoir over a migration season of approximately 120 nights (December to March inclusive). While this is a coarse estimate, based on several assumptions, existing data do suggest that the number of elvers successfully climbing the reservoir spillway is likely to be relatively low.

In addition, there is likely to be some attrition during the climb, as illustrated by the dead elvers found on the spillway during the surveys. Elvers also appear to be exposed to relatively high predation risk in attempting to reach the reservoir, since they are concentrated in locations predictable by predators. Predation risk appears particularly high at the top and bottom of the spillway, with large trout and eels consistently observed patrolling these areas, although other predators may also be targeting elvers while they are on the spillway.

In addition to fish climbing the Maitai Reservoir spillway, trap and transfer operations have been carried out from time to time over the years, to move eels upstream of the reservoir (Doehring & Hay 2014). This has involved catching eels in the river downstream of the spillway and releasing them upstream of the reservoir. The existing consent conditions (Consent No. RM025151/1 paragraph 6) stipulate that up to 200 eels of differing sizes should be relocated from the lower reaches of the Maitai to the reservoir each year, unless the Department of Conservation advises that this should not apply for any particular years. However, it is our understanding that this eel transfer has not occurred every year; rather it has been undertaken intermittently on a fairly ad hoc basis. Eels have been transferred on four occasions, amounting to 70 eels in 2007, 50 eels in 2008, 23 eels in 2014, and 65 eels in 2015 (Alex Miller, NCC, pers. comm.).

Maitai South Branch weir

The water intake weir on the Maitai South Branch is relatively low, less than 2 m high, so ought to present a more tractable fish passage obstacle even for relatively weak climbing species. A fish pass was installed on the true left of the weir in the early 1980s by the Nelson Acclimatisation Society, for the purpose of providing fish passage past the weir for trout (pers. comm. Lawson Davey [Fish & Game] and Alex Miller [NCC]). The presence of trout upstream of the weir suggests that the fish pass is successful for salmonids. However, the fish pass was not designed with passage for non-jumping fish species, such as kōaro, bully species and eels, in mind. Nelson City Council undertook remedial alteration work on the South Branch weir during summer 2014/15, aimed at improving passage opportunity for native fish species with a range of climbing abilities.

The following fish passage remediation works were undertaken on 2 December 2014 (Figure 37, Figure 38):

1. Providing a smooth wetted margin along the true left side of the weir adjacent to the intake screen, to improve passage opportunity for climbing species.

2. Six retrofits to the existing step-pool salmonid fish pass, to improve fish passage for non-jumping fish species:

   i. Reconstruction of the water level regulator (wooden board): Ensuring that the bottom of the board forming the upper step of the pass was sealed so that water flows only over the top, to avoid the problem of high velocity water jetting under the board.

   ii. Tapering the true left side of the board down at an angle to concentrate flow to this side during low flow periods.

   iii. Bevelling the square edged concrete back from the top of the board on true left, to remove hard edge (right angle) transitions for climbing fish.

   iv. Constructing a sloped wetted margin (rock ramp) on the true left immediately below the upper step to provide for non-jumping fish species.

   v. Filling a leak immediately above bottom step on the true left, to stop water seeping underneath, so that flow is redirected over the v-notch native fish pass.

   vi. Cutting the concrete on the true left of the existing lower step at a shallow angle to allow fish passage at a range of flows, and constructing a concrete and cobble rock ramp along the true left edge of the lower weir.

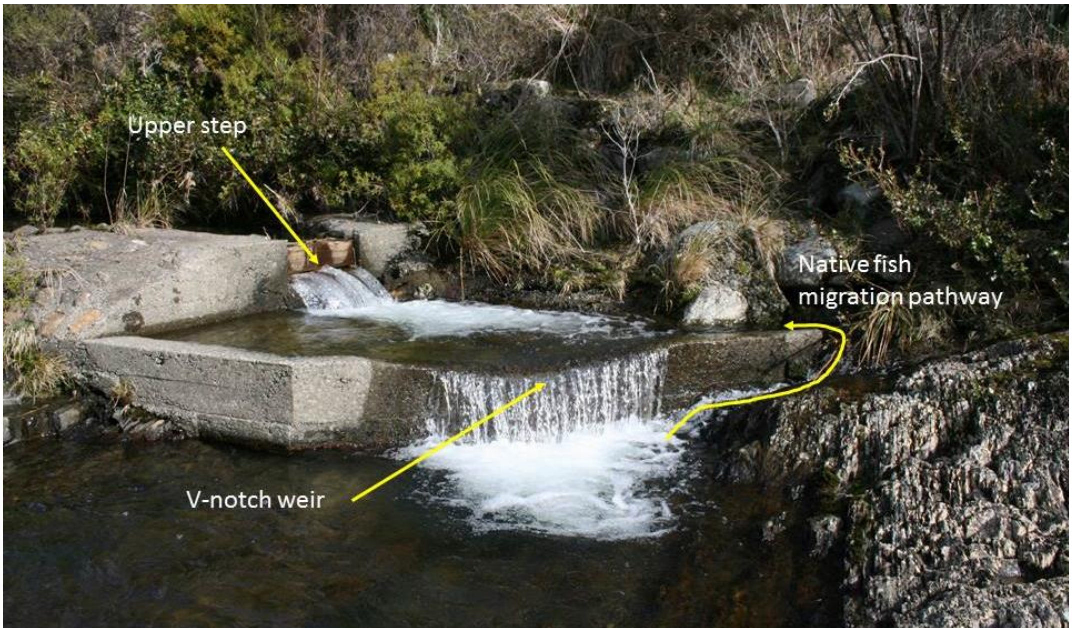


Figure 37. Step-pool fish pass on true left of the Maitai South Branch weir, prior to remediation work.

Figure 38. Step-pool fish pass on true left of the Maitai South Branch weir, following remediation work. Numbered arrows indicate remediation undertaken, with numbers referring to the points outlined above. Note: river flow in this image is substantially lower than in Figure 36.

Figure 39. The water intake screen in the Maitai South Branch weir, showing the smooth wetted margin constructed with epoxy cement as part of the remediation works (highlighted within the white oval). Insert shows the screen prior to remediation.

Following the remedial works elvers have been observed successfully passing the weir (Hay et al. 2015), predominantly via the smooth wetted edge adjacent to the true left of the intake screen (Figure 39). However, the weir may still impede passage for some weaker climbing species, e.g. redfin bully, which has been found immediately downstream of the South Branch weir, but has not been recorded upstream of the weir, since its construction.

There also remains an issue with relatively large numbers of elvers being attracted to the large attractant flow from the backfeed discharge (Hay et al. 2015). These elvers climb the wet rocks in the splash zone of the backfeed, but appear unable to find a way upstream over the dry area on top of the weir.

2.8.3. Fisheries

Trout

Prior to the 1990s, the Maitai River is reported (anecdotally) to have supported a popular and productive fishery for high numbers of small to medium-sized trout. Most of the angling effort occurred in the mid and lower reaches (Crowe et al. 2004). However, it is apparent that over the past few decades the popularity of the fishery has declined. The most recent National Angler Survey indicates relatively low usage of the Maitai River. It was estimated that 90 angler days occurred during 2007 / 08 angling season (+/- 50 days). Angler usage was likewise low during the previous angler surveys undertaken in the 2001 / 02 and 1994 / 95 seasons (280 and 180 days respectively; Unwin 2009).

Tributaries such as Sharlands Creek and Packers Creek historically provided ‘abundant spawning grounds’ (Graynoth & Skrzynski 1974). However, more recent electric fishing surveys of these tributaries reportedly show low densities of juvenile trout (unpublished data, Fish & Game 2013) compared to densities expected in a healthy spawning tributary (pers. comm. Neil Deans, Fish & Game New Zealand). Subsequent electric fishing surveys in December 2014 indicated a density of around 0.1/m juvenile brown trout in the lower portion of Sharlands Creek (Cawthron unpublished data). This is considerably less than rivers with known abundant trout spawning and rearing habitat, however it is unknown the extent to which this might affect adult populations in the Maitai River mainstem. It should also be noted that the design of the 2014 electric fishing surveys was not quantitative (i.e., using stop nets and multiple passes) as they were conducted predominantly to inform an understanding of native fish species distributions in the wider Maitai River catchment. However, the data do provide some indication that juvenile trout populations in these spawning tributaries are relatively low.

Consistent with these anecdotes, electric-fishing surveys undertaken in the mainstem at (and around) the South Branch ‘Site B’ long-term biomonitoring site indicate that juvenile trout abundance has declined during the past two decades. Trout numbers were variable over the period 1998 - 2002, with abundance dropping and remaining depressed from 2002 to the present (Figure 40; Newton 2015).

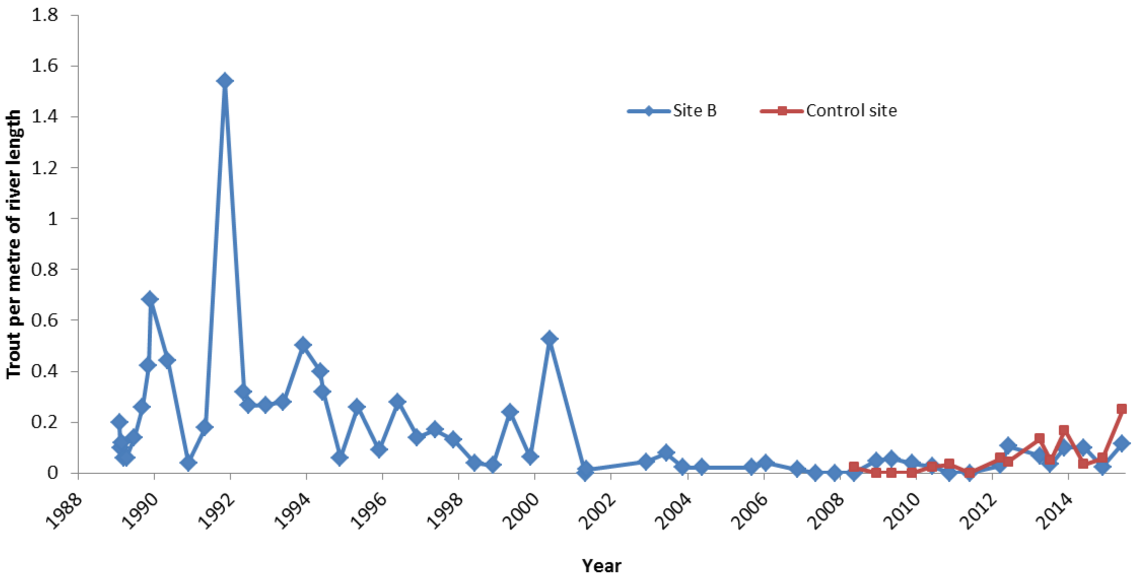


Figure 40. Trout abundance (mostly juvenile fish) at the Site B biomonitoring site (blue diamonds) and the upstream Control site (red squares) upstream of the Backfeed (upper sub-catchment, Maitai South Branch). Abundances calculated using single pass electric-fishing data 1988–2015 (Newton 2015).

In clear rivers, drift dive surveys are the best available method for surveying populations of the medium to large-sized trout that are of interest to anglers (i.e. fish more than 200 mm). This is because larger trout can easily evade capture during single pass electric fishing surveys. Drift dive surveys have been undertaken intermittently by Fish & Game New Zealand in the middle mainstream around Pole Ford bridge since 1992 (Figure 41). These records show that adult trout abundance has decreased during the five surveys carried out since 1992 (Figure 41). This result is consistent with the decline observed in juvenile trout abundance apparent from the biomonitoring electric fishing records (Figure 40).

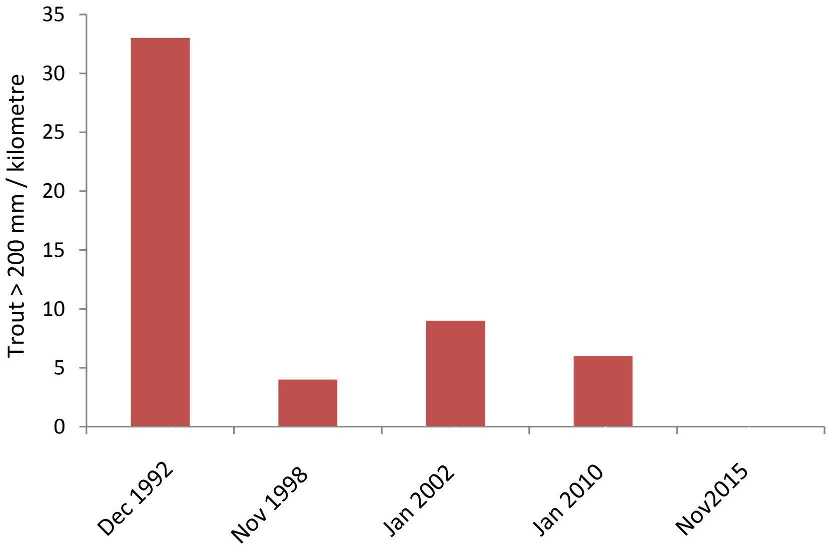


Figure 41. Abundance of trout (> 200 mm) around Pole Tree Ford Bridge (middle sub-catchment, mainstem Maitai River) during five drift-dive surveys carried out between 1992 and 2015. 1992 to 2015 data are unpublished Fish & Game information (received from Rhys Barrier, Fish & Game New Zealand, 22 January 2016).

To improve knowledge on the trout fishery value in the Maitai River NCC contracted Cawthron to undertake an extensive drift dive survey. This survey was carried out on 12 January 2016. In total, 5.2 kilometres of the (approximate) 17 km of habitat capable of supporting adult trout were surveyed (see Appendix 8 for a description of the survey methods and results).

Results from the Cawthron drift dive survey indicate that the adult trout population within the entire river is very low. On average there were 2.9 trout (> 200 mm) per kilometre. This figure is lower than any of the densities observed in the '100 rivers survey', where 340 segments from more than 70 rivers were surveyed by drift diving throughout New Zealand (range = 4–410 fish / km, median = 25 fish / k; Jowett 1990, 1992). Densities of medium and large fish recorded in the Cawthron drift dive survey were marginally higher than densities observed in the most recent (November 2015) Fish & Game survey. During this survey no medium or large fish were observed at the Pole Tree Ford drift dive site (Figure 41).

Brown trout usually take three years to reach maturity and can migrate throughout a catchment during their various life history stages. Thus the population at any point in a river may be influenced by pressures occurring elsewhere in the catchment. In addition, significant flood events or prolonged drought periods, which have been a feature of the catchment over the past decade, can cause substantial mortality and population recovery can take several years (Young et al. 2010). Given the catchment-scale nature of the Maitai River trout population it is unclear what, if any, contribution that the construction and / or operation of the Maitai Reservoir has had on the apparent deterioration of the Maitai River fishery.

As mentioned in Section 2.4.2, the reservoir has increased the 7-day MALF relative to the 'pre-dam with abstraction period'. Higher minimum flows provided by the scheme have the potential to positively influence the fish population (Hayes 2003). Conversely, compared to the pre-dam with abstraction period, trout and invertebrate food producing habitat, provided by the occurrence of flows between the 7-day MALF and the median, has been moderately reduced. Nevertheless, it is unlikely that this modest change in flow regime would have degraded trout habitat significantly compared with the 'pre-dam with abstraction period' (1963–1987)—when the Maitai River was reported to support a productive fishery.

Reduced food quality, due to changes in the invertebrate community (as measured by the declining trends in invertebrate community metrics, see Section 2.8.3), or reduced recruitment, as a consequence of forestry-induced sedimentation and passage barriers in the tributary spawning areas, are possible factors contributing to the apparent decline of the fishery. However, without a detailed investigation into the potential factors limiting the trout population, at present it is unclear why there are so few trout in the Maitai River.

Whitebait

Whitebaiting is a popular recreational activity in the lower reaches of the Maitai River, with the whitebaiting season running from August 15 to November 30 and fishing allowed between 0600 and 2100 during daylight savings time.

Whitebait is a name commonly used to describe the juvenile forms of five species of the fish family Galaxiidae. These are targeted by patient anglers using scope or set nets as they migrate into rivers and streams from the sea with incoming tides during spring. The five species are īnanga (*Galaxias maculatus*), kōaro (*Galaxias brevipinnis*), banded kōkopu (*Galaxias fasciatus*), giant kōkopu (*Galaxias argenteus*), and the shortjaw kōkopu (*Galaxias postvectis*). Of all these species īnanga is the most commonly caught species and most widely studied (McDowall 1990).

Īnanga eggs are laid in estuary vegetation around the high-water mark on a very high tide (known as a spring tide). The eggs are then fertilised by male adult īnanga. The eggs incubate above the water line for a number of weeks, but remain moist among the vegetation. When another spring tide reaches the eggs, the larvae hatch and the falling tide carries them out to sea, where the hatchlings spend the winter, feeding on small crustaceans. Juveniles (i.e. whitebait) make their way back upriver during spring to live in freshwater habitats. The whitebait swim near the river's edge with the large shoals referred to as runs. Big runs often follow floods, a few days after the water clears and usually in the daytime on a rising tide. By autumn the mature īnanga are ready to swim back downriver to spawn in the estuaries[34]. The other four whitebait species are longer lived and may take longer to reach maturity. They also grow larger than īnanga and do not return to estuaries to spawn. However, all share the trait of a short period of growth in a marine environment before returning to freshwater for the majority of their lifecycle.

Recent initiatives through council-led projects have been undertaken to protect whitebait and native fish habitat in the lower reaches of the Maitai. For example, the natural īnanga spawning area in the Maitai has been extended by digging a trench next to the river at the Shakespeare Walk Reserve and planting it with grasses. The trench was also filled with hay bales to provide spawning habitat as an interim measure until the grasses became established. A sign was also erected to educate the public on the life cycle of īnanga– the most commonly caught whitebait species (Figure 42).

Figure 42. Sign erected at the Shakespeare Walk Reserve explaining the life cycle of īnanga.

Structures in the river, such as fords and weirs have the potential to impede the upstream migration of whitebait species to their adult habitat. The Maitai Reservoir and South Branch weir represent a potential barrier to kōaro which can comprise a

[34] Most of the information on the life cycle was cited from http://www.teara.govt.nz/en/whitebait-and-whitebaiting/page-1

component of the whitebait catch. This species penetrates far inland (see Section 2.8.2). If obstacles are unsurpassable, whitebait distributions could become restricted, and some potential adult habitat may be unreachable, which could ultimately lead to a decline in adult stocks.

The effect of the reservoir on the whitebait fishery in terms of reduced access for kōaro to the upper catchment is likely to be minor. This is because kōaro typically make up a small proportion of the overall whitebait catch (McDowall and Eldon 1980) and the majority of the catchment is accessible to these species. Passage improvements for kōaro to habitat upstream of the reservoir structures are ongoing (Section 2.8.2).

Recent work undertaken to improve fish access to upstream habitat up the Maitai River, including fish passage improvements at the dam spillway and South Branch weir are described in previously in Section 2.8.2. While some of the whitebait species are good climbers and can scale the wetted margins of waterfalls, rapids and spillways (e.g. kōaro), īnanga – the most commonly caught whitebait species – cannot climb and must swim past such obstacles (Baker & Allibone 2002). It is not uncommon to see fish such as īnanga congregating in large numbers below obstacles. Here they are vulnerable to high mortality from predation, competition and disease (Baker & Allibone 2002). Īnanga usually do not penetrate far inland except in very low gradient rivers, and it is unlikely that their natural range extended as far up the Maitai River as the reservoir.

Eel (Tuna)

The iconic New Zealand freshwater tuna fishery is predominantly comprised of two species—the Australasian shortfin eel (*Anguilla australis*) and the endemic longfin eel (*Anguilla dieffenbachii*). Tuna are a taonga (treasured species) and are vital to the sustainability of Māori customary and commercial fisheries (e.g. McDowall 2011; Jellyman 2003, 2012).

Tuna start their life cycle in spawning grounds deep in the tropical Pacific Ocean. The leaf-shaped larvae passively migrate 5,000 kilometres along surface currents to New Zealand. When they reach the coast, they morph into glass eels and as elvers (juveniles) spend several years penetrating New Zealand's estuaries, wetlands, rivers and lakes. They can take decades to reach sexual maturity before migrating back to the tropics (along the deep ocean currents) to spawn and die (McDowall 1990; Jellyman & Tsukamoto 2005).

The importance of tuna to the local Nelson iwi is displayed in the artwork on the Aratuna Normanby Bridge, which was opened in 2008 after extensive renovations. However, there is currently no information available on the harvest of tuna from the Maitai which could be used to assess the relative value or productivity of the fishery.

The only long-term data available on tuna are from the electric-fishing surveys carried out as part of the biomonitoring at Site B. These data indicate that the number of juvenile longfin eels have decreased markedly since 1988 (Figure 43; Newton 2015). Numbers have been variable prior to 2002 but have declined and remained depressed at very low abundances since about 2004. The decline in juvenile eels occurs in parallel with the apparent decline in juvenile brown trout (Figure 40). There is no way to determine if this apparent decline in the upper river is typical of native fish populations in the rest of the catchment. In addition, at present it is unclear as to the reasons for this decline, which could be due to instream conditions (e.g. floods or food production) or factors affecting the oceanic life history stages. However this species remains of concern with longfin eel is listed as “At Risk – declining” in the latest threat classification lists (Goodman et al. 2014).

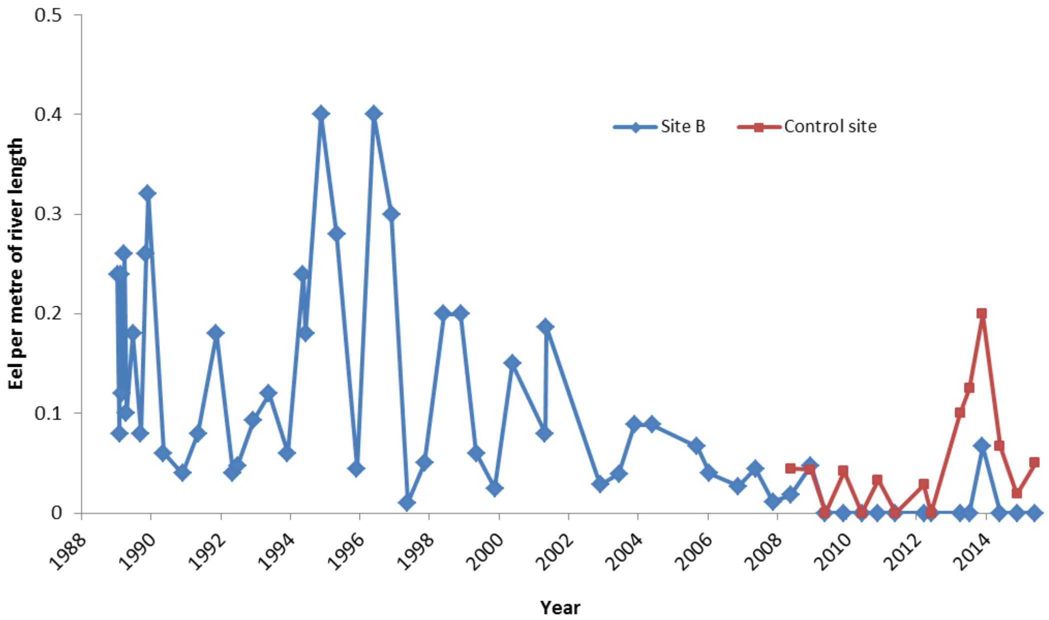


Figure 43. Number of eels caught per electric-fishing sampling occasion at Site B and the Control Site (single-pass method) standardised by the length of river fished (total number / length of river fished). Surveys were undertaken monthly from 1989–1990 and after 1990 surveys have been undertaken biannually. Taken from Newton (2015).

2.8.4. Summary of key findings

Summary – Fish distributions, passage and fisheries

- Fourteen species of native fish have been identified in the Maitai River as well as the introduced brown trout. Of these fish, eight have been recorded in the upper catchment around the Maitai Reservoir. With the exception of longfin eels, data are deficient to undertake a trend analysis on the native fish populations.
- The Maitai Reservoir and South Branch weir are both partial barriers to fish passage, particularly for fish moving upstream.
- The location of the Maitai Reservoir and South Branch weir in the upper catchment means they are likely an impediment only to relatively strong migrants, such as redfin bully, longfin eel and kōaro and trout.
- Nelson City Council have recently undertaken remedial work to improve fish passage opportunities at both the Maitai Dam spillway and the South Branch weir (Hay et al. 2015).
- Monitoring following the remedial work indicates that some elvers are successfully climbing these structures. However, the numbers climbing the Maitai Reservoir spillway are likely to still be relatively low (perhaps in the order of 480 elvers per summer), and both structures are likely to still present a passage barrier for non-climbing fish species.
- Prior to the 1990s the mid-lower Maitai River is reported to have supported a popular and productive trout fishery. Currently the river is not a popular fishery. Electric fishing and drift dive surveys indicate a sustained decline in the trout population over the past two decades. At present it is unclear as to the reasons for the population decline.
- The popular mixed-species whitebait fishery in the tidal reach of the Maitai River is likely to be predominantly based on juvenile īnanga which are a low-land river species. Therefore, there is little potential for the reservoir (in the upper catchment) to influence this value. However, the NCC initiative to improve access for kōaro to habitat upstream of the reservoir may have a modest positive impact on the fishery.
- Tuna (eels) are valued for biodiversity reasons as well the customary and recreational fisheries they provide. However, there is little available information on the use or productivity of the tuna fishery in the Maitai River. Based on electric fishing records at Site B juvenile eel numbers appear to be in decline since 2002. This decline occurs in parallel with a decline in trout numbers. At present it is unclear as to the reasons for the apparent decline in the juvenile eel population.

3. PROPOSED OPERATIONAL AND MITIGATION MEASURES

Several operational measures are considered here for mitigating the observed environmental effects of the current Maitai Reservoir operations. These include a range of options that would see improvements in the following ecological areas:

1. Water quality of backfeed-source water
2. Aeration of bottom waters of the reservoir
3. Flows in the Maitai River below the reservoir
4. Passage of fish over the spillway and weir
5. Fishery enhancement in the Maitai River.

3.1. Alternative management of water quality of discharges from the reservoir

Due to the higher water treatment demands of the reservoir waters in comparison to the Maitai River, under normal flow conditions the municipal supply water is preferentially abstracted directly from the South Branch of the Maitai River at the intake weir, rather than the reservoir. Abstracted Maitai River water is replaced by water from the Maitai Reservoir (termed the ‘Backfeed’) which is discharged at the foot of the intake weir. Reservoir water discharged to the South Branch from the backfeed is required to meet temperature conditions in the Maitai River. In late summer-autumn when river temperatures begin to decline, backfed water is usually required to be extracted from the lower intakes (Intake 3 or Scour) of the reservoir in order to meet temperature consent requirements. However, the discharge of deoxygenated hypolimnetic water and associated toxicants (Mn, Fe) is undesirable, and may be contributing to the decline in stream health observed at the monitoring site below the backfeed (Holmes 2010).

Two options around reducing or rectifying issues associated with poor water quality being released from the reservoir have been investigated.

1. Backfeed management option—To source water only from oxygenated layers of the reservoir during anoxic periods, with potential effects of temperature regime changes as investigated by Hay and Allen (2015).
2. Reservoir aeration option—Aerating the reservoir bottom waters using a reservoir destratification or aeration device to prevent low dissolved oxygen in bottom waters and the release of contaminants (Kelly 2015, and discussed in Section 3.2).

3.1.1. Backfeed management

Management of outflows from the reservoir could maintain DO at levels greater than 50% saturation. This level would prevent the discharge of elevated concentrations of dissolved metals (e.g. Mn and Fe) and nutrients (e.g. ammonium-N and P) downstream, and is considered best management for reservoirs (Gibbs & Hickey 2012). If NCC adopted the 50% DO minimum for the discharge of Maitai Reservoir water, the source of backfeed would need to be changed over the seasonal stratification period between November and May (Figure 44). The Council could adopt the following backfeeding process, which uses the DO patterns observed across 2013–2014 as a model (and is based on these dates during that period):

1. Use the **inlet 3 valve** during spring, up until the 50% DO saturation level was reached (26 November 2013 during that monitoring year).
2. Use the **inlet 2-valve** while deoxygenation persists in the lower hypolimnion (27 November–28 December 2013 during that monitoring year).
3. Use the **inlet 1 valve** when deoxygenation progresses to the mid-valve level over the remainder of the stratified period (29 December 2013 to 16 April 2014 in that monitoring year).

Because backfeed sourcing from hypolimnetic depths assists to entrain more oxygenated surface-water into the hypolimnion during stratified conditions (McQueen and Lean 1986; Gibbs & Hickey 2014), it is recommended that the bottom or mid-valve depths are used as much as possible when DO minima at these depths are met.

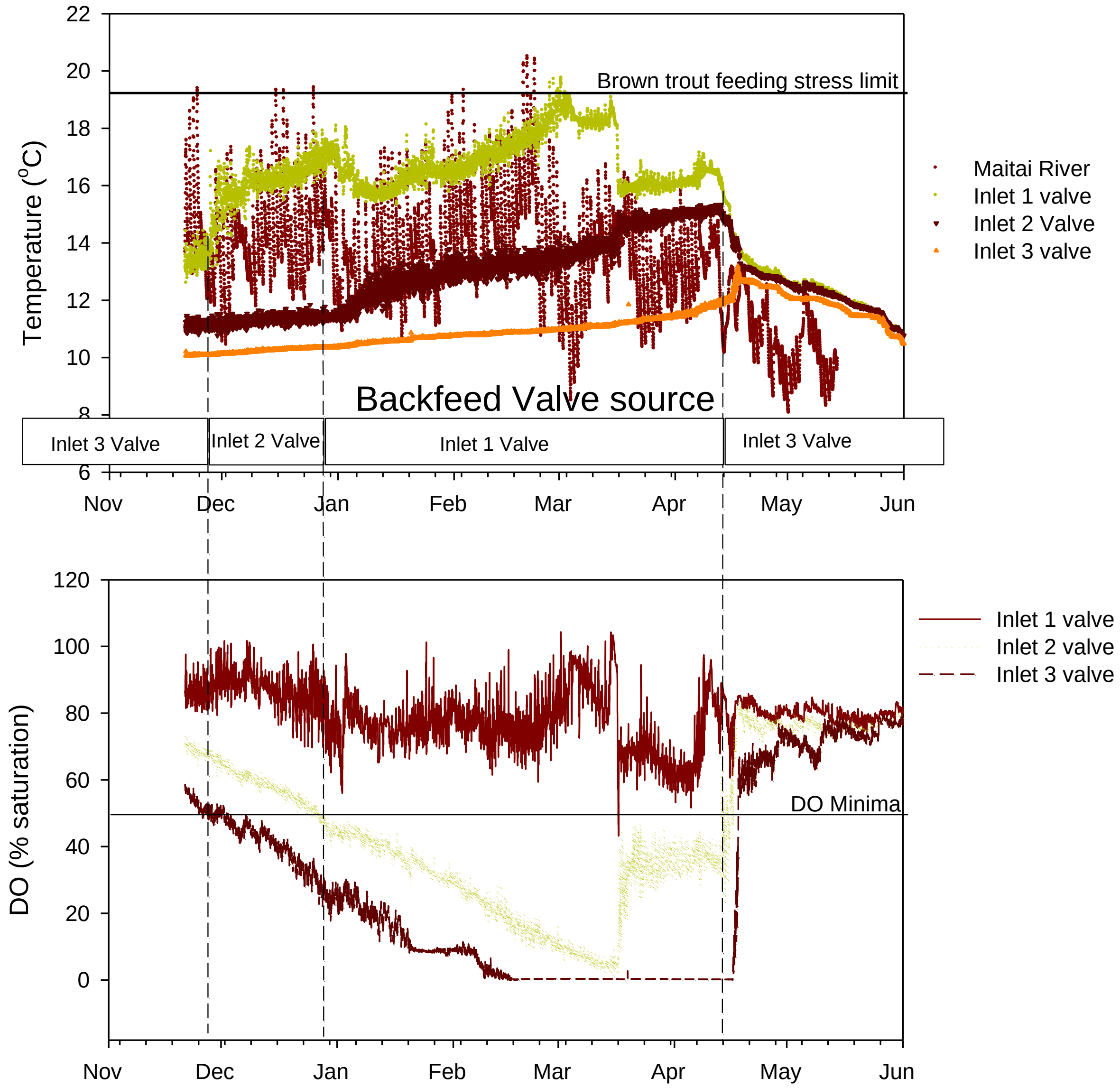


Figure 44. Temperature and dissolved oxygen (DO) trends at valve depths and in the Maitai River, with potential periods for backfeed valve sourcing to meet a 50% DO saturation minima in backfeed waters.

3.1.2. Temperature related effects of backfeed discharge

Potential temperature-related effects of managing the backfeed source from oxic layers (>50% saturation) in the reservoir low in their Mn and Fe concentrations is discussed below. We suggest that it is possible to manage the backfeed from these oxic layers with only relatively minor changes in outflow water temperature.

Since water temperature varies with depth in the reservoir's water column it is possible to selectively control the temperature, and water quality, of the backfeed discharge. However, the poor water quality associated with the hypolimnion during thermal stratification events, means the selection of backfeed water is currently a trade-off between water temperature and other water quality parameters. Releasing cool water from the lower intakes may comply with temperature-related consent conditions, but in summer this bottom water is deoxygenated and has poor water quality. On the other hand, releasing better quality water from nearer the surface may breach temperature conditions.

Existing resource consent conditions require that the backfeed discharge at the South Branch weir must not alter the water temperature in the river by more than 3 °C, and must not cause water temperature to alter beyond certain bounds (maximum 20 °C and minimum 6 °C), as discussed in Section 2.5.2.

There is a sound ecological basis for the existing consent conditions prohibiting the backfeed discharge from raising the temperature of the river above 20 °C and the 3 °C maximum permitted increase in temperature downstream of the reservoir compared with upstream (Olsen et al. 2011; Davies-Colley et al. 2013). However, reductions in temperature of more than 3 °C seem less likely to incur adverse effects than temperature increases of similar magnitude. Furthermore, short term breaches of the 3 °C maximum permitted change might be expected to have less significant adverse effects than breaches of the 20 °C maximum temperature threshold. The rationale for the minimum temperature threshold of 6 °C is unclear, although it seems unlikely to ever cause problems for operation of the water supply scheme during summer stratification events (see Section 2.5.2).

On the basis of water temperature data from the reservoir and the South Branch it appears that if backfeed water was sourced from the upper and middle intake valves, it would comply with existing water temperature consent conditions and avoid release of deoxygenated water most of the time. Water at the top intake reservoir level (6 m) was below the 20°C temperature threshold for most of the 2014/15 summer and temperatures at the middle (15 m) and bottom (24 m) intake levels were below this threshold for the entire summer (Hay & Allen 2015). During the previous summer temperature at the 6 m valve depth always remained below 19°C. This suggests that it is not usually necessary to source backfeed discharge water from the deeper valves in order to comply with the 20°C maximum temperature threshold.

Furthermore, compliance with the 3 °C maximum change in water temperature below the backfeed would have been possible by drawing water from a combination of the upper and middle intakes for most of time. Figure 45 shows the difference between the water temperatures at each of the three reservoir intake levels compared with those of the South Branch upstream of the weir for the summer of 2014/15. This figure suggests that to comply with the 3 °C maximum change in water temperature below the backfeed it would have been possible to draw water from a combination of the upper and middle intakes for most of the summer, at least up until early April 2015.

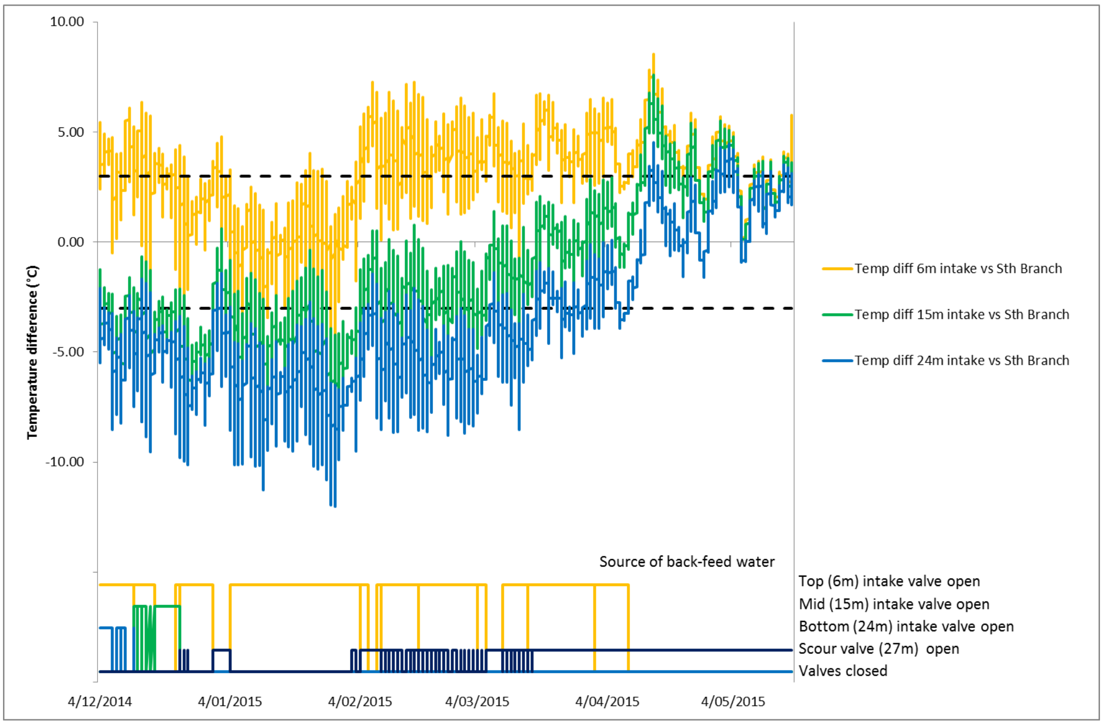


Figure 45. Time series of the difference in water temperature in the Maitai South Branch upstream of the backfeed discharge, at the South Branch weir, compared with the three intake valves in the Maitai Reservoir during summer 2014/15. Negative values indicate the intake valve level is cooler than the South Branch upstream of the weir. Dashed horizontal lines indicate the threshold maximum permissible temperature change of 3 °C stipulated in consent conditions. Time series at the bottom of the figure shows which valves the backfeed water was being sourced from.

It is worth noting that discharging water from the backfeed that is more than 3 °C different from the ambient water temperature in the South Branch would not necessarily result in a breach of the 3 °C maximum allowable temperature change condition, since the rate of discharge relative to the South Branch flow passing over the weir would also influence the resultant water temperature following mixing. The resultant temperature from mixing two volumes of water of different temperatures can be calculated by the following formula:

Equation 1. Calculation of the resultant temperature from mixing two volumes of water of differing temperatures.

$$T_{final} = \frac{m_1(T_1) + m_2\,(T_2)}{m_1 + \ m_2}$$

Where:

> m_1 and m_2 are the masses of the respective volumes of water to be mixed, with temperatures of T_1 and T_2. Although the density of water changes with temperature, over the range of temperatures considered here this density change is negligible and consequently, mass is taken to be equivalent to volume.

Falling river water temperatures during the autumn period (April-May), mean that even water taken from the bottom intake would have been more than 3 °C warmer than the South Branch (Figure 45), potentially constraining the volume of water that could be discharged via the backfeed during this period. Water released from the scour valve would have been a similar temperature to that at the 24 m bottom intake valve during this period. Consequently, releasing water from the scour valve would also breach the 3 °C temperature change condition during this period. In fact, this appears to have happened some of the time (Hay & Allen 2015).

Kelly (2014) suggested that the greatest potential warming effect of sourcing backfeed water from the upper valve would probably occur immediately after floods, due to substantial declines in river temperature at these times. However, the backfeed discharge tends to be reduced during high flow events (although scour water is sometimes still released), presumably because water for municipal supply is being sourced from the reservoir at these times to avoid elevated suspended sediment loads in the river. Furthermore, increased river discharge rates during these events are likely to overwhelm any temperature influence from the backfeed. For example, following a fresh event on 6 March 2015 water temperature in the South Branch fell to about 11.7 °C (on 8 March 2015), while the temperature at the 6 m reservoir intake level remained at about 18.4 °C, producing a potential 6.7 °C temperature difference. However, the flow in the South Branch at this time was about 1.233 m^3/s, while the backfeed discharge was only 0.163 m^3/s. Consequently, based on Equation 1[35], even if the entire backfeed discharge had been sourced from the 6 m intake valve, the temperature below the backfeed would have been only 12.6 °C (i.e. 0.9 °C warmer than upstream). If the backfeed discharge had been higher at the time, i.e., 0.317[36] m^3/s (which was the maximum backfeed discharge during summer 2014/15) the resulting temperature downstream of the backfeed would still be only 13.4 °C (i.e. 1.7 °C warmer than upstream).

As discussed above, the DO status of water at the various intake levels also needs to be taken into consideration with sourcing of backfeed water. In early February 2015, when water temperatures at the level of the 6 m (top) intake began to exceed South Branch temperatures by more than 3 °C (Figure 45), the cooler water at the 15 m level

[35] These calculations assume that a volume equal to the backfeed discharge was being abstracted at the weir, i.e. the South Branch flow contribution to flow below the weir was reduced by a volume equivalent to the backfeed, before the backfeed water was added to it.

[36] The maximum rate of discharge from the backfeed is nominally 0.3 m^3/s, and equal to the consented abstraction from the South Branch, source (Alex Miller, NCC, pers. comm.).

was still at about 50% DO saturation. However, DO levels continued to track down over time. By early April it would have been about 13% saturation at the 15 m intake level, and remained low until the thermal stratification of the reservoir broke down in early May. Nevertheless DO levels at the middle intake level were consistently higher than the scour water that was actually being released during this period, with the bottom water of the reservoir having been completely anoxic since January. Furthermore, by sourcing backfeed water from a mix of the upper and middle intake valves the, low DO and potentially low water quality of water sourced from the middle intake would be mitigated by dilution with the well oxygenated water from the upper intake.

Installing water temperature sensors at each reservoir intake level would allow backfeed water to be sourced to match ambient temperatures in the South Branch, as recommended by Hay and Allen (2015). With real time data from these sensors, along with data that is already collected (e.g. South Branch flow and temperature, abstraction rate at the weir and required backfeed discharge rate), it would be a relatively simple task to derive an algorithm (based on Equation 1, above) that would calculate the mix of water from the intake valves required to match the temperature in the South Branch. Sourcing water from the top and middle valves could be prioritised during thermal stratification events, to avoid releasing the low quality anoxic bottom water. The temperature of water discharged from the backfeed may also be moderated to some extent by heat exchange with the ground, during transit through the backfeed pipe (which is predominantly underground). The magnitude of any such effect could be determined empirically and used to adjust the algorithm suggested above, if necessary.

Extent of backfeed thermal influence

The thermal influence of the backfeed, as it is currently operated, does not appear to extend far downstream. Even though operation of the backfeed discharge complies with temperature related conditions most of the time, river water temperature tends to increase rapidly downstream during the warm settled periods (Hay & Allen 2015). For example, daily maximum temperatures from a site immediately upstream of the spillway discharge pool on downstream were often above 20 °C throughout much of a period of settled fine weather in late January 2015. Temperatures observed downstream of the Maitai Forks flow recorder site, in particular, during late January of that summer would be expected to induce thermal stress in a range of aquatic organisms, with the likely elimination of some sensitive species. This illustrates that the backfeed discharge tends to influence water temperature for only a relatively short section of the river.

This situation would likely have been exacerbated had the spillway been operating during this period, since this can produce greater water temperature increases downstream of the spillway discharge pool. For example, the maximum water temperature difference upstream and downstream of the spillway discharge pool for periods when the spillway was operating during summer 2014/15, was 2.87 °C, compared with 1.82 °C when it was not. On average the temperature downstream of the spillway discharge pool was 1.11 °C warmer than that immediately upstream during periods when the spillway was operating during summer 2014/15, compared with 0.28 °C when it was not. Thus, the discharge of surface water via the spillway has the potential to release warm surface water, notwithstanding the consent conditions controlling the temperature of water released via the backfeed. However, the magnitude of this potential warming may be reduced to some extent if the reservoir water was kept well mixed during summer (see Section 3.2), as this would be expected to slightly reduce the temperature of reservoir surface water released over the spillway. Shading of the spillway may also help reduce the heating influence of the spillway discharge.

Despite these factors, it is possible that the cooler water of the South Branch could provide a thermal refuge for mobile species, such as fish, during periods when the lower Maitai River experiences potentially stressful water temperatures. Hence, while the water temperature may be maintained below ecological stress thresholds for a relatively short length of river during hot periods in summer, this section of the river may be important to maintaining aquatic populations in the wider catchment. There is little monitoring data available to reveal whether this actually occurs, since biological monitoring in the vicinity of the reservoir usually occurs during spring and autumn. However, a longitudinal study downstream of the backfeed discharge during February 2014 reported higher densities of eels and trout in the reach immediately below the backfeed than further downstream (Allen et al*.* 2014). Spot water temperatures recorded during that study were approaching 20 °C at the most downstream sites, but were cooler (~14-16 °C) upstream of the spillway discharge pool. Drift dive surveys in January 2016 also found that trout density in the reach immediately below the backfeed discharge was higher than in all other reaches surveyed elsewhere in the catchment (see Appendix 8). The divers noted that the water temperature in the surface layer of the plunge pool below the spillway and in the river downstream of this pool was appreciably warmer than in the reach upstream. The plunge pool below the spillway becomes thermally stratified during summer and may also provide some thermal refuge habitat. Medium to large trout and eels were consistently observed in this pool during summer 2015/16, when the drift dive surveys found very few trout elsewhere in the catchment. In addition, these fish appeared to be in good condition.

The extent of the potential thermal refuge habitat in the upper Maitai River is sensitive to the backfeed temperature and discharge rate. Temperature modelling, predicting longitudinal profiles of daily mean and maximum water temperatures through the upper Maitai River, shows that the backfeed discharge can alter the length of potential thermal refuge habitat available (Appendix 9), by in the order of 1-2 km. Releasing warm water from the reservoir can reduce the length of river remaining below 20 °C, which potentially acts as a thermal refuge, while releasing cooler water can extend this potential refuge habitat. The potential for the backfeed to influence the temperature of the river also depends on the discharge rate relative to the South Branch flow at the time (see Equation 1). Thus, its potential influence is diminished at higher river flows, because it makes a smaller proportional contribution to the flow in the river.

On the basis of the discussion above, it may be worthwhile retaining similar backfeed operation water temperature consent conditions, in order to maintain this potential thermal refuge.

The South Branch upstream of the weir also has the potential to provide thermal refuge habitat. However, notwithstanding recent fish passage remediation work, the weir is likely to present an impediment to passage for fish attempting to access this habitat during low flow periods (Doehring & Hay 2014; Hay et al. 2015).

3.1.3. Summary of key findings

Summary – Water temperature mitigation / Source of backfeed water

- Since water temperature varies with depth in the reservoir's water column it is possible to selectively control the temperature, and water quality, of the backfeed discharge through the choice of intake valve. However, the poor water quality associated with the hypolimnion during thermal stratification events, means the selection of backfeed water is currently a trade-off between water temperature and other water quality parameters.
- Existing resource consent conditions require that the backfeed discharge at the South Branch weir must not alter the water temperature in the river by more than 3 °C, and must not cause water temperature to alter beyond certain bounds (maximum 20 °C and minimum 6 °C).
- There is a sound ecological basis for the existing consent conditions prohibiting the backfeed discharge from raising the temperature of the river above 20 °C and the 3 °C maximum permitted increase in temperature downstream of the reservoir compared with upstream.
- Water temperature data suggest that if backfeed water was sourced from the upper and middle intake valves, it would comply with existing water temperature consent conditions and avoid releasing deoxygenated water most of the time.
- Installing water temperature sensors at each reservoir intake level would allow backfeed water to be sourced to match ambient temperatures in the South Branch. It would then be a relatively simple task to derive an algorithm that would calculate the mix of water from the intake valves required to match the temperature in the South Branch.
- The thermal influence of the backfeed, as it is currently operated, does not appear to extend far downstream. Even though operation of the backfeed discharge complies with temperature-related conditions most of the time, river water temperature tends to increase rapidly downstream during the warm settled periods, and can exceed thresholds for ecological stress from the vicinity of the spillway pool on downstream.
- The discharge of surface water via the spillway has the potential to exacerbate this through release of warm surface water, notwithstanding the consent conditions controlling the temperature of water released via the backfeed. However, the magnitude of this potential warming may be reduced to some extent if the reservoir water was kept well mixed during summer.
- It appears that the cooler water of the South Branch could provide a thermal refuge for mobile species, such as fish, during periods when the lower Maitai River experiences potentially stressful water temperatures. Hence, while the water temperature may be maintained below ecological stress thresholds for a relatively short length of river during hot periods in summer, this section of the river may be important to maintaining aquatic populations in the wider catchment.
- Temperature modelling shows that the backfeed discharge can alter the length of potential thermal refuge habitat available, in the order of 1–2 km.

3.2. Reservoir aeration

Detailed assessments of methods that could be employed to destratify (mix) and aerate bottom waters in the Maitai Reservoir were investigated as a means of managing reservoir discharges from the backfeed by improving the water quality in reservoir source waters (Kelly 2015). This option would have the benefit of enhancing water quality of the reservoir backfeed source-water, and also improve conditions in the reservoir for aquatic life. Following an initial review of the literature, a meeting between NCC and Cawthron identified three preferred options that were thought most applicable for managing hypolimnetic deoxygenation in the Maitai Reservoir. This included:

1. destratification of the reservoir through aeration mixing
2. hypolimnetic aeration through compressed air injection
3. hypolimnetic water transfer (pumping) using aerated surface waters.

Assessment of these three options included detailed designs and required outputs of the equipment (e.g., compressed air, water flow) to mix or aerate the reservoir at a rate sufficient to offset normal hypolimnetic deoxygenation. This included an evaluation of the advantages / disadvantages of each method, and approximate capital and operational costs for each option.

3.2.1. Reservoir mixing and aeration approaches

Management measures to reverse and slow the effects of hypolimnetic deoxygenation have been tested extensively around the world (Ashley 1985; Cooke & Carlson 1989; Schladow 1992; Wüest et al. 1992; Kortmann et al. 1994). These measures are essentially based on one of two mechanisms:

1. Reservoir destratification–the creation of upwelling water currents that act to break down physical stratification of the water column allowing surface-aerated water to circulate to bottom waters.
2. Hypolimnetic aeration–Introduction of oxygen (as air, water or liquid oxygen) below the thermocline at a rate sufficient to offset the rate of oxygen consumption.

There have been many engineering solutions in which these measures have been implemented in reservoirs. A review of the three potential and more commonly employed engineering solutions to reservoir destratification and hypolimnetic aeration is summarised in the following sections.

Destratification aeration mixing

The goal of a destratification device is either to prevent a water body from stratifying, or mixing an already stratified water body. It achieves this by introducing sufficient energy to disrupt the water-column density gradient created by thermal stratification. If properly designed, an artificial circulation system will create isothermal conditions in a lake or reservoir. This can greatly improve water quality by oxygenating the water and preventing conditions that can lead to the formation of toxicants. This generally starts to occur when DO conditions decline below 5 mg/L (Section 2.2.3).

Destratification devices are most often designed around creating circular water currents through pumping compressed air to the bottom of the water column through diffuser ports (Fast 1968: Cooke & Carlson 1989). Compressed air exits the diffuser as fine-bubbles (3–5 mm) which entrain hypolimnetic water upwards as the bubbles expand and rise to the surface (Zic & Stefan 1990; Figure 46). Cooler, denser water then sinks horizontally along density strata. Bottom water currents are entrained horizontally towards the diffusers to replace water that is entrained in the bubble plume.

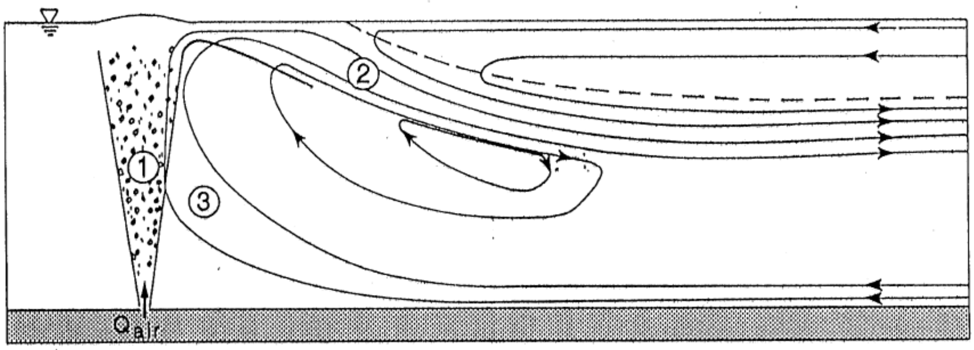


Figure 46. Theoretical water circulation pattern caused by vertical entrainment of the water column with a bubble plume mixer (modified from Zic & Stefan 1990). Circulation currents shown are (1) upwelling bubble plume current, (2) denser water downwelling to a lower depth strata, (3) horizontal hypolimnetic current entrained to the point of the bubble plume.

The effectiveness of air bubbles in entraining water currents is based on bubble size as well as the depth of the water column before the thermocline is reached in the mid-portion of the water column. The energy generated by the induced currents must be sufficient to break down the potential energy stored in the density gradient of the thermocline (Bernard et al. 2000). This density gradient can be measured from temperature profile data for the waterbody, with the destratification devices generally designed to mix the water column at its maximum thermal stratification gradient. In an operational environment, the compressors are left to operate for a period long enough to re-aerate the water column, typically a period of 1–2 weeks. After the destratification is completed, they may be shut off to reduce running costs.

Advantages to using destratification mixing devices for addressing hypolimnetic deoxygenation are:

1. energy efficiency—relying on surface aeration to reoxygenate the water column
2. capability of rapidly reoxygenating the water column should it become deoxygenated

3. mixing devices do not need to be left running continuously, and can be turned on when required to mix and re-oxygenate the water column.

Possible disadvantages of destratification include:

1. an overall warming of the hypolimnetic water which may slightly increase the DO consumption rate, and provide less cool water to discharge from the bottom inlet
2. a poorly designed destratification system can potentially increase nutrients and turbidity in the water body if it disturbs sediment layers or entrains nutrient rich water in the photic zone (Cooke & Carlson, 1989). Anchoring of the diffusers off the bottom sediment reduces the likelihood for this occurrence
3. upfront capital costs may be high, as large compressors are required.

In the context of the Maitai Reservoir, the main issues around hypolimnetic oxygen depletion have now been relatively well documented (See section 2.2.3). These include solubilisation of metals (Mn and Fe) and hydrogen sulphide gas releases in reservoir bottom waters, which are subsequently discharged to the Maitai River during certain periods when cooler water discharges are required to meet temperature consent requirements (Kelly & Shearer 2013; Kelly 2014). There have been no observations of increases in hypolimnetic dissolved phosphorus (or nitrogen) over anoxia cycles. This is possibly related to redox pathways being dominated by calcium and sulphur metal oxide reduction over anoxic periods linked to upstream catchment limestone geology.

An effectively designed destratification system would correct problems associated with toxicant formation and subsequent downstream effects associated with this water into the Matai River. This would also improve the reservoir as a habitat for some species, which could utilise deeper water habitats during warm summer periods. A management trigger for initiating destratification mixing could be considered, such as DO approaching or breaching a 5 mg/L limit. This is a concentration value which marks the point at which Mn solubilisation in bottom waters occurs (Gibbs & Hickey 2012).

Hypolimnetic aeration

Hypolimnetic aeration involves oxygenation of the hypolimnion without disturbing the thermal-density gradient associated with stratification (Kortmann et al. 1994). The goal of the aeration is to add oxygen to the hypolimnion at a sufficient rate to offset oxygen consumption from biological and chemical oxygen demand. Hypolimnetic aeration has several advantages over artificial circulation, including:

1. an oxygen-enriched, cold-water habitat is maintained for fish species (e.g., trout, longfin eels)
2. normal summer temperature stratification allows flexibility in reservoir offtakes (through the backfeed) for meeting discharge temperature requirements

3. lower risk of transporting nutrients from the hypolimnion to the epilimnion where they can contribute to phytoplankton growth
4. aeration requires less energy and lower airflow rates to achieve hypolimnetic destratification, consequently smaller compressors may be used reducing initial capital outlay.

However, the approach also has some disadvantages, including:

1. it cannot be used to react quickly to low oxygen events
2. it must be operated continuously, potentially increasing operating costs.

McQueen and Lean (1986) reviewed the outcomes of several hypolimnetic aeration projects and summarised the results of the studies as follows: (1) well-designed aeration systems have maintained stratification and have not increased hypolimnetic water temperature significantly; (2) hypolimnetic oxygen levels increased; (3) Fe, Mn, hydrogen sulphide decreased; (4) zooplankton populations were unaffected; (5) chlorophyll levels were usually not altered; and (6) depth distributions of cold-water fish populations increased. The effects of hypolimnetic aeration on phosphorus and nitrogen levels have been more variable. McQueen and Lean (1986) attribute this to pH levels and Fe availability for phosphorus sedimentation.

In the context of the Maitai Reservoir, a well-designed hypolimnetic aeration system would rectify all of the issues in the reservoir associated with deoxygenation. A major advantage of hypolimnetic aeration (over hypolimnetic destratification) is the maintenance of seasonal thermal stratification patterns. This would preserve the existing ability to manage backfeed temperatures by changing (or mixing) the depth of the valve takes. This could allow release of cool hypolimnetic water to the Maitai River during late-summer and autumn periods when the river temperatures tend to be cooler than reservoir surface layers (Hay & Allen 2015). Consequently, it appears this management option is well aligned with objectives to improve the habitat quality of the lower Maitai River.

Hypolimnetic water transfer

Water oxidation ponds in some instances utilise water pumping systems rather than compressed air to exchange oxygenated surface layers with deoxygenated bottom waters. Typically this is accomplished through pumping of hypolimnetic waters to the surface of the waterbody. However, power usage typically limits the efficiency of such systems to waterbodies which are reasonably shallow (< 4 m deep). This is because of the energy usage associated with pumping large volumes from deeper depths (Cooke et al. 2013). Pumping of deoxygenated hypolimnetic water from the Maitai Reservoir hypolimnion would necessitate pumping from depths exceeding 20 m, and would be highly inefficient by comparison to aeration entrainment of water currents.

An alternative to pumping was considered by NCC which involves transferring (piping) oxygenated inflow water downwards through the reservoir water column into the hypolimnion. Inflows from the North Branch tributary are typically slightly cooler than reservoir surface waters, ranging between 11–14 °C under normal flow conditions. Therefore it is expected that surface water inflows are likely to sink below the surface level of the reservoir. However, they are warmer than hypolimnetic temperatures (9-11 °C) and therefore are expected to remain within the upper water column and unlikely to transfer significant amounts of DO to the reservoir hypolimnion. During larger flood events (e.g., > 35 m^3/s for North Branch flows), entrainment of oxygenated surface water in to the reservoir hypolimnion has been shown to occur over short durations, as evidenced by changes in temperature and DO levels in the upper hypolimnion measured around the valve tower (Kelly 2014).

Transfer of oxygenated surface water to the Maitai Reservoir hypolimnion would be accomplished via a water intake structure on the North Branch tributary, which because of its steepness, could potentially create hydraulic head sufficient to pump water to the depth required (estimated 15–20 m). A review of the international literature revealed only one example of where this has been attempted, in Lake Ballinger, Washington State, USA. In this instance, the combination of drawing water from the hypolimnion (i.e. outflow) and diverting tributary inflows into the hypolimnion decreased the rate of hypolimnetic deoxygenation and reduced the period when the lake was anoxic to approximately 2 weeks (KCM 1981). However, the inflow transfer was only to a depth of 4 m, and thus would have presented less of a challenge in designing a diversion structure.

Given the lack of information available on this approach, the engineering of the river water intake and transfer infrastructure for the Maitai Reservoir was considered beyond the scope of this investigation. However, at this initial feasibility stage several factors around this option were scoped as a possible management option. This included:

- rates of water transfer required to offset hypolimnetic deoxygenation rate
- hydraulic (and oxygen) retention of transferred river water in the hypolimnion given it is likely to be a rising plume of warmer, less dense river water
- the potential implications of the water diversion on environmental flows in the North Branch tributary.

3.2.2. Assessing feasibility of the options

The three options are evaluated in terms of three key aspects:

1. technical design and the likely ability to address hypolimnetic deoxygenation in the reservoir
2. capital and construction costs for the device design
3. ongoing operational and maintenance costs of the device.

These are summarised separately for each of the three potential options considered with advantages and disadvantages discussed in the recommendations section of the technical report by Kelly (2015; section 4).

Technical methods and modelling procedures for determining the system requirements for reservoir destratification and hypolimnetic aeration devices are detailed in Kelly 2015.

3.2.3. Destratification aeration

Over the two years of continuous temperature monitoring, the intensity of thermal stratification in the reservoir started increasing in September, progressively deepening the thermocline extent between October and April (see Figure 8). The maximum difference in temperature between surface and bottom waters occurred during late February in both monitoring years. This period is when stratification was strongest, and therefore would require the greatest energy to break down the thermocline. There were some small differences in stratification patterns between years; however, the timing of thermocline development and breakdown were consistent between the years. The thermocline extent was deeper in 2014 by comparison to 2015.

The strength of the thermocline can be quantified by calculating the potential energy anomaly (PEA), which takes into account the rate of water density change over the depth of the water column (Figure 47). The PEA value is informative for determining the energy output requirements of a destratification mixing system, with a robust system designed to break down the water column at its peak PEA level. For both years of monitoring in the Maitai Reservoir, PEA increased relatively constantly onward from September to as high as 50 J/m^3 around the end of February. The effects of floods (in inflows) can be seen on several occasions where sharp declines in PEA occurred during January and March in both years. Overall, PEA was greater during 2014 to 2015 by comparison to the previous year, most likely a consequence of warm-dry summer conditions that occurred in the second year of monitoring. The overlap of the monitoring period with warm-dry summer conditions is useful, because it provides assurance that stronger stratification cycles are accounted for in the system design.

The timing and frequency for destratification mixing can vary depending on thresholds established by NCC. For example, these could be specified in terms of acceptable levels of deoxygenation in bottom waters of the reservoir. Should a DO cut-off of 5 mg/L be used, as recommended by Gibbs and Hickey (2012), this would necessitate that an initial destratification mixing event would need to occur in December based on rates of DO decline observed between 2013 to 2015 (Figure 9). Following this initial destratification mixing period, an aeration device could either be left to operate (at a lower airflow) to maintain a homogeneous water column, or turned off after a period of mixing and the reservoir allowed to re-stratify and progress through another deoxygenation cycle. The DO cut-off is therefore important for determining the frequency of further mixing events over the seasonal stratification cycle, and would influence the operational costs for the destratification system. This is considered in greater detail in the section examining operating costs.

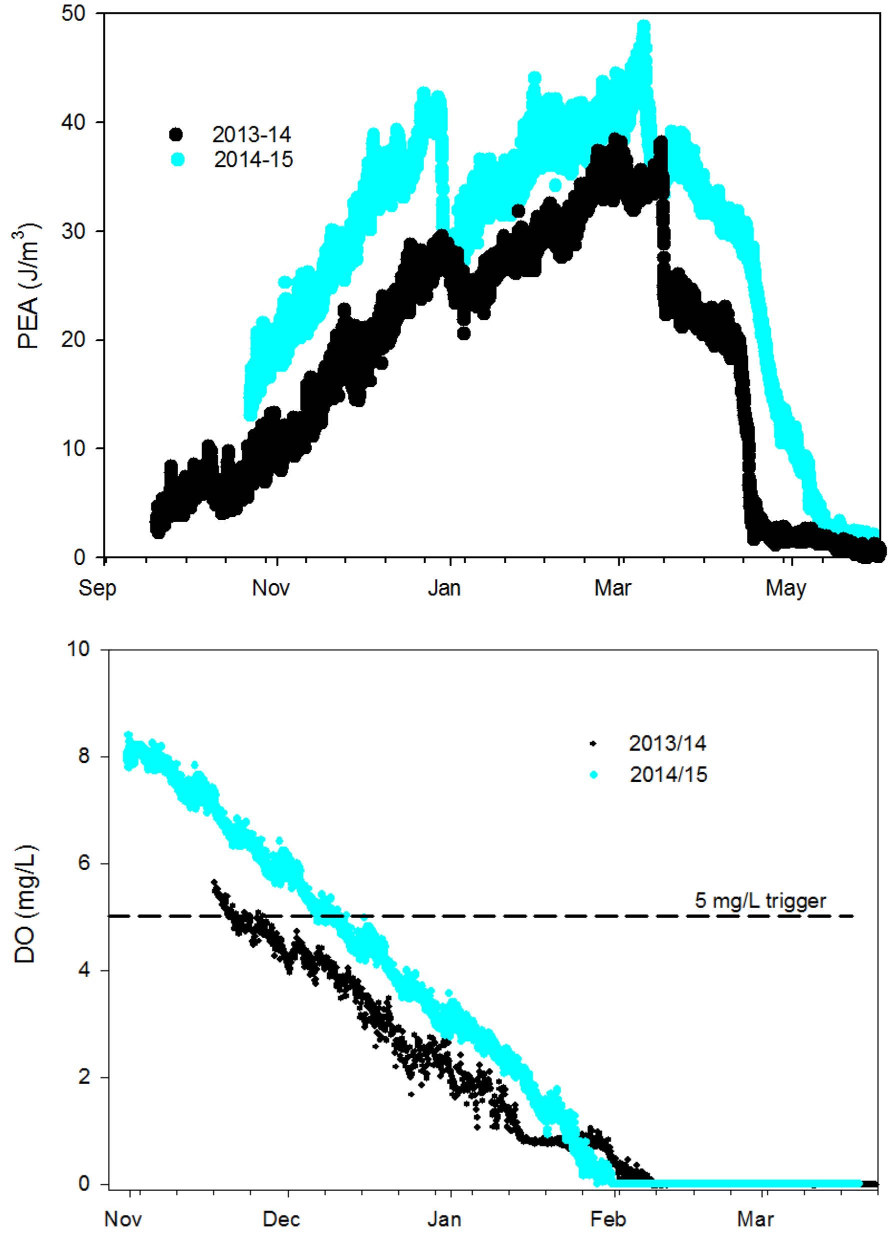


Figure 47. Seasonal trend in the (a) potential energy anomaly (PEA) of the Maitai Reservoir water column (upper) and (b) dissolved oxygen (DO) at 24 m depth (lower). Note the development of stratification and subsequent breakdown and associated reduction in DO over the summer period.

Considerations for the design of the destratification system

The Maitai Reservoir is a small reservoir in terms of surface area and volume. The dam is an elongated shape with a bend in the middle which may present some hindrance to mixing from an aeration system. The best location for an aeration line is in the deepest part of the reservoir through the centre, running east-west. This positioning should provide optimum destratification potential but some stratification may occur in the upper extents of the reservoir. Key data for the design of the destratification system in the Maitai Reservoir included:

- maximum operating depth – 32 m
- maximum storage volume – 4.4 GL
- maximum surface area – 32.1 ha.

The period at which maximum thermal stratification occurred was used in sizing of the compressor and air distribution pipework. This maximum occurred in late February where surface temperatures and bottom waters differed by approximately 12 °C (Figure 48).

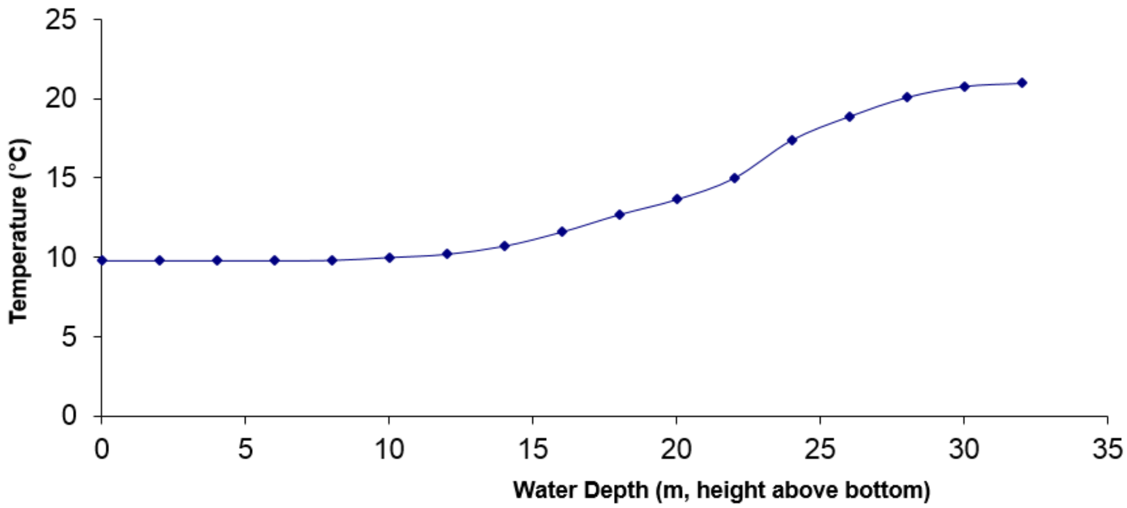


Figure 48. Temperature profile data used for designing output of a destratification mixing system taking into account the maximum summer difference between surface and bottom waters. Taken from Kelly (2015).

To ensure that the destratification system can effectively mix the reservoir, a system designed for destratification over 10 days was selected. Selecting a shorter (more compressor airflow) or longer (less compressor airflow) design for destratification time may be suitable, but would need to be considered in future investigations.

A modelling investigation identified that a total of 8 bubble port diffusers at 20 metre centres would be required with a design air flow rate of 3.4 L/s per diffuser (Kelly 2015). The diffuser structures would be situated at approximately 0.5 m from the bottom sediments (anchored and floated above the bed of the reservoir). The total diffuser airline was estimated at 165 m in length with a recommended siting of the line along the central basin of the reservoir (Figure 49). Modelling results were provided by an external consultant and were detailed for all three methods (Kelly 2015). As noted in the methods section although all three methods are presented, it is considered that the method of Schladow (1992) provides the most reliable estimate. This result is used as the basis for system requirements in subsequent costings.

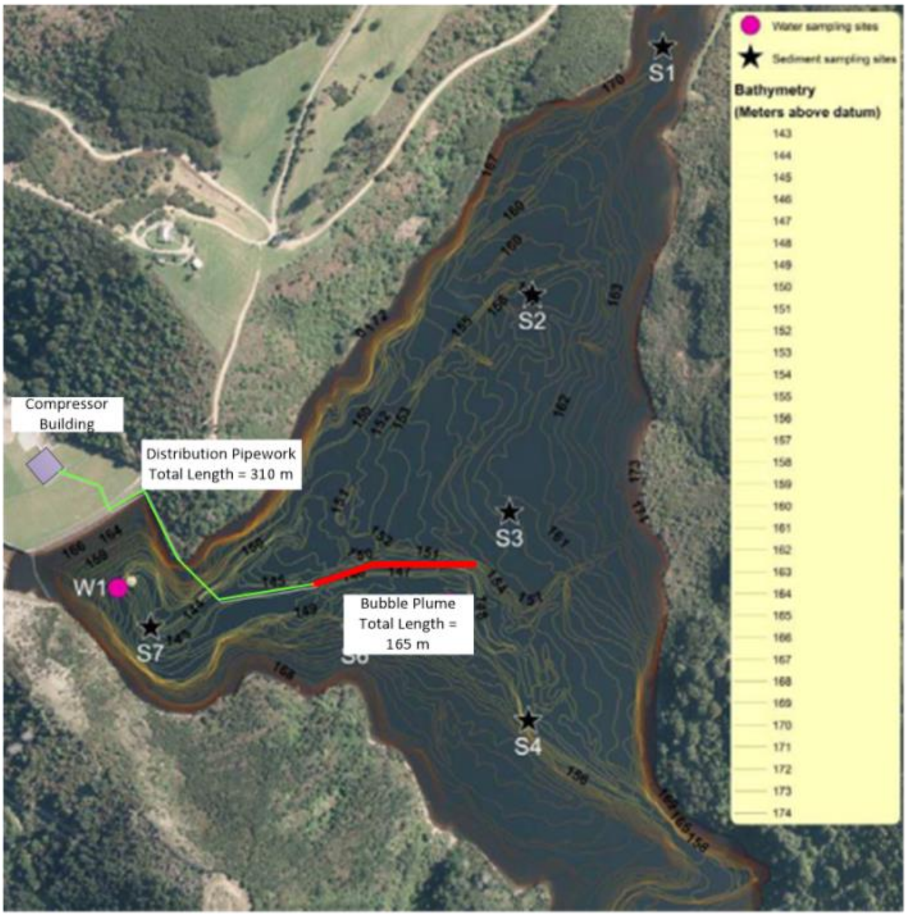


Figure 49. Destratification system layout on the Maitai Reservoir showing the location of the 165 m sparge line and connection with compressor building at the foot of the dam. Also shown are water (W1) and sediment (S1-S7) quality monitoring sites for the reservoir.

Based on the provided calculations, the destratification system would therefore include:

1. a pair of 15 kW duty/standby variable speed water injected screw compressors
2. a total free air flow rate of 30 L/s
3. a building to house the duty/standby compressors (possibly tied in with existing pump house)
4. electrical supply to the compressed air system
5. approximately 310 m of feed pipework from the compressor building to the air line
6. pipe lagging, fixings and condensate traps

7. a 165 m air line with 8 outlets at 20 m centres
8. airline anchor blocks and floats to keep the airline out of the sediment
9. the air line would be at an approximate depth of RL 31 m.

The use of variable speed compressors has been selected in this analysis, as it will enable power savings during times when the minimal destratification energy input from the bubble plume system is required. Consideration may also be given to the supply of one compressor only, however this would require further discussion with suppliers.

Consideration by NCC could also be given to the possibility for the intermittent operation of the destratification system when dissolved oxygen levels in the hypolimnion reach a threshold level. This would potentially reduce operational costs in terms of total power usage over the stratification season. Modelling of DO fluctuations under an intermittent operating regime was conducted based on the destratification system being activated at a hypolimnetic DO cut-off of 5 mg/L (Gibbs & Hickey 2012), and the operation of the destratification occurring over a 10 to 14 day period. Following each mixing period, the destratification system was turned off, and the reservoir allowed to re-stratify and progress through another deoxygenation cycle. Rates of bottom water oxygen depletion were based on continuous DO and thermistor chain data collected between 2013 and 2015. Modelling of deoxygenation rates were not able to not account for hypolimnetic water that could potentially be further warmed subsequent to destratification mixing. This could potentially affect the rate of hypolimnetic oxygen depletion to a small extent.

Based on modelling results, it was predicted the reservoir would need to be destratified three times over the course of the stratification season (i.e., October-May; Figure 50). The requirement for three mixing events was consistent for both years of monitoring data considered. Based on this, it is predicted that the destratification system will need to be operated over a period of six weeks annually. The implications, in terms of effects on operational costs, are detailed in section 3.1.2.

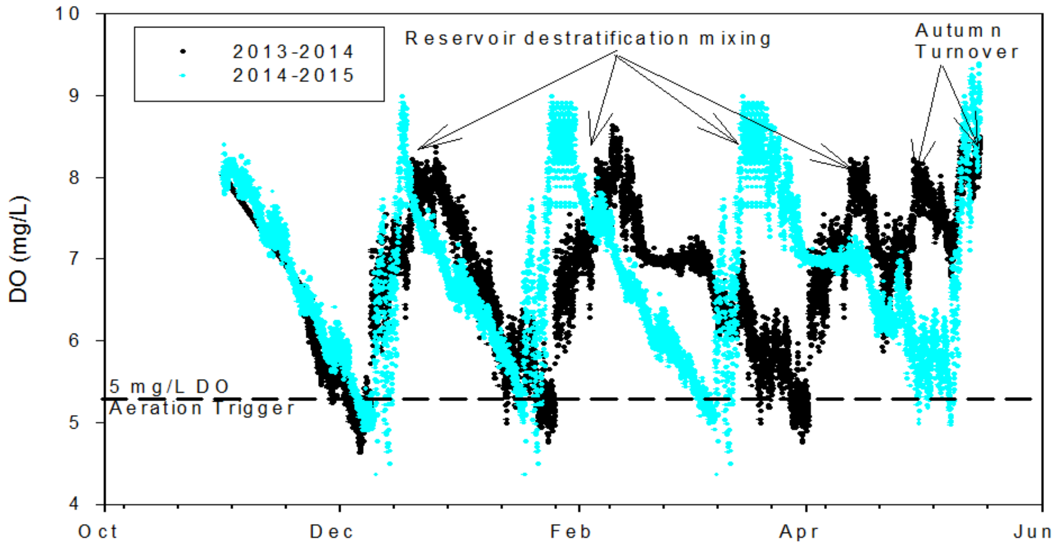


Figure 50. Dissolved oxygen (DO) model predictions for the Maitai Reservoir during the 2013 to 2014 and 2014 to 2015 summer seasons with destratification mixing. Modelling assumes destratification mixing can increase water column DO to 8 mg/L operated over a two week period. Oxygen decline rates were calculated from actual deoxygenation rates over the stratified period.

Destratification system cost estimate (provided by HunterH20)

Summaries of the capital cost estimates for the provision of a bubble plume destratification system for the Maitai Reservoir were estimated (Table 20). Where applicable, quotations were obtained directly from suppliers for any major equipment items and included delivery costs to the Nelson area. The remaining costs were generated using previously tendered costs, and an independent consultant's cost database for other costs.

Additional costs may be incurred due to the need for power supply upgrades and / or the presence of unfavourable geotechnical data. Furthermore, no allowance has been made for encountering significant submerged objects when installing the air line. To reduce the cost of the compressor installation, it may be possible to use temporary buildings such as the one pictured in Figure 51.

Table 20. Capital cost estimate of a destratification system for the Maitai Reservoir. Note costs were provided with input from HunterH20 based in New South Wales

Parameter	Variable	Cost
Site preliminaries & general construction		$ 18 K
Compressor building		$ 67 K
Compressors		$ 160 K
Feed pipework & associated equipment		$ 56 K
Air distribution pipework & fittings		$ 55 K
Electrical works		$ 302 K
Sub Total		**$ 656 K**
Contractor overheads & profit	18%	$ 118 K
Project management	5%	$ 33 K
Base Cost		**$ 807 K**
Contingency	30%	$ 242 K
Total Capital		**$ 1,049 K**

Figure 51. Examples of temporary container buildings used for housing destratification compressor systems.

Operational costs

The monthly temperature differential profile shows that destratification of the reservoir may be required for seven months of the year on average. Based on a six month per year usage of the destratification system, the estimated annual operating cost is in the order of:

- $3,643 *per annum* for mechanical maintenance based on 1.0% of capital spend
- $2,265 *per annum* for electrical maintenance based on 0.75% of capital spend
- $13,608 *per annum* for electrical power based on $0.18 per kWh.

If intermittent operation of the destratification system was effective this could reduce the overall power usage costs as follows:

- $2,722 *per annum* for electrical power use if operated intermittently estimated on 6 weeks *per annum* based on $0.18 per kWh.

The total operating (power) and maintenance cost is therefore estimated to be $19,516 *per annum* (if operated continuously over six months) and $8,630 *per annum* if operated intermittently. Additional allowance will also be required for maintenance of civil structures over the longer term.

3.2.4. Hypolimnetic aeration

Several designs of hypolimnetic aerators have been used in lakes and reservoirs (Fast & Lorenzen 1976). Three of the most commonly employed designs include full (or partial) lift aerators, Speece cones, and bubble plume diffusers. A brief outline of each design's functionality is described in the following section, which is based on an extensive review by McGinnis (2000).

There is considerable complexity around the design and performance efficiency of hypolimnetic aeration systems. A number of parameters must be optimised to local reservoir conditions (e.g. depth of hypolimnion, temperature gradients, oxygen depletion rates), and the designs of the diffuser and manifolds are often system specific (Ashley & Hall 1990). Relatively small changes in design can result in significant variation in the system's performance (McQueen & Lean 1986; Wüest et al. 1992). In this respect, it was difficult within the scope of this feasibility study to make detailed predictions of system requirements, without further detailed engineering design works being undertaken.

Full- and partial-lift hypolimnetic aerators

Full- and partial-lift hypolimnetic aerators consist of diffusers that supply an air-bubble flow into a long riser tube and one or more 'downcomer' structures that return oxygenated water back to the water column below the thermocline depth (Figure 52). Full-lift aerators extend from the reservoir bed to the water surface where it is open to the atmosphere, whereas partial-lift aerators are sealed at the top (except for the exhaust pipe), and remain submerged. In both devices, air bubbled into the riser tube creates an upward water current of less dense bubble-water mixture. As the bubble-water mixture rises through the hypolimnion, oxygen is dissolved into the water from the bubbles. Gas bubbles exit the water (via a water/air separator exhaust manifold) and oxygenated water is returned to the hypolimnion via the downcomers. Water velocity through the riser and downcomers is a function of the volume of air injected and the diameter of the bubbles. The performance of such devices generally improves with reservoir depth because of the increased time period bubbles can exchange with the water column, and is poor in shallow reservoirs (< 10 m depth).

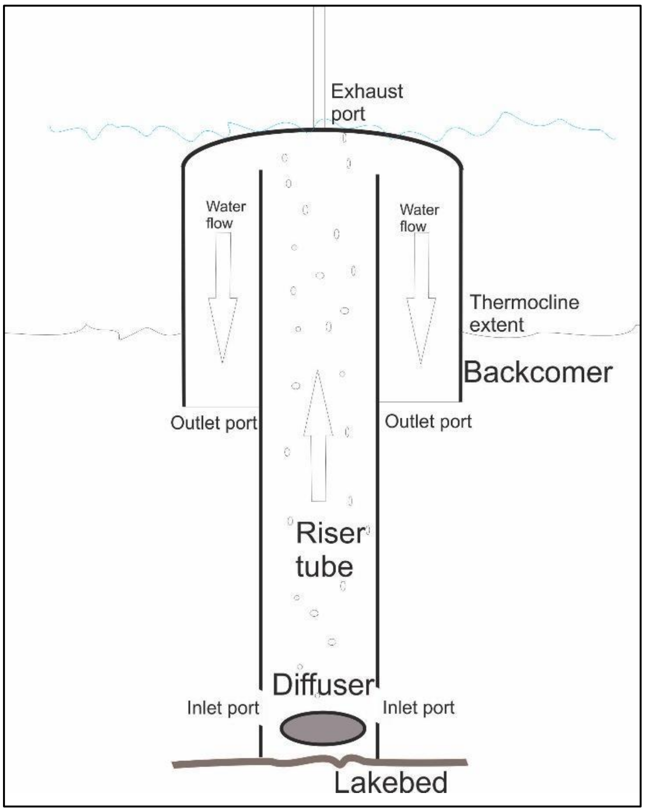


Figure 52. Schematic of the typical full-lift aerator showing main features of the riser tube, downcomers, and diffuser. Air is introduced as fine bubbles through the diffuser, creating water currents that travel through the inlet ports, up the riser tube and down the downcomers where they exit the aerator.

Diffuser dimensions and airflow rate are very important for controlling rise velocity and therefore the amount of time bubbles remain in contact with the water column. Probably the most important factor is the size of bubbles formed from the diffuser, with very fine bubbles (typically 2–3 mm diameter) providing optimum velocity rates and gas exchange to the water column.

Speece Cone

The Speece Cone consists of a conical chamber with the large diameter of the cone resting near the bottom of the reservoir (Speece et al. 1973). Water is introduced to an opening at the top of the cone via a submersible pump. Air, or pure oxygen, bubbles are also introduced at the top of the cone with a bubble diffuser and migrate slowly down the cone as they dissolve into the pumped water stream. The discharge from the cone is located at the base where the highly oxygenated water is introduced to the hypolimnion via a diffuser. The water velocity is faster than the bubble rise velocity, which results in gas bubbles being slowly dragged downwards in the cone. This allows rapid dissolution of oxygen and high oxygen transfer efficiency, which is due to the increasing hydrostatic pressure from the bubbles travelling downward. Because gas transfer is determined principally by pumping rate, rather than upward rise velocity, these devices are suitable for shallower reservoirs (i.e., < 10 m) where transfer from a rising bubble plume would be less efficient.

Hydrodynamically, this is one of the simplest devices, because the water velocity is known based on the cone geometry and the pump capacity. As with the full-lift hypolimnetic aerators, bubble size is also an important factor in determining the gas transfer efficiency. Efficiencies of up to 92% gas transfer have been reported using this approach (McGinnis 2000).

Bubble plume diffusers

For bubble plume aerators, air or oxygen bubbles are introduced into the bottom of the reservoir via a large unconfined diffuser (e.g., circular or long rectangular diffusers; Wüest et al. 1992). These devices are similar in principle to hypolimnetic destratification devices, however bubble diameter is much smaller and the gas transfer rate lower so as to not induce rapid upwelling gas-water plumes capable of modifying the overlying thermocline. Similar to the full-lift aerators, as the bubbles are introduced into the water in the hypolimnion, the bubble-water mixture becomes less dense than the surrounding water, inducing an upward velocity. As the plume water rises, the oxygen dissolves from the bubbles traveling with the water until the plume loses its vertical momentum. Oxygenated water falls back to the layer of neutral buoyancy (Wüest et al. 1992). Remaining oxygen in the bubbles continue to be transferred to the surrounding water until the bubbles are completely dissolved or they pass through the thermocline.

Hydrodynamic and oxygen transfer properties of bubble plume diffusers are complex because the plume is unconstrained and can interact with the water column to entrain water as it rises upwards through the thermocline. Given the uncertainties around oxygen exchange rates and hypolimnetic mixing around bubble plume diffusers, this would be seen as the least certain option. The number of diffusers and their placement would greatly depend on water column mixing, and therefore if this option was considered it would have to be using an adaptive approach to determine efficiency.

Predicting hypolimnetic aeration system requirements

Reservoir hypolimnetic aeration requirements were predicted from volumetric hypolimnetic oxygen depletion (VHOD) rates in the reservoir hypolimnion at 24 m depth (Kelly 2015). Monthly rates of hypolimnetic aeration required to offset deoxygenation were made considering two main factors:

1. monthly variation in volume of the hypolimnion
2. oxygen transfer efficiency of the aeration device.

Total volume of the hypolimnion diminished over the progression of stratification as the depth of the thermocline deepened until January, and then progressively increased through to April. This meant that hypolimnion volume was initially around 3.89 million cubic metres in early spring (October), but then declined by over 70% to 1.37 million cubic metres in January. This seasonality had a very pronounced effect on aeration airflow requirements to offset hypolimnetic deoxygenation. Predicted airflow rates were as high as 17.1 L/s in spring and as low as 6 L/s in mid-summer (Table 21).

As previously discussed, the efficiency of the aeration device in transferring oxygen to the water column is difficult to accurately predict. Efficiency depends on a number of factors such as the partial pressure coefficients of gases in the water column, bubble diameter, velocity of water within the aeration unit, and depth of the water column. Therefore, the efficiency of the hypolimnetic aeration unit was not able to be addressed in detail as part of this initial feasibility investigation. However, aeration rates were calculated based on oxygen transfer efficiency data reported from previous studies and reviews, and assumed such a device could be operated with an oxygen transfer efficiency ranging between 60-92% (McQueen & Lean 1986; Wüest et al. 1992; Burris & Little 1998; McGinnis 2000). There were unfortunately no case studies of hypolimnetic aeration devices being used in New Zealand lakes and reservoirs, and therefore the design and implementation of such a system would likely have to come from overseas experience.

Based on the range of oxygen transfer efficiencies and patterns in seasonal hypolimnetic volume, the average airflow rates through the hypolimnetic aeration system is estimated to be between 5–7 L/s (Table 21). Based on maintaining hypolimnetic DO concentrations in excess of 5 mg/L, the aeration system would be required to be operated continuously between October and April. If the hypolimnetic aeration system was operated to offset the entire rate of oxygen decline (i.e. maintaining DO near saturation levels) it is estimated that the average airflow rates would need to be between 7-10 L/s depending on oxygen transfer efficiencies.

Table 21. Predicted monthly airflow rates of a hypolimnetic aeration system in the Maitai Reservoir required to offset the rate of oxygen depletion in the hypolimnion to a dissolved oxygen (DO) concentration of no less than 5 mg/L. Rates were calculated based on two oxygen transfer efficiencies (OTE), 60% and 92%, based on ranges reported in the literature (Wüest et al. 1992; McGinnes 2000). Note that an average hypolimnetic oxygen depletion rate of 0.08840 g/m^3/d, calculated over 2013-1015, was used to determine airflow rates.

Parameter	October	November	December	January	February	March	April	Average
Thermocline depth extent (m)	8.65	9.1	10.1	11.3	10.1	10.1	9.4	10.0
Hypolimnetic volume (million m^3)	3.89	1.79	1.57	1.37	1.57	1.57	1.79	1.61
Total DO reduction (kg/d)	257.6	118.4	104.0	90.8	104.1	104.1	118.4	106.6
Total airflow rate–92% OTE (L/s)	11.2	5.1	4.5	3.9	4.5	4.5	5.1	4.6
Total airflow rate–60% OTE (L/s)	17.1	7.8	6.9	6.0	6.9	6.9	7.8	7.1

The number of diffuser manifolds that would need to be constructed to ensure aeration occurred over the entire extent of the hypolimnion is difficult to predict. The number of manifolds required is dependent upon the rate of airflow a diffuser manifold design can accommodate, as well as horizontal mixing patterns of the hypolimnion, which are presently unknown. Nevertheless, it is estimated that between 3 and 7 diffuser manifolds could be required. This estimate is based on previous studies overseas (e.g., Burris & Little 1998, McGinnis 2000) and the T-shaped basin of the Maitai Reservoir. Investigation into horizontal water circulation patterns in the basin using long-term deployments of acoustic-Doppler current meters could provide additional information around the number of diffuser manifolds required.

The operation of the hypolimnetic aeration system (e.g. airflow rate, number of diffusers) would probably need to be operated in an adaptive manner. The adaptive management of the system could be informed by continuous DO monitoring at the valve tower location, as well as intermittent profile data collected in other portions of the reservoir basin.

Hypolimnetic aeration system cost estimate (prepared with input from HunterH20)

Summaries of the capital cost estimates for a hypolimnetic aeration system in the Maitai Reservoir are detailed in Table 22. Where applicable, quotations were obtained from suppliers for any major equipment items which included delivery costs to the Nelson area. Much of the remaining costs were generated using costs provided on the aeration destratification system works, and the consultant’s cost database for mechanical and process equipment and civil unit rates and quantities.

Table 22. Capital cost estimate of a hypolimnetic aeration system for the Maitai Reservoir. Note costs were provided with input from HunterH20 based in New South Wales, with major capital items being sourced by Australian contractors and equipment suppliers.

Parameter	Variable	Cost
Site preliminaries & general construction		$ 18 K
Compressor building		$ 67 K
Compressors		$ 60 K
Aeration diffusers & associated equipment		$ 70 K
Air distribution pipework & fittings		$ 55 K
Electrical works		$ 302 K
Sub Total		**$ 572 K**
Contractor overheads & profit	18%	$ 103 K
Project management	5%	$ 29 K
Base Cost		**$ 704 K**
Contingency	30%	$ 211 K
Total Capital		**$ 915 K**

No allowance has been made for encountering significant submerged objects when installing the air lines. To reduce the cost of the compressor installation it may be possible to use temporary buildings.

Hypolimnetic aeration operational costs

The monthly stratification data suggest the hypolimnetic aeration will be required to be operated over a six month stratification period. Based on a six month per year usage of the aeration system, the estimated annual operating cost is approximately:

- $1,320 *per annum* for mechanical maintenance based on 1.0% of capital spend
- $2,265 *per annum* for electrical maintenance based on 0.75% of capital spend
- $3,808 *per annum* for electrical power based on $0.18 per kWh.

The total operating (power) and maintenance cost is therefore estimated to be $ 7,393 per annum if operated continuously over six months. Additional allowance will also be required for maintenance of civil structures over the longer term.

3.2.5. Tributary inflow transfer

Information on hypolimnetic aeration requirements, described previously, was also used to calculate tributary inflow transfer rates required to offset deoxygenation. In this case, calculations only took account of the total mass of oxygen required to be replenished within the hypolimnion. Total transfer volumes required to achieve this mass transfer were calculated based on mean monthly monitoring data of dissolved oxygen concentration in the North Branch tributary (near the inflow delta). This information was then converted to an instantaneous flow transfer rate for the month period. This simple calculation provides an indicative flow requirement for a water transfer system, should it be considered as a potential option.

These calculations were not able to take into account other potential complicating factors, such as plume mixing dynamics within the hypolimnion, or daily fluctuations in temperature and DO that were not accounted for in our instantaneous (day-time) monitoring. These would likely need to be explored further, if this was considered a viable management option for the reservoir.

Based on mass transfer modelling, the rate of water transfer required to offset deoxygenation ranged between 244.4 L/s in October, to 97.3 L/s in March (Table 23). This seasonal variation was driven mostly by changes in the total hypolimnetic volume, and to a lesser extent by variation in dissolved oxygen concentration in tributary water. On average, an instantaneous transfer rate of 129.1 L/s would need to be diverted from the North Branch tributary to offset hypolimnetic deoxygenation occurring in the reservoir.

Table 23. Predicted mean monthly water transfer rates for a North Branch tributary water diversion required to offset the rate of oxygen depletion in the Maitai Reservoir hypolimnion to no less than 5 mg/L dissolved oxygen (DO) concentration. Inflow rate requirements were calculated based on monthly tributary DO concentrations assuming 100% retention of the water plume within the reservoir hypolimnion. Note that an average hypolimnetic oxygen depletion rate of 0.08840 $g/m^3/d$, calculated over 2013–1015, was used to determine oxygenation requirements.

Parameter	October	November	December	January	February	March	April	Average
Thermocline depth extent (m)	8.65	9.1	10.1	11.3	10.1	10.1	9.4	10.0
Hypolimnetic volume (million m^3)	3.89	1.79	1.57	1.37	1.57	1.57	1.79	1.61
Total DO reduction (kg/d)	257.6	118.4	104.0	90.8	104.1	104.1	118.4	106.6
Inflow temperature (°C)	10.7	11.6	13.2	14.2	12.5	11.3	11.2	12.3
Inflow DO (mg/L)	12.2	11.0	10.2	10.2	11.5	12.4	12.5	11.3
Required water transfer rate (L/s)	244.4	124.6	118.7	103.5	105.1	97.3	109.9	129.1

Flow statistics for the Maitai River North Branch have been calculated using a flow relationship determined by Hewitt and Kemp (2004) (North Branch = 0.6892 × South Branch - 21.693). Seven day mean annual low flows (7-d MALF) in the Maitai River subcatchment were calculated at:

- South Branch 7-d MALF (1995-2014) = 161 L/s
- North Branch 7-d MALF = 89 L/s.

Requirements for transfer of North Branch tributary water to offset hypolimnetic deoxygenation were on average 129 L/s, comprising 145% of the 7-d MALF for this tributary. Moreover, water diversion requirements coincide with the summer period in which flows are lowest and ecological effects of abstraction (e.g. temperature increases) are likely to be greatest. As discussed in Beca (2008), the level of investigation required should be matched to the relative in-stream values and the level of abstraction pressure (i.e. the degree of hydrological alteration). In cases with high abstraction pressure and/or high in-stream values, more in-depth investigation, including habitat modelling and flushing flow analysis, is warranted. Beca (2008) state that 'Abstraction of more than 40% of MALF, or any flow alteration using impoundments would be considered a high degree of hydrological alteration, irrespective of region or source of flow.'

The requirement for such a high rate of abstraction associated with the inflow diversion, often exceeding total flows available in the river, suggests there to be low likelihood for such a diversion to be a practical management option. As a result of this finding, further considerations of capital equipment, construction, and operational costs associated with this option were not pursued.

3.2.6. Reservoir aeration system recommendations

The reservoir aeration feasibility study identified two potential options that could improve water quality issues in the Maitai Reservoir that are associated with hypolimnetic deoxygenation (Kelly 2015). These options would require construction of hypolimnetic aeration or destratification devices, and could be designed and operated to prevent significant deoxygenation in the reservoir. Both options could feasibly address the extent and rate of deoxygenation, and be scaled to a reservoir of this size and shape. An alternative approach investigated hypolimnetic inflow diversion, but based on initial calculations it does not appear that this could be implemented without seriously compromising environmental flows in the North Branch tributary.

Some of the key advantages and disadvantages of the two feasible options are outlined in Table 24. Possibly the most recognisable advantage from a water management perspective is that hypolimnetic aeration would preserve the cool-water habitat in the reservoir hypolimnion. Preservation of the thermal structure in the reservoir could allow release of cooler water to the downstream river during sensitive periods. Although a destratified (mixed) reservoir could still maintain water temperatures downstream of the Maitai River backfeed within the current consented limits (i.e., < 3 °C change, and < 20 °C) most of the time, it would give less flexibility on operational control. In this context the hypolimnetic aeration option is more appealing.

Table 24. Key advantages and disadvantages of the destratification and hypolimnetic aeration options for addressing water quality problems in the Maitai Reservoir.

Destratification	Hypolimnetic aeration
Advantages - well proven technologies - working New Zealand examples (Auckland, Canterbury) - capital equipment readily available -expertise within NZ and Australia - cooler reservoir water passed over spillway	Advantages - proven technologies - cool water habitat preserved for backfeed over summer/autumn - Lower operational expenditure - Lower capital costs (depending on manifold design costs) - Maintenance of coldwater habitat in summer for sensitive species
Disadvantages - homogenisation of reservoir water temperature during summer - potentially higher operational expenditure (if intermittent operation is not effective) - higher overall capital costs	Disadvantages - capital equipment not readily available - diffuser manifold design requiring overseas engineering expertise

While hypolimnetic aeration is recommended, there is presently no New Zealand expertise and engineering experience for designing such systems. Consequently design expertise would likely need to be sought from overseas, particularly to assist with the design of a suitable diffuser manifold. Destratification devices are more likely to be more easily available, and are presently in operation at several reservoirs within New Zealand (e.g. Watercare, Auckland region; Opuha Dam Company, South Canterbury).

Costs associated with the two options are likely to be similar. Both require the construction of compressor and air-transfer systems to a reasonable extent of the reservoir basin. There is greater uncertainty around costs for hypolimnetic aeration because of the difficulties in estimating engineering costs for the diffuser manifolds. It is probable that the costs identified may be in excess of actual costs, as there was uncertainty around whether the equipment could be accommodated (e.g. housing, electrical) by infrastructure presently located at the dam site. Therefore estimates of construction costs are likely to be at a higher end of the actual project costs.

The water management, construction design, and project cost advantages and disadvantages will therefore need to be considered by NCC. Other engineering options could also be considered by NCC water treatment engineers to mitigate the downstream effects on the lower Maitai River. Although not investigated in detail as part of this AEE, this could include

- Aeration of the backfeed pipeline using compressed gas aeration
- Construction of a turbulent open channel for transferring backfeed waters to the Maitai South Branch
- Use of a greater portion of Maitai Reservoir water for the municipal supply thereby reducing the required backfeed flow rates

3.3. Ecological implications for backfeed management versus aeration and destratification options

Implementation of either of the options of seasonal backfeed management, destratification or hypolimnetic aeration is expected to result in significant improvements in backfeed source-water released to the Maitai River via the backfeed (Table 25). This would include the following:

1. Increases in DO to > 50% saturation.
2. Decreases in dissolved trace metals to equivalent levels of the North Branch tributary.
3. Minor reductions in reservoir nitrogen and phosphorus concentrations

The major difference between the aeration options versus the backfeed management are related to improvements in DO, temperature, and trace metal concentrations in the reservoir itself, as well as some decreases in nutrients transported to the river via the backfeed through reducing internal recycling.

It is expected that reductions in trace-metals and micronutrient concentrations achieved by reservoir aeration or destratification could also reduce periphyton cover in the river downstream of the backfeed. Presently there is a marked transition of periphyton cover downstream of the backfeed weir; with moderate to high coverage by filamentous and medium thickness mats (see Section 2.6.2). These changes in periphyton cover are thought to be linked with associated declines in invertebrate community metrics (e.g., MCI, QMCI) downstream of the backfeed.

The extent to which improvements in reservoir water quality will improve periphyton cover in the South Branch is likely to be related to the manner in which the backfeed and the aeration devices are operated. With hypolimnetic aeration, cooler bottom water that remains below the thermocline depth is likely to be slightly elevated in dissolved N and P concentrations relative to reservoir surface waters because phytoplankton is not present to uptake nutrients at these depths due to insufficient light. As a result the change in dissolved N exported from the reservoir could be relatively minor. The option of reservoir destratification would reduce differences between surface and bottom waters by continually mixing the reservoir, and reservoir productivity (phytoplankton abundance) could be slightly greater overall because of these mixing processes, but this is expected to be small given the reservoir's low P content.

Changes in macroinvertebrate communities of the South Branch from aeration or destratification would be expected to track overall improvements in periphyton cover in the river. However because changes in macroinvertebrate composition are also associated with the river changing to a lake outlet type community (responding to seston discharging from the reservoir), it is probable that these changes would not result in the community changing to a community comparable to the upstream control site (see Section 2.7.3). Therefore more appropriate targets for macroinvertebrate community metrics would need to be considered, characteristic of a lake outlet type community. This approach has been undertaken for other hydro-reservoir outlets in New Zealand (e.g., Moawhango Dam).

In respect to how mitigation options are predicted to affect the likelihood of the receiving environment meeting water quality standards, the NRMP provides directions on the 'priority for improvement'. In the case of the relevant reach the priority is 'third' and to 'upgrade to B where practicable' (Appendix 28.4 NRMP). The NRMP also contains district-wide policies (e.g. DO19.1.4 and DO19.1.6) that seek the improvements in water quality. As such, water quality standards for the Maitai Reservoir and downstream waters were evaluated under the proposed improvement options in terms of the likelihood of meeting water standards for Class B waters, considered to have 'very good' water quality.

Significant improvements in the Upper Maitai River, and to some extent the Middle Maitai River, are expected to occur under all of the proposed mitigation options. The option around management of the backfeed to source waters only from oxic layers of the reservoir would improve conditions around clarity, aesthetics (iron staining), macroinvertebrates, but there could be some minor adverse water temperature effects.

For the aeration destratification and hypolimnetic aeration mitigation options (which are aimed at reversing water quality issues associated with reservoir stratification and anoxia), these options would result in much wider improvements in water quality relative to the NRMP. Both options would significantly improve conditions for turbidity, clarity, temperature, toxicants in water (trace metals, nutrients), aesthetics, periphyton, macroinvertebrates. Moreover, these improvements would be more widespread, by improving conditions in the river downstream of the backfeed as well as within the Reservoir.

Overall, it is expected that improvements in water quality of reservoir water using either the hypolimnetic aeration or destratification aeration options would result in greater improvements in water backfed to the river, and expected improvements in the ecological health of the upper Maitai River below the reservoir.

Table 25. Predicted likelihood of meeting Nelson Resource Management Plan water quality standards for Class B waters under the Reservoir operation mitigation options of backfeed management, destratification aeration and hypolimnetic aeration. L = low, M = moderate, H = high, NA = not applicable

Nelson Resource Management Plan Parameter	**Backfeed Management**	**Destratification aeration**	**Hypolimnetic aeration**
Temperature - Mean daily 20 °C, daily maximum 24 °C			
Reservoir	NA	NA	NA
South Branch	L	H	H
d/s Forks	L	H	M
Dissolved oxygen - River mean DO 98-105% sat., Reservoir DO range 90-110% sat.			
Reservoir	L	H	H
South Branch	L	L	M
d/s Forks	L	L	M
Clarity - River black disk 4 m, Reservoir Secchi disk 5m			
Reservoir	L	L	L
South Branch	M	H	H
d/s Forks	H	H	H
Trace metal toxicants – 95% percentile ANZECC			
Reservoir	L	H	H
South Branch	L	H	H
d/s Forks	H	H	H
Nutrients (mg/m^3)– River Class B DIN 120 & DRP 9; Reservoir TN 160 & TP 9			
Reservoir	L	M	M
South Branch	H	H	H
d/s Forks	H	H	H
Periphyton–River <60% cover medium mats & <30% cover long green filaments			
South Branch	L	M	M
d/s Forks	L	M	M
Macroinvertebrates – River 100 MCI & 5 QMCI			
South Branch	M	H	H
d/s Forks	M	H[DD]	H[DD]

[DD] = data deficient, and therefore based on a limited set of data.

3.3.1. Summary of key findings

Summary – Reservoir aeration

- Based on deoxygenation patterns observed over 2013–2015, analyses suggest reservoir destratification using aeration mixing, is a viable option for mixing and re-aerating the reservoir during periods of low oxygen.
- Using this approach, destratification and reoxygenation of the reservoir is predicted to be achievable within 10–14 days. Continuous or intermittent operation of the device could be considered over the stratification period, with the key time period for operation being between December and April. The total cost of the design and installation of the device is estimated at $1,049,000 with annual operational costs of $20k per annum (if operated continuously over seven months) or $9k per annum if operated intermittently.
- Analysis of total oxygen consumption rates in the reservoir hypolimnion indicate that hypolimnetic aeration could also be a viable option for reversing deoxygenation in the reservoir. Based on deoxygenation patterns observed over 2013 / 2015, it is expected that between 3 to 7 separate diffuser manifolds distributed across the reservoir basin may be required, but this would depend on the design of the manifolds and horizontal current patterns in the hypolimnion, which are presently unknown. The total cost of the design and installation of the device is estimated at $915,000 with total operating (power) and maintenance estimated to be $7k per annum if operated continuously over six months.
- Overall, either destratification or hypolimnetic aeration devices could feasibly improve water quality in the Maitai Reservoir. A distinct advantage of hypolimnetic aeration over destratification would be that it would preserve the cool-water habitat in the reservoir hypolimnion. This could allow release of cooler water to the Maitai River during sensitive periods. It is probable that a destratified (mixed) reservoir could generally maintain water temperatures within the current consented limits (i.e. < 3 °C change, and < 20 °C) downstream of the Maitai River backfeed; however, it would give less flexibility.
- Implementation of destratification or hypolimnetic aeration is expected to result in significant improvements in backfeed source-water released to the Maitai River via the backfeed including increases in DO, reduction of trace metal and nutrient concentrations.
- These improvements in water quality will likely reduce periphyton cover in the river downstream of the backfeed, and are expected to have flow on effects in terms of improving invertebrate community metrics (e.g., MCI, QMCI). The extent to which improvements in reservoir water quality will improve periphyton cover in the South Branch is likely to be related to the system of aeration implemented, and the manner in which the backfeed and the aeration devices are operated.

3.4. Flow regime

The dam and associated abstraction regime influence mainly flows in the low to median flow range, as discussed above.

3.4.1. Minimum flow

As discussed in Section 2.4, the existing summertime minimum flow below the Maitai Dam (175 L/s at the Maitai Forks flow recorder site) substantially reduces habitat availability for flow-demanding fish species and their invertebrate prey, relative to that provided at the naturalised MALF. The levels of habitat retained by this minimum flow are low compared to precedents of flow setting in recent years in other regions. For example the existing summertime minimum flow is predicted to retain only 20% of the torrentfish habitat at the MALF, compared with habitat retention levels of 70-90% of that at the natural MALF being commonly applied elsewhere (Hay & Allen 2014). This restriction of habitat could be interpreted as a significant reduction in life-supporting capacity of the river, and may be a contributing factor to the apparently low density of this, and other fish species, in the Maitai River.

On this basis, Hay and Allen (2014) suggested considering increasing the minimum flow in the Maitai River below the dam, to maintain in-stream values closer to natural levels. In the Maitai, torrentfish habitat is the most flow demanding, with prospective minimum flows, based on the approach described above, of circa 228-235 L/s (at the Maitai Forks) depending on the habitat retention level applied. As a fast water specialist, torrentfish is a candidate critical value species because its habitat is relatively sensitive to flow reductions, torrentfish is listed as ‘Declining’ in the latest Department of Conservation threat classification listings (Goodman et al. 2014), and they were traditionally caught by Māori and are still considered to be a taonga by some. A minimum flow of 230 L/s would retain more than 70% of the torrentfish habitat available at the natural MALF, and provide greater than 80% habitat retention for all other native fish species and trout.

In practice abstraction from the Maitai Reservoir and South Branch is managed so that flow is usually above the minimum. For this reason the 7-day MALF at the Maitai Forks is greater than the minimum flow. The existing 7-day MALF (220 L/s at the Maitai Forks) is actually quite close to the prospective minimum flows presented for torrentfish. Increasing the minimum flow to about the magnitude of the existing MALF would substantially increase the level of habitat retention for torrentfish (to 59%) and other fish species. Hay and Allen (2014) suggested that this existing practice of maintaining flows above the minimum flow level as much as possible could be formalized under consent conditions, as an alternative to actually increasing the minimum flow. For example, augmenting flows during low flow conditions could occur when surplus water is available in the reservoir beyond the Municipal Supply requirements. This could be scheduled over the summertime low-flow period relative to reservoir levels.

3.4.2. Flushing flows

As discussed in Sections 2.3 and 2.4.3, the operation of the Maitai Reservoir has very little influence on potential flushing flows. The magnitude and frequency of large channel forming floods are not materially influenced by the dam, and the average annual frequency of moderate freshes, in the order of 3 times the median flow[37] is reduced only slightly. While changes in the flow regime associated with the Maitai Reservoir are not considered to have influenced the prevalence of periphyton and cyanobacteria blooms in the river, the possibility of helping to manage these blooms through release of flushing flows from the reservoir has been explored (Hay & Allen 2014).

This flushing flow analysis, as well as observations of cyanobacteria and periphyton coverage in the lower Maitai, indicates that in the mid to lower reaches of the river effective flushing of periphyton and fine sediment actually requires flows substantially higher than three times the median flow (Hay & Allen 2014). Flows in the order of 9 m^3/s and 17 m^3/s, respectively, were predicted to be required to effectively flush 50% of the baseflow stream bed in Smith's Ford reach and the reach immediately downstream of Sharlands Creek. Higher flows would be required further downstream as channel capacity increases.

The Maitai reservoir does not have infrastructure to allow release of flushing flows of this magnitude. However, naturally occurring flow events could be augmented by flow releases of up to 3.5 m^3/s from the Maitai Reservoir (Hay & Allen 2014). This could help to control periphyton proliferations in the upper reaches of the river. Augmenting freshes in the order of 1.5–3 m^3/s would increase potential surface flushing from circa 15%–25% of the base flow bed with the natural flow alone, up to circa 35%–50% in the Smith's Ford reach. However, to achieve deep flushing of 50% of the baseflow channel at the modelled reaches would require 3.5 m^3/s augmentation of natural flow events of approximately 5.5 m^3/s in this reach. The timing of this would be dependent on these natural events and outside of the control of dam operations. While freshes in the order of 1.5–3 m^3/s occur reasonably commonly during summer, events of 5.5 m^3/s and higher are quite rare. Augmentation of flushing events is unlikely to be effective for the lower river due to the rarity of natural flow events of sufficient magnitude.

Using water from the dam for flushing flow releases would result in a reduction of the amount of water stored in the Maitai Reservoir that is able to be released to maintain

[37] The average annual frequency of flow events exceeding 3 times the median flow (FRE3) is widely used as an indicator of the regularity of flows flushing of periphyton and fine sediment from the river bed, maintaining the quality of benthic invertebrate habitat is the main ecological benefit of this process.

higher minimum flows. Given these competing demands for water (minimum flow/flushing flows), community values need to be evaluated with respect to using stored water either to enhance recreational uses (e.g. swimming) through flushing flows or retaining habitat availability for key species during low flow periods. As a further alternative, the potential to reduce abstraction rates (e.g. through rationing) during low flow periods could also be explored through community consultation.

3.4.3. Summary of key findings

Summary – Flow regime and habitat suitability mitigation

- The existing summertime minimum flow below the Maitai Dam (175 L/s at the Maitai Forks flow recorder site) substantially reduces habitat availability for flow demanding fish species and their invertebrate prey, relative to that provided at the naturalised MALF. This reduction in life-supporting capacity of the river may be a contributing factor to the apparently low density of torrentfish, and other fish species, in the Maitai River.
- It is suggested increasing the minimum flow in the Maitai River below the dam, to maintain in-stream values closer to natural levels. Prospective minimum flows based on torrentfish habitat were suggested in the order of circa 228-235 L/s (at the Maitai Forks), depending on the habitat retention level applied. Historical operations have delivered flows close to these levels, despite the minimum flow being considerably lower.
- Alternatively, the existing practice of maintaining flows above the minimum flow level as much as possible could be formalised under consent conditions when water surplus to Municipal Supply requirements is available in the reservoir.
- While changes in the flow regime associated with the Maitai Reservoir are not considered to have influenced the prevalence of periphyton and cyanobacteria blooms in the river, the possibility of helping to manage these blooms through release of flushing flows from the reservoir has been explored.
- The Maitai Dam does not have infrastructure to allow flow releases of the magnitude required to provide effective flushing in the mid to lower reaches of the river, but could help manage periphyton proliferations in the upper river.
- Naturally-occurring flow events could be augmented by flow releases from the dam. But the relative merits of releasing water for flushing flows versus augmenting minimum flows would need to be considered.

3.5. Fish passage

As discussed in Section 2.8.2, the Maitai Dam and South Branch weir are both partial barriers to fish passage, particularly for fish moving upstream (Doehring & Hay 2014; Hay et al. 2015).

Monitoring following fish passage modifications at the Maitai Reservoir spillway and the South Branch weir has shown that elvers are successfully passing both obstacles (Section 2.8.2). However, existing data suggests that the number of elvers successfully climbing the dam spillway is likely to still be relatively low, perhaps in the order of 480 elvers per summer. In addition, no other fish species have yet been observed attempting to pass the spillway since the modifications.

As recommended by Hay et al. (2015), given the apparent degree of difficulty for elvers of scaling the spillway and the apparently low numbers successfully reaching the reservoir via this route, it would be prudent to continue and intensify existing trap and transfer operations to augment fish numbers passing into the North Branch and reservoir. Ideally trap and transfer operations should be carried out on a more regular basis, with migrant fish in the vicinity of the dam being targeted for transfer. Trap and transfer has the potential advantage of avoiding concentrating migrants in locations that are easily predictable by predators, which renders them vulnerable to predation. As recommended by Doehring and Hay (2014), the trap and transfer operation should be extended to include kōaro as well as elvers and possibly also redfin bullies, and the methods of capturing fish for transfer should be extended to include electric-fishing as well as trapping/netting.

At the South Branch weir there remains an issue with high numbers of elvers being attracted to the large attractant flow from the backfeed discharge (Hay et al. 2015). These elvers climb the wet rocks in the splash zone of the backfeed, but appear unable to find a way upstream over the dry area on top of the weir. This situation could be addressed by piping a small amount of water onto the weir crest, to create a continuous wetted surface from the backfeed splash zone to the upstream side of the weir. This concept has was recommended by Hay et al. (2015) and discussed on site with NCC representatives, but has not yet been implemented.

The South Branch weir may still impede passage for some weaker climbing species, e.g. redfin bully, which has been found immediately downstream of the South Branch weir, but has not been recorded upstream of the weir, since its construction. This could also be addressed through occasional manual trap and transfer operations.

3.5.1. Summary of key findings

Summary – Fish passage mitigation

- Monitoring following recent fish passage remediation work indicates that some eel elvers are successfully climbing the dam spillway and backfeed weir. However, the numbers climbing the Maitai Dam spillway are likely to still be relatively low, and both structures are likely to still present a passage barrier for non-climbing fish species.
- Based on restricted passage, it would be prudent to continue and intensify existing trap and transfer operations to augment fish numbers passing the dam.
- Ideally trap and transfer operations should be carried out on a more regular basis, with migrant fish in the vicinity of the dam being targeted for transfer.
- The trap and transfer operation should also be extended to include kōaro as well as elvers and possibly also redfin bullies.
- At the South Branch, further fish passage modifications are required. Piping a small amount of water onto the weir crest to create a continuous wetted surface from the backfeed splash zone would enable passage by the large number of elvers attracted to backfeed flow.

3.6. Fishery

As discussed in Section 2.8.3 the brown trout fishery in the Maitai River has declined in value during the past two decades. The river does not currently support a productive fishery. Historically, and prior to the creation of the Maitai Reservoir, the river is reported to have supported a popular fishery. It is unclear what (if any) impact the Maitai Reservoir has on the trout population. Nevertheless, it is possible that changes in invertebrate communities, observed for some distance below the backfeed discharge, are contributing to the decline of the fishery through reducing the quality of the invertebrate food base for trout. This is just one impact that may be occurring in parallel with other pressures elsewhere in the catchment (e.g. extreme high and low flows, increased fine sediment inputs, passage barriers and urbanisation).

Restocking the lower river with 'takeable' sized brown trout (e.g. > 500 g) is an option to address the current poor quality of Maitai River fishery. Releasing hatchery reared trout is a common mitigation strategy in other impounded systems. For example, Trustpower and Nelson Fish & Game facilitate regular releases of rainbow trout in the Branch River upstream of the Branch River Hydropower scheme. With the support of Nelson Fish & Game the cost of hatchery releases in the Maitai River are estimated to be in the order of $5,000 per annum. This would be a fraction of the cost of long-term scientific investigations required to determine the potential role, and mechanisms by which, the operation of the Maitai Reservoir affects fishery values.

Rhys Barrier (Nelson Fish & Game manager, pers. comm.19 February 2016) has suggested that the biannual release of 100 takeable-sized brown trout (i.e. 200 fish annually) in the mid-catchment could adequately mitigate the declining recreational fishery value of the Maitai River. In combination with the remnant wild trout population these releases would result in a population density able to support a medium quality fishery. The Maitai River fishery was (historically) largely patronised by junior anglers; releases should coincide with school holidays and adequate public notification to encourage junior angler participation (Rhys Barrier pers. comm.).

Trout releases will increase predation pressure on native fish populations to some extent. Common bullies, smelt, īnanga, kōaro and small eels are likely to be predated upon by the hatchery released fish. However, based on anecdotal information, historic trout densities would have been higher than the densities that will result from the proposed hatchery releases. Densities of native fish are currently low even in the absence of a substantial trout population, and furthermore, riverine trout predominantly feed on drifting invertebrates (Hayes et al. 2000). With adequate public notification of trout releases the removal of trout through angling could also limit this potential impact. Therefore, although native fish predation pressure will be increased as a result of the hatchery releases, we suggest that the impact on native population densities will be undetectable.

Trout removal in the Maitai Reservoir, and North Branch upstream, could offset the negative impacts on native fish as a result of hatchery releases in the mainstem. Removal of trout from the reservoir would reduce predation pressure on small eels and kōaro entering the reservoir as a result of trap and transfer programmers and the recent fish passage improvements to the Reservoir spillway (see Section 2.8.2). If trout removal upstream of the Reservoir spillway is successful then reestablishment of lake-rearing native fish species could be considered (the Reservoir spillway will remain an effective barrier to upstream migration by trout).

3.6.1. Summary of key findings

Trout fishery mitigation

- The Maitai River brown trout population has declined over the past two decades and no longer supports a productive fishery.
- It is unclear what (if any) impact the Maitai Reservoir has had on the fishery - although it is possible that changes in invertebrate communities, observed for some distance below the backfeed discharge, have reduced the quality of the invertebrate (trout) food base.
- The biannual release of 100 'takeable'-sized brown trout (i.e. > 500 g) in the mid-catchment could adequately mitigate for the declining value of the Maitai River fishery
- The increased predation pressure on native fish populations, as a result of hatchery releases in the mid-catchment, could be offset by trout removal in the Maitai Reservoir and North Branch upstream (this action would support native fish passage improvement initiatives in the Maitai North Branch).

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6. APPENDICES

Appendix 1. Resource consents relevant to the operation of the Maitai Reservoir.

RM 025151 (Commissioner Decision)

IN THE MATTER of the Resource Management Act 1991

AND J104 300

IN THE MATTER of an application by **NELSON CITY COUNCIL** for various Resource Consents in respect of the Maitai Water Supply Scheme.

BACKGROUND

1. Nelson City Council (the Council) has made application for the following resource consents:

a) A *water permit* to dam and divert the North Branch of the Maitai River and a *land use consent* to place structures, namely the dam and ancillary structures, on the bed of the North Branch, pursuant to Sections 14(1)(and 13(1) of the RMA respectively.

b) A *water permit* to take surface water, being the full flow of the Maitai River, subject to maintenance of specified minimum flows at the junction of the North and South Branches (*"the forks"*) below the dam, pursuant to Section 14(1) of the RMA.

c) A *discharge permit* to discharge scour water, mixing box overflow water and compensation water from the North Branch Reservoir into the North Branch below the dam at a maximum rate of 1500 l/sec, pursuant to Section 15(1) of the RMA.

d) A *discharge permit* to discharge water from the Reservoir overflow spillways into the South Branch of the Maitai River, pursuant to Section 15(1) of the RMA.

These consents are in reality replacement consents for those which presently authorise operation of the Maitai Water Supply Scheme.

Appendix 1 continued…

2. The Maitai Water Supply Scheme consists of the Maitai dam, an intake tower in the reservoir, service tunnel, control building, a main spillway and an auxiliary spillway, a South Branch river intake, screen house, a back feed pipeline from the reservoir to the south branch, control valves, mixing box, logic controller and chlorinator. The scheme enables the abstraction of water from the North Branch reservoir, run of the river intake on the South Branch, or both.

3. The Maitai dam was constructed during the period 1984-1986 pursuant to four (4) water rights issued in 1982 under the Water & Soil Conservation Act 1967 (now repealed). I note that the four consents were each issued on the 20th July 1982 for a term of twenty (20) years and accordingly are due to expire on 20th July 2002. It is the impending termination of theseconsents which has given rise to these present applications.

4. An additional consent authorising the abstraction of water from the South Branch of the Maitai river for water supply and to discharge reservoir water back into the South Branch at the same point as compensation flow was issued under number RC960396 in 1977. That consent remains current and is due to expire on 1st February 2017. The application for the four consents subject to my consideration has been made on the basis that those four consents ought also expire on 1st February 2017 so that in future all consent renewals relating to the Maitai Water Supply Scheme can be considered together. That is obviously a very sensible proposal.

4. The application was made on behalf of the Council by Montgomery Watson Harza. The application is a comprehensive document containing detailed information as to the current operation of the Maitai Scheme and incorporating a series of appendices which contain:

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- Copies of the original water rights showing proposed amendments to their conditions.
- Copies of other consents issued to authorise establishment and variation of the scheme.
- Water demand projections for Nelson City.
- Miscellaneous flow records for the Maitai River.
- Cawthron Institute biological monitoring results.

5. The application was publicly notified by the Council and in the event four (4) submissions were received. Two submissions, from Department of Conservation and Nelson Marlborough Fish and Game opposed the application. A submission from Ngati Awa Manawhenua (Central and Southern) Trust supported the application and Ngati Awa did not seek to be heard in support of the submission. A fourth submission from Te Atiawa Manawhenua ki Te Tau Ihu Trust raised issues of kaitiakitanga and considered three specific issues arising out of that concept in relation to the Maitai proposal. Te Atiawa did not indicate that it wished to be heard in support of its submission and accordingly pursuant to Section 101(3)(b) RMA Council was not obliged to advise Te Atiawa as to the hearing date in respect of the application.

6. The report in respect of the application prepared by Mr Briggs provided information as to meetings and correspondence between the Council, DOC and Fish and Game. As a consequence of that process both DOC and Fish and Game withdrew the right to be heard in support of their submissions. They do however remain parties to the application. The withdrawal of both DOC and Fish and Game was on the basis that conditions be imposed on the application. Those draft conditions were volunteered by the Council as part of the application process and have been considered by me in detail.

7. There is one issue of particular concern arising out of the

Appendix 1 continued…

applications to which I now wish to refer. That arises out of the provisions of Section 107 RMA which provides (in summary):

"107 Restriction on Grant of Certain Discharge Permits

1. Except as provided in subsection (2) a consent authority shall not grant a discharge permit allowing –

a) The discharge of a contaminant or water into water;

if, after reasonable mixing the contaminant or water discharged (either by itself or in combination with the same, similar, or other contaminants or water), is likely to give rise to all or any of the following effects in the receiving waters:

d) Any conspicuous change in the colour or visual clarity:

2. A consent authority may grant a discharge permit or a coastal permit to do something that would otherwise contravene Section 15 that may allow any of the effects described in subsection (1) if it is satisfied –

a) "That exceptional circumstances justify the granting of the permit;

- and that it is consistent with the purpose of this Act to do so"

8. Consideration of the provisions of Section 107 is mandatory in this instance because it is apparent from the application papers that there is an impact on the colour or visual clarity of the river water arising as a result of discharge of spillway water into the South Branch. The application acknowledged that under some circumstances this discharge can result in a conspicuous change

Appendix 1 continued…

to the colour or clarity of the South Branch below the discharge point. That issue was raised at the time of hearing of consent RC960396. The Council commissioned Cawthron Institute to undertake investigation of the effects of the discharge (Stark & Hayes 1997) and that report was considered by Commissioner Fowler prior to issue of consent RC960396. At that time the Commissioner concluded that exceptional circumstances existed which enabled issue of the consent notwithstanding its effects. In considering these applications I took the view that I was obliged to readdress the issue of Section 107 and could not simply rely upon the finding of the earlier Commissioner. I accordingly requested that Council forward a copy of the Stark & Hayes report to me and I have taken the opportunity of reading that report. Having done so I accept the conclusions and recommendations of that report and in particular the final paragraph which provides:

> *"We consider that under Section 107(2)(a) of the RMA, there are exceptional circumstances to allow the granting of a consent permitting a conspicuous change to colour and clarity in the Maitai River. These include the fact that influence of reservoir water on the colour and clarity of the river downstream is a direct consequence of the decision to permit the dam to be built in the first place. Furthermore, the discharge is of natural substances, does not appear to have significant adverse consequences for freshwater life, and any slight negative impacts of reduced water clarity are more than compensated for by the increased flows provided via the backfeed"*

I accordingly determine that exceptional circumstances exist which allow the relevant water permits to be granted pursuant to the provisions of Section 107(2)(a) RMA.

9. In considering the applications I have of course taken into account the fact that the Maitai Water Supply Scheme has been in operation for some twenty (20) years and that all of the various

Appendix 1 continued…

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structures are in place. I have compared the new proposed conditions with the conditions imposed on the original consents. I note that the conditions vary in a number of respects. On examination it is apparent that some of the conditions imposed on the original consents (eg the right to cancel the consent) would be ultra vires under the Resource Management Act regime, some of the conditions were clearly applicable to the initial establishment and construction phase of the Scheme and some have been amended to reflect experience over the years in operating the Scheme. I have considered the conditions of consent proposed by the Council and I have determined that the conditions as proposed are appropriate except only (in each instance) the review condition which Council has proposed which does not appear to comply with the requirements identified by both the Environment Court and the High Court in:

NZ Rail Ltd v Marlborough District Council [1974] NZRMA70 (page 91).

The High Court confirmed the Environment Court's finding that it was not possible to have an *"open ended"* review condition whereby consent holders can in effect be subject to the daily possibility of review and that what was required was specificity of review timing.

In all other respects I am satisfied that the proposed conditions of consent are appropriate.

10. Having considered the application, the various reports filed with it and subsequently I have determined that it is appropriate to grant the consents sought upon the terms and conditions and for the reasons hereinafter set out. Additionally I have incorporated a review condition in each of consent numbers RM025151/3 and RM025151/4 where review conditions were not proposed by Council. Again, it is apparent from a consideration of the *"New Zealand Rail"* case that where any proposal contains multiple consents it is appropriate that specific review conditions are

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incorporated into each of the various consents.

DATED this 19th day of July 2002

BP Dwyer
Commissioner

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Ex-Water Right No: 82 0490

CONSENT NO: RM025151/1

Pursuant to Sections 13(1) and 14(1) of the Resource Management Act 1991, this consent is hereby **granted** by the Nelson City Council to:

NAME OF GRANTEE: Nelson City Council

ADDRESS: PO Box 645, Nelson

(1)**LOCATION:** North Branch of the Maitai River at or about NZMG 2541038-5990278

LEGAL DESCRIPTION OF LAND WHERE RIGHT IS TO BE EXERCISED:
Section 62 of Square 18, Block II, Mangatapu SD, Maitai River, CT 1A/267.

PURPOSE FOR WHICH RESOURCE CONSENT IS GRANTED:
To place, a dam and ancillary structures in the bed of the North Branch of the Maitai River and to dam and divert the full flow of the North Branch for urban water supply purposes. The maximum height of the dam above the bed of the river is to be 39 metres, being 166 metres above mean sea level.

EXPIRY DATE: This consent will expire on 01 February 2017.

SUBJECT TO THE FOLLOWING CONDITIONS:

Maintain and Supply Records

1. The consent holder shall keep such records as may reasonably be required by the consent authority and shall, if so requested by the consent authority, supply this information to the consent authority, and make available for viewing by other groups or individuals.

Access for Consent Authority

2. The consent is granted, subject to the consent authority or its servants or agents being permitted access at all reasonable times for the purposes of carrying out inspections, taking measurements and collecting samples.

Maintenance of Structures

3. The consent holder shall ensure that the structural integrity and safety of the dam and associated ancillary structures (including spillways, pipelines, inlet and outlet structures) is monitored and maintained in

Appendix 1 continued…

strict accordance with the original design and maintenance specifications.

Safety Inspections and Independent Safety Reviews

4. The consent holder shall engage the dam designers to undertake an annual inspection, and an independent engineer or firm of engineers to undertake a five yearly review, of the safety of the dam and ancillary structures. Copies of the inspection and review reports are to be forwarded to the consent authority.

Maximum Storage Level

5. The maximum retained storage level of the reservoir shall be 162 metres above mean sea level.

Eel Management

6. Subject to obtaining any necessary permit or authorization to do so, the consent holder shall in each year following the commencement of this consent carry out a relocation from the lower reaches of the Maitai River to the dam reservoir of up to 200 eels of differing sizes. Before carrying out the relocation the consent holder shall consult with the Department of Conservation and Cawthron Institute in respect of the timing, duration and method of the relocation. This condition shall not apply if the Department of Conservation advises the consent holder that it is not to apply for any particular year or years.

7. The consent holder shall pay for the scientific advice from the Cawthron Institute that the Department of Conservation may seek as part of its ongoing eel monitoring programme in the Maitai dam and tributary watercourses, for the duration of this consent.

Environmental Enhancement

8. Subject to obtaining any necessary permit or authorization to do so, the consent holder shall carry out an environmental enhancement programme along the Matia river below the dam. The programme shall be agreed upon by the consent holder and the Department of Conservation, in consultation with Fish and Game New Zealand, and shall be provided to the Divisional Manager Planning and Consents, Nelson City Council ("the Manager"). If the consent holder and the Department of Conservation are unable to agree upon the programme, the programme shall be determined by the Manager after consultation with the consent holder, the Department of Conservation and Fish and

Appendix 1 continued…

Game New Zealand. The programme shall make provision for (but need not be restricted to) the planting of native species along banks and rock protection and bank enhancement.

9. The consent holder shall expend a sum of not less than $30,000.00 over the duration of this consent (but for the avoidance of doubt is not obliged to expend any more than $30,000.00) in giving effect to the enhancement programme referred in Condition 8 above.

10. The agreed programme referred to in Condition 8 above shall be provided to the Manager within 6 months of the commencement of this consent. If the consent holder and the Department of Conservation are unable to agree, the Manager shall determine the programme within 9 months of the commencement of this consent,

11. The consent holder shall commence the programme in the year commencing 1 July 2003.

Review of Conditions

12. The consent authority may review any conditions of this resource consent by giving notice of its intention to do so pursuant to Section 128 of the Resource Management Act 1991, during the months of March and September in each year for the duration of this consent, for the purpose of ensuring that the said conditions are appropriate having regard to:

    (a) any adverse effect on the environment arising out of the exercise of this consent; or

    (b) putting into effect an annual review of the effectiveness of the eel management programme and its monitoring, including such matters as the extent of releases, and the enhancement of the eel populations; or

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(c) carrying out a review of the riparian enhancement programme and the success of the planting such review to be carried out in conjunction with both DOC and Fish and Game New Zealand.

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Ex-Water Right No 820 540

CONSENT NO: RM025151/2

Pursuant to Section 14(1) of the Resource Management Act 1991, this consent is hereby **granted** by the Nelson City Council to:

NAME OF GRANTEE: Nelson City Council

ADDRESS: PO Box 645, Nelson

LOCATION: North Branch of the Maitai River at or about NZMG 2541086-5990216

LEGAL DESCRIPTION OF LAND WHERE RIGHT IS TO BE EXERCISED:
Pt Section 49 of Square 18, Block II, Mangatapu SD, Maitai River, CT 69/207.

PURPOSE FOR WHICH RESOURCE CONSENT IS GRANTED:
To take up to the full flow of the North Branch of the Maitai River for both storage in the North Branch Reservoir and for direct supply for urban use.

EXPIRY DATE: This consent will expire on 01 February 2017.

SUBJECT TO THE FOLLOWING CONDITIONS:

Maintenance of Monitoring Equipment and Records

1 The consent holder shall maintain suitably calibrated equipment and sufficient records to monitor compliance with the permit conditions. An annual summary report assessing compliance with consent conditions shall be provided to the consent authority. Copies of the records and summary reports shall be made available for viewing by any other interested party on request.

Access for Council Staff and Agents

2 The consent authority, its staff or agents, shall be permitted access at all reasonable times for the purpose of carrying out inspections, taking measurements and collecting samples.

Review of Conditions

3 The consent authority may review any of the conditions of this resource consent by giving notice of its intention to do so pursuant to Section 128 of the Resource Management Act 1991, during the months of March and September in each year for the duration of this consent for the purpose of ensuring that the said conditions are appropriate having regard to:

- Any adverse effect on the environment arising from the exercise of this consent; or

Appendix 1 continued…

- Any new information or results of monitoring which suggest an adverse effect on the environment has occurred or is likely to occur;

Minimum Flow Requirements

4. The following minimum flows shall be maintained in the river immediately below the forks:-

4.1 From 1 May to 31 October [Winter]

The flow in the South Branch shall be measured at the existing water level recording station and:

4.1.1 when the South Branch **instantaneous** flow exceeds 140 ℓ/sec, the minimum **instantaneous** flow at the forks shall be 300 ℓ/sec;

4.1.2 when the South Branch **instantaneous** flow is less than or equal to 140 ℓ/sec, the minimum **instantaneous** flow at the forks shall be 225 ℓ/sec. This minimum flow shall remain effective until the South Branch flow exceeds 140 ℓ/sec **and** the water level in the Maitai Reservoir exceeds the level shown in Figure 1 attached.

4.1.3 When the South Branch **instantaneous** flow is less than or equal to 130 ℓ/sec, the minimum **instantaneous** flow at the forks shall be 190 ℓ/sec. This minimum flow shall only remain effective until the South Branch flow exceeds 130 ℓ/sec.

4.2 From 1 November to 30 April [Summer]
175 litres per second

Determination of South Branch Instantaneous Flow and Backfeed Adjustment

5. South Branch instantaneous flow determinations [see condition 4.1] shall be undertaken daily at 9am or thereabouts. Back flows from the Reservoir to the South Branch is to be adjusted at the same time, to ensure that the minimum flow regimes stipulated in Condition 4 of this consent are met and that Condition 6 of RC 960396 is met in full. Adjustments to the backflow may be made during the day subject to continued compliance with the minimum flow requirements.

Installation and Maintenance of Flow Recorders

6. The consent holder shall be responsible for the installation and maintenance of structures and equipment required to measure and record both the rates of withdrawal direct to the City supply and the rates of discharge to the river other than discharges from the spillway and the release of scour water. The recorded information shall be made available to the consent authority.

Appendix 1 continued…

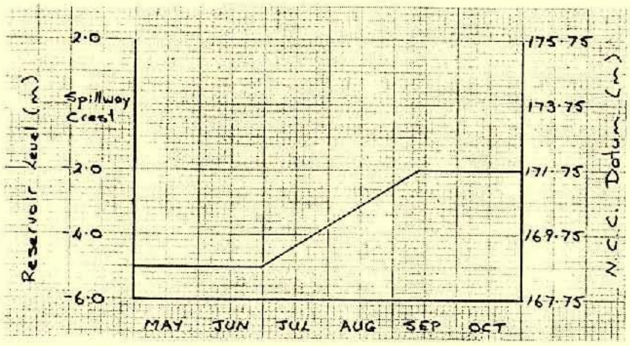
Release of Surplus Water during Summer

7. The consent holder shall ensure that, over the period 01 January – 30 May, surplus water [as identified by the label B on the attached graph] is released at a steady rate from the reservoir, whenever the flow at the forks drops below 300 ℓ/sec and the lake level is above the acceptable draw down line.

Winter Conservation Measures

8. During any period that the minimum river flow is reduced in accordance with Clause 4.1.2(1) and 4.1.3(2), the consent holder shall apply hosing restrictions and generate publicity to encourage water conservation in accordance with the NCC Water Conservation Strategy.

Figure 1



Appendix 1 continued…

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Ex-Water Right No: 820510

CONSENT NO: RM025151/3

Pursuant to Section 15(1) of the Resource Management Act 1991, this consent is hereby **granted** by the Nelson City Council to:

NAME OF GRANTEE: Nelson City Council

ADDRESS: PO Box 645, Nelson

POINT OF DISCHARGE: North Branch of the Maitai River, below the dam, at or about NZMG 2540997-5990368

LEGAL DESCRIPTION OF LAND WHERE RIGHT IS TO BE EXERCISED: Section 60 of Square 18, Block II, Mangatapu SD, Maitai River, CT 1A/267.

PURPOSE FOR WHICH RESOURCE CONSENT IS GRANTED: Discharge of scour water, compensation water or mixing box overflow water at a maximum rate of 1500 litres per second from the North Branch reservoir.

EXPIRY DATE: This consent will expire on 01 February 2017.

SUBJECT TO THE FOLLOWING CONDITIONS:

Access for Council Staff or Agents

1. The consent authority, its staff or agents shall be permitted access at all reasonable times for the purpose of carrying out inspections, taking measurements, and collecting samples.

Notification of Scouring Events

2. The consent holder shall notify the consent authority prior to the release of any scour water, and the consent authority shall determine the minimum downstream river flow at which the release may occur and the maximum duration. Other than in emergencies, the discharge of scour water shall only occur when the river is in fresh and naturally discoloured, and at times when there will be no detrimental effect on fish spawning processes.

Responsibility for Cost of Remedial Works

3. If, in the opinion of the consent authority, the discharge causes unacceptable erosion or deposition in the river channel, the consent holder shall be responsible for the cost of remedial works.

5. All compensation water discharged under this consent shall be taken from the supply pipeline.

Appendix 1 continued…

6. If requested by the consent authority, the consent holder shall be responsible for the installation of a measuring device to clearly show the rate of compensation discharge below the dam.

Review of Conditions

7. The consent authority may review any conditions of this resource consent by giving notice of its intention to do so pursuant to Section 128 of the Resource Management Act 1991, during the months of March and September in each year for the duration of this consent, for the purpose of ensuring that the said conditions are appropriate having regard to any adverse effect on the environment arising out of the exercise of this consent.

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Ex-Water Right No: 82 0500

CONSENT NO: RM025151/4

Pursuant to Section 15(1) of the Resource Management Act 1991, this consent is hereby **granted** to the Nelson City Council to:

NAME OF GRANTEE: Nelson City Council

ADDRESS: PO Box 645, Nelson

POINT OF DISCHARGE: South Branch of the Maitai River, at or about NZMG 2540830-5990314

LEGAL DESCRIPTION OF LAND WHERE RIGHT IS TO BE EXERCISED:
Section 62 of Square 18, Block II, Mangatapu SD, Maitai River, CT 1A/267.

PURPOSE FOR WHICH RESOURCE CONSENT IS GRANTED:
Discharge of water into the South Branch of the Maitai River via the overflow spillways from the North Branch reservoir.

EXPIRY DATE: This consent will expire on 01 February 2017.

SUBJECT TO THE FOLLOWING CONDITIONS:

Access for Council Staff or Agents

1. The consent authority, its staff or agents shall be permitted access at all reasonable times for the purpose of carrying out inspections, taking measurements, and collecting samples.

2. If, in the opinion of the consent authority, the discharge causes unacceptable erosion or deposition in the river channel, the consent holder shall be responsible for the cost of remedial works.

Review of Conditions

3. The consent authority may review any conditions of this resource consent by giving notice of its intention to do so pursuant to Section 128 of the Resource Management Act 1991, during the months of March and September in each year for the duration of this consent, for the purpose of ensuring that the said conditions are appropriate having regard to any adverse effect on the environment arising out of the exercise of this consent.

Appendix 1 continued…

REASONS FOR DECISION AND CONDITIONS

Reasons for Decision

1. The existing operation of the dam, its water takes and discharges has been efficient and effective over the lifetime of the existing consents, without significant adverse effects on the quality of the water and the natural ecosystems of the Maitai river and its tributaries.

2. The conditions imposed on the existing consents were created for the initial operation of the dam and its processes. Some of these are no longer appropriate, and can readily be modified to meet changing circumstances.

3. The monitoring programmes that have been carried out for water quality, water flows and for impacts on the ecosystems have indicated that adverse effects have been minimal. Several conditions have been modified to take these results into account.

4. An opportunity has been provided for reviewing the monitoring programmes. A review clause included will enable a flexible approach to be taken with respect to establishing the effectiveness of the programme and the extent and nature of the monitoring.

5. Nevertheless, there have been some concerns expressed by both DOC and Fish and Game NZ that the effects of the dam on water quality and the habitats is more than minor, and efforts should be made to enhance the fish density in the upper reaches. There are potential adverse effects from the modification of the natural stream regime and water flows that resulted from the construction and operation of the dam and its associated structures.

6. It is considered appropriate to support some additional riparian enhancement initiatives, over and above what are already being (and are to be) implemented by the Council in the medium to long term future. This is to be given effect to by a riparian margin enhancement

Appendix 1 continued…

programme, which will be undertaken as agreed by the parties. This will include measures such as native specie planting, bank and rock wall replacement and enhancement.

7. The fund proposed for this purpose should be expended in the most cost effective manner as part of an enhancement programme mutually agreed by both the Department and the consent holder, with additional input from the Fish and Game Council and the Council's Parks and Community Assets Department.

8. Nevertheless, the presence of the dam and its associated structures has created a manmade restriction for easy passage for the native fish species, including eels, which will be enhanced by the regular transportation of the eels through this management programme.

9. The objective is to improve the eel density and habitats in the Maitai river, and to enhance the eel populations. Such a programme will provide an opportunity to study the effectiveness of such a management technique, with scientific benefits to the Department.

10. Similarly, concerns were expressed by iwi that more acknowledgement needs to be made of the mauri of the river, and of the kaitianga of the manuwhenua of the iwi of Whakatu. This decision and the conditions imposed recognise the important role of iwi in the kaitiakitanga of the Maitai, and acknowledge the positive contribution that iwi has made to its management. Council wishes to maintain and extend the partnership inherent in the principle of kaitiakitanga in the development of the fisheries and riparian enhancement programmes, with iwi through the mechanism of the Iwi Resource Management Advisory Komiti.

planning02.nelson city maitairiverscheme.bpd.amp
17th July 2002

Appendix 1 continued…

27 March 1997

Nelson City Council
PO Box 645
NELSON

Dear Sir/Madam

Notice of Decision - Resource Consent Application : 960396
Section 88 of the Resource Management Act 1991

Applicant:	Nelson City Council
Site:	Maitai River Maitai Dam
Discretionary Activity:	Water Permit
Discretionary Activity:	Discharge Permit

Your application for resource consent for:

1. a water permit to allow for the abstraction of water at a rate of up to 300 litres/sec (25920m3/day, 1080m3/hr) from the Maitai South Branch; and
2. a discharge permit to allow for the discharge of water from the North Branch dam at a maximum rate of400 litres/sec into the Maitai South Branch; was considered by Commissioner Fowler at a hearing on 13 March 1997.

Consent was granted by Commissioner Fowler on 24 March 1997 and his decision and the conditions of consent are attached.

Your status as applicant for this resource consent provides you with certain rights with regard to the Council's decision.

For your general guidance, Sections 120, 127 and 357 of the Resource Management Act 1991 provide rights with respect to:

1) Objection to certain decisions and requirements of consent authorities. (Section 357) If your consent was not publicly notified, or was notified and no submissions were received or any submissions received were withdrawn, you have the right to object to all or part of this decision. An objection must be lodged with the Council within 1 5 working days of your receipt (or receipt by the person who filed the application on your behalf) of the Council's formal decision. Reconsideration of the decision will require further assessment of costs incurred in accordance with Council processing charges.

6. Also in attendance were Mr. Armstrong (a consultant retained by the Council in its regulatory capacity and the author of the Officers' Report) and Mr. Ballagh (Resource Consent Officer for the Council in its regulatory capacity).

7. One submitter, Mr. Jack Brown, appeared and also tabled written evidence.

8. The hearing first addressed the draft suggested conditions in respect of remaining differences between the applicant and Mr. Armstrong's recommendations. Those differences were resolved or rendered negligible.

9 The hearing then turned to address Mr Brown's concerns. He gave broad ranging evidence based on a lifetime of angling experience. His thesis was the decline of the Maitai as an angling resource for trout fishermen over some 50 or 60 years and in the context of an overall decline of the angling resource in the rivers of the region.

10. The applicant responded to that through, initially, Mr. Beckett who emphasised that Mr. Brown's observations were largely anecdotal and that even he, Mr. Brown, had acknowledged that 'people have got to live before they can fish for trout'. Then Mr. Stark observed that a comparison of surveys from electric fishing in 1952, 1982 and 1983, and then more recently since 1989 show no significant change and therefore since the abstracting commenced in 1963, he tended to the view that the decline in the angling resource (which he acknowledged) was unlikely to be linked to the water abstraction.

11 Mr. Dougherty explained some aspects of the flushing regime and, in particular, the consequences of the way the cone discharge valve worked which in those conditions seems only to trigger further complaints about the presence of a dirty slug in the flow. He also observed that when the minimum flow levels were fixed it was in an attempt to mimic the natural flow pattern of the south branch.

12. Mr. Armstrong then observed that he had some sympathy for what Mr. Brown was saying and indicated that he was riot surprised to hear anecdotal evidence of the decline of some river fisheries. He considered, however, that that was attributable to a combination of factors. He expressed some caution about accepting the conclusions drawn from the electric fishing results and acknowledged that there could certainly be a link between abstraction from a river and an angling resource decline. However, he stressed that there is a subtle mix of factors in the nationwide decline in the angling resource and that it would be difficult to identify a specific minimum flow regime that would provide a consequential improvement hi the Maitai fishery.

The applicable planning law

13. The statutory position can be dealt with quite shortly. Sections 104, 107 and 108 of the Resource Management Act 1991 apply to the consideration of these resource consents. The gauntlet of criteria that that creates is well known.

14. Perhaps the more acute legal planning issues arise under s107. The framework of subsection (1) proscribes certain discharges if their effects display the characteristics set out in that subsection 'after reasonable mixing'. Then subsection (2) goes on to provide a further exit from the prohibition where there are 'exceptional circumstances'.

15. As for the planning instruments arid regimes to be taken into account under the above provisions of the Act on this application, there are a number of general statements in the Regional Policy Statement that have some relevance. The proposed Nelson Resource Management Plan notified on 25 October 1996 does not deal with water management issues, the intention being to deal with these specifically by way of separate plans at some future date.

Reasoning

16. The critical issues on the evidence relate to the existing turbidity levels of the south branch discharge and their effect on the fisheries' habitat values, the altered flow regime of the Maitai River and whether it is adversely affecting the downstream fishery, whether the south branch discharge alters the downstream temperature regime in a way that adversely affects that fishery and whether the discharge gives rise to a 'conspicuous' change in the colour or visual clarity of the river.

17. It seems plain on the evidence that the most significant effect of the discharge is the visual one - ie. when the reservoir backfeed water goes into the south branch of the

Maitai. Undoubtedly this results in a ‘conspicuous’ change within the meaning of S1O7(1).

18. However, given that that visual change attenuates downstream quite rapidly and given that this discharge is from an existing facility that is not an issue in this application and is necessary to ensure the effective operation of the water supply scheme, it would seem that there are exceptional circumstances within the meaning of S107(2). However, even if that were not so, on the basis of the conventional approach to ‘reasonable mixing’, this Commissioner is by no means persuaded that the application would have been caught by s107(l) proscriptions in any event

19. Whatever the correct position on whether and to what extent the abstraction for water supply has had a direct impact on the trout fishery, one thing is for certain and that is that the relationship between the depletion/recovery of that resource and a change in abstraction regimes is a complex one and there are many other factors that bear and would bear on that depletion/recovery that likewise lie outside this application.

Decision

20. On the basis of the above conclusions, the application of the statutory principles compels the grant of the resource consents listed in paragraph I above, but subject to the conditions set out in the annexure.

21. The expiry date is to be 1 February 2017.

DATED this day of March 1997

R J B Fowler
Hearings Commissioner

Annexure: Conditions for resource consent no. 960396

1 Records to be kept

1.1 The applicant shall maintain suitably calibrated equipment and sufficient records to monitor compliance with the permit conditions. An annual summary report assessing compliance with consent conditions shall be provided to the Director of Resource Management. Copies of the records and summary reports shall be provided to any other interested party on request.

2 Access for Council staff and agents

2.1 The Director of Resource Management, his staff and agents, shall be permitted access at all reasonable times for the purpose of carrying out inspections measurements and the taking of samples.

3 Review of conditions

3.1 The consent authority may review any of the conditions of this resource Consent by giving notice of its intention to do so pursuant to s128 of the Resource Management Act, for the purpose of ensuring that the said conditions are appropriate having regard to:

a) any adverse effect on the environment arising from the exercise of this consent; or
b) any new information or results of monitoring which suggest an adverse effect on the environment is likely to occur; or
c) the need to achieve a coordinated approach with the renewal of other consents relating to the operation of the Maitai Water Supply Scheme and its effects on the environment.

3.2 The review under condition 3.1 may be initiated annually at any time within the period 1 June to I September for the duration of this consent

4 Fish passage

Any structures used for the purposes of this permit shall be operated and maintained or modified if necessary in such a manner that will facilitate the passage of fish.

5 Ecological monitoring

5.1 Monitoring of the effects of the abstraction and discharge on the ecology of the south branch of the Maitai River shall be carried out at the site identified as site B in the Cawthron Institute Report of 12 January 1990 on an annual basis. The monitoring programme shall be approved by the Director of Resource Management.

5.2 An annual report summarising the monitoring results shall be provided to the Director of Resource Management. Copies of the report shall be provided to any other interested parties on request.

6 Abstraction condition

6.1 Water shall be released from the reservoir into the south branch immediately downstream of the intake weir at the same time as water is being abstracted pursuant to this consent and at a rate not less than the abstraction rate.

7 Discharge conditions

7.1 All discharges from the north branch reservoir shall be carried out in such a manner that the water in the south branch measured at the same site identified in condition 5 meet the criteria as shown in conditions 8 to 12 below.

8 Water temperature

a) When the water temperature prevailing immediately above the intake is between 8° C and 18° C inclusive, the discharge shall not change the temperature of the river water by more than 3° C.
b) When the water temperature prevailing immediately above the intake is greater than 18° C, the discharge shall not reduce the temperature of the river water below 15° C.
c) When the water temperature prevailing immediately above the intake is less than 8° C, the discharge shall not increase the temperature of the river water above 11° C.
d) When conditions (b) or (c) are in force, the discharge shall only be turned on or off at a progressively even rate over a minimum period of 2 hours.

960396
Don Ballagh
MAITAI RIVER SOUTH BRANCH
MONITORING PROGRAMME

1 INTRODUCTION

1.1 Condition 5, 'Ecological Monitoring' of Resource Consent No 960396, directs the consent holder to monitor the effects on the South Branch, of water abstraction and discharge. The condition further requires that the monitoring programme be approved by the Director Resource Management.

1.2 Monitoring has been carried out by Cawthron on a six monthly basis to examine the effects, if any, on the South Branch arising from the take and discharge of Water. An extensive data base of biological community data now exists which indicates to date, abstraction and discharge activities within the South Branch have had no noticeable adverse effects on macro invertebrate and fish communities

1.3 It is proposed that the six monthly monitoring programme be continued in accordance with the specifications and original objectives outlined in. Cawthron's report, dated 12 January 1990.

2 MONITORING PROGRAMME

The consent holder will, on two occasions each year (May and November)3 undertake the following monitoring programme at Site B identified in the Cawthron Institute report of l2 January 1990.

2.1 Physio-chemical sampling

- measurements of water temperature, dissolved oxygen, pH and conductivity will be recorded.

2.2 Biological sampling

- macro invertebrate samples will be collected and all animals identified and counted. The samples will be assessed for species richness, density, community composition and macro invertebrate community index

- fish communities will be assessed utilising an appropriate electric fishing technique

2.3 The data collected will be assessed by Cawthron who will report to Council on the biological effects of water abstraction and discharge on the South Branch of the Maitai River.

Appendix 2. Analysis report for water samples from the Maitai South Branch and Maitai Dam 28 May 2015.

Hill Laboratories
BETTER TESTING BETTER RESULTS

R J Hill Laboratories Limited
1 Clyde Street
Private Bag 3205
Hamilton 3240, New Zealand

Tel +64 7 858 2000
Fax +64 7 858 2001
Email mail@hill-labs.co.nz
Web www.hill-labs.co.nz

ANALYSIS REPORT

SPv1

Client:	Fulton Hogan Nelson	**Lab No:**	1432787
Contact:	Andrew Maxwell	**Date Registered:**	29-May-2015
	C/- Fulton Hogan Nelson	**Date Reported:**	16-Jun-2015
	Private Bag 1	**Quote No:**	55261
	NELSON 7040	**Order No:**	
		Client Reference:	
		Submitted By:	Andrew Maxwell

Sample Type: Aqueous

Sample Name:		NWTP Clearwater 28-May-2015 9:55 am	Maitai South Branch 28-May-2015 10:45 am	Maitai Dam 28-May-2015 11:05 am	Roding Dam 28-May-2015 8:00 am	
Lab Number:		1432787.1	1432787.2	1432787.3	1432787.4	
Individual Tests						
Total Alkalinity	g/m³ as $CaCO_3$	79	81	62	84	-
Total Hardness	g/m³ as $CaCO_3$	86	83	66	90	-
Dissolved Calcium	g/m³	17.2	12.1	19.1	19.8	-
Dissolved Magnesium	g/m³	10.5	12.9	4.4	9.7	-
Total Cyanide	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	-
Fluoride	g/m³	< 0.05	< 0.05	< 0.05	0.06	-
Total Ammoniacal-N	g/m³	-	< 0.010	0.012	< 0.010	-
Nitrite-N	g/m³	< 0.002	< 0.002	< 0.002	< 0.002	-
Nitrate-N	g/m³	0.050	0.045	0.038	0.056	-
Nitrate-N + Nitrite-N	g/m³	0.050	0.045	0.040	0.056	-
Dissolved Reactive Phosphorus	g/m³	-	< 0.004	< 0.004	0.004	-
OrganoNitrogen & Phosphorus pesticides, trace, liq/liq GCMS						
Acetochlor	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Alachlor	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Atrazine	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Atrazine-desethyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Atrazine-desisopropyl	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Azaconazole	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Azinphos-methyl	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Benalaxyl	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Bitertanol	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Bromacil	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Bromopropylate	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Butachlor	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Captan	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Carbaryl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Carbofenothion	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Carbofuran	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Chlorfluazuron	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Chlorothalonil	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Chlorpyrifos	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Chlorpyrifos-methyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Chlortoluron	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Cyanazine	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Cyfluthrin	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Cyhalothrin	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-

Sample Type: Aqueous						
Sample Name:		NWTP Clearwater 28-May-2015 9:55 am	Maitai South Branch 28-May-2015 10:45 am	Maitai Dam 28-May-2015 11:05 am	Roding Dam 28-May-2015 8:00 am	
Lab Number:		1432787.1	1432787.2	1432787.3	1432787.4	
OrganoNitrogen & Phosphorus pesticides, trace, liq/liq GCMS						
Cypermethrin	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Deltamethrin (including Tralomethrin)	g/m³	-	< 0.00006	< 0.00006	< 0.00006	-
Diazinon	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Dichlofluanid	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Dichloran	g/m³	-	< 0.0002	< 0.0002	< 0.0002	-
Dichlorvos	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Difenoconazole	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Dimethoate	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Diphenylamine	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Diuron	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Fenpropimorph	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Fluazifop-butyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Fluometuron	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Flusilazole	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Fluvalinate	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Furalaxyl	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Haloxyfop-methyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Hexaconazole	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Hexazinone	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
IPBC (3-Iodo-2-propynyl-n-butylcarbamate)	g/m³	-	< 0.0002	< 0.0002	< 0.0002	-
Kresoxim-methyl	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Linuron	g/m³	-	< 0.00005	< 0.00005	< 0.00005	-
Malathion	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Metalaxyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Metolachlor	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Metribuzin	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Molinate	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Myclobutanil	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Naled	g/m³	-	< 0.0002	< 0.0002	< 0.0002	-
Norflurazon	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-
Oxadiazon	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Oxyfluorfen	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Paclobutrazol	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Parathion-ethyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Parathion-methyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Pendimethalin	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Permethrin	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Pirimicarb	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Pirimiphos-methyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Prochloraz	g/m³	-	< 0.0002	< 0.0002	< 0.0002	-
Procymidone	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Prometryn	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Propachlor	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Propanil	g/m³	-	< 0.0002	< 0.0002	< 0.0002	-
Propazine	g/m³	-	< 0.00002	< 0.00002	< 0.00002	-
Propiconazole	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Pyriproxyfen	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Quizalofop-ethyl	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Simazine	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Simetryn	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Sulfentrazone	g/m³	-	< 0.0002	< 0.0002	< 0.0002	-
TCMTB [2-(thiocyanomethylthio) benzothiazole,Busan]	g/m³	-	< 0.00008	< 0.00008	< 0.00008	-

Sample Type: Aqueous						
Sample Name:		NWTP Clearwater 28-May-2015 9:55 am	Maitai South Branch 28-May-2015 10:45 am	Maitai Dam 28-May-2015 11:05 am	Roding Dam 28-May-2015 8:00 am	
Lab Number:		1432787.1	1432787.2	1432787.3	1432787.4	
OrganoNitrogen & Phosphorus pesticides, trace, liq/liq GCMS						
Tebuconazole	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Terbacil	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Terbufos	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Terbumeton	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Terbuthylazine	g/m^3	-	< 0.00002	< 0.00002	< 0.00002	-
Terbuthylazine-desethyl	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Terbutryn	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Thiabendazole	g/m^3	-	< 0.0002	< 0.0002	< 0.0002	-
Thiobencarb	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Tolylfluanid	g/m^3	-	< 0.00002	< 0.00002	< 0.00002	-
Triazophos	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Trifluralin	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Vinclozolin	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Drinking water metals suite, totals, trace						
Total Aluminium	g/m^3	< 0.0032	0.0057	0.063	0.052	-
Total Antimony	g/m^3	< 0.00021	< 0.00021	< 0.00021	< 0.00021	-
Total Arsenic	g/m^3	< 0.0011	< 0.0011	< 0.0011	< 0.0011	-
Total Barium	g/m^3	0.0041	0.0033	0.0052	0.0052	-
Total Beryllium	g/m^3	< 0.00011	< 0.00011	< 0.00011	< 0.00011	-
Total Boron	g/m^3	0.028	0.0120	0.0139	0.036	-
Total Cadmium	g/m^3	< 0.000053	< 0.000053	< 0.000053	< 0.000053	-
Total Calcium	g/m^3	16.7	11.9	18.6	19.5	-
Total Chromium	g/m^3	0.00093	0.00094	0.00178	0.00178	-
Total Copper	g/m^3	< 0.00053	< 0.00053	< 0.00053	< 0.00053	-
Total Iron	g/m^3	< 0.021	< 0.021	0.133	0.103	-
Total Lead	g/m^3	< 0.00011	< 0.00011	< 0.00011	< 0.00011	-
Total Lithium	g/m^3	0.0057	0.00101	0.00034	0.0085	-
Total Magnesium	g/m^3	9.9	12.3	4.2	9.5	-
Total Manganese	g/m^3	0.0030	< 0.00053	0.028	0.0040	-
Total Mercury	g/m^3	< 0.00008	< 0.00008	< 0.00008	< 0.00008	-
Total Molybdenum	g/m^3	< 0.00021	< 0.00021	< 0.00021	< 0.00021	-
Total Nickel	g/m^3	0.0024	0.0038	0.0052	0.0044	-
Total Potassium	g/m^3	0.31	0.21	0.34	0.36	-
Total Selenium	g/m^3	< 0.0011	< 0.0011	< 0.0011	< 0.0011	-
Total Silver	g/m^3	< 0.00011	< 0.00011	< 0.00011	< 0.00011	-
Total Sodium	g/m^3	6.4	3.4	3.2	6.7	-
Total Tin	g/m^3	< 0.00053	< 0.00053	< 0.00053	< 0.00053	-
Total Uranium	g/m^3	< 0.000021	< 0.000021	< 0.000021	< 0.000021	-
Total Zinc	g/m^3	< 0.0011	< 0.0011	0.0031	< 0.0011	-
Acid Herbicides Trace in Water by LCMSMS						
Acifluorfen	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Bentazone	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Bromoxynil	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Clopyralid	g/m^3	-	< 0.00006	< 0.00006	< 0.00006	-
2,4-Dichlorophenoxyacetic acid (24D)	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
2,4-Dichlorophenoxybutyric acid (24DB)	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Dicamba	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Dichlorprop	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Fluazifop	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Fluroxypyr	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
Haloxyfop	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
2-methyl-4-chlorophenoxyacetic acid (MCPA)	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-

Sample Type: Aqueous						
Sample Name:		NWTP Clearwater 28-May-2015 9:55 am	Maitai South Branch 28-May-2015 10:45 am	Maitai Dam 28-May-2015 11:05 am	Roding Dam 28-May-2015 8:00 am	
Lab Number:		1432787.1	1432787.2	1432787.3	1432787.4	
Acid Herbicides Trace in Water by LCMSMS						
2-methyl-4-chlorophenoxybutanoic acid (MCPB)	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Mecoprop	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Oryzalin	g/m³	-	< 0.00006	< 0.00006	< 0.00006	-
2,3,4,6-Tetrachlorophenol (TCP)	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
2,4,5-trichlorophenoxypropionic acid (245TP,Fenoprop, Silvex)	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
2,4,5-Trichlorophenoxyacetic acid (245T)	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Pentachlorophenol (PCP)	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Picloram	g/m³	-	< 0.00006	< 0.00006	< 0.00006	-
Quizalofop	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Triclopyr	g/m³	-	< 0.00004	< 0.00004	< 0.00004	-
Haloethers Trace in SVOC Water Samples by GC-MS						
Bis(2-chloroethoxy) methane	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Bis(2-chloroethyl)ether	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Bis(2-chloroisopropyl)ether	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
4-Bromophenyl phenyl ether	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
4-Chlorophenyl phenyl ether	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Nitrogen containing compounds Trace in SVOC Water Samples, GC-MS						
3,3'-Dichlorobenzidine	g/m³	-	< 0.003	< 0.003	< 0.003	-
2,4-Dinitrotoluene	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
2,6-Dinitrotoluene	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Nitrobenzene	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
N-Nitrosodi-n-propylamine	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
N-Nitrosodiphenylamine	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Organochlorine Pesticides Trace in SVOC Water Samples by GC-MS						
Aldrin	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
alpha-BHC	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
beta-BHC	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
delta-BHC	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
gamma-BHC (Lindane)	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
4,4'-DDD	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
4,4'-DDE	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
4,4'-DDT	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Dieldrin	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Endosulfan I	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Endosulfan II	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Endosulfan sulfate	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Endrin	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Endrin ketone	g/m³	-	< 0.0010	< 0.0010	< 0.0010	-
Heptachlor	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Heptachlor epoxide	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Hexachlorobenzene	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Polycyclic Aromatic Hydrocarbons Trace in SVOC Water Samples						
Acenaphthene	g/m³	-	< 0.0003	< 0.0003	< 0.0003	-
Acenaphthylene	g/m³	-	< 0.0003	< 0.0003	< 0.0003	-
Anthracene	g/m³	-	< 0.0003	< 0.0003	< 0.0003	-
Benzo[a]anthracene	g/m³	-	< 0.0003	< 0.0003	< 0.0003	-
Benzo[a]pyrene (BAP)	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Benzo[b]fluoranthene + Benzo[j] fluoranthene	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Benzo[g,h,i]perylene	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
Benzo[k]fluoranthene	g/m³	-	< 0.0005	< 0.0005	< 0.0005	-
2-Chloronaphthalene	g/m³	-	< 0.0003	< 0.0003	< 0.0003	-

Sample Type: Aqueous						
Sample Name:		NWTP Clearwater 28-May-2015 9:55 am	Maitai South Branch 28-May-2015 10:45 am	Maitai Dam 28-May-2015 11:05 am	Roding Dam 28-May-2015 8:00 am	
Lab Number:		1432787.1	1432787.2	1432787.3	1432787.4	
Polycyclic Aromatic Hydrocarbons Trace in SVOC Water Samples						
Chrysene	g/m^3	-	< 0.0003	< 0.0003	< 0.0003	-
Dibenzo[a,h]anthracene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Fluoranthene	g/m^3	-	< 0.0003	< 0.0003	< 0.0003	-
Fluorene	g/m^3	-	< 0.0003	< 0.0003	< 0.0003	-
Indeno(1,2,3-c,d)pyrene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
2-Methylnaphthalene	g/m^3	-	< 0.0003	< 0.0003	< 0.0003	-
Naphthalene	g/m^3	-	< 0.0003	< 0.0003	< 0.0003	-
Phenanthrene	g/m^3	-	< 0.0003	< 0.0003	< 0.0003	-
Pyrene	g/m^3	-	< 0.0003	< 0.0003	< 0.0003	-
Phenols Trace (drinkingwater) in SVOC Water Samples by GC-MS						
2-Chlorophenol	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
2,4-Dichlorophenol	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
2,4,6-Trichlorophenol	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Phenols Trace (non-drinkingwater) in SVOC Water Samples by GC-MS						
4-Chloro-3-methylphenol	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
2,4-Dimethylphenol	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
3 & 4-Methylphenol (m- + p-cresol)	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
2-Methylphenol (o-Cresol)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
2-Nitrophenol	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Pentachlorophenol (PCP)	g/m^3	-	< 0.010	< 0.010	< 0.010	-
Phenol	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
2,4,5-Trichlorophenol	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Plasticisers Trace (non-drinkingwater) in SVOC Water by GCMS						
Butylbenzylphthalate	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Diethylphthalate	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Dimethylphthalate	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Di-n-butylphthalate	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Di-n-octylphthalate	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Plasticisers Trace (drinkingwater) in SVOC Water Samples by GCMS						
Bis(2-ethylhexyl)phthalate	g/m^3	-	< 0.003	< 0.003	< 0.003	-
Di(2-ethylhexyl)adipate	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Other Halogenated compounds Trace (drinkingwater) in SVOC Water						
1,2-Dichlorobenzene	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
1,3-Dichlorobenzene	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
1,4-Dichlorobenzene	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Other Halogenated compounds Trace (non-drinkingwater) in SVOC						
Hexachlorobutadiene	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Hexachloroethane	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
1,2,4-Trichlorobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Other SVOC Trace in SVOC Water Samples by GC-MS						
Benzyl alcohol	g/m^3	-	< 0.005	< 0.005	< 0.005	-
Carbazole	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Dibenzofuran	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Isophorone	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Tributyl Tin Trace in Water samples by GCMS						
Dibutyltin (as Sn)	g/m^3	-	< 0.00006	< 0.00006	< 0.00006	-
Tributyltin (as Sn)	g/m^3	-	< 0.00005	< 0.00005	< 0.00005	-
Triphenyltin (as Sn)	g/m^3	-	< 0.00004	< 0.00004	< 0.00004	-
BTEX in VOC Water by Purge&Trap GC-MS						
Benzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Toluene	g/m^3	-	< 0.0010	< 0.0010	< 0.0010	-
Ethylbenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-

Sample Type: Aqueous						
Sample Name:		NWTP Clearwater 28-May-2015 9:55 am	Maitai South Branch 28-May-2015 10:45 am	Maitai Dam 28-May-2015 11:05 am	Roding Dam 28-May-2015 8:00 am	
Lab Number:		1432787.1	1432787.2	1432787.3	1432787.4	
BTEX in VOC Water by Purge&Trap GC-MS						
m&p-Xylene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
o-Xylene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Halogenated Aliphatics in VOC Water by Purge&Trap GC-MS						
Bromomethane (Methyl Bromide)	g/m^3	-	< 0.002	< 0.002	< 0.002	-
Carbon tetrachloride	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Chloroethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Chloromethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,2-Dibromo-3-chloropropane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,2-Dibromoethane (ethylene dibromide, EDB)	g/m^3	-	< 0.0004	< 0.0004	< 0.0004	-
Dibromomethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Dichlorodifluoromethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1-Dichloroethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,2-Dichloroethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1-Dichloroethene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
cis-1,2-Dichloroethene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
trans-1,2-Dichloroethene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Dichloromethane (methylene chloride)	g/m^3	-	< 0.010	< 0.010	< 0.010	-
1,2-Dichloropropane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,3-Dichloropropane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1-Dichloropropene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
cis-1,3-Dichloropropene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
trans-1,3-Dichloropropene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Hexachlorobutadiene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1,1,2-Tetrachloroethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1,2,2-Tetrachloroethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Tetrachloroethene (tetrachloroethylene)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1,1-Trichloroethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1,2-Trichloroethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Trichloroethene (trichloroethylene)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Trichlorofluoromethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,2,3-Trichloropropane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,1,2-Trichlorotrifluoroethane (Freon 113)	g/m^3	-	< 0.004	< 0.004	< 0.004	-
Vinyl chloride	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Halogenated Aromatics in VOC Water by Purge&Trap GC-MS						
Bromobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Chlorobenzene (monochlorobenzene)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
2-Chlorotoluene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
4-Chlorotoluene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,2-Dichlorobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,3-Dichlorobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,4-Dichlorobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,2,3-Trichlorobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,2,4-Trichlorobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,3,5-Trichlorobenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Monoaromatic Hydrocarbons in VOC Water by Purge&Trap GC-MS						
n-Butylbenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
tert-Butylbenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Isopropylbenzene (Cumene)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
4-Isopropyltoluene (p-Cymene)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
n-Propylbenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
sec-Butylbenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Styrene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-

Sample Type: Aqueous						
Sample Name:		NWTP Clearwater 28-May-2015 9:55 am	Maitai South Branch 28-May-2015 10:45 am	Maitai Dam 28-May-2015 11:05 am	Roding Dam 28-May-2015 8:00 am	
Lab Number:		1432787.1	1432787.2	1432787.3	1432787.4	
Monoaromatic Hydrocarbons in VOC Water by Purge&Trap GC-MS						
1,2,4-Trimethylbenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
1,3,5-Trimethylbenzene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Ketones in VOC Water by Purge&Trap GC-MS						
Acetone	g/m^3	-	< 0.05	< 0.05	< 0.05	-
2-Butanone (MEK)	g/m^3	-	< 0.005	< 0.005	< 0.005	-
Methyl tert-butylether (MTBE)	g/m^3	-	< 0.005	< 0.005	< 0.005	-
4-Methylpentan-2-one (MIBK)	g/m^3	-	< 0.005	< 0.005	< 0.005	-
Trihalomethanes in VOC Water by Purge&Trap GC-MS						
Bromodichloromethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Bromoform (tribromomethane)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Chloroform (Trichloromethane)	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Dibromochloromethane	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
Other VOC in Water by Purge&Trap GC-MS						
Carbon disulphide	g/m^3	-	< 0.005	< 0.005	< 0.005	-
Naphthalene	g/m^3	-	< 0.0005	< 0.0005	< 0.0005	-
System monitoring Compounds for VOC - % Recovery						
4-Bromofluorobenzene	%	-	99	99	101	-
Toluene-d8	%	-	103	102	105	-

Analyst's Comments

Samples 2-4 Comment:
It has been noted that the method performance for Hexachlorocyclopentadiene for SVOC analysis is not acceptable therefore we are unable to report this compound at this present time.

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-4
Total Digestion	Boiling nitric acid digestion. APHA 3030 E 22nd ed. 2012 (modified).	-	1-4
Total acid digest for Silver analysis	Boiling nitric / hydrochloric acid digestion (5:1 ratio). APHA 3030 F (modified) 22nd ed. 2012.	-	1-4
Total Cyanide Distillation	Distillation following the addition of sulphuric acid, alkaline trapping solution. APHA 4500-CN^- C (modified) 22nd ed. 2012.	-	1-4
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	4
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	1-3
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	1-4
Filtration for dissolved metals analysis	Sample filtration through 0.45µm membrane filter and preservation with nitric acid. APHA 3030 B 22nd ed. 2012.	-	1-4
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.05 g/m^3	1-4
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-4
Total Cyanide	Distillation, colorimetry. APHA 4500-CN^- C (modified) & E (modified) 22nd ed. 2012.	0.0010 g/m^3	1-4
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F^- C 22nd ed. 2012.	0.05 g/m^3	1-4

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Total Ammoniacal-N	Filtered sample from Christchurch. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH_3 F (modified from manual analysis) 22nd ed. 2012.	0.010 g/m³	2-4
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m³	1-4
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m³	1-4
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m³	1-4
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd ed. 2012.	0.004 g/m³	2-4
OrganoNitrogen & Phosphorus pesticides, trace, liq/liq GCMS	Liquid/liquid extraction, GPC (if required), GCMS analysis	-	2-4
Acid Herbicides Trace in Water by LCMSMS	Acid Herbicides in water, trace level	0.00003 - 0.00004 g/m³	2-4
Semivolatile Organic Compounds Trace in Water by GC-MS	Liquid/Liquid extraction, GPC cleanup (if required), GC-MS FS analysis	0.0003 - 0.010 g/m³	2-4
Tributyl Tin Trace in Water samples by GCMS	Solvent extraction, ethylation, SPE cleanup, GC-MS SIM analysis	0.00003 - 0.00005 g/m³	2-4
Volatile Organic Compounds Trace in Water by Purge&Trap	Purge & Trap, GC-MS FS analysis [KBIs:28233,2694]	0.0004 - 1.0 g/m³	2-4
Drinking water metals suite, totals, trace			
Total Aluminium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.0032 g/m³	1-4
Total Antimony	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00021 g/m³	1-4
Total Arsenic	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.0011 g/m³	1-4
Total Barium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00011 g/m³	1-4
Total Beryllium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00011 g/m³	1-4
Total Boron	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.0053 g/m³	1-4
Total Cadmium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.000053 g/m³	1-4
Total Calcium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.053 g/m³	1-4
Total Chromium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00053 g/m³	1-4
Total Copper	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00053 g/m³	1-4
Total Iron	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.021 g/m³	1-4
Total Lead	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00011 g/m³	1-4
Total Lithium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.00021 g/m³	1-4
Total Magnesium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.021 g/m³	1-4
Total Manganese	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00053 g/m³	1-4
Total Mercury	Bromine Oxidation followed by Atomic Fluorescence. US EPA Method 245.7, Feb 2005.	0.00008 g/m³	1-4
Total Molybdenum	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00021 g/m³	1-4
Total Nickel	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00053 g/m³	1-4
Total Potassium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.053 g/m³	1-4
Total Selenium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.0011 g/m³	1-4
Total Silver	Boiling nitric / hydrochloric acid digestion (5:1 ratio), ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.00011 g/m³	1-4

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Total Sodium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.021 g/m^3	1-4
Total Tin	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.00053 g/m^3	1-4
Total Uranium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.000021 g/m^3	1-4
Total Zinc	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.0011 g/m^3	1-4

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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Client Services Manager - Environmental Division

Appendix 3. Nelson Resource Management Plan water standards for Class B and C rivers and the classifications of different portions of the Maitai Catchment

AP28.5 Water quality standards - freshwater

Class A Excellent (high conservation / ecological value)	
General Characteristic	Water quality of this class markedly and uniformly exceeds the requirement for all or substantially all uses
Characteristic uses	Characteristic uses include but are not limited to the following: Spiritual and cultural Water supply (untreated domestic, industrial, irrigation, livestock). Human consumption of aquatic biota. Aquaculture Aquatic ecosystem (including migration) Wildlife habitat Recreation and Aesthetics (primary and secondary contact recreation, visual use, fishing, boating, aesthetic enjoyment)
Water Quality Criteria	
Waterborne Disease Risk	Faecal coliforms: at least 98% of samples contain no faecal coliforms or E. coli in 100ml. Viruses: no enteric viruses are detectable in 100l of sample. Protozoa (pathogenic e.g. Giardia and Cryptosporidium): not detectable in 100l of sample. Helminths (pathogenic): not detectable in 100l of sample
Toxic Algae	No toxic algae detectable in 100l of sample.
Dissolved Oxygen	Rivers and streams: median or mean dissolved oxygen measured under low flow conditions in daytime is within the range of 99 – 103% saturation. Lakes and reservoirs: dissolved oxygen is in the range of 90-110% saturation.
Turbidity	Turbidity (mean or median) in rivers and streams does not exceed 1.0 NTU.
Clarity	Clarity (median) – Rivers and streams (black disc) is not less than 6.0m. Lakes and reservoirs (secchi disc) is not less than 7m.
Colour	Colour – hue does not change by more than 5 points on the Munsell scale.
Temperature	Temperature in rivers and streams does not exceed a daily mean of 18^0C or a daily maximum of 20^0C due to human activities.
pH	pH is within the range of 7.2 and 9.0.
Periphyton (rivers and streams)	Maximum cover of diatoms and cyanobacteria: more than 0.3cm thick in gravel/cobble bed streams does not exceed 60% and filamentous algae more than 2cm long does not exceed 30% unless there have been no significant freshes (> 6x baseflow) for a period longer than 50 days.
Nutrients	Phosphorus and nitrogen. Rivers and streams: mean monthly concentrations of soluble inorganic phosphorus (SIP) and soluble inorganic nitrogen (SIN) measured under low flow conditions are less than 5 and 80ug/l respectively. Lakes and reservoirs: mean monthly concentrations of total phosphorus (TP) and total nitrogen (TN) are less than 5 and 80ug/l respectively.
Toxicants	Toxic, radioactive or deleterious material concentrations are below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon these waters and bed sediments, or adversely affect public health, as determined by the 99% level of protection for toxicants in water (AP28.6.i in Appendix 28) and the ISQG-Low Trigger Value for toxicants in sediments (AP28.6.ii in Appendix 28.6)
Objectionable material	Waters are free from: floating debris, oil, grease and other objectionable material, excluding those of natural origin.
Aesthetic	Aesthetic values are not impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, taste or touch.

Macroinvertebrates (rivers and streams)	Species richness of the predominant invertebrate assemblages in gravel/cobble bed rivers and streams, as measured by the macroinvertebrate community index (MCI), are not less than 120, and/or the semi-quantitative MCI (SQMCI) is not less than 6.00.
Aquatic habitat	Aquatic habitat, including riparian habitat, is not impaired by the activities of humans, either directly or indirectly.
Class B Very Good	
General Characteristic	Water quality of this class markedly and uniformly exceeds the requirement for all or substantially all uses
Characteristic uses	Characteristic uses include but are not limited to the following: Spiritual and cultural Water supply (treated domestic, industrial, irrigation, livestock). Human consumption of aquatic biota. Aquaculture Aquatic ecosystem (including migration) Wildlife habitat Recreation and Aesthetics (primary and secondary contact recreation, visual use, fishing, boating, aesthetic enjoyment)
Water Quality Criteria	
Waterborne Pathogens	E.coli.: running median (estimated monthly) of E.coli. is less than 126/100ml. Single sample is not more than 410 E. coli per 100ml. Faecal coliforms:(estimated monthly) no greater than 20% of samples will exceed 400/100ml. Median value does not exceed 100 FC/100ml
Toxic algae	No criteria.
Dissolved oxygen	Rivers and streams: median or mean dissolved oxygen measured under low flow conditions in daytime is within the range of 98 – 105% saturation. Lakes and reservoirs: dissolved oxygen is in the range of 90-110% saturation.
Turbidity	Turbidity (mean or median) in rivers and streams does not exceed 2.0 NTU
Clarity	Clarity (median) in rivers and streams (black disc) shall not be less than 4m. In lakes and reservoirs (secchi disc) clarity shall not be less than 5m.
Colour	Colour: hue does not change by more than 5 points on the Munsell scale.
Temperature	Temperature in rivers and streams: does not exceed a daily mean of 20 degrees C or a daily maximum of 24 degrees C due to human activities.
pH	pH is within the range of 7.2 and 9.0.
Periphyton (rivers and streams)	Maximum cover of diatoms and cyanobacteria: more than 0.3cm thick in gravel/cobble bed streams does not exceed 60%, and for filamentous algae more than 2cm long, cover does not exceed 30% unless there have been no significant freshes (more than 6x baseflow) for a period longer than 30 days.
Nutrients	Phosphorus and nitrogen. Rivers and streams: mean monthly concentrations of soluble inorganic phosphorus (SIP) and soluble inorganic nitrogen (SIN) measured under low flow conditions are less than 9 and 120ug/l respectively. Lakes and reservoirs: mean monthly concentrations of total phosphorus (TP) and total nitrogen (TN) are less than 9.0 and 160ug/l respectively.
Toxicants	Toxicants – toxic, radioactive or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon these waters and bed sediments, or adversely affect public health, as determined by the 95% level of protection for toxicants in water (AP28.6.i in Appendix 28) and the ISQG-Low Trigger Value for toxicants in sediments (AP28.6.ii in Appendix 28).
Objectionable material	Waters are free from: floating debris, oil, grease and other objectionable material, excluding those of natural origin.
Aesthetic	Aesthetic values are not impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, taste or touch.
Macroinvertebrates (rivers and streams)	Species richness of the predominant invertebrate assemblages in gravel/cobble bed rivers and streams, as measured by the macroinvertebrate community index (MCI), are not less than 100, and/or the semi-quantitative MCI (SQMCI) is not less than 5.00.

Aquatic habitat	Aquatic habitat, including riparian habitat, is not impaired by human activities, either directly or indirectly.
Class C Moderate	
General Characteristic	Water quality of this class markedly and uniformly exceeds the requirement for most uses
Characteristic uses	Characteristic uses include but are not limited to the following: Water supply (industrial). Human consumption of aquatic biota. Aquaculture Aquatic ecosystem (including migration) Wildlife habitat Recreation and Aesthetics (secondary contact recreation, visual use, fishing, boating, aesthetic enjoyment)
Water Quality Criteria	
Waterborne Pathogens	E.coli. running median (estimated monthly): less than 500/100ml. Faecal coliforms (estimated monthly): no greater than 20% of samples exceed 400/100ml.
Toxic algae	No criteria.
Dissolved oxygen	Rivers and streams: minimum dissolved oxygen measured under low flow conditions over 24 consecutive hours is not less than 90% saturation. Lakes and reservoirs: dissolved oxygen is in the range of 90-110% saturation..
Turbidity	Turbidity (mean or median) in rivers and streams does not exceed 3.0 NTU.
Clarity	Clarity - Natural visual clarity not reduced by more than 33%. Or Clarity (median) - rivers and streams (black disc) shall not be less than 2.5m. Lakes and reservoirs (secchi disc) shall not be less than 4m.
Colour	Colour – hue is not changed by more than 10 points on the Munsell scale.
Temperature	Temperature in rivers and streams, does not exceed a daily mean of 22^0C or a daily maximum of 27^0C due to human activities.
pH	pH is within the range of 6.5 and 8.5.
Periphyton (rivers and streams)	Maximum cover of diatoms and cyanobacteria: more than 0.3cm thick in gravel/cobble bed streams does not exceed 60% cover and filamentous algae more 2cm long does not exceed 30% cover unless there have been no significant freshes (more than 6x baseflow) for a period longer than 20 days.
Nutrients	Phosphorus and nitrogen. Rivers and streams: mean monthly concentrations of soluble inorganic phosphorus (SIP) and soluble inorganic nitrogen (SIN) measured under low flow conditions are less than 26 and 295ug/l respectively. Lakes and reservoirs: mean monthly concentrations of total phosphorus (TP) and total nitrogen (TN) are less than 20 and 250ug/l respectively.
Toxicants	Toxicants – toxic, radioactive or deleterious material concentrations are below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon these waters and bed sediments, or adversely affect public health, as determined by the 95% level of protection for toxicants in water (AP28.6.i in Appendix 28) and the ISQG-Low Trigger Value for toxicants in sediments (AP28.6.ii in Appendix 28).
Objectionable material	Waters are free from: floating debris, oil, grease and other objectionable material, excluding those of natural origin.
Aesthetic	Aesthetic values are not reduced by dissolved, suspended, floating, or submerged matter not attributed to natural causes, so as to affect water use or taint the flesh of edible species.
Macroinvertebrates (rivers and streams)	Species richness of the predominant invertebrate assemblages in gravel/cobble bed rivers and streams, as measured by the macroinvertebrate community index (MCI), are not less than 80, and/or the semi-quantitative MCI (SQMCI) is not less than 4.00.
Aquatic habitat	No criteria.

Appendix 4. Freshwater classification for Nelson (Wilkinson 2007).

Class A: EXCELLENT - Natural State Ecosystems (High conservation/ecological value).
Effectively unmodified or other high value ecosystems, typically (but not always) occurring in conservation reserves or in remote, inaccessible, or restricted access locations. The ecological integrity of high conservation/ecological value systems is regarded as intact.
Uses and Values: Water uses which require, or water which is managed for, the highest possible natural water quality (pristine). Provides for flow and fauna, cultural and Tangata Whenua values.

Class B: VERY GOOD - Slightly disturbed ecosystems (generally healthy).
Ecosystems in which aquatic biological diversity may have been adversely affected by a relatively small but measurable degree of human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained. Typically freshwater systems would have slightly to moderately cleared catchments and/or reasonably intact riparian vegetation. These systems could include rural streams where there is no significant contamination from grazing (restricted stock access) or forestry, or urban streams with intact or extensive riparian planting and/or esplanade reserves.
Uses and Values: This class includes water managed for values and uses requiring high quality water. Uses and values include aquatic ecosystems and fisheries, water bodies having significant cultural and spiritual values, aquaculture, shellfish and mahinga kai for human consumption, flow and fauna, Tangata Whenua values, human drinking water or contact recreation.

Class C: MODERATE - Moderately disturbed ecosystems (healthy but ailing).
Aquatic biological diversity has been moderately affected by human activity. The biological communities are under some stress from disturbance of their natural habitat. Typical Class C ecosystems would have cleared catchments with only sporadic riparian vegetation. These systems could include rural streams which receive some contamination from grazing (limited stock access) or forestry, or urban streams with limited building setbacks and only limited riparian vegetation.
Use and Values: Includes water managed for uses which require moderately high quality water, such as irrigation and stock water and general water use. Would also provide for limited contact, and non-contact recreation and aesthetic values where the visual characteristics of the water (clarity, colour and hue) are not compromised. May retain some spiritual and Tangata Whenua values.

Class D: DEGRADED – Highly disturbed ecosystems (unhealthy).
Highly degraded ecosystems of lower ecological value. Examples of highly disturbed systems would be urban streams receiving high volumes of road and stormwater contamination with no or little riparian protection, or rural streams which are contaminated by unrestricted stock access.
Uses and Values: Water quality which is suitable only for abstraction where quality is not an issue and contains few instream values, Tangata Whenua values or ecological values.

Class E: VERY DEGRADED - Severely degraded ecosystems.
Severely degraded ecosystems with few or no ecological values. Urban examples would include streams with historical industrial discharges and cumulative sediment contamination, or which have been highly modified or channelised to the extent that natural habitat is no longer retained. Rural streams might be subject to high intensity and frequent contamination from agriculture or land use activities, such as discharge of untreated effluent and uncontained large-scale sedimentation.
Uses and Values: Instream values are severely depleted and water is generally unsuitable for any use. Few values (*e.g.* Tangata Whenua values).

Appendix 5. Use of naturalised flow statistics calculated in 2004 to cross check new naturalised statistics.

In 2004 Envirolink Ltd. produced naturalised flow statistics for rivers in Nelson to inform water allocation policy for the Nelson Resource Management Plan (below). Predictions for Maitai at Riverside, located 400m downstream from Maitai at Avon Terrace, were based on a regression using South Branch flow data (1981-2004) with 21 flow gaugings. Results were very similar to those calculated for Avon Terrace, with mean, median and 7dMALF values being 1%, 3% and 5% lower than those calculated in 2015.

River	Site	TDC Site	Grid Reference	Catchmen Area (km2)	Contro l Site	R2	mean l/s	median l/s	7 day mean low flows MALF l/s	5 year l/s	10 year l/s	year l/s	Specific MALF	Type of estimate*	Length of record	Data Quality 4=low)	# of gaugings
Control Sites																	
Maitai	Forks	57808	O27:407907	35.7			1455	499	192	181	174	169	5.4	FR	7 Mar 97 - 7 Jan 04		
Maitai	South Branch	57804	O27:411891	14.4	MS		862	380	148	126	114	105	10.3	FR	20 Feb 81 - 17 Aug 04	1	
Wakapuaka	Hira	58101	O27:431991	41.9	W		1344	765	284	242	219	201	6.8	FR	9 Aug 78 - 28 Aug 04	1	
Collins	Drop Structure	58301	O27:547052	17.6	C		546	228	56	44	37	32	3.2		5 Mar 62 - 17 Aug 04	1	
Correlated Sites																	
Oldham	Corder		O27:367966	3.4	W	0.41	28.8	18.4	9.8	9.0	8.6	8.3	2.9	G		3	8
Oldham	Upper		O27:372960	1.5	W	0.93	22.9	11.3	1.8	0.9	0.5	0.1	1.2	G		2	4
Hillwood	Water Supply Intake		O27:409987	1.8	W	0.98	6.1	3.5	1.4	1.2	1.1	1.1	0.8	G	Using updated correlation @ 23/12/04 rather than report data	1	8
Hillwood	Water Supply Intake		O27:409987	1.8	W	0.90	21.4	12.5	2.7	2.0	1.5	1.0	1.5	RP		1	3
Hillwood	Edwards-upstream (Unique		O27:403989	0.5	W	0.43	1.6	0.9	0.3	0.2	0.2	0.1	0.5	G		2	5
Teal	Glenwood (road end)		O27:435960	13.8	W	0.87	385.4	223.8	89.5	77.7	71.3	66.3	6.5	G		2	12
Teal	Fantail Reach		O27:433971	14.9	W	0.98	305.7	198.3	109.0	101.2	96.9	93.6	7.3	G		1	17
Lud	Murdochs		O27:420951	2.2	W	0.99	55.5	30.4	9.5	7.7	6.7	5.9	4.3	G		2	5
Lud	Omahanui		O27:429980	9.4	W	0.99	135.6	72.8	20.7	16.1	13.7	11.7	2.2	G		3	23
Todds V	SH6		O27:382992	5.1	W	0.38	42.2	24.1	9.1	7.8	7.1	6.5	1.8	G		2	11
Todds V	Upper		O27:386980	1.6	W	0.92	20.5	10.8	2.6	1.9	1.5	1.2	1.6	G		3	4
Whangamoa	Hippolite		O27:505019	18.7	W	0.99	1088.5	586.6	169.7	133.3	113.3	97.7	9.1	G		2	11
Whangamoa	Kokoroa		O27:554085	77.7	W	0.99	2849.8	1500.5	379.5	281.7	228.1	186.1	4.9	G		2	6
Wakapuaka	Maori Pa R		O27:454020	61.0	W	0.99	1755.1	975.9	328.6	272.1	241.1	216.9	5.4	G		2	12
Wakapuaka	Picnic Ground (Duck Pond Rd)		O27:437975	13.4	W	0.97	794.4	465.2	191.7	167.8	154.7	144.5	14.3	G		2	10
Blue Creek	Happy Valley		O27:453005	4.0	W	0.56	122.9	68.3	22.9	19.0	16.8	15.1	5.7	G		3	5
Waihi	Glen		O27:409024	2.1	W	0.51	12.5	9.0	6.1	5.8	5.7	5.6	3.0	G		3	5
Poorman V	Barnicoat		O27:321864	2.9	MS	0.93	101.2	43.2	15.3	12.7	11.2	10.1	5.4	G		2	8
Poormans	Seaview R		N27:295889	7.9	MS	0.73	120.2	48.5	14.0	10.7	9.0	7.6	1.8	G		3	9
Saxtons	MR Stoke		N27:273862	6.0	MS	0.91	98.7	28.6	Dry	Dry	Dry	Dry		G		3	8
Brook	Dam		O27:344878	8.2	MS	0.70	219.4	92.7	31.7	26.0	22.8	20.4	3.9	G		2	13
Brook	Manuka St		O27:343920	17.2	MS	0.88	318.7	135.4	47.2	38.8	34.3	30.9	2.7	G		2	9
Brook	Middle Site		O27:343911	15.7	MS	0.91	338.2	139.9	44.5	35.5	30.5	26.8	2.8	G		2	10
Jenkins	Enner Glyn		O27:332880	3.7	MS	0.97	46.2	15.4	0.6	Dry	Dry	Dry	0.2	G		3	9
Jenkins	Pascoe St		O27:302901	4.9	MS	0.92	69.3	25.2	3.9	1.9	0.8	0.0	0.8	G		2	12
Maitai	Picnic grounds		O27:374910	48.0	MS	0.82	1403.7	680.4	332.3	299.3	281.3	267.8	6.9	G		2	10
Maitai	Riverside		O27:344926	89.2	MS	0.90	2765.5	1138.9	356.0	281.8	241.3	210.9	4.0	G		2	21
Orchard	Nayland R		N27:285879	0.5	MS	0.99	27.5	11.0	3.0	2.3	1.9	1.6	5.7	G		3	4
Orphanage	Netball Cts		N27:282867	7.9	MS	0.93	129.6	49.6	11.1	7.5	5.5	4.0	1.4	G		2	11
Orphanage	Recorder		O27:304865	2.6	MS	0.92	46.1	14.0	1.7	1.3	0.9	0.5	0.7	RP		3	15
Sharlands	Carpark		O27:380927	15.3	MS	0.79	306.9	125.3	38.0	29.7	25.2	21.8	2.5	G	417.5	2	9
York	Caltex		O27:323900	1.3	MS	0.56	4.7	3.7	3.3	3.3	3.2	3.2	2.5	G		2	9
Blunder	Collins Vly		O27:554051	6.3	C	0.62	90.3	50.2	28.5	27.0	26.1	25.5	4.5	G			8
Dencker	Kokoroa		O27:551071	6.8	C	0.99	184.8	81.6	25.7	21.8	19.6	17.9	3.8	G		3	5
Graham	SH6		O27:509023	6.6	C	0.99	302.0	144.3	59.0	53.0	49.5	47.1	9.0	G		3	5

Type of estimate*
flow recorder (FR), gauging correlation (G), report (RP)
Further information available from Tasman District Council

MS=Maitai South
W=Wakapuaka at Hira
C=Collins at Drop Structure

These correlations focus on low flow estimates and may not perform well at higher flows from which the mean and median flows are derived. For example, the correlations predict greater flow in the upper reaches of the Teal River than the lower reach when in actual fact

Maitai at Picnic ground versus Maitai at Riverside comparisons, appear anomolous, but this is purely due to the correlation process at low flows. A better relationship can be achieved by adding Sharlands Creek and Brook at Manuka St, to Picnic Grounds to determine flows at Riverside at levels below the 5 year low flow.

Appendix 6. Macroinvertebrate indices and their interpretation.

Taxa richness / Number of taxa: This is simply the number of different kinds (i.e. taxa) of animals present. Sometimes a taxon is resolved down to the species level (e.g. *Oxyethira albiceps*), but it may be taken only to the genera level (e.g. *Deleatidium* sp.) or even higher taxonomic level (e.g. Oligochaeta), depending on the practicality of identification.

Density: This is the abundance (count) of animals collected in a sample multiplied by the area sampled. Density is commonly reported as numbers of invertebrate per m^2.

% EPT taxa or abundance: The EPT taxa are mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) – these groups of freshwater insects are generally intolerant of pollution. % EPT taxa is the proportion of the number of kinds of EPT invertebrates found in a sample relative to number of taxa. % EPT abundance taxa is the proportion of the count (or density) of EPT invertebrates found in a sample relative to the total count (or density of all taxa found.

The index is based on the number of kinds of mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) found in a sample relative to the total number of different taxa found. The invertebrates belonging to the EPT invertebrates of freshwater insects are generally intolerant of pollution.

% EPT abundance: The EPT abundance index is based on the total number of mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) found in a sample relative to the total number of different taxa found.

Macroinvertebrate Community Index (MCI): MCI values are calculated according to the method of Stark (1985, 1993b, 1998b). The MCI relies on prior allocation of scores (between 1 and 10) to different kinds of freshwater macroinvertebrates based on their tolerance to pollution. Macroinvertebrates that are characteristic of unpolluted conditions and/or coarse stony substrates score more highly than those found predominantly in polluted conditions or amongst fine organic sediments. In theory, MCI values can range between 200 (when all taxa present score 10 points each) and 0 (when no taxa are present) but, in practise, it is rare to find MCI values greater than 150. Only extremely polluted or sandy and/or muddy sites score under 50.

Semi-Quantitative Macroinvertebrate Community Index (SQMCI): The, SQMCI accounts for the different kinds of invertebrates and their relative abundances into its calculation. Although the MCI, SQMCI and QMCI (see below) were developed to assess organic pollution in stony-bottomed streams, they have proven useful in other stream types for assessing habitat quality and environmental health. The SQMCI is calculated in instance where the area sampled is unknown. Values range from 0 to 10 (although, in practise, it is rare to find SQMCI values less than 2.00 or greater than 8.00), and are directly comparable to QMCI (see below).

Quantitative Macroinvertebrate Community Index (QMCI): The QMCI, like the SQMCI, reflects the abundance and types of macroinvertebrates found at a site. However, the QMCI incorporates the scores of the each taxon in the community in a unique way: each taxon's score is weighted by its abundance (as calculated by its percentage contribution to the total community), so that the overall index value is weighted towards the scores of the dominant taxa. The QMCI is calculated in instance where the area sampled is known. Values range from 0 to 10 (although, in practise, it is rare to find QMCI values less than 2.00 or greater than 8.00), and are directly comparable to SQMCI. MCI, SQMCI and QMCI scores from hard-bottomed streams can be interpreted using the ranges described in Table A4.1.

Table A4.1. Interpretation of the Macroinvertebrate Community Index (MCI) and Quantitative Macroinvertebrate Community Index (QMCI) scores in stony streams with respect to water quality and/or pollution levels. Adapted from Stark & Maxted (2007).

Water quality	MCI	SQMCI / QMCI
Excellent (clean water)	> 120	> 6
Good (possible mild pollution)	100–119	5–5.9
Fair (probable moderate pollution)	80–99	4–4.9
Poor (probable severe pollution)	< 80	< 4

Appendix 7. Letter describing fish passage monitoring undertaken at the Maitai dam spillway during January and February 2016.

18 February 2016

Becky Marsay
Asset Engineer - Utilities
Nelson City Council
03 546 0267

Dear Becky

MAITAI DAM SPILLWAY FISH PASSAGE SURVEY

This letter is to confirm that the efficacy of fish passage modifications made to the Maitai Dam spillway in the autumn of 2015 was assessed during January and February 2016. These modifications were made with the aim of improving fish passage over the spillway for climbing species (e.g. juvenile eels [elvers] and kōaro).

The fish passage remediation work undertaken at the Maitai dam spillway during autumn 2015 included:

- Installation of a pump to deliver water from the reservoir to the spillway crest, at times when the reservoir water level is too low for spilling to occur, ensuring continuous flow down the spillway during summer migration periods.
- Plugging the drainage outlets in the flip bucket with bungs to maintain the pool that usually forms in this bucket when spilling occurs.
- Installation of mussel spat ropes down the length of the spillway and downstream of the flip-bucket, adjacent to the true left spillway wall, to provide additional cover, as well as resting and climbing opportunities for migratory fish.
- Installation of a short ramp from the lip of the flip-bucket to the spillway apron below to allow climbing fish to avoid the steep transition into the flip-bucket.

Infrared Video Surveillance

Video surveillance was used to monitor fish movements over the spillway crest. The video camera was set up with an infrared light source to monitor the top section of the spillway (Figure 53). It was focused on the true right of the spillway crest, where the recently installed pumped discharge and spat ropes intersect the spillway crest. The camera was set to record at one frame every 15 seconds, and recorded continuously for three nights between 22:23 on 22 January and 09:08 on 25 January 2016. Another camera was also set up at the bottom of the spillway over this period to record the number of fish beginning to climb. The intension was to compare the numbers beginning the climb with numbers successfully passing over the spillway crest. Unfortunately, a fault with the infrared light source associated with the camera at the bottom of the spillway meant that there was insufficient light for effective video footage.

Figure 53. Infra-red time-lapse video camera at the Maitai Dam spillway crest, intended to monitor fish passage.

To count fish passing over the spillway crest the footage was replayed at four times normal play back speed – to help make detection of movement easier and to reduce total play back time and therefore reduce observer fatigue. Each night of footage was watched twice.

We could not definitively identify any fish successfully negotiating the spillway crest in the video footage. This was despite being able to see objects of similar size to elvers (e.g. twigs, leaves, spat rope filaments), and even smaller things (e.g. insects and insect larvae).

During most of the period that the video camera was deployed there was a small amount of natural spill occurring, in addition to the pumped discharge to the weir crest. This natural spill was concentrated close to the centre of the spillway crest, out of the field of view of the video camera, but the wetted surface intersected that from the pumped discharge further down the spillway, from which point the entire flow was concentrated on the true right of the spillway.

Consequently, it is possible that a proportion of elvers attempting to climb the spillway may have surmounted the spillway crest undetected.

To identify whether elvers were in fact climbing the spillway, but not being detected in the video footage, spotlight surveys of the spillway were subsequently undertaken.

Spotlight Surveys

During January and February 2016 three spotlight surveys were carried out (on the nights of 26 of January, 10 February and 15 February 2016) in order to assess whether fish were attempting to climb the spillway. The first two of these surveys were conducted between approximately 04:00-06:00, while the third was conducted between midnight and 01:00. The intension was that by conducting these surveys several hours after sunset that fish would have had time to make substantial progress up the spillway. The natural spilling had ceased by the time these spotlight surveys were undertaken, so the pumped discharge to the spillway crest was the only source of water on the spillway.

Eel elvers were observed climbing the spillway during these spotlight surveys (Table 26; Figure 53a). These elvers ranged in size from ~80-130 mm long (estimated lengths). Elvers were the only fish seen on or in the vicinity of the spillway, aside from medium to large trout and eels consistently observed patrolling in the vicinity of the bottom of the spillway in the plunge pool below (Figure 53b), and occasionally also in the reservoir above. A single koura (freshwater crayfish) ~50 mm long was also seen crawling down the spillway on the night of 26 January, and another was seen at the spillway crest on 10 February. In addition, some dead elvers were found on the spillway in the second and third surveys. Although a few elvers were observed within five metres of the spillway crest on each survey occasion, only two were seen to have passed beyond the crest (Table 26), with one of these entering the reservoir and swimming away during observation.

Table 26. Summary of elver numbers observed on and in the vicinity of the Maitai Dam spillway during spotlight surveys on the nights of 26 January, 10 February and 15 February 2016.

Survey date	Number of elvers on the spillway	Number of elvers beyond the spillway crest	Number of elvers holding in the flip-bucket
26 January 2016	21(including several descending)	0	>100
10 February 2016	14 (including 3 descending)	0	~8 seen
15 February 2016	24 (including 2 descending)	2	>30

Climbing velocity of elvers generally appeared to become slower with distance up the spillway, with longer resting periods. The time taken for one elver near the top of the spillway to climb approximately 0.5 m was measured at approximately eight minutes (i.e. ~0.06 m per minute, or 3.75 m/hr). This elver appeared to be climbing at a fairly typical rate compared to others observed, with periods of relatively rapid progress interspersed with periods of resting. This climbing velocity is comparable with an average climbing velocity of 2.5 m/hr (range1.3 – 4.8 m/hr), from nine elvers observed in video footage climbing the South Branch weir during February 2015 (Hay et al. 2015). Assuming this climbing velocity is representative, it would take elvers in the order of 40 hours to climb the spillway (approximately 150m long). Again this is comparable with predicted passage times for the Maitai Dam spillway in the range of 31.5 - 116 hours calculated by Hay et al. (2015) based on climbing speeds observed at the South Branch weir. This is might be expected to be spread over several nights, given that climbing activity is mainly nocturnal.

The hours of darkness during these surveys extended from approximately 21:15 to 05:45 (i.e. 8.5 hr). On this basis it might take about 5 nights for an elver to climb the entire spillway. Therefore, in the order of a fifth of the 20 or so elvers generally observed on the spillway during the spotlight surveys might be expected to reach the top on a given night (i.e. 4 elvers per night). This would equate approximately 480 elvers reaching the reservoir over a migration season of approximately 120 nights (December to March inclusive). Obviously this is a coarse estimate, based on several assumptions. However, it does seem that the number of elvers successfully climbing the dam spillway is likely to be relatively low.

In addition, there is likely to be some attrition during the climb, as illustrated by the dead elvers found on the spillway during the last two surveys. The video footage also showed birds (e.g. swallows and ducks) were active on the spillway during the day, with the possibility that some may be predating elvers caught out on the spillway. The koura observed on the spillway may also have been attempting to predate elvers, as koura have been observed apparently attempting to catch migrating elvers elsewhere. Furthermore, elvers appear to be exposed to relatively high predation risk at the top and bottom of the spillway, where they are concentrated in locations predictable by predators, with large trout and eels consistently observed patrolling areas.

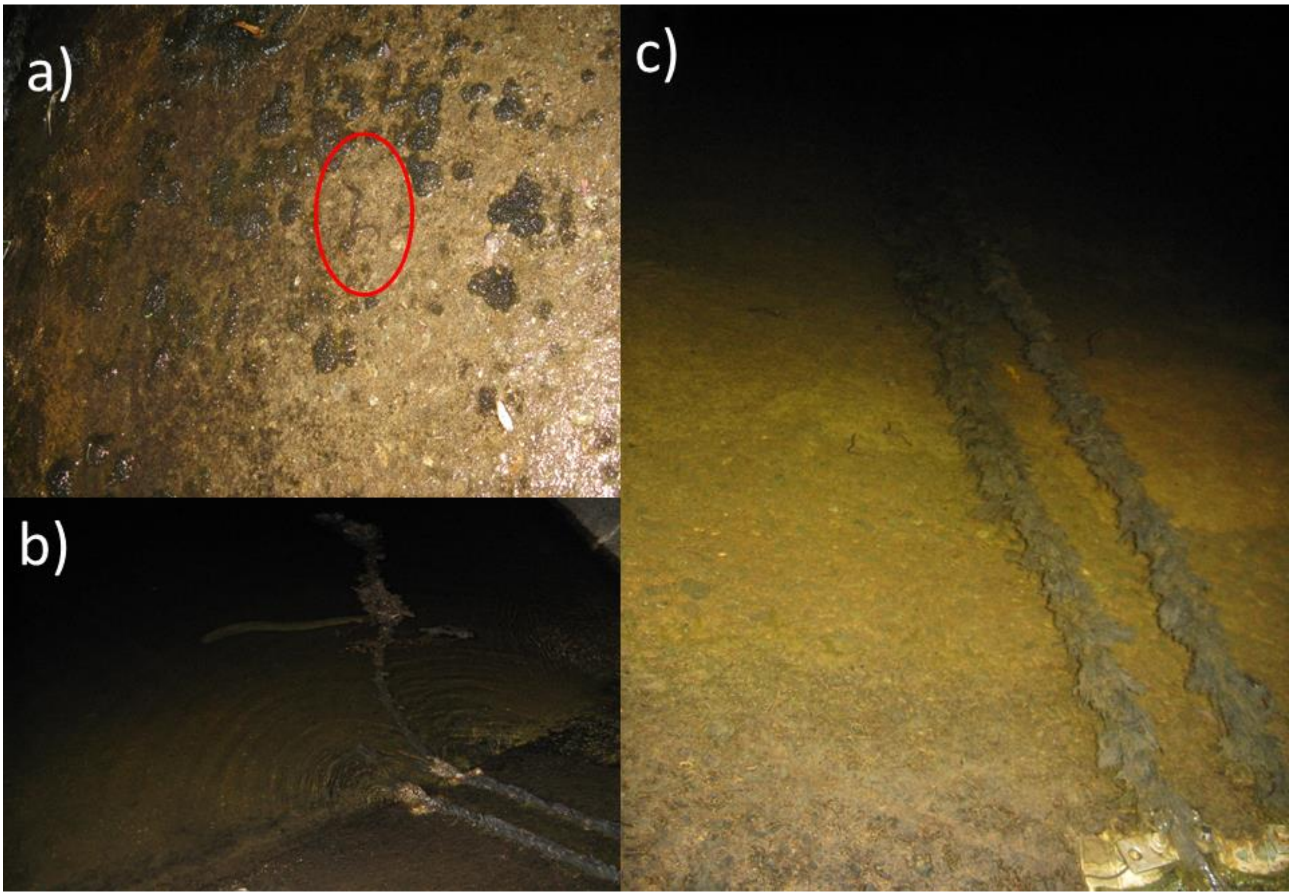


Figure 54. Photographs taken during spotlight surveys of fish passage on the Maitai Dam spillway during January and February 2016, showing: a) an elver climbing the spillway above the flip-bucket, b) elvers holding in the flip-bucket pool in association with the spat ropes, c) a large eel lurking at the bottom of the spillway in the vicinity of the spat ropes.

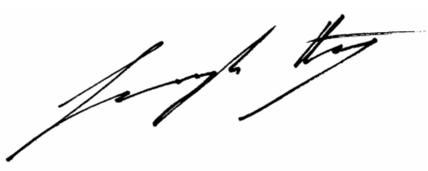
Notwithstanding the apparently low numbers of elvers successfully completing the climb, the remediation modifications carried out during autumn 2015 have undoubtedly improved the situation for elvers attempting to climb the spillway. Before the installation of the pumped water supply, and bungs in the flip-bucket drains, the spillway was often dry for long periods during summer. For example, during the summer migration season (December to March inclusive) of 2014/15 the reservoir was below the spillway level for all but approximately one month (between 21 December 2014 and 20 January 2015). Consequently, there was no opportunity for fish passage during the rest of the migration season. The spillway was not spilling during any of the spotlight surveys discussed above. So all elvers observed attempting to climb the spillway, including the two seen successfully beyond the spillway crest (Table 26), were only able to climb due to the pumped water supply.

The spat rope was being used for cover by resting elvers, particularly in the flip-bucket pool (Figure 53c), but also on the spillway. The resting cover habitat provided by the spat ropes may well assist elvers avoid predation and thermal stress when caught out on the spillway during the day. Fortunately the true right of the spillway remains shaded by the side wall most of the day even during summer, reducing the potential thermal stress for migrants. However, the video footage showed that the sun did reach the true right edge of the spillway from about 16:00 during late January. The spat rope was also observed being used to assist climbing by a few elvers, though the majority of climbing occurred in the wetted splash zone on the spillway, away from the spat ropes (Figure 54a).

As recommended by Hay et al. (2015), given the apparent degree of difficulty for elvers of scaling the spillway and the apparently low numbers successfully reaching the reservoir via this route, it would be prudent to continue and intensify existing trap and transfer operations to augment fish numbers passing the dam. Trap and transfer also has the advantage of avoiding concentrating migrants in locations that are easily predictable by predators, rendering them vulnerable to predation. As recommended by Doehring and Hay (2014), the trap and transfer operation should be extended to include kōaro as well as elvers and possibly also redfin bullies, and the methods of capturing fish for transfer should be extended to include electric-fishing as well as trapping/netting.

Further, interpretation of these results will be included in the fish passage section of the upcoming “Effects of the Maitai River municipal supply— Summary of Environmental Effects” report.

Yours sincerely



Joe Hay
Freshwater Biologist

Reference:

Doehring K, Hay J 2014. Fish passage assessment of the Maitai River North Branch Dam and South Branch weir. Prepared for Nelson City Council. Cawthron Report No. 2601. 38 p. plus appendices.

Hay J, Chandler M, Kelly D. 2015. Maitai South Branch weir fish passage remediation efficacy monitoring. Prepared for Nelson City Council. Cawthron Report No. 2730. 17 p.

Appendix 8. Letter to Nelson City Council describing Maitai River catchment drift dive on 12 January 2016

27 January 2016 ID: 1604

Becky Marsay
Asset Engineer - Utilities
Nelson City Council
03 546 0267

Dear Becky

MAITAI RIVER CATCHMENT DRIFT DIVE

This letter is to confirm that a drift dive was undertaken in the Maitai River on 12 January 2016. The purpose of this survey was to assess the current state of the brown trout fishery in the Maitai River as part of a wider ecological affects assessment of the NCC Maitai municipal water supply scheme. Prior to undertaking the drift dive a meeting was held with Rhys Barrier—the Nelson Fish & Game Council staff manager—where he provided input into the selection of sites.

The drift dive survey was undertaken during a low–moderate flow (< 1 m^3/s at the forks recorder) by three certified drift divers from the Cawthron Institute (Robin Holmes, Dave Kelly and Karen Shearer). A long river reach was surveyed in the lower catchment from the ‘Sunday Hole’ swimming and picnic area to the Collingwood Street Bridge. Shorter reaches were surveyed around Smiths Ford, the Maitai Reservoir spillway and Backfeed structures and upstream of the Backfeed (Figure 1, Table 1).

Black disk visual clarity measurements ranged from 14 m (upstream of the Backfeed) to three metres around the dam structures (Table 1). Clarity was adequate for drift diving throughout the survey area except in the Spillway plunge pool and immediately below the Backfeed (for approximately 50 m).

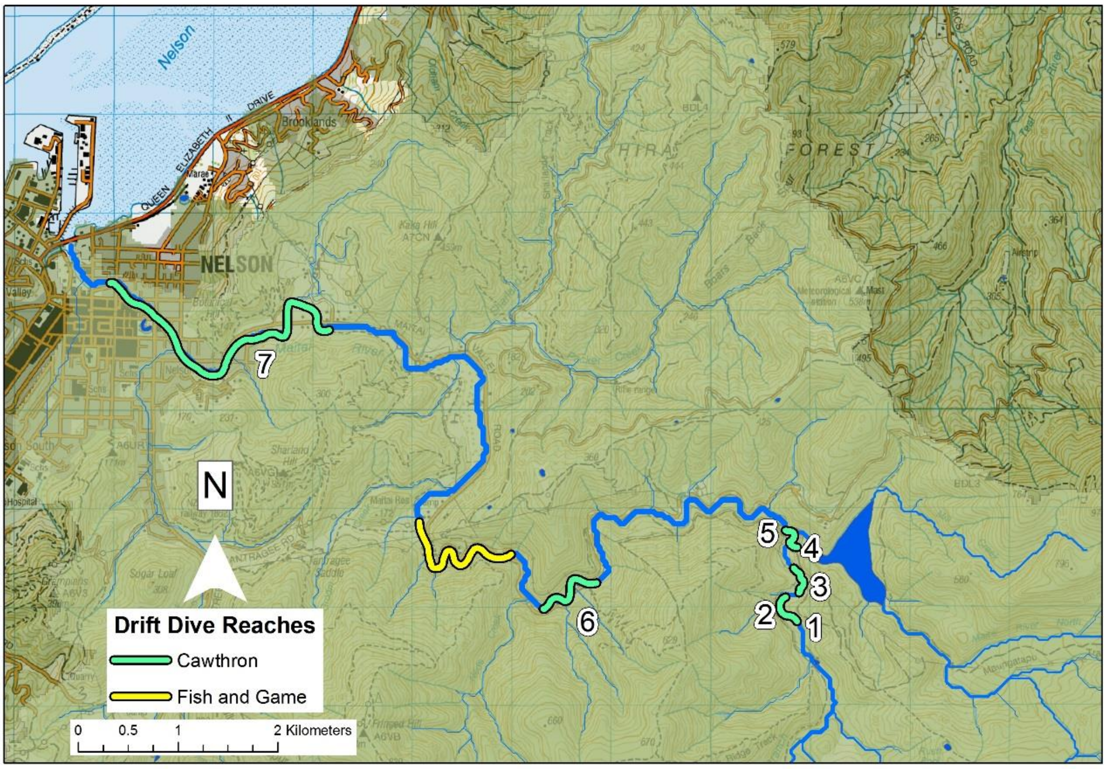


Figure 55. Maitai River (in blue) showing the various drift dive reaches in green. The long-term Fish & Game drift dive monitoring site is also shown in yellow.

Table 27. **Brown trout numbers (by size category) for each of the Cawthron drift dive sites shown in Figure 1. U/S = upstream, D/S =downstream.**

Site location	Reach length (km)	Clarity (black disk m)	Number of small trout (<200 mm)	Number of medium trout (200 – 400 mm)	Number of large trout (>400)	Number of medium and large trout per kilometre
(**1**) South Branch (U/S of backfeed)	0.24	14	1	0	0	0
(**2**) South Branch (D/S of backfeed)	0.11	3.5	2	1	0	8.9
(**3**) South Branch (U/S of biomonitoring Site – Site B)	0.22	4.5	1	1	0	4.5
(**4**) Spillway plunge pool	0.20	3	0	0	1	4.9
(**5**) D/S of South and North Branch confluence	0.16	4.5	1	1	0	6.4

(**6**) Smiths Ford	0.80	4.5	6	0	0	0
(**7**) Sunday Hole to Collingwood Street	3.40	4.3	6	7	4	3.2

Trout greater than 200 mm are of interest to anglers. Therefore, the abundance of these larger fish can provide an indication of the potential value of a fishery. In the Maitai River numbers of trout (> 200 mm) per kilometre ranged from 8.9 in the short reach downstream of the Reservoir backfeed to 0 in the Smiths Ford reach and the South Branch upstream of the backfeed (Table 1). Overall, 5.2 kilometres of the (approximate) 17 kilometres of river capable of holding adult trout was surveyed. A total of 15 fish > 200 mm were counted in all the surveyed reaches—giving an average of 2.9 catchable fish per kilometre.

Interpretation of these results will be provided in the trout fisheries section of the upcoming ‘Effects of the Maitai River municipal supply—Summary of Environmental Effects’ report.

Yours sincerely

Scientist

Robin Holmes
Freshwater Ecologist
Cawthron Institute

Reviewed by

Roger Young
Coastal and Freshwater Group Manager—Freshwater

Appendix 9. Temperature modelling of the influence of the backfeed on temperatures in the Maitai River.

The influence of releasing water of different temperatures from the backfeed was modelled with the software package SEFA (System for Environmental Flow Analysis; I Jowett, B Milhous, T Payne, JM Diez Hernández; www.sefa.co.nz), using numerical solutions to the heat flux and transport equations as described in Theurer et al. (1987).

The model was calibrated by manipulating the shade, wind speed and bed conductivity parameters to optimise predictions of mean and maximum water temperature relative to observed data at a given location downstream (i.e. minimise the root-mean-squared error of prediction of these two parameters). The recorded daily mean and maximum water temperature downstream of the South Branch weir were used as input for the top of the reach, while data from the Smith's Ford temperature logger (approximately 5.66 km downstream of the South Branch weir) were used as input for the bottom of the reach during calibration. The time of maximum daily air temperature was also adjusted to improve the prediction of maximum water temperatures.

Calibration was undertaken to represent two periods:

1. The hot period with maximum recorded river temperatures in the South Branch, in late January 2015. Represented by daily averages for 29 January 2015.
2. The period in summer 2014/15 with maximum differences between temperatures recorded in the South Branch and reservoir temperatures at the 6 m (top) intake level, in mid-April 2015. Represented by daily averages for 15 April 2015.

For modelling scenarios of differing backfeed temperature, the water temperature at the top of the modelled reach was calculated as the temperature downstream of the backfeed for a given backfeed temperature and discharge rate, and a given South Branch temperature and discharge rate (using Equation 1 shown above). The combined temperature and discharge were then used to initiate the reach model, along with meteorological and reach parameters used in the calibration process.

Influence of varying backfeed temperature during peak summer river temperatures

Figure 56 shows model predictions of longitudinal water temperature profiles for three backfeed source temperature scenarios, during the period of maximum recorded water temperature in the Maitai River over the summer of 2014/15.

The first scenario used the actual backfeed discharge temperature on 29 January 2015 (mean = 17.1 °C, max = 18.1 °C).

The second scenario assumed a constant backfeed discharge temperature on that day of 22 °C. This is 1.1 °C warmer than the maximum temperature recorded at the 6m (top) intake level in the reservoir during the 2014/15 summer, and is equivalent to the maximum temperature recorded at the 3 m (surface) level. This was intended to illustrate an extreme worst case scenario of releasing warm water from the top intake.

The third scenario assumes backfeed water was being sourced from the middle (15 m) intake from the reservoir, and uses the mean and maximum temperatures recorded at that level in the reservoir on 29 January 2015 (13.1 °C and 14.3 °C, respectively). This was intended to illustrate the extent to which there is potential to mitigate temperature effects downstream by releasing cooler water from the middle intake.

The modelled flow was 0.260 m^3/s (based on the daily mean flow for that date at the Forks recorder), with 0.201 m^3/s of this coming from the backfeed discharge (based on the daily mean backfeed discharge rate for that date) and the balance (0.059 m^3/s) from the South Branch above the weir. The backfeed discharge rate on this date was relatively high, compared with the median and maximum over summer 2014/15 (0.151 m^3/s and 317 m^3/s, respectively). The spillway was not discharging on this date.

Figure 56 illustrates that although release of warmer water from the back feed would initially increase river water temperatures downstream, the magnitude of this effect diminishes with distance downstream, as equilibrium temperature is approached. Once equilibrium temperature is reached the backfeed discharge no longer influences temperatures further down the catchment. Likewise, the influence of releasing cooler water from the backfeed is most pronounced immediately below the discharge and diminishes downstream.

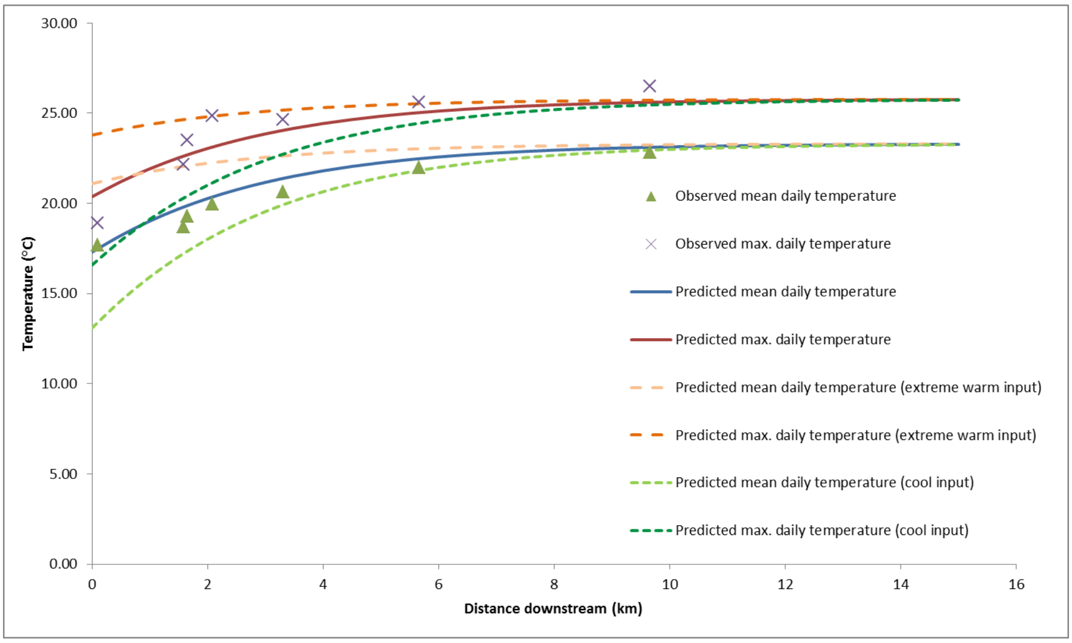


Figure 56. Observed and modelled longitudinal water temperature profiles downstream of the Maitai water supply weir on the South Branch for the 29 January 2015, for three alternative backfeed temperature scenarios: 1) the recorded backfeed temperatures for that date, 2) a warmer backfeed discharge based on the maximum recorded reservoir surface temperature for this summer (22 °C), and 3) a cool backfeed discharge based on recorded temperatures at the middle (15 m) reservoir intake level for that date.

The warm input scenario depicted in Figure 56 would represent non-compliance with existing consent conditions, since increasing river water temperatures above 20 °C is currently not permitted. As discussed above, the section of river where this temperature guideline is complied with has the potential to act as a thermal refuge for sensitive species. The observed daily maxima in Figure 56 suggest that during this very warm period in late January the extent of this potential refuge habitat was in the order of only 1 km downstream of the backfeed. Under the warm input scenario this short section of potential refuge would be lost. Conversely, releasing cooler water from the backfeed (of the temperature recorded at the 15 m middle intake level) could lengthen the extent of this refuge habitat where daily maximum temperatures were below 20 °C by about 1km (from ~1 km out to ~2 km).

These scenarios demonstrate that while the influence of backfeed discharge on river water temperatures diminishes downstream, there may still be localised ecological effects in the first few km below the discharge. It should be remembered that these scenarios represent an extreme case of ambient river water temperatures. Daily maximum water temperatures over this extreme warm period of late January were in excess of 20 °C upstream of the South Branch weir, and the backfeed discharge was actually cooling the river slightly already. For most of the rest of the summer longitudinal daily average temperature profiles remained below 20 °C, at least as far downstream as the Maitai Camp, although daily maximum temperatures often exceeded this threshold for much of December to February, inclusive, from the Maitai Forks recorder site downstream.

However, the concept still holds that releasing warm water from the reservoir has the potential to reduce the length of river remaining below 20 °C, that potentially acts as a thermal refuge, while releasing cooler water can extend this potential refuge habitat. But releasing cooler water during reservoir stratification events comes with the risk of impacting water quality. Consequently, the situation remains a trade-off. However, as discussed in section 3.1.2, it should be feasible to closely match ambient river temperatures most of the time, if temperature sensors are installed at the intake valves, allowing calculation of the required mix of water from the upper and middle intake levels. This solution should minimise temperature alteration and reduce the potential for releasing poor quality, deoxygenated bottom water from the reservoir.

Influence of varying backfeed temperature during peak differences between reservoir surface temperatures and river temperatures

Figure 57 shows model predictions of longitudinal water temperature profiles for three backfeed source temperature scenarios, during the period of maximum recorded difference in water temperature between the 6 m (top) reservoir intake level and the Maitai South Branch over the summer of 2014/15. These scenarios illustrate the influence of releasing water from the backfeed that is warmer than the equilibrium temperature in the river. During this period the water available for discharge from the top and middle intake valves was warmer than the South Branch.

The first scenario used the actual backfeed discharge temperature on the 15 April 2015 (mean = 11.3 °C, max = 11.5 °C).

The second scenario assumes backfeed water was being sourced from the top (6 m) intake from the reservoir, and uses the mean and maximum temperatures recorded at that level in the reservoir on 15 April 2015 (15.7 °C and 15.86 °C, respectively).

The third scenario assumes a constant backfeed discharge temperature on that day of 22 °C[38].

The modelled flow was 0.510 m^3/s (based on the daily mean flow for that date at the Forks recorder), with 0.121 m^3/s of this coming from the backfeed discharge (based on the daily mean backfeed discharge rate for that date) and the balance (0.389 m^3/s) from the South Branch above the weir. The backfeed discharge rate on this date was relatively low, compared with the median and maximum over summer 2014/15 (0.151 m^3/s and 317 m^3/s, respectively). The spillway was not discharging on this date.

[38] As discussed above, this is 1.1 °C warmer than the maximum temperature recorded at the 6 m (top) intake level in the reservoir during the 2014/15 summer, and is equivalent to the maximum temperature recorded at the 3 m (surface) level

Figure 57 demonstrates that although release of warmer water would initially increase river water temperatures, the magnitude of this effect would diminish with distance downstream, as heat is lost from the river and equilibrium temperature is approached.

The low backfeed discharge rate, relative to the South Branch flow on this date, means that the temperature of the water released from the backfeed has only a moderate influence on river temperatures. This reinforces the point that both the volume and temperature of the backfeed, relative to the South Branch contribution, together control the degree of influence on temperatures downstream. Even the extreme worst case scenario of releasing 22 °C water from the backfeed (scenario three), would increase average daily temperatures immediately below the backfeed by only about 3.2 °C, with this ratio of backfeed to river discharge rates. However, the influence of this extreme scenario of warm backfeed input water was predicted to extend a considerable distance downstream. Under this scenario equilibrium temperatures had not been reached even by the most downstream temperature logger site (downstream of the Maitai Campground).

Sourcing backfeed water from the top (6 m) reservoir intake during this period would also have resulted in an increase in average daily temperatures immediately below the backfeed (compared with upstream) by only about 1.7 °C, and maximum daily temperature would be increased by about 1.4 °C. This relatively small influence on river water temperature was predicted to have attenuated substantially by the sixth temperature logger site, at Smith’s Ford. It is possible that a slight warming of this section of river at this time could have increased productivity slightly, though this is not likely to have been a significant effect. Instead, backfeed water was being sourced from the scour valve on this date, resulting in poor quality anoxic water being released into the river.

Rates of warming or cooling downstream are also influenced by river discharge rates, with temperatures more rapidly reaching equilibrium during low flows. Consequently, the length of river where the temperature influence of the backfeed discharge is detectable will tend to be shorter during low river flows. Conversely though, the potential for the backfeed discharge to influence the temperature of the river is diminished at higher river flows, because it makes a smaller proportional contribution to the flow in the river.

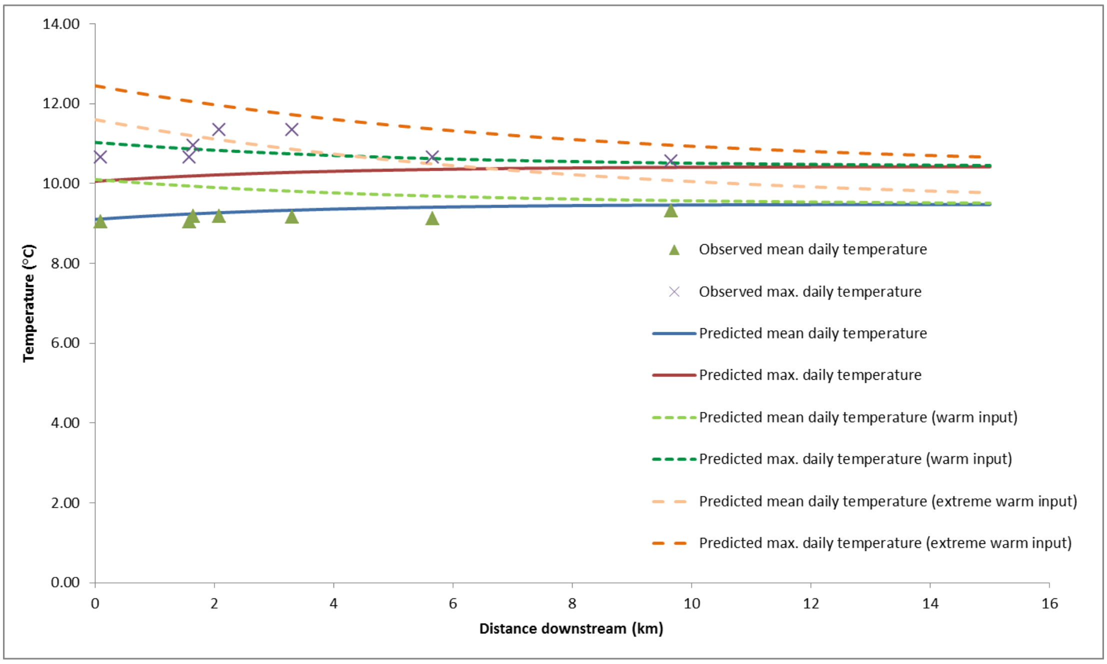


Figure 57. Observed and modelled longitudinal water temperature profiles downstream of the Maitai water supply weir on the South Branch for 15 April 2015, for three alternative backfeed temperature scenarios: 1) the recorded backfeed temperatures for that date, 2) a slightly warmer backfeed discharge based on recorded temperatures at the top (6 m) reservoir intake level for that date, and 3) a warmer backfeed discharge based on the maximum recorded reservoir surface temperature for this summer (22 °C).