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TEKAPO POWER SCHEME RECONSENTING: ASSESSMENT OF AQUATIC ENVIRONMENTAL EFFECTS

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Prepared for Genesis Energy Ltd

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EXECUTIVE SUMMARY

The Tekapo Power Scheme (TekPS) is owned and operated by Genesis Energy Ltd (Genesis). Resource consents for the TekPS expire on 30 April 2025 and Genesis has contracted the Cawthron Institute to assist with the assessment of ecological effects of the scheme as part of the reconsenting process.

This report provides an assessment of the existing aquatic environment in Lake Tekapo, Tekapo Canal, Tekapo River and the receiving waters (Lake Pukaki and Lake Benmore) that are influenced by the existing operation of the TekPS. The report should be read in conjunction with PDP (2025) and Waterways Consulting (2025), which provide more detail on hydrology and native fish assessments, respectively. We understand that no changes are being sought to the operation of the TekPS through the reconsenting process, therefore no further change to the existing environment is expected as part of continued operation.

Lake Tekapo

Lake Tekapo is a large, natural glacial lake. It is fed predominantly from the Godley River and its main tributary, the Macaulay River, and also by the Cass River. These rivers are glacial-fed, remote and largely unmodified. The TekPS altered Lake Tekapo by increasing its natural water levels and their fluctuation range. Water levels in Lake Tekapo have been controlled for hydro-generation purposes for 70 years following the commissioning of Tekapo A in 1951. The current regime specifies minimum and maximum lake levels within which the lake is to be managed.

Lake Alexandrina and Lake MacGregor also drain into Lake Tekapo. The level and ecology of Lake Alexandrina is not directly affected by the TekPS. There is a minor effect of occasional high lake levels in Lake Tekapo on the level of Lake McGregor. We expect this to have negligible effect on the ecology of Lake McGregor.

Water quality in Lake Tekapo is excellent, with low concentrations of nutrients, minimal phytoplankton growth and high dissolved oxygen concentrations, even in the bottom waters of the lake. Water clarity in Lake Tekapo has historically been low, due to inputs of glacial 'flour' (glacial silt) from the tributaries, but has been increasing in recent years due to change in precipitation patterns. Water clarity has increased in recent years, because of reductions of glacial flour within the rivers prior to entering the lake. This is an effect of climate change. Clarity is now close to double what it was in the previous decade and is likely to increase further. It is unlikely that the TekPS has resulted in any appreciable changes to water quality within Lake Tekapo.

Phytoplankton and aquatic plant (macrophyte) richness and abundance are naturally low in Lake Tekapo. The existing operation of the TekPS is unlikely to have resulted in any appreciable changes to phytoplankton in Lake Tekapo. The distribution of submerged aquatic plants, which is governed by the depth to which sunlight can penetrate, is typically confined to a relatively thin band around the lake edge in lakes with low water clarity. By increasing the range of water levels in Lake Tekapo, the existing operation of the TekPS has likely reduced aquatic plant distribution and abundance by exposing macrophytes to wave disturbance and desiccation during low lake levels. However, the maximum depth where aquatic plants are found increased in the period 2012–2017, likely due to the increasing water clarity allowing sunlight (and plants) to reach greater depths. The magnitude of effect of the TekPS can be numerically summarised as follows. Until the mid-2000s, macrophytes in Lake Tekapo grew down to 10.5 m deep, leaving 1.7 m (i.e. 16%) of littoral habitat outside of the depth range of the 8.8 m of annual water level fluctuation. Water clarity in Lake Tekapo has doubled and now the maximum extent of macrophytes is down to 21.3 m deep, while the range of water level fluctuation remains at 8.8 m. Therefore, the extent of littoral habitat beyond that potentially exposed by lake level variations has increased to 12.5 m. Considering the current water clarity of the lake as the baseline, the TekPS, through water level fluctuation, influences 41% of the potential productive littoral zone. By comparison, 26% of the productive littoral zone was affected prior to scheme commissioning in the 1950s and 88% was affected since the 1970s, until the onset of the recent trend of reduced glacial flour.

Dense populations of macroinvertebrates in lakes are often associated with aquatic plant beds. Macroinvertebrate richness and abundance is relatively low in Lake Tekapo, reflecting the limited aquatic plant growth in the lake (due to the historically naturally low water clarity caused by glacial flour). As for aquatic plants, the TekPS has likely reduced macroinvertebrate abundance and diversity due to it increasing the range of water level variation in Lake Tekapo. However, given the increasing water clarity of the lake, the relative effect of the TekPS on macroinvertebrate abundance and diversity has reduced and will reduce further if water clarity continues to increase.

There are several native fish species in Lake Tekapo; these are identified and assessed in the Waterways Consulting (2025) report. There are also salmonids such as brown trout, rainbow trout and Chinook salmon present in Lake Tekapo. However, due to the relatively low productivity of the lake, the fishery is naturally restricted. Nevertheless, it is more popular with anglers than Lake Pukaki (which is highly turbid), but much less popular than Lakes Benmore and Aviemore. Angler use of Lake Tekapo has increased since 1994/95, possibly due to increased salmonid abundance in response to the increasing productivity around the shallow margins of the lake as water clarity has improved. As mentioned above, the lake level regime in Lake Tekapo is influenced by the TekPS and contributes further to the naturally low productivity of the lake.

The ongoing operation of the TekPS has no more than minor effects on the water quality in Lake Tekapo. Water level fluctuations in Lake Tekapo resulting from TekPS operation impedes macrophyte growth in the variable zone. The loss of perennially wetted littoral habitat due to water level fluctuations has flow-on effects of low benthic macroinvertebrate production and restricted food to support the salmonid fishery. The annual range of water level fluctuations is not proposed to change with reconsenting; therefore, there will be no change to the effects on Lake Tekapo.

Tekapo Canal

The Tekapo Canal is a 26 km-long trapezoid-shaped channel that diverts water from Lake Tekapo, via generation at the Tekapo A power station, and then discharges into Lake Pukaki via the Tekapo B power station. It has a median and mean flow of 90 and 76 m^3/s, respectively.

The water quality in the canal is excellent, reflecting that of Lake Tekapo, including being relatively turbid (for a flowing waterbody) owing to naturally occurring glacial flour. Salmon farming takes place in the lower reaches. The existing operation of the TekPS has no adverse effect on the water quality within the Tekapo Canal.

The canal has developed the characteristics of a highly stable, deep river ecosystem. The aquatic vegetation cover in the canal consists of a community of macrophyte beds, including both native and introduced species. These macrophyte beds support an abundant community of macroinvertebrates with densities observed in the top 15% of rivers throughout New Zealand where comparable data are available. Native fish including common bully, upland bully and longfin eel are present in the Tekapo Canal, as discussed in the Waterways Consulting (2025) report. Juvenile kōaro have been observed anecdotally (pers. obs. John Hayes, Cawthron). The canal supports a nationally significant (and world-class) fishery for brown and rainbow trout and Chinook salmon, supported by natural recruitment, some stocking and escapees from the salmon farm. Salmonids in the canal attain sizes and abundances that are phenomenal relative to natural rivers in New Zealand. The canal system is now one of the most popular fisheries in New Zealand; angler usage has tripled since 1994, more than compensating for declines in angler participation that have occurred in the Tekapo River after the invasion of didymo.

It was originally believed that the exceptional canal fishery resulted directly from food waste leaving the salmon farms, yet the high macroinvertebrate and bully abundances observed in the canal suggests this is not necessarily the case. To address this, the contributions of farm-derived feed and wild prey to the diet of wild-caught trout were quantified using stable isotope analyses. The results suggest that the farm-derived food typically comprised between 16–22% of wild fish diet, although larger fish did have a higher farm-derived diet contribution. Hence, while salmon farming contributes to the size of the trophy fish, the canal would likely have a good fishery regardless.

The canal provides a habitat for productive macrophyte, macroinvertebrate and fish communities and supports an exceptional salmonid fishery. The on-going operation of the TekPS maintains the current state of the canal ecosystem. As the TekPS operation regime is planned to remain unchanged, the current state of the canal’s ecology and fishery is also expected to remain unchanged following reconsenting.

Tekapo River

Prior to construction of the TekPS, the Tekapo River was the outlet for Lake Tekapo. As a result of diversion first for Tekapo A (in 1951) and then later into the Tekapo Canal (in 1977), there is usually little or no surface flow in the upper reaches of the Tekapo River between the Lake Tekapo Control Structure and its confluence with Fork Stream (approximately 6.6 km downstream). The diversion of water from Lake Tekapo for the TekPS through the Tekapo Canal resulted in significant changes to the Tekapo River, including:

- substantially reduced flow in the Tekapo River, particularly above the Fork Stream confluence
- high water clarity associated with the diversion of glacial flour from Lake Tekapo
- reduced high-flow events conducive to greater annual production of periphyton and macroinvertebrates
- physical habitat (depths, velocities and substrate) downstream of the Grays River confluence that is highly suitable for trout food production and trout spawning.

The existing operation of the TekPS has meant that water quality in the Tekapo River largely reflects that of tributaries like the Fork Stream, Grays River and Mary Burn, rather than the glacial water from Lake Tekapo. Water quality is good in the Tekapo River and largely complies with the National Policy Statement for Freshwater Management (NPS-FM 2020) and the Canterbury Regional Plan (2018) – the only minor concern being night-time dissolved oxygen dropping to around 80% saturation, probably due to high biomass of the invasive introduced diatom didymo. Environment Canterbury monitors water quality in the Tekapo River at a site just upstream of the confluence with the Pukaki River (at Steel Bridge). Overall, water quality has always been relatively good at this site. However, there has been an increase in concentrations of nitrate and phosphorus in the lower river in recent years, likely due to the intensification of agriculture in tributary catchments.

Relatively high daily fluctuations in dissolved oxygen concentration (with associated relatively low daily minima) have been recorded and are caused by the relatively high biomass and cover of periphyton, which often exceed guidelines for the protection of trout habitat and general recreational aesthetic guidelines. The periphyton mats in the river include native algae and cyanobacteria, and didymo, which proliferates particularly in the upper and lower sections of the river. Didymo commonly reaches nuisance levels in natural lake-fed rivers due to the stable flow regimes, immobile substrate and low sediment supply, allowing it to accrue with little bed disturbance. The results of our longitudinal survey and the monthly sampling suggest that existing periphyton biomass occurs at 'nuisance' levels throughout the year. The long periods of steady flow that are experienced in the Tekapo River contribute to the accumulation of high biomass of periphyton. The ongoing operation of the TekPS results in a stable flow regime in the Tekapo River, providing good conditions for periphyton (including didymo) proliferation. This effect will not change with reconsenting. Didymo commonly reaches nuisance levels in natural lake-fed rivers (e.g. the Buller, Gowan, Clutha and Hurunui Rivers). Consequently, didymo would probably flourish in the Tekapo River, even if it were flowing naturally in the absence of the TekPS. However, we recognise that the Tekapo River would have had a naturally higher glacial sediment load than the other unregulated lake outlets mentioned above, which might have influenced didymo growth.

The macroinvertebrate communities in the Tekapo River have moderate ecosystem health scores (MCI – macroinvertebrate community index), indicative of a moderately nutrient/organically enriched river with abundant periphyton on the riverbed, reflecting the stable flow regime and presence of didymo. Despite some indications of negative impact from catchment land use intensification and proliferations of didymo based on ecosystem health metrics, the macroinvertebrate communities in the Tekapo River provide an abundant food resource for fish and birds. The macroinvertebrate communities achieve moderate to high densities and biomass, with a typical mix of both large and small invertebrates. The effects of the existing operation of the TekPS on macroinvertebrates in the Tekapo River prior to the arrival of didymo were likely positive, with reduced fine sediment and increased water clarity (due to diversion of glacial lake water to the canal) and a stable flow regime. However, these conditions also provide good habitat for didymo, which has likely increased the proportion of pollution-tolerant macroinvertebrates, many of which are small and less preferred as food for fish and birds. This effect will not change with reconsenting.

As with other fisheries in the Waitaki catchment, the Tekapo River contains brown and rainbow trout. Sockeye salmon also occur in the river periodically as they run up from Lake Benmore to spawn. Salmonid habitat in the Tekapo River is usually limited to below the Fork Stream confluence where there are substantial permanent flows. Prior to the arrival of didymo, the Tekapo River supported a very popular and highly regarded trout fishery. During that time, the existing operation of the TekPS likely had positive effects on salmonid abundance in the Tekapo River, due to reduced fine sediment and improved water clarity resulting from diversion of glacial Lake Tekapo water. Angler use has declined since the appearance of didymo, but the Tekapo River continues to be a moderately popular fishery compared with other rivers throughout New Zealand. The decline in angling use aligns with the result of our survey of trout abundance in the Tekapo River in 2021, which showed trout abundance was about half of that reported prior to didymo arrival. However, despite these adverse changes associated with didymo, trout abundance in the Tekapo River is still in the top 30% of New Zealand rivers where comparable data are available.

The ongoing operation of the TekPS results in an existing environment within the Tekapo River that provides good water quality and a stable flow regime. This supports a productive ecosystem (abundant periphyton and invertebrates); habitat for six species of native fish; and habitat for brown trout, rainbow trout and sockeye salmon, which in turn supports a relatively popular trout fishery. Periphyton, particularly the invasive didymo, is currently abundant in parts of the Tekapo River, which is reflected in the relatively high proportion of pollution-tolerant macroinvertebrates in the river and a less popular fishery than prior to didymo. The overall effects of the existing operation of the TekPS on the Tekapo River are somewhat difficult to assess given the invasion of didymo. The generally positive effects of the TekPS scheme on the salmonid fishery in the Tekapo River have been reduced, due to the negative effects associated with didymo. However, the river still supports important values and on-going operation of the TekPS is not expected to have a more than minor effect on these existing values.

Lake Pukaki

Lake Pukaki is managed by Meridian Energy. The lake receives water discharged from the Tekapo Canal. The lake is microtrophic (very low nutrient levels) and has naturally high turbidity owing to glacial flour in the water derived from the large proportion of glaciation within the catchment. Lake Pukaki has low macroinvertebrate diversity and supports native fish populations, including kōaro, upland and common bullies, and a remnant population of longfin eels. Brown and rainbow trout are also present, as are land-locked sockeye salmon, which have become more abundant in recent years. Water entering the lake via the Tekapo Canal has excellent water quality, slightly better than that of the receiving environment. The existing operation of the TekPS therefore has no adverse effect on Lake Pukaki.

Lake Benmore

Lake Benmore is managed by Meridian Energy. The lake consists of two essentially independent flooded river valleys, the Ahuriri Arm to the south (receiving water from the Ahuriri River) and the Haldon Arm to the north. The Haldon Arm receives water from the Tekapo River and water from the Ohau Canal.

Water quality in Lake Benmore is generally good. The lake has a 10-year mean trophic level index (TLI) score of 2.18, classifying it as oligotrophic[1]. The possibility that didymo and other periphyton, sloughed from the Tekapo River during large flow releases, affect water quality in the Haldon Arm was investigated. The modelling study assessed a 'worst case scenario' for didymo biomass in the Tekapo River and assumed very high scouring and transport rates. The results showed that there is negligible risk from didymo and other periphyton accumulations to dissolved oxygen in Lake Benmore. This assessment, coupled with our assessment of monitored water quality parameters, indicates that the TekPS has no adverse effects on Lake Benmore.

Environmental effects

As there are no changes to the operation of the TekPS being sought as part of the reconsenting process, we do not expect any changes to the existing environment. Two key broad-scale environmental factors have become evident in recent years and are influencing the interactions between the TekPS and the surrounding environment. The effects of a recent trend of increasing water clarity in the lake is related to reduced glacial flour load linked to changes in precipitation patterns (and hence further reducing the existing effects of the TekPS). The other is didymo, which thrives in stable, low nutrient rivers and invaded the Tekapo River in 2007. It will have affected the macroinvertebrate community in the Tekapo River and probably has contributed to a decline in trout fishery. This has, in turn, negated the positive effects that the TekPS provided to the trout fishery in the Tekapo River.

[1] Oligotrophic indicates low concentrations of phytoplankton, nitrogen and phosphorus. It is a classification on the trophic level index (TLI) which ranges from microtrophic (extremely low) through oligotrophic, mesotrophic and eutrophic through to supertropic/hypereutrophic (extremely high nutrient enrichment).

Overall, the existing operation of the TekPS:

- has no effects on the water quality and contributes to the naturally low productivity and restricted food supply for salmonids in Lake Tekapo through increasing the range of water level fluctuation
- provides a productive environment for macroinvertebrates and salmonid fish in the Tekapo Canal, supporting a popular fishery
- has minor adverse effects, as well as minor positive effects, on water quality and aquatic ecology within the Tekapo River
- has no more than minor adverse effects on receiving waters in Lake Pukaki and Lake Benmore.

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1. INTRODUCTION

1.1. Purpose of this report

The Tekapo Power Scheme (TekPS) is owned and operated by Genesis Energy Ltd (Genesis). Resource consents for the TekPS expire on 30 April 2025 and Genesis has contracted the Cawthron Institute (Cawthron) to assist with the assessment of ecological effects of the scheme as part of the reconsenting process. This report provides an assessment of the existing aquatic environment in the Tekapo and upper Waitaki catchments that are influenced by the TekPS. The report should be read in conjunction with PDP (2025) and Waterways Consulting (2025), which provide more detail on hydrology and native fish assessments, respectively. The report summarises existing information on the aquatic environment within the Tekapo catchment and provides updated information from recent Cawthron studies conducted in association with the reconsenting process to fill information gaps identified during that process. We understand that no changes are being sought to the scheme operation through the reconsenting process; therefore, no further change to the existing environment is expected as part of continued operation of the TekPS.

1.2. Tekapo Power Scheme overview

The TekPS controls Lake Tekapo water levels for storage purposes and diverts water from Lake Tekapo to Lake Pukaki along the 26-km Tekapo Canal. Electricity is generated at Tekapo A power station (Tekapo A) and Tekapo B power station (Tekapo B). Tekapo A is situated at the start of the canal and Tekapo B in Lake Pukaki at the downstream end of the canal. Tekapo A was commissioned in 1951, while the Lake Tekapo Control Structure, which controls the levels of Lake Tekapo, was completed in 1954. The Tekapo Canal and Tekapo B were completed in the 1970s, enabling the outflow of Tekapo A to be diverted along the canal into Lake Pukaki. The TekPS diverts almost all water exiting Lake Tekapo through the Tekapo Canal, except occasionally, for operational reasons, when water is spilt down the Tekapo River. There are also periodic recreational releases of water down the upper Tekapo River that flow through the Tekapo White Water Course downstream of the Lake Tekapo Control Structure. This water is transferred into the canal via the Lake George Scott Control Weir.

Prior to construction of the TekPS, the Tekapo River was the outlet for Lake Tekapo. Following commissioning of Tekapo A in 1951, there usually has been no outlet discharge from Lake Tekapo in the upper reaches of the Tekapo River between the Lake Tekapo Control Structure and Lake George Scott. A reduced, persistent flow forming an interconnected series of pools remains in the upper reaches due to groundwater seepage. Following commissioning of Tekapo B, and the opening of the Tekapo Canal, in 1977, flow was similarly reduced in the Tekapo River between Lake

George Scott and its confluence with Fork Stream (approximately 6.6 km downstream from the Tekapo River outlet from Lake Tekapo). From Fork Stream down, tributary flows and groundwater inputs provide a persistent and increasing flow until the river enters Lake Benmore (Figure 1).

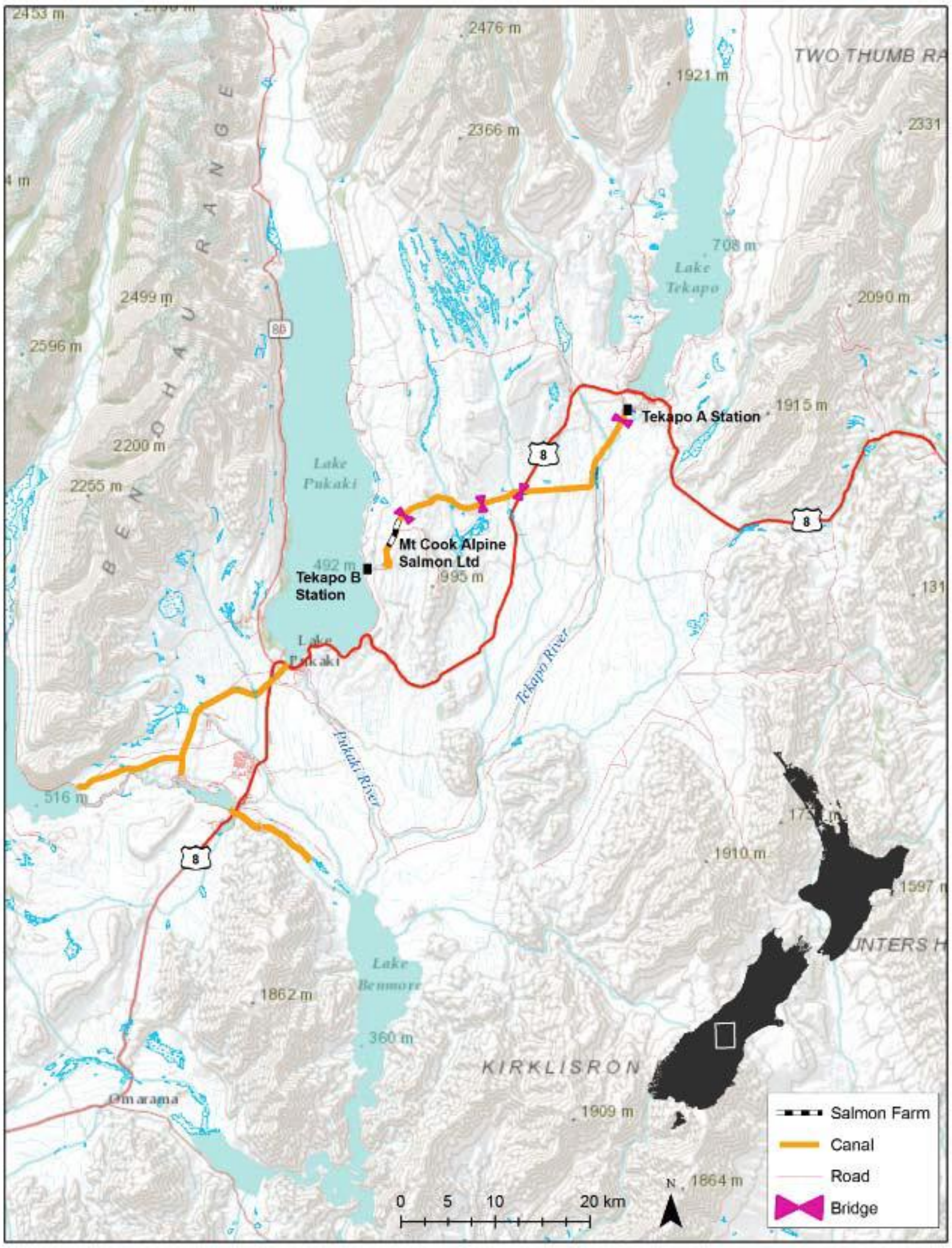

Figure 1. Location of Lakes Tekapo, Pukaki and Benmore; and the Tekapo Canal, Tekapo River and other catchment features.

1.3. Report structure

This report is focused on aquatic environmental effects associated with the TekPS. For each of the major waterbodies within the TekPS footprint, which includes Lake Tekapo, the Tekapo River and Tekapo Canal (Figure 1), we have summarised environmental information on the existing environment under the major ecological domain headings, including physical habitat, water quality, periphyton/macrophytes and salmonid fisheries. We also summarise the existing environment within receiving waterbodies (Lake Pukaki and Lake Benmore) that are influenced by the TekPS. This report complements reporting by PDP and Waterways Consulting on hydrology and native fish, respectively (PDP 2025; Waterways Consulting 2025). Our assessment of environmental effects follows the summary of environmental information for each environmental domain.

This report includes a review of the substantial amount of information available on the catchment that has been generated as part of previous investigations associated with the development and operation of the TekPS and the Combined Waitaki Power Scheme (CWPS), which also includes the six power stations owned and operated by Meridian Energy Ltd (Meridian). Over the past three years, Genesis has commissioned further investigations to update existing knowledge and / or fill knowledge gaps. Within this report, the investigations that were undertaken specifically to support the current reconsenting application are described under sub-headings that start with 'Cawthron investigation' and are described in some detail since they have not been reported elsewhere.

1.3.1. Consideration of effects

The TekPS has been operating for over 40 years. Its construction involved some substantial changes to the environment; specifically, changes to the lake level regime within Lake Tekapo and construction of the Tekapo Canal, which diverted water that would have naturally flowed down the Tekapo River to the Tekapo Canal and subsequently Lake Pukaki. We understand that no changes are being sought to the scheme operation through the reconsenting process, therefore no change to the existing environment is expected as part of continued operation of the TekPS. We also understand that the existing environment, with the infrastructure and current operating regime in place, is recognised as the environmental baseline for assessment of effects associated with the reconsenting of the TekPS. Therefore, our assessment focuses on the effects of the on-going operation of the TekPS on values currently supported by waterways influenced by the TekPS. It does not attempt to compare current state with conditions that were likely present before the development of the TekPS.

2. LAKE TEKAPO

2.1. Physical description

Lake Tekapo was formed from glacial processes. It has a surface area of 86.8 km^2, is steep-sided to a depth of 90 m, and ends in a flat bottom. The main inflows are the Godley–Macauley and Cass rivers, originating in the main divide. PDP (2025) estimated a mean total inflow to Lake Tekapo of around 83 m^3/s. Owing to fine glacial silt or 'flour' in the inflows, the lakebed sediments are mainly silty clays, which become finer-grained towards the southern end (Irwin 1978). Lake Tekapo is a monomictic[2] lake, developing a deep thermocline during the summer months. Surface water temperatures typically range from 6.2 to 16.6 °C.

Before the construction of Tekapo A and the Lake Tekapo Control Structure, Lake Tekapo water levels were controlled by natural inflows and outflow. Prior to 1951, lake levels varied between 704.4 and 707.1 metres above sea level (masl). Lake Tekapo water levels are now controlled by Genesis within the consented minimum and maximum levels. The maximum and minimum possible extent of Lake Tekapo could now be considered 710.9 masl and 701.8 masl, respectively.

Maximum and minimum consented operating levels vary throughout the year; however, the normal minimum and maximum lake levels are 702.1 masl and 710.6 masl, respectively. The minimum operating level between 1 April and 30 September is 702.1 masl. Between 1 October and 31 March, it is normally 704.1 masl, but can be further reduced to 701.8 masl in an electricity supply emergency. Lake levels are continuously monitored by Genesis near the Lake Tekapo Intake Structure.

The current maximum operating levels for Lake Tekapo are:

- September to February – 709.7 masl
- March – 710.0 masl
- May – 710.6 masl
- April and August – 710.3 masl
- June and July – 710.9 masl.

The lower part of the range has been entered less often since 1991, with minimum lake levels for the periods 1951-1978 and 1979-1990 of 701.7 masl and 702.1 masl respectively. This compares with a minimum of 702.9 masl for the period 1991–2020. (PDP 2025). A detailed overview of the hydrology of Lake Tekapo and surrounding groundwater are provided in PDP (2025).

[2] Monomictic refers to the thermal mixing regime whereby the lake stratifies (the surface water becomes more bouyant than the bottom water, thus seperating them by a density gradient) and mixes once per year.

2.2. Water quality

All the significant tributaries to Lake Tekapo (Godley, Macauley, Mistake and Cass rivers) have very low levels of land use intensity in their catchments. Much of the lake margin is used for low-intensity high country sheep farming, with limited areas under irrigation. The upper catchment of the lake is largely in the conservation estate and there is about 3% glaciation of the higher parts (Irwin & Pickrill 1983).

Lake Tekapo is microtrophic,[3] with a trophic level index (TLI) of 1.0–2.0. There was an exception in 2010 when the TLI briefly reached 2.1 – entering the range of oligotrophic waters (Figure 2). Monitoring by Environment Canterbury (ECan), available on LAWA (https://www.lawa.org.nz/explore-data/canterbury-region/lakes/lake-tekapo/ - accessed 05/08/2021), indicates that the TLI has fluctuated but remains microtrophic. Water clarity in Lake Tekapo, as in Lake Pukaki, is almost entirely affected by inputs of glacial flour, with little algal biomass or dissolved organic material (Winterbourn et al. 2008). Turbidity is usually higher over the summer months due to sediment-laden snowmelt (Irwin & Pickrill 1982). Yearly variations in clarity are caused by rain events that result in sporadic inputs of fine sediment. Based on historical data, the minimum recorded Secchi disc clarity for Lake Tekapo is 0.5 m and the maximum is 13.4 m, with a mean of 5 m (Jowett et al. 2012). Visual clarity, recorded by Secchi disc, has not been included in routine monitoring by ECan, but occasional Secchi measurements have been recorded.

[3] Microtrophic refers to low nutrient concentrations and minimal phytoplankton growth.

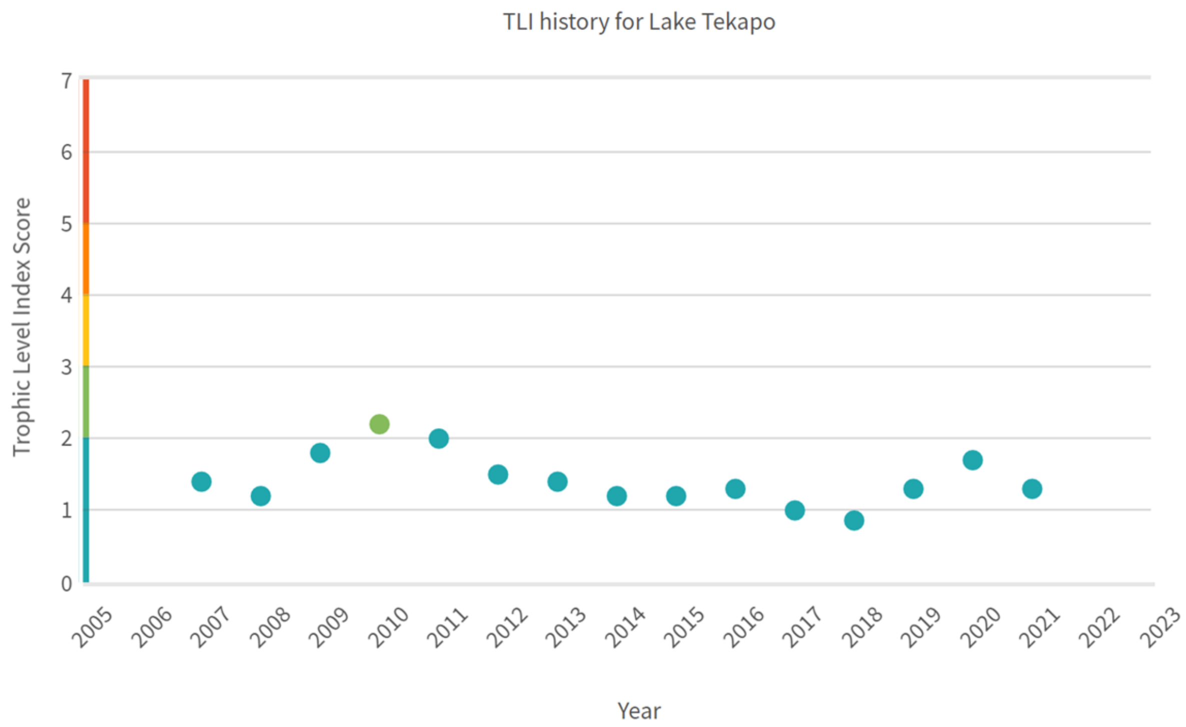

Figure 2. Annual trophic level index[4] (TLI) scores for Lake Tekapo between 2004 and 2019. Data are taken from lawa.org.nz. The colour coded Y-axis and dots are interpreted as follows: teal = microtrophic, green = oligotrophic, yellow = mesotrophic, orange = eutrophic, red = supertrophic.

ECan monitors water quality monthly during summer (December to April). This monitoring shows that Lake Tekapo water quality is excellent, other than its historically naturally low clarity owing to glacial flour inputs. It is well oxygenated at all depths and has consistently low concentrations of ions, including the primary plant nutrients nitrogen and phosphorus. Water clarity (based on NTU) appears to have improved in recent years (ECan state of the environment monitoring). Visual clarity is now close to double what it was between 1990 and 2010. There is a possibility that lake level fluctuations could exacerbate the resuspension of fine sediment by wave action in the lake margins. However, Single (2022) suggests that the lake shoreline morphology has largely adjusted to the current operating regime. Therefore, lake level variations as a result of the TekPS are unlikely to have resulted in any appreciable changes to water quality.

[4] Trophic level index (TLI) is a metric measuring the level of nutrient enrichment in the water column of a lake. The TLI value, on a scale of 0–7, is an aggregate score calculated using concentrations of total nitrogen (TN), total phosphorus (TP), chlorophyll-*a* and, optionally, visual clarity (Secchi depth). TLI in Lake Tekapo did not include clarity.

2.3. Phytoplankton

Phytoplankton are photosynthetic microorganisms that live within the water column and form the basis of aquatic food webs in lakes. Phytoplankton biomass and production, as indicated by concentrations of the photosynthetic pigment chlorophyll-*a*, are low in Lake Tekapo. The low productivity arises from low nutrient concentrations and naturally low water clarity – owing to naturally high levels of glacial flour – in a deep-water column. The phytoplankton community is dominated by the diatoms *Cyclotella* spp. and *Gymnodinium* spp., which are typical of low productivity South Island lakes (Flint 1966). The TekPS is unlikely to have resulted in any appreciable changes to phytoplankton in Lake Tekapo.

2.4. Macrophytes

The macrophyte community comprises *Myriophyllum elatinoides*, *Ranunculus fluitans* and *Potamogeton cheesemanii.* This community was first described in 1970 (Hill 1970) and has essentially remained unchanged (Sutherland & Burton 2016). Among the 17 natural and hydro lakes in the South Island surveyed by Stark (1993), Lake Tekapo was ranked the lowest for taxonomic richness and densities of submerged macrophytes. The low taxonomic richness of macrophytes is predominantly a result of the natural low water clarity of the lake. Macrophytes are therefore restricted predominantly to the lake margins, making them vulnerable to changes in lake levels. The TekPS has increased the magnitude of water level variation in Lake Tekapo, which has restricted the upper extent and productivity of macrophytes in the lake, both of which are discussed in Section 2.8 of this report.

Increases in lake clarity over the past two decades have resulted in the Lake Submerged Plant Indicator (LakeSPI) improving by 38% between 2012 and 2017, while the maximum depth of aquatic plants has increased from 10.8 m to 21.3 m (NIWA LakeSPI https://lakespi.niwa.co.nz/). This means that macrophytes are now present in areas beyond the margins affected by lake level fluctuation resulting from the operation of the TekPS. Therefore, previously reported adverse effects of the TekPS on macrophytes in Lake Tekapo (James & Graynoth 2002) should continue to reduce over time if water clarity in the lake continues to increase. Increased clarity will also benefit phytoplankton production in the limnetic zone[5], by increasing the euphotic depth[6]. However, the positive response of macrophytes to increased clarity will be greater than that of phytoplankton.

[5] Limnetic zone refers to the open water area of the lake where the water column is deeper than the extent of light penetration.
[6] Euphotic depth refers to the depth over which light can penetrate to allow photosynthesis by phytoplankton, submerged macrophytes and attached algae.

No invasive aquatic macrophytes occur in the lake. In a survey of the Waitaki hydro lakes, Sutherland and Burton (2016) found that Lake Tekapo presents a low risk of developing invasive macrophyte issues. They found no invasive macrophytes in a snorkel/dive survey along the beach in front of the Tekapo township. Lake Tekapo does contain the invasive benthic mat-forming algae *Didymosphenia geminata* (didymo), although this does not occur at nuisance levels.

2.5. Macroinvertebrates

The invertebrate community in Lake Tekapo has low diversity and abundance. Among 19 South Island lakes surveyed by Timms (1982), Lake Tekapo was ranked 16th and 13th lowest in terms of benthic invertebrate species richness and biomass, respectively; ranking above Lake Pukaki but below Ohau. Similarly, Stark (1993) found that Lake Tekapo had low diversity and abundance of invertebrate taxa relative to other large lakes in the South Island. Macroinvertebrates in lakes are often associated with macrophytes. The production of macroinvertebrates in lakes increased at a 1:1 rate, with increasing benthic primary production (e.g. macrophytes) both across and within lakes (Vadeboncoeur & Power 2017). Therefore, the low diversity and abundance of macroinvertebrates reflects the naturally turbid conditions and low light penetration in Lake Tekapo, which reduce abundance and diversity of the macrophyte community. As discussed above for macrophytes, the increased variation in lake levels due to the TekPS will have further contributed to the naturally low macroinvertebrate abundance and diversity. However, the recent increases in water clarity in the lake means that macrophytes and macroinvertebrates can occupy deeper areas of the lake not exposed to lake level variations. Therefore, the effects of the TekPS on macrophytes and macroinvertebrates have been reduced relative to 20 years earlier and will reduce further if water clarity continues to increase as it is assumed to do due to climate change. These effects are discussed in more detail in Section 2.8.

2.6. Native fish

Lake Tekapo has resident populations of common bully (*Gobiomorphus cotidianus*) and kōaro (*Galaxias brevipinnis*). Longfin eel (*Anguilla dieffenbachii*) have historically been present in the lake; however, none were caught in a recent survey (Waterways Consulting 2025). As mentioned above, more details on native fish communities and any potential effects of the TekPS are discussed in detail in Waterways Consulting (2025).

2.7. Salmonid fisheries

Lake Tekapo supports populations of three introduced salmonids: brown trout, rainbow trout and Chinook salmon. Relative to similarly sized adjacent lakes, Lake Tekapo is more popular with anglers than Lake Pukaki, but much less popular than Lakes Benmore and Aviemore. Angler usage will be broadly related to productivity of the fishery. Salmonid production in Lake Tekapo can be expected to be comparatively low, mainly due to the low primary production, related to natural low water clarity. A survey of trout abundance across eight South Island lakes undertaken during the late 1990s found that trout in Lake Tekapo were small and occurred at low densities relative to those in clear lakes (James & Graynoth 2002).

Due to the turbid water, shore anglers fishing Lake Tekapo tend to target relatively clear water at tributary stream mouths such as the Lake McGregor and Cass River outlets (Kent 1998). Boat angling (e.g. trolling) is thought to have become increasingly popular in Lake Tekapo over the last two decades (Hamish Stevens, Central South Island Fish & Game Officer, pers. comm.). Angler usage of the lake has increased since 1994/95, perhaps due to the increasing water clarity. National Angler Survey estimates of angler usage of Lake Tekapo range from 3,000 (1994/95 season) to 8,910 (2014/15) angler days of effort (Unwin 2016) (7,550 and 8,730 angler days were estimated for the 2007/08 and 2001/02 seasons, respectively). This makes it a moderately popular lake fishery on a national scale relative to lakes of a similar size.

While the lake level fluctuations associated with the TekPS have affected macrophyte and macroinvertebrate abundance and diversity in the shallow margins of the lake, the trend of increasing water clarity is likely to improve productivity in Lake Tekapo and hence improve the conditions for salmonids and the lake's angling values. These effects are discussed in more detail in Section 2.8.

2.8. Lake Tekapo effects assessment

The main effect of the TekPS on Lake Tekapo is increased water level fluctuations over those naturally occurring, reducing the extent of macrophytes in the littoral zone[7].

This assessment of this effect, relative to other potential effects, is made in the context of general knowledge on the different zones within a lake and how they contribute to ecosystem biodiversity and productivity. The littoral zone plays a disproportionately large role in supporting the ecology in low nutrient lakes such as Lake Tekapo (Vadeboncoeur et al. 2002). In much the same way as coral reefs function in tropical waters, macrophyte beds provide important structure in lakes that support the growth of periphyton and macroinvertebrates, which in turn support fish.

[7] Littoral zone refers to the shallow water around the lake margin where light reaches the lake bed.

Even within lakes with very small littoral zones and very expansive deep open-water habitat (e.g. Lake Taupō), littoral food items can comprise over 80% of the diet of fishes (Stewart et al. 2017). The extent of the littoral zone (and thus its volume) is determined by the maximum depth that light can penetrate – the euphotic depth. Fluctuating water levels and the associated intermittent drying/exposure of the upper extent of the littoral zone prevent macrophyte growth in this variable zone. This reduces the amount of production available to higher trophic levels from the littoral zone.

Prior to the TekPS scheme, the lake level naturally fluctuated over a range of 2.7 m (PDP 2025). Historical Secchi data (i.e. water clarity) suggest that, in the past, the euphotic depth was 10.2 m (i.e. 2× median Secchi depth; see French et al. 1982). This suggests that 74% of the potential euphotic zone (i.e. 7.3 m) supported a stable and productive littoral ecosystem. The commissioning of the TekPS increased the water level operating range to 8.8 m (PDP 2025), which would affect 86% of the euphotic zone, resulting in only 14% (1.2 m) of productive littoral zone. Relative to the naturalised lake level variation, the level variation caused by the TekPS has reduced the productive littoral zone by 84% (i.e. (7.3 to 1.2 m) / 7.3 m).

A recent trend of increasing water clarity in the lake is related to the reduced glacial flour load linked to change in precipitation patterns. This effect is driven by climate change through glacial retreat. The reduced glacial flour load has doubled the water clarity and increased the euphotic depth to > 20 m. A recent macrophyte survey showed that the maximum macrophyte depth has increased to 21.3 m (Sutherland & Burton 2016). This increase in euphotic depth means that there is at least 12.5 m of stable productive littoral zone not exposed by water level fluctuations. Considering the current water clarity of the lake as the baseline, the effect of the TekPS, through water level fluctuation, removes 41%[8] of the potential productive littoral zone. By comparison, 26% of the productive littoral zone was affected prior to commissioning of the scheme in the 1950s, and 88% was affected since the 1970s, until the onset of the recent trend of reduced glacial silts. Compared to other large South Island lakes, based on data from James and Graynoth (2002) and Stark (1993), the percentage of littoral habitat affected by ongoing lake level fluctuations in Lake Tekapo is greater than Lakes Wanaka (4%), Hawea (29%) and Te Anau (14%); comparable to Lake Ohau (41%); and less than Pukaki (> 1000%) (Table 1). It is difficult to attribute effects to the TekPS. On one hand, 41% of the potential littoral extent is impacted by water level fluctuations; however, this is within the upper and lower extent of lake levels. On the other hand, the extent of littoral habitat below the variable zone is greater than it ever has been historically. The current consent does not propose changes in the annual range of water level fluctuations; therefore, there will be no change to the effects on Lake Tekapo.

[8] This value of 41% reduction in littoral habitat is calculated by: current lake level fluctuation (8.8 m) / euphotic depth (21.3 m).

Table 1 Comparison of water clarity (Secchi depth) and mean annual water level fluctuation (MAWLF) for 10 South Island lakes. The percent of littoral habitat affected by water level fluctuation is calculated from the euphotic depth (2× Secchi depth; French et al. 1982). Maximum (Z_{max}) and mean (Z_{mean}) depths are provided for context. All measurements are in m.

Lake	Z_{max}	Z_{mean}	MAWLF	Secchi	Euphotic zone impact (%)
Lake Coleridge	200	99	4.0	13.0	15.4
Lake Tekapo (post 2018)	120	69	8.8	10.7	41.3
Lake Tekapo (circa 2000)	120	69	8.8	5.1	86.3
Lake Pukaki	70	–	14.0	0.6	1,166.7
Lake Ruataniwha	28	–	0.3	0.6	25.0
Lake Hawea	384	170	11.0	18.8	29.3
Lake Wanaka	311	99	1.5	17.0	4.4
Lake Te Anau	417	169	2.7	10.0	13.5
Lake Manapouri	444	100	3.3	6.5	25.4
Lake Onslow	12	6	3.0	1.0	150.0
Lake Ohau	129	70	2.7	3.3	40.6

2.8.1. Consideration of effects on Lakes Alexandrina and McGregor

Lakes McGregor (709.2 masl) and Alexandrina (711.9 masl) are within the Lake Tekapo catchment. Analysis by PDP (2025) showed that water levels in Lake Alexandrina are not influenced by the TekPS; therefore, it has no effect on this lake. At times, the TekPS can have minor effects on the water level on Lake McGregor, when Lake Tekapo is filled to its maximum operating level (710.9 masl). However, the minor effect on water levels is expected to have a negligible effect on the ecology of Lake McGregor.

3. TEKAPO CANAL

3.1. Physical description

The Tekapo Canal is a 26 km-long permanent aquatic environment created by the diversion of Tekapo River water. Water enters the canal from the Tekapo A power station, along with some spill flows from Lake George Scott. The canal ends at the intake structure for Tekapo B power station. Flow through the canal varies, depending on several factors such as power demand and maintenance requirements. The discharge of Tekapo B power station provides the best indication of canal flow, with median and mean flows of 90 and 76 m^3/s, respectively. The mean monthly flows are highest in late winter, 86 m^3/s, and lowest in October, 58 m^3/s (PDP 2025). There was no flow through the canal for about 8% of the time between 1991 and 2020, due to occasional 'parking' of the canal for maintenance activities (PDP 2025). The canal was designed for a flow of 130 m^3/s, which is the consented maximum.

The canal has a homogeneous trapezoid shape: the water surface width is about 35 m and the average depth is about 5.8 m. The side gradients are 1 (vertical):2 (horizontal) in the upper section of the canal (upper 15.8 km) and 1:2.5 in the lower section downstream of 15.8 km. The canal bed is composed of gravels and cobbles (Jowett et al. 2012), although some short sections are now lined with geotextile material (Kelly & Barter 2013). The construction and operation of the canal has created a highly stable aquatic environment – analogous to a large, deep spring-fed river.

Nine culverts along the length of the Tekapo Canal convey the flow in Fork Stream, Irishman Creek, Mary Burn and several unnamed waterways beneath the canal. Some culverts may act as a barrier to fish passage underneath the canal during some flow conditions, but this is likely to be beneficial in terms of reducing the number of salmonids that are able to migrate upstream into habitats occupied by the threatened native fish species that occupy some of these tributaries. This concept is discussed further in Waterways Consulting (2025).

3.2. Water quality

Because the water in the Tekapo Canal comes directly from Lake Tekapo, it is slightly turbid due to glacial flour, with suspended sediment concentration varying over the range 2–6 mg/L (Jowett et al. 2012) and decreasing in recent years as the lake has become clearer. Otherwise, the canal water is of a very high quality. The only potential significant influence on canal water quality is from the Mount Cook Alpine Salmon farm at the lower end of the canal, where waste organic material from the salmon farm is known to deposit (Kelly & Baisden 2014). However, water quality monitoring by the salmon farm operators shows that the farm has a minimal effect on water quality (Jowett et al. 2012), because of the large volume of water that passes through the cages.

3.3. Algal/macrophyte community

The bottom and side walls (Figure 3) of the Tekapo Canal contain extensive macrophyte communities (Gabrielsson 2013). Macrophyte surveys are undertaken annually in the Tekapo Canal as part of NIWA macrophyte surveys in the wider catchment. Macrophyte beds below the salmon farm comprise both native and introduced species, *Myriophyllum triphyllum*, *Potamogeton cheesemanii*, *Ranunculus trichophyllus* and the invasive Canadian pondweed, *Elodea canadensis* (Sutherland & Burton 2016). The same species composition was also observed in the upper reaches of the canal (Gabrielsson 2013).

Well-established periphyton mats, characteristic of a highly stable spring-fed river, are present near the waterline; but generally, macrophyte beds are the dominant vegetation type in the canal. Within the periphyton community, didymo is present throughout the surveillance area, forming mats on cobbles and on plants. However, didymo does not seem to be causing operational issues or obvious problems for instream ecology.

In summary, the Tekapo Canal has a well-established aquatic vegetation community consistent with a highly stable low-nutrient river such as a large spring-fed river or an outlet of a large stable lake.

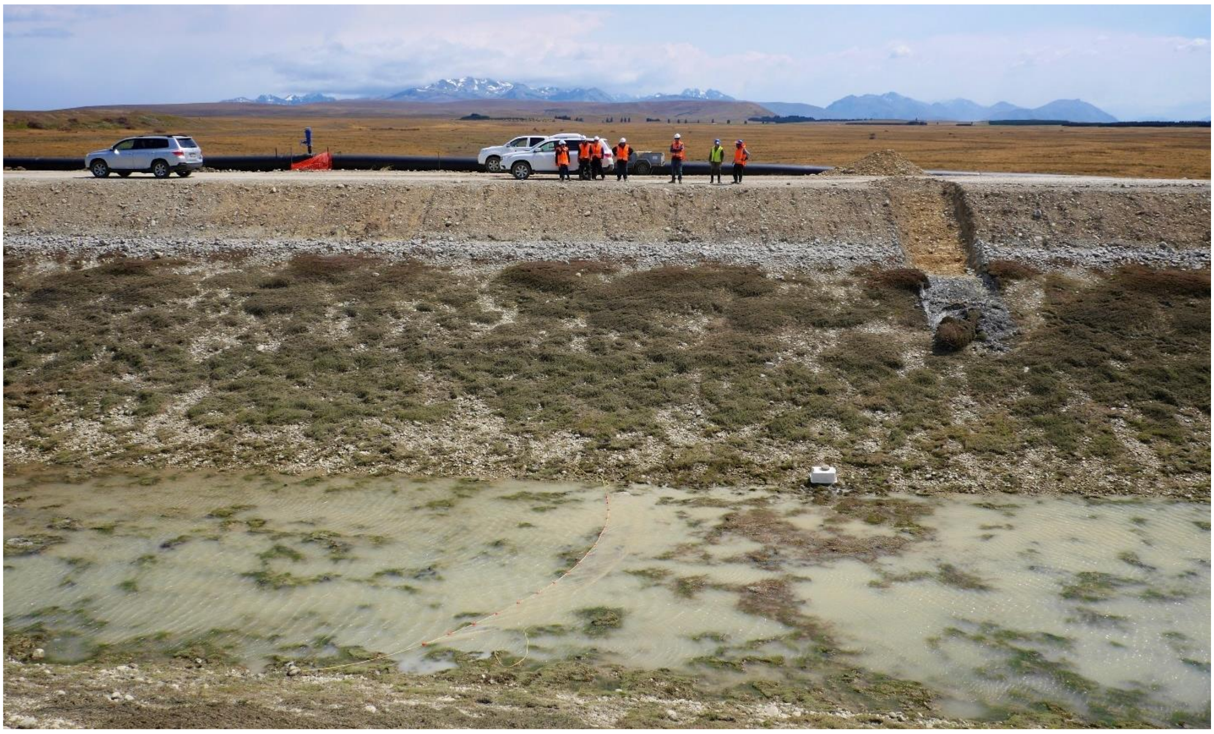

Figure 3. Dewatered section of the Tekapo Canal during a fish salvage operation undertaken in 2013. Note the heavily vegetated margins and bottom of the canal (habitat for invertebrates and fish).

3.4. Macroinvertebrates

No published records describing the macroinvertebrate community in the Tekapo Canal were found. Anecdotal observations from a fish salvage operation (Gabrielsson & Doehring 2014) indicate high densities of native fish (mainly bullies) and some invertebrate species (e.g. the introduced snail *Lymnaea* sp. in particular) (Figure 4). The aquatic macroinvertebrates inhabiting the bed on the sides and bottom of the Tekapo Canal are highly likely to be important for sustaining native fish populations and salmonids.

Figure 4. Contents of a seine net dragged along the bottom of the Tekapo Canal during a fish salvage operation in 2014. *Lymnaea* sp. snails, a known prey of large trout, can be seen on the net in the centre of the photograph.

3.4.1. Cawthron investigation: characterising the macroinvertebrate community in the Tekapo Canal

To boost the available information on macroinvertebrates in the Tekapo Canal, Cawthron analysed archived samples collected during maintenance operations when some sections of the canal were being relined – described in the next section.

Data collection

Five transects extending from the side to the middle of the Tekapo Canal were selected along a de-watered reach. Five corer samples (130 mm diameter, 0.5 mm mesh) were collected across each transect. After collection, each sample was placed in a labelled 600 ml pottle, preserved in 70% ethanol and transported to the laboratory.

For each transect (except Transect 2), two samples were randomly selected for processing – one sample from the side of the channel (sample A, B or C), and one from the bottom (sample D, E or F). The samples were processed using a modified version of macroinvertebrate sampling protocol P3 (Stark et al. 2001). The samples were washed through four sieves (mesh size ranging from 2.0 to 0.5 mm) to facilitate processing. The larger portions were placed into a white sampling tray and the smaller portions into Petri dishes. Invertebrates were then removed from the trays and dishes. Each taxon was identified, counted and recorded with the aid of a binocular microscope. A note was also made of the vegetative content in each sample. All samples from Transect 2 had been processed in 2014 to provide some basic invertebrate information for the Gabrielsson and Doehring (2014) report. The results from Transect 2 are included in this report for completeness.

Canal macroinvertebrate results

In total, 17 taxa were found in the samples (Appendix 1). The snail *Potamopyrgus antipodarum* was the most abundant taxon found overall, often contributing over 50% to the density in most of the samples. Oligochaete worms and nematodes (roundworms) were often the next most abundant taxa. The cased caddisfly *Oecetis unicolor* and the non-biting fly *Chironomus* sp. (commonly known as the bloodworm midge) also featured sporadically.

The Tekapo Canal invertebrate densities were higher than 50% of 88 rivers surveyed throughout New Zealand by Quinn and Hickey (1990); densities estimated from 11 of the samples were higher than the 15th percentile. This result indicates that a very productive environment exists in the Tekapo Canal upstream of the salmon farm.

Furthermore, the invertebrate samples we collected are likely to underestimate the true densities. As mentioned earlier, some invertebrate species noted in the field were not picked up during the invertebrate sampling. There were high abundances of the snail *Lymnaea* sp. in nets used to dredge the canal bottom for native fish in 2014 (see Figure 4), but the snails were rare in the core samples. This may have been due to difficulties in collecting the samples (i.e. it was sometimes difficult to push the corers into the stony cobble/gravel substrate), or because the distribution of animals (e.g. large snails) was clumped and the probability of sampling a clump was low, given the few samples taken. Furthermore, the more mobile animals were able to swim away, thereby avoiding collection (e.g. damselfly larvae).

3.4.2. Canal macroinvertebrate summary

Overall, the Tekapo Canal is a very productive aquatic environment with a macroinvertebrate community that is more representative of a lake environment than a river, reflecting the very stable flow regime and the high water quality. The macroinvertebrate communities present are an important food source for native fish and salmonids.

3.5. Native fish

The Tekapo Canal has populations of common bully (*Gobiomorphus cotidianus*), upland bully (*Gobiomorphus breviceps*) and longfin eel (*Anguilla dieffenbachii*). Juvenile kōaro (*Galaxias brevipinnis*) are anecdotally present in the canal, based on bankside observations (pers. obs. Dr John Hayes, Cawthron). The two species of bully are known to reach high abundances in the Tekapo Canal (Gabrielsson & Doehring 2014). More details on native fish communities and any potential effects of the TekPS are discussed in detail in Waterways Consulting (2025).

3.6. Salmonid fisheries

The Tekapo Canal contains brown and rainbow trout and Chinook salmon that attain phenomenal sizes and abundances relative to salmonids in natural rivers in New Zealand (Holmes 2011; Gabrielsson 2013). Accordingly, the Tekapo Canal is an exceptionally popular and important recreational fishery. Unwin (2016) estimates that anglers spent 23,050 days of effort fishing the Tekapo Canal over the 2014/15 angling season, making the canal one of the most popular 'river' fisheries in New Zealand. In a national survey that excluded Lake Taupō, the upper Waitaki hydro canals (combined) are now the most popular salmonid fishery in New Zealand. Usage has tripled since the earliest national angler survey assessments on the canal in 1994/95.

A DIDSON (Dual-frequency Identification Sonar) survey conducted by Cawthron during June 2011 revealed that the highest densities of adult salmonids occur in the vicinity of the salmon farms, and in the first 100 m below Tekapo A power station (Holmes 2011). Unsurprisingly, this is where most of the fishing effort is focused (Adams 2017).

Early investigations of the fishery values in the Ohau and Pukaki hydro-canals report poor-quality fisheries because of inadequate food resources (James 1990; Bloomberg & Graynoth 1991). However, since the establishment of the salmon farms, fish living in the Tekapo Canal can take advantage of commercial fish food that drifts beyond the salmon farm enclosures. The Tekapo Canal now has a reputation for yielding high catch rates of exceptionally large (> 4.5 kg) trout (Adams 2017). The nutrient loss from the farm may also boost the benthic productivity downstream, thereby indirectly supplementing the food resource for trout and escaped salmon. Accordingly, there is a popular perception that the nutrients derived from the salmon farms are the primary cause of the high fishery values in the upper Waitaki canals. However, food resources and fish numbers observed well upstream of the salmon farm enclosures, during the Tekapo Canal remediation project, suggest that the canal has matured into a highly productive ecosystem in areas unaffected by the salmon farms. It is possible that the canal would support a reasonably good-quality fishery without the influence of the salmon farms (Gabrielsson 2013 and Section 3.4 of this report).

Trout recruitment in the canal is thought to be sustained by juveniles migrating downstream from Lake Tekapo, a percentage of which survive passage through the turbines at Tekapo A power station (Davies 1988; Cada 1990). Trout can also enter the canal via a spillway from Lake George Scott that is connected to the Tekapo River during water releases from the dam at the Lake Tekapo Control Structure, although the relative contribution of these recruitment sources is unknown. In addition to natural recruitment sources, Chinook salmon are accidently released occasionally into the canal from the Mount Cook Alpine Salmon farm located at the lower end of the Tekapo Canal.

Recently, successful spawning of rainbow trout has been observed in the upper reaches of the Tekapo Canal, where some areas of the canal have pockets of gravels conducive to salmonid spawning. Central South Island Fish & Game have recently implemented a seasonal closure in this area to protect fish spawning (Adams 2020).

3.6.1. Cawthron investigation: quantifying the contribution of salmon farm-derived food to the diet of trout in the Tekapo Canal

The common assumption among anglers that residual feed escaping the salmon farm pens is the primary factor contributing to the exceptionally large trout in the Upper Waitaki hydro-canals currently remains speculative. However, highly productive communities of macroinvertebrates and small fish (bullies) are found in the Tekapo Canal and very likely contribute to the productivity of the salmonid populations. Cawthron undertook an investigation of the relative influence of salmon farm food versus natural food in the Tekapo Canal using stable isotope analysis of trout flesh samples. Stable isotopes are an environmental tracer that can be used to identify a ‘fingerprint’ for food sources originating from different locations and positions within the food chain. Different energy pathways, such as terrestrial versus aquatic, have distinct $\delta^{13}C$ (carbon) signatures. Animals that feed at higher trophic positions have higher $\delta^{15}N$ (nitrogen) values. In the case of the Tekapo Canal, salmon farm food contains marine-derived nutrients that have distinct $\delta^{15}N$ and $\delta^{13}C$ signatures compared with food produced within the canals (i.e. macroinvertebrates and small fish). When combined with statistical-based diet apportionment models, stable isotope data can be used to quantify long-term (i.e. weeks to months) diet composition of animals.

Stable isotope data collection and analysis

Fish flesh samples were collected during March 2012. Flesh samples from farmed salmon that were assumed to feed exclusively on the farm food, along with samples of the farm food itself, were supplied by Mount Cook Alpine Salmon. The farm food samples were used to represent salmon farm subsidies available to wild trout and the farmed salmon, and provided a control to validate observed farm food contributions within the wild trout populations. Common bullies (*Gobiomorphus cotidianus*) were collected at six sites representing canal reaches upstream, within proximity of, and downstream of, the salmon farm. The bullies, which indicate the stable isotopic signature of within-canal production, were used to represent the wild diet for trout. Comparing isotope signatures of bullies collected at and below the salmon farm to those collected above further enabled investigation into whether the diet of ‘wild’ bullies was subsidised by farm-derived products. Samples of wild trout caught in the canal were collected from anglers who allowed researchers to remove trout tissue samples from their catch. In total, four brown trout (all at Sites 1 and 2 upstream of the salmon farm) and seven rainbow trout (three within proximity of the salmon farm, three upstream and one downstream) were sampled. The lengths of all sampled trout were measured in the field.

Upon arrival at the laboratory, fish tissue samples were oven-dried and homogenised into a fine powder. Samples were then sent for determination of δ15N and δ13C signatures at the National Isotope Centre at GNS Science in Lower Hutt. Detailed information on stable isotope analysis can be obtained from the GNS website (https://www.gns.cri.nz/Home/Services/Laboratories-Facilities/Stable-Isotope-Laboratory/Prices-Analytical-methods/Carbon). Carbon isotope data were corrected for interference from variable lipid content by applying a numerical correction using reported tissue %N and %C data following McConnaughey and McRoy (1979).

The R package MixSIAR (Moore & Semmens 2008) was used to estimate wild- and salmon farm-derived diet contributions for the trout caught in the Tekapo Canal. A Bayesian inference model was fitted to the data to infer best estimates of diet contributions. The model works by having three parallel iterative processes (Markov chains) fitting possible diet compositions to the observed isotope data. At each iteration, the diet composition is slightly adjusted and the solution that best fits the data is kept for comparison with the next iteration. For this study, the model was run for 50,000 iterations. The model is assumed to have converged on the 'best fit' of the data once the Markov chains have stabilised (i.e. optimal modelled diet composition stops changing between iterations) and all three iterative chains have converged upon a similar composition. The model included one categorical variable, species identity (rainbow trout and brown trout), and one continuous variable, fish length. All brown trout were caught upstream of the salmon farm and only one rainbow trout was caught downstream, negating the possibility of including a variable for spatial proximity to the salmon farm within the model. This model structure enabled examination of whether: 1) rainbow trout had more farm food in their diet than brown trout, and 2) larger fish had more farm food in their diet than smaller fish.

Stable isotope mixing model results

The model performance was satisfactory. The Markov chains all converged to a common modelled diet structure within 5% with a 97.5% confidence interval. The deviance of the three chains stabilised within 37,500 iteration steps. Overall, this provides confidence in the modelled results.

The mixing model predicted that farm salmon supplied by Mount Cook Alpine Salmon have a diet that on average comprised 97.6 ± 2% (97.5% confidence limit) of fish farm food. There was no detectable effect of fish size on this relationship. This result is expected and acts as a validation that the model performed effectively.

Rainbow and brown trout caught within the Tekapo Canal had a diet primarily composed of wild food. On average, only 17% of rainbow trout diet and 22% of brown trout diet was estimated to be derived from salmon farm food (Table 2). However, there was substantial variation within the sample population, with several individual fish having substantially higher reliance on salmon farm food as reflected by the high standard deviations of 13% and 11% for rainbow and brown trout, respectively. Considering fish size, the model was able to account for some of the intra-population variation. Larger rainbow trout tended to have a greater proportion of diet derived from farm food (Figure 5). The model indicated that diet contribution from the salmon farm began to increase greatly for rainbow trout over 400 mm in length. However, it should be noted that the relationship between fish size and farm food diet contribution had broad confidence intervals. While the general relationship holds true, the model is not able to provide accurate diet for a specific fish size.

Table 2. Means and standard deviations of estimated diet contribution from salmon farm food to wild rainbow trout and brown trout and caged Chinook salmon within the Tekapo Canal. Results are based on a Bayesian-inferenced stable isotope mixing model.

Fish species	**Mean farm-derived diet contribution (%)**	**Standard deviation**
Brown trout	21.6	11.4
Rainbow trout	16.8	13.2
Chinook salmon	97.6	2.2

Although the diet contribution of salmon farm food to brown trout caught within the Tekapo Canal was estimated to be slightly higher (5% greater) than that of rainbow trout, this difference was within the margin of confidence (standard deviation) of the estimated mean salmon farm diet contribution (Table 2). Like rainbow trout, larger brown trout tended to have a greater estimated diet contribution of salmon farm food (Figure 5). The model indicated that diet contribution from the salmon farm began to increase greatly for brown trout over 350 mm.

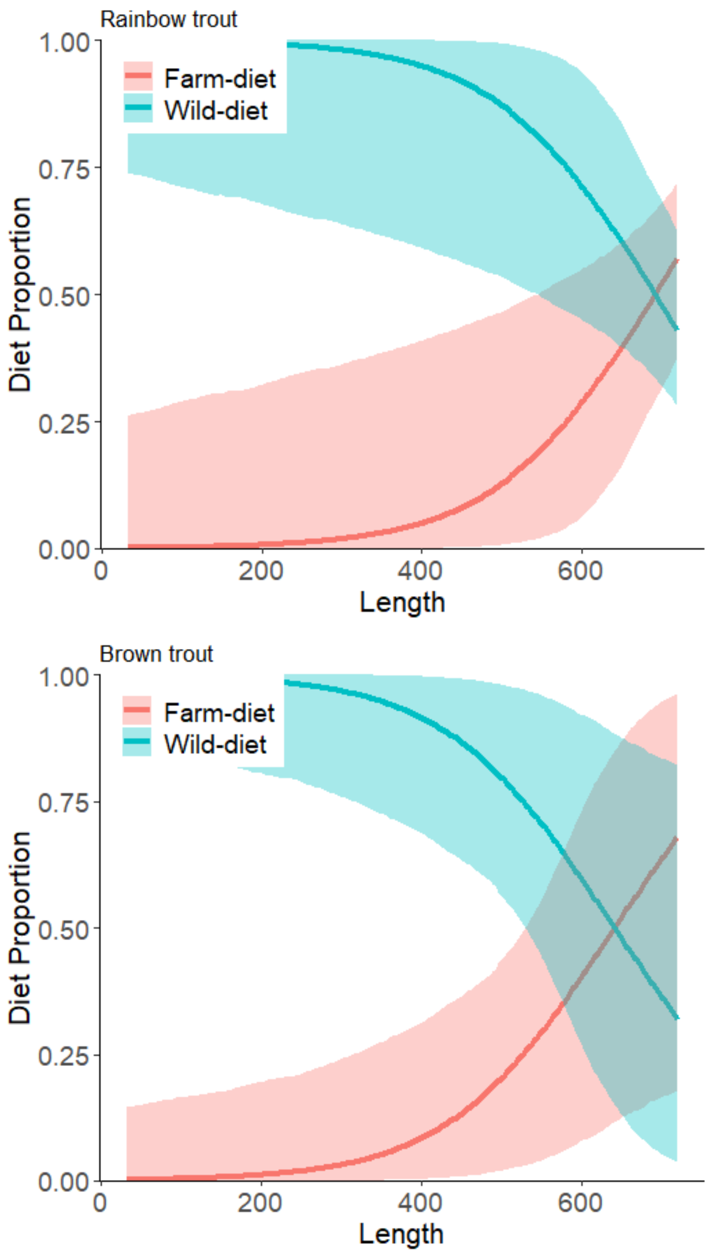

Figure 5. Relationship between fish size (fork length) and diet contribution from salmon farm and wild-derived sources for rainbow trout (upper panel) and brown trout (lower panel) caught within the Tekapo Canal. Results are based on a Bayesian-inferenced isotope mixing model.

In summary, these findings suggest that trout in the Tekapo Canal system have a predominantly wild diet, with salmon farm feed accounting for an estimated 17 and 22% of the diet of rainbow and brown trout, respectively. The data support other lines of evidence suggesting that the canal fishery is self-sustaining and primarily supported by natural production within the system. However, the data indicated that consumption of salmon farm food increased with the size of trout, suggesting that the largest fish, for which the Tekapo Canal fishery is highly prized, may be substantially more reliant on salmon farm food.

3.7. Tekapo Canal effects assessment

The Tekapo Canal was created as part of the TekPS. The canal provides habitat for productive macrophyte, macroinvertebrate and fish communities, and supports an exceptional salmonid fishery. The ongoing operation of the TekPS maintains the current state of the canal ecosystem. As the TekPS operation regime is planned to remain unchanged, the current state of the canal's ecology and fishery is also expected to remain unchanged following reconsenting.

4. TEKAPO RIVER

4.1. Physical environment

Prior to construction of the TekPS, the Tekapo River was the outlet for Lake Tekapo. As a result of diversion, first for Tekapo A (in 1951) and then later into the Tekapo Canal (in 1977), there is usually little surface flow in the upper reaches of the Tekapo River between the Lake Tekapo Control Structure and its confluence with Fork Stream (approximately 6.6 km downstream). The Tekapo River receives flow from the following tributaries: Fork Stream, Mary Burn, Irishman Creek (via the Mary Burn) and Grays River (Figure 6), although the combined flow from these sources is much less than the historic flows from Lake Tekapo. The river has a median flow of 2.5 m^3/s downstream of the Fork Stream confluence and 10 m^3/s immediately below the Mary Burn, after flow contributions from groundwater and tributaries (PDP 2025).

Freshes and flood events of various magnitudes (e.g. 3, 6 and 10 times the median flow as reported in PDP 2025) scour and mobilise the riverbed substrate, resulting in the loss of accrued periphyton biomass and a 'reset' of the growth cycle. Below the Forks Stream confluence, events 3 and 6 times the median flow occur approximately five times annually and less than twice annually, respectively. Downstream of the Mary Burn confluence, flow is more stable, with flows 3 or more times the median flow occurring less than three times annually on average. Flow is most variable below the Pukaki River confluence – due to spill flows down the Pukaki River from Lake Pukaki by Meridian – with flows of 3, 6 and 10 times the median occurring approximately six, four and three times annually, respectively (PDP 2025). Accrual times (the time over which periphyton can accumulate biomass) are longest at the Mary Burn confluence, shortest below the Pukaki River confluence and intermediate below the Fork Stream confluence. Flood flows are generally more common over the summer months than the winter months (PDP 2025).

A flow stability classification from Jowett and Duncan (1990) classifies the upper two segments of the Tekapo River (upstream of Fork Stream confluence, and downstream of Fork Stream to Mary Burn confluence, including spills from Lake George Scott weir) in Category 1 – very stable flow characteristic of larger lake outflow and spring-fed rivers (e.g. Gowan River, Clutha River and Waihou River; see Table 3). Flow variability metrics could not be calculated for the lower section of the Tekapo River (downstream of Pukaki River confluence). However, the main distinction between the lower Tekapo River and the upper sections is the influence of the variably flowing Pukaki Spillway (operated by Meridian) on the lower river. The spillway has an extremely variable flow regime (category 6 – the highest classification), and thus we expect the lower segment of the Tekapo River to be in a higher flow variation category than the upper two segments.

Table 3. Summary of flow variability statistics for the two upper segments of the Tekapo River. Flow variability metrics are mean annual flow (MeanF), mean annual 7-day low flow (MALF) and mean annual flood (MAF), all expressed relative to median flow (MedianF). Metric values are categorised using the Jowett and Duncan (1990) classification: grouping from 1 to 6 with increasing flow variability. Flow parameters for the three river sections were adapted from PDP (2025).

	Downstream of Fork Stream confluence		Mary Burn confluence to Pukaki Spillway	
Flow stability metric	**Value**	**Classification**	**Value**	**Classification**
MeanF/MedianF	1.32	1	1.57	1
MALF/MedianF	0.64	1	0.59	1
MAF/MedianF	10.59	1	10.24	1

Morphological surveys of the Tekapo River were undertaken as part of Instream Flow Incremental Habitat (IFIM) surveys in 1978 and 2004. Based on the 2004 survey, the river channel between the lake outlet and the Fork Stream confluence can be categorised as a single channel lined with boulders (*c.* 400 mm). When flowing, the upper river forms a series of pools (or slow runs), runs and riffles. Below the Fork Stream confluence, the substrate in the river begins to change from boulder to boulder/cobble, and braiding starts. In the first 10 km below the Fork Stream confluence, the river is confined between terraces and is mainly a single channel. Below this, the flood plain widens, and the substrate is predominantly cobbles. In this segment the river typically forms two braids, with about 20% single channel, 50% in two braids and 30% with three or more braids (Jowett & Wing 1980; Jowett 1982).

4.2. Water quality

4.2.1. Groundwater quality

Groundwater chemistry in aquifers connected to the Tekapo River is considered typical of groundwater in New Zealand; although many of the water quality parameters, including chloride and nitrate-nitrogen, are very low compared to other areas in the region such as the Canterbury Plains. The highest concentrations of nitrate-nitrogen (1.6–4.2 g/m^3) and chloride (4.2 g/m^3) in Tekapo basin groundwater are low relative to groundwater in the rest of the Canterbury region (Cooksey 2008). The highest recorded nitrate level (4.2 g/m^3) was measured at bore BZ16/0073 in August 2017 below intensive irrigation from Grays Hills (PDP 2025). Levels of *E. coli* in the groundwater are also generally low and indicative of good water quality throughout the catchment. Groundwater ion concentrations and *E. coli* levels in the Tekapo basin are considered unlikely to increase significantly from current concentrations under current and consented land use (PDP 2025).

4.2.2. Surface water quality

ECan monitors water quality in the Tekapo River at a site just upstream of the confluence with the Pukaki River (at Steel Bridge). Overall, water quality has always been relatively high at this site: the median suspended sediment concentration is less than 2 mg/L and the average turbidity of the water (1.2 NTU) is about a third of that in Lake Tekapo (3.9 NTU) (Jowett et al. 2012). However, the recent intensification of land use in the Mary Burn, Irishman Creek and Grays River is leading to a trend of higher nitrate and phosphate levels in the Tekapo River downstream of the confluences with these tributaries (Gray 2015). The increasing trend in nutrient concentrations in the lower catchment is unrelated to the TekPS, and land use development was initiated after the TekPS became operational. Water quality is still considered to be high in the lower Tekapo River – despite increases in dissolved nutrients since 2000.

4.2.3. Cawthron investigation: updating water quality data in the Tekapo River

Several information gaps were identified in the existing long-term water quality data from the lower Tekapo River. Two changes have occurred in the Tekapo River catchment in recent years that may affect water quality: land use intensification and the invasion of didymo (*Didymosphenia geminata*). These warranted higher spatial and temporal analysis of water quality and ecological effects. To address these information gaps, Cawthron carried out water quality, periphyton and macroinvertebrate surveys at multiple sites longitudinally down the mainstem Tekapo River (Figure 6) over the period March 2019 to March 2020. The water quality sampling included:

- a one-off longitudinal water quality survey undertaken at nine sites along the Tekapo River over three consecutive days in March 2019 measuring:
  - dissolved inorganic nitrogen
  - total nitrogen
  - total phosphorus
  - ammoniacal nitrogen
  - nitrate nitrogen
  - dissolved reactive phosphorus
  - physicochemical measures (conductivity, temperature, dissolved oxygen, pH)
- monthly water quality sampling (as described above) at three of the nine longitudinal water quality sites (Sites 2, 5 and 8)
- continuous dissolved oxygen monitoring over approximately a 48-hour period from the afternoon of 4 March 2019 to the afternoon of 6 March 2019 at Sites 2, 5 and 8.

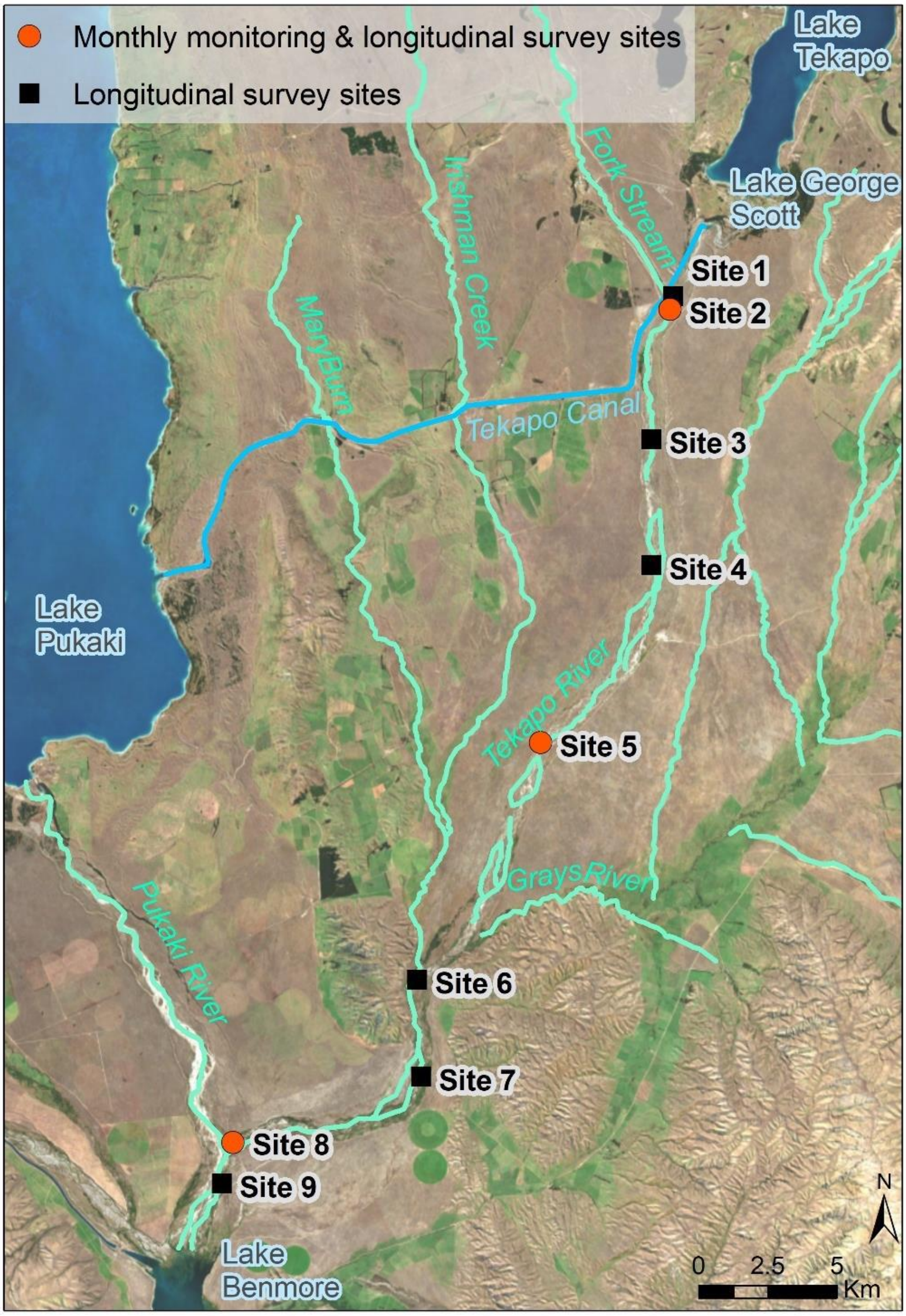

Figure 6. The Tekapo River and its main tributaries, showing the locations of the survey sites for the different study components. At the longitudinal survey sites, water quality and periphyton information were collected at all sites (1–9). In addition, at Sites 2, 5 and 8, continuous oxygen loggers were installed for 2 days and macroinvertebrate samples were collected on one occasion. Water quality and periphyton data were collected monthly at Sites 2, 5 and 8 over the period March 2019–March 2020. Imagery sourced from the Land Information New Zealand Data Service.

Data collection

Physicochemical spot measurements were undertaken using a YSI Pro-Plus multiparameter meter (YSI Instruments, Yellow Springs, OH, USA). Water samples were taken and sent to Hill Laboratories (Christchurch) for determination of the additional suite of dissolved and total nutrient concentrations.

For the continuous dissolved oxygen (DO) monitoring, a DO logger (Zebratech D-Opto Probe) was deployed about mid-water depth from a waratah fixed into the riverbed (midstream). Loggers were deployed during the afternoon of 4 March 2019 and their data were retrieved during the afternoon of 6 March 2019. This ensured that at least one complete 24-hour photosynthesis-respiration cycle was captured from three sites to indicate metabolism dynamics in the river. At each site, DO concentrations were recorded every 15 minutes for the entire logger deployment period.

Periphyton and macroinvertebrate assessments were undertaken at the same time as water quality data collection and analysis. The periphyton results are presented in subsequent sections of this report (Sections 4.3.1 and 4.4.1).

Water quality results

One-off longitudinal monitoring

The longitudinal sampling showed good visual clarity at all sites (as indicated by turbidity below 1.7 NTU at all sites). Turbidity tended to increase with increasing distance downstream, probably reflecting increased suspended particulates entering the Tekapo River from the Grays River and Mary Burn (Table 4). The Grays River in particular has some light humic/tannin staining near its confluence with the Tekapo River (R. Holmes, pers. obs.). The pattern of increasing turbidity with increasing distance down the Tekapo River is the reverse of the longitudinal clarity/turbidity pattern that was observed by Jowett (2004) when lake water was being spilt downriver (i.e. simulating natural conditions). He found that water clarity, measured with a black disc, varied from 3.6 m to 5.7 m during a spilling event from Lake Tekapo and increased downstream. Similarly, during spilling turbidity dropped gradually (from 2 to 1.4 NTU) from the outlet to the downstream-most site near Lake Benmore, also indicating increasing clarity downstream through settling of suspended particles.

Conductivity measured during the Cawthron survey was low overall, and temperature ranged from 15 to 23 °C. Spot DO saturation measurements ranged from 98.9 to 114.7% and were consistent with the DO concentrations observed during the day from the continuous DO monitoring dataset (Table 4).

Table 4. Spot physicochemical measurements taken at all sites sampled during the longitudinal survey undertaken 4–6 March 2019. Survey sites start at Site 1 in the upper catchment above the Fork Stream and progress downstream to Site 9 below the Pukaki River confluence.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Time	11:50	13:50	13:00	13:51	15:40	14:30	13:00	18:35	11:00
Temperature	15.1	15.1	18.5	20.4	23.0	18.4	17.0	18.2	16.0
SPC (µS/cm)	57.7	38.2	44.7	48.3	52.2	57.0	57.6	57.8	58.6
DO%	101.3	98.9	101.9	101.6	102.4	107.8	114.7	102.3	106.2
DO (mg/L)	10.09	9.92	9.49	9.18	8.77	10.18	10.96	9.5	10.46
pH	6.02	6.37	6.06	5.53	6.22	6.16	6.33	5.75	6.45
Turbidity (NTU)	0.89	0.57	0.80	1.10	1.08	1.33	1.70	1.20	0.97

All sites had very low concentrations of dissolved nutrients, with most samples having concentrations below laboratory detection thresholds. Dissolved reactive phosphorus was highest at Sites 5, 6 and 7, but still low relative to the guideline levels provided by Biggs (2000) and ANZECC (2000) of 0.026 and 0.01 g/m^3, respectively, that are near to typical reference conditions. Total nitrogen increased with increasing distance downstream, likely reflecting inputs from agricultural land use in the Grays River and Mary Burn (Table 5—also note improved pasture in these catchments visible in Figure 6). If Site 1 is discounted, the increasing trend becomes more apparent. Site 1 is somewhat anomalous because it was in a residual pool upstream of the Fork Stream confluence where the river had almost no surface flow. Overall, total nitrogen concentrations were very low at all sites, even at Site 7, at which the highest level of 0.08 g/m^3 was recorded (Table 5). The Canterbury Land and Water Plan has a default nitrate (NO_3) toxicity limit of 3.8 g/m^3 in place as the environmental 'bottom line' for all waterbodies in the region (Environment Canterbury 2018). The highest nitrate concentration recorded in the Tekapo River during our surveys was 0.03 g/m^3 (Site 8, 5 August 2019) – two orders of magnitude below the ECan default nitrate toxicity limit. However, it is well recognised that the effects of nitrate on stimulation of periphyton growth occur at concentrations well below toxicity limits.

Table 5. Water quality parameters (g/m³) taken at all sites sampled during the longitudinal survey over 4–6 March 2019. Survey sites start at Site 1 in the upper catchment above the Fork Stream and progress downstream to Site 9 below the Pukaki River confluence.

	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**
Dissolved inorganic nitrogen	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.010
Total nitrogen	0.054	0.024	0.036	0.041	0.056	0.069	0.077	0.075	0.063
Total phosphorus	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.00	0.00	0.01	0.01
Total ammoniacal-N	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Nitrite-N	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Nitrate-N	0.0069	0.0042		< 0.001	< 0.001	< 0.001	0.0032	0.0056	0.0079
Dissolved reactive phosphorus	< 0.001	0.002	< 0.001	< 0.001	0.002	0.003	0.002	< 0.001	< 0.001

Monthly water quality monitoring over an annual period

Monthly water quality sampling was scheduled to be undertaken at Sites 2, 5 and 8 between March 2019 and March 2020. Sampling was not undertaken in December 2019 or February 2020 due to high river flows resulting from flow releases to maintain the level of Lake Tekapo levels as per consent requirements. In addition, sampling was not undertaken during March 2020 because of lockdown and travel restrictions associated with the nationwide COVID-19 pandemic response. In total, sampling occurred on 10 occasions. Despite missing three monthly monitoring occasions, we consider the 10-month record collected is adequate to determine seasonal variation in water quality variables over a year.

Spot physicochemical results are summarised in Appendix 2. Monthly temperatures, DO and turbidity (NTU) were indicative of good water quality in every instance where measured.

Nitrate-nitrogen remained below 0.03 g/m^3 at all sites during all sampling occasions (Figure 7). Dissolved reactive phosphorus (DRP) was below laboratory detection limits at most sites on most occasions, as well as guideline levels provided by Biggs (2000) and ANZECC (2000) of 0.026 and 0.01 g/m^3 (Figure 7). For all nutrient parameters, there were no discernible seasonal patterns, and concentrations were very low overall. Of the three monitoring sites, Site 8 in the lower catchment consistently had the highest dissolved nutrient concentrations (Figure 7).

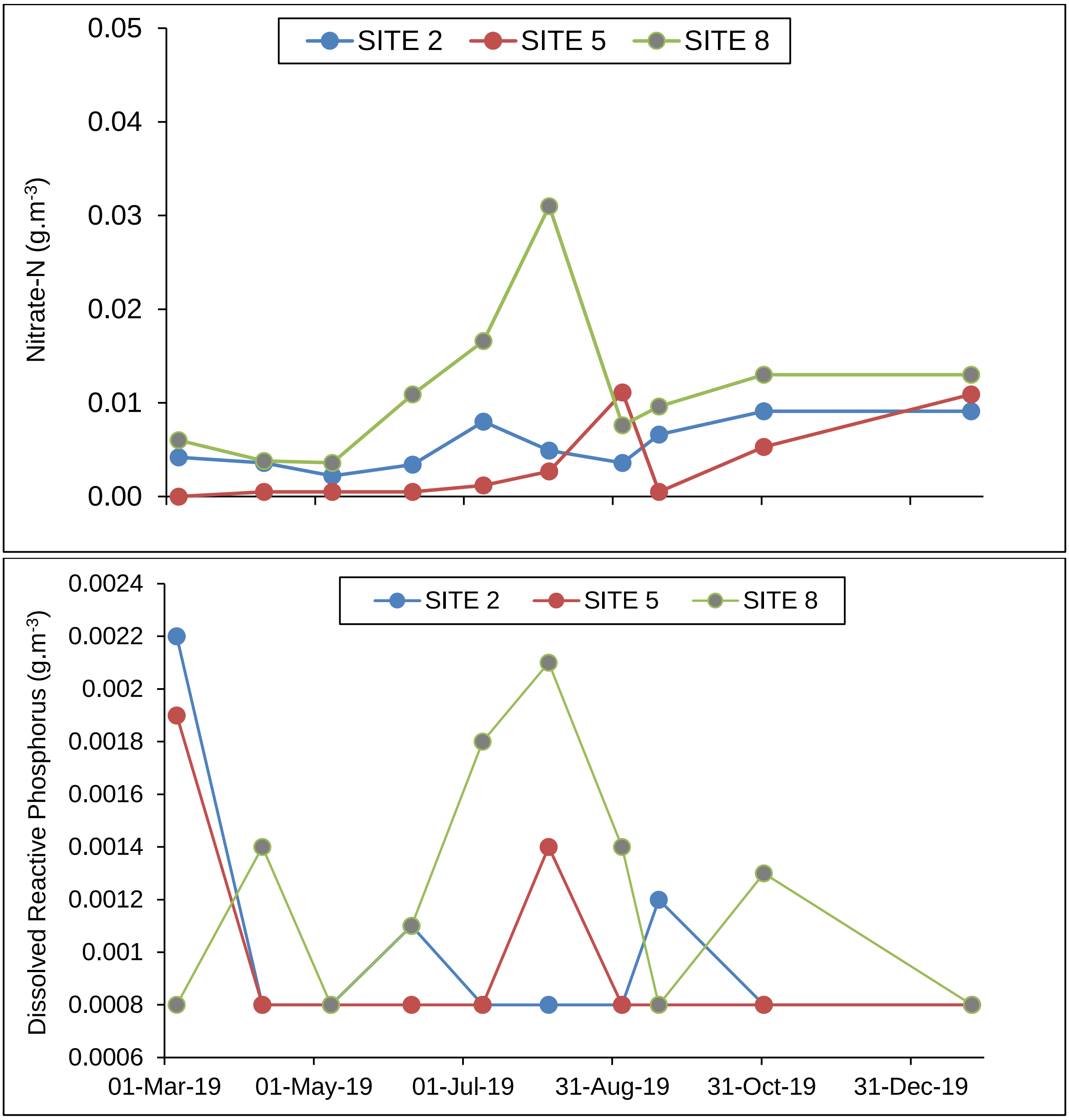

Figure 7. Monthly results for total nitrogen (upper panel) and dissolved reactive phosphorus (lower panel) concentrations (g/m³) in the Tekapo River for Sites 2, 5 and 8, located in the upper, mid and lower catchment, respectively. Laboratory detection limits were set at < 0.01 g/m³ and < 0.001 g/m³ for total nitrogen and dissolved reactive phosphorus, respectively. Dissolved reactive phosphorus values below detection limit of 0.001 g/m³ are recorded on the graph as 0.0008 g/m³.

Our results are equivalent to those found by ECan, whose long-term monitoring site is very close to Site 8 in the present study (Figure 6). Based on the ECan water quality data, median dissolved inorganic nitrogen (DIN) and DRP concentrations are 0.012 g/m³ (range 0.01–0.059) and 0.002 g/m³ (range 0.002–0.013), respectively (Gray 2015). This compares well with our monthly monitoring surveys at Site 8, where median DIN and DRP concentrations of 0.013 g/m^3 (range 0.01–0.032) and 0.0012g/m^3 (range 0.0008–0.0021), respectively, were recorded.

Diel dissolved oxygen monitoring

Continuous DO monitoring at Sites 2, 5 and 8 showed moderate variation in DO concentrations as a result of the photosynthesis–respiration cycles in the Tekapo River. Of note is that all sites had DO concentrations near or below 80% saturation during the night-time respiration phase. Minimum percent DO saturation levels were 86.3, 79.7 and 83.8 at Sites 2, 5 and 8, respectively (Figure 8). These values are not typical of high-altitude streams, which usually have minimum DO saturation greater than 90% (Dupree et al. 2016). It is likely that the fluctuations in percent DO saturation were caused by respiration of benthic algae. Didymo and some other benthic algae are prolific within the river and can form very dense mats with high biomass levels. There are no substantial macrophyte growths present in the Tekapo River that could potentially cause more substantial variations in DO concentrations over 24-hour periods.

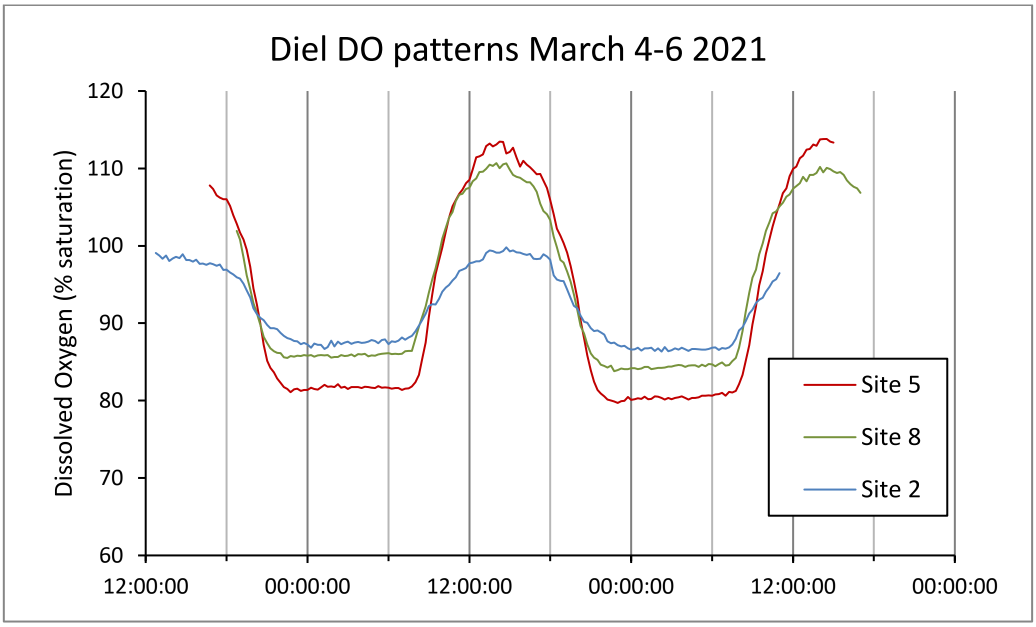

Figure 8. Dissolved oxygen saturation recorded every 15 minutes over the period between noon 4 March and midnight 6 March 2019 at three sites within the Tekapo River. Site 2 (blue) was located just below the Fork Stream, Site 5 (red) between the Fork Stream and Mary Burn confluences and Site 8 (green) in the Tekapo River upstream of the Pukaki River confluence.

Our continuous DO data suggest that algal blooms in the Tekapo River result in DO fluctuations that may cause ‘minor stress’ to sensitive organisms such as juvenile salmonids and some macroinvertebrates (Davies-Colley et al. 2013; Environment Canterbury 2018; NPS-FM 2020).

4.2.4. Water quality summary

Overall, the water quality of the Tekapo River is good. Concentrations of dissolved nutrients are low and indicative of good water quality throughout the catchment. Nutrient concentrations do indicate slight enrichment below the Grays River and Mary Burn confluences, reflecting recent agricultural land use intensification in those tributary catchments. Nonetheless, the water remains within the 'A band' for all nutrient parameters based on the NPS-FM (2020) and largely complies with the Canterbury Regional Plan. Minimum night-time dissolved oxygen concentrations at Sites 2, 5 and 8 would place those sites close to the boundary of the NPS-FM A and B-bands, reflecting the high biomass of periphyton (including didymo) that is present in some parts of the Tekapo River.

4.3. Periphyton

Periphyton forms the base of the food web for most riverine fauna. However, under some circumstances periphyton can reach nuisance levels that degrade habitat quality for benthic invertebrates and fish, as well as reduce human aesthetic and recreational values.

Periphyton communities are controlled by nitrogen and phosphorus concentrations, flow variability, light and grazing pressure from macroinvertebrates. However, in most predominantly rain-fed rivers, the frequency of bed-scouring flood flows is the dominant control on biomass dynamics (Clausen & Biggs 1997). Flood flows dislodge algal material and the sediments that comprise the river substrate. Substantial high-flow events can 'reset' the algal community to visually clean rocks and gravels (although thin biofilms are almost always present). After a bed-scouring flood, river periphyton communities take typically between 2 and 6 weeks to reach high biomasses and / or high percentage coverage of a riverbed (Biggs 2000). Accrual time for benthic periphyton during stable flow periods is dependent on variables such as competition between algal communities, temperature, nutrient concentrations, light availability and invertebrate grazing pressure.

Despite the Tekapo River having low nutrient concentrations, periphyton cover assessments by ECan undertaken between 2006 and 2014 show that periphyton cover regularly exceeds Ministry for the Environment guidelines for the protection of recreational and aesthetic values (Matheson et al. 2016; Snelder et al. 2013). Percentage cover guidelines were exceeded on 67 and 30% of assessment occasions at sites in the mid (n = 16) and lower river (n = 9), respectively.

An algal cover survey undertaken by Freshwater Solutions (2014) found that the benthic periphyton community in the Tekapo River is composed primarily of stalked diatoms, filamentous green algae and cyanobacteria. The invasive diatom didymo also occurs in the Tekapo River and was first found there in 2007. Didymo is unique among benthic freshwater algae because it can reach very high biomasses in near-pristine rivers. It blooms in water with relatively low levels of dissolved nutrients, particularly low levels of phosphorus, which are features that characterise water chemistry conditions in the Tekapo catchment (Gray 2015). Large accumulations of didymo can smother benthic habitats, alter water quality, and change macroinvertebrate and fish communities (Bothwell et al. 2014; Kilroy & Larned 2014; Kilroy et al. 2016; Jellyman & Harding 2016). Didymo now periodically dominates the periphyton community in the Tekapo River (Freshwater Solutions 2014). Recent work undertaken by NIWA scientists in the neighbouring Ohau River catchment suggests that didymo dominates periphyton cover during winter, with a more mixed benthic periphyton community composition occurring during summer and autumn (Cathy Kilroy, NIWA, pers. comm.). Didymo is abundant in lake-outlet rivers, including ones that retain a natural unregulated outlet (e.g. Clutha, Hurunui, Buller and Gowan rivers). This is the case regardless of river size or flow since it is flow variability and associated bed mobilisation, rather than flow itself, that seems most important for controlling didymo (Cullis et al. 2015). If all the natural flow was allowed down the Tekapo River, it is very likely that there would still be abundant didymo blooms that would affect macroinvertebrate communities and other aquatic life. However, we recognise that the Tekapo River would have had a naturally higher glacial sediment load than the other unregulated lake outlets mentioned above, which might have influenced didymo growth.

The magnitude of flood, relative to base flow, required to dislodge periphyton and didymo mats varies between rivers but is typically between 1.5 and 10 times the median flow (Kilroy et al. 2017). Smaller freshes are only effective at removing didymo mats in rare situations where there is sufficient sand within the riverbed to enable a ‘sand-blasting’ effect (Biggs 2000). In general, bed mobilisation is required to dislodge didymo mats (Cullis et al. 2015). The Tekapo River has relatively coarse substrates and wide channels, meaning relatively large floods will be required to mobilise the bed. Based on these broad geomorphological principles, we anticipate that a flow of between 6 and 10 times the median flow would be required to cause periphyton and didymo scouring. The effectiveness of individual flushes at removing periphyton and didymo is somewhat uncertain and the effects will be temporary.

4.3.1. Cawthron investigation: updating periphyton data in the Tekapo River

To develop a greater temporal picture of periphyton patterns along the Tekapo River, Cawthron conducted a longitudinal periphyton cover survey during March 2019. Periphyton surveys were subsequently undertaken monthly at Sites 2, 5 and 8 from within the original longitudinal survey sample frame (Figure 6). These results provide an update on earlier studies conducted in the Tekapo River.

Periphyton data collection

During each visit to every site (i.e. during both the longitudinal survey and the monthly monitoring) the benthic periphyton community was assessed using a modified version of the Rapid Assessment Method (RAM) 2 method (Biggs & Kilroy 2000). As part of this assessment, didymo biovolume was estimated according to the visual assessment methodology developed by Kilroy et al. (2006). In addition, periphyton biomass samples were taken according to the method described in section 6.5.5 of the Ministry for the Environment's Stream Periphyton Monitoring Manual (Biggs & Kilroy 2000). In the laboratory at the Cawthron Institute, periphyton biomass samples were analysed for chlorophyll-*a* and ash-free dry mass (AFDM).

Periphyton results

Longitudinal sampling March 2019

During March 2019, the periphyton community in the Tekapo River was diverse throughout the length of the river, with most major typical South Island periphyton community assemblages present. These included filamentous algae, cyanobacteria, stalked diatoms and didymo (Figure 9).

Figure 9. Different types of periphyton cover observed in the Tekapo River during March 2019. Clockwise from top left: didymo, mixed stalked diatoms, *Nostoc*, filamentous green algae and *Microcoleus* (the potentially toxic cyanobacteria formerly known as *Phormidium*).

The results of the longitudinal survey and the monthly sampling suggest that existing periphyton biomass occurs at 'nuisance' levels. During the longitudinal survey, we found that five of the nine sites exceeded general recreational aesthetic guidelines (i.e. > 60% cover of algal mats > 3 mm thick) (Biggs 2000) (Table 6). Matheson et al. (2016) defined bands A to D for the protection of trout fishery values based on periphyton cover. During the longitudinal survey, Sites 1 and 5 were in the top band A, indicating good trout habitat. By contrast, Sites 3, 4, 7, 8 and 9 were classified in band D, indicating that trout habitat values were likely impaired by nuisance algal growths at these sites (Table 6).

Table 6. Periphyton assessment at nine sites in the Tekapo River undertaken on 4–6 March 2019, including: percentage cover of thick mats (> 3 mm) of filamentous green and didymo algae; respective band values (A–D) for the protection of trout habitat (Matheson et al. 2016); RAM2 scores; and didymo % cover.

Site	% cover of thick mats (> 3 mm) of filamentous green and didymo algae	Band (A–D) for the protection of trout habitat	RAM2 score	Didymo % cover
1	0	A	10	0
2	53	C	7	40
3	86	D	5	15
4	77	D	4	10
5	0	A	10	0
6	34	B	7	0
7	83	D	6	10
8	99	D	5	75
9	86	D	6	20

Temporal periphyton sampling

Among the sites that were sampled monthly, Site 2's position ranged between band B and C, and Site 5 was in either band A or B. However, Site 8 (in the lower river) had periphyton cover levels that consistently classified it in the low D band for protection of trout habitat values (Table 7). Where didymo was present (i.e. Sites 2 and 8), some differing seasonal patterns were observed. At Site 2, periphyton biomass was reduced during May and June, then progressively increased to a peak in late September, before rapidly declining in January. At Site 8, periphyton biomass remained very high throughout autumn and winter, before reducing in January. The reductions in biomass at both sites in January likely reflect high flow events in December when the river could not be sampled. Didymo was consistently absent from Site 5. These results are broadly consistent with previous long-term periphyton survey data from regional council monitoring (Gray 2015) and recent periphyton monitoring undertaken in the neighbouring Ohau River catchment by NIWA.

Table 7. Percentage cover of thick mats (> 3 mm) of filamentous green and didymo algae at three sites in the Tekapo River sampled once a month for the period March 2019 to January 2020. Also shown are the respective band values (A–D) for the protection of trout habitat (Matheson et al. 2016).

Site	Month	% cover of thick mats (> 3 mm) of filamentous green and didymo algae	Band (A–D) for the protection of trout habitat
2	March	53	C
2	April	34	B
2	May	31	B
2	June	32	B
2	July	47	C
2	August	51	C
2	September (4th)	64	C
2	September (19th)	74	C
2	November	51	C
2	January	3	A
5	March	0	A
5	April	0	A
5	May	0	A
5	June	0	A
5	July	0	A
5	August	0	A
5	September (4th)	0	A
5	September (19th)	0	A
5	November	0	A
5	January	1	A
8	March	99	D
8	April	100	D
8	May	99	D
8	June	97	D
8	July	99	D
8	August	81	D
8	September (4th)	92	D
8	September (19th)	90	D
8	November	70	C
8	January	40	B

The chlorophyll-*a* and AFDM results from samples taken during the March sampling occasion at Sites 2 and 8 were above the maximum guideline values for the protection of biodiversity (< 50 mg/m^2 chlorophyll-*a*) and trout habitat (< 200 mg/m^2 chlorophyll-*a*, 35 mg/m^2 AFDM) provided by Biggs et al. (2000) (Table 8). Site 5 had lower biomass overall, but still exceeded guideline values within the riffle area sampled but not within the run (Table 8).

Table 8. Chlorophyll-*a* (Chl-*a*) and Ash Free Dry Mass (AFDM) from algal samples taken from Sites 2, 5 and 8 in March 2019. Also shown are the relevant National Objective Framework (NOF) guideline bands for riverine Chl-*a* values (A < 50, B 50–120, C 120–200, D > 200, all mg/m^2) (Snelder et al. 2013).

	Chl-*a* mg/m^2	AFDW mg/m^2	Autotrophic Index	NOF Chl-*a* band
Site 2 run	60.8	111.1	1827.59	B
Site 2 riffle	18.7	52.4	2808.99	A
Site 5 run	8.2	7.6	923.08	A
Site 5 riffle	100.6	58.7	583.33	B
Site 8 run	119.5	73.4	614.04	B
Site 8 riffle	209.6	83.8	400.00	D

4.3.2. *Periphyton summary*

The periphyton community in the Tekapo River reaches high biomasses, particularly in the lower reaches and during spring. These high biomasses are due largely to a combination of: 1) the invasion of didymo into the catchment, which, unlike other periphyton taxa, reaches high biomasses despite low nutrient concentrations; and 2) the long potential accrual period between freshes.

Didymo commonly reaches nuisance levels in natural lake-fed rivers (e.g. the Buller, Gowan, Clutha and Hurunui Rivers). The stable flow regimes, immobile substrate and low sediment supply of such rivers allow didymo to accrue with little bed disturbance and sandblasting. Consequently, didymo would probably flourish in the Tekapo River, even if it were flowing naturally in the absence of the TekPS.

There is likely to be a complex interaction between didymo and other periphyton species in different parts of the Tekapo River. Contrasting patterns of algal dominance in different reaches along the river were observed during the Cawthron studies. Fluctuations over time in the types of periphyton dominating in particular reaches are likely to occur.

4.4. Macroinvertebrates

Benthic macroinvertebrates play an important role in streams and rivers, as grazers of periphyton biomass and as the main food source for fish. Because of the high species diversity and range of environmental tolerances within these taxa, the macroinvertebrate community is an important indicator of ecosystem health.

Macroinvertebrate surveys were undertaken in the Tekapo River (and its tributaries) in 1982, 2009 and 2014 (Stancliff et al. 1982; Coffey 2009; and Freshwater Solutions

2014, respectively). No rare macroinvertebrates with conservation significance have been found in the Tekapo River. Generally, macroinvertebrate community health metrics indicate a community in the mainstem Tekapo River that reflects moderate water quality, whereas communities in the Mary Burn and Grays River reflect moderate or poor water quality, respectively. To the best of our knowledge, no macroinvertebrate surveys were conducted in the Tekapo River prior to the diversion of Lake Tekapo water. However, hydraulic habitat modelling by Jowett (2005) suggests that the creation of a more stable flow environment and increased water clarity (due to diversion of glacial flour-laden lake water) as a result of the TekPS created better macroinvertebrate habitat, resulting in higher production and densities of benthic macroinvertebrates in the Tekapo River.

ECan has also collected macroinvertebrate data on various occasions from the mainstem and major tributaries as part of state of the environment monitoring (summarised in Grey (2015); Freshwater Solutions (2015)). From these data, the macroinvertebrate communities are generally indicative of moderate water quality. Macroinvertebrate taxa tolerant of organic enrichment and thus lower macroinvertebrate health metric scores are often abundant when periphyton biomass is high. None of the regular ECan macroinvertebrate sampling in the Tekapo River and its tributaries predates the arrival of didymo, except for some early sampling in the Fork Stream.

Freshwater Solutions (2014) undertook two longitudinal surveys (at eight sites along the river), one in autumn 2013 and one in spring 2013. Macroinvertebrate community index scores varied widely down the river, with the best scores immediately below the Fork Stream confluence. Macroinvertebrate taxa diversity differed substantially between sampling occasions, probably because of different antecedent flow conditions. On the autumn sampling occasion, taxa richness was very low, between 5 and 10 species, whereas, during spring sampling, it was between 12 and 20. A series of large flow releases over late summer, the last being a 42 m^3/s release 28 days before the autumn sampling, may have flushed some taxa from the sampling sites prior to the autumn sampling event. During the autumn sampling event, the relative percentages of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa were very high (74–92% below the Fork Stream, with the exception of a site below the Grays River, where it was 39%). Conversely, during the spring survey, when didymo was relatively abundant, macroinvertebrate community index scores declined substantially at sites where didymo was in bloom (Freshwater Solutions 2014). The longitudinal study (Freshwater Solutions 2014) was broadly consistent with ECan monitoring data in indicating that the river has macroinvertebrate communities that reflect moderate organic enrichment associated with periphyton accumulation and occasional flushing flows.

4.4.1. Cawthon investigation: updating macroinvertebrate data in the Tekapo River

The Cawthron Institute undertook macroinvertebrate sampling in the Tekapo River to improve the spatial and temporal coverage of information available. Furthermore, macroinvertebrates were sampled at the same sites and same occasion that water quality and periphyton data were collected to complement the interpretation of spatial and temporal patterns in the macroinvertebrate communities. Lastly, the abundance and size of macroinvertebrate taxa were also evaluated, enabling them to be assessed with regards to the food quality they provide to fish and aquatic birds. Macroinvertebrate food quality assessments differ from the traditional macroinvertebrate community health assessments (e.g. MCI, see Stark et al. 2001) in that the former demonstrate implications for higher trophic levels (i.e. fish and birds) whereas the latter reflects responses to environmental stressors (e.g. temperature, nutrient/ organic enrichment).

Data collection

Six Surber samples (0.1 m^2, 0.5 mm mesh) were randomly collected from riffle habitat at Site 2, 5, and 8 (Figure 6) in March 2019. The six macroinvertebrate samples were pooled before preservation to create a single composite sample (from a riffle area of 0.6 m^2) for each site.

The samples were processed following a modified version of macroinvertebrate sample processing Protocol P3 (Stark et al. 2001). The samples from each location were washed through sieves (4 mm, 1 mm and 0.5 mm mesh) to assist separation of animals from debris. The larger sample portion was placed into a white sampling tray and the smaller into a series of Petri dishes. Invertebrates were then removed from the trays and placed in Petri dishes. Each transparent Petri dish sat over a 3 × 3 mm grid attached to the base-plate of the microscope to guide invertebrate size assessment. For each sample, invertebrates were sorted into 3 mm body length classes, identified (to genus level where practical, or coarser) and counted[9]. Sub-sampling was undertaken on some taxa if abundances were very high. A binocular microscope (35×–160× magnification) was used to aid identification.

The results of this survey are summarised in indicators of ecosystem health (macroinvertebrate community index – MCI and quantitative macroinvertebrate community index – QMCI) as well as fish food resource values (macroinvertebrate community density, biomass and body size structure).

Size class- and taxon-specific densities (no./m^2) for each sample were calculated by dividing invertebrate counts per size class by the area sampled. Dry weights (mg) were estimated for each taxon/size class using length:dry weight relationships from

[9] Note: For completeness, pupae were included in the total count of invertebrates. Their overall influence of pupae in the analysis of the data was small, as they contributed less than 5% to the density and biomass estimates presented in Section 4 of this report (K Shearer unpublished data).

the literature (Sample et al. 1993; Towers et al. 1994; Stoffels et al. 2003). Invertebrate biomass (mg/m^3) for each taxon/size class per sample was calculated by multiplying density and mean dry weight. The products for each taxon/size class were summed to give total biomass per site.

Macroinvertebrate results

Ecosystem health macroinvertebrate indices

Based on the macroinvertebrate community index classes of Stark and Maxted (2007), MCI values indicated 'good' condition at Site 2 and 'fair' condition at Sites 5 and 8 (Table 9). This was caused by a greater occurrence of low-scoring (i.e. pollution/organic enrichment-tolerant) taxa at the downstream sites than upstream (see Appendix 3). According to the macroinvertebrate community attribute descriptions in the NPS-FM (2020), the above MCI scores place Site 2 in the upper Tekapo River in B band, Site 5 (mid-river) in D band and Site 8 (lower river) in C band. The D band (MCI values < 90) is the national bottom line to protect ecosystem health (NPS-FM 2020).

The QMCI values indicated 'poor' macroinvertebrate community quality at all three sites (Table 9). A lower occurrence of low-scoring (i.e. pollution/organic enrichment-tolerant) taxa at Site 5 resulted in a slightly better QMCI value than for the other two sites (see Appendix 3). Nuisance benthic algal (including didymo) growth is the major contributor to these relatively low MCI and QMCI scores.

Table 9. Common macroinvertebrate community based biotic indices calculated for Sites 2, 5 and 8 in the Tekapo River (4–5 March 2019).

Biotic index	Site 2	Site 5	Site 8
MCI	116	86	94
QMCI	2.44	3.46	2.38
%EPT (by taxa)*	51.9	29.0	35.5
% EPT (by abundance)*	9.6	21.9	15.6

*EPT indices exclude the caddis fly family (Hydroptilidae). Hydroptilids are small algal-piercing caddis that, because of their food requirements, are often strongly associated with enrichment.

The macroinvertebrate communities in the Tekapo River are indicative of a moderately enriched river – which is somewhat contrary to the water quality results in Section 4.2 of this report. The apparent contradiction is due to the influence of didymo, which, unlike native algae, forms high biomass in rivers with low nutrient concentrations and creates conditions for a wider variety and abundance of invertebrates, including those that typically inhabit nutrient enriched waterways. The effects of didymo on the macroinvertebrate community are consistent with those reported previously (Kilroy et al 2009; Gillis & Chalifour 2010; Larned & Kilroy 2014; Jellyman & Harding 2016).

Macroinvertebrate community abundance/size metrics
Total macroinvertebrate density increased progressively down the Tekapo River, with small invertebrates (< 6 mm) making up the bulk of the numbers (Figure 10). Site 5 had a slightly higher proportion of large animals (> 9 mm) than the other two sites, otherwise the proportional contribution of each size class to density was relatively similar between the sites.

Total macroinvertebrate densities at all sites were above the 75^{th} percentile of 88 rivers surveyed nationwide by Quinn and Hickey (1990) in the 1980s. However, macroinvertebrate biomass exceeded the 75^{th} percentile only at Site 5. Biomass at Site 8 was above the 50^{th} percentile and at Site 2 below it. The moderate to high macroinvertebrate densities and biomass in the Tekapo River are expected given its very stable flow regime. Long periods of stable flow allow invertebrates to accrue to carrying capacity.

Total macroinvertebrate biomass was highest at Site 5, followed by Site 8, which had a biomass approximately half of that found at Site 5 (Figure 10). Biomass at Site 2 was just under a third of that found at Site 8. Small invertebrates (< 6 mm) made up just under half of the biomass at Site 8, and over 25% at Site 2 (Figure 10). At Site 5, over 85% of the biomass was small animals.

The size-structured density and biomass results indicate that small invertebrates dominate numerically at all the sites; however, biomass of larger animals was higher at Sites 2 and 8. At Site 8, the high density of invertebrates overall, coupled with almost half of biomass > 6 mm, indicates that the food base for trout and birds in the lower segment of the river is of higher quality compared with the other two sites, given that trout and birds prefer large invertebrate prey.

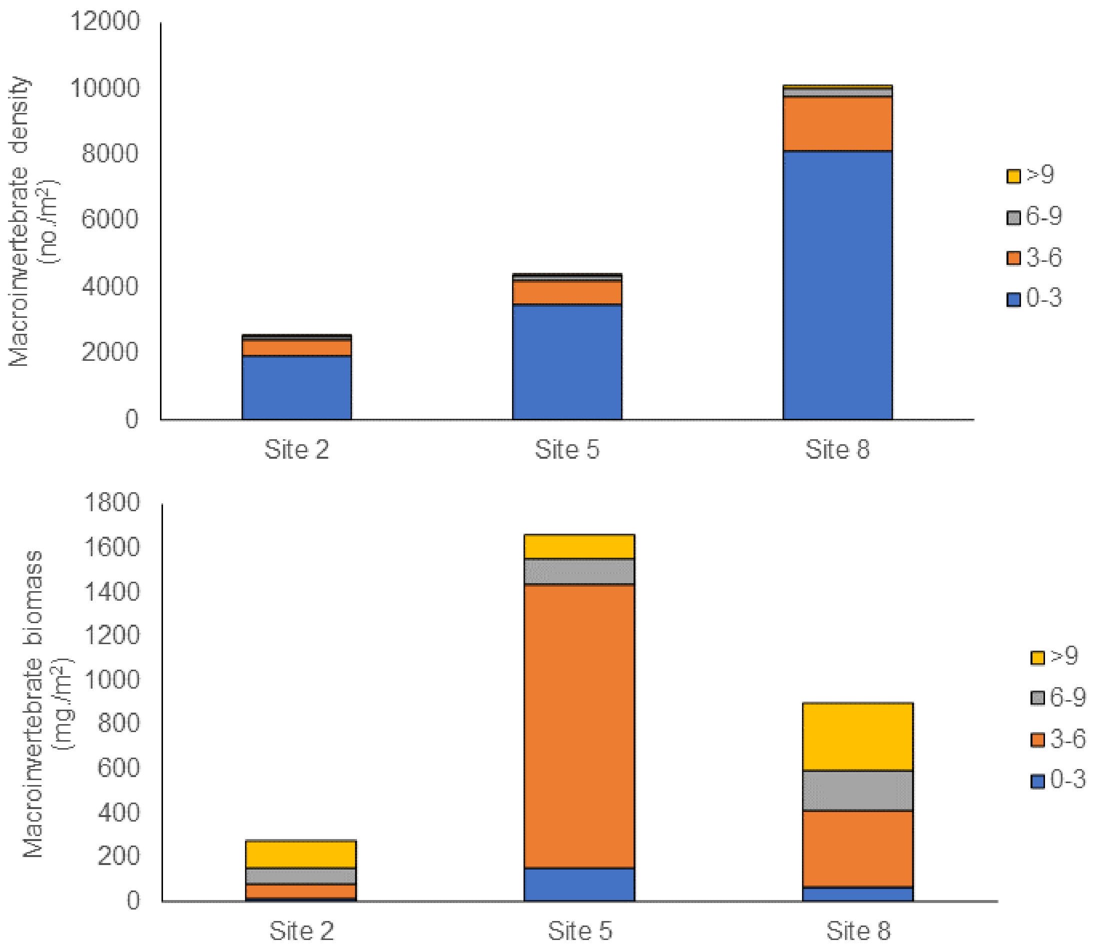

Figure 10. Size-structured density (top) and biomass (bottom) of macroinvertebrates of each 3 mm size class for three sites in the Tekapo River (4–5 March 2019).

In a national drift-dive survey of New Zealand rivers in the 1980s, trout biomass was shown to be positively correlated with invertebrate biomass (Jowett 1992). In the rivers that were above the 75th percentile for trout biomass, invertebrate biomass ranged from 105 to 4,100 mg/m^2 (Jowett 1992). Total benthic invertebrate biomass recorded in the Tekapo River during the present study (280–1,660 mg/m^2) fell within Jowett's (1992) range of pre-didymo invertebrate biomass for rivers with high trout biomass.

4.4.2. Macroinvertebrate summary

The macroinvertebrate community in the Tekapo River is indicative of moderate nutrient/organic enrichment or high periphyton biomass. The most pollution-tolerant taxa were common at sites that had higher didymo biomass, indicating that didymo is the primary driver of current community composition. High densities of macroinvertebrates were found in the didymo mats.

We found moderate to high densities and biomass of macroinvertebrates in the Tekapo River, and generally a typical mix of both large and small invertebrates. These results suggest that the river supports a good macroinvertebrate community food resource for fish and birds despite including taxa that are often associated with enriched rivers with high periphyton biomass.

4.5. Native fish

The Tekapo River has populations of upland bully (*Gobiomorphus breviceps*), common bully (*Gobiomorphus cotidianus*), Canterbury galaxias (*Galaxias vulgaris*), alpine galaxias (*Galaxias paucispondylus*) and kōaro (*Galaxias brevipinnis*). Longfin eels (*Anguilla dieffenbachii*) have also been found in the Fork Stream close to the Tekapo River. More details on native fish communities and any potential effects of the TekPS are discussed in detail in Waterways Consulting (2025).

4.6. Salmonid fishery

The Tekapo River supports brown and rainbow trout. Sockeye salmon (*Oncorhynchus nerka*) also occur in the river periodically, as they run up from Lake Benmore to spawn during March. In recent years the numbers of sockeye salmon have been increasing (Couper 2020). Spawning sockeye in the Tekapo River are protected from anglers under local Fish & Game regulations.

Salmonid habitat in the Tekapo River is primarily limited to below the Fork Stream confluence where surface flows are sufficient to provide permanent habitat. There appear to be no reports, and only sparse anecdotal information, on fish abundance, quality and popularity of the Tekapo River fishery prior to diversion of river's flow into the Tekapo Canal. The Tekapo River was not mentioned in angling surveys of the time, and there are no records of any trout abundance surveys occurring there (Graynoth & Skrzymski 1973). Previous assessments of the value of the Tekapo River fishery (e.g. Jowett & Biggs 2006) assumed that the lack of evidence for its value equated to evidence for its low value. However, these assessments may not have factored in the difficult access to the river as a reason for its low popularity and the potential of the trout population to increase following the filling of Lake Benmore.

The Tekapo River fishery is supplied by salmonid recruits from spawning areas in the tributaries, primarily the Mary Burn and Grays River, as well as the mainstem. The Tekapo River flows into Lake Benmore and is an important source of recruitment for the popular lake fishery there. Spawning in the mainstem Tekapo River is common and successful given the very stable flow regime and suitable substrate (Jowett & Biggs 2006). Trout recruitment in the Tekapo River is also thought to occur from fish migrating downstream from Lake Tekapo during spills through Lake George Scott.

The diversion of lake outlet water from the Tekapo River has changed the natural character from a large turbid river to a small to medium-sized clear-water river with very stable flows, and thereby changed the fishing experience. Since the diversion, the river has supported a premier clear-water ‘backcountry’ fishery (Webb 1989), although angler usage decreased between 2007/2008 and 2014/2015 (coinciding with the arrival of didymo in 2007 and the increase in use of the canal fishery). Unwin (2016) estimated 1,710 angler days were spent on the Tekapo River during the 2014/2015 fishing season; this compares with 4,460 days during the 2007/2008 season, 4,910 days in 2001/2002 and 2,420 days in 1994/1995. Nevertheless, despite the drop in angler usage, the Tekapo River is still a moderately popular angling destination when compared with other ‘medium-sized’ fishing rivers in the country (i.e. rivers with median flows within the 5–15 m^3/s range). The reach of the Tekapo River below the Mary Burn confluence down to Lake Benmore is the most popular segment of the Tekapo River for fishing and provides high-quality physical habitat for trout spawning and trout food production (Kent 1998; Jowett & Biggs 2006).

Didymo can affect the food resources of trout and makes certain angling methods difficult. Didymo may have reduced the productivity of the trout fishery through changing the macroinvertebrate community and impairing visual feeding by trout (Jellyman & Harding 2016). Alternatively, or in addition, didymo may have reduced angler success and satisfaction through fouling of anglers’ lures and influencing aesthetics and perception of success – contributing to the river being less attractive for angling. Also, while didymo is present in the Tekapo Canal, it is at much lower densities there. The canal fishery also has much easier and safer access. Consequently, the arrival of didymo, and the increase in popularity of the canal fishery, probably have contributed to the decrease in angler use of the Tekapo River fishery.

4.6.1. Cawthron investigation: salmonid drift dive in February 2021 to determine trout abundance after the arrival of didymo

Our review of existing information identified a lack of fishery data from the Tekapo River after the invasion of didymo in 2007. Assessments of the distribution and abundance of adult trout along the Tekapo River have been made periodically since the 1980s by drift diving. However, recent attempts to survey in 2014 (Freshwater Solutions 2014) and 2016 (pers. comm. 2021, Hamish Stevens, CSIFG field officer) have been unsuccessful owing to difficulties associated with poor visibility caused by disturbed didymo mats during the drift dive. No successful drift dives had been undertaken since didymo invasion, making it impossible to determine if trout numbers were stable in the catchment, or had declined since the arrival of didymo.

A drift dive was conducted in the mainstem of the Tekapo River over the period 15–19 February 2021. February was chosen to avoid counting migratory (spawning) fish from Lake Benmore, which are thought to start moving into the river in late March.

Twelve dive reaches were chosen to capture the variation in channel character down the river's length (Figure 11). Some of the dive reaches were chosen because they had been surveyed in the past, providing historical data for comparison, while additional sites in between these reaches were included to provide longitudinal representation down the Tekapo River.

Between four and 10 divers drifted the reaches, depending on underwater visibility and wetted width. Enough divers were used to ensure that, when evenly spread across the channel, almost all the width could be viewed for trout. Divers covered all main braids when the river split into multiple channels. In general, more divers were required for the lower reaches below the Mary Burn as the wetted channel widens substantially from there (to about 30 m wide on average). The Central South Island Fish & Game Council provided two staff members to assist with drift diving in the lower river.

Divers drifted down each reach in a line perpendicular to the banks, counting only the trout that passed beneath the 'lane' apportioned to them. Rainbow and brown trout were counted separately and coded into three broad size classes: small (< 200 mm), medium (200–400 mm) and large (> 400 mm). Diver observations were tallied regularly throughout each dive reach.

Didymo and other benthic algae can be problematic when drift diving because divers dislodge algae from the streambed and it then becomes entrained in the water column, reducing visibility. To address this issue, we ensured that there were enough divers to spread across the channel of each dive reach, with no more than 5 m between each diver (i.e. enabling near full coverage of reach widths down to a minimum of 2.5 m visibility). At each dive reach, visual clarity was assessed using the black disc method (Davies-Colley 1988).

Figure 11. The Tekapo River (blue line) and the February 2021 drift dive reaches (orange lines). Imagery sourced from the LINZ Data Service.

The highest densities of medium and large brown and rainbow trout (i.e. trout > 200 mm) were found in Reach 10, which was located a short distance below the Pukaki River confluence (Table 10). The reaches with the highest trout densities broadly align with the segments over which anglers tended to focus most of their effort before didymo invasion (Kent 1998; Jowett & Biggs 2006).

Overall, 451 brown and 110 rainbow trout were counted. Across the whole river there was an average of 29.8 trout/km, with a range of 2.4–74.9 trout/km. Most trout were generally in average condition, with a few, in the lower reaches, showing moderate to poor condition (pers. obs. R. Holmes, Figure 12).

On average, there were 47.5 medium and large trout/km in the reaches downstream of the Mary Burn confluence, where most fishing effort occurs. Reasonable abundances of small trout (< 200 mm) were also recorded there. However, drift diving provides unreliable estimates of small trout numbers, so these results are not discussed further. A single mature male sockeye salmon (approximately 250 mm) was seen in Reach 7 (Figure 12).

Table 10. Counts of small (< 200 mm), medium (200–400 mm) and large (> 400 mm) brown and rainbow trout per kilometre made during the February 2021 Tekapo River drift dive.

Site/dive	**Brown trout**			**Rainbow trout**			**Water clarity (assessed using black disc method)**	**Total medium + large (brown and rainbow) per km**
reach	small	medium	large	small	medium	large		
1	4	0	3	0	0	0	6.0	3.4
2	5	2	5	0	0	0	5.9	4.8
3	3	0	7	1	0	1	6.0	2.4
4	11	4	32	0	1	2	6.0	9.7
5	8	8	11	3	2	4	5.5	26.1
6	17	6	31	1	1	20	5.5	17.9
7	41	7	3	6	2	2	3.3	52.0
8	7	3	6	1	1	0	3.1	18.5
9	30	13	40	3	2	32	3.2	47.5
10	34	20	4	0	1	0	5.8	74.9
11	27	9	6	1	2	10	5.9	30.4
12	31	2	11	0	1	10	5.1	62.0
Totals:	**218**	**74**	**159**	**16**	**13**	**81**	**Average: 5.1**	**Average: 29.8**

Figure 12. A large male (> 400 mm) and medium female (200–400 mm) brown trout sheltering under submerged branch cover in the mid-Tekapo River. The large trout (left) is in poor to moderate condition (i.e. slightly underweight for its length). A mix of didymo, fine sediment and green filamentous algal can be seen covering 100% of the substrate.

This was the first time the river was successfully surveyed by drift diving since the arrival of didymo in the catchment. Trout numbers appear to be reduced, in the order of 50%, relative to historical drift dive survey estimates (undertaken prior to the arrival of didymo). This is consistent with anecdotal reports by anglers of reduced fish numbers and about a 50% reduction in angler usage of the Tekapo River between 2007/2008 and 2014/2015.

Despite an apparent reduction in trout abundance, our observations of current abundances of catchable trout suggest that the lower Tekapo River still supports relatively high trout numbers when compared with other medium to large trout rivers in New Zealand (it currently ranks in the top 30th percentile of abundances reported for 305 New Zealand river reaches surveyed in 1986–1989; Teirney & Jowett 1990).

The recent decrease of angler usage of the Tekapo River also coincides with a substantial increase in the popularity of the Tekapo Canal, as well as a moderate increase in the popularity of Lake Tekapo. However, the fishing experience offered by the lake and canal are different and likely to attract different types of anglers.

4.6.2. Tekapo River salmonid summary

Prior to the arrival of didymo, the Tekapo River supported a popular backcountry fishery. This was associated with good physical habitat, and clear stable flows supporting high macroinvertebrate densities and biomass, enabling successful salmonid spawning within the river (Jowett & Biggs 2006). However, the invasion and proliferation of didymo in the river since 2007 has been associated with a decline in the fishery. The available data suggest that the trout population may have reduced by half relative to pre-didymo surveys.

4.7. Tekapo River assessment of effects

The implementation of the TekPS and associated diversion of water from Lake Tekapo away from the Tekapo River and through the Tekapo Canal resulted in substantial changes to the Tekapo River, including:

- very limited surface flows in the Tekapo River above the Fork Stream confluence
- high water clarity associated with the diversion of glacial flour from Lake Tekapo
- reduced high flows conducive to high production of periphyton and macroinvertebrates and successful salmonid spawning
- physical habitat (depths, velocities and substrate) downstream of the Grays River confluence that are highly suitable for trout food production and trout spawning (Jowett & Biggs 2006).

The invasion of didymo in 2007 has further altered the Tekapo River environment, although this is largely unrelated to the operation of the scheme. Didymo commonly reaches nuisance levels in natural lake-fed rivers (e.g. the Buller, Gowan, Clutha and Hurunui rivers). The stable flow regimes, immobile substrate and low sediment supply of such rivers allow didymo to accrue with little bed disturbance and sandblasting. Consequently, didymo would probably flourish in the Tekapo River, even if it were flowing naturally in the absence of the TekPS.

In a sense didymo has changed the effect-response relationship between the TekPS and macroinvertebrate production and the Tekapo River fishery. The establishment of the TekPS, and subsequent ongoing diversion of water from Lake Tekapo into the canal resulted in clearer water and a reduced range of flows in the Tekapo River. The stable flow regime and clear water in the Tekapo River supported a very popular trout fishery since the 1970s (Jowett & Biggs 2006). These same conditions, however, also provide good conditions for didymo, reducing some of the benefit of the benign environment for the trout fishery (Jowett et al. 2012). As discussed in Section 4.6, the abundance of trout in the Tekapo River recorded in 2021 was about half of that recorded prior to didymo invasion. The arrival of didymo is also likely to have affected river bird feeding (BlueGreen Ecology 2025).

The ongoing operation of the TekPS results in an existing environment within the Tekapo River that provides good water quality and a stable flow regime. This supports a productive ecosystem (abundant periphyton and invertebrates); habitat for six species of native fish; and habitat for brown trout, rainbow trout and sockeye salmon, which in turn supports a relatively popular trout fishery. Periphyton, and particularly the invasive didymo, is currently abundant in parts of the Tekapo River, which is reflected in the relatively high proportion of pollution-tolerant macroinvertebrates in the river and a less popular fishery than prior to didymo. The overall effects of the existing operation of the TekPS on the Tekapo River are somewhat difficult to assess given the invasion of didymo – the stable-flowing, clear-water habitat enhances the macroinvertebrate and trout production while also promoting didymo, which simultaneously reduces them. The generally positive effects of the TekPS scheme on the salmonid fishery in the Tekapo River have been reduced, due to the negative effects associated with didymo. However, the river still supports important values, and continuing operation of the TekPS is not expected to have more than a minor effect on these existing values.

5. RECEIVING ENVIRONMENTS

5.1. Lake Pukaki

Water from the Tekapo Canal is discharged to Lake Pukaki via the Tekapo B power station. Lake Pukaki is a natural lake that was first controlled for hydro-electric storage and power generation in 1947. It has a catchment area of 1,420 km^2 and a surface area of 169 km^2. Lake Pukaki is shallower and more turbid than Lake Tekapo and contains more clay-rich sediment because a larger amount of the catchment is glaciated (Irwin 1978).

Consents relating to the control of water levels for hydroelectric storage are held by Meridian Energy Ltd.

The mean inflow (1990–2010) into Lake Pukaki is about 198 m^3/s (Caruso et al. 2017), of which 76 m^3/s comes from Lake Tekapo via the Tekapo Canal (PDP 2025). Apart from the high turbidity, the water quality in Lake Pukaki is excellent (lawa.org.nz – accessed 11 August 2021). For comparison, the 10-year mean TLI in Lake Pukaki (1.68) is slightly higher than Lake Tekapo (1.61) and slightly lower than Lake Ohau (1.75). The difference between Lake Pukaki and Lake Tekapo is within the standard error of the mean (0.02) and all three lakes are classified as microtrophic. Lake Pukaki has showed no indication of change in water quality based on total nitrogen, total phosphorus and chlorophyll-*a* concentrations since 2006, when routine monitoring data collection began. Interannual patterns in TLI show strong regional correlation across the lakes (Table 11), suggesting that climatic factors are the strongest determinant of water quality trends within these lakes (Shuvo et al. 2021). The water discharged from Tekapo B is generally considered to be similar in quality relative to the receiving environment in Lake Pukaki, with the exception that turbidity is substantially lower. The water quality of discharge water exiting the TekPS is generally excellent.

Lake Pukaki was ranked second lowest in terms of benthic invertebrate species richness and biomass out of 19 South Island lakes surveyed by Timms (1982). As outlined in Section 2.5, the explanation for this low diversity is the naturally low water clarity (due to glacial silts) as well as the large water level fluctuations relative to the euphotic depth. Lake Pukaki supports native fish populations, including kōaro, upland and common bullies, and a remnant population of longfin eels. Brown and rainbow trout are also present, and land-locked sockeye salmon, which have become more abundant in recent years.

Table 11. Correlation comparison between annual trophic level index (TLI) scores for four lakes within the Waitaki hydro-scheme 2006–2019. Data sourced from lawa.org.nz – accessed 11 August 2021.

	Tekapo	Pukaki	Ohau	Benmore
Tekapo	1			
Pukaki	0.360	1		
Ohau	0.417	0.153	1	
Benmore	0.174	0.042	0.325	1

5.1.1. Cawthron investigation: monitoring of thermal stratification and bottom water dissolved oxygen in the Stilling Basin

One aspect of water quality entering Lake Pukaki from TekPS that has not been considered to date is dissolved oxygen. In an extreme situation, anoxia (zero oxygen concentrations) may develop in the bottom of waterbodies, such as the Stilling Basin at the bottom of the Tekapo Canal, where waste organic material from the salmon farm is known to deposit (Kelly & Baisden 2014). Anoxia can result in the release of bound nutrients from the sediment. If periods of anoxia in the Stilling Basin occur during normal TekPS operations, this will reduce the quality of water (decreased DO levels and increased nutrient concentrations) prior to it being discharged through Tekapo B into the receiving environment of Lake Pukaki. To assess any potential risk of low-oxygen water being discharged into Lake Pukaki, Cawthron monitored stratification and bottom water dissolved oxygen (DO) in the Stilling Basin during late summer, the highest risk period.

Data collection

Monitoring of DO and water column temperature over the period from 22 February to 26 March 2021 was achieved by installing a thermistor chain and DO sensor in the Stilling Basin near the inlet to Tekapo B (Figure 13).

We deployed calibrated D-Opto® DO/temperature loggers (www.d-opto.com) and Hobo Pendant® temperature loggers (www.onsetcomp.com/products) at multiple depths along a mooring line placed at the deepest point within the central basin, at approximately 13 m water depth. The D-Opto logger was positioned in the bottom water (suspended 1 m above sediment) and recorded DO and temperature every 5 minutes. The DO logger was fitted with a PVC shroud to prevent particles and debris in the water column from settling on the optical sensor and interfering with measurements. The Hobo temperature sensors were installed at water depths of 1, 2, 4 and 8 m and set to record data at 5-minute intervals over the period 9:00am, 20 February 2021 to 1:00pm, 26 March 2021.

Data were downloaded, and calibration checks performed using a two-point (0% and 100%) linear correction, at the end of the logging period. The offset in DO saturation at the end of the 34-day deployment was:

$$DO\ saturation_{calibrated} = 1.039 \times [DO\ saturation_{measured}]$$

A negative linear trend in dissolved oxygen over the deployment period indicated that this offset was due to gradual sensor drift. A linear correction was incrementally applied to the data set over the period (i.e. 0% of the offset correction was applied at the beginning and the correction increased progressively through to 100% at the end).

Temperature loggers were calibrated in the laboratory after deployment using a calibration thermistor with ± 0.01 ˚C accuracy. This demonstrated that all temperature readings were accurate within 0.11 ˚C of absolute temperature and precise within 0.10 ˚C of each other.

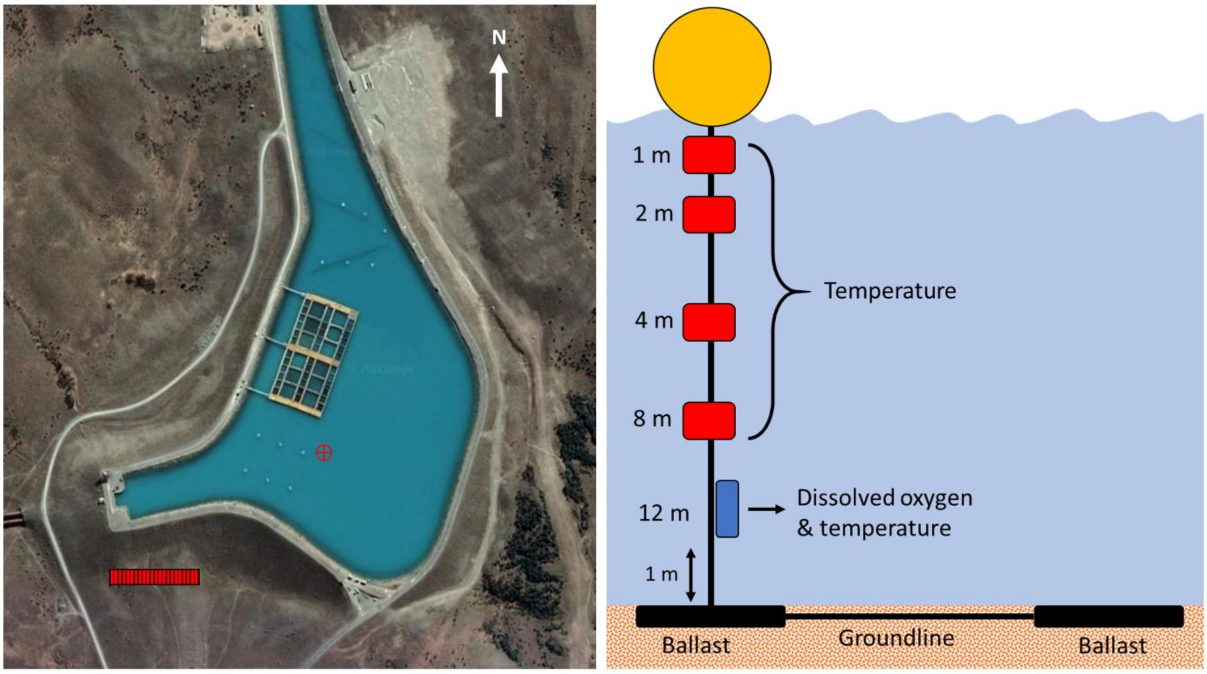

Figure 13. Location (left) and configuration (right) of the temperature and dissolved oxygen monitoring buoy deployed in the Stilling Basin. The crossed red circle on the left indicates the location of the monitoring buoy and the red scale bar represents 100 m.

Data from the thermistor chain demonstrated that the Stilling Basin consistently stratified and mixed on a daily cycle, including during two periods when the canal ceased flowing for > 24 hrs. The lack of development of a persistent thermocline meant that dissolved oxygen concentrations remained above 40% saturation throughout the study period (Figure 14).

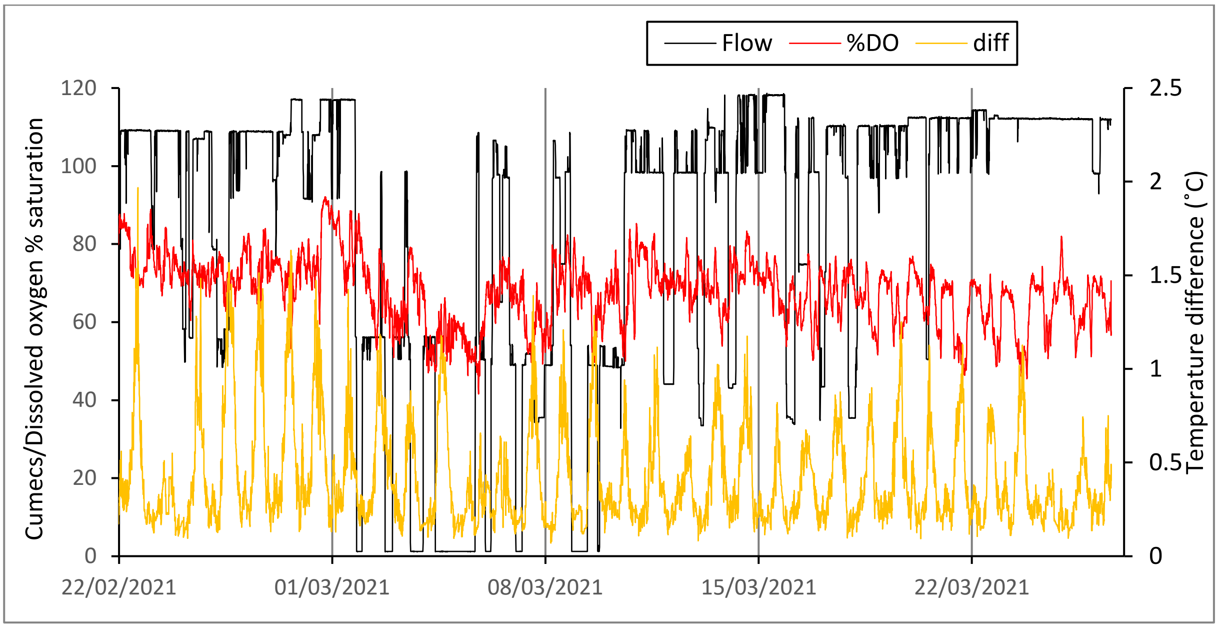

Figure 14. Comparison of bottom water dissolved oxygen saturation (%DO), canal discharge into the Stilling Basin (Flow) and thermal stratification (diff = the temperature difference between 1 and 12 m depth) between 20 February and 26 March 2021.

Calculated depletion rates for DO suggest that the Stilling Basin does have sediments with a high bottom water oxygen demand. Calculated oxygen depletion rates ($\Delta O_{2\text{ - \% Saturation}}$ per hour) varied between 0.7 and 2.9. The relatively high rates of oxygen demand are due to deposited organic-rich sediment, most likely from salmon farming within the canal (Kelly & Baisden 2014). An assessment of the nitrogen budget from a similar salmon farm within the Waitaki Canal scheme also indicates that much of the nitrogen load settles out to the canal bed and very little is released downstream as dissolved nitrogen losses (Stewart et al. 2022). Under current typical operating, the Stilling Basin remains well oxygenated and does not appear to pose any risk to water quality entering Lake Pukaki. Monthly water quality monitoring data collected by Mt Cook Alpine Salmon Ltd for the stilling pond (i.e. the upstream end of the Tekapo B penstocks) in the Tekapo Canal from January 2020 to September 2023 indicate that the quality of the discharge water exiting the Tekapo B power station is generally excellent and complies with the limits set out in the Canterbury Land and Water Regional Plan.

5.1.2. Lake Pukaki assessment of effects

The quality of water that is discharged from the Tekapo Canal into Lake Pukaki is generally excellent and therefore the effects of the TekPS on the ecology of Lake Pukaki are less than minor.

5.2. Lake Benmore

Lake Benmore was commissioned in 1964 for hydro-power generation and is currently managed by Meridian Energy. The lake has a surface area of 75 km^2 and a maximum depth of 90 m. The lake consists of two flooded river valleys, the Ahuriri Arm to the south and the Haldon Arm to the north, which are essentially independent bodies of water. The Haldon Arm is a confluence of four rivers (the Pukaki, Ohau, Twizel and Tekapo rivers) and the Ohau Canal. It is typically 3–4 m deep in the Ohau delta region to the south and east of the Ohau Canal, and then deepens toward the south. Haldon Arm is subject to high sediment loads from the Ohau Canal (Figure 15) and is also exposed to variations in flows from the canal and the rivers.

Water quality of Lake Benmore is generally good. The lake has a 10-year mean TLI score of 2.18, classifying it as oligotrophic. Lake Benmore generally shows weaker correlation in TLI with the other lakes in the region (Table 11), which is likely a result of the significant decreasing trend in its water quality (TLI) (lawa.org.nz – accessed 11 August 2021). The declining trend in water quality, which is measured near the dam face, is driven by nutrient enrichment in the Ahuriri Arm. Water quality within the Haldon Arm, which receives water from the TekPS, is stable and higher (Spigel et al. 2015).

The Tekapo River enters the Haldon Arm over a shallow delta adjacent to, and east of, inflows from the Ohau Canal and the Ohau River. The diversion of the Pukaki River into the Ohau Canal has created a relatively small area with relatively low turbidity on the true left side (east) of the delta at the head of the lake, which would otherwise have received turbid water from the Pukaki and Tekapo rivers (Figure 15). Any effects on the ecology of Lake Benmore (e.g. turbidity and water level fluctuation) are largely the result of Meridian Energy's operation of Lake Pukaki. Therefore, ecological effects in Lake Benmore are generally of lesser interest to Genesis with respect to reconsenting. However, any flow releases down the Tekapo River, via Lake George Scott, are under the control of Genesis. Flow releases that occur to manage Lake Tekapo within maximum operating levels have some potential to adversely affect Lake Benmore. For example, a flow release down the Tekapo River could result in a large amount of didymo and other periphyton being scoured from the bed of the Tekapo River and washed into Lake Benmore. Potential effects of this organic material on water quality within Lake Benmore are discussed further below.

5.2.1. Cawthron investigation: potential for sloughed didymo and periphyton mats to contribute to low dissolved oxygen in Lake Benmore

To assess the existing effect of sloughed didymo and periphyton potentially driving low dissolved oxygen levels in Lake Benmore, we have:

1. determined the amount of periphyton organic material that could be supplied from the Tekapo River to the Haldon Arm of Lake Benmore during a flood flow
2. run possible scenarios for determining the amount of biological oxygen demand inputs of organic material could have on bottom waters in the lake
3. evaluated whether biological oxygen demand is likely to be ecologically significant for Lake Benmore.

Figure 15. Satellite image of the northern end of the Haldon Arm, showing the turbid waters of the Ohau C Canal (left) mixing with the clear riverine water at the confluence of the Pukaki, Ohau, Twizel and Tekapo Rivers.

Periphyton cover assessments in the Tekapo River were undertaken at nine sites (Figure 6) in March 2019, and periphyton biomass was measured as ash-free dry mass at Sites 2, 5, and 8 (for more details refer to section 4.5.1). At each site, percentage periphyton cover was estimated using a modified version of the Rapid Algal Assessment Method 2 (RAM2). The assessment included estimation of didymo cover as well as the standard periphyton colour categories used in the protocol (Biggs & Kilroy 2000). Detailed descriptions of the periphyton assessment and sample collection methodologies are provided in a previous section of this report (Section 4.3).

Calculating Haldon Arm dissolved oxygen depletion

Detailed bathymetric data for 400 × 400 m grids were available in Norton et al. (2009), from which the total hypolimnetic volume[10] of the Haldon Arm was calculated. For this volumetric calculation, the hypolimnetic layer was estimated to be below water depths of 30 m, which was the typical summer thermocline depth reported by Norton et al. (2009) and Spigel et al. (2015). The total oxygen content of the hypolimnion was then calculated from this volume, assuming typical background DO concentrations demonstrated in previous models: 10 mg/L (Norton et al. 2009; Spigel et al. 2015).

Consumption of oxygen by organic material transported into the Haldon Arm during flood flows was made with the following assumptions:

1. The amount of carbon contained in periphyton per unit of organic dry weight was calculated using previous information from an isotopic study in the Tekapo Canal that found the carbon content of periphyton to be on average 9.7%; based on samples from six Tekapo Canal sites (Kelly & Baisden 2014).
2. In all instances organic carbon decomposition was made to balance the observed oxygen depletion using a mass balance ratio of 1:2 moles of carbon to oxygen (Marcé et al. 2008).
3. We assumed 100% of the deposited carbon would be decomposed in the bottom waters within the stratified period, although some carbon could be buried in sediments and decompose over longer periods. As such, this would provide estimates of oxygen demand at the upper end of those expected.

Estimate of periphyton biomass delivery

During the March 2019 periphyton survey of the Tekapo River, the dry weight of periphyton organic matter ranged from 33.1 g/m^2 (Site 5) to 81.7 g/m^2 (Site 2). When standardised to the wetted channel width measured during the February 2019 longitudinal flow survey, reach biomass of periphyton ranged from a low of 642 kg/km in the mid-reaches (Sites 4 and 5), to 2,232 kg/km in the lower river (Sites 7 and 8) (Table 4). Based on the total river length between Site 1 and the Lake Benmore confluence, periphyton total dry organic weight was estimated to be 60,210 kg over the approximately 49 km of river. Based on an average carbon content of 9.7% by dry mass (from Tekapo Canal isotope study; Kelly & Baisden 2014), 15,534 kg of carbon was potentially available in periphyton matter to be flushed from the river during March 2019.

[10] Hypolimnetic volume is the volume of water below the thermocline in a lake. It is used, in combination with oxygen concentrations, to calculate the total mass of oxygen available to support sediment and bottom water respiration.

Contribution of periphyton to lake oxygen depletion

The hypolimnetic volume of the Haldon Arm of Lake Benmore was estimated to be 237.5 million m^3 of water, based on bathymetric data, the hypolimnetic depth from Norton et al. (2009) and an average thermocline depth of 30 m, modelled by Spigel et al. (2015). This meant that an estimated 4.3 tonnes of dissolved oxygen were available in the hypolimnion in spring prior to formation of the thermocline, based on a starting DO concentration in the hypolimnion of 10 mg/L (Norton et al. 2009). This calculation assumed that no further oxygen was supplied to the lake hypolimnion through diffusion or entrainment of oxygen via inflows. As such, it is a conservative estimate of the hypolimnetic oxygen pool because some diffusion and entrainment of oxygen during floods probably contributes to oxygen content of bottom waters during stratified periods.

Based on this relatively conservative approach of calculating potential oxygen depletion in Lake Benmore, the extent of hypolimnetic oxygen depletion is likely to be insignificant. The most conservative estimate is a 0.189 mg/L decline in bottom water DO, assuming the high biomass of periphyton will be entirely scoured from the bed during a flood and fully decompose in the hypolimnion of the lake over the stratified period. It is more likely that the biological oxygen demand would be considerably lower and result in a decline in DO of 0.03–0.1 mg/L. This is what we expect under the more likely scenario when the removal of periphyton from the river is closer to 60–80% (Jowett & Biggs 2006), and only some material decomposes (e.g. 25–50% burial or material in the sediment).

Therefore, even if multiple floods were to occur over a summer recreation season in the Tekapo River, the associated biological oxygen consumption in Lake Benmore would likely result in less than a 0.5 mg/L reduction concentration (e.g. resultant concentration of ~ 9.5 mg/L), and therefore have minimal ecological effects. Environment Canterbury data have indicated declines in dissolved oxygen in the Haldon Arm during summer, but these are likely related to normal lake ecosystem processes and driven by nutrient inputs and phytoplankton blooms in the lake, not sloughing of didymo and other periphyton from the Tekapo River.

5.2.2. Lake Benmore assessment of effects

Flow releases past the Lake George Scott Weir are occasionally of a size sufficient to scour didymo and other periphyton mats from the Tekapo River. The deposition and decomposition of these sloughed mats in the hypolimnion of the Haldon Arm of Lake Benmore represents a potential risk to bottom water oxygen concentrations. However, a mass balance assessment using worst case scenario estimates of biomass and decomposition rate demonstrated that this potential risk is less than minor. This assessment, coupled with our assessment of monitored water quality parameters, indicates that the TekPS has no adverse effects on Lake Benmore.

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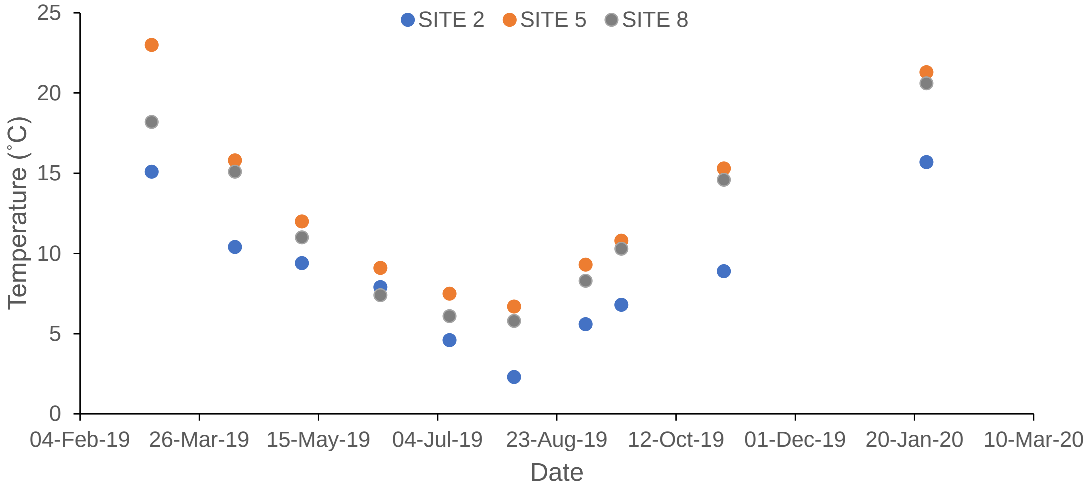
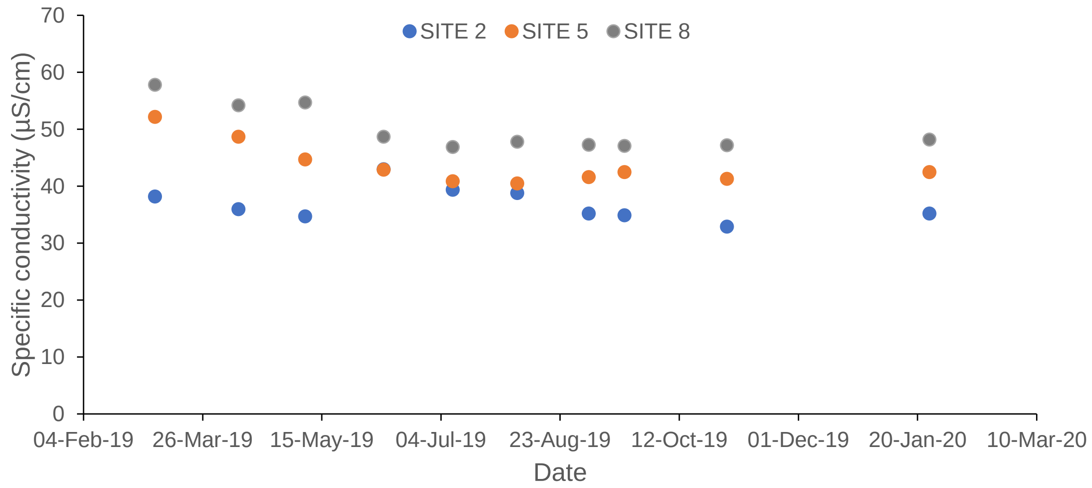
8. APPENDICES

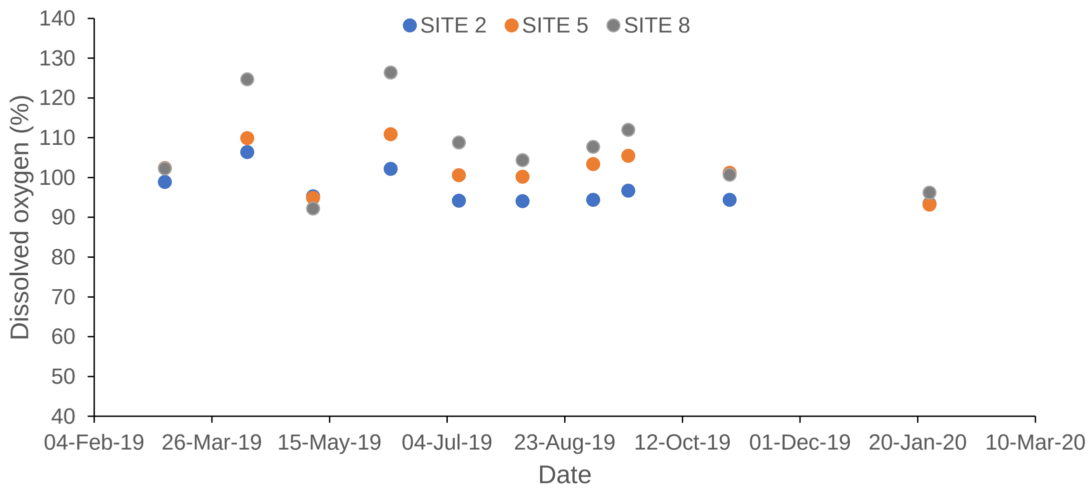
Appendix 1. Macroinvertebrates collected from the Tekapo Canal (2014) using a core sampler (130 mm diameter, 0.5 mm mesh). See Section 3.4 of this report for a description of study design and processing methodology.

	Transect 1		Transect 2						Transect 3		Transect 4		Transect 5	
Taxa	**A**	**F**	**A**	**B**	**C**	**D**	**E**	**F**	**C**	**F**	**A**	**E**	**B**	**D**
Diptera (flies)														
Chironomus sp. A	6	-	2	15	1	-	-	-	1	-	5	-	1	7
Cladopelma curtivalva	-	-	-	-	-	-	-	-	-	-	1	-	1	1
Orthocladiinae	1	-	-	-	1	-	-	-	-	-	1	-	2	1
Tanypodinae	-	-	1	1	-	-	-	-	-	-	1	-	1	2
Odonata (damselflies)														
Zygoptera	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Trichoptera (caddis flies)														
Hudsonema amabile	-	-	-	-	-	-	-	-	-	-	1	-	1	1
Oxyethira sp.	-	-	-	-	-		-	1	-	-	-	-	-	-
Paroxyethira sp.	-	-	-	-	-	1	-	-	-	-	-	-	4	1
Oecetis unicolor	1	1	3	-	1	-	5	2	3	-	3	2	3	9
Nematoda (roundworms)	55	10	-	-	-	3	-	3	26	2	14	16	67	5
Oligochaeta (worms)	52	4	6	6	5	5	-	13	19	17	12	23	81	10
Mollusca (snails, bivalves)														
Lymnea stagnalis	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Physa sp.	-	-	1	2	-	-	3	-	-	3	-	1	-	2
Potamopyrgus antipodarum	-	41	9	61	30	9	27	102	52	42	41	69	92	212
Sphaeriidae	7	-	-	9	2	-	-	1	-	-	1	1	-	2
Crustacea (crustaceans)														
Ostracoda	-	-	-	-	-	-	-	-	-	-	2	-	-	-
Acarina (mites)	-	-	-	1	-	1	-	-	-	-	-	-	-	-
Number of taxa	6	4	6	7	7	5	3	6	5	4	11	7	10	12
Number of animals	122	56	22	95	41	19	35	122	101	64	82	113	253	253
Density (m^2)	9191.4	4219.0	1657.5	7157.3	3088.9	1431.5	2636.9	9191.4	7609.3	4821.7	6177.8	8513.4	19060.9	19060.9

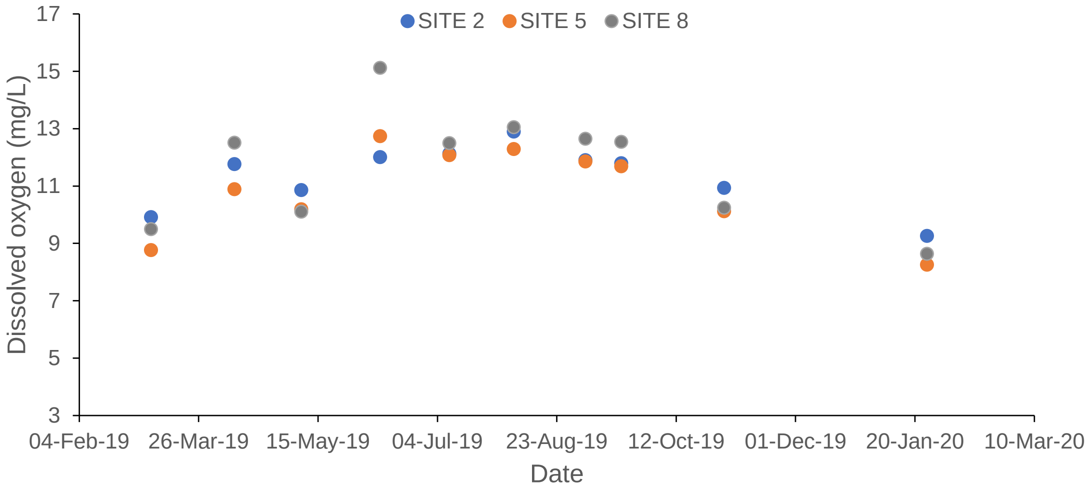
Appendix 2. Monthly results for temperature, conductivity, dissolved oxygen (% and mg/L), pH and turbidity (NTU) in the Tekapo River for Sites 2, 5 and 8, located in the upper, middle and lower catchment, respectively.

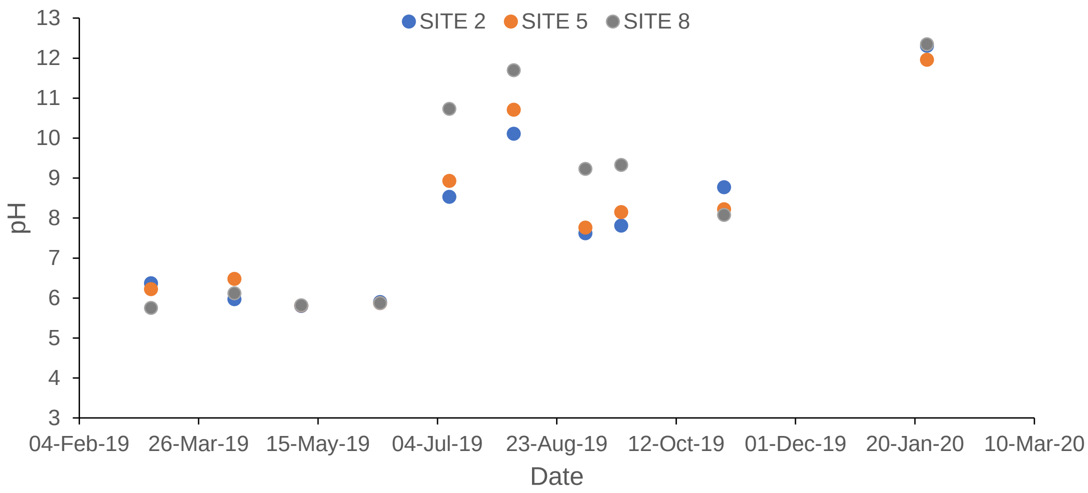


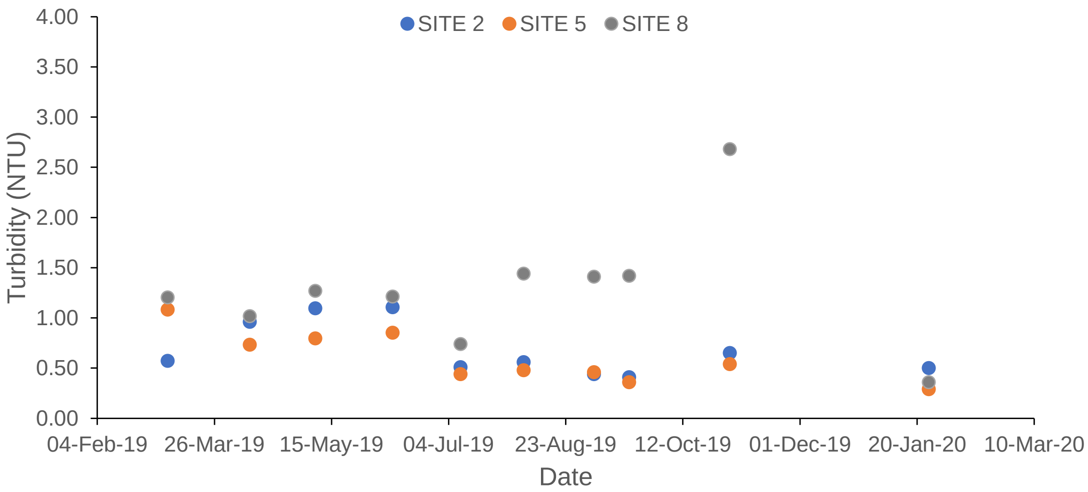




Appendix 2 (continued).







Appendix 3. Macroinvertebrates collected in composite Surber samples (0.6 m^2 area, 0.5 mm mesh) from the Tekapo River at Sites 2, 5 and 8 on 4–5 March 2019, and the MCI score for each taxon. '-' indicates taxon was not found in sample.

		Tekapo River		
Taxa	**MCI taxon score**	**Site 2 04-Mar-19**	**Site 5 05-Mar-19**	**Site 8 04-Mar-19**
Ephemeroptera (mayflies)				
Austroclima.	**9**	9	1	19
Coloburiscus	**9**	4	-	-
Deleatidium	**8**	45	68	340
Nesameletus	**9**	2	-	-
Zephlebia	**7**	-	-	2
Plecoptera (stoneflies)				
Zelandobius	**5**	2	-	-
Zelandoperla	**10**	-	-	1
Megaloptera (dobsonflies)				
Archichauliodes	**7**	1	-	1
Lepidoptera (moths)				
Hygraula	**4**	-	3	-
Coleoptera (beetles)				
Elmidae	**6**	22	42	6
Diptera (flies)				
Aphrophila	**5**	-	-	2
Austrosimulium	**3**	1	16	23
Chironomidae	**2**	-	-	1
Empididae	**3**	-	1	27
Eriopterini	**9**	2	-	-
Maoridiamesa	**3**	1	4	160
Molophilus	**5**	1	-	-
Muscidae	**3**	-	8	6
Orthocladiinae	**2**	1264	40	1936
Tanypodinae	**5**	-	4	6
Tanytarsus	**3**	48	144	860
Trichoptera (caddis flies)				
Hydropsyche (*Aoteapsyche*)	**4**	33	156	581
Beraeoptera	**8**	1	-	-
Costachorema	**7**	4	-	-
Hudsonema	**6**	8	13	7
Hydrobiosis	**5**	37	30	68
Neurochorema	**6**	-	2	23
Olinga	**9**	6	1	-
Oxyethira	**2**	60	728	160
Psilochorema	**8**	17	-	2
Pycnocentria	**7**	-	2	4
Pycnocentrodes	**5**	1	404	58
Zelolessica	**10**	1	-	-

Appendix 3 (continued).

Taxa	MCI taxon score	Tekapo River Site 2 04-Mar-19	Site 5 05-Mar-19	Site 8 04-Mar-19
Mollusca (snails)				
Austropeplea	**3**	-	153	-
Glyptophysa	**5**	-	5	-
Gyraulus	**3**	-	36	-
Lymnaea	**3**	-	5	-
Physa	**3**	-	324	1
Potamopyrgus	**4**	2	704	98
Crustacea (crustaceans)				
Amphipoda	**5**	-	-	2
Cladocera	**5**	8	28	-
Nematomorpha (horsehair worm)	**3**	-	2	-
Nematoda (roundworms)	**3**	-	11	2
Nemertea (proboscis worm)	**3**	-	8	3
Oligochaeta (worms)	**1**	186	112	2623
Platyhelminthes (flatworms)	**3**	-	-	3
Acarina (mites)	**5**	4	40	40
Total taxa		27	31	31
Total abundance		1770	3095	7065
Total density (No/m^2)		2531	4426	10103
MCI		116	86	94
QMCI		2.44	3.46	2.38
%EPT (by taxa)*		51.9	29.0	35.5
% EPT (by abundance)*		9.6	21.9	15.6

* %EPT calculations exclude Hydroptilidae