CAWTHRON
The power of science®

30 June 2020

ID: 2045
Cawthron Ref No: 70/17436

Tasman District Council
189 Queen Street
Richmond 7020

Re. Envirolink Grant 2030-TSDC161 Takaka ecological freshwater data

Dear Joseph

Please find attached a Cawthron Advice Letter in fulfilment of the requirements for Envirolink Grant 2030-TSDC161: Takaka ecological freshwater data.

Yours sincerely

Scientists

Karen Shearer John Hayes
Freshwater Biologists
Cawthron Institute
Ph: 0800 80 98 98 ext. 271

Reviewed by

Roger Young
Freshwater Group Manager
Cawthron Institute

Introduction

The Tasman District Council (TDC) is developing a Water Management Plan (WMP) under the National Policy Statement for Freshwater Management (NPS-FM) for the Tākaka Water Management Zone. This area covers the Tākaka River catchment and the river catchments towards Tukurua and Wainui Bay.

There are a range of rivers, streams and springs, including the nationally famous Te Waikoropupu Springs, in this area, with variable flow characteristics and the added complexity of karst geology. TDC considers establishing baseline ecological monitoring for the rivers/streams and springs for this area will be important for ensuring that good quality and robust ecological data are available for Council to:

- increase Council's ability to detect change in ecological state over time (whether that be due to anthropogenic or natural causes) and,
- inform comparative analyses between catchments in relation to hydrological effects/impacts and within the constraints of national policy as it evolves.

TDC is required to implement the National Policy Statement for Freshwater Management (NPS-FM 2014, 2019) by 2030 at the latest. This means:

- identifying community values of water and freshwater objectives to enable these values
- avoiding over allocation of water and avoiding degradation of water quality
- putting in place policy, rules, targets and limits to meet the freshwater objectives.

Water allocation provisions have been developed in consultation with the Tākaka Freshwater and Land Advisory Group (FLAG) and local iwi. A primary consideration when setting flow limits and allocation rates is determining potential effects on instream ecology. Robust ecological data are essential to future decision-making around water quality and quantity pressures in the Tākaka Water Management Zone. A more comprehensive knowledge of the river and stream ecosystems in the Golden Bay region will aid in giving effect to Objective 2.1 of the draft NPS-FM (2019) (i.e. to ensure resources are managed in a way that prioritises: the health and wellbeing of water bodies and freshwater ecosystems, the health needs of the people and the ability of people and communities to provide for their social economic and cultural wellbeing now and in the future).

With any reduction in flow below a low flow statistic such as the 7-day mean annual low flow (7-day MALF), regardless of whether the reduction is natural or anthropogenic, there will be some negative effects on the river ecology (see Effect of water abstraction on river biology section below). In the Tākaka Water Management Zone, some river reaches naturally go dry (i.e. there is no apparent surface water flow). A good knowledge of how river ecosystems respond to natural low flows generally is required before the effects of altering flow can be understood.

The Council sought advice on how to establish a baseline survey for monitoring to meet the above NPS-FM requirements. This letter outlines the design of a proposed baseline monitoring programme including:

- what ecological aspects should be monitored and why
- timing of monitoring work.

We also provide a cost estimate for the field component that could be undertaken by Cawthron staff, should TDC choose to contract Cawthron.

It is important that the data collected can be placed in context of flow and time so that meaningful comparisons of results can be made when/if the monitoring survey is replicated in the future. It should be noted that biological data collected would need to be placed in context of hydrological statistics that are known to be ecologically relevant in order to determine responses of ecosystem variables to flow change. A one-off survey will have little value by itself for detecting effects of low flow unless flow is low enough to cause catastrophic direct effects on survival via low dissolved oxygen and high water temperature. To detect more subtle indirect effects on density and/or population abundance, temporal, as well as spatial, variability needs to be accounted for in the study design. Furthermore, the ecological data need to be complemented with flow and hydraulic geometry data and ecologically relevant flow statistics (e.g.7-day MALF).

Purpose of letter (survey/monitoring aims)

The letter provides practical guidance on the collection of relevant ecological data that could be used:

a) for consideration in consent applications relating to water takes
b) as a valuable resource for public outreach/education on safeguarding water resources
c) to enable council to target the most at-risk streams (ecologically) for future monitoring
d) as biological background that can complement instream habitat versus flow (e.g. IFIM) studies undertaken to assess the effect of flow change on available habitat for invertebrate and fish
e) for assessing the effectiveness of water minimum flow and allocation limits and water quality limits in the WMP.

Biological water quality variables relevant to water abstraction assessments

Effect of water abstraction on river biology

Setting minimum flow and allocation limits on rivers is a difficult task, as the need for water for out-of-stream water uses must be balanced with the instream needs of aquatic life—such that the life-supporting capacity[1] of the river is safeguarded. The hydrological effects of water

[1] Note: from an ecological perspective it could be argued that "life-supporting capacity" refers to the capacity of a water body to support life in all its variety to survive and reproduce. Unlike most water quality variables that have a threshold below which the life-supporting capacity of a river is considered to be diminished, there

abstraction include reduction in flow (e.g. low flow) and flow variability (e.g. increased periods of low flow as when flow is flatlining at minimum flow). Flow variability is important for flushing rivers and even small freshes encourage a natural resetting of a river system (e.g. maintaining levels of periphyton biomass below nuisance levels).

Long periods of stable low flow (usually common during the summer months) can be extended with water abstraction, potentially exacerbating stress on aquatic organisms. The physical habitat available for invertebrates and fish dries up in river margins and riffles, and water quality begins to deteriorate; e.g. temperature can increase with reduced flows in rivers, periphyton can proliferate (especially during the summer months), which can adversely influence daily cycles of dissolved oxygen and pH.

The magnitude, and risk, of adverse ecological effects of flow alteration depends on the degree of hydrological alteration, i.e. the magnitude and duration of flow reduction relative to natural flow magnitude and variability. For example, small abstractions from rivers with high MALFs and/or high variability will have smaller hydrological and ecological effects.

Biological variables

In this section we address the biological variables, or attributes of ecosystems, that are relevant to, and should be considered in, water abstraction assessments. These are variables that we consider would be important in a biological monitoring programme for the Tākaka region.

1. Dissolved oxygen (DO) and temperature (continuously logged)

Dissolved oxygen and temperature are the two most important water quality variables for maintaining the life supporting capacity of a river. Of particular importance is the daily cycle (i.e. change) in DO and temperature. Water temperature can affect the metabolic rates and biological activity of aquatic organisms. High temperatures outside the normal tolerance

---

is no single minimum flow that provides for life-supporting capacity of aquatic life. The key point is that the responses of most ecological attributes to flow change are continuous, not binary or threshold, relationships [DO and temperature are exceptions: low flows can drive them beyond lethal thresholds]. Thus, any natural reduction in flow (at low flows) has the potential to reduce the life supporting capacity of a river, and by association, further reductions will occur as a result of water abstraction. Conversely, life-supporting capacity increases again when flows are naturally restored as a result of natural flow variability with trophic levels recovering at different rates. In respect of meeting freshwater management objectives, it is commonly the case that regional plans state that minimum flow limits safeguard life supporting capacity (Hayes 2019). However, this implies a binary ecological response, i.e. life supporting capacity is either safeguarded or not. Given the continuous nature of ecological responses to flow, it would be better if flow management objectives, and limits based on ecological attribute–flow relationships, were more transparently articulated than has been common in the past. For example, rather than saying that a flow or allocation limit "safeguards life-supporting capacity", and "maintains", or "provides for", habitat and ecological processes, it would be more transparent and ecologically honest to say that the limit "safeguards life supporting capacity, and maintains habitat and ecological processes, to a degree that could be considered precautionary". If a limit cannot be defended as being precautionary then the level of protection could be articulated as a percentage of instantaneous flow, MALF, or flow-related ecological attribute at the reference flow, or by narrative as a level of risk (e.g. low, moderate, high risk of adverse effect) (Hayes 2019). It must also be appreciated that flows naturally fall below minimum flow limits.

ranges of fish and invertebrates can have profound negative physiological effects. Dissolved oxygen is critical for supporting aquatic life, and low concentrations can cause death—particularly for sensitive fish and aquatic organisms. Dissolved oxygen can vary widely over a 24-hour period, especially in systems where there is significant nutrient enrichment. As photosynthesis is light-dependent, the DO peaks during daylight hours and declines at night.

Daily mean water temperature is relatively insensitive to altering flow; it is affected more by climate. Natural variation in water temperature depends on a rivers source and distance from that source. Spring-fed rivers in the Golden Bay region will experience less temperature variation than hill-fed rivers; for example, the water in the Waikoropupu Springs is fairly constant at around 11.7 °C (± 0.03 °C). As a river flows downstream, the water reaches an equilibrium temperature where cooling equals heating. Abstracting water when the river is at equilibrium temperature has little effect on mean water temperature. Abstraction has more effect on the amplitude of daily temperature fluctuations. It should be noted that a large abstraction relative to the natural flow would be required before temperature changes would occur. As a result of diurnal heating and nocturnal cooling, daily fluctuations in water temperature increase as the flow reduces, but perhaps by less than 1.5 °C for a halving of flow (pers. comm. Ian Jowett—experience from modelling water temperature in rivers).

2. Nutrients (DIN, DRP) (spot water sample)

Nutrients (along with light and temperature) are key variables in controlling the growth of algae, other aquatic plants and cyanobacteria. Algal blooms and cyanobacteria blooms can degrade aesthetic and recreational values and have potential health implications for humans and animals. High algal and plant biomass can cause large fluctuations in pH and DO, smother habitat for stream invertebrates, and cause taste and odour problems for water supplies.

3. Water quality (Turbidity) (field meter)

Turbidity is a measure of water clarity and discolouration by particulate material. Excessive suspended sediment can impair water quality for aquatic life (e.g. by clogging fish gills and smothering habitat). High levels of total suspended solids increase water temperatures because suspended particles absorb more heat than water. In turn this can decrease dissolved oxygen (DO) levels, because warm water cannot hold as much DO as cold water.

4. Periphyton (qualitative survey – percentage cover)

Periphyton cover can provide an indication of enrichment, and during extended periods of low flows (with no flushing flows) biomass can often accrue to nuisance levels. The effects of high biomass can be concerning for other aquatic life (invertebrates and fish), as the natural cycle of algal photosynthesis and respiration might exacerbate overnight DO minimum to the extent that animals are placed under stress or die. Excessive periphyton growth can also potentially smother the riverbed, resulting in loss of sensitive invertebrate taxa through habitat alteration, possible reduction in benthic biodiversity, and impairment to fish spawning and living habitat.

5. Macroinvertebrates (quantitative survey – Surber samples)

Macroinvertebrate communities can provide an indication of water quality and are the food for higher trophic levels. Water abstraction will restrict invertebrate habitat and potentially aspects of water quality key to sustaining life in a river (e.g. DO and temperature). As flows decline and the wetted width of a river decreases, invertebrate densities may well increase, as animals are forced to move and inhabit a shrinking habitat. Some may drift out of overcrowded areas, but this is only an option insofar as river flows are maintained. Invertebrates have relatively short life spans (usually annual) so recovery from low flows can be relatively quick (months) as long as there is a source of nearby colonists.

6. Fish surveys (quantitative survey – electric fishing)

The effects of water abstraction on fish are similar to those for invertebrates—restriction of habitat and potential reduction in habitat and water quality that could cause animals to become stressed, emigrate or potentially die. Fish have longer life spans than invertebrates (e.g. īnanga 1-2 years, bullies 2-3 years, trout 5 to 15 years, eels up to 100 years), so recovery from low flows can be slow, especially if spawning grounds are affected or too many mature adult fish die. Most (not all) fish species are more mobile than invertebrates, so they can move to refuge environs (e.g. reaches of a river where there is cool upwelling water if temperature is an issue or by moving upstream of abstraction (assuming suitable habitat is available)). Crowding is a greater problem for fish than invertebrates, especially if fish populations begin to exceed the carrying capacity of a river with flow reductions. If flow abstraction results in this situation, over the course of a few years fewer fish will survive into maturity and fish populations will decline.

River/site selection and timing of survey

Selection of rivers for the monitoring survey will be determined by the Council and may include community feedback. A suggested approach would be a hydrological classification of rivers based on flow magnitude and variability at different scales broadly following the 'ecological limits of hydrologic alteration' (ELOHA) method (see Poff et al. 2010). Geology could be considered in the classification framework. The first step is to collate existing, or develop synthetic flow records, in rivers throughout a region of interest. The next step is to use ecologically relevant flow variables (e.g. the 7-day MALF, FRE_3) to classify river segments into a few flow regime types that are expected to have different ecological–flow responses. Finally, the values and the likely degree of hydrological alteration of the rivers should be considered.

Site selection within the rivers will be influenced by whether sampling has been done previously (i.e. there are pre-existing sites, e.g. TDC SOE monitoring sites; Shearer & James (2019)). Sites need to easily accessible, contain mesohabitats (e.g. runs, riffle, pools) that are representative of the river, and below potential sites of abstraction.

Surveys should be undertaken in late summer/early autumn when rivers are around or below the 7-day MALF[2] (the ecologically relevant low statistic most commonly used for setting minimum flows, including in the Tākaka Water Management Zone—Tākaka FLAG report 2019). Sampling at this time of year would provide a measure of stream functioning under potentially low flow conditions. Monitoring should be for a minimum of five years, as this would provide a more robust baseline for ecological assessment against the background of natural variability in periphyton cover, invertebrate and fish abundance.

Survey programme – outline

At each site, a D-opto logger (that continuously measures DO and temperature) should be placed in a run. The logger should be set at mid-water column to avoid picking up oxygen anomalies, e.g. logger being placed on groundwater upwelling. Preferably, DO and temperature should be logged for at least two full daily cycles.

A run and conjoining riffle should be selected for the ecological fieldwork. The width and length of each mesohabitat should be measured and recorded.

Water samples (nutrients and bacteria should be collected from a selected run). Turbidity would be measured using a turbidity meter.

Periphyton cover in the run and riffle should be assessed using Rapid Assessment Method (RAM)-2 (Biggs & Kilroy 2000).

Three quantitative macroinvertebrate samples should be collected in both the riffle and run, one near the margin of the stream, the next between the margin and thalweg (i.e. the deepest point across the riffle or run transect conveying most of the flow) and the final one in the thalweg, or nearer to the margin if thalweg depth exceeds that practical for sampling (e.g. ≤ 0.6 m for Surber sampling). The purpose of the design is to account for depth/flow variation and hence the use of a systematic collection design and not random sample collection. Samples should be collected with a Surber sampler (0.1 m^2, 0.5 mm mesh), as per Protocol C3 in Stark et al. (2000). Each sample is placed into labelled pottle and preserved with 70% ethanol (or like preservative e.g. isopropyl alcohol). The invertebrate density data would be used to provide an approximate indication of invertebrate population (calculated by multiplying the density data by the mesohabitat area). The mesohabitat population estimate (areal abundance) can then be converted to a linear abundance (i.e. number of invertebrates per lineal metre of river) by dividing by mean wetted width. Linear abundance is free from the influence of variation in river width with flow, which confounds areal abundance and density estimates when investigating flow effects on invertebrate (and fish) abundance.

Fish should be collected from the riffle using Smith Root LR-24 backpack electric fishing machines. Depending on the size of the river, different fishing techniques may be deployed. For small rivers (< 5 metres wide), stop nets can be placed at the head and tail of the riffle

[2] Assuming the MALF occurs in summer, otherwise surveys should be conducted around the mean 7-day mean summer low flow.

as a block. This should be done before invertebrate samples were collected to avoid fish escaping downstream due to the movement of fieldworkers within the riffle. Using single pass techniques, one or two machines, depending on river width, should be used to electric fish in a downstream direction. Fish collected by the machine operators using dip nets, hand-held seine nets, and in the downstream stop net should be placed in a bucket. Fish would be anaesthetised using Aqui-S (a clove oil derivative) identified, counted and measured (length) and then placed in a fish bin to recover before being released back into the river. In larger rivers 2 x 10 m lanes of homogenous depth and velocity should be fished, one lane near the river margin, another near the thalweg (or as close to it as can be safely waded and efficiently electro-fished (≤ 0.75 m deep)), and another lane midway between the other two lanes[3]. The fish density data is used to estimate mesohabitat population size (by multiplying density by the mesohabitat area) and then converted to linear abundance (i.e. the number of fish per lineal metre of river).

In the riffle and run, two cross sections should be selected, and the wetted widths measured. Spray painted rocks would be placed at the edge of the measured cross sections.

Drone video/photographs could also be taken over each site to provide a snapshot of the sample reach (i.e. footage taken from just below to just above the run and riffle, inclusive of the painted rocks). The drone height would be set at 20 metres above the wetted width cross sections. With a known drone height above the river, the coloured rocks could then be used to calibrate the drone footage such that the wetted width at the site can be calculated from aerial photographs. This would enable efficient data collection of wetted widths at flows other than the survey flow (e.g. later in a flow recession at more extreme low flows than may have been surveyed in any one summer; assuming the channel geomorphology does not change due to floods in the interim and the coloured rocks remain in place and can be identified).

For the biological data to be meaningful, it is important that the river flow during the survey is known. The survey flow can be expressed as a percentage of the river's 7-day MALF (i.e. the flow most likely to be used for setting flow minimum and allocation limits). This provides an index of the low-flow severity of the survey flow. Hydraulic geometry (wetted width, mean depth and velocity) and generalised habitat quality can also be standardised with respect to their predicted values at MALF and then regressed against ecological metrics (e.g. density and linear abundance) estimated over space and time. Such standardisation is necessary to assess ecological responses to flow within sites over time and between sites at one time.

In that regard, it is critical that there be hydrologists available to undertake a flow gauging and collect other flow-related measurements to ensure all relevant flow data required for future assessment of the ecological data are recorded.

In rivers without flow recorders, temporary staff gauges should be placed in the run and riffle to estimate water level for the gauged flow at the time of the ecological survey and at other flows to construct water level-flow rating curves. Wetted width and mean depth should also

[3] The design for large rivers will be biased against the collection of large strong swimming fish (mainly trout) as the electric field cannot be confined.

be estimated on two more cross sections in both the run and riffle. These data could then be used to estimate wetted width and mean depth and velocity at the MALF (and other flows). Recorded or synthetic flow records for the survey sites (rivers) would also be helpful for assessing flow variability preceding ecological surveys to assist in interpretation of ecological flow responses. Collection of hydraulic geometry data should involve:

- selection of 3 cross sections in the run and the riffle (e.g. at the head, middle and bottom of each mesohabitat—6 cross sections in total). The wetted width, and depth at five points along each cross section, should be recorded (following a modified, and cut-down, version of the WAIORA approach[4]).
- Placement of a temporary staff gauge in the run/pool and riffle and the water level measured. Stage at zero flow (maximum depth at zero flow) should also be estimated (to provide another point on the water level–flow rating curve).
- The above data (except stage at zero flow) should be collected on at least two other flows (differing by about 20%) to establish water level–-flow rating curves and provide data that could be used to develop wetted width, mean depth and velocity relationships relative to flow. One of the surveys should coincide with the biological survey. These data can then be used to assess the invertebrate and fish density and population response to the flow-related hydraulic geometry variables in addition to flow itself.

At least two field teams will be required to undertake the above work, for example:

a) Team 1 (4-person): Water quality samples, macroinvertebrate samples, electric fishing, periphyton cover. Note: a minimum of two staff are required for the water quality, periphyton and invertebrate sampling components.
b) Team 2 (2-person): Hydrological work including flow measurements, run and riffle cross-sectional data, drone work.

Data analysis

The ecological data collected would provide information on responses of aquatic fauna to flow related variables and to flow itself over the low-flow range (around the 7-day MALF and or below). DO and temperature cycles can be analysed with respect to invertebrate and fish DO and temperature sensitivities. Invertebrate and fish density and population abundance data would provide background biological background that can complement instream habitat versus flow (e.g. IFIM) studies undertaken to assess the effect of flow change on available habitat for invertebrates and fish. The proposed modified WAIORA methodology aimed at obtaining hydraulic geometry–flow relationships will allow generalised habitat quality–flow predictions to be made for selected invertebrate and fish species to aid interpretation of invertebrate and fish density data over space and time (with flows differing among sites and within sites over time).

[4] However, ideally if time and resources permitted, hydraulic geometry data should be collected from 3 runs, more closely following the WAIORA methodology. This would give a better representation of average hydraulic geometry variables and generalised habitat suitability–flow responses based on them.

As mentioned earlier, the biological data need to be placed in context of hydrological statistics/indices (summarising flow magnitude and variability) that are known to be ecologically relevant to determine responses of ecosystem variables to flow change.

The conversion of invertebrate and fish density data to abundance per linear metre of river allows for comparison among flows at a site at different times (as it accounts for the confounding effects of differences in river width). Ecological–flow responses (periphyton cover, fish and invertebrate density and population abundance) would be interpreted with respect to survey flows, preceding flow variability and flow-related water quality (DO, water temperature, pH) and physical variables (wetted width, mean depth and velocity and optionally generalised habitat suitability[5]).

Maps showing the proportion of riparian cover in river catchments of interest would be useful in complementing the above assessment of effects on river ecology of flow change. For example, a river may have high nutrients but little periphyton growth during periods of low flow if growth is being limited by light reaching the stream bed (i.e. through shading by riverside vegetation). If the vegetation is removed periphyton biomass would more likely accrue to nuisance levels in the absence of flushing flows. In this sense a consideration of riparian shading in the study catchments will complement assessment of temperature and periphyton data at survey sites.

Indicative cost of biological survey work

Below is an approximate cost estimate should Cawthron be commissioned to undertake the biological survey work at five sites (based on charge-out rates for the 2020/21 financial year). The labour estimate covers fieldwork-related costs for two scientists, including collation of gear, travel to and from Golden Bay and field work hours. Analytical services include what it would cost should Cawthron be commissioned to process invertebrate samples and organise/send nutrient samples to Hill Laboratories for analysis. Other direct costs include estimates for accommodation, meals, and vehicle use. Finally, the equipment use price is based on hire of Cawthron field meters, loggers and an electric fishing machine. The estimate below does not include any costs around data analysis or reporting.

Below the cost estimate table are the daily charge-out rates for Cawthron electric fishing machines and DO/temperature loggers. It should be noted however, that hire of the electric fishing machines would be provisional on there being at least one Cawthron staff member involved in electric fishing survey work.

Under the above scenario, TDC would need to account for a hydrological and hydraulic geometry data collection team, plus two staff in addition to the Cawthron staff for the electrofishing component of the fieldwork.

[5] Predicted from a generalised habitat model (Booker et al. 2016).

Indicative costs if Cawthron was to be involved in the biological survey. Services would be performed for a fixed fee of NZ$24,893.90 plus Other Costs and Expenses.

Cawthron labour	19,992.00
Analytical services, etc.	2,372.50
Other direct costs	1,554.40
Equipment use	975.00
Subtotal	24,893.90
GST at 15%	3,734.09
Total fee amount	28,627.99

Note: Hourly rates are reviewed annually, effective 1 July in each year.

Daily charge-out rates for Cawthron electric fishing machines and DO/temperature loggers:

- Smith Root EF machine $150.00 p/day (Cawthron has 2 machines)
- D-opto logger $25 per day (Cawthon has at least 5 loggers).

Summary

This letter sets out a sampling approach to provide baseline information on the response of river ecosystem to flow change, with particular regard to low flows and assessing the effects of minimum flow and water allocation limits. To provide a good baseline dataset, the survey design should be repeated yearly for a minimum of five years weather permitting to account for the high natural variability in periphyton, invertebrate and fish abundance.

The water quality, biological, hydrological and hydraulic geometry variables suggested for the survey(s) are discussed in the body of the letter. In the table below, the variables are ranked in order of their importance for achieving the survey/monitoring aims (see Purpose of letter section).

Suggested survey variables for achieving the survey/ monitoring aims	Rank of variables in descending order of importance to survey/monitoring aims[1]
Flow (at survey and preceding flow history)	1
Continuous dissolved oxygen/temperature	1
Hydraulic geometry (wetted width, mean depth and velocity)	2
Invertebrates	3
Periphyton cover	3
Fish	4
Nutrients (DRP, DIN)	5
Turbidity	6

[1] Rank 1: essential variables for inferring at least catastrophic effects of low flow relatively cheaply.
Ranks 2, 3, and 4: important variables for determining physical habitat and biological effects.
Rank 5: supplementary variable for inferring effects of flow on periphyton i.e. the interaction of nutrients and flow variability on periphyton accrual.
Rank 6: supplementary variable for isolating the effects of flow from land use impacts. For example, intensive agriculture and forest harvest can increase turbidity/suspended sediment, which limits periphyton growth (by reducing light penetration) and the efficiency of visual feeding by fish. Turbidity is also associated with fine sediment deposition that adversely effects macroinvertebrate habitat through smothering of the riverbed.

References

Biggs BJF, Kilroy C 2000. Stream periphyton monitoring manual. Prepared for Ministry for the Environment. 226 p.

Booker DJ, Hayes JW, Wilding TK, Larned ST 2016. Advances in environmental flows research. Chapter 23 in: Jellyman PG, Davie TJA, Pearson CP, Harding JS (eds.) Advances in New Zealand freshwater science. Pp 445-468.

Hayes JW 2019. Evidence presented on environmental flow assessment and fish passage. Presented to the Environment Court in support of Otago Fish and Game Council's appeal of an application by the Lindis Catchment Group for resource consents to replace water permits for abstraction from the Lindis River, Otago.

MfE 2017. National Policy Statement for Freshwater Management 2014 (amended 2017). Ministry for the Environment, Wellington, New Zealand. 47 p.

MfE 2019. Draft National Policy Statement for Freshwater Management. Ministry for the Environment, Wellington, New Zealand. 58 p.

Shearer K, James T 2019. Effects of the 2019 drought on aquatic ecology in selected waterways in Golden Bay. Prepared for Tasman District Council. Cawthron Report No. 3361. 21 p. plus appendices.

Stark JD, Boothroyd IKG, Harding JS, Maxted JR, Scarsbrook MR 2001. Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report No. 1. Prepared for Ministry for the Environment. Sustainable Management Fund Project No. 5103. 57 p.

Poff LN, Richter BD, Arthington AH, Bunn SE, Naiman RJ, Kendy E, Acreman M, Apse C, Bledsoe BP, Freeman MC, Henriksen J, Jacobson RB, Kennen JG, Merritt DM, O'Keeffe JH, Olden JD, Rogers K, Tharme RE, Warner AW 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology 55: 147–170.

Tākaka Freshwater and Land Advisory Group (FLAG) 2019. Recommendations report for freshwater management in the Tākaka Freshwater Management Unit. 151 p.