Manapōuri Lake Control Flow Improvement Project

Assessment of Environmental Effects: Freshwater Ecology

Prepared for Meridian Energy Limited

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Executive summary

Meridian Energy Limited (Meridian) releases flows through the Manapōuri Lake Control Structure (MLC) to the Lower Waiau River (LWR) in accordance with existing resource consent conditions. These flows include minimum flows, lake and flood flows, recreational flows and flushing flows, all of which assist with managing nuisance periphyton growth and which have benefits for river health. The current depth and alignment of the lower Waiau Arm is limiting the conveyance and reliability of these flow releases. Meridian proposes to construct a new and deeper channel adjacent and parallel to the Waiau Arm (i.e., the Project) and remove accumulated gravel and bed material to improve the conveyance and reliability of these flows.

The purpose of this report is to outline the existing aquatic environment in the vicinity of the Project and in the receiving environment downstream, and to assess the potential environmental effects of the proposed Project. The assessment focuses on the how the Project may affect hydrology, flow variability, suspended and deposited fine sediment, plant communities (macrophytes, periphyton, and phytoplankton), macroinvertebrates, freshwater fish and freshwater birds.

This report also outlines proposed thresholds for suspended sediment (measured as turbidity) and deposited fine sediment (DFS) and how these could be monitored during the Project to minimise adverse effects on the aquatic ecology. We propose that turbidity is measured at a new monitoring station located in the Waiau River in the reach below the MLC but upstream of the confluence with Excelsior Creek. Deposited fine sediment should also be monitored at this site on a weekly basis during the Project. The effects of the Project on turbidity will be taken as the difference between turbidity at this new monitoring station and turbidity monitored at the existing monitoring station on the Mararoa River (at Weir Road). The proposed turbidity thresholds, based on the effects of the Project only, are as follows:

Turbidity threshold 1: 12.4 FNU, exceedance allowance of 945 hours (~39 days) total over the Project, with a maximum consecutive exceedance of 315 hours.

Turbidity threshold 2: 30 FNU, exceedance allowance of 504 hours (~21 days) total over the Project, with a maximum consecutive exceedance of 168 hours.

Turbidity threshold 3: 160 FNU, exceedance allowance of 95 hours (~4 days) total over the Project, with a maximum consecutive exceedance of 32 hours.

Turbidity threshold 4: 330 FNU, exceedance allowance of 36 hours (~1.5 days) total over the Project, with a maximum consecutive exceedance of 12 hours.

Turbidity threshold 5: 1000 FNU, no exceedance allowance. Mean hourly FNU must not exceed 1000 FNU.

Deposited fine sediment threshold: exceedance allowance of an increase of no more than 20% cover on the baseline value (long-term median % cover) at the start of the excavation, based on a rolling 4-week average of weekly observations in the Waiau River upstream of Excelsior Creek (the long-term monitoring site). If this exceedance occurs and the Project has generated a turbidity of 30 FNU for 37 hours, then the Project will be deemed responsible for the DFS increase. This level and duration of turbidity, when generated by the Mararoa River, is known to be sufficient to cause an increase in DFS cover of 20% at the Waiau River upstream of Excelsior site.

Our assessment concludes that the adverse effects of the Project on aquatic ecology will be minor or less than minor as follows:

- **Plant communities**
    - Waiau Arm
        - Macrophytes: minor
        - Periphyton: minor
        - Phytoplankton: minor
    - Lower Waiau River
        - Periphyton: minor
- **Macroinvertebrates**
    - Waiau Arm: minor
    - Lower Waiau River: minor
- **Freshwater fish**
    - Waiau Arm and Lower Waiau River
        - Salmonids: minor
        - Longfin and shortfin eels: minor
        - Galaxias species: minor
        - Lamprey: less than minor
        - Other species: nil
- **Freshwater birds**
    - Waiau Arm: minor
    - Lower Waiau River: nil

These predicted effects assume that:

- Suspended sediment and deposited fine sediment threshold exceedances are monitored and mitigated as proposed,
- the longfin eel migrant trap-and-transfer programme is modified such that downstream migrating adult eels captured in Lake Manapōuri for the programme are released further downstream (i.e., not directly below MLC) to areas not at risk of high levels of increased suspended sediment from the Project,
- a fish salvage programme is developed and undertaken during the instream excavation phase of the Project (where practicable within the excavation methodology) to minimise effects on fish in the area (particularly longfin eels), and

- ensuring the instream excavation phase of the Project does not commence until after mid-March to avoid effects on upstream migrating juvenile eels (elvers).

1 Introduction

1.1 Purpose of the Project

Meridian Energy Limited (Meridian) releases flows through the Manapōuri Lake Control Structure (MLC) to the Lower Waiau River (LWR) in accordance with existing resource consent conditions. The types of flow released include minimum flows, lake and flood flows, recreational flows and flushing flows. Each of these assists with managing nuisance periphyton growth and has benefits for river health. However, the current channel depth and alignment, and gravel accumulation in the Waiau Arm[1], immediately upstream of the MLC, have been identified as the primary physical constraints affecting flow conveyance and reliability, particularly for flushing flows. The aim of this Project is to reduce these constraints by constructing a new and deeper channel adjacent and parallel to the Waiau Arm and by removing accumulated gravel, and to provide for any necessary maintenance of the Waiau Arm channels. Following construction of the new and deeper channel, more reliable conveyance of consented flows into the LWR is expected. A more comprehensive description of the Project, and the proposed methodology, is included in the AEE, and the construction methodology report prepared by Damwatch Engineering Ltd.

1.2 Purpose of this report

The purpose of this report is to outline the existing aquatic environment in the vicinity of the Project and in the receiving environment downstream, and to assess the potential environmental effects of the proposed Project. The assessment focuses on the how the Project may affect hydrology, flow variability, suspended and deposited fine sediment, plant communities (macrophytes, periphyton, and phytoplankton), macroinvertebrates, freshwater fish and freshwater birds.

[1]The ~10 km section of the Waiau River between Lake Manapōuri and the MLC.

2 Background

2.1 Context

Meridian owns and operates the Manapōuri Power Scheme (MPS), the largest single hydroelectric scheme in the country. Water in Lake Manapōuri is used to generate electricity at the underground station at West Arm. The MPS is operated under the Operating Guidelines for Lakes Manapōuri and Te Anau (the Guidelines) which was set in place under the Manapōuri – Te Anau Development Act 1963 (MTADA) and gazetted on 21 November 2002.

The catchment area for the MPS includes Lakes Manapōuri and Te Anau, and water that is diverted into Lake Manapōuri from the Mararoa River catchment at the Manapōuri Lake Control (MLC) structure. Meridian holds a suite of resource consents for water takes, diversions, discharges and maintenance associated with the MPS and the MLC.

The MLC is located southeast of Lake Manapōuri, at the confluence of the Waiau and Mararoa Rivers, forming the downstream control of the outlet of Lake Manapōuri. The MLC is a key component of the MPS, essential to the operation and management of the scheme. It assists in controlling and managing the level of Lake Manapōuri, diverting water from the Mararoa River into Lake Manapōuri for hydro-electric generation, and controlling the discharge of water to the LWR catchment, including for minimum flow, lake and flood spill, recreational and flushing flow purposes.

Investigations have confirmed the Waiau Arm channel at the MLC does not currently have the flow conveyance capacity to reliably pass in particular flushing flows to the LWR. This is due to the bed material that has accumulated over time upstream of the MLC and the existing channel depth and alignment. Deepening the Waiau Arm channel reach and constructing a new channel parallel to the current Waiau Arm channel would allow for more reliable flow conveyance and delivery in particular for flushing flows over a wider range of lake conditions.

2.2 Trial excavations

The potential for sediment generation from the Project works was recognised early in the development of the construction methodology. To inform the option selection process, Meridian undertook a series of trial excavations in February 2023. The purpose of the trials was to:

a) assess the ability to excavate the riverbed material from a bund platform to target excavation depths,

b) quantify the level of likely suspended sediment, deposited sediment and increase in turbidity resulting from the work, and

c) better understand the nature and characterisation of channel substrate material within the Project footprint.

The trials involved the construction of bunds and the excavation of bed material along an approximately 900 m stretch of the Waiau Arm. NIWA were engaged by Meridian to quantify the suspended sediment generated from the trial works. Monitoring comprised:

- periodic observations of visual clarity (VC) and suspended sediment concentration (SSC) in the LWR at Duncraigen Bridge, approximately 375 m downstream of the MLC gates,
- continuous recording of turbidity using a bank-attached turbidity sensor located approximately 50 m downstream of Duncraigen Bridge, and

- visual estimates of net changes in deposited fine sediment at six locations between the MLC and the turbidity recorder, and
- The SSC and VC observations were used to establish relationships with turbidity, which were used to generate a continuous record of SSC and VC for the period of the trial.

The results of the trial excavation are detailed in Hoyle et al. (2023). In summary, the trials concluded the following:

a. the riverbed material is sufficient to support the excavator machinery proposed for the Project,

b. monitoring showed that bund construction and removal, and excavation of bed material, causes rapid increases in SSC and decreases in VC. The trial appeared to cause little increase in deposited fine sediment (DFS), but the results were inconclusive, and

c. river substrate was highly variable across the 900 m site, ranging from sandy gravels to silts and clays.

Maximum turbidity recorded during the trial was 36.8 FNU[2], which is equivalent to an SSC of 25.7 g/m^3 and a minimum VC of 0.5 m. These values typically occur in the lower Mararoa River during flows that are exceeded about 10% of the year (equivalent to about 62 m^3/s and over), and with a short recession time (approximately 40 hours).

2.3 Option selection process

The selection of the parallel channel methodology has been subject to an extensive assessment and multi-criteria analysis involving multiple technical specialists. The trial investigations undertaken established that a predominantly instream excavation had a high likelihood of suspended sediment generation and discharge into the LWR. For this reason, options involving excavation over several months within the wet area of the Waiau Arm were not progressed further. The proposed parallel channel works occur substantially offline or outside of the wetted area of the Waiau Arm. As such, it has been assessed as the 'least effects' option for releasing suspended and deposited sediment to the LWR during the excavation works, while appropriately managing all other environmental effects.

Details of the option selection process are addressed in the Assessment of Environmental Effect (AEE), but by way of summary:

- Instream option of deepening the existing Waiau Arm, using a range of different methodologies and techniques (including excavators working from constructed bunds), was discounted due to the potential high levels of rapid sediment generation over long periods for instream works, which are difficult to practically manage;
- Cutter suction dredging was discounted due to the range of bed materials found in the LWR which is unsuitable for this methodology and mobilisation of plant and facilities was considered to be more complex;
- Dragline excavation was ruled out due to limited operators and equipment available;

[2] Formazin Nephelometric Units. For further information see Section 3.6.2

- Excavation from barges was ruled out due to the relatively confined work area and potential safety issues, complex set up and ability to be dismantled if flooding were forecast; and
- Temporary damming structures were ruled out due to constructability and potential safety issues.

3 Description of the Project

3.1 Overview

The Project will involve the construction of a new channel which is parallel to, and largely offline, from the current bed and channel of the Waiau Arm. Approximately 225,000 m^3 of gravel and bed material will be excavated (with approximately 15% of this being instream) and disposed of on Meridian-owned land near the new channel.

The works will be undertaken in three stages: Stage 1 involves site establishment and the development of haul roads and temporary bunds adjacent to the Waiau Arm to prevent the direct flow of water into the excavation area. We understand that these will be undertaken completely in the dry (out of stream); Stage 2 involves the bulk of the channel excavation within the area isolated by temporary bunds; Stage 3 involves the excavation of 'breakout channels' (upstream and downstream cuts with a total volume of 29,500 m^3 of material to be excavated, i.e., 15% of the total excavation volume) which will link the parallel channel with the existing Waiau Arm.

Subject to obtaining resource consents, and with appropriate hydrological conditions (see below), Meridian proposes to undertake the works within a 10-month window of January to October 2025. The overall construction period within this window is envisaged to be approximately four to five months. The upstream and downstream cuts to connect the parallel channel to the current bed and channel (the part of the Project that will require works in water) is anticipated to take approximately five weeks if the cuts are undertaken simultaneously. The remainder of the construction window is required for establishment, disestablishment, and rehabilitation activities. Works are proposed to occur on an up to 7-days per week and up to 24-hours per day basis.

The bulk channel excavation works are targeted at the time of year when hydrological conditions are likely most favourable for safe and efficient delivery of the work. The construction window has also been identified to limit disruption to Meridian's monitoring requirements under existing resource consent conditions. Ideal conditions for the work would be generally low flows and lake levels for the duration of the excavation with no stoppages due to high flow conditions. Based on past hydrological patterns (Section 6.1), lake levels are often low in March, July and August and flows in the Mararoa River are generally lowest from February to April. However, there is potential for moderate to large floods in the Mararoa River and from Lake Manapōuri in all months. Meridian's existing MLC resource consents require that works in the MLC area shall not occur during the bird nesting season (15 September to January) if the works would disturb any colonies of birds. Key migration periods for native freshwater fish and salmonids in the Waiau catchment are provided in Appendix A. The best timing for the Project from an ecological perspective would be between April and July.

Full details of the Project, and the proposed construction methodology and sequencing, are provided in the AEE.

3.2 Site location

The MLC is located approximately 9 km south-east of Lake Manapōuri and the Manapōuri township, at the confluence of the Waiau and Mararoa Rivers (Figure 3-1). The site is located in a rural environment. The Project site is bounded by the Waiau Arm and farmland to the north and west, the LWR and farmland to the south, and the Mararoa River to the east. The site extends down the LWR to just above the point where Excelsior Creek joins the main stem of the LWR. A site location plan is shown in Figure 3-1 with full details of the Project site contained in the AEE.

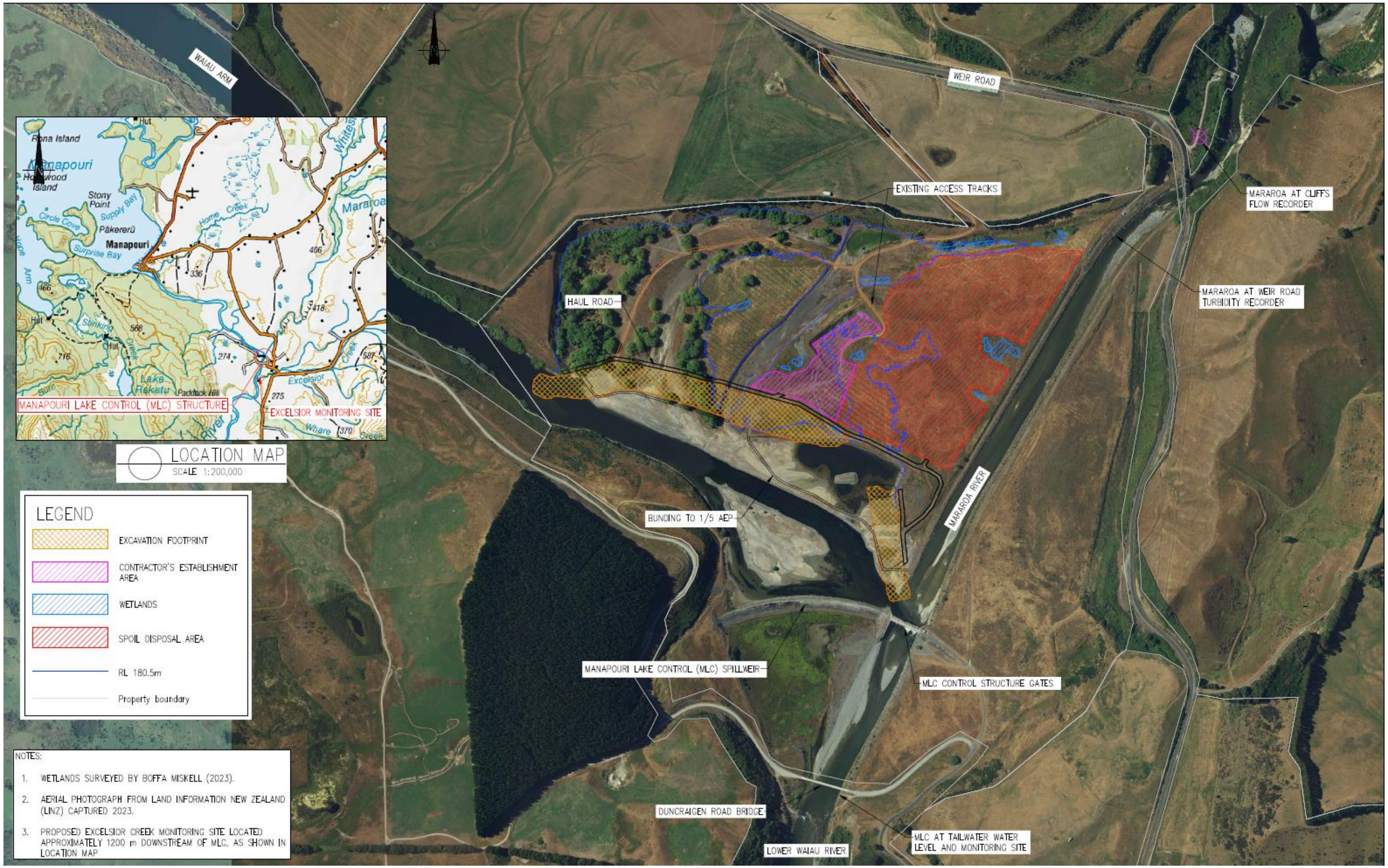


Figure 3-1: Map of the area surrounding the Project site in the Waiau Arm.

3.3 Sediment generation potential

The highest potential for generation of suspended sediment and deposited fine sediment is during Stage 3 when the breakout channels are excavated. Three weeks have been allowed for the upstream breakout and four weeks for the downstream breakout. If carried out concurrently (which we understand is the preferred option), the total duration would be five weeks. If excavated sequentially (i.e., with the upstream breakout likely carried out first) total duration of instream excavation would be seven weeks. In summary, the period of potentially high sediment generation could range from five to seven weeks. The greatest concentration of sediment release is expected at the final step when the downstream 'breakout' is completed, exposing the excavated channel to flow for the first time, flushing out suspended sediments contained within, and scouring fines from, the new bed.

Stages 1 and 2 involve no instream works so are not anticipated to generate high levels of suspended sediment. The bunds constructed during Stage 1 are in an area that can become inundated during high lake levels or high flows down the Waiau Arm. Our understanding is that it is highly unlikely that these bunds could be overtopped, however, during high lake levels or high flows down the Waiau Arm, it is possible that some fine sediment could be eroded out of the new temporary bunds[3] and released downstream during Stages 1 or 2. However, this situation would be associated with an increase in low turbidity water from Lake Manapōuri, so SSC should remain low. If high levels of suspended sediment are generated by the Project, there is high potential for at least a proportion of this sediment (i.e., silt and sand fractions) to be deposited on the bed downstream. This is because suspended sediment generated by the Project may occur during low flows (and associated low velocities), relative to equivalent levels of suspended sediment that are naturally generated from the Mararoa River during high flows. Higher flows help flush the fine sediment downstream. The amount of fine sediment generated, and potentially deposited, depends on the particle size distribution of the material being added to (i.e., from temporary bunds) or excavated from instream areas, and the flows in the Mararoa River and down the Waiau Arm at the time. Each of these factors is highly uncertain but flows down the Waiau Arm can be managed to a degree.

3.4 Flow management

During the Project and once excavation commences, it is proposed that all flow from the Mararoa River will be directed down the LWR. Therefore, there will be no negative flows in the Waiau Arm (i.e., flows towards Lake Manapōuri) during this period. Positive flows from Lake Manapōuri (as opposed to no flow in either direction) will occur in the following circumstances:

- when flow from the Mararoa River is insufficient to provide minimum flows in the LWR (i.e., 12 m^3/s from May to September, 14 m^3/s in October and April, and 16 m^3/s from November to March);
- to provide monthly recreational flows in the LWR (approximately 35 m^3/s for 24 hours on the last Sunday of the month from October to April);
- when Lake Manapōuri is above 187.6 m a.s.l. and when flood rules will apply. At high lake levels rising above maximum control level, Waiau Arm discharge will be high and increasing, and conditions will likely be unsuitable for the excavation works.

[3] The mobilisation of fine material out of temporary ramps was observed during the excavation trial. The temporary bunds proposed for the Project would be constructed from similar material to that used during the trial so a similar result could be expected if exposed to flow.

Flushing flows or dilution flows can be used as a mitigation tool to reduce levels of suspended or deposited fine sediment during the Project. However, the ability to do this will be limited to a degree by lake levels.

3.5 Sediment management

The main fine sediment release management method is the excavation methodology itself. The parallel channel option avoids working instream as much as possible and also minimises the period over which fine sediment may be generated. Despite this, there is still uncertainty around the degree to which fine sediment will be generated from the excavation. Therefore, we recommend an adaptive management approach as the most effective way of minimising adverse effects. This recommended approach involves setting sediment thresholds, monitoring sediment generation during the works and, if thresholds are exceeded, undertaking mitigation actions. The components of this recommended approach are discussed below.

3.6 Proposed sediment thresholds: principles and derivation

3.6.1 Suspended fine sediment and deposited fine sediment

Fine sediment (defined as particles < 62 µm across for suspended sediment and including particles up to 2 mm across in deposited fine sediment) is a natural component of river-bed substrate. Its abundance in a catchment and rates of sediment transport and deposition within rivers depend on catchment characteristics such as geology, slope, and hydrological characteristics such as rainfall. Catchments with soft-rock geology tend to have a higher supply of fine sediments than those with hard-rock geology, and fine sediment deposition is higher in low-gradient streams than in those with steeper slopes. Thus, there is high natural variation across catchments in the state of both suspended and deposited fine sediments (Franklin et al. 2019).

Land-use change within a catchment, such as introduction of agricultural or forestry activities can add to the naturally occurring fine sediment supply. A combination of natural and anthropogenic fine sediment sources likely makes up the sediment signature of the Mararoa River, which is described in Section 5.3.

Both SSC and DFS in rivers vary over time. SSC increases as river flow increases, as more fine material is entrained by higher water velocities. In most rivers, flow and SSC are positively related to each other, although the relationship is typically complicated by hysteresis. Hysteresis refers to the case when SSC differs at the same flow rate depending on whether the flow rate is increasing (i.e., the rising limb of a flood event) or decreasing (i.e., the falling limb of a flood). Hysteresis can be caused by, for example, variation in sediment generation from different sources, delay between runoff and geomorphic adjustment during floods, spatial and temporal variation in rainfall, and distance of sediment sources from the monitoring site of interest. With clockwise hysteresis the turbidity peaks earlier in the flood event and with anticlockwise hysteresis turbidity peaks later in the flood event. The Mararoa River experiences both clockwise and anticlockwise hysteresis, but in both cases turbidity recedes much more quickly than flows recede.

In the Mararoa River, daily mean flow at Mararoa at Cliffs site explains only about 20% of the variance in daily mean turbidity (representing SSC – see below) measured at Mararoa at Weir Road[4]. This is shown by high variability in turbidity at flows between about 12 m^3/s and 100 m^3/s in the

[4] The Mararoa at Cliffs and Mararoa at Weir Road sites are only ~300 m apart, with the Weir Road sensor located just downstream of the bridge.

Mararoa River, within the expected positive relationship (Figure 3-2). Turbidity was generally low up to about 12 m³/s (96% of mean daily turbidity < 5 FNU) (Figure 3-2).

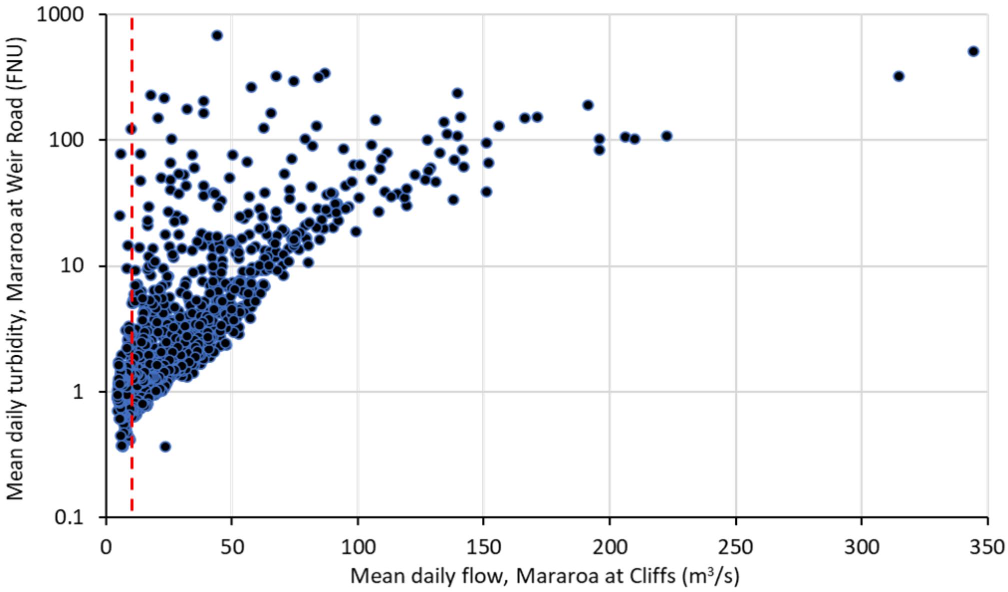


Figure 3-2: Log-transformed mean daily turbidity (Mararoa at Weir Road) plotted against mean daily flow at Mararoa at Cliffs. Data from November 2019 to February 2023. The red dashed line at 12 m³/s shows that turbidity at lower flows is typically < 5 FNU with only a few outlying higher values.

The relationship between DFS (measured as % cover) and flow is likely to be more complex than that between SSC and flow because both deposition and entrainment of fine sediment from the bed are related to hydraulic parameters (e.g., depth, velocity, shear stress), and hydraulic parameters vary both temporally and spatially within a river. Temporal variability in water velocity is inherent as flow magnitude changes. Spatial variability of hydraulic parameters occurs across all scales in a river across distances of centimetres (rocks on the riverbed) to metres (proximity to the water's edge within a reach) to kilometres (slope variation between reaches). Correspondingly, DFS cover can vary greatly over time and space.

3.6.2 Suspended sediment concentration, turbidity and visual clarity

Suspended sediment can be measured directly (as SSC) or via the proxy variable turbidity. Direct measurement of SSC involves collection of a water sample followed by laboratory analysis, which is expensive and time-consuming. Turbidity (an optical measurement that indicates the presence of suspended particles in water) is considered a good proxy variable for both SSC and VC. It is relatively easily measured using logging devices. However, turbidity measurements are instrument dependent, and turbidity units (NTU/FNU[5]) are relative and not standardised SI units. Turbidity can vary by up to a factor of two depending on the sensor used (Haddadchi 2022). Therefore, a site-specific relationship between SSC and turbidity must be established before turbidity records can be converted to absolute measures of SSC.

VC is the distance objects can be seen through water. VC is important in its own right because of its relevance to visual cues for biota. VC results (m) are directly comparable across sites, which is why

[5] Turbidity has traditionally been measured in NTU (Nephelometric Turbidity Units), a relative measure of side-scattered visible light from an incident light beam. The NTU unit been superseded by FNU (Formazin Nephelometric Units) which specify side scattering centred on 90 of near infra-red (NIR) radiation in the 830-890 nm range of wavelengths (Daveis-Colley et al. 2020). FNU are the units used to report turbidity measured with instruments that meet the ISO 7027 Standard, which is required for achieving QC600 in the NEMS Turbidity.

VC is used as a compliance measure (e.g., in the National Policy Statement for Freshwater Management, NPS-FM 2020). Measurements of VC are usually discrete (e.g., using the black disk method), but a continuous record of VC can be generated from continuous turbidity records if there is an established turbidity vs VC relationship. Because VC is affected by factors other than SSC (e.g., particle size, or the amount of dissolved organic matter in the water), it is necessary to establish site-specific relationships with SSC and/or turbidity to enable prediction of one from the other.

Relationships between SSC, turbidity and VC were developed for the reach of the Waiau River just downstream of MLC during the trial excavation (see Section 2.2):

$$\text{Total SSC} = 0.745 * \text{turbidity (FNU)} \qquad \text{[Equation 1]}$$

$$\text{VC} = 4.48\,(\text{turbidity (FNU)})^{-0.61} \qquad \text{[Equation 2]}$$

These relationships will be used to convert monitored turbidity to SSC and VC during Project monitoring.

3.6.3 General effects of suspended sediment concentration and deposited fine sediment on river biota

The effects of fine sediment on the biological communities in rivers depend on a range of factors, including magnitude of SSC, duration of elevated SSC, and particle size. Effects on biota may result from sediment in suspension or through the deposition of fine sediment on the riverbed. Increased sediment in suspension reduces VC, and sunlight penetration. Degraded visual clarity reduces feeding opportunities for water birds and fishes and causes certain fish species to avoid turbid water. Elevated suspended sediment reduces the amount of light that reaches the riverbed, slowing the process of photosynthesis that drives the growth of plants (macrophytes and algae). Increased SSC can also have direct effects on organisms (e.g., clogging of gills and physical abrasion).

Increases in cover by DFS affects benthic habitat. Sediment deposition can smother parts of the stream bed and associated periphyton, reducing both habitat and food sources for some macroinvertebrates and fish. DFS can also smother fish eggs (e.g., trout redds). Macroinvertebrate communities are generally more sensitive to deposited sediment than fish communities, and vice versa for suspended sediment (Franklin et al. 2019).

3.6.4 Tolerance of biota to variability in fine sediment

Given the intrinsic flow variability of most rivers (including the Mararoa River), river biota at adapted to variability in SSC (e.g., range shown in Figure 3-2 measured as turbidity) and DFS. Because the tolerance of different species to fine sediment varies, variability in biological communities is also expected across different rivers, with taxa present generally tolerant of the range of SSC and DFS typically experienced in a particular river or stream (Franklin et al. 2019). If either or both of SSC or DFS start to exceed the upper limits of existing variation, then changes to biota can be expected. The extent of any changes to biota will depend on all three of: (a) the magnitude of the departure from existing conditions (of fine sediment), (b) the duration of the departure from existing conditions, and (c) the responses of individual taxa to elevated SSC or DFS (e.g., see review in Franklin et al. 2019).

In general, the tolerance of different taxa may be measured by responses to short-term acute exposure (e.g., very high SSC for very short periods such as minutes to hours), or by responses to longer-term chronic exposure (e.g., higher than the “normal” SSC tolerated by an organism, for longer periods such as weeks to months or years).

In free-flowing hill-fed rivers such as the Mararoa River, large floods pass high sediment loads through the system, which may affect biota as outlined above in tandem with the effects of the high flow itself (i.e., the effects of elevated water velocity). The consequences of large floods for biota (including increased SSC and DFS) are natural and temporary effects, from which river biota recover naturally over time through regeneration of remnant populations and recolonisation from tributaries or from upstream (e.g., Smith et al. 2019).

3.6.5 Setting appropriate thresholds to protect ecosystem health during periods of atypical elevated suspended sediment concentration

Thresholds set to protect river ecosystems from the potential effects of an expected atypical increase in SSC, such as from the Project, require justification (i.e., an expectation of a biological effect), a numerical concentration threshold, and an exposure duration. The latter two need to be converted to metrics that can be monitored during the Project so that mitigation action can be taken if any of the thresholds are exceeded for particular durations. The thresholds apply both to SSC and to DFS.

The numeric thresholds for SSC (detailed in Section 3.6.6) are expressed as values of turbidity (FNU) that should not be exceeded for more than a specified duration, because turbidity is what will be measured in the monitoring programme. The equivalents of turbidity in SSC and VC are provided (based on Equation 1 and Equation 2 above). Note that while SSC and equivalent turbidity thresholds represent upper limits, VC thresholds are minimum values (i.e., the aim is to keep VC higher than the threshold).

Because the detrimental effects of SSC can range from acute to chronic, a set of "nested" turbidity thresholds is proposed. High threshold concentrations averaged over short durations (protecting against potential acute effects, including sublethal stress effects on fish) are nested within lower thresholds averaged over longer durations (protecting against chronic and longer-term stress effects on fish and macroinvertebrates). All levels can be monitored by daily calculation of cumulative exceedances starting from day 1 of the Project (see Section 3.3 on sediment generation potential and Section 3.7 on proposed monitoring).

The approach taken in establishing reasonable turbidity thresholds was to allow exceedances of each turbidity threshold (hereafter exceedance allowances) for durations <u>that represent the approximate upper limit of exceedances that would occur naturally</u>. The Project is expected to add suspended sediment to the system at low flows over a relatively short period (4–5 months). The proposed allowances recognise that river biota already experience periodic disruptive, high turbidity events (i.e., Mararoa floods), and recover from these events. The thresholds and exceedance allowances have been calculated based on the assumption that the excavations in the Project will take four months and do not change if the works take a greater or lesser time within the proposed 10-month window. If excavation activities need to occur over two seasons, then exceedance durations could reset, as long as there was at least a six-month break between significant sediment generating activities (i.e., activities generating > 160 FNU) and excavation should not recommence until the majority of the elver migration was completed.

Based on the results of the excavation trial, levels of SSC are expected to remain within the range experienced normally in the lower Mararoa River and upper reaches of the LWR as flow conditions vary. This expectation is considered reasonable because most of the material to be excavated has originated from the Mararoa River and should therefore have similar characteristics to suspended material measured in the lower Mararoa River.

High flow events in the Mararoa River large enough to increase turbidity to exceed one or more of the thresholds (e.g., >~40 m^3/s, see Figure 3-2) may occur during the Project. The turbidity from these events will be excluded from the exceedance allowances.

The proposed exceedance allowances for each numeric turbidity threshold during the Project were based on:

1. turbidity observations in the Mararoa River at Weir Road between November 2019 and May 2023[6], and
2. estimates of annual exceedances of the selected thresholds in the Mararoa River over a 33-year period based on the flow record from Mararoa at Cliffs and the 3.5-year turbidity record from the Mararoa River at Weir Road. A description of this analysis is provided in Appendix B.

Elevated SSC may also lead to increases in DFS. No relationship has been established between SSC (represented by turbidity) in the Mararoa River at Weir Road and observations of DFS in the LWR. However, a 4.5-year record of monthly observations of DFS from the LWR at a site 1.5 km downstream of the MLC (Waiau River u/s Excelsior Creek) is available (August 2018 to March 2023). This time series was used to describe variability of DFS over time under existing conditions. The DFS threshold is expressed as a maximum increase in percentage cover over baseline cover calculated from the mean, monitored as described in the monitoring section below. The threshold includes only DFS that can be attributed to the Project. A test is provided to establish whether the Project is responsible for increased DFS, based on turbidity. Details are provided in Appendix B.

The proposed turbidity thresholds are summarised in Table 3-1 and the DFS threshold in Table 3-2. Detailed justification for each threshold, and its associated duration, is provided below.

It should be noted that occasional large floods following the completion of the Project are expected to reset river biota to its typical state following completion of the work, by flushing out excess DFS thereby resetting habitat, and, along with lower flows, bringing in colonists to replace potentially depleted populations. Such resetting of river communities during and following high flows is part of the natural variability of river ecosystems (e.g., Robinson 2012). The time required to reset communities varies depending on a range of physical and in-stream factors (Milner et al. 2018, Smith et al. 2019).

3.6.6 Justification for selected turbidity and DFS thresholds and exceedance durations

Five turbidity thresholds are proposed, with decreasing exceedance duration allowances as the thresholds increase (Table 3-1). The exceedance allowances exclude high turbidity that can be attributed to high flows in the Mararoa River. Turbidity due to the Project will be identified as the difference between turbidity measured in the LWR upstream of Excelsior Creek and turbidity in the Mararoa River at Weir Road. Any positive difference (i.e., higher turbidity downstream) will be assumed to have originated from the Project. See the monitoring section below for details of proposed monitoring procedures.

Reasons for the choice of each threshold for turbidity and DFS are set out below and summarised in Table 3-1 (for turbidity) and Table 3-2 (for DFS). The turbidity threshold choices were based on evidence for effects on biota, taking into account the rate of natural exceedances in the Mararoa

[6] The record of quality controlled high-frequency turbidity data in the Mararoa River at Weir Road started on 6 November 2019 and is ongoing.

River. The proposed threshold values have been selected to cover a range of turbidity levels because the detrimental effects of increasing SSC and reducing VC on biota gradually increase as turbidity increases and duration of exposure increases. Table 3-1 outlines the natural annual average duration of threshold exceedance (i.e., from the Mararoa, see Table 3-1, column 4), and the Project allowance (which is calculated at 0.75 of this average, see Table 3-1, column 6). This means that the river downstream (last column) may experience 1.75 times what is average for the river. Keeping the total duration within 1.75 of what is average ensures the total is still within the natural range of turbidity produced by the Mararoa River (Table 3-1, column 5).

<u>Turbidity threshold 1</u>: 12.4 FNU, exceedance allowance of 945 hours (~39 days) total over the Project, with a maximum consecutive exceedance of 315 hours.

Turbidity of 12.4 FNU is equivalent to SSC of 9.2 g/m^3 and VC of 0.96 m. Turbidity has exceeded 12.4 FNU for 14.4% of the time (52.5 days per year on average) in the 3.5 years of record in the Mararoa at Weir Road, and has occurred for 1% of the time when flows (Mararoa at Cliffs) are less than 40 m^3/s. The estimated maximum annual exceedance of 12.4 FNU in the Mararoa River was 98 days (2343 hours) and occurred in 1994 (see Table B-2, in Appendix B).

Feeding behaviour in salmonids starts to be affected around this threshold. For example, the reaction distance of drift-foraging salmonids is predicted to reduce by at least 50% between 0.5 NTU[7] (the lowest practical value for comparison in the Mararoa River) and 10 NTU (Gregory and Northcote 1993). Macroinvertebrate communities may also be affected. Increases in SSC of < 5 mg/L (or turbidity < 5 NTU) over baseline values were recommended to prevent substantial impacts on invertebrate communities of West Coast streams affected by mining operations, or <20 NTU to at least maintain all taxa (Quinn et al. 1992, Reid and Quinn 2011). In the longer-term, ensuring that VC remains > ~1 m for at least 33% of the time during the Project (assuming a four-month excavation period) is consistent with staying above the bottom line of the NPS-FM Suspended Fine Sediment attribute in the LWR upstream of Excelsior Creek (applicable bottom line of 2.2 m, median value over 5 years (60 records) of monthly spot measurements). Staying close to or above the NPS-FM band C/D threshold is indicative that water clarity remains at a minimally acceptable level.

<u>Turbidity threshold 2:</u> 30 FNU, exceedance allowance of 504 hours (~21 days) total over the Project, with a maximum consecutive exceedance of 168 hours.

Turbidity of 30 FNU is equivalent to SSC of 22 g/m^3 and VC of 0.56 m. Turbidity has exceeded 30 FNU for 7.4% of the time (28 days per year on average) in the 3.5 years of record in the Mararoa at Weir Road, and has occurred for 33% of the time when flows (Mararoa at Cliffs) exceed 40 m^3/s. The estimated maximum annual exceedance of 30 FNU in the Mararoa River was 53 days (1283 hours) and occurred in 1994 (see Table B-2, in Appendix B).

At turbidity greater than 30 FNU, chronic stress effects have been documented on some aspects of salmonid life history, in addition to effects on feeding rates. For example, SSC ~47 g/m^3 for 48 days led to 10% mortality of incubating eggs of rainbow trout (Slaney et al. 1977) and this threshold may help avoid that effect, if the Project coincides with spawning (generally from May to September). Visibility for salmonid feeding is reduced by well over 50% from optimal conditions with turbidity > 30 FNU (Gregory 1993). Boubée et al. (1997) recommended that turbidity was limited to 15 NTU to ensure that the upstream migration of key native fish species was not affected, therefore, some effect would be expected at 30 FNU. Macroinvertebrate densities declined across a gradient of SSC

[7] Note that this literature uses NTU as the unit of turbidity, whereas in this report we use FNU (see earlier footnote 1). Although the two units describe different measures, for the purposes of this report they can be taken as generally equivalent.

of 8 to 177 mg/L in West Coast streams affected by mining (Quinn et al. 1992). In general, across rivers, macroinvertebrate indices (MCI, QMCI[8]) tend to decline as VC decreases (and SSC or turbidity increases) (Franklin et al. 2021), although the contribution of VC in driving such declines cannot be separated from other potential drivers.

<u>Turbidity threshold 3:</u> 160 FNU, exceedance allowance of 95 hours (~4 days) total over the Project, with a maximum consecutive exceedance of 32 hours.

Turbidity of 160 FNU is equivalent to SSC of 119 g/m^3 and VC of 0.2 m. Turbidity has exceeded 160 FNU for 1.5% of the time (5.3 days per year on average) in the 3.5 years of record in the Mararoa at Weir Road, and has occurred for 6.5% of the time when flows (Mararoa at Cliffs) exceed 40 m^3/s. The estimated maximum annual exceedance of 160 FNU in the Mararoa River was 10 days (240 hours) and occurred in 1994 (see Table B-2, in Appendix B).

At turbidity greater than 160 FNU, the chronic stress effects documented for lower turbidity (e.g., 30 FNU) are exacerbated. In general, across rivers, macroinvertebrate indices (MCI, QMCI) tend to decline as VC decreases (and SSC or turbidity increases) (Franklin et al. 2021), although the contribution of VC in driving such declines cannot be separated from other potential drivers. Visibility for salmonid feeding is further reduced (Gregory 1993).

<u>Turbidity threshold 4:</u> 330 FNU, exceedance allowance of 36 hours (~1.5 days) total over the Project, with a maximum consecutive exceedance of 12 hours.

Turbidity of 330 FNU is equivalent to SSC of 250 g/m^3 and VC of 0.13 m. Turbidity has exceeded 330 FNU for 0.5% of the time (~ 2 days per year on average) in the 3.5 years of record in the Mararoa at Weir Road, and has occurred for 70% of the time when flows (Mararoa at Cliffs) exceed 200 m^3/s. The estimated maximum annual exceedance of 330 FNU in the Mararoa River was ~4 days (105 hours) and occurred in 1999 (see Table B-2, in Appendix B).

Turbidity exceeding 330 FNU has been associated with acute stress effects on salmonid feeding through loss of visibility. For examples, exposure to SSC of 450 mg/L for just 1.5 h led to a 22% reduction in feeding rate, due to reduced ability to detect prey in juvenile trout at (Greer et al. 2015). In general, across rivers, macroinvertebrate indices (MCI, QMCI) tend to decline as VC decreases (and SSC or turbidity increases) (Franklin et al. 2021), although the contribution of VC in driving such declines cannot be separated from other potential drivers.

<u>Turbidity threshold 5:</u> 1000 FNU, no exceedance allowance. Mean hourly FNU must not exceed 1000 FNU.

Turbidity of 1000 FNU is equivalent to SSC of 750 g/m^3 and VC of 0.07 m. Mean hourly turbidity has never exceeded 1000 FNU in the 3.5 years of record in the Mararoa at Weir Road. Instantaneous (5 min intervals) turbidity exceeded 1000 FNU for three consecutive readings on 4 February 2020 during a flood event that peaked at ~500 m^3/s.

Extremely high turbidity can directly affect salmonids through physical damage to gills, and indirectly through the effects of low visual clarity. Juvenile brown trout subject to SSC of 810 g/m^3 for 21 days showed gill thickening in response to physical abrasion (Herbert and Merkins 1961). Juvenile brown trout subject to SSC of 450 g/m^3 for 90 minutes showed a 22% reduction in feeding rate due to reduced ability to detect prey (Greer et al. 2015). On the other hand, some sensitive New Zealand macroinvertebrates were shown to tolerate short-term exposure (4 h) to ~ 1000 NTU (Suren et al.

[8] Macroinvertebrate Community Index (MCI) and its quantitative variant (QMCI).

2005). However, the effect of longer-term durations of such high turbidity is unknown, but is likely to lead to declines in macroinvertebrate indices (Franklin et al. 2021), and through the indirect effects of DFS.

<u>Deposited fine sediment threshold</u>: exceedance allowance of an increase of no more than 20% cover on the baseline value (long-term median % cover) at the start of the excavation, based on a rolling four-week average of weekly observations.

The long-term mean and median of DFS in the Waiau River u/s Excelsior Creek are 26% and 22% cover respectively, with cover ranging from 0% to 77%. Broad month-to-month fluctuations in DFS in the Waiau River u/s Excelsior Creek can be partly explained by flow conditions (Kilroy et al. 2023). Ideally, weekly records of DFS should be taken for as long as possible before the Project starts to help establish the "baseline conditions". The threshold allows for short-term (i.e., weekly) exceedances beyond the threshold but if an increase of 20% cover persists over a rolling four-week average[9] then mitigation should be considered. To exclude the potential role of the Mararoa River in causing increased DFS (due to turbid flows), it is suggested that if elevated DFS occurs and turbidity attributed to the Project alone (i.e., the difference between turbidity at Excelsior and turbidity at Weir Road) has been at least 30 FNU for 37 hours, then the Project will be deemed responsible for the increase in DFS. This is because a turbidity of 30 FNU for 37 hours is sufficient to cause an increase in DFS of 20% cover (NIWA analysis). As an increase of 20% cover is considered an adverse effect, if the Project alone could cause this, then we consider that mitigation should be required.

DFS cover of >20% is associated with declines in the abundances or taxa richness of potentially sensitive macroinvertebrate EPT taxa (i.e., Ephemeroptera (mayfly larvae), Plecoptera (stonefly larvae) and Trichoptera (caddisfly larvae)), caused by streambed habitat loss (e.g., Wagenhoff et al. 2012, Burdon et al. 2013). Reduction in macroinvertebrate abundance has been reported following increases in DFS of 12–17% (Ryan 1991) and also when DFS increased from already high levels (~80% cover, Matthaei et al. 2006). Changes in macroinvertebrate community structure have been recorded over time as habitat changes with increasing DFS (e.g., Rabeni et al. 2005). While the more severe effects of increased DFS are on macroinvertebrates, decreasing density of juvenile and adult trout have also been reported as sediment was added to streambed habitat over a month (Ramezani et al. 2014).

[9] We note that due to historical monthly variability a 4-week rolling average may appear too short a duration, however, we consider that this duration needs to be limited to prevent excessive accumulation of DFS during the 5-7 week instream excavation period of the Project.

Table 3-1: Proposed SSC thresholds for protection against unacceptable effects on biota in the Waiau Arm and downstream in the LWR during the Project, with metrics for monitoring. The monitoring unit is turbidity (FNU), shown in bold. Equivalent VC shown is based on the relationship developed in trial excavation in Waiau Arm (Equation 2).

Threshold level			What occurs naturally		Threshold duration before mitigation				Predicted total effect on river
Turbidity threshold (FNU)	Equivalent VC (m)	Brief justification for threshold turbidity level	Average natural duration of threshold exceedance in a year (days) based on 3.5 yr turbidity record	Estimated range of natural duration of threshold exceedances in a year (days) based on flow record (and flow-turbidity relationship) from 1990-2022	Duration (days) that Project can exceed threshold before mitigation	Duration (hours) that Project can exceed threshold before mitigation	% of time that the threshold can be exceeded due to Project (assuming 4-month duration) before mitigation	Maximum consecutive duration (hours) that threshold can be exceeded before mitigation (1/3 of total allowable exceedance duration)	Predicted total duration (days) that threshold could be exceeded over a year (based on Project + average Mararoa year = 1.75 x average natural exceedance)
12.4	0.96	occurs 1% of time when flow <40 m3/s	52.5	25 - 98	39	945	33	315	92
30	0.56	reduced salmonid feeding by >50%	28	12 - 53	21	504	18	168	49
160	0.20	Exacerbated chronic stress effects	5.3	2 - 10	4	95	3	32	9.3
330	0.13	affects salmonid feeding & egg mortality	2	1 - 4	1.5	36	1	12	3.5
1000	0.07	max limit - physical damage to organisms	0	0	0	0	0	0	avoid

Table 3-2: Proposed DFS threshold for protection against unacceptable effects on biota in the Waiau Arm and downstream in the LWR during the Project, with metrics for monitoring. Natural long-term data are based on monitoring from August 2018 to February 2023.

Threshold level			What occurs naturally		Threshold duration before mitigation	
Deposited fine sediment threshold (% cover)	Baseline	Brief justification for threshold level	Long-term mean DFS at LWR u/s Excelsior (% cover)	Long term range of DFS at Excelsior (% cover)	Duration of DFS increase	Test if Project is responsible
Increase of 20% cover over baseline	Long-term median cover as measured monthly at Excelsior (22%)	Loss of habitat and food for macroinvertebrates	26	0 - 77	4-weekly rolling average during Project based on weekly monitoring at Excelsior	Turbidity due to Project (Excelsior - Mararoa) exceeds 30 FNU for 37 hours consecutively, then mitigation required.

3.7 Monitoring sediment thresholds

3.7.1 Monitoring sites for SSC (turbidity) and DFS, and outline of methods

Suspended sediment release from the excavation will be monitored for the duration of the excavation using a turbidity sensor installed in the LWR about 100 m upstream of the confluence with Excelsior Creek (hereafter the Excelsior sensor) (Figure 3-3). It is assumed that at this distance from the Project site (approximately 1300 m from the downstream breakout area), any sediment from the Project will be well mixed so that the turbidity recorded is representative of the whole cross-section, and therefore includes both Mararoa and Waiau Arm flow and sediment. It is also assumed that this site will be affected to the maximum extent by sediment from the Project compared to the river downstream. Monitoring at this site will therefore represent the worst-case scenario of effects.

The turbidity sensor (a Hach Solitax field turbidity sensor, set to log at 5-minute intervals) will be installed with real-time connectivity.

Figure 3-3: Locations of turbidity and flow recorders to be used in the monitoring programme over the duration of the Project.

Data from the turbidity sensor installed just downstream of Weir Road bridge, upstream of MLC (hereafter the Weir Road sensor) will also be used in the monitoring programme. This instrument (also a Hach Solitax field turbidity sensor, logging at 5-minute intervals) is used for real-time compliance monitoring. The Excelsior sensor will be an identical instrument, configured in the same way, so that turbidity data from the two sensors can be directly compared.

Cover by DFS will be measured in wadeable depths in the river reach starting about 100 m upstream of the confluence with Excelsior Creek (Figure 3-3), using the method required for comparison with thresholds in the NPS-FM (SAM2, Clapcott et al. 2011). This is the same site that DFS is currently monitored by Environment Southland (see Section 5.3.3). An alternative monitoring site about 250 m downstream of the Excelsior Creek confluence is also marked on Figure 3-3. If at all possible, monitoring should be undertaken upstream of Excelsior Creek because this is where we have a long-term DFS record and DFS results would be less impacted by sediment delivered from Excelsior Creek. The alternative site is suggested because carrying out the required instream assessments at the site upstream of Excelsior Creek may become difficult or impossible once the Project is underway. This is because all Mararoa flow will be passed through the MLC to the LWR for the duration of the channel construction associated with the Project. This will mean that flows in the LWR may be higher than the minimum flow during this period of the Project.

To date, all DFS surveys in the Waiau River u/s Excelsior Creek have been carried out at or only slightly over minimum flow (maximum flow of 26 m^3/s on 26 April 2019). Surveys have been "missed" in about 20% of all months between August 2018 and March 2023, and most of these missed surveys can be attributed to high flows. It is likely that the site downstream of Excelsior Creek will be more easily accessed under elevated flows than the upstream site because of the shape of the river cross-section: at the upstream site, the square cross section means that water depth close to the edge increases quickly under elevated flows; at the downstream site the river is much wider and a boulder/cobble bank slopes gradually into the water, so that some part of the river bed is accessible under a wider range of flows.

3.7.2 Monitoring and calculations prior to the start of the Project

Installation of the Excelsior sensor at least a month (and longer if possible) ahead of the start of the excavation will allow a period of parallel data collection at the two sites, to assess differences in turbidity between the two sites under existing conditions.

A pre-Project baseline value for DFS will need to be established before the excavation starts, and would be based on the long-term (i.e., full DFS record from 2018) median % cover in the Waiau River u/s Excelsior. We anticipate that this will be close to the current long-term median of 22%.

3.7.3 Turbidity monitoring

Turbidity monitoring will require simultaneous checking of both the Weir Road and Excelsior data. The monitoring will be in two parts:

Part 1: Responses to automated alarms from the Excelsior instrument for exceedances of the two highest turbidity thresholds that have short duration exceedance allowances (1000 FNU, 330 FNU).

Part 2: Daily monitoring of both the Weir Road and Excelsior datasets of 330 FNU and the three lower turbidity thresholds with longer duration exceedance allowances (160, 30 and 12.4 FNU). The daily monitoring will include maintaining a cumulative total of all exceedances (hourly medians) starting on Day 1 of the excavation.

Alarms

After a notification that 1000 FNU has been exceeded:

a. Check the output from the Weir Road sensor.

b. If the Weir Road sensor indicates similar or higher turbidity has originated from the Mararoa River, then the alarm has not been caused by the excavation and can be ignored.

c. If Excelsior turbidity minus Weir Road turbidity is less than 1000 FNU, then the turbidity exceedance applies to the next threshold (330 NTU). See below.

d. If **Excelsior turbidity minus Weir Road turbidity is more than 1000 FNU**, then assume that high turbidity has originated from the excavation. Immediate mitigation is required (stop work).

After a notification that 330 FNU has been exceeded:

a. Check the output from the Weir Road sensor.

b. If the Weir Road sensor indicates that similar or higher turbidity has originated from the Mararoa River, then the alarm has not been caused by the excavation and can be ignored.

c. If Excelsior turbidity minus Weir Road turbidity is less than 330 FNU, then the turbidity exceedance applies to the next threshold (160 NTU). See below.

d. If **Excelsior turbidity minus Weir Road turbidity is more than 330 FNU**, then assume that high turbidity has originated from the Project and update the running totals (for 330 FNU and all lower thresholds).

   A running total of 330 FNU occurrences (hourly medians) of more than 24 h is considered an alert level because there are fewer than 12 exceedance hours left. Continue to monitor turbidity hourly. Consider mitigation action within the next 24 hours, to be confirmed if there are further alarms.

e. If **Excelsior turbidity minus Weir Road turbidity has been more than 330 FNU** for more than 11 consecutive hours, then mitigation is required regardless of the total.

   Refer to Mitigation flows in Section 3.8.

f. If the cumulative total is less than 24 h, with consecutive exceedances for not more than 11 h, stand down until the next alarm.

Daily checks for exceedances of 160, 30 and 12.4 NTU

a. At the same time each day, check the outputs from both sensors.

b. If the Weir Road sensor indicates that similar or higher turbidity has originated from the Mararoa River, then the exceedance of any of the thresholds has not been caused by the Project and can be ignored.

160 FNU

a. If **Excelsior turbidity minus Weir Road turbidity is more than 160 FNU**, then assume that high turbidity has originated from the Project and add the total number of hours of exceedance to the 160 FNU running total, and to the running totals for exceedances of 30 and 12.4 FNU.

For 160 FNU occurrences (hourly medians), a running total of more than 72 h is considered an alert level because there are fewer than 24 exceedance hours left. Consider mitigation action within the next 24 hours, and continue to monitor turbidity every few hours to confirm whether mitigation is required.

b. If **Excelsior turbidity minus Weir Road turbidity has been more than 160 FNU** for more than 31 consecutive hours, then mitigation is required regardless of the total.

   Refer to Mitigation flows in Section 3.8.

c. If the cumulative total is less than 72 h, with consecutive exceedances for no more than 31 h, resume daily checks.

30 FNU

a. If **Excelsior turbidity minus Weir Road turbidity is less than 160 FNU, but more than 30 FNU**, then the turbidity exceedance applies to the 30 FNU threshold. Add the number of hours of exceedance to the 30 FNU running total and to the running total for exceedances of 12.4 FNU.

   For 30 FNU occurrences (hourly medians), a running total of more than 400 h is considered an alert level because there are fewer than 105 exceedance hours left. Consider mitigation action within the next 5 days, to be confirmed or not over the next four daily checks.

b. If **Excelsior turbidity minus Weir Road turbidity has been more than 30 FNU** for more than 167 consecutive hours, then mitigation is required regardless of the total.

   Refer to Mitigation flows in Section 3.8.

c. If the cumulative total is less than 400 h, with consecutive exceedances for no more than 167 h, resume daily checks.

12.4 NTU

a. If **Excelsior turbidity minus Weir Road turbidity is less than 30 FNU, but more than 12.4 NTU**, then the turbidity exceedance applies to the 12.4 NTU threshold. Add the total number of hours of exceedance to 12.4 FNU running total.

   For 12.4 FNU occurrences (hourly medians), a running total of more than 805 h is considered an alert level because there are fewer than 240 exceedance hours left. Consider mitigation action within the next 10 days, to be confirmed or not at the next eight to 10 daily checks.

b. If **Excelsior turbidity minus Weir Road turbidity has been more than 12.4 FNU** for more than 314 consecutive hours, then mitigation is required regardless of the total.

   Refer to Mitigation flows in Section 3.8.

c. If the cumulative total is less than 805 h, resume daily checks.

If none of the thresholds have been exceeded, or periods of consecutive exceedances has been exceeded, resume daily checks.

3.7.4 Monitoring deposited fine sediment

Environment Southland (ES) currently carry out monthly surveys of DFS in the Waiau River u/s Excelsior Creek as part of their State of the Environment (SoE) monitoring programme, within the wadeable reach adjacent to the proposed site for the Excelsior turbidity instrument. The ES surveys at Excelsior began in August 2018 and are part of an expanded monitoring network in the Waiau catchment funded by Meridian. The DFS survey results have been used to grade the site against the DFS attribute of the NPS-FM. The data from the monthly surveys provide baseline data on DFS in the Waiau River. DFS is generally higher in the Waiau River u/s Excelsior Creek than at two sites downstream (Waiau at Sunnyside and Tuatapere, Hogsden et al. 2023a).

The survey method used is Sediment Assessment Method 2 (SAM2: in-stream visual assessment of % sediment cover) set out in Clapcott et al. (2011), as required by the NPS-FM. Briefly, estimates of percentage cover of the stream bed by DFS are made in each of 20 views through an underwater viewer. Five views are assessed along each of four part-transects out to depths of about 0.7 m.

It is proposed that monitoring of DFS at this site continues under the ES programme, with frequency increased to weekly during the Project and covered by the Project programme. The timing of the extra surveys would fit in with the schedule of the regular monthly surveys.

During the excavation it is proposed that percentage cover by DFS should not increase by more than 20% cover compared to the long term median value at the start of the excavation (currently 22%).

Weekly checks for DFS exceedances

a. If DFS has exceeded baseline by more than 20% cover then check turbidity records.

b. If Excelsior turbidity minus Weir Road turbidity has been more than 30 FNU for more than 37 consecutive hours, then mitigation is required.

c. If Excelsior turbidity minus Weir Road turbidity has not been more than 30 FNU, continue weekly monitoring.

3.8 Mitigation flows

An analysis has been undertaken to assess how managed flow releases down the Waiau Arm of varying magnitude will dilute suspended sediment from the Project. Table 3-3 summarises the proportion by which turbidity (or SSC) generated from the Project will be reduced by a series of flow scenarios. This assumes that flows down the Waiau Arm (flushing flows) all have zero turbidity (see Section 5.1.2 below) and the turbidity from the Mararoa, at various flows, is based on the turbidity versus flow relationship for Mararoa at Weir Road. The analysis methodology is summarised in Appendix C. Appendix C also provides a series of tables than can be used to look up the effect of a given flushing flow on turbidity due to the Project or due to both the Project and the Mararoa under different scenarios.

Table 3-3: Proportion reduction of turbidity (or SSC) due to the Project under different flushing flow scenarios.

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	5	50%	25%	17%	13%	10%	8%	6%	5%	3%	2%
	10	67%	40%	29%	22%	18%	14%	12%	9%	6%	5%
	15	75%	50%	37%	30%	25%	20%	17%	13%	9%	7%
	20	80%	57%	44%	36%	31%	25%	21%	17%	12%	9%
	25	83%	62%	50%	42%	36%	29%	25%	20%	14%	11%
	30	86%	67%	55%	46%	40%	33%	29%	23%	17%	13%
	35	88%	70%	58%	50%	44%	37%	32%	26%	19%	15%
	40	89%	73%	62%	53%	47%	40%	35%	29%	21%	17%
	45	90%	75%	64%	56%	50%	43%	38%	31%	23%	18%
	50	91%	77%	67%	59%	53%	45%	40%	33%	25%	20%
	120	96%	89%	83%	77%	73%	67%	62%	55%	44%	38%

The size of flushing flow required to reduce turbidity generated by the Project down to acceptable levels (i.e., below a given threshold) will depend on the level of turbidity being generated. Thresholds are not 'reset' after a flushing flow, however flushing flows may be used to lower turbidity sufficiently that threshold durations are not exceeded. If a given activity during the Project is causing a sustained exceedance of one or more turbidity thresholds, such that a turbidity threshold duration allowance is at risk of being exceeded, then a flush will be required and that flush will need to continue for the duration of that activity or until turbidity naturally falls to the acceptable level.

To remove DFS that is exceeding the DFS threshold, we predict that a flush of 50 m^3/s (average over the flush) for at least 77 hours or a flush of 120 m^3/s (average) for at least 24 hours will be required.

4 Assessment method

The assessment of environmental effects on freshwater ecology (as outlined in this report) considered the potential effects of excavation using the parallel channel option. Effects were considered within the Waiau Arm from the upstream extent of the Project site and downstream to MLC, and also downstream in the LWR (the receiving environment).

We made the following assumptions about the excavation work required for the parallel channel option:

- almost 90% of the excavation work (by volume of material moved) will be completed out of stream,
- the Project will be carried out within a 10-month period (January to October) with an overall construction period of approximately 4–5 months within this window,
- instream excavation will occur at “breakout” points at the upstream and downstream extremities of the newly excavated channel during the latter 5 to 7 weeks of the excavation,
- the largest release of sediment will be during the 4-week period when the downstream ‘breakout’ is completed,
- the excavation works will occur on an up to 7-days per week and up to 24 hours per day basis,
- the overall effect (in terms of fine sediment released from the Project) will depend on flows and lake levels, and
- the greatest effects of the works will be in the reach immediately downstream of the works, with the greatest effects of sediment on the receiving environment (LWR) being best represented u/s of the Excelsior Creek confluence. This point is considered close to the works but far enough downstream to enable full mixing of water from the Mararoa River and Waiau Arm.

The assessment focuses on the potential effects of (a) bed disturbance, sedimentation and elevated SSC (at times) on the biota of the Waiau Arm in the Project area, and (b) elevated SSC and DFS in the LWR downstream of the Project area. Communities considered were freshwater flora (macrophytes, periphyton, and phytoplankton) and fauna (macroinvertebrates, fish, and freshwater birds).

The assessment was guided by the combination of the information acquired from the trial excavation, a synthesis of existing information on the existing environment (in terms of both fine sediment and biota) and the outcome of a review of the literature. The aims of the literature review were to confirm the general effects of SSC and DFS on the biotic communities considered, and to identify thresholds or gradients (of SSC, turbidity or VC) that had specific effects on individual taxa or groups of taxa. Using the trial and review information, we considered how the taxa or communities currently present in the affected area might be affected by higher SSC (as anticipated from the Project). This process guided a final assessment of effect magnitude which also considered the intrinsic value of the taxa/communities (e.g., rare/endangered vs common and widespread taxa) and the potential for recovery from any effects following the excavation.

5 Existing environment

5.1 Summary of existing environment

5.1.1 Hydrology / flow variability

Flows from both Lake Manapōuri (via the Waiau Arm) and the Mararoa River together contribute to the composition of water and flow variability in the LWR. Under normal operations of the MPS, once the minimum flow in the Waiau River has been provided, Mararoa River water is diverted to Lake Manapōuri via the Waiau Arm for power generation. Therefore, flows in the Waiau Arm can be in either direction. High flow events in both the Waiau Arm and the Mararoa River tend to be lowest in both magnitude and frequency in the summer months, especially February and March. Managed flow releases increase flow variability in the LWR in summer, although ability to release large flushing flows for periphyton management has been limited in recent years (to 1.5 per year on average over the past seven years, compared to the four releases that are provided for in Meridian's protocol for the management of nuisance periphyton in the river) due to sediment build up at the MLC, and primarily because low lake levels precluded releases of sufficient size.

5.1.2 Suspended and deposited fine sediment

Concentrations of suspended sediment in the Waiau Arm in the Project area are generally low (and hence water clarity is relatively high) because the water originates primarily from Lake Manapōuri. Water clarity in the Waiau Arm is typically lower than that in the lake because of the effect of nutrient-enriched tributary inflows, which may exacerbate phytoplankton growth, especially in summer. However, the Waiau Arm is characterised by relatively high water-clarity and low turbidity compared to the Mararoa River. Turbidity in the Mararoa River just upstream of the MLC has been characterised using a 3.5-year record of high-frequency (5-minute intervals) turbidity observations. The record provides estimates of the proportions of time turbidity exceeds certain thresholds. For example, turbidity of ~225 FNU is associated with high flows (>~100 m^3/s) that occur less than 1% of the time. Turbidity in the upper reaches of the LWR tends to reflect that observed in the Mararoa River because all turbid Mararoa River flows are passed through to the LWR. When flows in the LWR are dominated by flood events from the Mararoa, turbidity tends to reduce in a downstream direction as suspended sediment concentrations are diluted with additional flows from tributaries and coarser fractions of the suspended sediment are deposited on the bed.

DFS cover in the Waiau River u/s Excelsior Creek has been highly variable over time, fluctuating between 0% and over 75% cover. The variability can be partly explained by preceding flows, which indicates that the DFS is primarily sourced from the Mararoa River and catchment.

5.1.3 Plant communities

Benthic plant communities in the Waiau Arm near the Project area currently consist of sparse populations of non-native weeds and native characean algae and vascular plants, all of which also occur in greater densities farther upstream in the Waiau Arm. The native plant taxa encountered, and also periphyton taxa identified, are all nationally widespread and abundant with no special conservation status. Plant communities in the LWR comprise primarily periphyton dominated by the invasive non-native diatom *Didymosphenia geminata* (didymo). The potentially toxic cyanobacterium *Microcoleus* can proliferate during summer. Periphyton biomass is moderate to high reaching nuisance levels at times, with no special ecological value.

5.1.4 Macroinvertebrates

Existing macroinvertebrate communities in the Waiau Arm near the Project area reflect a habitat with slow-moving water and fine substrate. The community has no taxa/species that are not commonly found elsewhere in the Waiau Arm; the most notable feature of the community is the presence of low numbers of kākahi (conservation status, At Risk – Declining).

Macroinvertebrate communities in the LWR are considered moderate to poor, falling into Bands C or D of the NPS-FM macroinvertebrate attribute (MCI). The taxa present are common and widespread with no special ecological values.

5.1.5 Freshwater fish

At least 15 native fish species are known from the Waiau Arm and LWR; noting that this diversity for the LWR is inclusive of species caught downstream to the river mouth. These include longfin eels, which have a conservation status of “At Risk – Declining”. Longfin eels are present in the Waiau Arm. A survey in 2022 indicated high densities of longfins but relatively poor body condition. A trap-and-transfer programme supports the upstream migration of elvers and downstream migration of adults (migrants) via the LWR. Other native fish species include two non-migratory galaxias species known from the Waiau catchment that are classed as “Threatened - Nationally Vulnerable”: the southern flathead galaxias and the Gollum galaxias. Both have been found in the LWR just downstream of the MLC. The “Threatened – Nationally Vulnerable” lamprey has also been caught below the MLC in summer although it is highly likely that most adults reside in tributaries. The location of adult lamprey habitat is not well known in the main stem of the LWR. In addition, introduced salmonids in the Waiau catchment, including those found in the Waiau Arm and the LWR, support a recreational fishery that is among the most valued in New Zealand, although densities in the LWR are 10% of those in the Upper Waiau River, and based on Southland Fish and Game drift-diving data have declined over the past two decades. Brown trout density in the Mararoa River has also declined since ~2000. Salmonid spawning habitat is limited in the LWR. Pre-spawning trout tend to aggregate just upstream of the MLC.

5.1.6 Freshwater birds

Twenty freshwater bird species have been identified in and around the Project area, including two (black-billed gull and banded dotterel) that are listed as “At Risk – Declining” and one (black-fronted tern) listed as “Nationally Endangered”. The latter two are also found downstream in the LWR. The Project area is a known roosting and nesting area, particularly for black-billed gulls. Meridian’s current consent conditions include measures to avoid disturbance of black-billed gulls, black-fronted terns and banded dotterels. In particular, MLC resource consents require that works in the MLC area (e.g., gravel excavation, dam safety protection works) shall not occur during the bird nesting season (15 September to January) if the works would disturb any colonies of birds.

5.2 Hydrology / flow variability

5.2.1 Waiau Arm

Since construction of the MLC, the Waiau Arm has effectively been an extension of Lake Manapōuri and often has lake-like rather than river-like characteristics. As previously noted, once minimum flows[10] to the LWR have been provided (downstream of the MLC), surplus Mararoa River water (i.e., river water not required to be released downstream to meet minimum flow requirements) is

[10] Minimum flows are: 12 m^3/s (May to September), 14 m^3/s (October and April), 16 m^3/s (November to March).

diverted towards Lake Manapōuri via the Waiau Arm for power generation. As noted in Section 5.1.1, flow in the Waiau Arm can be either towards MLC (i.e., its natural direction, positive flows) or towards Lake Manapōuri (i.e., the reverse direction, negative flows).

Since 2012 (i.e., under the current operating regime of the Manapōuri Power Station which includes the Manapōuri Tailrace Amended Discharge, MTAD), net mean flow in the Waiau Arm has been towards MLC (overall net mean flow of 38 m^3/s, between September 2012 and June 2023). The overall mean of negative flow (towards the lake) was -9.9 m^3/s. On average, negative flows have been highest from June to September and lowest from December to April. Positive flows in the Waiau Arm (towards MLC) tend to be highest from May to December (on average) and lowest in March and April (Table 5-1).

High flows either from Lake Manapōuri or the Mararoa River can occur at any time of year (Table 5-2). The four-month period with the lowest likelihood of a high flow (e.g., > 200 m^3/s) in the Waiau Arm is from February to May, with an event exceeding 200 m^3/s occurring in one of every five years (or less often) in those months (probability of 0.2 or less in Table 5-2).

Table 5-1: Mean flow in the Waiau Arm and Mararoa River by month. Means are averages within months from 2012 to 2023. Positive flow towards MLC, negative flow towards Lake Manapōuri.

	Average of flow in each month (m^3/s)												Mean annual flow
Month:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Waiau Arm (MLC flow minus Mararoa flow)													
Positive	48	36	13	11	121	87	52	106	114	158	123	116	71
Negative	-6	-6	-6	-5	-8	-12	-15	-13	-10	-11	-9	-5	-10
Net flow	41	29	11	7	60	36	14	28	28	71	65	66	38
Mararoa River													
	21	18	16	22	34	39	36	38	41	41	36	26	31

Table 5-2: Mean numbers of flow events in the Waiau Arm and Mararoa River in each month. Means are averages within months from 2012 to 2023 for the Waiau Arm and from 1990 to 2023 for the Mararoa River. The bottom line shows the mean percentage of time in each month when flows at MLC are at minimum flow, assumed to be <18 m^3/s, which allows for variability and occasional slightly higher releases when flow ratings change. Note that Waiau Arm flow events in the 100–200 m^3/s band include flow releases for nuisance periphyton management in the LWR (see below). Shaded cells highlight the consecutive four-month period with the lowest probability of high flows in the Waiau Arm (on average).

Flow band (m^3/s)	Average number of events in each month, in specified flow range											
Month:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Waiau Arm (net flow)												
40-100	0.0	0.2	0.0	0.1	0.3	0.0	0.4	0.3	0.0	0.1	0.1	0.1
100-200	0.6	0.2	0.4	0.0	0.2	0.5	0.3	0.1	0.0	0.1	0.0	0.1
>200	0.3	0.2	0.1	0.1	0.2	0.4	0.1	0.2	0.0	0.4	0.3	0.2
Mararoa River												
40-100	1.2	0.5	0.5	0.9	0.4	0.4	0.9	1.0	0.2	0.7	1.1	0.6
100-200	0.1	0.1	0.2	0.2	0.6	1.1	0.8	0.5	0.9	1.1	0.4	0.3
>200	0.1	0.1	0.0	0.1	0.3	0.1	0.2	0.3	0.4	0.2	0.2	0.1
Lower Waiau at MLC	Approximate mean percentage of time at monthly-varying minimum flow											
<18 m^3/s	57	55	85	75	41	41	50	59	63	45	55	74

5.2.2 Lower Waiau River

Flows released to the Waiau River through the MLC comprise a combination of water from the Waiau Arm and from the Mararoa River, which can vary from:

1. 100% water from the Mararoa River (at minimum flow, when Mararoa water is being diverted for power generation (i.e., negative flows in the Waiau Arm)), or during high flows across a range of magnitudes from the Mararoa River; to

2. More than 80% water from Lake Manapōuri via the Waiau Arm (at minimum flows when flow in the Mararoa River is extremely low, or during large magnitude lake floods (typically >250 m^3/s)).

Reflecting the frequency of high flow events from both Lake Manapōuri and the Mararoa River, minimum flows in the LWR on average occur for the highest percentage of the time in the months of March and April (Table 5-2).

Flow variability in the LWR is increased during the summer months by the release of relatively large flushing flows for nuisance periphyton management and smaller recreational flow releases. The current protocol for monitoring and management of nuisance periphyton in the LWR provides for the release of up to four flushing flows in each season (between November and May) in response to "Red status" (i.e., high periphyton cover as quantified in instream surveys). Releases effective in reducing periphyton cover generally average at least 120 m^3/s over 24 hours and reach a peak flow of around 160 m^3/s. However, in the past seven seasons (i.e., November 2016–May 2017 through to November 2022–May 2023), fewer than 1.5 flushing flows per season have been released (on average), primarily because low lake levels precluded releases of a sufficient size (e.g., Kilroy 2022).

In addition, smaller "recreational flows" (typically 35–45 m^3/s (at MLC) for 24 hours) are released monthly from October to April. These releases have been provided consistently over the years. Occasionally, a small proportion may have been omitted because of extremely low lake levels (Kilroy 2023).

High flows in the Mararoa River are naturally turbid. To prevent turbid water entering the Waiau Arm and eventually Lake Manapōuri, all turbid flows with an NTU of more than 30 are required to be passed through MLC to the LWR. These small to large Mararoa floods add further variability to flows in the LWR. High flows in the Mararoa River generally occur with lowest frequency in February and March (Table 5-2). The composition of flow at MLC determines the levels of naturally occurring fine suspended sediment delivered to the LWR (see next section).

5.3 Suspended and deposited fine sediment

5.3.1 Suspended sediment, Waiau Arm

The water in the area of the Waiau Arm affected by the proposed Project is usually a combination of water from Lake Manapōuri (via the Waiau Arm) and water from the Mararoa River. No monitoring of water clarity or turbidity has been carried out in the area immediately upstream of MLC. Monitoring during summer (January to March/April) at a site in the Waiau Arm about 2.3 km upstream of the MLC showed that water clarity was rarely less than 4 m and median turbidity in surface waters of ~0.7 FNU (data from 2021 to 2023, e.g., Hogsden et al. 2023b). While water clarity in the Waiau Arm is typically lower than that in Lake Manapōuri (median of 5.7–5.8 m VC in the Waiau Arm compared to 9 m in the lake, summer data, Hogsden et al. 2023b), it is higher than the median of monthly spot measurements of water clarity measured just upstream in the Mararoa River (at Weir Road), as part of the ES SoE monitoring programme (~3.1 m).

Lower water clarity in the Waiau Arm compared to Lake Manapōuri is likely partly attributable to elevated nutrient concentrations in inflows from tributaries such as Home Creek, about 1.5 km from Lake Manapōuri. Especially during periods of low flows and warm temperatures, higher nutrient availability may stimulate phytoplankton growth in the water column, which can increase turbidity and reduce water clarity. Nevertheless, the Waiau Arm is characterised by relatively high water-clarity and low turbidity compared to the Mararoa River.

Preventing turbid water from the Mararoa River being diverted into the Waiau Arm ensures that Mararoa River water with turbidity greater than 9 FNU rarely enters the Waiau Arm. For example, turbidity measured in the Waiau Arm during 12 years of monitoring during summer (January to March) has exceeded 3 FNU on only three occasions at a site 2.3 km upstream of the MLC and was less than 2 FNU in >95% of measurements.

5.3.2 Suspended sediment, Lower Waiau River

Flows at MLC that come from the Waiau Arm originate from Lake Manapōuri and comprise generally clear water with low SSC. Therefore, the primary source of suspended sediment to the upper reaches of the LWR is the Mararoa River. SSC naturally increases during floods and, typically, the greater the flood magnitude the greater the SSC (Figure 3-2). The record of high-frequency (5-minute intervals) turbidity observations from the Mararoa River at Weir Road (November 2019 to May 2023) is summarised in the frequency duration curve in Figure 5-1. Figure 5-1 highlights that turbidity is low for most of the time (e.g., turbidity exceeds 1.9 FNU for only 10% (10^1 in Figure 5-1) of the time), and periods with high turbidity are rare (e.g., 225 FNU exceeded for less than 1% (10^0 in

Figure 5-1) of the time). Similar curves can be constructed for SSC and VC after using the equations in Section 3.6.2.

Numerical examples of turbidity, SSC and VC with varying frequency of occurrence are shown in Table 5-3. For example, 0.5% of the time (i.e., for 44 hours total each year) turbidity is ≥ 331 FNU and SSC is ≥ 246 g/m^3. The infrequent levels of elevated suspended sediment in the Mararoa River represent normal (natural) occurrences for this river and normal inputs to the LWR immediately upstream of the MLC.

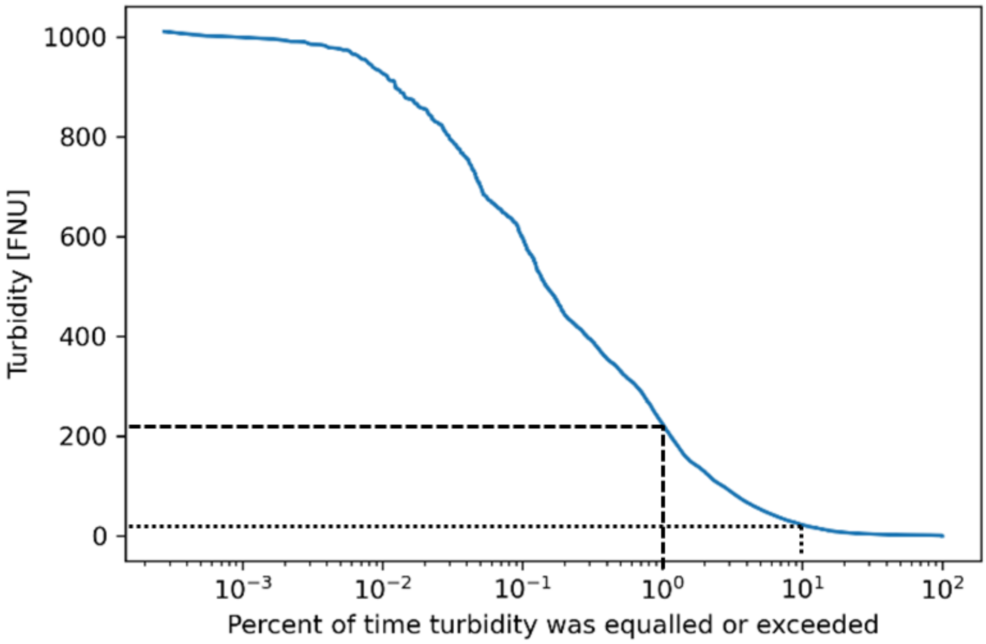


Figure 5-1: Duration curve for turbidity in the Mararoa River at Weir Road. Data from 6 November 2019 to 22 May 2023. The horizontal axis is log-transformed to show the typical distribution of turbidity over time more clearly, i.e., very small proportions of time with high turbidity. The dashed and dotted lines show turbidity exceeded for 1% (10^0) and 10% (10^1) of the time (refer to text).

Table 5-3: Values of turbidity (and the equivalent VC and SSC) based on established relationships that are exceeded in the Mararoa River for specified percentages of time. Percentages are also shown as the equivalent numbers of hours or days per year.

Percent of time equalled or exceeded	Equivalent no. hours or days per year (on average)	Turbidity (FNU)	VC (m)	SSC (g/m^3)
0.01	<1 hour	921	0.07	686
0.1	9 hours	598	0.09	446
0.5	~2 days	331	0.13	246
1	~4 days	225	0.16	168
2.5	~9 days	105	0.26	79
5	~18 days	53	0.39	40

Episodes of naturally high turbidity in the Mararoa River are relatively brief, with turbidity typically declining rapidly once the flood peak has passed. To establish these typical durations, we selected four scenarios with varying frequency of occurrence (i.e., conditions exceeded 0.1, 0.5, 1.0 and 2.5% of the time) and identified flood events in the Mararoa River that were approximately equivalent to these frequencies[11]. For these events we calculated from the record how long it took for the turbidity to drop from its peak back to base levels (recession time) (Table 5-4). The longest recession time of the scenarios considered was 173 hours (or approximately one week).

Table 5-4: Turbidity, VC, SSC, and recession time for a series of Mararoa River flood scenarios with different exceedance frequencies.

Scenarios	Percent Exceedance (for flow)	Turbidity (FNU)	VC (m)	SSC (g/m³)	Event start date	Mararoa flow which generates equivalent turbidity (m³/s)	Recession time (hr)
1	0.11	573	0.09	427.0	5-Jul-20	151.8	127.0
	0.074	647.6	0.08	482.6	26-Jun-21	264.1	172.8
	0.077	641.01	0.08	477.7	13-Sep-21	272.1	136.3
2	0.35	374.2	0.12	278.8	26-Oct-20	202.9	47.6
	0.54	321.8	0.13	239.8	17-Aug-21	176.2	90.2
3	0.75	277	0.14	206.4	17-Sep-20	178	125.1
	0.87	249.7	0.15	186.1	2-Jan-21	67.3	67.5
	0.786	269	0.14	200.4	15-Jun-21	133	123.1
	0.721	285.6	0.14	212.8	12-Jun-22	180.3	111.9
	0.926	238.2	0.16	177.5	7-Aug-22	182.6	116.6
4	2.14	121.3	0.23	90.4	18-Jun-20	63.2	43.7
	2.12	121.8	0.23	90.8	5-Sep-20	70.68	46.6
	2.67	100.9	0.26	75.2	6-Oct-20	117.7	96.8
	3.03	90.1	0.28	67.1	11-Oct-21	92.47	40.3
	2.68	100.5	0.26	74.9	19-Aug-22	84.12	43.5

These conditions in the Mararoa River, in terms of levels and frequencies of suspended sediment and recession times, are generally considered representative of conditions in the upper reaches of the LWR because they occur during elevated flow events when all flow from the Mararoa River would be directed into the LWR (i.e., no flow up the Waiau Arm). However, there may be some dilution by additional flows from the Waiau Arm so these levels of suspended sediment can be considered an upper limit for each frequency of occurrence in the LWR.

The effects of floods (and the proposed Project) on suspended sediment will vary further down the LWR due to dilution, as additional flow joins the LWR (e.g., tributary flows) and as coarser fractions fall out of suspension and are deposited on the bed.

[11] Note: events do not perfectly match these frequencies and in some cases, due to the relatively short turbidity record, there are only a few example events.

5.3.3 Deposited fine sediment

ES have carried out monthly surveys of DFS in the LWR u/s Excelsior Creek, within the wadeable reach, since August 2018. Provisional grading against the NPS-FM DFS attribute[12] (using data from August 2018 to March 2023) placed the site in Band C, with median cover of 22%.

DFS cover in the Waiau River u/s Excelsior Creek has been highly variable over time, fluctuating between 0% cover and over 75%. This has resulted in variability in the long-term median over time, ranging from 22% to 37% (based on varying numbers of samples). The variability can be partly explained by preceding flows. An analysis of DFS against a range of flow metrics showed that high cover by DFS (~50% cover on average) was strongly associated with the recent occurrence (fewer than 11 days prior to a survey) of small to medium-sized flows of Mararoa-dominated water (which typically have high turbidity). Also, low cover by DFS (less than 5% on average) was associated with longer periods elapsing since small to medium-sized Mararoa dominated events, in combination with a relatively recent large lake-dominated flows (up to ~3 months prior to a survey) (Kilroy et al. 2023). These associations suggested that the DFS is primarily sourced from the Mararoa River and catchment.

Kilroy et al. (2023) also investigated the spatial and temporal variability of DFS farther downstream in the LWR in the reaches as far downstream as Sunnyside. Conclusions from the investigation were:

- Cover by DFS was generally greater in the upper reaches closer to the MLC, with consistently high levels (i.e., >70% especially near the water's edge) around Excelsior Creek, Whare Creek, and Jericho angler's access;
- High DFS cover was patchy (i.e., not covering the whole bed in these areas) and was typically found close to the bank in low velocity environments;
- Cover by 'sludge' (a category of periphyton that encompasses loose unconsolidated algae, including didymo, which often incorporates high proportions of fine sediment) was more widespread than DFS;
- During low flows, fine sediment can become trapped in periphyton, as the algae grows around it, in the form of either mats or sludge. Sludge is readily removed by flushing flows;
- Larger, but more localised, deposits of fine sediment may accumulate in low velocity environments over short periods of time during small to medium-sized flood events in the Mararoa River. These sediment deposits gradually move through the system but appear to require larger lake-water dominated flushing flows to remove.

5.4 Plant communities

5.4.1 Waiau Arm

Macrophytes

Benthic plant communities in the Waiau Arm within the Project area are currently dominated by macrophytes, primarily the non-native weed *Elodea canadensis* ("pondweed") and native characean algae (two species) (de Winton et al. 2022). In 2022, *E. canadensis* had the highest cover on three transects within ~600 m of MLC, with mean cover estimated at <25% to >75% of the bed in different

[12] Grading against the deposited fine sediment attribute requires calculation of the median value using data from "a monthly monitoring regime where sites are visited on a regular basis regardless of weather and flow conditions. Record length for grading a site based on 5 years" (NPS-FM 2023).

locations in shallower marginal areas (up to 3 m deep) (de Winton et al. 2022). *E. canadensis,* native characean algae, and other native and non-native plant species were also observed in a “control” area surveyed farther upstream in the Waiau Arm. Plant abundance was generally greater in the control areas than in the Project area, likely caused by differences in bed sediment composition. Upstream bed sediment was primarily fine material, which provided good anchorage for macrophytes, compared to larger and more unstable substrate closer to the MLC. Plants were sparse to absent in the centre of the channels, especially closest to MLC, where drifts of didymo debris had accumulated (de Winton et al. 2022).

Periphyton

Periphyton (benthic algae) is likely present on hard surfaces around the shallow margins and as epiphytic communities on and among macrophyte beds in the Waiau Arm within the Project area. A survey in the Waiau Arm upstream of the MLC (just upstream of the Project area) in 2002 found that periphyton on hard surfaces in the Waiau Arm within 250 to 500 m of the MLC had low biomass consistent with thin films of algae (~15 mg/m^2 chlorophyll *a*) and comprised only three species of attached diatoms. The study concluded that “the periphyton community at all these sites [in the Waiau Arm] is considered depauperate and has no special ecological value” (Kilroy and Suren 2002). Apart from the arrival of the introduced diatom didymo (which was first observed in the Waiau catchment in 2004), there is no reason to expect that the periphyton community has changed since 2002.

Phytoplankton

Phytoplankton abundance is measured at sites farther upstream (than the Project area) in the Waiau Arm by Meridian (a voluntary addition to consent monitoring of Waiau Arm Water Quality in summer, from January through to March, began in January 2020), as chlorophyll *a* in samples taken from surface waters. Based on the year-round ES dataset, chlorophyll *a* rarely exceeds 5 mg/m^3 (< 2% of samples), exceeds 2 mg/m^3 for about 25% of the time, and is < 2 mg/m^3 for the remaining 73% of the time. Following Burns et al. (2000), chlorophyll *a* concentrations > 5 mg/m^3 represent eutrophic conditions, 2–5 mg/m^3 represent mesotrophic conditions, and < 2 mg/m^3 microtrophic to oligotrophic. These trophic states align with the bands for annual median chlorophyll *a* in the NPS phytoplankton attribute (NPS-FM 2020, Appendix 2a Table 1). Lake Manapōuri itself is consistently classed as microtrophic to oligotrophic. Chlorophyll *a* concentrations are influenced by multiple factors including water temperature, season, water velocity and nutrient availability. Currently, water velocities in the Waiau Arm near the Project area are generally greater than farther upstream (Clunie 2023b, Kilroy 2023). Consequently, chlorophyll *a* concentrations are likely to be lower (under current conditions) than those farther upstream in the Waiau Arm (closer to Lake Manapōuri), although data are lacking.

5.4.2 Lower Waiau River

In the LWR downstream of MLC, the plant community is primarily periphyton. The periphyton community is often dominated by didymo, which regularly attains nuisance levels, as indicated by visual assessments of periphyton cover (e.g., Kilroy 2022) and high benthic chlorophyll *a* concentrations (Hogsden et al. 2023a).

ES have monitored both periphyton cover and biomass (as chlorophyll *a,* mg/m^2) in the Waiau River u/s Excelsior Creek monthly since August 2018. Based on monthly data from August 2018 to

February 2023, the 92nd percentile[13] of chlorophyll *a* was ~110 mg/m^2, which places the site close to the threshold separating Bands B and C of the periphyton attribute in the NPS-FM (120 mg/m^2).

During summer, the potentially toxic cyanobacterium *Microcoleus autumnale (*previously *Phormidium*) can proliferate to levels sufficient to warrant public health warnings in the Waiau River u/s Excelsior Creek (e.g., at the in December 2020, Kilroy 2021).

In recent years, non-didymo-dominated periphyton mats appear to have become more common than didymo at times in the LWR, especially at a site just downstream of Excelsior Creek. However, the non-didymo algae similarly attains cover and biomass that are considered a nuisance (Kilroy 2022). Excessive amounts of periphyton biomass at times in the LWR are managed by Meridian using a programme of flushing flows (see Section 6.1). The flushing flows, and also natural floods from the Mararoa River, can reduce the biomass and cover of periphyton in the LWR, especially in the reaches immediately downstream of the MLC (Kilroy 2022).

5.5 Macroinvertebrates

5.5.1 Waiau Arm

Macroinvertebrate communities in the Waiau Arm in the vicinity of the Project area are dominated by the native mud snail *Potamopyrgus antipodarum*, with oligochaete worms also common, especially in areas of decomposing didymo covering the channel substrate that presumably washed in from the Mararoa River (de Winton et al. 2022). These taxa are tolerant of low-quality habitat and water quality and slow-flowing water. Kilroy and Suren (2002) reported macroinvertebrate communities in the lower Waiau Arm similar to those found by de Winton et al. (2022), suggesting little change in community composition in the intervening 20 years.

Low densities of kākahi (freshwater mussel) were observed during a survey in 2022 and should be expected in the Project area (de Winton et al. 2022). Based on our current understanding of the distribution of this species, it is likely that these were *Echyridella menziesii*, which is currently listed with a conservation status of "At Risk – Declining" (Grainger et al. 2018)[14]. Kākahi were also observed in the Waiau Arm at sites upstream of the Project area during the 2022 survey.

5.5.2 Lower Waiau River

The status of macroinvertebrate communities in the LWR is generally considered moderate to poor, as represented by MCI and relative to national standards (NPS-FM; Hogsden et al. 2023a). The NPS-FM bottom line for MCI was not met at Waiau River at Tuatapere and was equalled at Waiau River 100 m u/s Clifden Bridge from 2016–2020. There was also evidence for a deteriorating trend in both MCI and the semi-quantitative MCI (SQMCI) at the above two sites on the LWR (Hogsden et al. 2023a).

Limited data (three samples) indicate that the macroinvertebrate community in the Waiau River u/s Excelsior Creek is similar (i.e., close to the NPS-FM bottom line). In the last five years, oligochaete worms, chironomids, *Deleatidium* mayflies, *Hydropsyche* (Aoteapsyche group) caddisflies, and *Potamopyrgus* snails are among the most locally abundant macroinvertebrates at sites monitored by ES in the LWR, from upstream of Excelsior Creek to Tuatapere. Across a sediment gradient, most

[13] The 92nd percentile of chlorophyll *a* is the metric specified in the NPS-FM periphyton attribute for grading sites. The 92nd percentile allows an average of one exceedance of a threshold in every 12 observations, based on monthly samples. At least three years of data are required to grade a site.

[14] As a species of conservation concern, kākahi is included in the definition of 'fish' in the Conservation Act (Indigenous Freshwater Fish) Amendment Bill 2019. Therefore, kākahi is afforded the same protection from disturbance and taking as freshwater fish species in New Zealand (MfE 2021).

chironomids, *Deleatidium*, *and Hydropsyche* are considered 'decreasers' (i.e., sensitive taxa) whereas *Potamopyrgus* is an 'increaser' (i.e., tolerant taxa) (Clapcott et al. 2017).

5.6 Freshwater fish

Recent surveys of native fish in the Waiau catchment identified four non-native and 15 native fish species in the Waiau Arm and LWR (Table 9). Introduced (non-native) salmonids are part of a nationally important fishery. Of the native species present, several have been classed as under threat in the Department of Conservation's most recent classification (Dunn et al. 2018) and are also thought to be especially sensitive to elevated sediment. The following focuses on the current status of these species (Table 5-5).

Table 5-5: Freshwater fish species found in areas of the Waiau catchment that could be affected by the Project. Location is noted to distinguish between fish subject to direct effects (i.e., in the Project area) versus indirect effects (downstream in the LWR).

Species	DOC Threat status	Location relative to Project area
Rainbow trout	Introduced and naturalised	In Project area and LWR
Brown trout	Introduced and naturalised	In Project area and LWR
Chinook salmon	Introduced and naturalised	Unknown (Very few records of Chinook Salmon distribution in the catchment)
Perch	Introduced and naturalised	In Project area
Longfin eel	At Risk – Declining	In Project area and LWR
Shortfin eel	Not Threatened	In Project area and LWR
Common bully	Not Threatened	In Project area and LWR
Southern flathead galaxias (non-migratory galaxiid)	Threatened – Nationally Vulnerable	LWR
Gollum galaxias (non-migratory galaxiid)	Threatened – Nationally Vulnerable	LWR
Lamprey	Threatened – Nationally Vulnerable	Adult lamprey are transitory and migrate via the MLC into the Mararoa Catchment.
Banded kōkopu	At Risk – Declining	LWR
Torrentfish	At Risk – Declining	LWR
Redfin bully	Not Threatened	LWR
Upland bully	Not Threatened	LWR
Bluegill bully	At Risk – Declining	LWR
Īnanga	At Risk – Declining	LWR (lower reaches)
Black flounder	Not Threatened	LWR (lower reaches)
Giant kōkopu	At Risk – Declining	LWR (lower reaches)
Yellow-eye mullet	Not Threatened	LWR (lower reaches)

5.6.1 Salmonids

Brown and rainbow trout are broadly distributed throughout the Waiau catchment (Figure 5-2). These two species support a recreational fishery that is among the most valued in New Zealand (Unwin 2013). The Waiau catchment is considered the most popular sports fishery in Southland and, although the angling water downstream of the MLC had lower angler use in the most recent survey (~2,200 days), it has previously had over 7,000 angler days on average each year (Unwin 2016).

There are too few records of Chinook salmon (n = 1) from the Waiau catchment in the New Zealand Freshwater Fish Database to characterise their spatial distribution. Anecdotal reports suggest Chinook salmon run up the LWR in sufficient numbers to comprise a valued fishery. Chinook salmon are typically found in the LWR and Mararoa catchment, but a recent catch of sea-run salmon was recorded in Lake Te Anau[15].

Trout density in the LWR is approximately 10% of that observed in the Upper Waiau River and declined significantly between 1996 and 2013 (Stoffels et al. 2019). Trout density in the Mararoa River has also declined significantly during the last two decades. Brown trout density in the middle reaches of Mararoa River during 2015–2017 was approximately 30% of that observed during 1999–2001. There was no evidence for a significant change in rainbow trout abundance in the Mararoa River, but there was evidence for a shift in their distribution with declining abundance in the middle reaches but increasing abundance in the lower reaches over the last two decades (Stoffels et al. 2019).

Pre-spawning salmonids (brown trout and rainbow trout) migrate upstream from April through to September and use the vertical slot fish way (VSFW) at the MLC to access the Waiau Arm (see Appendix A).

Salmonids use instream gravel and cobble habitat to lay their eggs and the Upper Waiau River is recognised as one of the most important spawning areas in the Waiau catchment. Trout (mostly pre-spawning trout) aggregate just above the MLC at the confluence of the Mararoa River and the Waiau Arm[16]. There is limited substrate suitable for salmonid spawning from directly below the MLC to the Borland Burn (Jellyman and Jowett 2019).

[15] Big catch reeled in, shoes kept dry | Stuff.co.nz

[16] Watch | Facebook

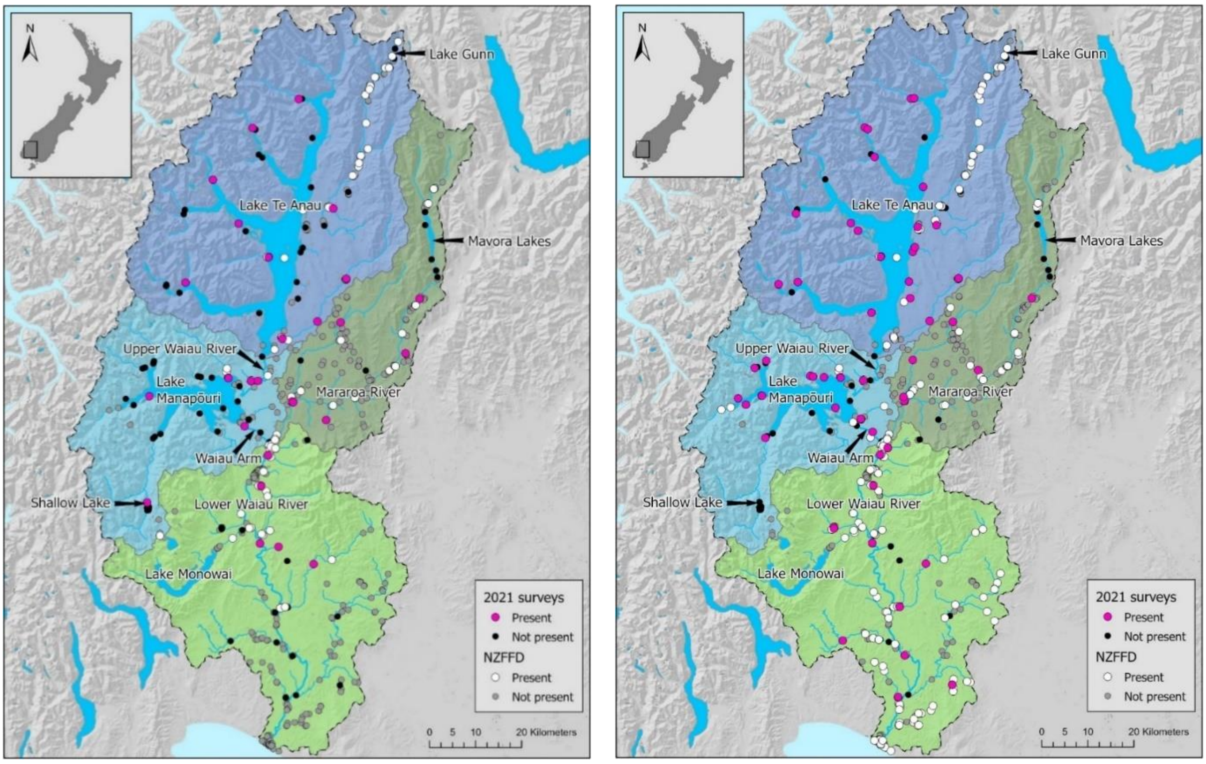


Figure 5-2: Salmonid distribution in the Waiau catchment - rainbow trout (left), brown trout (right).

5.6.2 Longfin eel

Longfin eels/tuna (*Anguilla dieffenbachii*) have a conservation status of "At Risk – Declining" with a "very large population and low to high ongoing or predicted decline". The species is considered to be dependent on conservation, although data-poor (Dunn et al. 2018).

Longfin eels are expected to be present both within the Project area in the Waiau Arm and in the LWR downstream of the MLC depending on the time of year. The greatest catch-per-unit-effort (CPUE) of longfin eels in the Waiau catchment during surveys in 2021 was in the Waiau Arm (mean CPUE for the Waiau Arm = 9.1 individuals/net/night; Figure 5-3) (Egan et al. 2022a). Approximately 43.5% were estimated to be males and they were mostly 500–600 mm long. These longfin eels had the lowest body condition of those surveyed in the catchment, which might reflect that the densities were too high in the Waiau Arm and/or the existing habitat in the Waiau Arm is poor quality (Egan et al. 2022a).

The extent of the juvenile eel population in the Waiau Arm is not well understood because the habitat was too deep to electric fish in the 2021 surveys (Egan et al. 2022a). It is unlikely there is much suitable habitat in the lower reach of the Waiau Arm to support juvenile eels.

Elver trap-and-transfer[17] occurs between December and March. Elvers are collected downstream of the MLC (and can be stocked at the Mararoa above Weir Road bridge when daily catches at the MLC are less than 2 kg) and are manually transferred to Lake Manapōuri and Lake Te Anau and selected tributaries.

Adult migrant eels will exit Lake Manapōuri and migrate via the Waiau Arm towards the MLC and eventually down the LWR and out to sea for reproduction. The Waiau trap and transfer programme

[17] See Tuna/eel trap and transfer programme — Te Waiau Mahika Kai Trust

also manually transfers adult migrant eels from Lake Manapōuri to below the MLC. Migrant eel activity is related to mean monthly water temperatures and typically little activity is observed during the coldest months (between June and August) (Jellyman and Unwin 2017, and see Appendix A). The last day of May is typically taken to be the end of the migration season in this population, however, longfin eels can migrate most months of the year except July. Almost two-thirds of successful migration occurs between March and May (Jellyman and Unwin 2017). Longfin eels can migrate downstream via the MLC (the safe passage route) provided discharges at the MLC are not high (Jellyman et al. 2010). Migration via the Waiau Arm has occurred on a flow as low as 4 m^3/s but are likely to occur only when water is flowing in the direct from Lake Manapōuri towards the MLC.

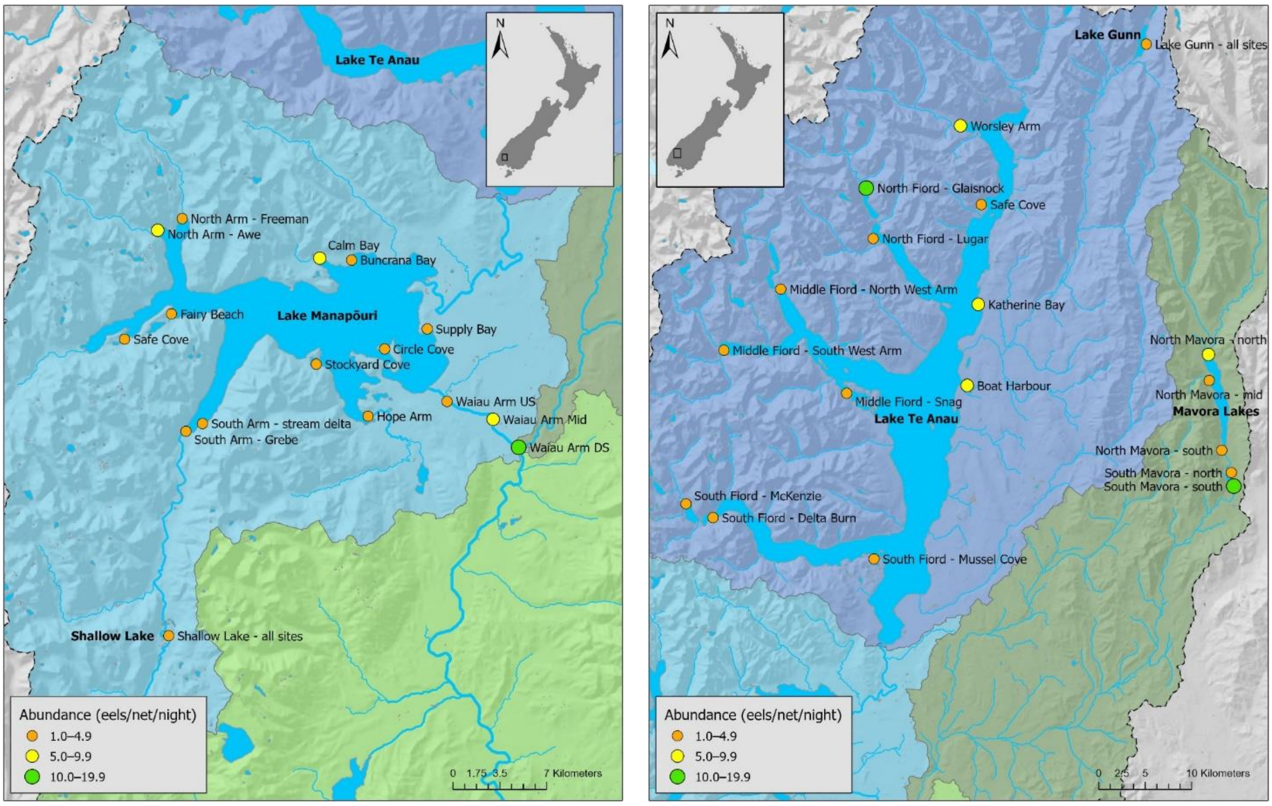


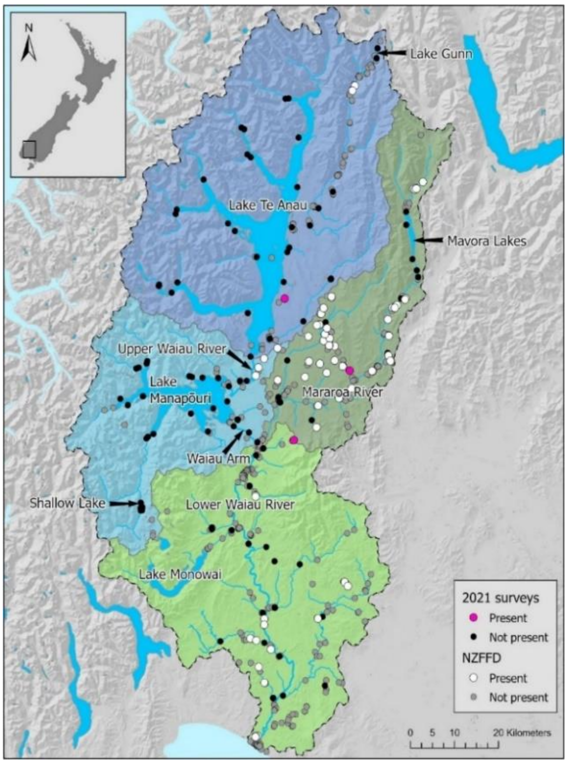
Figure 5-3: Longfin eel catch-per-unit-effort in the Waiau Catchment including the Waiau Arm and Project area.

5.6.3 Non-migratory galaxias species

Two non-migratory galaxias species known from the Waiau catchment are classed as "Threatened – Nationally Vulnerable": the southern flathead galaxias (*Galaxias* "southern") and the Gollum galaxias (*Galaxias gollumoides*). Both are considered to have moderate populations, but with a declining population trend, although both are data poor. The southern flathead also has a restricted range (Dunn et al. 2018).

The Southern flathead galaxiid occurs in stony streams and rivers and shows some preference for cobble and boulder habitats (Sinton et al. 2016). In the Lower Waiau catchment, they are most abundant in smaller tributaries although they are also found below the MLC and further downstream in the Lower Waiau mainstem albeit in low numbers, as they struggle to co-exist with trout (Figure 5-4). They are generally site-attached with little movement (Crow et al. 2009). They spawn in spring (October to November) laying their eggs in saucer-shaped depressions beneath large cobbles or boulders in fast-flowing riffles[18]. The location and extent of their spawning habitats in the Waiau catchment are unknown.

Gollum galaxias are found in the mainstem of the LWR below MLC (Figure 5-5). Spawning takes place in late winter and early spring (late August to October). The eggs are deposited under boulders in streams and on plants in wetlands[19]. They are generally site-attached with little movement (Crow et al. 2009).



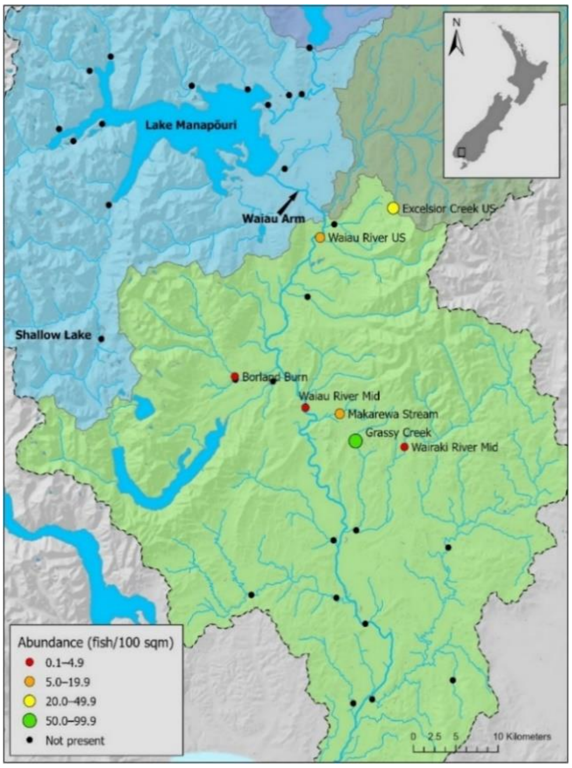


Figure 5-4: Distribution of Southern flathead galaxias in the Waiau Catchment (left) and abundance in the LWR (right).

[18] Southern flathead galaxias: Non-migratory galaxiids (doc.govt.nz)
[19] https://www.doc.govt.nz/nature/native-animals/freshwater-fish/non-migratory-galaxiids/gollum-galaxias/

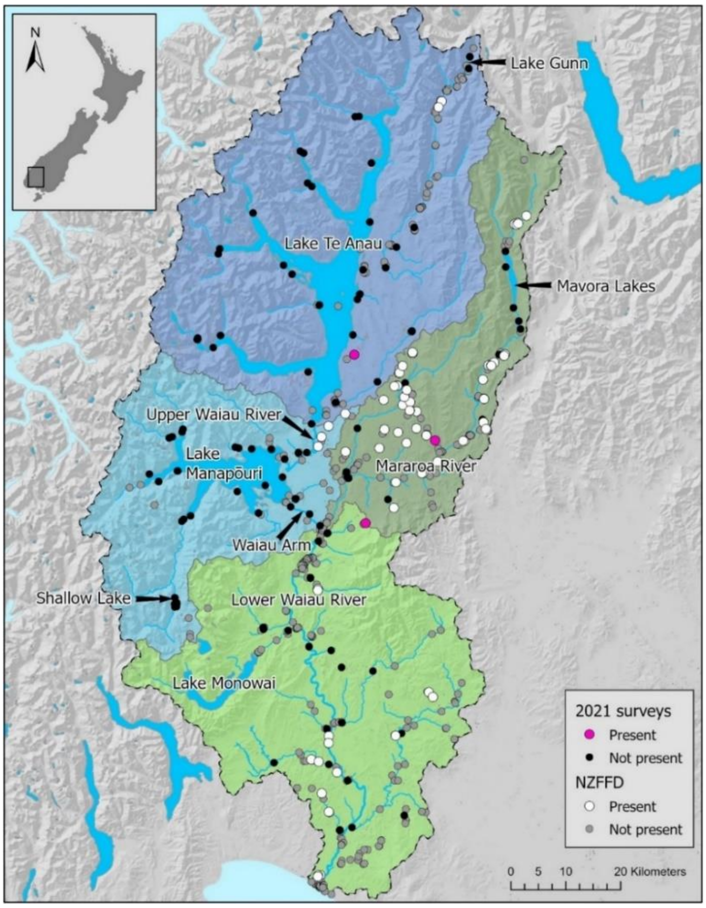


Figure 5-5: Gollum galaxias distribution in the Waiau catchment.

5.6.4 Lamprey

Lamprey/kanakana (*Geotria australis*) have a conservation status of "Threatened – Nationally Vulnerable", with a moderate population, but a declining population trend. The species is considered to be data poor, although the species is "secure overseas" (Dunn et al. 2018).

In the LWR, upstream migration of adult lamprey typically occurs from August–December. Spring is considered the peak migration period, but adult lamprey have also been caught below the MLC in summer (late January; Boubée et al. 2003). The upstream migrations of lamprey are stimulated by increases in stream discharge. Migrations can occur during the day but they occur most often at night. Migrations are linked to receding flood waters and occur on small and large flood flows. The location of adult lamprey habitat is not well known in the Waiau catchment, particularly the extent of any habitat in the main stem of the LWR. However, it is highly likely most adults reside in tributaries. Juvenile lamprey habitat is found at the Mararoa Weir Road bridge ~600 m u/s of MLC in the Mararoa River (Egan et al. 2022b).

5.6.5 Other fish species

Most other native fish species found in the Waiau Arm and LWR have no special conservation status (i.e., Not Threatened, Dunn et al. 2018) (Table 5-5). The non-native perch (*Perca fluviatilis*) is found in the Waiau Arm and Lake Manapōuri.

5.7 Freshwater birds

Information on the bird fauna of the Waiau River catchment is available from periodic formal surveys since the mid-1990s, and from informal observations. Formal surveys include those carried out by the Waiau Trust, Department of Conservation, and Fish and Game. These surveys were summarised by Whitehead (2019), who concluded that the distribution and abundances of freshwater birds of the LWR and Te Waewae Lagoon reflect the availability of suitable habitats. Coastal waders and aerial gulls and terns are most prevalent in the lower reaches of the river, while dabbling water fowl and open water divers are present in areas of deeper, slow flowing water.

The Project area (upstream of MLC) is a known roosting and nesting area for freshwater birds and its freshwater bird community was summarised by Whitehead (2021). Meridian's current consent conditions include measures to avoid disturbance of these birds. In particular, MLC resource consents require that works in the MLC area (e.g., gravel excavation, dam safety protection works) shall not occur during the bird nesting season (15 September to January[20]) if the works would disturb any colonies of birds.. Bird Island at the MLC was created as mitigation to provide vegetation free gravel habitat for roosting and nesting birds.

Whitehead (2021) reported that the bird fauna observed at the MLC is characteristic of South Island freshwater habitats. Twenty freshwater bird species have been identified in the area, including two listed as "At Risk – Declining" and one as "Nationally Endangered" (Robertson et al. 2021). Twelve bird species that are not dependent on freshwater habitats have also been recorded at the MLC. Refer to Appendix D for a list of birds recorded at the MLC.

Black-billed gulls (*Larus bulleri*) are the world's most threatened gull and are currently listed as "At Risk – Declining" in New Zealand (Robertson et al. 2021), reclassified from "Threatened – Nationally Critical" (Robertson et al. 2017) after recent surveys suggested that historical data overestimated the magnitude of population decline. Black-billed gulls utilise braided river habitats for feeding and breeding during the summer, with lake habitats more commonly used in the winter. They typically feed on invertebrates in riverine habitats and adjacent paddocks during the breeding season, migrating to coastal areas in the winter. Black-billed gulls are colonial nesters that primarily breed on sparsely-vegetated gravel bars on inland rivers (McClellan 2009). Colonies often change location and densities from year to year (McClellan and Habraken 2019). An intensive national survey in 2016–17 found approximately 60,000 nests, with the majority of these in Southland and Canterbury, including the Waiau (Mischler 2018). Black-billed gulls are the most abundant freshwater bird species observed at the MLC, with large breeding colonies of up to 3,250 adult birds present in most surveyed years (Whitehead 2021).

Black-fronted terns (*Chlidonias albostriatus*) are endemic and listed as "Nationally Endangered", with qualifiers including a climate effect, and that more research is needed (Robertson et al. 2021). They feed by taking aquatic and terrestrial invertebrates and fish 'on the wing' over riverine habitats, as well as from terrestrial habitats adjacent to the river. They are colonial breeders that predominantly breed on river terraces and gravel bars of braided riverbeds of the eastern South Island. Colonies typically form on non-vegetated, gravel bars. Black-fronted terns have been recorded in low numbers at the MLC in the eBird database but have not been recorded during formal surveys. However, breeding colonies have been recorded at downstream sites in the LWR (e.g., McClelland 2001, 2002).

[20] Consent condition doesn't specify when in January.

Banded dotterels (*Charadrius bicinctus bicinctus*) are listed as “At Risk – Declining” (Robertson et al. 2021), moved out of “Threatened – Nationally Vulnerable” in the previous assessment (Robertson et al. 2017). While a total declining population of approximately 50,000 birds was assessed by Pierce (2013), national wader counts undertaken between 1983 and 2019 (Riegen and Sagar 2020) showed that the rates of decline of banded dotterel were slower than previously feared (O’Donnell and Monks 2020). However, they are still assessed as “conservation dependent” (among other qualifiers) by Robertson et al. (2021). Banded dotterels breed only in New Zealand, with breeding habitat predominantly in riparian areas, river terraces and gravel bars of braided rivers in both the North and South Islands. After breeding, most birds flock together and migrate to coastal New Zealand or Australia for the winter. Banded dotterels preferentially feed in shallow pools and riffles associated with minor channels, typically on sand and fine gravel substrates in water less than 10 mm deep. They also feed in terrestrial habitats. Banded dotterels have been recorded at the MLC in low numbers (six or fewer) in the eBird database but have not been recorded during formal surveys. They are also present elsewhere in the LWR in low numbers (e.g., Sagar 1994; McClelland 1996).

Most other freshwater bird species known from the LWR and the Project area around the MLC have a threat status of “Not threatened” (see Appendix D). Two birds (the Black shag and Little shag) are classified as “At Risk – Relict”, which means a species’ range is considerably reduced from its original range. These open water divers have been recorded in most formally surveyed habitats in the Waiau River catchment, except downstream in the Clifden to Tuatapere reach (Whitehead 2021).

6 Actual and potential effects

6.1 Summary of actual and potential effects

6.1.1 Water quality

The predominant effect of the Project on water quality is expected to be on water clarity due to increased suspended sediment. Increased suspended sediment may lead to a slight increase in water temperature (as suspended sediments absorb heat energy) and small changes in dissolved oxygen (due to a decrease in photosynthesis by aquatic plants). Depending on the chemistry of the sediments, pH may also be slightly altered. In terms of nutrients, an increase in suspended sediment is likely to increase phosphorus concentrations in the river. Most of the additional phosphorus would be total phosphorus, and therefore generally biologically unavailable. Each of these potential changes is expected to be minor, temporary and within the range of natural variation.

6.1.2 Plant communities

Operations in the Project area will temporarily destroy habitat for macrophytes and periphyton. The predicted effect is considered to be minor because the communities will gradually recover following the Project and the plant communities encountered in this part of the Waiau Arm do not have any special ecological values.

In the LWR, elevated SSC and DFS are expected to affect the periphyton community primarily through growth reduction (because of reduced light from decreased water clarity and direct smothering by sediment), followed by increased potential for sloughing of existing periphyton mats. Given the existing state of periphyton in the LWR (i.e., frequent nuisance growths in summer) and the relatively short duration of potentially elevated sediment inputs, these effects can be considered less than minor.

6.1.3 Macroinvertebrates

Macroinvertebrates present within the breakout areas (which may include low densities of kākahi) will be temporarily destroyed through turnover of the substrate at the time of the excavations in those areas. Macroinvertebrates downstream of the Project area will potentially be affected by both suspended and deposited sediments, as entrained sediments drop out of suspension with varying flows. High levels of turbidity and increased sediment deposition may result in increased drift, with some taxa moving downstream. Reduced light penetration is expected to limit periphyton growth, which will reduce food availability for some macroinvertebrates, while the settling and incorporation of sediment into periphyton mats may also reduce food quality. The deposition of fine sediment has a greater effect on benthic macroinvertebrates than suspended sediments, primarily through habitat alteration and reduction in food availability and quality. These effects are expected to be temporary as the key sediment generating phase of the Project is expected to last only five to seven weeks. Effects are likely to be greatest closest to the MLC (depending on flow conditions), where DFS cover can already be high at times, and the DFS will gradually move downstream as it is remobilised by flow events. The effects for aquatic macroinvertebrates are assessed as minor on the above basis.

6.1.4 Freshwater fish

Considering known freshwater fish species distributions in the Waiau catchment, as well as expected sensitivities to elevated fine sediment, the greatest effects of the Project are likely to be on salmonids (brown trout and rainbow trout) and longfin eel. Species that might be at risk from elevated sediment in the LWR include Southern flathead galaxias and Gollum galaxias.

The effects of additional DFS to salmonid spawning grounds is considered negligible because most spawning will occur in tributary headwaters. In low flow conditions, elevated suspended sediment may impede migration of trout aggregating at the confluence of the Mararoa River and Waiau Arm, which would be expected between May and July. This effect is likely to be minor given the expected relatively short duration (five to seven weeks) of instream excavation (for breakout areas).

Effects on longfin eels are possible due to increased SSC and DFS near the MLC. Suggested mitigation during the Project is for migrant adult eels captured in Lake Manapōuri as part of the trap-and-transfer programme to be released further downstream (i.e., not directly below MLC).

Non-migratory galaxias species, such as the Southern flathead galaxias and the Gollum galaxias, are regarded as highly sensitive to increased fine sediment levels. Both are found in the LWR below the MLC, although they are rare. Potential effects are more likely at low flows.

Perch are found in the Waiau Arm and Lake Manapōuri. Perch are considered resilient to increased sediment levels and we do not expect any negative effects on this species.

Overall, we consider that, as long at the suspended sediment and DFS thresholds are adhered to, the effects of the Project will be less than minor for lamprey and minor for other fish species.

6.1.5 Freshwater birds

While high turbidity and low VC due to high levels of suspended sediment could negatively affect freshwater bird species (through altering or reducing food availability), freshwater birds are mobile and individuals would likely move away from the area for the duration of the Project if the effects are too great. Carrying out the excavations during the breeding season (September to January) would be most problematic, particularly if there are any black-billed gull colonies nearby. Effects outside of the breeding season should be less than minor.

6.2 Water quality

The predominant effect of the Project on water quality is expected to be on water clarity due to increased suspended sediment. The sediment generation potential is discussed in detail in Section 3.3. The potential effects of increased suspended sediment on other water quality variables is discussed here. The follow-on effects of potential changes in water quality on biota are considered to be captured by the effects of the increased sediment and so are not discussed separately.

Suspended sediments absorb heat energy and, therefore, increased suspended sediment may slightly increase water temperatures. This effect is likely to be very small relative to other factors that affect water temperature (e.g., season). Turbidity can reduce light transmission through the water, leading to a decrease in photosynthesis by aquatic plants, consequently affecting dissolved oxygen levels during daylight hours. Again, this effect is likely to be very small relative to other factors that affect dissolved oxygen (e.g., temperature and turbulence).

In terms of nutrients, phosphorus (P) adsorbs easily to fine sediment. Therefore, higher than normal sediment inputs are likely to increase P concentrations in the Lower Waiau River. ES data (Mararoa River at Weir Road[21]) confirms the strong positive correlation (r = 0.8) between turbidity and total phosphorus (TP) at that site. At turbidities that occur about 5% of the time (~50 FNU) median TP is about 10 times median TP across all data (noting data are limited). Dissolved reactive phosphorus (DRP) is the biologically available form of P, however, most of the additional P would be TP and

[21] The ES water quality monitoring site is a different site to the Meridian turbidity monitoring site, and is located just upstream of the Weir Road bridge.

therefore generally biologically unavailable. Biochemical processes within periphyton mats can lead to P adsorbed to trapped fine sediment becoming biologically available and this can stimulate the growth of algae and cyanobacteria under certain conditions (e.g., Wood et al. 2015). The negative effect of low water clarity on periphyton growth (see Section 6.3.2) would likely negate this effect. While the TP concentration increases could be quite high, the effect on river ecology would likely be negligible (compared to the effects of low water clarity). Depending on the chemistry of the sediments, pH may also be slightly altered, but the effect is expected to be negligible. Nitrogen variables are not expected to be noticeably affected by increased turbidity, and the data from Mararoa at Weir Road supports that (i.e., both nitrate-nitrogen and total nitrogen are only weakly correlated with turbidity, $r < 0.4$). We would not expect other variables such as E. coli to be affected by mobilised sediment from the Waiau Arm.

Overall, the predicted effects of the Project on water quality (beyond the direct sediment effects) are considered to be minor, temporary, and within the range of effects expected from natural flood events."

6.3 Plant communities

6.3.1 Waiau Arm

Macrophytes

In the Project area, excavation works will temporarily destroy existing macrophyte communities in affected parts of the wetted channels predominantly at each end of the new channel. We expect that the communities will gradually re-establish as the excavated areas recover from being physically disturbed. Macrophyte communities upstream will provide propagules for recolonisation (de Winton et al. 2022). These direct effects will be confined to the relatively small areas of the upstream and downstream breakout excavations.

In areas affected by suspended sediment from the breakout excavations, the additional suspended and deposited fine material will reduce light penetration through the water column (i.e., VC), thereby reducing photosynthesis (i.e., primary production) in all affected plant cells. Any increase of flow in the Waiau Arm either during or following the excavations will help to clear deposited material, and plants are expected to recover and continue growing.

There may be an effect following the Project because, once the breakout excavations are completed, water velocities are expected to be lower in the Waiau Arm just upstream of the MLC than those experienced in the current channels (Clunie 2023b). The lower water velocities may result in a more favourable environment for macrophyte establishment than at present.

Periphyton

In the relatively small areas directly affected by the Project, existing periphyton communities will be temporarily destroyed by excavation works. We expect that existing thin film communities will gradually re-establish as the disturbed substrate ages. Periphyton communities upstream will provide propagules for recolonisation.

Phytoplankton

Phytoplankton growth will not be affected during the Project. Current concentrations of chlorophyll *a* (representing phytoplankton) are expected to be low, and the Project will not affect this, except that increased turbidity at times may limit phytoplankton growth (through reduced light availability).

Directing all Mararoa River flow down the LWR during the excavation activities may increase the risk of phytoplankton blooms farther upstream in the Arm because there will be no negative flows that increase water velocity (which helps to reduce the risk of blooms, Kilroy 2023). In practice, negative flows in the Arm are lowest during January to April or May (when the Project is likely to occur) (see Table 4). Therefore, the increased risk is likely to be small compared to the risk under typical summer conditions. In any event, Meridian's usual summer monitoring in the Waiau Arm (see Hogsden et al. 2023b) is designed to pick up warning signs of developing blooms. If blooms are detected, mitigation could be implemented (e.g., a flushing flow).

There may be an effect following the Project because, once the breakout excavations are completed, water velocities are expected to be lower in the Waiau Arm just upstream of MLC than those experienced in the current channels (Clunie 2023b). Decreased water velocity in the channels following the Project could increase the risk of development of high levels of phytoplankton in this part of the Waiau Arm (Kilroy 2023). However, this increased risk is likely to be offset by the release of more effective flushing flows during summer than are possible at present, which is the primary reason for the Project. These additional flow releases, in combination with the releases possible currently, will provide a core set of flow events that will, in most cases, reduce and/or delay the risk of phytoplankton blooms developing in the post-Project channels just upstream of the MLC.

6.3.2 Lower Waiau River

Periphyton

Under normal conditions, turbid waters from the Mararoa River occur under high flows, with flows exceeding about 120 m^3/s also having a significant scouring effect on periphyton in the reaches of the LWR immediately downstream of the MLC (e.g., Kilroy 2022). High levels of suspended sediment associated with high flows can cause physical damage or removal of periphyton (and macrophytes) through abrasion or scouring (Lloyd et al. 1987, Davies-Colley et al. 1992, Wood and Armitage 1997, Hoyle et al. 2017).

During the Project, fine sediment inputs may occur at lower flows than typical for high turbidity waters from the Mararoa River. The implications for periphyton of the combination of high turbidity and low VC at lower flows (that may occur during the Project) are that the periphyton will remain in place and reduced light will prevent or reduce rates of photosynthesis and therefore cell growth. The effect becomes more pronounced as the duration of low VC increases. The most noticeable effects of suspended sediment will be in the reaches immediately downstream of the MLC. As the fine sediment is carried down the LWR under low flows, we expect VC to gradually increase, but more fine sediment is expected to settle out of the water column. This fine sediment could accumulate in areas of low water velocity and either become incorporated into or smother periphyton (i.e., become DFS).

Sediment settling out of the water column may be incorporated into periphyton mats (especially into the extracellular polysaccharide matrix produced by diatoms, Jones et al. 2014). Gradual incorporation of fine sediment into periphyton reduces its organic content, which may make the periphyton less palatable as a food source for macroinvertebrates. When sediment is associated with adsorbed phosphorus (which is typically the case), conditions inside periphyton mats may facilitate release of phosphorus in a bioavailable form, which can exacerbate growth of some periphyton taxa (e.g., *Microcoleus,* formerly *Phormidium*, Wood et al. 2015).

Smothering of periphyton with DFS potentially causes death of the cells underneath, which can lead to weakening of the attachments of cells to the river substrate (Jones et al. 2014). The combination of curtailment of algal growth because of low light conditions and excessive deposition of fine sediment can cause periphyton mats to senesce and detach from the bed (i.e., slough). Sloughing is a natural process for periphyton (Bouletreau et al. 2006) but is expected to occur more readily under the influence of fine sediment in both suspended and deposited forms.

The above effects of suspended sediment and DFS on periphyton may increase as the duration of exposure increases but the effects will decrease in a downstream direction. The duration of release of the highest sediment loads (during the upstream and downstream breakout excavations) is expected to be relatively short (five to seven weeks). Furthermore, high cover by DFS has already been observed in parts of the LWR at times and fine sediment is already a prominent component of algal mats (Kilroy et al. 2023 and see Section 6.2 above). The effect of the Project may therefore be to temporarily exacerbate what is already a problem in the river.

The thresholds for SSC and DFS outlined in Section 4 are designed to allow additional sediment inputs that are no more than those experienced naturally by biota in the LWR. Provided the thresholds are adhered to, any temporary effects will lie within the range of natural variability. Following the excavation, the river would be expected to return to its usual state through gradual transport of sediment downstream, especially during large natural and managed flow events that would remove periphyton at the same time.

It is noted that the primary motivation for the Project is to improve conveyance of flushing flows large enough to effectively reduce periphyton cover to levels that better support a healthy benthic ecosystem in the LWR.

6.4 Macroinvertebrates

6.4.1 Waiau Arm

In the small areas directly affected by the Project, existing macroinvertebrate communities (including low densities of kākahi) will be temporarily destroyed through turnover of the substrate. We expect that the communities will gradually re-establish over time, through recolonisation from upstream sources. This direct effect will be confined to the relatively small areas of the upstream and downstream breakout excavations.

6.4.2 Lower Waiau River

Suspended sediment affects benthic macroinvertebrates directly in several ways, including clogging of gills and physical abrasion, reduced feeding efficiency of filter-feeders and increased drift (Ryan 1991, Wood and Armitage 1997, Franklin et al. 2019). Increasing fine sediment loads that promote drift can result in the loss of macroinvertebrates from affected areas and, over time, can contribute to changes in density, diversity, and distribution in communities (Ryan 1991).

Macroinvertebrate community changes associated with increased sediment (both suspended and deposited) include declines in abundance and diversity and shifts in community structure from invertebrate taxa that favour stony substrates (e.g., Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) (EPT)) to more tolerant burrowing taxa (e.g., chironomids and worms) (e.g., Wood and Armitage 1997, Quinn and Hickey 1990, Townsend et al. 2008, Burdon et al. 2013).

The deposition of fine sediment has a greater effect on benthic macroinvertebrates than suspended sediments, primarily through habitat alteration and reduction in food availability and quality (Wood and Armitage 1997, Crowe and Hay 2004). DFS covers or buries substrate and infills interstitial spaces, reducing habitat availability, habitat complexity and suitable substrates for attachment, pupation or feeding. DFS can create habitat for burrowing taxa (e.g., oligochaete worms) and may result in changes in community structure over time (e.g., Rabeni et al. 2005). Periphyton or organic matter (e.g., leaf litter), which are food for macroinvertebrates, can be smothered by fine sediment, reducing food availability, or interfering with feeding. Thin films are the preferred type of periphyton for grazers, such as *Deleatidium* mayflies. The entrapment of fine sediment in periphyton reduces food quality for macroinvertebrates and has been shown to reduce the growth of early instars (Ryder 1989).

We expect a greater effect of DFS during the Project than was detected during the trial excavation (i.e., small 2% increase in cover; Hoyle et al. 2023, and see Section 3). More localised deposits of fine sediment may accumulate in low velocity areas during the proposed excavations in the breakout areas. Effects are likely to be greatest closest to the MLC (depending on flow conditions), where DFS cover can already be high at times. If monitoring of DFS at the Waiau River u/s Excelsior Creek ensures that the long-term (five years) median increases by no more than 20% cover over baseline (as described in Section 4), it is considered that the effects of the Project will generally lie within the range of natural variability.

We consider that any effect of additional DFS from the Project on macroinvertebrate habitat will be temporary. We expect that macroinvertebrates will recolonise from upstream and tributary sources following the Project and that the provision of improved flushing flows following the Project will also help improve benthic habitats by reducing the accumulation of nuisance periphyton and DFS on the substrate.

6.5 Freshwater fish

The expected sensitivity of different freshwater fish species found in the Waiau catchment to elevated suspended sediment is summarised in Figure 6-1. Potential effects of the Project on fish species can be divided into the direct effects of the Project on species in the Waiau Arm and the indirect effects of increased suspended sediment and DFS downstream in the LWR. In general, fish are more likely to undergo sublethal stress from suspended sediments rather than lethal stress. Fish are highly mobile and can avoid high sediment concentrations by moving into unaffected stream reaches (Kemp et al. 2011). Any temporary reductions in macroinvertebrate abundance or diversity caused by increased SSC or DFS could potentially reduce availability of preferred prey for salmonids (i.e., mayflies, stoneflies, caddisflies) or common prey for galaxiids (e.g., mayflies).

Figure 6-1: Expected sensitivity of freshwater fish species found in the Waiau catchment to chronic (long exposure) elevated suspended sediment. Sediment sensitivity information is from Franklin et al. (2019). Red shading denotes species considered most at risk from the Project based on their distribution and sensitivity. Yellow shading denotes species with high sensitivity but the effects are on the LWR populations. ? = unknown.

Species	DOC Threat status	Sensitivity to elevated sediment	Hypothesised mechanism(s)	Expected spatial location of effects from the Project
Longfin eel	At Risk – Declining	Medium	Reduced habitat suitability	In Project area and LWR
Rainbow trout	Introduced and naturalised	High	Reduced habitat suitability, reduced feeding, and growth, reduced spawning success	In Project area and LWR
Brown trout	Introduced and naturalised	High	Reduced habitat suitability, reduced feeding, and growth, reduced spawning success	In Project area and LWR
Chinook salmon	Introduced and naturalised	Not classified	Reduced habitat suitability, avoidance of the reach?	? (Very few records of Chinook salmon distribution in the catchment)
Southern flathead galaxias (non-migratory galaxiid)	Threatened – Nationally Vulnerable	High	Reduced habitat suitability, reduced feeding, and growth	LWR
Gollum galaxias (non-migratory galaxiid)	Threatened – Nationally Vulnerable	High	Reduced habitat suitability, reduced feeding, and growth	LWR
Lamprey	Threatened – Nationally Vulnerable	?	?	Adult lamprey are transitory and migrate via the MLC into the Mararoa Catchment.
Banded kōkopu	At Risk – Declining	High	Avoidance, reduced feeding	LWR
Torrentfish	At Risk - Declining	High	Reduced habitat suitability	LWR
Redfin bully	Not Threatened	High	Reduced habitat suitability	LWR
Upland bully	Not Threatened	High	Reduced habitat suitability	LWR
Bluegill bully	At Risk - Declining	Medium	Reduced habitat suitability	LWR

Species	DOC Threat status	Sensitivity to elevated sediment	Hypothesised mechanism(s)	Expected spatial location of effects from the Project
Common bully	Not Threatened	Low	?	In Project area and LWR
Shortfin eel	Not Threatened	Low	?	In Project area and LWR
Īnanga	At Risk – Declining	High	Reduced feeding and growth	LWR (lower reaches)
Black flounder	Not Threatened	Not classified	?	LWR (lower reaches)
Giant kōkopu	At Risk - Declining	Not classified	?	LWR (lower reaches)
Yellow-eye mullet	Not Threatened	Not classified	?	LWR (lower reaches)
Perch	Introduced and naturalised	Not classified	?	In Project area

6.5.1 Salmonids

The excavation will not directly destroy any salmonid spawning habitat in the Waiau Arm because suitable spawning habitat conditions do not exist there.

Elevated suspended sediment (as well as noise disturbance) will likely induce avoidance behaviour in pre-spawning trout. Presumably they can leave the Project area by swimming upstream or swim up the Mararoa River to reach suitable spawning habitats. However, the extent and/or quality of suitable spawning habitats in the Mararoa River are currently unknown. Movement away from the lower Mararoa River assumes that there is a suitable flow regime to cue movement upstream, which, in other New Zealand rivers, can occur under a diversity of flow conditions (e.g., freshes; Venman and Dedual 2005). There is a risk that in low flow conditions, trout aggregating at the confluence of the Mararoa and Waiau Arm between May and July will be exposed to elevated suspended sediment caused by Project, depending on the timing of the breakout excavation.

Salmonids are considered most sensitive to suspended sediment during the winter as this is when spawning and fry emergence occurs. Avoiding instream activities in winter would reduce effects on salmonids (Espa et al. 2019). Predator avoidance behaviour has also been observed to reduce under conditions of elevated turbidity in juvenile Chinook salmon (*Oncorhynchus tshawytscha*; Gregory 1993), and although juvenile salmon would not be expected to be present, it is unknown whether such behaviour would be replicated by juvenile trout.

DFS can clog the spawning substrates used by benthic-spawning fish species such as salmonids. However, existing DFS cover within salmonid spawning habitats in the Waiau catchment is unknown (Stoffels et al. 2019). Given the little information we have on (a) DFS throughout the river network in Southland, and (b) the spatial distribution of preferred salmonid spawning grounds, we are in a weak position to ascertain potential additive effects from the Project particularly to populations in the LWR. However, we expect any additive effects of DFS to spawning grounds to be negligible as most spawning will occur in the headwaters of any tributaries and the abundance of trout in the LWR is much lower than in the upper catchment (Stoffels et al. 2019).

The NPS-FM (2020)[22] Band D (national bottom line) for the DFS attribute indicates that “sensitive fish species are lost or at high risk of being lost”. Salmonids present in the Waiau Arm might therefore be at risk if conditions reach Band D, although they may also move into adjacent tributaries.

Increased suspended sediment in the Project area may impede a portion of the pre-spawning salmonid population from migrating via the Arm to the Upper Waiau River for spawning. Given that the Project will likely be ongoing for approximately 4–5 months, the main migration season of salmonids is expected to be affected, but in the context of the entire Waiau Catchment population (Stoffels et al. 2019) this effect could be considered negligible, especially as sediment release is expected to be concentrated into the 5–7 weeks when work is carried out at the upstream and downstream breakout areas.

Pre-spawning salmonids (brown trout and rainbow trout) migrate upstream from April through to September (see Appendix A) and use the vertical slot fish way (VSFW) at the MLC for migration at this time. Therefore, any modifications to the flow regime during the Project (e.g., additional flow to flush sediment) may affect fish pass operations and salmonid access to the Upper Waiau and Mararoa catchments. Presumably for fish where passage is blocked at the MLC/VSFW, they would migrate downstream and could enter tributaries for spawning.

6.5.2 Longfin eel

Longfin eels are thought to prefer stream habitat with low levels of DFS (McDowall, 1990). Significant reductions in biomass of resident eels were found because of increased DFS in a New Zealand stream (Holmes et al. 2019). Although longfin elvers showed no avoidance behaviour to very high turbidity levels (1100 NTU), Boubée et al. (1997) recommended that turbidity was limited to 15 NTU to ensure that the upstream migration of key native species was not affected.

Even in highly modified habitats (including the Waiau Arm, which can be considered as highly modified in the Project area), further habitat modifications can reduce instream habitat quality and displace eels. For example, Holmes et al. (2019) found that a 31% increase in DFS (from a mean value of 65%) one year after instream works displaced eels for at least one year. DFS cover in the Waiau Arm is not fully understood and therefore the anticipated effects on longfin eels are difficult to resolve. However, we expect that any further degradation of the instream habitat in the Waiau Arm due to increased DFS may affect longfin eels, particularly under low flow conditions. Increased DFS will reduce existing habitat quality by clogging the interstitial spaces on the stream bed used by juvenile eels, although we suspect that there is little habitat suitable for juvenile eels in the lower Waiau Arm.

We suggest that an appropriate mitigation programme is developed to minimise effects on migrating longfin eels and elvers as well as longfin eels resident in the Waiau Arm. Elver trap-and-transfer activities will be affected if elevated SSC or DFS occur before mid-March but otherwise the elver trapping programme will not be impacted. Therefore, we suggest that instream works do not commence until after mid-March. Migrating adult eels captured in Lake Manapōuri for the trap-and-transfer programme could be released further downstream (i.e., not directly below MLC as presently done) to a location not affected by the Project to minimise any potential effects of increased suspended sediment on migration. We anticipate that larger eels will be more resilient to increased DFS than juvenile eels. High numbers of longfin eels have been found in the Waiau Arm (greatest CPUE of longfin eels in the Waiau catchment, Egan et al. 2022a). Larger eels are generally site-attached and while it is possible that they will move out of the Project area there is much

[22] National Policy Statement for Freshwater Management 2020 Amended February 2023 | Ministry for the Environment

uncertainty in this. Therefore, we suggest that consideration be given to developing a fish salvage programme[23] where practicable and able to be accommodated within the excavation methodology during the instream excavation phase of the Project to minimise direct effects of excavation on longfin eels. Fish salvage would also be beneficial for stranded kākahi (see Section 6.4.1).

6.5.3 Non migratory galaxias species

The highly restricted ranges of non-migratory galaxiids (including the Southern flathead) mean that any changes to their environment can be considered a threat. While almost nothing is known about the effects of suspended sediment and deposited sediment on both Southern flathead and Gollum galaxias, there is potential for DFS to affect spawning habitat. Non-migratory galaxiids are benthic spawning species and DFS likely clogs the interstitial spaces used for spawning (Franklin et al. 2019). However, given that the window in which increased sediment is expected is relatively short, we expect that any effects on the Southern flathead and Gollum galaxias will be minimal. Whilst there are some records of these species from the Lower Waiau mainstem, the larger populations are found in tributary habitats (Figure 5-4, Figure 5-5).

6.5.4 Lamprey

The sensitivity of lamprey to elevated SSC is not known in New Zealand (Franklin et al. 2019), although elevated turbidity is considered a significant stimulus of migration activity.
Based on our understanding of the material to be excavated in the breakout areas, the Project should not have direct effects on juvenile lamprey habitat. We also do not anticipate any effects on juvenile lamprey habitat from any changes in DFS levels because of the Project. Lamprey spawning habitat in the lower Mararoa River will not be affected by the Project. While lamprey spawning habitat is known to occur downstream of the MLC in Excelsior Creek, the ammocoete larval life stage of the lamprey utilise DFS as a key habitat within streams (McDowall 1990). Therefore, existing relatively high DFS and the potential for short-term increases as a result of the Project, is unlikely to have any adverse effect on this life stage in the area of the Waiau River u/s of Excelsior Creek.

6.5.5 Other fish species

Decreased water clarity is known to reduce the feeding rate of adult perch when held in experimental tanks (Estlander et al. 2015), but perch are non-territorial, mobile predators (Eklöv 1992) that are likely to simply move to clearer water to feed. Perch spawning is unlikely to be affected by DFS because they are known to spawn by attaching their egg strands to a wide range of substrates including sand, gravels, aquatic vegetation, and detritus (Čech et al. 2009). We do not expect any negative effects on this species from the excavations.

6.6 Freshwater birds

Freshwater birds are susceptible to disturbance by human activities during the breeding season, such as the movement of heavy machinery associated with the Project. The breeding season for most freshwater birds present at the MLC occurs from September–December (O'Donnell 2000). Highly camouflaged nests and chicks may be crushed by people walking or driving vehicles on the riverbed and birds may abandon nests or colonies if disturbed. Also, chicks may become separated from adults. Breeding success can decline, if brooding adults frequently leave the nest for extended periods of time (O'Donnell et al. 2016). Because freshwater birds are relatively mobile, it is likely that adult individuals would move away from the area for the duration of the Project if the effects are too great. This would be problematic if works were to occur during the spring-early summer

[23] Fish-Salvage-Guidance-for-Works-in-Waterways.pdf (ccc.govt.nz)

breeding season when individuals are sitting on nests or chicks are present. However, it is unlikely to be an issue at other times of the year. For this reason, the Project is only expected to substantially affect freshwater birds if the Project commences in January or extends to September, which coincides with the roosting and nesting season. This is particularly relevant for black-billed gulls as they are the most abundant freshwater bird species observed at the MLC, have a high conservation status, are colonial breeders and can abandon colonies if disturbed.

There is limited information about the effects of suspended sediment on freshwater birds in New Zealand, so this assessment is based largely on expert opinion, with additional evidence from New Zealand coastal birds and international aquatic birds (Hoyle et al. 2022b). High turbidity and low VC, due to high levels of suspended sediment, are likely to negatively affect freshwater bird species through two primary mechanisms:

a. reducing food availability for pursuit and plunge-diving species (e.g., black-billed gulls, black-fronted terns, shags) by reducing their ability to see prey items, and

b. altering prey communities (e.g., changes to macrophyte, macroinvertebrate and fish community composition and/or abundance).

DFS may be an issue for wading species (e.g., dotterels, pied stilts, South Island pied oystercatcher, white-fronted herons) that forage in slow-flowing shallow water if prey availability is affected.

The effects of disturbance and changes in suspended sediment and/or DFS outside the breeding season (i.e., avoiding the period from September to January) are likely to be minimal, with many of the freshwater species observed at the MLC, including the threatened species, migrating outside of the Waiau catchment.

7 Summary and conclusions

7.1.1 Existing environment

Waiau Arm

Flow in the Waiau Arm can be either towards MLC (i.e., its natural direction, positive flows) or towards Lake Manapōuri (i.e., the reverse direction, negative flows). Negative flows occur when Mararoa River water is diverted towards Lake Manapōuri for power generation, once the required minimum flows in the LWR have been provided. Waiau Arm flows towards MLC tend to be lowest in March and April.

Concentrations of suspended sediment in the Waiau Arm in the Project area are generally low because the water originates primarily from Lake Manapōuri. Overall, the Waiau Arm is characterised by high water clarity and low turbidity compared to the Mararoa River.

The current ecological value of the aquatic environment in the Waiau Arm in the Project area is low in terms of aquatic plants and macroinvertebrates. Macrophyte beds are sparse, and all taxa found are also present in greater abundance farther upstream in the Waiau Arm. Periphyton is primarily thin films comprising a few widespread taxa. Macroinvertebrate communities comprise mainly the tolerant taxa *Potamopyrgus antipodarum* (mud snail) and oligochaete worms. However, kākahi (freshwater mussel; conservation status: “At Risk – Declining”) were observed in low abundance in recent surveys. Kākahi are also present farther upstream in the Waiau Arm.

Habitat for fish is limited in the Waiau Arm in the Project area. Pre-spawning salmonids (brown trout and rainbow trout) migrate upstream from April through to September and use the vertical slot fish way (VSFW) at the MLC. Trout (mostly pre-spawning trout) aggregate just above the MLC at the confluence of the Mararoa River and the Waiau Arm. Longfin eels (conservation status: “At Risk – Declining”) are expected to be present within the Project area. Although the highest CPUE of longfin eels was in the Waiau Arm in a survey in 2021, the eels had the poorest body condition in the Waiau catchment, suggesting that densities were too high and/or habitat was poor quality.

The Project area is a known roosting and nesting area for freshwater birds. Meridian’s current consent conditions include measures to avoid disturbance of these birds. In particular, the period 15 September to January is highlighted as a period when maintenance works (e.g., gravel excavation, dam safety protection works) should not occur if the works would disturb any colonies of birds. Twenty freshwater bird species have been identified in and around the Project area, including two (black-billed gull and banded dotterel) that are listed as “At Risk – Declining” and one (black-fronted tern) listed as “Nationally Endangered”. The latter two are also found downstream in the LWR. Large breeding colonies of black-billed gulls are present at the MLC in most years.

Existing ecological values of the Waiau Arm are summarised in Table 7-1.

Lower Waiau River

Flows in the LWR are a combination of water from the Mararoa River and from Lake Manapōuri via the Waiau Arm. The Mararoa River provides much of the minimum flow to the LWR, supplemented by water from Lake Manapōuri when Mararoa River flows are low, especially in the summer months. The proportion of time under minimum flows in the LWR is highest in March and April. Managed flow releases increase flow variability in the LWR in summer, although ability to release large flushing flows for periphyton management has been limited in recent years (to 1.5 per year on average, compared to the four releases that are provided for in Meridian's protocol for the management of nuisance periphyton in the river).

Turbid high flows in the Mararoa River are always passed through to the LWR to prevent turbid water entering Lake Manapōuri. These events add to flow variability in the LWR.

The Mararoa River is the primary source of both suspended and DFS in the LWR, especially the reaches closest to MLC. Turbidity in the Mararoa River just upstream of the MLC has been characterised using a 3.5-year record of high-frequency turbidity observations. The record provides estimates of the proportions of time turbidity exceeds certain thresholds. For example, during high flows (>~100 m^3/s) that occur less than 1% of the time, turbidity typically peaks at ~225 FNU.

Plant communities in the LWR are primarily periphyton dominated by didymo or non-didymo algae, both of which often attain nuisance levels. Excessive periphyton biomass at times in the LWR is managed by Meridian using a programme of flushing flows mentioned above. The ability to release these flushing flows is a key motivation behind the Project. The Project also provides greater ability and certainty to manage and deliver other flow requirements associated with the MPS.

The status of macroinvertebrate communities in the LWR is generally considered moderate to poor, as represented by the MCI with several sites being below or close to the NPS-FM bottom line. The taxa present are common and widespread with no special ecological values.

Trout density in the LWR is approximately 10% of that observed in the Upper Waiau River and there is limited spawning habitat. Trout densities have also declined significantly between 1996 and 2013 in the LWR based on drift-diving survey data. However, the LWR is an important passage for upstream migration of pre-spawning adults, who use the VSFW at the MLC. The LWR is also important for upstream migration of longfin elvers (via the elver trap-and-transfer programme) and downstream migration of adult longfin eels via the MLC (between March and May), provided flows are not high. Two native galaxias species with conservation status "Threatened – Nationally Vulnerable" (the Southern flathead and Gollum galaxias) have been recorded from the LWR.

The freshwater bird species in the LWR are the same twenty species observed in the Project area.

Existing ecological values of the LWR are summarised in Table 7-1.

Table 7-1: Summary of key existing ecological values of the Waiau Arm and Lower Waiau River.

Biotic community	Location	Sub-community	Ecological value (conservation status) of existing community	Notes
Plants	Waiau Arm	Macrophytes	Low, no special status	Dominated by native characean algae, *Elodea canadensis*; both species also present upstream in the Waiau Arm
		Periphyton	Low, no special status	No recent data, but likely to reflect depauperate community reported in 2002, except for addition of didymo from 2004 onwards
		Phyto-plankton	No special status	Phytoplankton blooms currently unlikely
	Lower Waiau River	Periphyton	Low, no special status	Often dominated by didymo (but also other algae), regularly attains nuisance levels. *Microcoleus* (potentially toxic cyanobacterium) also present
Macro-invertebrates	Waiau Arm		Overall low, no special status, except Kākahi (At Risk – Declining)	Primarily snails and worms (tolerant taxa). Low numbers of kākahi (freshwater mussel) in the Project area, and also present upstream
	Lower Waiau River		No special status	NPS-FM bottom line for MCI not met or only just met at sites in the upper reaches downstream of MLC.
Freshwater fish	Waiau Arm, Lower Waiau River	Salmonids	Non-native, therefore no conservation status	Part of nationally significant trout fishery; use fish pass at MLC for upstream migration
		Longfin eels	At Risk – Declining	Trap-and-transfer (adult and elver) programmes in place to manage populations
		Non-migratory *galaxias* spp.	Threatened – Nationally Vulnerable	Data poor
		Lamprey	Threatened – Nationally Vulnerable	Most adults likely to reside in tributaries
Freshwater birds	Waiau Arm (upstream of MLC)		20 species incl.: Black-billed gull, banded dotterel (At Risk – Declining); Black-fronted tern, (Nationally Endangered)	MLC is a known roosting and nesting area, particularly for black-billed gulls. Meridian's current consent condition include measures to protect black-billed gulls, black-fronted terns and banded dotterels in nesting season (15 September to January), preventing works if they would disturb any colonies of birds.
	Lower Waiau River		As at MLC	Species at MLC also seen in Lower Waiau River

7.1.2 Actual and potential effects

Elevated SSC and DFS generated from the Project are the key factors expected to affect biota within the Project area and in the LWR downstream of the MLC. Potential effects are summarised in Table 7-2.

In the Project area, the operations will destroy habitat for macrophytes, periphyton and macroinvertebrates. However, we expect the communities to gradually recover following the Project. The predicted adverse effect is considered to be minor, noting that the benthic communities encountered in this part of the Waiau Arm do not have any special ecological values except for the rare occurrence of kākahi, which also occurs in the unaffected areas upstream.

Elevated levels of suspended sediment generated by the Project will flow into the LWR, affecting both SSC and DFS. Under normal conditions, turbid waters from the Mararoa River occur during high flows. During the Project there is potential for higher than typical SSC to occur at relatively low flows (e.g., minimum flow).

In the LWR, elevated SSC and DFS are expected to affect the periphyton community primarily through growth reduction (because of reduced light from reduced water clarity and direct smothering by sediment), followed by increased potential for sloughing of existing periphyton mats. Given the existing state of periphyton in the LWR (i.e., frequent nuisance growths in summer) and the relatively short duration of potentially elevated sediment inputs, these effects can be considered less than minor.

Another consequence of elevated suspended sediment on periphyton is the flow-through effect on macroinvertebrate communities. Excessive fine sediment reduces the availability of suitable food resources (e.g., thin algal films, a favoured food source of sensitive taxa such as *Deleatidium* may be smothered) while the settling and incorporation of sediment into periphyton mats may also reduce food quality.

The macroinvertebrate communities in the LWR already have moderate to poor status, and increasing fine sediment (both suspended and deposited) may temporarily lead to a further decline in status. High levels of turbidity and increased sediment deposition may also result in increased drift of macroinvertebrates, with some taxa moving downstream. However, the anticipated relatively short duration of elevated SSC and DFS from the Project (five to seven weeks) means that any effect on macroinvertebrate habitat will be temporary. We expect that macroinvertebrates will rapidly recolonise from upstream and tributary sources following the excavation and the overall effect can be considered minor.

Considering known freshwater fish species distributions in the Waiau catchment, as well as expected sensitivities to elevated fine sediment, the greatest effects of the Project are likely to be on salmonids (brown trout and rainbow trout) and longfin eels. Species that might be at risk from elevated sediment in the LWR include Southern flathead galaxias and Gollum galaxias, although they are in low numbers in the LWR.

Any temporary reductions in macroinvertebrate abundance or diversity, which may result from increased DFS, have the potential to reduce availability of preferred prey for salmonids (i.e., mayflies, stoneflies, caddisflies) or common prey for galaxiids (e.g., mayflies). The effects of DFS to spawning grounds is considered negligible because most spawning will occur in tributary headwaters. Pre-spawning trout can show behaviour changes in response to elevated suspended sediment. There is a risk that in low flow conditions, trout aggregating at the confluence of the

Mararoa River and Waiau Arm will be exposed to elevated suspended sediment, which may impede migration if the timing of the breakout excavation occurs between May and July, although any effect is likely to be minor given the expected relatively short duration of instream excavation. In addition to trout, perch are found in the Waiau Arm and Lake Manapōuri. Perch are considered resilient to increased sediment levels and we do not expect any negative effects on this species.

Effects on longfin eels are possible due to increased DFS and SSC around the MLC. Suggested mitigation during the period of the excavation works is for migrant adult eels captured in Lake Manapōuri for the trap-and-transfer programme to be released further downstream (i.e., not directly below MLC).

Non-migratory galaxias species, such as the Southern flathead galaxias and the Gollum galaxias, are regarded as highly sensitive to increased fine sediment levels. Potential effects are more likely at low flows. No effects on juvenile lamprey or lamprey habitat are anticipated from changes in DFS because of the Project.

While high turbidity and low VC due to high levels of suspended sediment could negatively affect freshwater bird species (through altering or reducing food availability), freshwater birds are mobile and individuals would move away from the area for the duration of the Project if the effects are too great. Carrying out the excavations during the breeding season (September to January) would potentially be more problematic (resulting in minor effects), particularly if there are any black-billed gull nesting colonies nearby. Effects outside of the breeding season are likely to be less than minor.

The thresholds for SSC and DFS outlined in Section 3.6 are designed to allow additional sediment inputs that are no more than those experienced naturally by biota in the LWR. Provided the thresholds are adhered to, any temporary effects will lie within the range of natural variability. Following the Project, the river would be expected to return to its usual state through gradual transport of sediment downstream, especially during large natural and managed flow events.

Table 7-2: Summary of expected magnitude of effects of the Project on ecological values in the Project area of the Waiau Arm and LWR.

Community	Location	Sub-community	Expected magnitude of effects	Details
Water quality	Waiau Arm, Lower Waiau River	N/A	Minor	Potential temporary increase in water temperature and change in DO due to increased turbidity. Possible minor change to pH depending on sediment chemistry. Likely increase in TP and DRP associated with an increase in sediment input. Effects temporary (while sediment levels are elevated) and within natural variability.
Plant communities	Waiau Arm	Macrophytes	Minor	Temporary destruction in a small area; recovery expected after Project ends
		Periphyton	Minor	Temporary destruction in a small area; recovery expected after Project ends
		Phytoplankton	Minor	Potential small increased risk of blooms upstream in the Waiau Arm during the Project, but this will be monitored and mitigated under the existing summer programme. Post-Project effect of slightly

Community	Location	Sub-community	Expected magnitude of effects	Details
				increased risk of blooms in area upstream of MLC, but largely mitigated by extra flushing flows facilitated by the Project
	Lower Waiau River	Periphyton	Minor	Temporary exacerbation of an existing DFS problem. No discernible effect of additional DFS or SSC if thresholds are adhered to. Recovery from minor effects expected over time and after high flow events
Macro-invertebrates	Waiau Arm		Minor	Temporary destruction in a small area, with recovery (recolonisation) expected following the Project
	Lower Waiau River		Minor	Most effects from DFS expected in reaches closest to MLC. DFS kept within thresholds likely covers natural variability. Recovery expected (recolonisation) following the Project
Freshwater fish	Waiau Arm, Lower Waiau River	Salmonids	Minor	Minimal direct effects of elevated SSC as fish are mobile, especially if thresholds are adhered to. Minimal risk to spawning habitat as little is available in affected area. Timing of Project may partly coincide with migration times (April to September) but negligible effect in context of whole catchment if sediment release is concentrated into 5–7 week period.
		Longfin and shortfin eels	Minor	Potential effects of SSC and DFS, but can be mitigated by adhering to thresholds, modifying migrant trap-and-transfer programme, developing fish salvage programme during breakout channel excavation phase (where practicable and can be accommodated within the excavation methodology), and ensuring breakout channel excavation does not commence until after mid-March.
		Non migratory galaxiids.	Minor	Species considered to be highly sensitive to elevated SSC, but effect likely to be mitigated if SSC thresholds adhered to.
		Lamprey	Less than minor	Juveniles prefer fine sediment habitat
		Other fish species (e.g., perch)	Nil	
Freshwater birds	Waiau Arm		Less than minor or Minor (timing dependent)	Potential effect of elevated SSC on feeding, but birds will move to better feeding areas. Less than minor effect only if breeding season avoided (September to March), otherwise minor.

Community	Location	Sub-community	Expected magnitude of effects	Details
	Lower Waiau River		Nil	No adverse effects predicted

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Appendix A Key migration periods for native freshwater fish and salmonids present in the Waiau River catchment

Table A-1: Key migration periods for freshwater fish. ↑ = upstream movement, ↓ = downstream movement. An asterisk (*) denotes species/life stages where more research is needed to confirm the migration period[24]. Note, black flounder and yellow-eye mullet are not included as there is very little known about their migration times.

	Freshwater fish			Summer			Autumn			Winter			Spring		
Group	**Common name**	**Species**	**Life stage**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Eels/tuna	Longfin eel	*Anguilla dieffenbachia*	Juvenile	↑	↑	↑	↑								↑
			Adult		↓	↓	↓	↓	↓				↓	↓	
	Shortfin eel	*Anguilla australis*	Juvenile	↑	↑	↑	↑								↑
			Adult		↓	↓	↓	↓							
Lamprey	Lamprey	*Geotria australis*	Juvenile					↓	↓	↓	↓	↓			
			Adult					↑	↑	↑	↑	↑	↑	↑	↑
Galaxiids	Giant kōkopu	*Galaxias argenteus*	Juvenile	↑								↑	↑	↑	↑
			Adult					↓	↓	↓	↓	↓			
	Īnanga	*Galaxias maculatus*	Juvenile	↑	↑	↓	↓	↓				↑	↑	↑	↑
			Adult	↑	↑	↓	↓	↓	↓↑	↑	↑	↑	↑	↑	↑
	Kōaro	*Galaxias brevipinnis*	Juvenile					↓	↓	↓		↑	↑	↑	↑
			Adult*					↓↑	↓↑	↓↑	↓↑				
Bullies	Bluegill bully	*Gobiomorphus hubbsi*	Juvenile	↑	↑	↑	↑								↑
			Adult	↓	↓	↓	↓						↓	↓	↓
	Common bully	*Gobiomorphus cotidianus*	Juvenile	↑	↑	↑	↓							↓↑	↓↑
			Adult					↓	↓	↓		↓	↓		
	Redfin bully	*Gobiomorphus huttoni*	Juvenile	↑	↑	↑	↑								↑
			Adult	↓	↓	↓	↓						↓	↓	↓
	Common Smelt	*Retropinna retropinna*	Juvenile	↑	↑	↑	↓	↓	↓	↓				↓↑	↓↑
			Adult	↑	↑	↑	↓	↓	↓						↑
	Torrentfish	*Cheimarrichthys fosteri*	Juvenile	↓	↓	↓	↓	↓	↓	↓					
			Adult*					↑	↑	↑	↑	↑	↑	↑	↑
Salmonids	Brown trout	*Salmo trutta*	Juvenile												
			Adult					↑	↑	↑	↑				
	Rainbow trout	*Oncorhynchus mykiss*	Juvenile												
			Adult							↑	↑	↑	↑		

[24] https://www.mpi.govt.nz/dmsdocument/7992/direct

Appendix B Estimating rates of exceedance of the proposed turbidity thresholds based on 33 years of flow record (Mararoa at Cliffs)

This Appendix contains background to (a) the method used to estimate the limits of natural exceedance of the specified turbidity thresholds, and (b) the method used to establish the "rule" for determining whether increased DFS in the Waiau River u/s Excelsior Creek is attributable to the Project.

The turbidity data available to support development of the proposed turbidity thresholds was a relatively short time series (~3.5 years) and it is unlikely that the period covered (November 2019 to May 2023) encompassed all of the natural flow variability (and therefore turbidity variability) in the river. The durations associated with the thresholds are intended to fall within the range of natural variability, once average natural turbidity exceedances are included. However, if 2019 to 2023 was a dry period (for example) then the top of the range of natural rates of exceedance could be underestimated. Therefore, an analysis was carried out to get a better understanding of natural flow and turbidity variability in the Mararoa River over a longer timeframe when continuous flow records were available, but not turbidity.

Estimates of variability in turbidity in earlier years (outside the turbidity record) were made by examining 33 years of annual flow statistics calculated from the Mararoa at Cliffs flow record (mean hourly data) from 1990 to 2022 or 1990 to 2023 (see below). The calculation comprised two steps.

Step 1 was to establish links between flow metrics and turbidity thresholds using the available turbidity record (November 2019 to May 2023). Although the relationship between turbidity and flow has high variability (Figure 3-2 in the main report), the data show clear differences in turbidity associated with different ranges of flow (Table B-1).

Assuming that the statistics in Table B-1 apply to all years, under natural conditions:

- Turbidity exceeds 12.4 FNU for about 1% of the time when flows are < 40 m^3/s and about 59% of the time when flows are greater than 40 m^3/s;
- Turbidity exceeds 30 FNU for about 33% of the time when flows are greater than 40 m^3/s;
- Turbidity exceeds 160 FNU for about 6.3% of the time when flows are greater than 40 m^3/s
- Turbidity exceeds 330 for about 5% of the time when flows are between 100 and 200 m^3/s, and about 70% of the time when flows are greater than 200 m^3/s.

Step 2 was to apply the rates of exceedance summarised in Table 5-2 to durations of flow in each flow band (i.e., less than 40 m^3/s, etc. as in Table 5-2) in all years (January to December) from 1990 to 2022 to estimate annual exceedances of the turbidity thresholds.

Rates of exceedance of each of the numeric thresholds in each year are shown in Table B-2, with overall ranges shown at the bottom.

Table B-1: Basic statistics for turbidity in different flow ranges calculated using hourly flow (Mararoa at Cliffs) and turbidity data (Mararoa at Weir Road), November 2019 to May 2023. Values approximately equivalent to the numeric thresholds in Table 3-1 are highlighted. Note that 40 m^3/s is the flow threshold above which turbidity is checked at Weir Road in Meridian's existing consent (to prevent turbid water from entering the Waiau Arm and Lake Manapōuri).

	Turbidity (FNU) under different flow ranges (m^3/s)				
Statistic	**Less than 40**	**40 and over**	**40 – 99.9**	**100 – 199.9**	**200 and over**
Mean	2.4	46.7	21.0	134.8	437.1
Percentiles					
6th	0.7	3.7	3.4	52	223
10th	0.8	4.2	4.0	58	264
20th	1.1	6.1	5.4	70	303
30th	1.3	8.2	6.9	82	333
41st	1.4	12.4	9.5	98	367
median	1.6	16.5	12.5	109	391
66th	2.0	30	19.3	140	437
75th	2.4	44	26	160	513
80th	2.7	58	30	182	574
89th	3.7	106	42	243	665
94th	4.8	160	55	295	769
95th	5.3	197	61	316	814
99th	12.4	433	120	447	960

Table B-2: Estimated hours per year that thresholds were exceeded in the Mararoa River 1990 to 2022. Estimates based on relationships between turbidity and flows. Shaded rows are years with turbidity data.

Year	Mean flow (m^3/s)	Estimated hours per year when turbidity threshold exceeded			
		12.4 FNU	30 FNU	330 FNU	330 FNU
1990	31.5	1545	829	158	26
1991	38.7	1540	826	158	99
1992	28.6	945	487	93	26
1993	31.0	1214	641	122	36
1994	48.0	2343	1283	245	66
1995	44.8	2274	1244	238	47
1996	34.3	1258	666	127	50
1997	32.8	1413	754	144	37
1998	42.6	2181	1191	227	53
1999	30.3	1052	548	105	105
2000	32.1	1331	707	135	26
2001	22.1	680	337	64	31
2002	36.6	1440	769	147	78
2003	30.0	1269	672	128	36
2004	33.4	1261	668	127	26
2005	25.3	595	288	55	29
2006	29.4	974	505	96	36
2007	27.7	1016	528	101	42
2008	24.7	684	339	65	30
2009	29.7	971	503	96	56
2010	34.9	1409	752	144	102
2011	25.2	795	403	77	26
2012	28.1	1133	595	114	51
2013	34.0	1148	604	115	75
2014	31.2	1222	645	123	35
2015	31.0	1280	678	129	26
2016	30.8	1208	637	122	56
2017	21.8	701	349	67	30
2018	34.0	1444	772	147	35
2019	38.7	1567	842	161	75
2020	31.1	1052	548	105	62
2021	32.6	1440	770	147	43
2022	27.5	973	504	96	40
Range:	Minimum	595 (25 days)	288 (12 days)	55 (2 days)	26 (1 day)
	Maximum	2343 (98 days)	1283 (53 days)	245 (10 days)	105 (4 days)

Rule for determining whether increased DFS can be attributed to the Project

During the Project, DFS exceedances in the Waiau River at Excelsior may be caused by the Project or by natural events in the Mararoa. Mitigation of the Project activities should only be required if the DFS exceedance could be attributed to the Project. We undertook an analysis to assess what conditions typically lead to high levels of DFS at the Waiau River u/s of Excelsior Creek. This involved:

- examining the DFS record from Waiau River u/s of Excelsior Creek to identify instances of high DFS (> 20% cover) over the period since there has been a turbidity record at Mararoa River at Weir Road (i.e., since November 2019),
- identifying flow events in the Mararoa in the month preceding those instances of high DFS cover,
- examining the turbidity record for each of those events to identify the duration of turbidity exceedances at the threshold levels already being monitored for the Project (12.4, 30, 160, 330 FNU),
- averaging these durations for each threshold level.

We found that the results were most consistent (narrowest range) for the 30 FNU turbidity threshold level. The average duration of turbidity > 30 FNU that was associated with DFS > 20% cover was 37 hours. Therefore, if DFS in the Waiau River u/s Excelsior Creek exceeds baseline by 20% cover and the Project alone has contributed a turbidity > 30 FNU for 37 hours it is feasible that the Project has caused the increase in DFS.

Appendix C Assessing the impact of mitigation (flushing) flows on reducing the effects of excavation activities on sediment attributes

Continuous turbidity records from the Mararoa at Weir Rd site were used for the purpose of this analysis. Suspended sediment concentration (SSC) and visual clarity (VC) were derived from the turbidity records, as a surrogate measurement, using calibration relationships developed from the trial excavation (i.e., Equation 1 and Equation 2 in the main text of this report). Turbidity data records from November 5, 2019 to September 19, 2023 together with concurrent flow records were used in this analysis.

The primary assumption when assessing the effectiveness of flushing flows as mitigation strategies is that these flows do not carry any sediment. In other words, it is assumed that the sediment concentration in these flows, regardless of their size, is consistently zero, and the same holds true for turbidity levels.

A set of representative flows from the Mararoa River (Q_M) were used in this study. These flows include: 5, 15, 25, 35, 45, 60, 75, 100, 150, and 200 m^3/s.

Flushing flows (Q_F) were ranged from 5 to 50 m^3/s with increments of 5 m^3/s (i.e., Q_F = 5, 10, 15, …, 50 m^3/s). An additional flushing flow of 120 m^3/s was also added to evaluate the effects of these higher flow rates. An evaluation of the absence of flushing flow (i.e., Q_F = 0 m^3/s) was also needed to make a baseline estimate of the effects of the Project on the LWR.

Five hypothetical turbidity scenarios of sediment generation were selected (see Table C-1) to help demonstrate the effect of different sized flushing flows.

Table C-1: Hypothetical scenarios of the excavation activities in terms of the sediment generation shown using SSC (g/m^3), turbidity (FNU) and visual clarity (m).

Turbidity scenario	Turbidity (FNU)	SSC (g/m^3)	VC (m)
1	0	-	-
2	15	11.2	0.86
3	50	37.3	0.41
4	200	149.0	0.18
5	350	260.8	0.13

The following steps were employed to assess the effectiveness of flushing flows as mitigation measures in reducing sediment transport:

Relate Mararoa flow to its relevant SSC for the whole monitoring record, between November 5, 2019 to September 19, 2023 (Figure C-1).

Find average of the Mararoa SSC (SSC_M) for the specified flow from the Mararoa site (Q_M) using the scatter relation developed in the previous step.

Calculate the sediment load by multiplying the Mararoa River flow with a combination of the sediment concentration obtained from step 2 and hypothetical SSCs generated from the Project (SSC_{Exc}), as listed in :

$$\boldsymbol{SSL_{M+Exc}} = \boldsymbol{Q_M} \times [\boldsymbol{SSC_M} + \boldsymbol{SSC_{Exc}}] \quad \text{[g/s]} \qquad \text{Equation D1}$$

Calculate the new SSC after combining the sediment concentration from the Mararoa River (SSC_M) with that from the Project (SSC_{Exc}) and incorporating the flushing flow to assess its dilution effect. The new SSC will be determined by dividing the sediment load resulting from the Mararoa flow and Project (SSL_{M+Exc} as calculated in Step 3) by the sum of the Mararoa flow and the flushing flow:

$$SSC_{M+F+Exc} = \frac{SSL_{M+Exc}}{(Q_M + Q_F)} \quad [g/m^3] \qquad \text{Equation D2}$$

Using the new SSC values determined in this step, turbidity and visual clarity were estimated. These estimates will then be used to assess the effect of the flushing flow on improving sediment conditions in the river (i.e., reducing SSC and turbidity and increasing VC) for different Mararoa flows.

Calculate % reduction on SSC (and turbidity) as a result of releasing flushing flow:

$$\%\, reduction\ of\ SSC = \frac{SSC_M - SSC_{M+F+Exc}}{SSC_M} \qquad \text{Equation D3}$$

The effect of different flushing flows on the reduction of turbidity (and SSC) across a range of Mararoa flows is documented in Table C-2.

The effect of the flushing flows on turbidity due to the Project (assuming a series of Project turbidity scenarios) are provided in Table C-3 to Table C-6. The effect of the flushing flows on the total turbidity due to the Project and Mararoa under the same Project turbidity scenarios are outlined in Table C-7 to Table C-11. The effect of the flushing flows on the VC in the LWR (due to turbidity from the Project and Mararoa) under the same Project turbidity scenarios are outlined in Table C-12 to Table C-16.

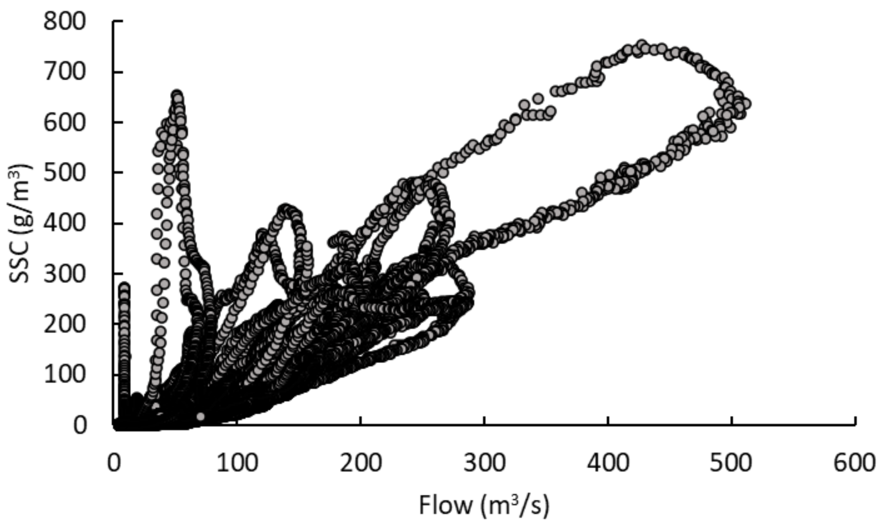

Figure C-1: Relation between flow and SSC for the Mararoa at Weir Rd site.

Table C-2: Proportion reduction of turbidity (or SSC) due to the Project under different flushing flow scenarios.

		Mararoa Flow (m^3/s)									
		5	**15**	**25**	**35**	**45**	**60**	**75**	**100**	**150**	**200**
Flushing Flow (m^3/s)	**5**	50%	25%	17%	13%	10%	8%	6%	5%	3%	2%
	10	67%	40%	29%	22%	18%	14%	12%	9%	6%	5%
	15	75%	50%	37%	30%	25%	20%	17%	13%	9%	7%
	20	80%	57%	44%	36%	31%	25%	21%	17%	12%	9%
	25	83%	62%	50%	42%	36%	29%	25%	20%	14%	11%
	30	86%	67%	55%	46%	40%	33%	29%	23%	17%	13%
	35	88%	70%	58%	50%	44%	37%	32%	26%	19%	15%
	40	89%	73%	62%	53%	47%	40%	35%	29%	21%	17%
	45	90%	75%	64%	56%	50%	43%	38%	31%	23%	18%
	50	91%	77%	67%	59%	53%	45%	40%	33%	25%	20%
	120	96%	89%	83%	77%	73%	67%	62%	55%	44%	38%

Table C-3: Effect of flushing flow on reducing turbidity due to the Project (i.e., excluding turbidity from the Mararoa River) assuming Project generated turbidity of 15 FNU (Scenario 2). The light pink cells highlight instances in which flushing flow reduced turbidity to levels < 12.4 FNU. Whereas white cells indicate instances where turbidity remains above 12.4 FNU.

		Mararoa Flow (m^3/s)									
		5	**15**	**25**	**35**	**45**	**60**	**75**	**100**	**150**	**200**
Flushing Flow (m3/s)	**0**	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	5	7.5	11.3	12.5	13.1	13.5	13.8	14.1	14.3	14.5	14.6
	10	5.0	9.0	10.7	11.7	12.3	12.9	13.2	13.6	14.1	14.3
	15	3.8	7.5	9.4	10.5	11.3	12.0	12.5	13.0	13.6	14.0
	20	3.0	6.4	8.3	9.5	10.4	11.3	11.8	12.5	13.2	13.6
	25	2.5	5.6	7.5	8.8	9.6	10.6	11.3	12.0	12.9	13.3
	30	2.1	5.0	6.8	8.1	9.0	10.0	10.7	11.5	12.5	13.0
	35	1.9	4.5	6.3	7.5	8.4	9.5	10.2	11.1	12.2	12.8
	40	1.7	4.1	5.8	7.0	7.9	9.0	9.8	10.7	11.8	12.5
	45	1.5	3.7	5.4	6.6	7.5	8.6	9.4	10.3	11.5	12.2
	50	1.4	3.5	5.0	6.2	7.1	8.2	9.0	10.0	11.3	12.0
	120	0.6	1.7	2.6	3.4	4.1	5.0	5.8	6.8	8.3	9.4

Table C-4: Effect of flushing flow on reducing turbidity due to the Project (i.e., excluding turbidity from the Mararoa River) assuming Project generated turbidity of 50 FNU. The pink and light pink cells highlight instances in which flushing flow reduced turbidity to levels between 12.4 – 30 FNU and < 12.4 FNU, respectively. Whereas white cells indicate instances where turbidity remains above 30 FNU.

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
	5	25.0	37.5	41.7	43.8	45.0	46.2	46.9	47.6	48.4	48.8
	10	16.7	30.0	35.7	38.9	40.9	42.9	44.1	45.5	46.9	47.6
	15	12.5	25.0	31.3	35.0	37.5	40.0	41.7	43.5	45.5	46.5
	20	10.0	21.4	27.8	31.8	34.6	37.5	39.5	41.7	44.1	45.5
	25	8.3	18.8	25.0	29.2	32.1	35.3	37.5	40.0	42.9	44.4
	30	7.1	16.7	22.7	26.9	30.0	33.3	35.7	38.5	41.7	43.5
	35	6.3	15.0	20.8	25.0	28.1	31.6	34.1	37.0	40.5	42.6
	40	5.6	13.6	19.2	23.3	26.5	30.0	32.6	35.7	39.5	41.7
	45	5.0	12.5	17.9	21.9	25.0	28.6	31.3	34.5	38.5	40.8
	50	4.5	11.5	16.7	20.6	23.7	27.3	30.0	33.3	37.5	40.0
	120	2.0	5.6	8.6	11.3	13.6	16.7	19.2	22.7	27.8	31.3

Table C-5: Effect of flushing flow on reducing turbidity due to the Project (i.e., excluding turbidity from the Mararoa River) assuming Project generated turbidity of 200 FNU (Scenario 4). The dark pink, pink, and light pink cells highlight instances in which flushing flow reduced turbidity to levels between 30 – 160 FNU, 12.4 – 30 FNU, and < 12.4 FNU, respectively. Whereas white cells indicate instances where turbidity remains above 160 FNU.

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0
	5	100.0	150.0	166.7	175.0	180.0	184.6	187.5	190.5	193.5	195.1
	10	66.7	120.0	142.9	155.6	163.6	171.4	176.5	181.8	187.5	190.5
	15	50.0	100.0	125.0	140.0	150.0	160.0	166.7	173.9	181.8	186.0
	20	40.0	85.7	111.1	127.3	138.5	150.0	157.9	166.7	176.5	181.8
	25	33.3	75.0	100.0	116.7	128.6	141.2	150.0	160.0	171.4	177.8
	30	28.6	66.7	90.9	107.7	120.0	133.3	142.9	153.8	166.7	173.9
	35	25.0	60.0	83.3	100.0	112.5	126.3	136.4	148.1	162.2	170.2
	40	22.2	54.5	76.9	93.3	105.9	120.0	130.4	142.9	157.9	166.7
	45	20.0	50.0	71.4	87.5	100.0	114.3	125.0	137.9	153.8	163.3
	50	18.2	46.2	66.7	82.4	94.7	109.1	120.0	133.3	150.0	160.0
	120	8.0	22.2	34.5	45.2	54.5	66.7	76.9	90.9	111.1	125.0

Table C-6: Effect of flushing flow on reducing turbidity due to the Project (i.e., excluding turbidity from the Mararoa River) assuming Project generated turbidity of 350 FNU (Scenario 5). The red, dark pink, and **pink** cells highlight instances in which flushing flow reduced turbidity to levels between 160 - 330 FNU, 30 – 160 FNU, and 12.4 – 30 FNU, respectively. Whereas white cells indicate instances where turbidity remains above 330 FNU**.**

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0
	5	175.0	262.5	291.7	306.3	315.0	323.1	328.1	333.3	338.7	341.5
	10	116.7	210.0	250.0	272.2	286.4	300.0	308.8	318.2	328.1	333.3
	15	87.5	175.0	218.7	245.0	262.5	280.0	291.7	304.3	318.2	325.6
	20	70.0	150.0	194.4	222.7	242.3	262.5	276.3	291.7	308.8	318.2
	25	58.3	131.3	175.0	204.2	225.0	247.1	262.5	280.0	300.0	311.1
	30	50.0	116.7	159.1	188.5	210.0	233.3	250.0	269.2	291.7	304.3
	35	43.8	105.0	145.8	175.0	196.9	221.1	238.6	259.3	283.8	297.9
	40	38.9	95.5	134.6	163.3	185.3	210.0	228.3	250.0	276.3	291.7
	45	35.0	87.5	125.0	153.1	175.0	200.0	218.7	241.4	269.2	285.7
	50	31.8	80.8	116.7	144.1	165.8	190.9	210.0	233.3	262.5	280.0
	120	14.0	38.9	60.3	79.0	95.5	116.7	134.6	159.1	194.4	218.8

Table C-7: Effect of flushing flow on reducing total turbidity (i.e., turbidity from the Mararoa River and Project) assuming no Project generated turbidity (Scenario 1).

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	1.4	1.6	2.4	4.9	8.6	21.9	31.1	66.1	166.8	326.7
	5	0.7	1.2	2.0	4.3	7.8	20.2	29.1	62.9	161.4	318.7
	10	0.5	1.0	1.7	3.8	7.1	18.7	27.4	60.1	156.3	311.1
	15	0.4	0.8	1.5	3.4	6.5	17.5	25.9	57.5	151.6	303.9
	20	0.3	0.7	1.3	3.1	6.0	16.4	24.5	55.1	147.1	297.0
	25	0.2	0.6	1.2	2.9	5.6	15.4	23.3	52.9	142.9	290.4
	30	0.2	0.5	1.1	2.7	5.2	14.6	22.2	50.8	139.0	284.0
	35	0.2	0.5	1.0	2.5	4.9	13.8	21.2	48.9	135.2	278.0
	40	0.2	0.4	0.9	2.3	4.6	13.1	20.3	47.2	131.7	272.2
	45	0.1	0.4	0.9	2.2	4.3	12.5	19.4	45.6	128.3	266.7
	50	0.1	0.4	0.8	2.0	4.1	11.9	18.7	44.1	125.1	261.3
	120	0.1	0.2	0.4	1.1	2.4	7.3	12.0	30.0	92.6	204.2

Table C-8: Effect of flushing flow on reducing total turbidity (i.e., turbidity from the Mararoa River and Project) assuming Project generated turbidity of 15 FNU (Scenario 2).

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	16.4	16.6	17.4	19.9	23.6	36.9	46.1	81.1	181.8	341.7
	5	8.2	12.5	14.5	17.4	21.3	34.0	43.2	77.2	175.9	333.3
	10	5.5	10.0	12.4	15.5	19.3	31.6	40.7	73.7	170.4	325.4
	15	4.1	8.3	10.9	13.9	17.7	29.5	38.4	70.5	165.2	317.8
	20	3.3	7.1	9.7	12.7	16.4	27.6	36.4	67.6	160.4	310.6
	25	2.7	6.2	8.7	11.6	15.2	26.0	34.6	64.9	155.8	303.7
	30	2.3	5.5	7.9	10.7	14.2	24.6	32.9	62.4	151.5	297.1
	35	2.1	5.0	7.3	10.0	13.3	23.3	31.4	60.1	147.4	290.8
	40	1.8	4.5	6.7	9.3	12.5	22.1	30.1	57.9	143.5	284.7
	45	1.6	4.2	6.2	8.7	11.8	21.1	28.8	55.9	139.8	278.9
	50	1.5	3.8	5.8	8.2	11.2	20.1	27.7	54.1	136.3	273.3
	120	0.7	1.8	3.0	4.5	6.4	12.3	17.7	36.9	101.0	213.5

Table C-9: Effect of flushing flow on reducing total turbidity (i.e., turbidity from the Mararoa River and Project) assuming Project generated turbidity of 50 FNU (Scenario 3).

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	51.4	51.6	52.4	54.9	58.6	71.9	81.1	116.1	216.8	376.7
	5	25.7	38.7	43.7	48.1	52.8	66.3	76.0	110.5	209.8	367.5
	10	17.1	31.0	37.4	42.7	48.0	61.6	71.5	105.5	203.2	358.7
	15	12.9	25.8	32.8	38.4	44.0	57.5	67.6	100.9	197.1	350.4
	20	10.3	22.1	29.1	35.0	40.6	53.9	64.0	96.7	191.3	342.4
	25	8.6	19.4	26.2	32.0	37.7	50.7	60.8	92.9	185.8	334.8
	30	7.3	17.2	23.8	29.6	35.2	47.9	57.9	89.3	180.6	327.5
	35	6.4	15.5	21.8	27.5	33.0	45.4	55.3	86.0	175.8	320.6
	40	5.7	14.1	20.2	25.6	31.0	43.1	52.9	82.9	171.1	313.9
	45	5.1	12.9	18.7	24.0	29.3	41.1	50.7	80.1	166.7	307.5
	50	4.7	11.9	17.5	22.6	27.8	39.2	48.7	77.4	162.6	301.3
	120	2.1	5.7	9.0	12.4	16.0	24.0	31.2	52.8	120.4	235.4

Table C-10: Effect of flushing flow on reducing total turbidity (i.e., turbidity from the Mararoa River and Project) assuming Project generated turbidity of 200 FNU (Scenario 4).

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	201.4	201.6	202.4	204.9	208.6	221.9	231.1	266.1	366.8	526.7
	5	100.7	151.2	168.7	179.3	187.8	204.8	216.6	253.4	354.9	513.8
	10	67.1	121.0	144.6	159.4	170.7	190.2	203.9	241.9	343.8	501.6
	15	50.4	100.8	126.5	143.4	156.5	177.5	192.6	231.4	333.4	489.9
	20	40.3	86.4	112.5	130.4	144.4	166.4	182.4	221.7	323.6	478.8
	25	33.6	75.6	101.2	119.5	134.1	156.6	173.3	212.9	314.4	468.1
	30	28.8	67.2	92.0	110.3	125.2	147.9	165.1	204.7	305.6	458.0
	35	25.2	60.5	84.3	102.5	117.4	140.1	157.6	197.1	297.4	448.2
	40	22.4	55.0	77.9	95.6	110.5	133.1	150.7	190.1	289.6	438.9
	45	20.1	50.4	72.3	89.7	104.3	126.8	144.4	183.5	282.1	429.9
	50	18.3	46.5	67.5	84.4	98.8	121.0	138.7	177.4	275.1	421.3
	120	8.1	22.4	34.9	46.3	56.9	74.0	88.9	120.9	203.8	329.2

Table C-11: Effect of flushing flow on reducing total turbidity (i.e., turbidity from the Mararoa River and Project) assuming Project generated turbidity of 350 FNU (Scenario 5).

		Mararoa Flow (m3/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	351.4	351.6	352.4	354.9	358.6	371.9	381.1	416.1	516.8	676.7
	5	175.7	263.7	293.7	310.6	322.8	343.2	357.3	396.3	500.1	660.1
	10	117.1	211.0	251.7	276.1	293.4	318.7	336.3	378.3	484.5	644.4
	15	87.9	175.8	220.3	248.4	269.0	297.5	317.6	361.8	469.8	629.4
	20	70.3	150.7	195.8	225.9	248.3	278.9	300.9	346.7	456.0	615.1
	25	58.6	131.9	176.2	207.0	230.6	262.5	285.8	332.9	442.9	601.5
	30	50.2	117.2	160.2	191.1	215.2	247.9	272.2	320.1	430.6	588.4
	35	43.9	105.5	146.8	177.5	201.7	234.9	259.8	308.2	419.0	575.9
	40	39.0	95.9	135.5	165.6	189.9	223.1	248.5	297.2	408.0	563.9
	45	35.1	87.9	125.9	155.3	179.3	212.5	238.2	286.9	397.5	552.4
	50	31.9	81.1	117.5	146.1	169.9	202.8	228.7	277.4	387.6	541.3
	120	14.1	39.1	60.8	80.1	97.8	124.0	146.6	189.1	287.1	422.9

Table C-12: Effect of flushing flow on increasing total VC (i.e., VC from the Mararoa River and Project) assuming no Project generated turbidity (Scenario 1).

		Mararoa Flow (m^3/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m^3/s)	0	3.59	3.34	2.60	1.68	1.19	0.67	0.54	0.34	0.19	0.13
	5	5.49	3.98	2.91	1.83	1.27	0.71	0.56	0.35	0.20	0.13
	10	7.05	4.57	3.20	1.96	1.35	0.74	0.59	0.36	0.20	0.13
	15	8.41	5.11	3.47	2.10	1.42	0.77	0.61	0.37	0.20	0.13
	20	9.00	5.62	3.73	2.22	1.49	0.80	0.63	0.38	0.21	0.14
	25	9.00	6.10	3.98	2.34	1.56	0.83	0.65	0.39	0.21	0.14
	30	9.00	6.55	4.22	2.46	1.63	0.86	0.67	0.40	0.22	0.14
	35	9.00	6.99	4.45	2.58	1.70	0.89	0.69	0.41	0.22	0.14
	40	9.00	7.42	4.68	2.69	1.76	0.92	0.71	0.42	0.22	0.14
	45	9.00	7.82	4.89	2.80	1.82	0.95	0.72	0.43	0.23	0.14
	50	9.00	8.22	5.11	2.90	1.89	0.98	0.74	0.44	0.23	0.15
	120	9.00	9.00	7.66	4.20	2.65	1.32	0.98	0.55	0.28	0.17

Table C-13: Effect of flushing flow on increasing total VC (i.e., VC from the Mararoa River and Project) assuming Project generated turbidity of 15 FNU (Scenario 2).

		Mararoa Flow (m^3/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m^3/s)	0	0.80	0.80	0.77	0.71	0.64	0.49	0.43	0.30	0.18	0.12
	5	1.23	0.95	0.87	0.77	0.68	0.51	0.44	0.31	0.19	0.13
	10	1.58	1.09	0.95	0.83	0.73	0.54	0.46	0.32	0.19	0.13
	15	1.88	1.22	1.03	0.89	0.77	0.56	0.48	0.33	0.19	0.13
	20	2.16	1.34	1.11	0.94	0.80	0.58	0.49	0.34	0.20	0.13
	25	2.41	1.46	1.18	0.99	0.84	0.60	0.51	0.35	0.20	0.13
	30	2.65	1.57	1.26	1.04	0.88	0.63	0.52	0.35	0.20	0.14
	35	2.88	1.67	1.33	1.09	0.91	0.65	0.54	0.36	0.21	0.14
	40	3.10	1.77	1.39	1.14	0.95	0.67	0.55	0.37	0.21	0.14
	45	3.30	1.87	1.46	1.18	0.98	0.69	0.57	0.38	0.22	0.14
	50	3.50	1.96	1.52	1.23	1.02	0.71	0.58	0.39	0.22	0.14
	120	5.80	3.07	2.28	1.78	1.43	0.96	0.77	0.49	0.26	0.17

Table C-14: Effect of flushing flow on increasing total VC (i.e., VC from the Mararoa River and Project) assuming Project generated turbidity of 50 FNU (Scenario 3).

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	0.40	0.40	0.39	0.38	0.37	0.32	0.30	0.24	0.16	0.12
	5	0.61	0.47	0.44	0.41	0.39	0.34	0.31	0.25	0.17	0.12
	10	0.78	0.54	0.48	0.45	0.42	0.36	0.32	0.26	0.17	0.12
	15	0.93	0.61	0.52	0.48	0.44	0.37	0.34	0.26	0.17	0.12
	20	1.07	0.67	0.56	0.50	0.46	0.39	0.35	0.27	0.18	0.12
	25	1.20	0.73	0.60	0.53	0.48	0.40	0.36	0.28	0.18	0.13
	30	1.32	0.78	0.64	0.56	0.50	0.42	0.37	0.28	0.18	0.13
	35	1.43	0.83	0.67	0.59	0.52	0.43	0.38	0.29	0.19	0.13
	40	1.54	0.88	0.71	0.61	0.54	0.44	0.39	0.30	0.19	0.13
	45	1.64	0.93	0.74	0.64	0.56	0.46	0.40	0.30	0.19	0.13
	50	1.74	0.98	0.77	0.66	0.58	0.47	0.41	0.31	0.20	0.13
	120	2.88	1.53	1.16	0.95	0.82	0.64	0.54	0.39	0.24	0.16

Table C-15: Effect of flushing flow on increasing total VC (i.e., VC from the Mararoa River and Project) assuming Project generated turbidity of 200 FNU (Scenario 4).

		Mararoa Flow (m³/s)									
		5	15	25	35	45	60	75	100	150	200
Flushing Flow (m³/s)	0	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.14	0.12	0.10
	5	0.26	0.21	0.19	0.18	0.18	0.17	0.16	0.15	0.12	0.10
	10	0.34	0.24	0.21	0.20	0.19	0.18	0.17	0.15	0.12	0.10
	15	0.40	0.26	0.23	0.21	0.20	0.19	0.18	0.16	0.13	0.10
	20	0.46	0.29	0.25	0.22	0.21	0.19	0.18	0.16	0.13	0.10
	25	0.52	0.31	0.26	0.24	0.22	0.20	0.19	0.17	0.13	0.10
	30	0.57	0.34	0.28	0.25	0.23	0.21	0.19	0.17	0.13	0.10
	35	0.62	0.36	0.29	0.26	0.24	0.21	0.20	0.17	0.14	0.11
	40	0.66	0.38	0.31	0.27	0.25	0.22	0.21	0.18	0.14	0.11
	45	0.71	0.40	0.32	0.28	0.26	0.23	0.21	0.18	0.14	0.11
	50	0.75	0.42	0.34	0.29	0.27	0.24	0.22	0.19	0.14	0.11
	120	1.24	0.66	0.51	0.42	0.37	0.32	0.28	0.24	0.17	0.13

Table C-16: Effect of flushing flow on increasing total VC (i.e., VC from the Mararoa River and Project) assuming Project generated turbidity of 350 FNU (Scenario 5).

		Mararoa Flow (m^3/s)									
		5	**15**	**25**	**35**	**45**	**60**	**75**	**100**	**150**	**200**
Flushing Flow (m^3/s)	**0**	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.10	0.08
	5	0.19	0.15	0.14	0.13	0.13	0.12	0.12	0.11	0.10	0.08
	10	0.24	0.17	0.15	0.14	0.14	0.13	0.13	0.12	0.10	0.08
	15	0.29	0.19	0.16	0.15	0.14	0.14	0.13	0.12	0.10	0.09
	20	0.33	0.21	0.18	0.16	0.15	0.14	0.13	0.12	0.10	0.09
	25	0.37	0.22	0.19	0.17	0.16	0.15	0.14	0.13	0.11	0.09
	30	0.40	0.24	0.20	0.18	0.17	0.15	0.14	0.13	0.11	0.09
	35	0.44	0.26	0.21	0.19	0.17	0.16	0.15	0.13	0.11	0.09
	40	0.47	0.27	0.22	0.19	0.18	0.16	0.15	0.14	0.11	0.09
	45	0.50	0.29	0.23	0.20	0.18	0.17	0.16	0.14	0.11	0.09
	50	0.53	0.30	0.24	0.21	0.19	0.17	0.16	0.14	0.12	0.09
	120	0.88	0.47	0.36	0.30	0.27	0.23	0.21	0.18	0.14	0.11

Appendix D Bird species observed at the Manapōuri Lake Control

Table D-1: Freshwater bird species observed in the Project area. Species are ordered by family, threat status and common name, with data based on a compilation of observations from eBird and formal surveys undertaken by the Department of Conservation, McClelland (McClelland 2001, 2002) and NIWA in 2020. Nomenclature and threat status from Robertson et al. (2021). Species typically associated with freshwater habitats (FWater) and those observed at the MLC during formal surveys (Survey) are indicated in the two right hand columns. Table adapted from Whitehead (2021).

Family	Common Name	Species	Threat Status	FWater	Survey
Acanthizidae	Grey warbler	*Gerygone igata*	Not threatened		
Accipitridae	Swamp harrier	*Circus approximans*	Not threatened	X	X
Alaudidae	Skylark	*Alauda arvensis*	Introduced & Naturalised		
Anatidae	Australasian shoveler	*Anas rhynchotis*	Not threatened	X	
	Black swan	*Cygnus atratus*	Not threatened		X
	Grey teal	*Anas gracilis*	Not threatened	X	X
	New Zealand scaup	*Aythya novaeseelandiae*	Not threatened	X	
	Paradise shelduck	*Tadorna variegata*	Not threatened	X	
	Canada goose	*Branta canadensis*	Introduced & Naturalised	X	
	Mallard	*Anas platyrhynchos*	Introduced & Naturalised	X	X
Ardeidae	White-faced heron	*Egretta novaehollandiae*	Not threatened	X	
Artamidae	Australian magpie	*Gymnorhina tibicen*	Introduced & Naturalised		
Charadriidae	Banded dotterel	*Charadrius bicinctus bicinctus*	At Risk – Declining	X	X
	Spur-winged plover	*Vanellus miles novaehollandiae*	Not threatened	X	X
Emberizidae	Yellowhammer	*Emberiza citrinella*	Introduced & Naturalised		
Fringillidae	Chaffinch	*Fringilla coelebs*	Introduced & Naturalised		
	Goldfinch	*Carduelis carduelis*	Introduced & Naturalised		
	Redpoll	*Carduelis flammea*	Introduced & Naturalised		
Haematopodidae	South Island pied oystercatcher	*Haematopus finschi*	Declining	X	X

Family	Common Name	Species	Threat Status	FWater	Survey
Hirundinidae	Welcome swallow	*Hirundo neoxena neoxena*	Not threatened		X
Laridae	Black-billed gull	*Larus bulleri*	At Risk – Declining	X	X
	Southern black-backed gull	*Larus dominicanus dominicanus*	Not threatened		X
Phalacrocoracidae	Black shag	*Phalacrocorax carbo novaehollandiae*	At Risk – Relict	X	X
	Little shag	*Phalacrocorax melanoleucos brevirostris*	At Risk – Relict	X	X
Prunellidae	Dunnock	*Prunella modularis*	Introduced & Naturalised		
Recurvirostridae	Pied stilt	*Himantopus himantopus leucocephalus*	Not threatened	X	X
Rhipiduridae	South Island fantail	*Rhipidura fuliginosa fuliginosa*	Not threatened		
Sternidae	Black-fronted tern	*Chlidonias albostriatus*	Nationally endangered	X	
Sturnidae	Starling	*Sturnus vulgaris*	Introduced & Naturalised		
Turdidae	Blackbird	*Turdus merula*	Introduced & Naturalised		
	Song thrush	*Turdus philomelos*	Introduced & Naturalised		