Westpower Limited Proposed Waitaha Hydro Scheme: assessment of environmental effects sediment

Prepared for Westpower Limited

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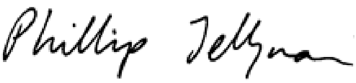	Approved for release by:	Phillip Jellyman

Cover photo: The Waitaha River in flood carrying a high suspended sediment load. Source: Martin Doyle.

Statement confirming compliance with the Environment Court's Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2023

As an expert witness or peer reviewer, I have read, and I am familiar with the Environment Court's Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2023.

I have prepared my, or provided input into, an assessment of effects for the Waitaha Hydro Scheme in compliance with the Code of Conduct and will continue to comply with it in this Fast-track Approvals Act process. In particular:

- my overriding duty is to assist the decision-maker impartially on matters within my expertise;
- unless I state otherwise, my assessment is within my area of expertise, and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express; and
- I have not, and will not behave as, an advocate for the Applicants.

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1 Introduction

Westpower Ltd (**Westpower**) proposes a run-of-the-river hydro-electric power scheme (the Scheme) for the Waitaha River, approximately 60 km south of Hokitika[1] on the West Coast of the South Island, New Zealand.

The Scheme would be a run-of-river design and so will not have instream storage. The proposed Headworks include a low weir and intake structure situated at the top of Morgan Gorge that will divert water into a tunnel and pressurised desander. A pressurised water tunnel will convey the diverted water down to a Power Station below Morgan Gorge. Having passed through the turbines the diverted water will be returned via a tailrace discharging to the Waitaha River mainstem in the vicinity (but upstream) of the confluence of Alpha Creek. The Scheme is to divert up to a proposed maximum of 23 m^3/s, whilst maintaining a minimum residual flow of 3.5 m^3/s immediately downstream of the intake. Diversions will cease during high-flow events when the river flow exceeds 250 m^3/s. The hydro design includes a 10 m^3/s bypass valve to maintain water flow following station outages. The abstraction reach would include approximately 2500 metres of the Waitaha River, including Morgan Gorge. Construction access to the Headworks above Morgan Gorge would initially be via helicopter and/or on foot and then via the access tunnel (once completed), while an access road and transmission line corridor would be required from the Waitaha Valley Road to the Power Station Site to enable a connection to the existing network. Further detail on the project design and project background information as it relates to sediment is set out in **Appendix A**. This information, as well as a description of the project site (**the Site**), is set out in the **Project Description** and the **Project Overview Report**.

Westpower has commissioned an assessment of the potential effects of the Scheme on sediment and sediment transport in the Waitaha River, focussing on the operational phase of the Scheme (**Sediment Report** and **Appendices**).

The report author's qualifications and experience relevant to the Scheme are included in **Appendix B**.

This report considers and assesses the following:

- How the Scheme will change the existing load, transfer, and deposition of sediment within and adjacent to the abstraction reach.
- Effects of maintenance operations at the intake and Macgregor Creek road-crossing, desander flushing, emergency power station shutdowns, and possible flushing flow releases into the abstraction reach on water clarity.
- Effects of the Scheme on the natural Waitaha channel morphology at Kiwi Flat and at the Power Station.
- Geomorphic effects of extracting gravel from the Waitaha braidplain for access road construction.
- How (if necessary) these effects are proposed to be effectively managed.

The scope and approach of this assessment are set out in **Appendix B**.

[1] Measured using local roads and tracks to the Power Station site.

2 Existing Environment

2.1 Waitaha sediment sources, sediment load, and channel bed characteristics

As detailed in **Appendix C**, the Waitaha River is an energetic, flashy mountain torrent draining a steep, highly erodible, schist catchment that experiences tectonic uplift rates averaging several mm/yr and receives rainfall volumes and intensities that rank among the highest in New Zealand. Accordingly, its water runoff and sediment exports per unit catchment area rate amongst New Zealand's highest. The estimated average annual load of suspended sediment passing through Morgan Gorge exceeds 1 million tonnes/yr (9000 t/km^2/yr averaged over the catchment). This represents 0.5% of New Zealand's total annual river suspended sediment load from 0.04% of our land area and would fill Wellington's "Cake Tin" Sky Stadium approximately 1.2 times every year.

The main sources of this sediment load, active during rainstorms, are the very high, steep, bare headwater slopes formed in fissile schist, which has a texture and durability akin to "Weet-bix". These sources feed sediment to the stream network by slips, slides, gullies, and debris flows (**Figure 2-1**). However, landslides that deliver large sediment volumes to the Waitaha Catchment's valley floors can occur anywhere across the catchment. These sometimes temporarily dam the Waitaha River or its tributaries, temporarily trapping sediment until the dam scours away, while the slide scars can "bleed" fine sediment for several years, so landslides can induce wide variability in the sediment load delivered downstream. Snowpack and glacial melt (6.6% of the catchment has permanent ice cover) provide a small residual suspended sediment load and turbidity even at baseflows. The upshot of these erosion and sediment delivery processes is that while there is an overall relationship between suspended sediment concentration (SSC) and flow in the river at Kiwi Flat, the SSC at a given flow can vary over at least a factor of 10, possibly 100, within and amongst runoff events and from year-to-year (**Figure 2-2**).

Seventy-three percent of the suspended load passing Morgan Gorge is transported by discharges greater than 250 m^3/s (which is when the Scheme intake will be closed), and floods peaking higher than 250 m^3/s occur 15 times/year on average. However, even very common smaller floods carry substantial suspended loads (for example, those that reoccur every two weeks on average carry at least 1600 tonnes, and annual floods carry at least 194,000 tonnes).

While suspended load, comprising mud to sand grade fine sediment, dominates the total sediment load entering Kiwi Flat during floods, a significant gravelly bedload, which is augmented by cobbles and boulders during the largest floods, is also transported by the river. The transport of sediment along and out of Kiwi Flat during runoff events is complicated by the narrow, slot entrance to Morgan Gorge. This causes the gorge entry flows to "choke" and form a temporary pond that backs-up sometimes as far upstream as the Whirling Waters confluence. This pond sets the base-level for the channel along the upper part of Kiwi Flat and for Whirling Waters, and the slower velocity through this pond causes mobile gravel and coarser sand grades arriving from Upper Kiwi Flat and Whirling Waters to deposit on delta lobes at its upstream end and as banks along the margins. As the flow wanes after the flood peak, the choking clears as the hydraulic control reverts to the riverbed at the gorge entrance, the water slope and flow velocities towards the gorge increase, the river scours into the lobe and bank deposits, reworking some downstream into the gorge but invariably leaving remnants behind, and the normal flow channel may be relocated from where it was before the flood. Consequences of this dynamic are that (i) the peak transfer of sand and gravel into Morgan Gorge will typically occur after flood peaks and (ii) the channel bed levels of Kiwi Flat and Whirling Waters can naturally fluctuate by several metres and the Waitaha River's normal flow channel can wander across the Flat. This morphological activity will be especially dynamic after 'slugs' of bed material are supplied to Kiwi Flat from upstream slips.

The Waitaha River's bed material at Kiwi Flat ranges from silt through sand, gravel, cobbles, and boulders. Silt and sand typically deposit from suspension on channel margins and in pools on flood recessions. However, even during only slightly turbid baseflows silt can deposit along the channel margins between partly exposed cobbles, transferred from the main flow by lateral diffusion, leaving a sludge that can build-up to several cm thick amongst the cobbles if the baseflow persists for several weeks (**Figure 2-3**). These fine sediments are typically re-entrained by subsequent floods.

Thus, the Waitaha channel at Kiwi Flat naturally exhibits considerable instability due to frequent large floods, high fluxes of bed-material, and transient deposition and re-working of sediment.

Between Kiwi Flat and the proposed powerhouse site (the abstraction reach), the Waitaha River falls first through Morgan Gorge, a slot-gorge cut into bedrock, then flows along a relatively steep, largely boulder-bed reach. The Waitaha River's capacity to transport its largely gravelly-cobbly bedload along this reach is generally greater than the supply of this material from upstream, and the boulders on the bed are lag deposits of low mobility and help to stabilise the channel character.

Figure 2-1: Typical sediment sources in the Waitaha Catchment. Top-left: Debris mantled slopes and gullies in Waitaha headwaters. Top-right: Gully complex and debris chute in County Stream reactivated between September 2016 and January 2018, damming a lake that stalled sediment delivery from Upper County Stream (image: Google Earth). Bottom: View up-valley of the sediment-draped County Glacier issuing turbid meltwater, upper Waitaha.

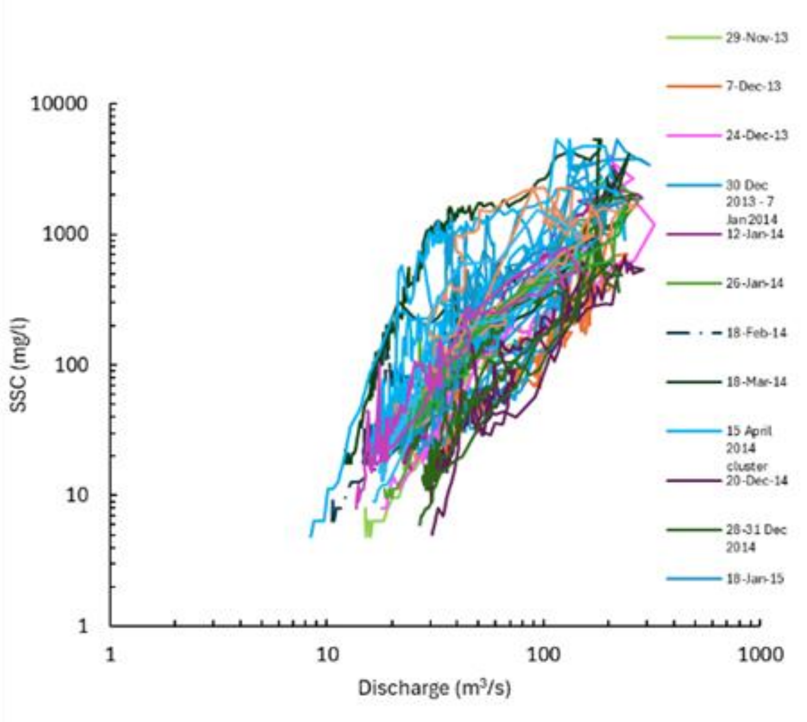

Figure 2-2: SSC vs water discharge relations tracked through runoff events observed at Kiwi Flat over 2013–2015. Note factor-of-100 range in SSC for given discharge.

Figure 2-3: Silty sludge draped over/among channel margin cobbles at Kiwi Flat during baseflow of 8–10 m^3/s that had persisted for at least 23 days in February 2013.

In summary, the Scheme is to be built in a natural environment that experiences, at times, intense but also variable sediment transport rates. The Scheme's design must:

- cope with this dynamic natural environment, as well as
- manage any side effects on the natural processes due to its hard structures and "replumbing" of the river flow and sediment load past the abstraction reach.

This report focusses on the latter.

Further detail of the existing river sediment environment is set out in **Appendix C**.

2.2 Investigations

As detailed in **Appendix D**, investigations focussed on seven topics:

- Collection and analysis of data on river turbidity and suspended sediment load to better quantify the natural suspended load and its variability and size grading and to inform on the Waitaha River's gravel bedload.
- Based on this dataset, estimating the redistribution of the natural sediment load between the Scheme intake and the abstraction reach, and then assessing the risk of fine sediment deposition in the abstraction reach.
- Assessing the risk of sand deposition downstream of the Power Station from desander flushing.
- Assessing the effects on water clarity of channel maintenance operations above the intake weir and at the Macgregor Creek road-crossing, desander flushing, flow transients associated with emergency shutdowns of the Power Station, and possible maintenance flushing in the abstraction reach.
- Assessing the extent of potential aggradation along Kiwi Flat upstream of the intake weir.
- Assessing the likelihood of bank erosion at the Power Station due to channel training.
- Assessing the geomorphic effects of extracting gravel from the Waitaha braidplain for use in access road construction.

2.2.1 River turbidity and sediment load

The core dataset that underpinned the analysis of sediment loads, with and without the Scheme, comprised 8½ months of high-frequency turbidity and water discharge data collected at the upper end of Kiwi Flat during the period 14 Nov 2013 to 7 March 2015. The turbidity record was converted to SSC using a relationship developed from a set of water samples collected over a flood event on 6 March 2015.

This proxied SSC record was then analysed to:

- assess the relationship between SSC and water discharge, overall and during and between individual runoff events over the turbidity monitoring period.
- develop a "sediment rating" function between SSC and discharge to combine with Doyle's (2013) 1973–2012 discharge record at Kiwi Flat to:

- estimate event and average annual suspended sediment loads entering Kiwi Flat for that 39-year period,
- assess the portions of the long-term average load carried by individual flow ranges and during events of given recurrence interval, to ascertain which flows were most important for sediment transport, and
- derive a gravelly bedload record using an empirical relationship between bedload and suspended load derived from the nearby Whataroa River

- derive a record of the load of sand coarser than 300 microns, which is the sand size that the underground desander is designed to trap, using suspended sediment size-grading data from the Hokitika and Haast Rivers (both with similar schist catchments and suspended sediment load to the Waitaha).

2.2.2 Distribution of sediment load at the Scheme intake

The above generated sediment load records for the 1973–2012 period were used to simulate the loads of suspended sediment and bedload that would be discharged into Morgan Gorge and the sand load (coarser than 300 microns) that would be intercepted by the underground desander while the Scheme operates, focussing primarily on periods when the residual flow into the abstraction reach would be steady at 3.5 m^3/s. The splits of water and sediment at the intake are shown schematically in **Figure 2-4**, scaled for an incoming river flow of 35 m^3/s.

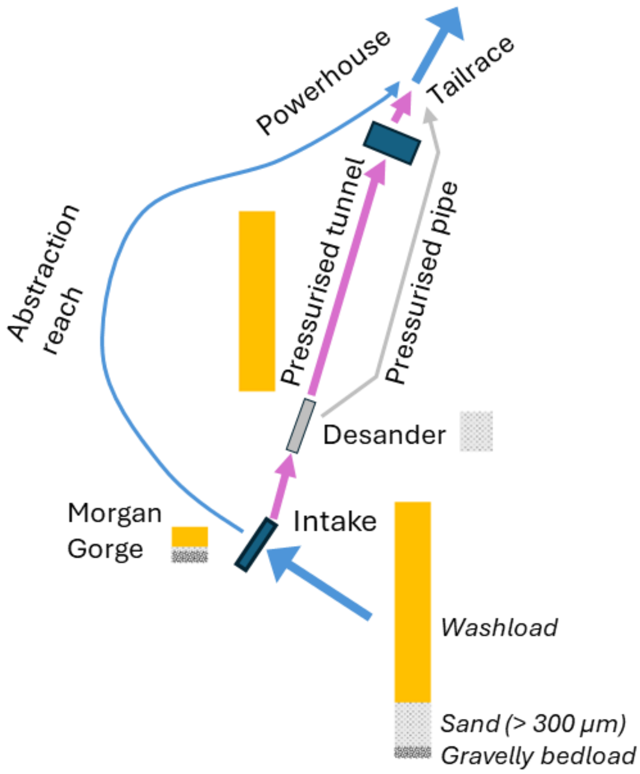

Figure 2-4: Schematic of sediment diversions under normal scheme operating conditions. Scaled for a river flow of 35 m^3/s at the intake site. Vertical bars scale relative amounts of suspended load coarser than 300 microns, finer suspended load (termed "washload"), and gravelly bedload. All bedload is sluiced into Morgan Gorge, while the suspended load is split between the intake and Morgan Gorge in proportion to the flow split. Sand coarser than 300 microns is intercepted by the desander which is periodically flushed to the tailrace, bypassing the Power Station, while the remaining finer fractions of the suspended load pass down the pressurised tunnel and through the Power Station.

2.2.3 Risk of sediment deposition in the abstraction reach

An essential question investigated is the extent to which the diminished flows in the abstraction reach might result in environmentally degrading sediment deposition in the abstraction reach (beyond what is observed naturally during baseflows, e.g., **Figure 2-3**). It is anticipated that any such deposits will be transient because they will be cleared during larger freshes and floods when the abstraction reach will again receive the bulk or all of the total river flow. Thus, the greatest risk will be during extended periods when the flow released to the abstraction reach is steady at 3.5 m^3/s but still carries fine suspended sediment at the concentration arriving at the intake with the natural river flow, plus all of any arriving gravelly bedload.

For fine sediment deposition, a conservative, "first-order" assessment was undertaken by (i) estimating the depth of fine sediment deposition along the littoral zone that would result during extended periods at 3.5 m^3/s, and (ii) deriving a cumulative probability distribution of these event deposition thicknesses. This fine sediment deposition should not occur in the highly turbulent torrent/cascade habitat of Morgan Gorge, but is expected along the relatively lower gradient, approximately 2.2 km long reach immediately upstream from the Power Station.

Based on inspection of wetted channel morphology given in the data of Allen and Hay (2013), it was estimated that fine sediment deposition — when the residual flow is 3.5 m^3/s — would occur over only 16% of the width of *fast run* habitat but over 50% of *slow run* habitat. Other key assumptions included that SSC in the residual flow was the same as that arriving at the intake, a worst case-scenario that all the incoming suspended load passed into Morgan Gorge was deposited evenly along this 2.2 km long river segment, and ignoring the small flow boost from the tributaries that enter the abstraction reach. Assuming a deposited fine sediment bulk density of 1.3 t/m^3, this led to the simple formula that every tonne of suspended sediment discharged into Morgan Gorge during periods of minimum residual flow would result in a sediment drape thickness of 0.06 mm along the marginal zones of the abstraction reach beyond Morgan Gorge.

In the simulations, the residual flow release into Morgan Gorge was assumed as follows:

- the full natural flow if it was less than 3.5 m^3/s or greater than 250 m^3/s;
- 3.5 m^3/s when the natural flow was between 3.5 and 26.5 m^3/s; or
- the natural flow minus 23 m^3/s when the natural flow exceeded 26.5 m^3/s and was less than 250 m^3/s.

While during normal operations, diversions to the Power Station will only cease when the natural flow falls below 3.5 m^3/s, and the analysis has focussed on that scenario, as a sensitivity exercise the analysis was repeated for the case of the Power Station diversions ceasing whenever the natural flow fell below 8.5 m^3/s.

For bedload deposition, the "first order" analysis task was simply to estimate the volumes of bedload sent down Morgan Gorge during events when the flow released to the abstraction reach is steady at 3.5 m^3/s, then estimate what the sediment depth would be if this was all deposited in the first pool below Morgan Gorge. Assumptions applied led to the simple formula that every tonne of bedload discharged into Morgan Gorge during periods of minimum residual flow would result in 0.92 mm of gravel being deposited over the bed of the first pool downstream of Morgan Gorge.

2.2.4 Risk of sand deposition downstream of Power Station from desander flushing

The potential issue is that when sand is periodically flushed into the tailrace from the underground desander, discharging some 250 m^3 of sand over a period of 30–60 minutes (as detailed by the Project engineers), this sand will accumulate in the Waitaha channel immediately downstream of the Power Station. Investigations for this involved estimating the average frequency that desander flushing would be required. Key assumptions were that the sand-diversion design of the intake structure would be 50% efficient while the desander itself would operate with an average trap efficiency of 90%. Comparisons were then made between the flushed sand discharge and the natural sand loads carried by the river during a runoff event of the same frequency and more common events.

2.2.5 Reduced water clarity during maintenance operations at intake and Macgregor Creek road-crossing, desander flushes, possible abstraction reach maintenance flushes, and emergency shutdowns of the Power Station

There are potential water clarity issues linked to five occasional Scheme operations: channel-maintenance works at the intake, maintenance work at the Macgregor Creek road-crossing, flushing the desander, emergency Power Station shutdowns, and flushing fine sediment deposited in the abstraction reach (should that prove necessary as a mitigation measure).

Intake. At the Scheme intake, large floods may, from time to time, deposit gravel that blocks the intake and/or realigns the river channel upstream, impeding the efficient functioning of the intake – particularly if compounded by jams of large woody debris. Such events would require in-channel mechanical works (by excavator and/or bulldozer) to clear the flood-deposited material and/or re-form the gravel training wall that directs flow to the intake. Such in-channel works would release mud bound with the riverbed gravels into the river flow, decreasing the clarity of the water passed into Morgan Gorge. This was investigated by using the 2013–2015 Kiwi Flat turbidity records, using the turbidity vs. water clarity relationship observed in the Haast River as a proxy for the Waitaha River, and assuming gravel working rates of 30–60 m^3/hour at the intake to simulate the changes in water clarity there during a hypothetical channel-maintenance event.

Macgregor Creek road-crossing. The road crossing of Macgregor Creek will comprise a “Hynds Driftdeck” structure (i.e., a concrete ford with a raised deck that the creek passes under at baseflows) set within a low causeway formed of in-situ creek-bed gravel. Like at the Scheme intake, floods down Macgregor Creek will sometimes scour and/or deposit gravel and woody debris at the road-crossing, or even relocate the baseflow channels, necessitating maintenance work by earth-moving machinery. At baseflows, the Macgregor Creek flow occupies one or two narrow braids set within a dry gravelly braidplain some 200 m wide, thus repairing the causeway should often be able to be done in the dry, with no impact on water clarity. However, some in-stream works will typically be necessary around the ford structure, and this will release embedded mud into the Macgregor Creek flow, which will then impact water clarity in the Waitaha River, some 400 m downstream of the road-crossing. This was assessed using much the same approach as used for the maintenance works at the Scheme intake.

Desander flushes. A similar approach was used to estimate the change in water clarity in the river at the Power Station when the desander was flushed and mud embedded with the sand in the desander was resuspended.

Engineered flush of Abstraction reach. The change in water clarity in the Waitaha River immediately downstream of the Power Station during a hypothetical engineered flush of the abstraction reach was also simulated using a similar approach. This used results from the analysis of fine sediment deposition in the abstraction reach during periods of minimum residual flow (described above) to set the mass of fine sediment remobilised, making the conservative assumption that all the sediment deposited during the minimum residual flow event would be remobilised.

Emergency Shutdown. Emergency Power Station shutdowns forced by network outages could occur about four times per year on average and lasting about one hour on average. In such events, the flow into the abstraction reach would increase suddenly while a short phase of reduced flow would translate downstream from the Power Station. The sudden increase in flow through the abstraction reach would scour fine sediment deposited in the abstraction reach, producing a turbid plume much the same as would the engineered flush described above. This was assessed using the same approach as for the engineered flush. Also, calculations were made of the sensitivity of the riverbed shear stress (which determines the river's ability to entrain sediment) in the lower abstraction reach to the rate at which the flow in the reach would be ramped up in an emergency shutdown situation.

2.2.6 Potential aggradation of Kiwi Flat

The potential issue is that the intake weir at the entrance to Morgan Gorge might, by lifting the hydraulic control for flows along Kiwi Flat, cause permanent aggradation (i.e., rise in bed level) along the whole length of Kiwi Flat. This could also cause the bed of Whirling Waters to rise and so change the existing landscape. This is indeed how an ideal and simple alluvial reach of river is expected to respond.

This was assessed by a combination of field observation and 1-dimensional hydraulic modelling undertaken in 2013. The field observations identified evidence (e.g., flat-topped sand bars/terraces) that the Morgan Gorge entrance chokes during flood flows, so the hydraulic modelling sought to confirm this and then evaluate the effect of the Scheme's intake weir. The model was run to simulate water surface profiles at discharges of 10 m^3/s and 1000 m^3/s with and without the intake weir present. The former flow is a typical baseflow and the model run at that flow indicated a reasonable hydraulic calibration. The latter corresponds to somewhere between a 5 and 10-year recurrence interval flood, and the no-weir run produced a water surface profile that aligned with the tops of the sand terraces observed between the Whirling Waters confluence and Morgan Gorge. The weir crest elevation (238 m) and location modelled in 2013 remain current.

2.2.7 Likelihood of bank erosion opposite the Power Station

There are two potential issues. The first is that the Power Station is to be built over, and will seal-off with an armoured floodwall, a natural flood-spill channel which runs along the tussock- and scrub-covered terrace on the Waitaha River right bank immediately upstream from Alpha Creek (**Figure 2-5**). This will concentrate all flood flows down the Waitaha River main channel past the Power Station, potentially causing its left bank to erode. This bank is already prone to erosion but its rate of erosion appears limited by natural armouring. The question is: how much further erosion could be caused by the floodwall?

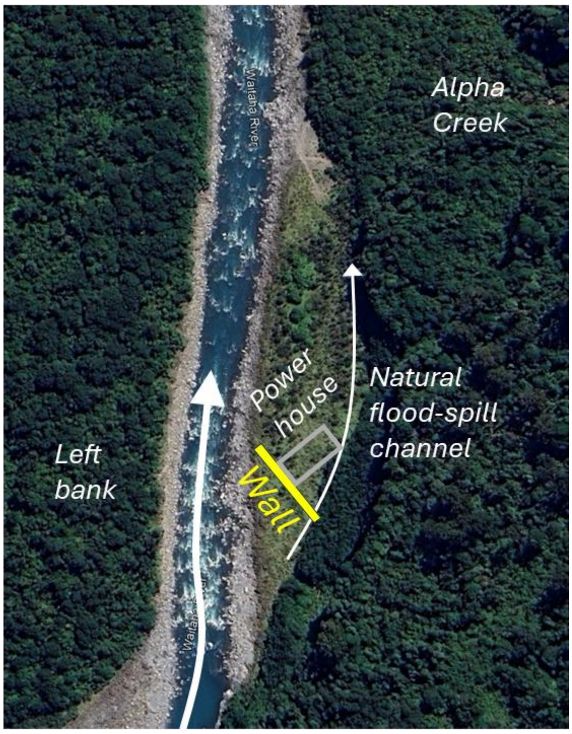

Figure 2-5: Right – schematic showing natural flood-spill channel and floodwall on the terrace where the Power Station will be located. Left – the Waitaha left bank, with a boulder lag on its lower slope.

Previous investigations (Hicks 2014) used a hydraulic model to predict water levels, calculate the flow drag on the banks, and estimate the likelihood of bank boulder entrainment and the potential erosion extent of the left bank, without and with the floodwall. Discharges of 1400 m^3/s and 812 m^3/s were modelled, where the former is something like a 100-year recurrence interval flood discharge and the latter is the estimated size of the mean annual flood (which has a 2.3-year recurrence interval).

The second potential issue is that the aerated water plume produced by the bypass valve at the Power Station (when opened during emergency shutdowns) could scour the opposite bank of the river if in range. No detailed investigations were done however, because the **Project Overview Report** has confirmed that the valve design and down-river plume orientation will mitigate this potential effect.

2.2.8 Geomorphic effects of gravel extraction

The potential issues are that if the proposed gravel volume extracted from the Waitaha braidplain is too large it could alter the local Waitaha channel morphology (and physical habitat) and induce a phase of reduced gravel supply that propagates downstream and even along the coast beyond the river mouth, affecting channel degradation and coastal stability.

Such potential "near-field" and "far-field" effects were investigated by (i) comparing the proposed gravel extraction volumes with estimated average annual river bedload transport rates in the Waitaha, (ii) inspecting historical satellite imagery to compare the size, shape and location of the extraction areas with the natural form and location of the river's bars and braids, and (iii) assessing downstream effects, including the cumulative effects of current gravel-extraction consents along the lower Waitaha channel, using guidelines developed for West Coast Regional Council (Hicks 2017).

Further detail of these investigations, including methodologies, is provided in **Appendix D**.

2.3 Values and significance assessment

Sediment transfer through the river network is a key geomorphological function of the existing environment in the Waitaha Catchment, and the Scheme has the potential to alter this transfer and induce transient and/or localised effects on sediment deposition, water clarity, and channel morphology.

2.3.1 Geomorphic significance

In the first instance and for this report, the geomorphic significance of any such sediment related effect was assessed by comparison with the existing river physical environment, thus:

- transient effects that would be difficult to discern and are well within the bounds of the natural variability observed to date in the Waitaha are graded **less than minor**;
- transient effects that are likely to be visible but still within the bounds of the natural variability observed to date in the Waitaha, or net morphological changes that might be measurable but are spatially limited and do not involve changes in channel form beyond that observed naturally from flood to flood, are graded as **minor**;
- transient effects that may have greater magnitude and/or spatial extent or occur more often than they naturally do are graded as being **potentially more than minor**.

2.3.2 Wider significance

Such sediment-related effects can potentially also impact biodiversity, natural character, and water quality values, all of which are values, the significance of which is considered in the various relevant planning instruments (e.g., the West Coast Regional Policy Statement [WCRC 2020], the Westland District Plan [WDC 2002], the proposed Te Tai O Poutini Plan [TTPP 2022], and the West Coast Conservation Management Strategy [DOC 2010]).

Assessments of the significance of the Scheme's sediment-related effects on biodiversity and water quality are covered in McMurtrie and Grima (2025, the **Freshwater Ecology Report).** For water quality, the relevant sediment-related attribute is water clarity, which is inversely related to the concentration of suspended fine, mud-grade sediment (which also directly influences water turbidity).

The significance of the Scheme's sediment-related effects on natural character are covered by Boffa Miskell (2025, the **Landscape Report**).

3 Environmental Effects Assessment

Seven potential sediment-related effects of the Scheme were assessed:

- The overall, "big picture" effect on sediment transport and channel morphology.
- Transient sediment deposition in the abstraction reach.
- Sand deposition downstream of the Power Station from desander flushing.
- Water clarity reductions associated with intake maintenance works, Macgregor Creek road-crossing maintenance works, desander flushing, any required flushes of fine sediment from the abstraction reach, and emergency shutdowns.
- Kiwi Flat aggradation.
- Bank erosion opposite the Power Station.
- Gravel extraction from the Waitaha channel for access-road construction .

The results and conclusions of the investigations on these potential effects are given below and summarised in **Table 4-1**. Expanded detail is given in **Appendix E**.

3.1 Overall effect on sediment transport and channel morphology

The Waitaha channel at Kiwi Flat naturally exhibits considerable instability due to frequent large floods, high but variable fluxes of bed-material, the choking of Morgan Gorge during floods, and transient deposition and re-working of sediment in response to these drivers. This is evident from abandoned branches (typically perched above the existing channel), terraces and banks of deposited sand and gravel, armoured segments of bed and bank, and places where the channel margins have eroded or are eroding. The Scheme will not alter this suite of natural processes and fluvial features, nor their frequencies of occurrence or physical characteristics.

Along the abstraction reach, bed material transport and channel morphology will also continue to be dominated by the frequent flood regime. The only potential effects are the transient fine sediment deposition during baseflow periods and potential bank erosion stemming from reduced channel conveyance past the Power Station, both of which are assessed below.

Downstream of the Power Station, the Waitaha River will always have its natural flow regime and supply of bedload and suspended load, so no downstream effects relating to permanent interruptions of sediment transport continuity (such as typically occur downstream of a large dam that stores both water and sediment) are anticipated.

It is concluded that generally, the Scheme will have **less than minor** effects on sediment transport processes and channel characteristics along the Waitaha channel, with the potential exceptions at specific locations addressed in the following sections.

3.2 Transient sediment deposition in abstraction reach

Deposits of fine sediment naturally accumulate along the Waitaha channel margin during baseflows and are flushed by the next fresh or flood. There is potential concern that during normal Scheme operations, the incidence and extent of fine-suspended sediment deposition, and also coarse-bedload deposition, will increase in the abstraction reach, particularly during extended baseflow periods when the residual flow will be steady at 3.5 m^3/s.

Using the simulated flow records, assuming the Scheme operated over the 1973–2012 period, there would have been 33 events/year on average when the residual discharge into Morgan Gorge was steady at 3.5 m^3/s for longer than a day (**Figure 3-1**). Most of these events (22 events/year) would have lasted from 1–7 days, with only 11 events/year lasting longer than one week. These longer events typically, but not always, occurred during the winter months. The longest event (June–August 1996) would have spanned just over 10 weeks.

Focussing on those steady-at-3.5 m^3/s events that last longer than one week, simulations showed that the gravelly bedload discharge into Morgan Gorge during such events would range from zero to 3.2 tonnes, which would deposit a layer 0–3 mm thick in the first pool downstream of the Gorge, with half of the events depositing less than 1 mm (**Figure 3-2**). These figures are very small, and even if they are underestimated by a factor-of-10, at worst bedload would produce only a 30 mm thick transient deposit in the first pool. Therefore, gravelly bedload deposition downstream of Morgan Gorge during extended periods of 3.5 m^3/s residual flow should be a **less than minor** effect.

In contrast, the simulations showed that the suspended sediment load entering the abstraction reach during such events would range from 25–254 tonnes and would deposit sediment drapes 2–14 mm thick (assuming all the incoming sediment was deposited uniformly along the abstraction reach). Half of the events (i.e., 5.5 events/yr) would deposit drapes over 5 mm thick but only a quarter of the events (less than 3 events/year) would deposit drapes over 7 mm thick (**Figure 3-2**). The simulations showed that the risk of measurable fine sediment deposits persists regardless of season. While the steady-at-3.5 m^3/s events tended to last longer on average over the winter months (May – September), the sediment loads associated with such events were as high on average during summer as during winter because the average summer inflows were higher, with associated higher SSC.

Repeating the simulations assuming, as a sensitivity exercise, that diversions to the Power Station would cease whenever the natural flow fell below 8.5 m^3/s (rather than below 3.5 m^3/s) made minimal difference to the above figures.

These thicknesses of fine sediment drape are likely to be upper-bound estimates because of the conservative assumptions made, notably that:

- the abstraction reach will trap <u>all</u> the incoming suspended load;
- it will be deposited over only a portion of the channel width; and
- increases in discharge above 3.5 m^3/s by tributaries entering the abstraction reach are ignored.

The effect of these transient fine sediment drapes on biota occupying the channel margins (blue duck, fish, invertebrates, and periphyton) is addressed in the **Freshwater Ecology Report**. In that context, and considering the uncertainty associated with the other assumptions in this report, the **Freshwater Ecology Report** concluded that there is the potential for **more than minor** adverse effects on biota. Thus, it would be prudent to monitor fine sediment accumulation in the lower part of the abstraction reach and to flush any excessive accumulations by temporarily reducing the take to the Power Station. A strategy for this management regime is developed in **Appendix F**.

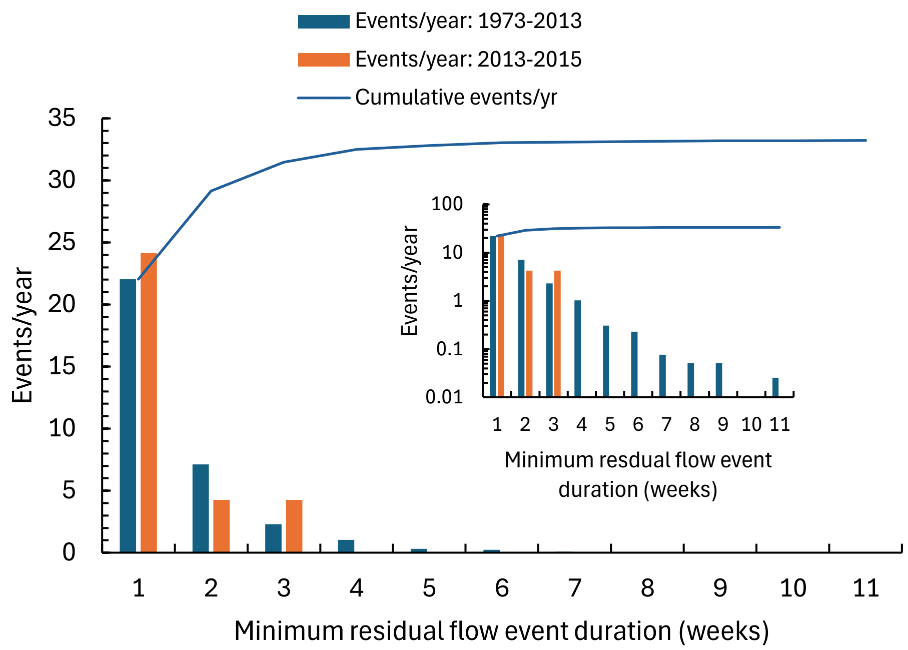

Figure 3-1: Frequency and cumulative distributions of duration of minimum residual flow events when the flow into the abstraction reach would be steady at 3.5 m^3/s. Events lasting less than 1 day excluded. Blue bars and line for 1973–2012 period, orange bars for 2013–2015 period. Inset graph plots same data with event-count on log-scale, highlighting data for events of longer duration. Example: Over 1973–2012, on average there were seven minimum residual flow events/year lasting between one and two weeks and 28 events/year lasting two weeks or less.

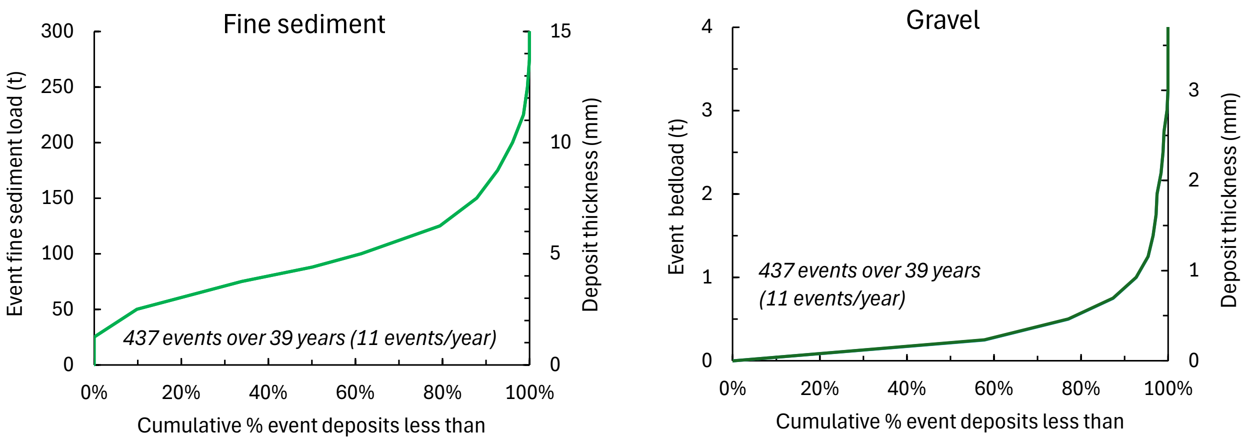

Figure 3-2: Cumulative distribution of suspended sediment and gravel. Left: Cumulative distribution of suspended sediment loads passed into abstraction reach and associated average deposit thicknesses along channel margins for minimum residual flow events lasting longer than one week over period 1973–2013 (when there were 437 such events). Right: Equivalent plot for gravelly bedload passed into abstraction reach and associated average deposit thickness in first pool encountered. Example, left plot: 50% of minimum residual flow events would have suspended sediment loads exceeding 90 t and would produce deposits over 5 mm thick.

3.3 Sand deposition downstream of powerhouse from desander flushing

The Scheme engineers estimate that some 375 t (250 m^3) of sand would be flushed each time the desander is cleared. As detailed in **Appendix E**, the desander sand entrapment analysis indicated that a flush should be required 8.4 times per year (every 6.2 weeks) on average. In comparison, a natural high-flow event of the same frequency as this desander-flushing (peak discharge exceeding 343 m^3/s) would carry a sand load of at least 4120 t. The flushed sand would, therefore, increase this event sand load by no more than 9%. Even events recurring 18.3 times per year (every 2.8 weeks) would carry a sand load at least twice the flushed sand mass. These changes to the natural sand load would be well inside the natural factor-of-10 (possibly 100) variation in suspended sediment load observed at Kiwi flat amongst runoff events (**Figure 2-2**) and would not be beyond the Waitaha River's sand transport capacity at the Power Station Site during such an event. So, provided that desander flushes are done during natural runoff events of adequate size (which are helpfully provided by nature at an adequate frequency on average), significant transient accumulations of sand deposited immediately downstream of the Power Station by desander flushing are unlikely, thus rendering an effect that is **no more than minor**.

3.4 Water clarity changes due to Scheme operations

Water clarity is inversely related to the concentration of suspended fine sediment (and turbidity). A key question is: "Will the Scheme degrade water clarity downstream?"

Because the Scheme is run-of-river, the only potentially noticeable effects on water clarity during normal operations would be during baseflows when the residual flow in the abstraction reach was steady at 3.5 m^3/s. In that state, expected enhanced fine sediment settling from suspension in the "depowered" flow along the abstraction reach would actually increase the clarity of the flow out of the abstraction reach. The tailrace outflow would also be slightly less turbid (by virtue of sediment removal in the desander), thus the combined flows passing downstream would be clearer most of the time.

The Scheme should only reduce water clarity during five aperiodic operations: channel maintenance works at the intake structure after floods, maintenance of the Macgregor Creek road-crossing after floods, desander flushes, during emergency Power Station shutdowns, and during any engineered flow releases along the abstraction reach to flush deposited fine sediment in that reach.

At the intake, it was found that the effect of transient channel works on water clarity into Morgan Gorge would be **minor** relative to the clarity reductions associated with natural freshes and floods; moreover, the effect of such works could be mitigated by limiting the rate of gravel shifting/excavation, working if safe and practical at higher river flows (when the "signal" of the works would be diluted), and minimising machine operation in-channel when possible.

Similarly at the Macgregor Creek road-crossing, the effect of maintenance works on water clarity in the Waitaha River downstream of the Macgregor Creek confluence would be **minor** relative to the clarity reductions associated with natural freshes and floods, particularly after limiting machine earth-moving rates and minimising in-channel operations whenever possible.

Similarly also, allowing that desander flushes occur during natural runoff events, the relative changes in water clarity in the river at the tailrace during desander flushes are expected to be **less than minor**. This is by virtue of the changes being hard to discern visually because of the high ambient suspended mud load of the river during the flushing event and the estimated low proportions of mud in the sediment trapped in the desander. The flushed sand itself should have low impact on water clarity because the sand coarser than 300 microns that is targeted by the desander has much less impact on water clarity than does suspended mud.

Regarding engineered flushes of fine sediment deposits in the abstraction reach (should such deposits occur at all to any significant extent), the effect of such flushes on downstream water clarity in the Waitaha River would be well within the bounds of water clarity changes experienced more frequently during natural runoff events and are therefore regarded as **minor**.

A rapidly ramped-up flow into the abstraction reach associated with an emergency shutdown of the Power Station should have a similar effect on fine sediment remobilisation from the abstraction reach as would an engineered flush. Indeed, the worst emergency shutdown case (in terms of relative increase in abstraction reach inflow), with the abstraction reach inflow increasing from 3.5 m^3/s to 16.5 m^3/s (with the bypass valve passing 10 m^3/s), is much the same as in the hypothetical flushing example of 15 February 2014 shown in **Figure E-7** (where the inflow increases from 3.5 to 14 m^3/s). In that context, the effect of an emergency Power Station shutdown on the river's water clarity would be no worse than experienced during an engineered flush of the abstraction reach and would be relatively insensitive to the flow ramping rate associated with the shutdown. Thus, the water clarity changes experienced with an emergency shutdown should also be **minor**.

3.5 Kiwi Flat aggradation

Field observations indicate that Kiwi Flat exhibits a more complex hydraulic and sedimentation behaviour than would a typical alluvial reach, due mainly to the constricting effect of the narrow entrance to Morgan Gorge which sets the hydraulic control for flood flows along the lower section of Kiwi Flat.

Hydraulic modelling at 1000 m^3/s without the weir in place confirmed this field-based appreciation, showing a choked backwater water surface profile extending some 700 m upstream (almost as far upstream as Whirling Waters) and aligning with the elevations of the recently deposited sand banks (**Figure 3-3**). Re-running the model with the weir in place made no difference to the 1000 m^3/s flood profile. This arises because during floods the weir will be submerged in the backwater reach upstream of the control point that occurs in the gorge throat. Thus, the weir at its proposed location and with its proposed profile would have **less than minor** impact on river processes during large floods along Kiwi Flat.

The weir's only impact would be developed at lower flows when the weir would set the hydraulic control at the gorge entrance. Under those conditions, the weir would initially create a backwater that would extend about 200 m upstream (**Figure 3-3**). The short pond created by the weir would have only a few thousand m^3 of storage, thus it would fill with cobbly-gravel material quickly, possibly over the first small high-flow event or flood recession. At that stage, assuming this deposit formed with a slope of 7.7 m/km (which is the surveyed riverbed slope along the alluvial segments of Kiwi Flat), then the re-graded riverbed profile would intersect the natural riverbed profile about 300 m upstream from the weir (**Figure 3-3**). Thus, this would be the likely upstream extent of the weir's influence on channel morphology at flows when the gorge does not choke. Moreover, downstream of Whirling Waters the Waitaha River at normal flows occupies a relatively narrow (30–60 m wide) channel that wanders between the high, flood-formed gravel bars and sand banks, so the width of the bed-level regrading would be confined to the relatively narrow and incised normal flow channel.

Since these effects would be limited spatially to within a few hundred metres upstream of the weir and would be small compared with the natural morphological variability associated with large, gorge-choking floods and erratic sediment supplies, it is concluded that overall, the effects of the weir on channel form and behaviour at Kiwi Flat would be **minor**.

Future LiDAR surveys of Kiwi Flat, repeated on a 5–10 yearly basis, would verify this projection when compared with the LiDAR survey of Kiwi Flat that was done in November 2024.

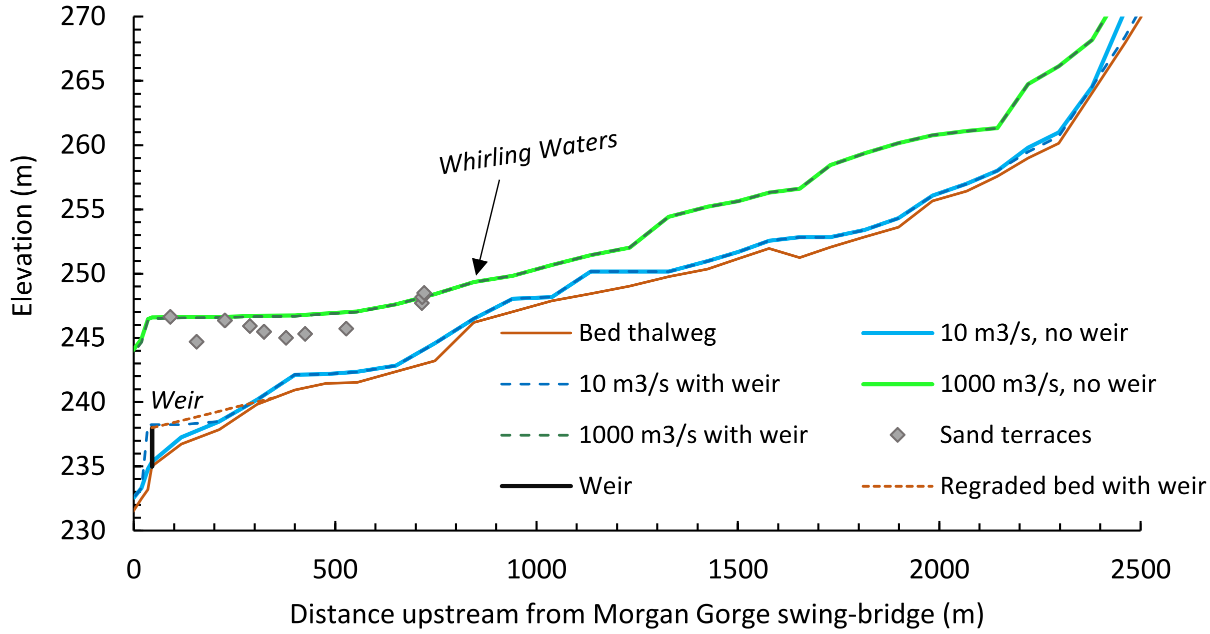

Figure 3-3: Modelled water surface profiles along Kiwi Flat at 10 and 1000 m³/s, without and with weir. Weir crest elevation 238 m. Diamonds show spot-elevation of sand terraces formed during recent floods. Dashed brown line shows estimated re-graded bed thalweg profile with weir. Whirling Waters joins the Waitaha some 700 m upstream from Morgan Gorge.

3.6 Bank erosion opposite Power Station

Regarding the potential for increased bank erosion opposite the powerhouse due to concentrated flood flows, the modelling of the 100-year recurrence interval flood showed that the floodwall would induce only small increases in water level (8–17 cm) and drag against the Waitaha left bank. While such an event would just have the competence to mobilise the boulders lining the left bank, and so some bank erosion is likely during an event of this size, bank retreat and consequent channel widening by only a few metres would be all that would be required to recover the hydraulic conditions without the floodwall. At the mean annual flood discharge, the modelling showed that all the flow would just be contained by the Waitaha channel and would not be concentrated by the floodwall. Thus, the hydraulic effects of the floodwall would only occur with floods with recurrence intervals exceeding ~ 2.3 years, and even during the largest of those events, bank retreat extents would be short and naturally mitigated by self-armouring. In conclusion, the effect of the floodwall on bank erosion of the left bank across from the Power Station would be **less than minor**.

The riverbank opposite the Power Station should not be eroded by spray from the emergency bypass valve since its discharge is to be directed downstream, not towards the bank (as per the **Project Description** and the **Project Overview Report**).

3.7 Geomorphic effects of gravel extraction

The assessment of the gravel extraction proposed from the Waitaha riverbank immediately downstream from the Macgregor Creek confluence showed that the total extracted gravel volume of up to 23,000 m³ would be at most (and more likely considerably less than) 61% of the Waitaha River's mean annual bedload. Also, the observed frequent shifting of braids in the extraction reach signals that the bar surfaces where extraction will occur beside the Waitaha are likely to be "worked-over" by the river within several years, possibly sooner depending on what floods occur after the extraction. Moreover, when diffused downstream along the 14 km span of braided channel to the SH6 bridge, the extracted volume would only induce a temporary average riverbed lowering of 3 mm. Thus, the impact of the proposed extraction on the local channel morphology and gravel transport would be short-lived and **minor**, and the downstream effects **less than minor**.

Satellite imagery from over the past decade shows frequent, flood-driven shifting of the Waitaha main braids at the proposed extraction area. Thus, to meet the Rule 29 (*Gravel Extraction*) of the West Coast Regional Land and Water Plan requirements of extracting only from dry riverbed and avoiding/minimising machinery movement in the wetted riverbed, the actual borrow-area will need to be located according to braid and bar locations at the time of extraction.

A decision tree in guidelines developed for West Coast Regional Council, which considers both the proposed gravel extraction and the cumulative effect with currently consented extraction by others from the Waitaha channel further downstream, indicated that the proposed gravel extraction should not significantly affect coastal stability near the Waitaha mouth. Setting aside cumulative effects of current gravel takes, the far-field effects of the proposed extraction would be **less than minor**. A potential opportunity to make use of an underutilised current consent would lessen any cumulative impact.

3.8 Conclusion on sediment related effects of the Scheme

The extent to which the Scheme's impact on sediment transport in the Waitaha River will affect the form and behaviour of the Waitaha River, including the duration and frequency of natural processes and any cumulative effects, will be limited. With the Scheme operating, the Waitaha River's geomorphic character will continue to be dominated by the action of frequent natural floods and very high and variable sediment loads delivered from upstream. In particular, the bulk of the Waitaha River's sediment load will continue to be carried by un-diverted flood flows. Minor interruptions to sediment transfer continuity, by way of coarse sand collection in the desander and transient fine sediment deposition in the abstraction reach at baseflows, will be recovered by regular desander flushing and natural channel flushing during high flow events. Downstream, the one-off extraction of bar-surface gravel for use in access-road construction should induce only a transient, **minor** effect.

As summarised in **Table 4-1**, the only potential sediment-related effect of the proposed Scheme that could lead to a **more than minor** adverse environmental effect (as assessed for biota in the **Freshwater Ecology Report**) is the transient deposition of fine sediment in the abstraction reach downstream from Morgan Gorge. A strategy to manage this potential effect is proposed in Section 4.

4 Adverse Effects Management Recommended

Recommended management of adverse sediment related effects is included in **Table 4-1** and is detailed in **Appendix F**.

4.1 Managing transient fine sediment deposition in abstraction reach

Acknowledging that exact predictions of this effect and its ecological consequences are not possible, the recommended management approach combines operational monitoring during extended periods when the residual flow is steady at 3.5 m^3/s, using a hybrid approach tailored to the Waitaha situation, and mitigation with engineered flushing flow releases if warranted.

4.1.1 Operational monitoring:

- Purpose: to assess if a reference state of fine sediment cover and depth was exceeded in the abstraction reach, which would then trigger a flushing flow release.
- Approach: a combination of methods from Clapcott et al. (2011), using visual bankside assessment of fine sediment cover to assess the width of any fine sediment depositional zone, then sampling the sediment thickness within that zone by direct measurement.
- Where: the nearest *slow run* habitat upstream from the Power Station.
- How often: every two weeks through minimum residual flow events lasting longer than two weeks.
- For how long: continue until such time as the monitoring shows no exceedances of the reference state over a two-year period but resume if casual observation indicates obvious fine sediment accumulation (due to a significant increase in fine sediment delivery from the catchment, such as from slips associated with a large storm and/or earthquake).
- Reference state: fine sediment cover and thickness observed at the monitoring site at the start of minimum residual flow periods, as established by more intensive baseline monitoring during the first year of the Scheme's operation.
- Threshold condition: When the observed fine sediment cover and thickness exceeds the reference values by more than 20% and there is no natural high flow event forecast over the next week.

4.1.2 Mitigation by flushing:

- Flushing flow source: by returning most of the natural river flow to the abstraction reach for a short period.
- Flush duration: less than one day, to be refined with trials evaluating effectiveness.
- When: when monitoring threshold is triggered but not if a natural flushing event is forecast.
- Trials: treat the first few flushes as trials, measuring their effect on sediment deposits and monitoring downstream turbidity, and using the results to optimise subsequent flush duration and assess downstream effects on water clarity and redeposition.
- Implementation: by developing interim Flushing Management Protocols set in the consent conditions, with subsequent protocol revisions informed by results of the trial flushes.

4.2 Sand deposition and water clarity downstream from tailrace during desander flushes

No management is required for sand flushed from the desander into the tailrace provided the desander is flushed during natural runoff events. Towards this, and acknowledging the assumptions made in the analysis, it would be appropriate to treat the initial desander flushes as trials, monitoring riverbed sand cover upstream and downstream of the tailrace before/after flushing and river turbidity/clarity upstream and downstream of the tailrace during flushing. This would inform on the optimal flush duration and river flow to minimise effects.

Further detail of the proposed management for the Scheme's effects is provided in **Appendix F**.

Table 4-1: Environmental effects relating to sediment associated largely with the operational phase of the Scheme, the suggested approaches to manage these effects, and effects after management measures have been applied. Refer Section 2.3 for definitions of levels of effect.

Environmental effects (positive and adverse effects)	Assessment of effects	Recommended effects management	Residual effects post mitigation
Transient fine sediment deposition along lower part of abstraction reach during extended periods when residual flow is steady at the 3.5 m^3/s.	Potentially more than minor.	Monitor fine sediment cover and thickness during minimum residual flow periods; mitigate with flushing releases into Morgan Gorge; review monitoring results to more accurately gauge significance of effect; monitor trial flushes to determine parameters that optimise flush effectiveness.	Minor effects. Flushing flows will temporarily increase turbidity (reduce clarity) downstream of site but within natural turbidity/clarity range of common freshes/floods.
Transient gravel deposition in pools downstream of Morgan Gorge during extended periods when residual flow is steady at 3.5 m^3/s.	Less than minor.	None.	Less than minor.
Improved water clarity downstream of Site due to fine sediment settling in abstraction reach.	Nil adverse effects.	None.	Nil.
Transient sand deposition in channel downstream of powerhouse after desander flushes.	Minor. Sand deposits in pools and on beaches near tailrace will be smeared downstream during flush-accompanying flood and by subsequent common floods.	Flush desander only during natural high-flow events. Conduct trials to establish optimal high river flows for flushing desander (measuring sand cover before/after flushes).	Less than minor.
Reduced water clarity downstream of Power Station during desander flushes due to resuspended mud embedded with sand in desander.	Less than minor, provided fuses undertaken during natural high-flow events.	Flush desander only during natural high-flow events. Include measurements of water clarity or turbidity upstream and downstream of tailrace during trial flushes noted above.	Less than minor.
Reduced water clarity downstream of Morgan Gorge during channel maintenance work clearing gravel at	Minor effects on water clarity. Reductions in water clarity within the extents and time frames of those induced naturally by runoff events.	Limit rate of mud resuspension by limiting gravel excavation rates;	Minor or potentially less than minor.

Environmental effects (positive and adverse effects)	Assessment of effects	Recommended effects management	Residual effects post mitigation
intake and reforming training wall as needed after floods.		maximise dilution by working at higher discharges as practical.	
Reduced Waitaha water clarity downstream of Macgregor Creek confluence during maintenance work of the Macgregor Creek road-crossing after floods.	Minor effects on water clarity. Reductions in water clarity within the extents and time frames of those induced naturally by runoff events.	Limit rate of mud resuspension by working in dry and limiting earth-moving rates as much as practical.	Minor or potentially less than minor.
Reduced water clarity downstream of Power Station during artificial flow releases to flush fine sediment deposits from abstraction reach.	Observable effects on water clarity, but only if flushes are needed. Reductions in water clarity would be within the extents and time frames of those induced naturally by runoff events.	Optimise effectiveness of flushes by monitoring during trial flushes.	Minor.
Reduced water clarity downstream of Power Station due to rapidly increased flow in abstraction reach associated with emergency shutdown of Power Station.	Observable effects on water clarity but within the extents and over shorter time frame of those induced naturally by runoff events.	Monitor turbidity during trial emergency shutdown to confirm expectations.	Minor.
Net permanent aggradation at Kiwi Flat due to intake weir lifting hydraulic control, altering landscape.	Minor effects on riverbed level. Intake weir will only impose hydraulic control on lower few 100 m of Kiwi Flat; channel deposition and erosion will remain dominated by frequent large floods and hydraulic control set by Morgan Gorge during such floods.	None.	Minor.
Increased erosion risk along Waitaha left bank opposite Power Station due to flow concentration by floodwall.	Less than minor effects on bank erosion. Floodwall effect only exerted during floods exceeding mean annual flood (> 2.3-year recurrence interval); left bank naturally erodes during large floods, and floodwall will only slightly increase erosion risk.	None.	Less than minor.
Erosion of Waitaha left bank opposite Power Station by a possible emergency bypass valve plume.	Nil effect provided plume directed directly down river or valve not included in final design as per **Project Description** and **Project Overview Report**.	Direct plume down river.	None.
Gravel extraction inducing near-field channel morphology change and far-field channel degradation and coastal instability.	Minor, temporary effects on bar morphology at the extraction areas, erased by floods over a time frame of up to several years. Less than minor downstream and coastal effects.	Locate borrow areas at time of extraction as main braids will likely have shifted since proposal was prepared.	Minor at the extraction areas, less than minor downstream and coastal.

5 Conservation Act 1987 Assessment

The above effects assessment is equally applicable to the application for concessions with respect to the Conservation Act.

6 Conclusions

6.1 The Scheme will operate in a vigorous mountain environment with frequent flood-flows that carry large loads of suspended mud and sand and gravelly-bouldery bedload at rates that can vary widely depending on the activity of up-catchment erosion sites. Most (73% at least) of this sediment load is transported by flows exceeding 250 m^3/s, in events that reoccur 15 times per year on average, and will bypass the Scheme infrastructure because the intake will be shut at those flows. Thus, the Scheme's potential to affect natural river sediment transport processes and channel characteristics is largely limited to the intervals between floods when it will be able to operate at flows under 250 m^3/s.

6.2 The only **potentially more than minor** sediment related effect of the Scheme stems from increased risk of transient deposition of fine sediment in the abstraction reach downstream from Morgan Gorge during extended periods when the residual flow is steady at 3.5 m^3/s. The significance of this is explained in the assessment in the **Freshwater Ecology Report** (i.e., it may, from time to time, impact on the quality of habitat for biota, such as blue duck, fish, invertebrates, and periphyton, occupying the channel margins). A strategy to manage this potential effect involves monitoring fine sediment accumulation in the abstraction reach and to flush any excessive accumulations by temporarily reducing the take to the Power Station.

6.3 Accumulations of gravelly bedload along the abstraction reach during periods when the residual flow is steady at 3.5 m^3/s would have **less than minor** effects.

6.4 Channel maintenance works with earth-moving machinery will be required periodically after floods both to clear the intake of gravel and reform the intake training wall and to repair the Macgregor Creek road-crossing. However, at both sites the downstream reductions in Waitaha River water clarity caused by re-suspending mud bound within the river gravels are expected to be within the extents and time frames of those induced naturally by runoff events.

6.5 Similarly, reductions in water clarity associated with any required flushes of fine sediment from the abstraction reach during extended periods of baseflow are expected to be within the extents and time frames of those induced naturally by runoff events, as would any water clarity reductions associated with emergency shutdowns of the Power Station.

6.6 The effects of periodic flushing of sand (and any embedded mud) from the desander on riverbed sand cover and water clarity downstream of the Power Station are expected to be less than minor, providing that the flushes are undertaken during runoff events. Trial flushes at different river discharges, with associated monitoring of riverbed sand cover and water clarity, could be used to minimise such effects.

6.7 Regarding effects of structures, the effect of the intake weir on riverbed levels along Kiwi Flat should be minor, since this would be limited in extent and regularly swamped by the natural flood-choking effect of Morgan Gorge, compounded by widely varying sediment deliveries from up-catchment. Also, the increased risk of erosion of the Waitaha left bank opposite the Power Station due to the floodwall would be **less than minor**.

6.8 The geomorphic effects of the proposed one-off gravel extraction from the active Waitaha braidplain for access-road construction would be **minor** at the extraction areas and **less than minor** downstream and at the coast. However, frequent, flood-driven braid shifts mean that the borrow areas may need to be shifted from those shown on earlier proposals to ensure extraction in the dry.

Appendix A Further project design detail relating to sediment

The Scheme will operate in a river that naturally, mainly during frequent and vigorous floods, transports large quantities of sediment that ranges in size from mud grains through sand and gravel to boulders. It will have four potential sediment-related effects:

- By altering the distribution of water and sediment load between the intake tunnel and the abstraction reach, the Scheme will alter the Waitaha River's sediment transport regime along the abstraction reach, with potential impacts on sediment deposition, channel physical habitat, and water clarity.
- By placing structures in or beside the channel at the intake and Power Station, the Scheme has the potential to impact the local channel morphology.
- By creating flow transients and re-suspending fine sediment during emergency shutdowns of the power-station and during maintenance operations at the intake structure and the Macgregor Creek road-crossing, the Scheme has the potential to temporarily reduce river water clarity in the Waitaha River downstream.
- By extracting gravel from the Waitaha braidplain for road construction the Scheme has the potential to induce near-field and far-field geomorphic effects on the Waitaha River and adjacent coast.

A.1 How design and operations could impact sediment transport/deposition in the abstraction reach

A key design imperative is to avoid passing sand and gravel through the powerhouse machinery because that will rapidly abrade the machinery, requiring frequent and expensive repairs and loss of generation. Therefore, the Headworks design must provide for the bypassing of this sediment during normal operations up to moderate sized flood flows and must also be able to "shut-off" completely during large floods when very large concentrations of abrasive sediment are being carried.

Specific design components at the headworks to manage sediment include:

- An intake structure design that diverts mobile gravel away from the water intake and into Morgan Gorge.
- A training wall formed of riverbed material that provides a flow-approach direction that optimises that gravel diversion and reduces the influx of suspended sand into the intake.
- A maintenance program that will rebuild the training wall as needed after floods.
- An underground "desander" near the tunnel portal to trap any residual un-diverted sand coarser than 0.3 mm. As needed, the trapped sand will be sluiced via a pressurised pipe from the desander, to be mixed with the Power Station water in the tailrace before re-entering the river which will then have recovered its full, natural flow. It is understood that desander flushes will normally:
  - discharge approximately 250 m^3 of sand with each flush
  - last for 30–60 minutes duration

    - be done during natural high-flow runoff events in the river (exceeding approximately 75 m^3/s).

  Occasionally, flushes may be required at lower flows but in such instances the flush will be done in stages spread over a longer duration.

- The ability to cease all water takes and bypass the full sediment load at river flows over 250 m^3/s when the quantities of sediment are very large.
- During normal maintenance operations that required a Power Station shutdown then startup, the "ramping rates" would be limited to 0.5 m^3/s/minute.

Details of these design components are provided in the **Project Description** and **Project Overview Report**.

The consequence of these sediment management works, plus the Scheme water take regime (i.e., 3.5 m^3/s residual flow and 23 m^3/s maximum water take) while the Power Station is running, is that the abstraction reach will receive a reduced water discharge but all the incoming gravel and a pro-rata (by flow) share of the finer-grained suspended load. So key questions are:

- Will the residual flow in the abstraction reach be capable of transporting the supplied sediment load or will some of it be deposited and build-up in the abstraction reach channel?
- If the latter, then are the amounts of sediment likely to be deposited of environmental significance?
- Will there be any similar issues when the desander is flushed of sand?

A.2 Potential geomorphic effects of structures

The Headworks/intake weir will lift the river channel invert level by several metres at the entrance to Morgan Gorge. This could promote a permanent rise in average river-bed levels along Kiwi Flat as the River regrades to the new control level, with consequent changes to the landscape of Kiwi Flat. A key question is: to what extent might this occur?

The infrastructure at the Power Station requires a concrete floodwall to be built along the true-right bank of the Waitaha channel. At present, there is a natural flood-spill channel passing through the Power Station Site including Construction Staging Area 2, so the floodwall will protect the Power Station infrastructure from spilled flood flows by diverting the full river flow into the main Waitaha channel. The key question is: will this concentration of flood flows promote erosion of the true-left bank of the Waitaha River opposite the Power Station?

A.3 Flow transients associated with emergency shutdowns

Doyle (2025, the **Hydrology Report**) and AusHydro (2025, the **Downstream Flow Modelling Report**) describe the effect of changes in Power Station generation flow on the river flow. Routine changes in generation flow will be undertaken at a rate of 0.5 m^3/s/minute, which is within the range of natural river flow variation rates.

However, an emergency shutdown (prompted by electrical load rejection, e.g., due to loss of transmission line connection) will require a more rapid (order 1 minute) reduction of the flow through the Power Station to protect the turbines from 'overspeed'. Based on Westpower's experience with the nearby Amethyst power station it is anticipated that such emergency shutdowns would occur four times per year on average and more-often-than-not these would be during rain events when the river is up. Such sudden shutdowns will produce transients in the Waitaha River flow downstream of the intake and Power Station.

At the intake there would be a sudden increase in the discharge to the abstraction reach. There would be minimal attenuation of the size of this surge through Morgan Gorge (due to the steep, slot nature of the channel) but it would then attenuate somewhat as it progressed downstream. Downstream of the Power Station, there would be a sudden reduction in the river flow until the increased flow surge arrived via the abstraction reach around 30 minutes later (the timing depending on the size of the natural flow), and in the meantime the flow reduction would translate downstream.

To mitigate the reduction in discharge from the Power Station (and increase to the abstraction reach) Westpower has included, as part of the project design, a bypass to route flow past the turbines directly to the tailrace (approximately 10 m^3/s capacity), with a fixed-cone valve to dissipate flow energy.

With the bypass valve operating, the magnitude of flow changes would depend on the natural river flow and the flow diverted to the Power Station. The worst-case situation (in terms of relative flow changes) occurs when the natural river flow at the intake is 26.5 m^3/s. In that case, before the shutdown the diverted flow would be 23 m^3/s and the river flow arriving at the Power-Station would be approximately 5 m^3/s (i.e., 3.5 m^3/s residual flow plus 1.5 m^3/s from tributaries to the abstraction reach), providing 28 m^3/s downstream of the Power Station. With 10 m^3/s mitigation through the bypass valve, the flow into Morgan Gorge would increase from 3.5 m^3/s to 16.5 m^3/s while the flow downstream of the Power Station would fall to 15 m^3/s until the arrival of the resumed natural flow down the abstraction reach. In comparison, if the natural flow was ≤13.5 m^3/s, then the ≤10 m^3/s through the Power Station could be fully mitigated by the bypass valve and there would be no river flow transients.

The **Downstream Flow Modelling Report**'s 2-d hydraulic modelling of the 26.5 m^3/s worst-case shutdown event with the bypass valve operated at 10 m^3/s showed that flow ramping-up rates would peak at 4.3 m^3/s/minute in the abstraction reach and at 2.1 m^3/s/minute immediately downstream of the Power Station, reducing progressively further downstream. Ramping-down rates would peak at 3.0 m^3/s/minute immediately downstream from the Power Station and would reduce progressively downstream. By comparison, the recorded natural ramping rates in the Waitaha do not exceed ±0.5 m^3/s/minute at discharges below 30 m^3/s nor ±2 m^3/s/minute at discharges below 100 m^3/s.

The flow transients associated with emergency shutdowns have the potential to temporarily impact sediment entrainment, impact instream biota, and compromise the safety of recreational river users. Biota impacts and river-user safety are addressed in the **Freshwater Ecology Report** and **Downstream Flow Modelling Report**. Sediment entrainment effects are influenced more strongly by rapidly increasing flows, so the key question with such emergency events is what effect would the rapidly increasing flows along the abstraction reach have on sediment entrainment in the abstraction reach?

A.4 Gravel extraction from Waitaha braidplain

The proposed gravel extraction from the Waitaha channel is up to 23,000 m^3 being taken from dry bar surfaces on the wider braidplain downstream from the Macgregor Creek confluence (**Figure E-9**). The total extraction area covers some 4.7 ha, and bars will be 'scalped' to a depth of approximately 0.5 m. It is assumed that the extraction will be done over a period of several months as river conditions permit.

Rule 29 (Gravel Extraction) of the West Coast Regional Land and Water Plan (RLWP, WCRC 2014) considers gravel extraction from the Waitaha River a permitted activity only if the extraction volume does not exceed 1000 m^3 in any 12-month period. Thus, the proposed extraction will require a consent.

The extraction has the potential to induce "near-field" and "far-field" geomorphic effects:

- Near-field effects consider the impact on local river morphology processes and around and immediately downstream of the extraction site and are relevant to Rule 29 of the RLWP.
- Far-field effects consider the effects of the gravel supply deficit further downstream, including channel degradation and effects on coastal erosion, considering also the cumulative effects of existing consents from the Waitaha River. Guidance developed for assessing such effects on the West Coast is provided by Hicks (2017).

Appendix B Report scope, approach, and author's qualifications

This report deals with the above matters relating to the potential effects of the Scheme on sediment transport/deposition in the abstraction reach and the local effects of the Scheme's structures in/by the Waitaha River channel at Kiwi Flat and at the Power Station.

B.1 Scope

The report scope covers:

- Background information on what is known of the sediment load of the Waitaha River, focussing on the load delivered to Kiwi Flat and the intake site at the entrance to Morgan Gorge. This aims to show:
  - the scale of the sediment load to be dealt with by the Scheme, and
  - the variability in the load (within floods and over longer terms) and its supply from up-catchment.
- Investigations undertaken directly for the Scheme.
- The results of these investigations around potential environmental effects of the Scheme.
- Proposed management of any potentially significant effects.

The investigations focussed mainly on sediment-related effects during the operational phase of the Scheme. Sediment-related effects during the construction phase largely relate to fine sediment discharges into the Waitaha River stemming from earthworks, in-stream works, and tunnelling – which are small compared with the natural sediment loads transported during runoff events and are addressed in the **Freshwater Ecology Report**. However, one construction activity involving larger sediment volumes concerns extracting gravel from the Waitaha River channel for use in access road construction. An assessment of the effects of this on channel morphology and sediment transfer in the Waitaha River is included herein. Potential ecological effects of this gravel extraction are covered in the **Freshwater Ecology Report**.

Climate change is covered in the **Hydrology Report** so is not considered in the analyses contained in this report.

Direct Waitaha investigations include a catchment aerial inspection in 2013 (Hicks 2013), data collection on turbidity and suspended sediment over 2013–15 and analysis of that data, simulation of sediment loads in the river with and without the Scheme, and hydraulic modelling of flows along Kiwi Flat and past the Power Station (Hicks 2013, 2014). Other data used included that collected in studies of sediment load in nearby rivers (Hokitika, Haast, Poerua, Whataroa) plus data and simulations of Waitaha flows (Doyle 2013), instream habitat studies in the Waitaha channel (Allen and Hay 2013), and river water quality data from the Haast River (LAWA 2024).

B.2 Approach

The overarching approach is to quantitatively assess potential effects of the Scheme in the context of the highly active natural environment.

B.3 Author's qualifications and relevant experience

The author of this report, Dr Murray Hicks, holds first-class honours degrees in Geology (University of Otago) and Civil Engineering (University of Canterbury) and a PhD in Earth Science (University of California). His career, beginning in 1977, spans employment with the Water and Soil Division of the Ministry of Works and Development and the National Institute of Water and Atmospheric Research (NIWA). His work has blended research with consulting on matters relating to sediment transport and geomorphic processes in rivers and on coasts. In 2012 he received the New Zealand River Group's *Arch Campbell Award* for his contribution to the advancement of knowledge in the field of river engineering. In 2017 he won the NIWA *Research Excellence Award*.

His published research has included measuring and modelling sediment loads in rivers around New Zealand, measuring and modelling morphological change in braided rivers, modelling the effects of hydro-operations on braided rivers, and estimating river flow hydraulic resistance. He has published over 70 papers in scientific journals and contributed material to 20 books. He is the lead author of New Zealand's National Environmental Monitoring Standards (NEMS) for *Turbidity Recording* and for *Measurement of Fluvial Suspended Sediment Load and its Composition*.

His consulting has included extensive work for hydro-power companies on rivers around New Zealand, focussing on investigations of sediment-related and geomorphic effects of dams and water-diversions to assist with consent applications. This has included work in the Waikato, Mohaka, Tongariro, Mokau, Mokihinui, Hurunui, Waitaki, Clutha, and Waiau (Southland) catchments.

His work on the South Island West Coast includes measuring/calculating sediment loads in most of the major rivers (Mokihinui, Buller, Grey, Taramakau, Hokitika, Cropp, Poerua, Amethyst, Waitaha, Whataroa, and Haast Rivers). Work in the Waitaha catchment includes the work for this report described above, as well as an earlier study of sediment deposition in Ivory Lake in the catchment headwaters. He has also consulted for the West Coast Regional Council on coastal hazards and shoreline stability at various locations along the West Coast and on river channel management issues.

Appendix C Detail of the existing environment

C.1 Waitaha catchment

The Waitaha River is an energetic, flashy mountain torrent draining a steep, highly erodible, schist catchment that experiences tectonic uplift rates averaging several mm/yr and receives rainfall volumes and intensities that rank among the highest in New Zealand. Accordingly, its water runoff and sediment exports per unit catchment area also rate amongst New Zealand's highest[2].

Most of the Waitaha River's sediment load is transported during runoff from rainstorms. The main sources of sediment during rainstorms are the very high, steep, bare headwater slopes formed in fissile schist (with a texture and durability akin to "Weet-bix"), which feed sediment to the stream network by slips, slides, gullies, and debris flows (**Figure C-1**). Large landslides that deliver large sediment volumes to the Waitaha Valley floors can occur and/or are reactivated periodically across the catchment. Sometimes, landslides or debris-flow fans fed by them temporarily dam the river or its tributaries, which can cut off the local sediment delivery until the lake fills and breaches the dam, which then produces an extended period of elevated sediment load while the dam is scoured away, even at baseflows (**Figure C-2**). Snowfall in the headwaters moderates winter runoff and erosion rates, but snowpack melt and glacial melt in summer typically also provide a small sediment load and turbidity even at baseflows (**Figure C-3**). Glaciers cover 6.6% of the Waitaha Catchment upstream from Morgan Gorge.

Figure C-1: Debris mantled slopes and gullies in Waitaha headwaters are major sediment sources.

[2] The Waitaha River delivers, on average, 1.0 million tonnes/year of suspended load (equating to 9,000 t/km^2/yr) to Morgan Gorge. This is approximately 0.5% of New Zealand's total suspended sediment annual sediment load from 0.04% of New Zealand's land area (Hicks et al. 2011). Only other, main-divide-draining schist catchments in South Westland (e.g., Hokitika, Whataroa, Haast) and the deforested mudstone hill country of East Cape (Waipaoa, Waiapu catchments) show similar erosion rates. One million tonnes of sediment would fill Wellington's "Cake Tin" stadium approximately 1.2 times over.

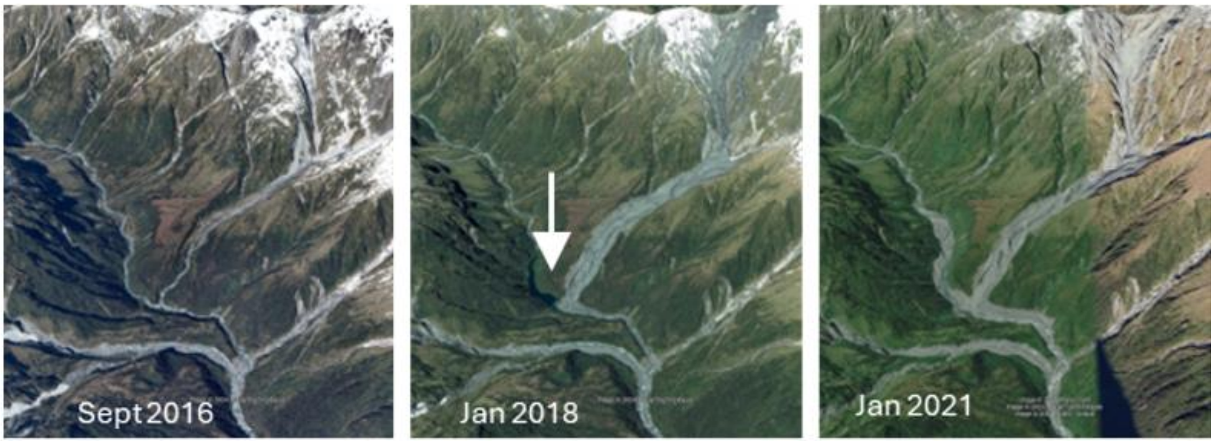

Figure C-2: Gully complex and debris chute in County Stream. Feature reactivated between September 2016 and January 2018, damming a lake that stalled sediment delivery from Upper County Stream (arrow, centre photo). Lake infilled and debris fan cut through by January 2021. Such events are common and produce great variability in the sediment supply to the lower Waitaha.

Figure C-3: View up-valley of the sediment-draped County Glacier issuing turbid meltwater, upper Waitaha.

C.2 Kiwi Flat

It was estimated that 95% of the Waitaha River's total sediment load entering Kiwi Flat is mud-sand grade (i.e., 1 micron to 1 mm in size)[3] and is transported as suspended load by the highly turbulent flow. Coarser sediment (gravel – boulder grade) is dragged by the current along the riverbed. This "bedload" is dominated by gravel but only represents about 5% of the total sediment load because it is harder to transport and most of the larger schist clasts entrained from upstream disintegrate during transport down the catchment, rendering sand and silt that adds to the suspended load.

At Kiwi Flat, peak SSCs, with units g of sediment per cubic metre of water, typically occur after flood peaks because while most of the water and sediment originates at the Waitaha headwaters, the sediment travels more slowly than does the flood wave. However, sometimes the SSC peak occurs before the flow peak because of a dominant more local sediment source. While the River typically clears-up moderately within a few days, this clearing may be limited by meltwater and mud "bleeding" from landslides. The upshot of these supply and transport processes is that while there is an overall relationship between SSC and flow in the river at Kiwi Flat, the SSC at a given flow can vary over a factor of 10, possibly 100.

The riverbed material at Kiwi Flat ranges from silt through sand, gravel, cobbles, and boulders (**Figure C-4**). Silt and sand typically deposit from suspension on channel margins and pools on flood recessions. However, even during only slightly turbid baseflows, silt can deposit along the channel margins between partly exposed cobbles, transferred from the main flow by lateral diffusion, and leaving a sludge that can build-up to up several cm thick amongst the cobbles if the baseflow persists for several weeks (**Figure C-5**). These fine sediments are typically re-entrained by subsequent floods. The gravel is the most mobile phase of the bedload during floods, and gravel patches come and go as well. Cobbles and boulders move less often, during bigger floods, so while they may be the dominant size seen on the riverbed, they are not the dominant part of the sediment load.

[3] While there are no measurements of the size grading of the suspended load at Kiwi Flat, such data as has been collected from the nearby Hokitika and Whataroa Rivers (Hicks et al. 2012) show that in these rivers it spans the range from 1–1000 microns, and while it varies on the day, the average size and the proportion exceeding 300 microns increase weakly as discharge increases.

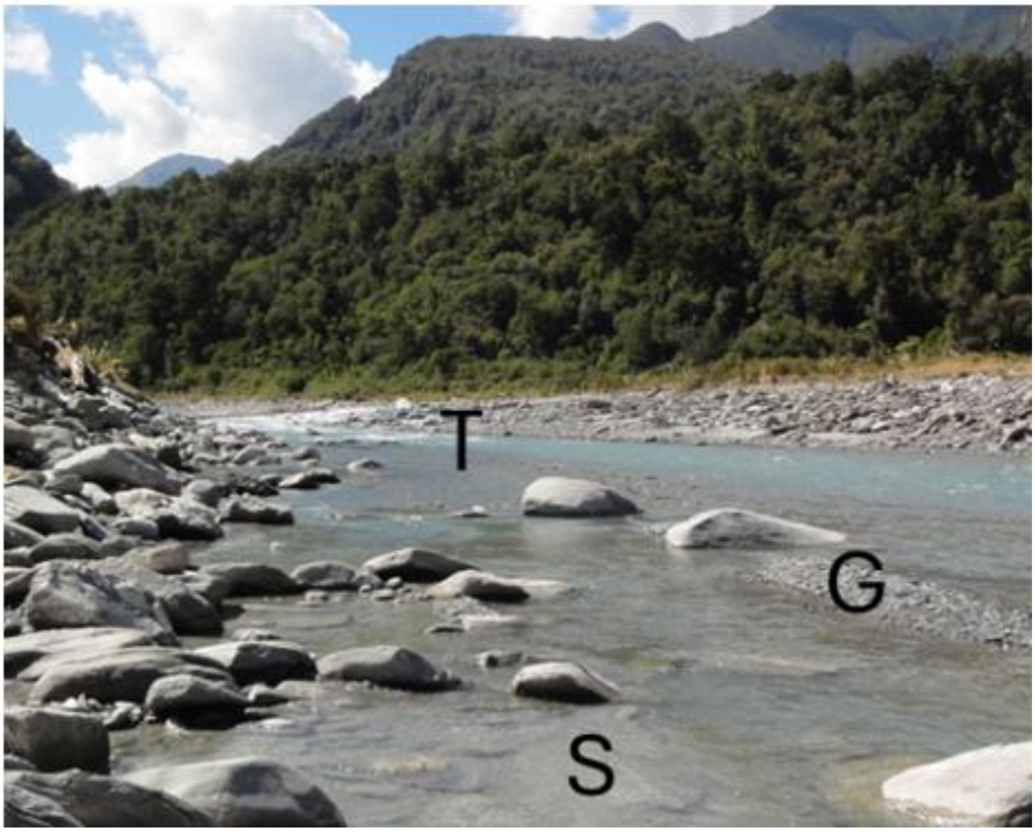

Figure C-4: Sand (S) and gravel (G) patches amongst boulders and baseflow turbidity (T) at Kiwi Flat.

Figure C-5: Silty sludge drape over channel margin cobbles at Kiwi Flat during baseflow of 8–10 m^3/s that had persisted for at least 23 days.

The transport of sediment along and out of Kiwi Flat during floods is further complicated by the narrow, slot entrance to Morgan Gorge (**Figure C-6**). This causes the Gorge entry flows to "choke" and form a temporary pond that backs-up sometimes as far upstream as the Whirling Waters confluence. This pond sets the base-level for the channel along the upper part of Kiwi Flat and for Whirling Waters, and the slower velocity through this pond causes mobile gravel and sand arriving from upper Kiwi Flat and Whirling Waters to deposit on delta lobes at its upstream end (**Figure C-7**). As the flow wanes after the flood peak, the choking clears, the pond drains rapidly, the water slope and flow velocities towards the Gorge increase as the hydraulic control shifts back to the Gorge entrance, and lobe deposits are reworked downstream and into the Gorge. Thus, the peak transfer of sand and gravel into Morgan Gorge will typically occur after flood peaks. A consequence of this dynamic is that the channel bed levels of Kiwi Flat and Whirling Waters can naturally fluctuate by several metres, especially after 'slugs' of bed material are supplied to Kiwi Flat from upstream slips. An example of this followed from a large slip in the first Whirling Waters tributary, which occurred circa. 2019 (as captured on *Google Earth* imagery, **Figure C-8**). This fed a rapid but transient build-up of gravel in the lower reach of Whirling Waters which pushed a gravel lobe into Kiwi Flat, now being eroded back by the Waitaha. Slips equalling or exceeding the size of this Whirling Waters slip are estimated to occur every 4.3 years on average across the Waitaha catchment above Morgan Gorge[4].

Thus, the Waitaha channel at Kiwi Flat naturally exhibits considerable instability due to frequent large floods, high fluxes of bed-material, and transient deposition and re-working of sediment. This is evident from abandoned branches (typically perched above the existing channel), terraces and banks of deposited sand and gravel, armoured segments of bed and bank, and places where the channel margins are actively eroding. The Scheme will not alter this suite of natural processes and fluvial features, nor their frequencies of occurrence or magnitude.

Figure C-6: "Slot" entrance to Morgan Gorge.

[4] This estimate derives from Hovius et al.'s (1997) empirical landslide magnitude-frequency relation, using a scar area of 4.5 ha for the Whirling Waters slip and a catchment area of 116.5 km^2 upstream of Morgan Gorge. Hovius et al. developed their equation by mapping landslides within the western Southern Alps east of the Alpine Fault between the Waitaha and Moeraki Catchments on aerial photography spanning the period 1948–1986.

Figure C-7: Sand lobe (SL) deposited when Morgan Gorge has "choked" at high flows.

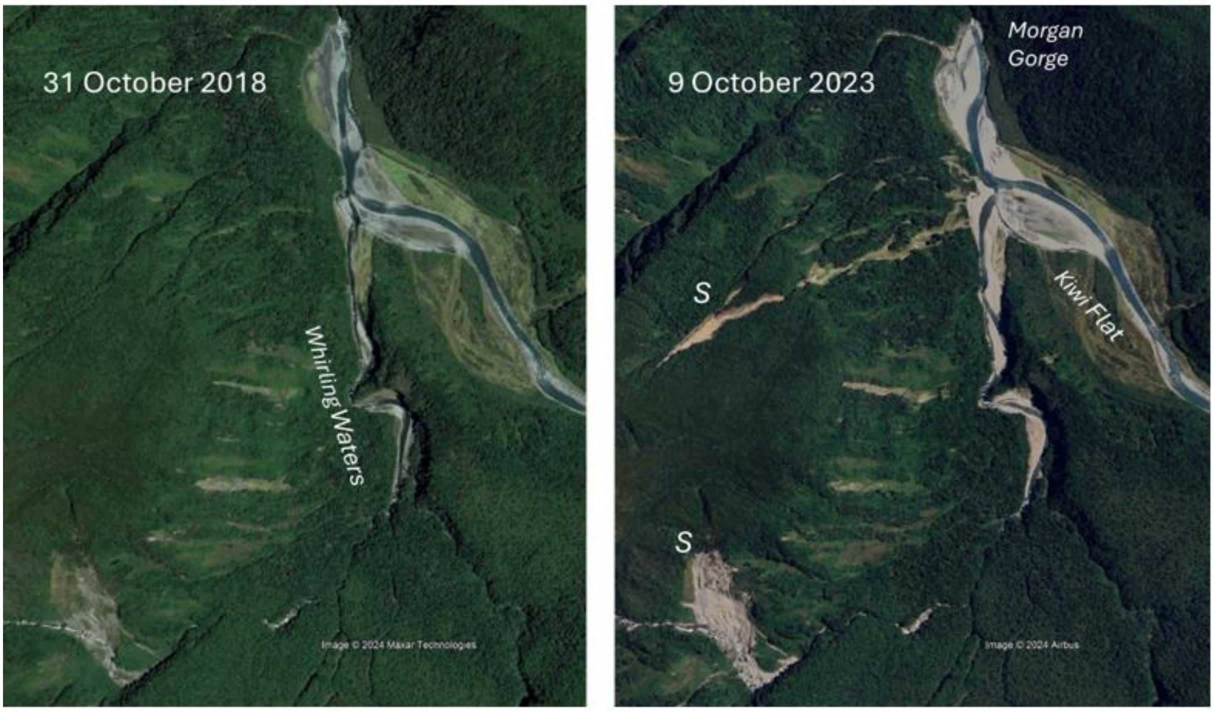

Figure C-8: Slips (S), reactivated soon after October 2018, feeding sediment into Whirling Waters and then Kiwi Flat. 2023 image shows gravel swamping previously grassed Whirling Waters terrace just above Kiwi Flat and Whirling Waters delta prograded out over Kiwi Flat.

C.3 Abstraction reach

Between Kiwi Flat and the proposed Power Station Site, the Waitaha River falls through Morgan Gorge (a slot bedrock-plus-large-boulder gorge) then flows along a relatively steep 'rock garden' largely boulder-bed reach (**Figure C-9**). The boulders in the latter reach are lag deposits of low mobility, even during floods. The bulk of the Waitaha's bedload here is finer material (cobbles, gravel and sand) that is generally supplied at rates less than the river's capacity to transport such material during floods, thus it generally overpasses the boulder-lined channel, and the channel is relatively stable. Since the proposed Scheme will have no significant effect on the discharge of water and bedload from Kiwi Flat during floods, it should also not affect channel processes, characteristics, and stability in this reach.

C.4 Summary

In summary, the Scheme is to be built in a natural environment that experiences at times intense but also variable sediment transport. The Scheme's design must (i) cope with this dynamic natural environment as well as (ii) manage any side effects on the natural processes due to its hard structures and "replumbing" of the river flow and sediment load past the abstraction reach. This report focusses on the latter.

Figure C-9: Waitaha channel in the abstraction reach between Morgan Gorge and Power Station site.

Appendix D Investigations

Beyond the overview of the natural environment summarised above, investigations focussed on seven topics:

- Collection and analysis of data on river turbidity and suspended sediment load to better quantify the natural suspended load and its variability and size grading, and the Waitaha River's gravel bedload.
- Based on this dataset, estimating the redistribution of the natural sediment load between the Scheme intake and the abstraction reach, and then assessing the risk of fine sediment deposition in the abstraction reach.
- Assessing the risk of sand deposition downstream of the powerhouse from desander flushing.
- Assessing changes in water clarity associated with maintenance operations at the intake and at the Macgregor Creek road-crossing, desander flushing, and any artificial flushing of the abstraction reach.
- Assessing the extent of potential aggradation along Kiwi Flat upstream of the intake weir.
- Assessing the likelihood of bank erosion at the power station due to channel training.
- Assessing the potential near-field and far-field geomorphic effects of extracting gravel from the Waitaha River braidplain for use in road construction.

This appendix details these investigations and some intermediary findings. The results around Scheme impacts are detailed in **Appendix E**.

D.1 Natural river turbidity and sediment load

Core dataset: 257 days of concurrent, 15-minute turbidity and water discharge data were collected at the upper end of Kiwi Flat during the period 14 Nov 2013 to 7 March 2015 (with a 7-month gap between May and December 2014)[5]. Water samples collected manually from the Waitaha riverbank during a high flow event on the 6 March 2015 and analysed for SSC showed a "tight" linear correlation between SCC and the turbidity recorded by the field instrument (**Figure D-1**), thus this relation was used to convert the 8.6-month turbidity record to an SSC record. That was then analysed to assess the relationship between SSC and discharge, overall and during and between individual runoff events. The bankside water samples may have underestimated the average SSC across the flow, but not excessively because of the highly turbulent sampling location which would have generated good mixing. The turbidity sensor "saturated" at 2600 nephelometric turbidity units (NTU), so higher turbidity values were under-recorded. Thus, the SSC record derived from the turbidity data is likely a lower bound on the actual SSC, particularly during large floods.

SSC and discharge relationships. Individual events often showed "hysteresis" loops in the SSC-discharge relation, and the relation often changed between events (**Figures D-2, D-3**). The upshot was a wide scatter in the overall SSC-discharge relationship, with SSC at a given discharge varying by a factor of at least 10, possibly 100. To some degree, this variability will be reflecting the varying

[5] Turbidity data and water samples collected by NIWA; discharge data provided by Martin Doyle.

sediment sources at play across the catchment from event to event but may also stem from unrecorded variations in the stage-discharge rating relationship. Separating these two causes is problematic. Nonetheless, to quantify the potential SSC variability, the dataset was analysed to determine the SSC exceedance probability as a function of discharge (**Figure D-4**). At discharges above 90 m^3/s, the maximum (i.e., 0% exceedance) SSC curve “plateaued-out” at 5300 g/m^3. This reflects the upper detection limit of the turbidity sensor (2600 NTU), so the true maximum SSC curve should plot higher. SSC values up to 31,300 g/m^3 have been measured in the nearby Hokitika River.

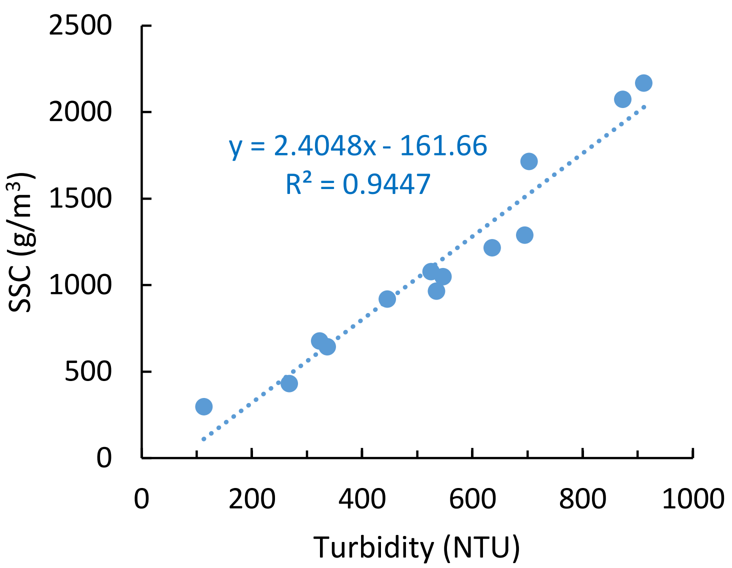

Figure D-1: Correlation between suspended sediment concentration (SSC) and turbidity, measured at Kiwi Flat on 7 March 2015.

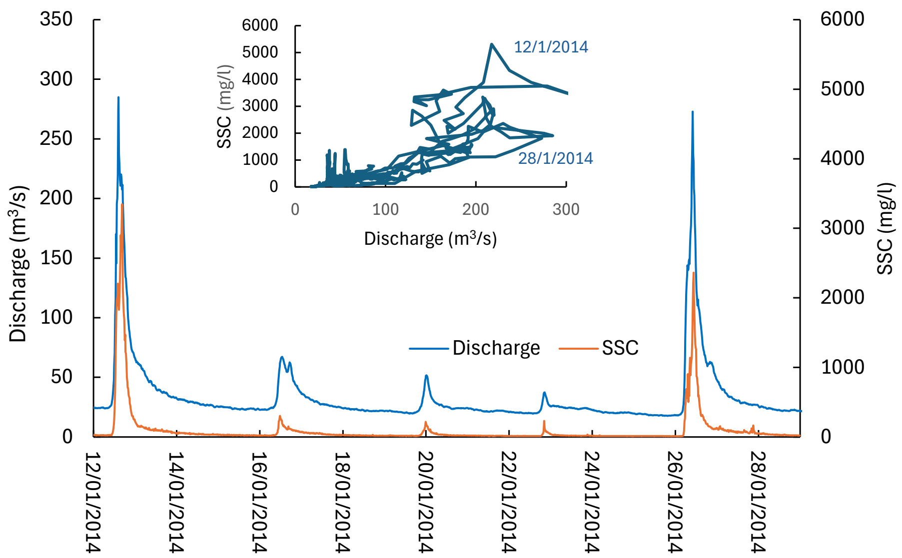

Figure D-2: Sample of SSC (calibrated from turbidity) and discharge records at Kiwi Flat, 12–28 January 2014. Inset tracks SSC-discharge relation.

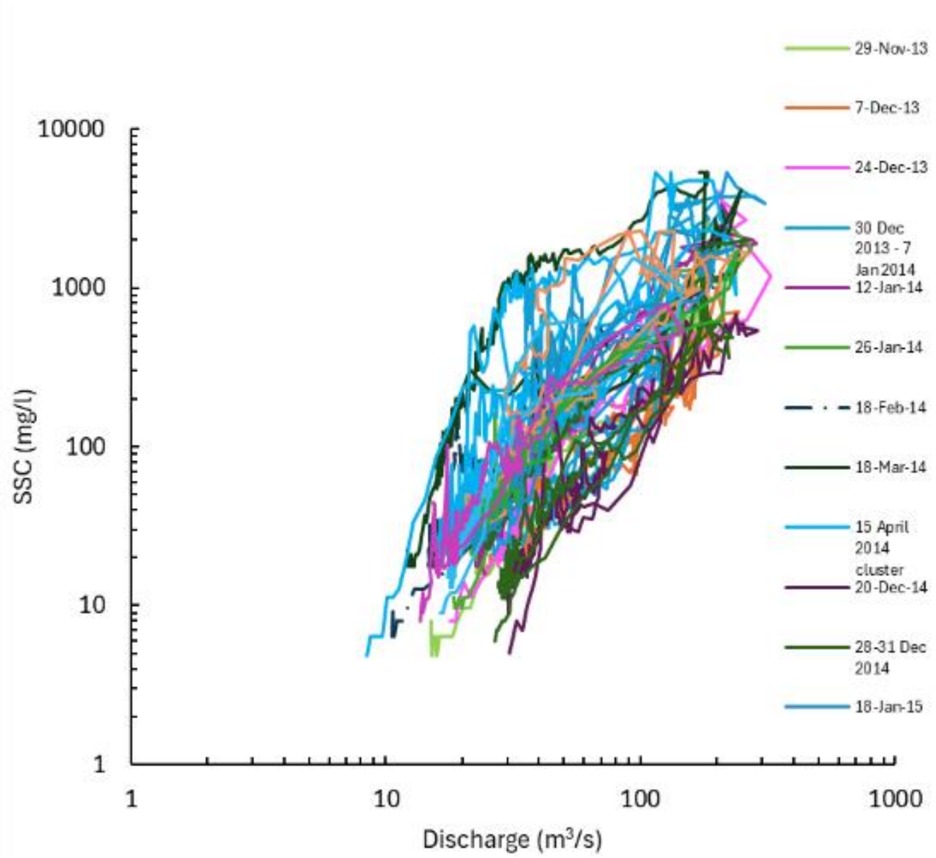

Figure D-3: SSC-discharge relations tracked through all runoff events at Kiwi Flat over 2013–2015 monitoring.

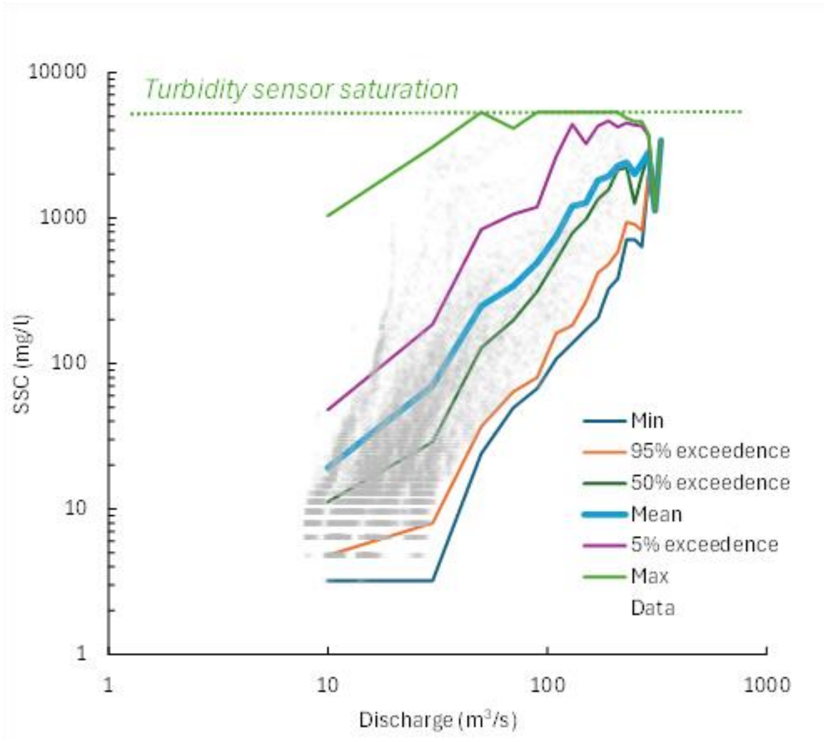

Figure D-4: SSC exceedance percentiles and mean by discharge at Kiwi Flat, 2013–2015, overplotted on data in Fig. D-3 (grey points). Turbidity sensor saturated at SSC = 5300 mg/L, limiting maximum SSC.

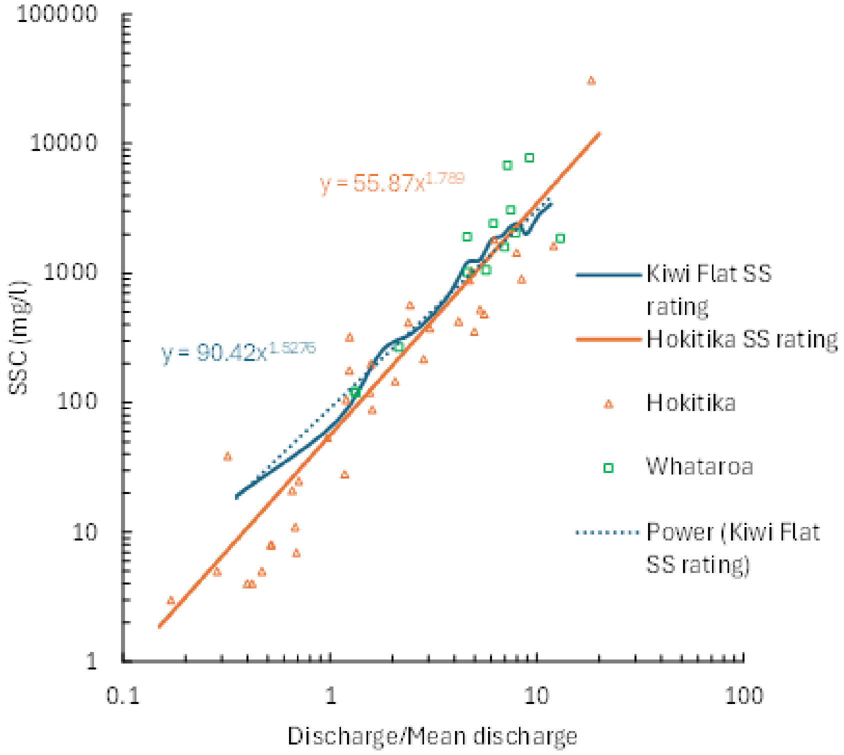

Figure D-5: Kiwi Flat mean SSC curve from Fig. D-4 overplotting suspended sediment rating data from Hokitika and Whataroa Rivers.

Long-term suspended load. The mean SSC vs discharge curve, when combined with the discharge record, provides an estimate of the suspended sediment load over the turbidity monitoring period. A power-law fit to this curve (**Figure D-5**) was used to estimate a "sediment rating" function that could be extrapolated to higher discharges, and this rating was combined with Doyle's (2013) 1973–2012 natural discharge record at the intake site to estimate the annual and mean annual suspended sediment loads exiting Kiwi Flat into Morgan Gorge for that 39-year period (1,050,000 ± 220,000 t/yr). This Kiwi Flat suspended sediment rating overplots onto the SSC data directly measured at the nearby Hokitika and Whataroa Rivers (after the discharge scale is normalised by mean discharge to account for differences in catchment size), which provides reassurance that the Kiwi Flat rating should be reasonably representative of higher discharges and for longer than the relatively short 2013–2015 turbidity data-collection period (**Figure D-5**). The Hokitika and Whataroa SSC data show a factor-of-10 variation in SSC at given discharge. This variation must stem from sediment delivery causes and cannot be influenced by any stage-discharge rating instability since at those rivers the discharge was gauged concurrently with the suspended sediment sampling. This suggests that varying sediment delivery could also account for a similar range of the SSC variability observed in the Waitaha.

Most-important flows and floods. This rating curve was also used to estimate the proportion of the total suspended load transported by discharges above a given size (Figure D-6) and to estimate the suspended load of all flood events over the 39-year period and thence the sediment loads carried by floods of a given recurrence interval (**Figure D-7**). The former analysis showed that 99% of the long-term average suspended load is transported at discharges greater than 26.5 m^3/s (which is when the intake is at its maximum of 23 m^3/s and the residual river flow starts to increase from 3.5 m^3/s), while 73% of the suspended load is transported by discharges greater than 250 m^3/s (when the intake will be closed). In fact if anything, flows exceeding 250 m^3/s will transport more than 73% because the “saturated” turbidity sensor effect will more strongly underestimate the true SSC at higher discharges. The latter analysis showed that even the very common runoff events carry substantial suspended loads (for example, those that reoccur every two weeks on average carry 1600 tonnes per event, monthly floods carry 14,400 tonnes, and annual floods (i.e., those that reoccur once per year on average) carry 194,000 tonnes). While floods more frequent than annual appear to transport 65% of the suspended load, in reality this percentage will be less than 65% because of the turbidity sensor saturation effect.

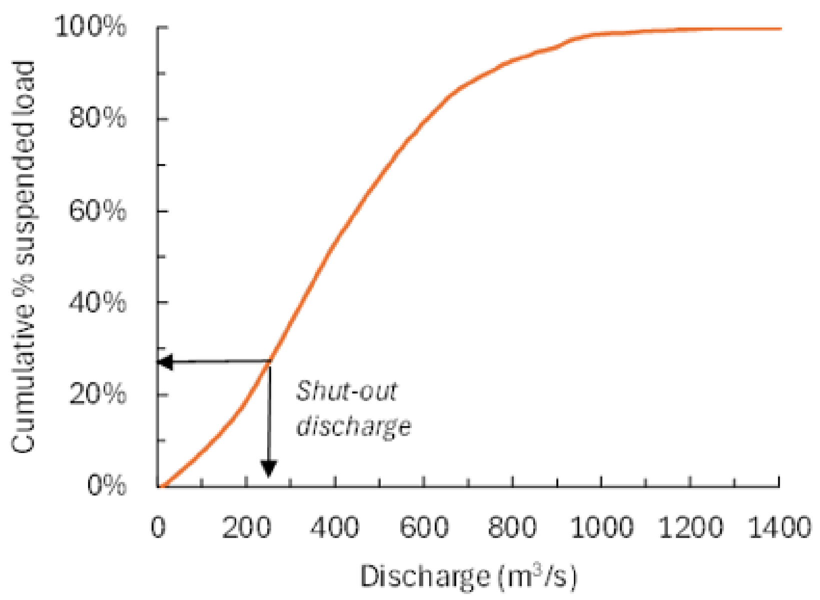

Figure D-6: Percentage of suspended load at Kiwi Flat intake transported by discharges less than plotted discharge. Example: 27% of the suspended load is transported at discharges less than the 250 m^3/s shut-out discharge.

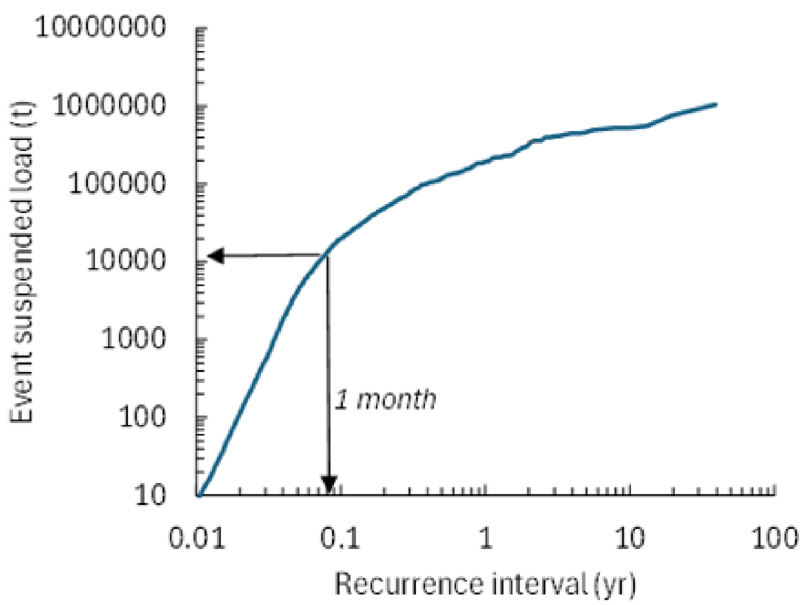

Figure D-7: Event suspended load at Kiwi Flat intake vs event recurrence interval. Example: events occurring every month on average have a load of at least 14,400 t.

Suspended sediment particle size. While no measurements have been made of the particle size grading of the Waitaha River's suspended load, the common catchment physiography and schist rock-type of the Waitaha, Hokitika, and Haast Rivers indicate that size grading data from the latter two rivers should be a reasonable proxy for the Waitaha River's suspended load. The pooled particle size data from these two rivers showed the suspended load ranging in size from fine silt to coarse sand (4–1000 microns) but with a trend for the sand content to increase somewhat as normalised discharge increases. In particular, a relation was derived to estimate the proportion of the Waitaha suspended load coarser than 300-micron sand (the sand diameter being used to design the desander). This relation[6] was used to estimate the mean annual load of sand coarser than 300 microns at Morgan Gorge (175,000 t/yr, equating to 16.6% of the total suspended load) and routed to the desander. The same Haast-Hokitika dataset indicated an average suspended load mud content (4–63 microns) of 54%, with this increasing to 61% at discharges less than five times the mean discharge.

Bedload. Similarly, use was made of a previous study on the Whataroa River (Hicks et al. 2012) to estimate the bedload of the Waitaha River. The Whataroa study, which compared theoretical calculations of the bedload with the measured suspended load rating, showed that the bedload to suspended load ratio increased as the normalised discharge increased[7]. Relying on the same catchment similarity basis as used for particle size, this relation was assumed appropriate to scale the Waitaha River's gravelly bedload off its suspended load. The mean annual bedload so predicted was 50,000 t/yr, equating to 5% of the mean annual suspended load. Thus, the total sediment load is dominated by the suspended load.

D.2 Risk of sediment deposition in the abstraction reach

Problem: The Scheme intake and Headworks are designed to avoid gravel and sand coarser than 300 microns passing through the powerhouse. This will be done by (i) sluicing all the gravel arriving as bedload at the intake structure into Morgan Gorge, and (ii) catching suspended sand taken into the intake using an underground desander (which is to be designed to be a highly efficient trap for grains coarser than 300 microns), from where it will be sluiced to the tailrace via a pipe as need be, thence returned to the River below the powerhouse. **Figure D-8** illustrates the approximate sediment budget during normal operating conditions: the abstraction reach receives all the incoming gravelly bedload and a share of the suspended load (subdivided into sand coarser than 300 microns and finer sand and silt, termed "washload") in proportion to the water split.

The essential question is the extent to which the diminished flows in the abstraction reach might result in environmentally degrading sediment deposition in the abstraction reach (beyond that observed naturally during baseflows, e.g., **Figure C-5**). It is anticipated that any such deposits will be transient because they will be cleared during larger freshes and floods when the abstraction reach will again receive the bulk of the total river flow. Thus, the greatest risk will be during extended periods when the flow released to the abstraction reach is steady at 3.5 m^3/s but still carries fine suspended sediment at the concentration arriving at the intake with the natural river flow plus all the arriving gravelly bedload.

[6] The relation for the proportion of the suspended load coarser than 300 microns (p300) is: for $Q/Q_{mean} > 7.22$, p300 = 17.8%, otherwise $p300 = 7.1(Q/Q_{mean})^{0.47}$, where Q is discharge and Q_{mean} is mean discharge.
[7] Whataroa relation is: bedload/suspended-load = $0.0172 \ln(Q/Q_{mean}) + 0.0094$, where ln is the natural log function, Q is discharge, Q_{mean} is mean discharge, and the ratio exceeds zero when $Q/Q_{mean} > 0.58$.

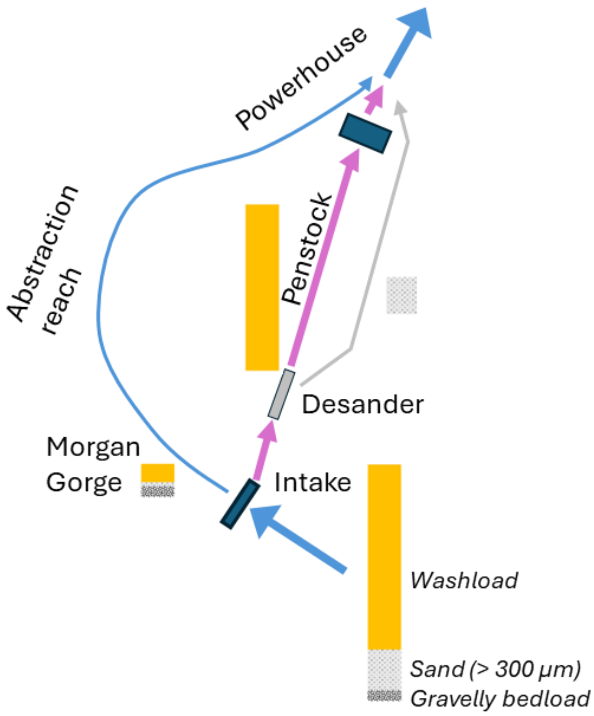

Figure D-8: Schematic of sediment diversions under normal operating conditions, scaled to a river flow of 35 m^3/s at the intake site. The suspended load is split into sand coarser than 300 microns and finer sediment (termed "washload").

Investigations. Deposition of at least some of this suspended, fine sediment load is expected in lower velocity zones along the abstraction reach. In contrast, deposition of the much heavier gravelly bedload should occur in the first significant pool downstream of Morgan Gorge. Therefore, the risks of fine sediment and bedload deposition were considered differently.

For fine sediment deposition, a conservative, "first-order" assessment was made by (i) estimating the depth of fine sediment deposition along the littoral zone that would result during extended periods at 3.5 m^3/s, and (ii) deriving a cumulative probability distribution of these event deposition thicknesses. This fine sediment deposition should not occur in the highly turbulent torrent/cascade habitat of Morgan Gorge but is expected along the lower gradient (but still relatively steep), 1.62 km reach upstream from the powerhouse, which comprises 79% fast bouldery run and 21% slower run (Allen and Hay 2013).

Allen and Hay (2013) estimated an average wetted width of 24 m along this reach at 3.5 m^3/s. It was estimated that fine sediment deposition during periods when the residual flow was steady at 3.5 m^3/s would occur over only 16% of this width in the fast run habitat (i.e., in 2 m wide zones along each bank) but over 50% in the slow run habitat (i.e., in 6 m wide marginal zones). Weighting these widths by the respective habitat proportions results in an effective depositional width of 5.6 m along the whole lower reach, and so a depositional area of 12,680 m^2. For simplicity, tributary inflows along the abstraction reach were ignored[8]. The SSC in the residual flow was assumed to be the same as

[8] Doyle's (2013) flow simulations showed that Anson Creek and Glamour Glen boost the natural discharge out of Kiwi Flat by 3.6% on average. This means that they should boost the discharge in the abstraction reach during minimum residual flow periods by 0.2 m^3/s to

that arriving at the intake and the worst case-scenario that all the incoming suspended load passed into Morgan Gorge was deposited along this approximately 2.2 km long river segment. A fine-sediment bulk density of 1.3 t/m^3 was assumed to convert sediment deposit mass to deposit volume. These assumptions led to the simple formula that every tonne of suspended sediment discharged into Morgan Gorge during minimum residual flow events would result in a sediment drape thickness of 0.05 mm along the marginal zones of the abstraction reach beyond the Gorge.

The analysis focussed on the 39-year period (1973–2012) for which Waitaha flow records have been derived, with incoming SSC over that period estimated using the SS rating curve described in **Appendix C**. However, the short 8.5-month period over 2013–2015 for which there are actual turbidity-based records of SSC was also analysed, using both this observed SSC and the SSC predicted from the rating curve, comparing the results to test the accuracy of the longer-term analysis.

The residual flow release into Morgan Gorge was assumed as follows:

- the full natural flow if it was less than 3.5 m^3/s or greater than 250 m^3/s;
- 3.5 m^3/s when the natural flow was between 3.5 and 26.5 m^3/s; or
- the natural flow minus 23 m^3/s when the natural flow exceeded 26.5 m^3/s and was less than 250 m^3/s.

The low flow diversion “rule”, which involves diverting surplus flow above 3.5 m^3/s to the Power Station until the natural flow falls below 3.5 m^3/s, is a worst-case situation. In practice, the Power Station will likely be shut down at natural low-flows somewhat higher than 3.5 m^3/s. Thus, as a sensitivity exercise, the analysis was repeated for the case of the Power Station being shut down whenever the natural flow fell below 8.5 m^3/s.

For the bedload, a “first order” analysis task was simply to estimate the volumes of bedload sent down Morgan Gorge during events when the flow released to the abstraction reach is steady at 3.5 m^3/s, and then what the sediment depth would be if this was all deposited in the first pool below the Gorge. For this: (i) the incoming bedload was estimated as a proportion of the incoming suspended load using the relation given in **Appendix C**, with the incoming suspended load derived as above, (ii) a bulk density of 1.8 t/m^3 was assumed for bedload, and (iii) the pool dimensions (30 m long by 20 m wide) were scaled from Google Earth imagery. These estimates led to the simple formula that every tonne of bedload discharged into Morgan Gorge during minimum residual flow events would result in 0.92 mm of gravel being deposited over the bed of the first pool downstream of the gorge.

0.95 m^3/s, depending on the natural discharge from Kiwi Flat. The latter flow boost figure would occur when the natural discharge from Kiwi Flat was 26.5 m^3/s. At higher natural discharges, the residual flow would no longer be steady at 3.5 m^3/s and the relative contribution of these two tributaries to it would quickly diminish as the natural discharge increased.

D.3 Risk of sand deposition downstream of Power Station from desander flushing

Problem: There exists the possibility that when sand is periodically flushed into the tailrace from the underground desander, this sand will accumulate in the Waitaha channel immediately downstream of the Power Station until it can be flushed and dispersed downstream by a subsequent natural high-flow event.

The Project engineers estimate that desander flushes will typically discharge around 250 m^3 (375 t) of sand[9]. The engineers have specified that the flushes will last 30–60 minutes and will normally be done during high-flow events when the natural river discharge exceeds 75 m^3/s in order to minimize any transient sand deposits near the tailrace.

Investigation: The investigation sought first to estimate the frequency that desander flushes will be required and then to compare the sand flush mass with the natural sand load carried by the river during "qualifying" natural runoff events (i.e., when the discharge exceeds 75 m^3/s for at least an hour) that reoccur at the same frequency. The aim was to assess the extent to which the natural event sand load would be increased by the desander flushes.

This analysis involved extending the analysis of the 1973–2012 runoff event sediment loads to include event sand loads (using the relation predicting the percentage of the suspended load coarser than 300 microns) and then estimating sand entrapment in the desander from the simulated flows diverted to the Power Station, the river's sand load at the intake, assuming that flow curvature at the intake structure would be 50% efficient at deflecting sand from the intake, and assuming that the desander itself would operate with a 90% trap-efficiency.

D.4 Effects of maintenance operations on water clarity

Problems: There are five potential water clarity issues linked to Scheme operations. The first is that large floods may, from time to time, deposit gravel that blocks the Scheme intake and/or realigns the river channel upstream, impeding the efficient functioning of the intake – particularly if compounded by jams of large woody debris. Such events would require in-channel mechanical works (by excavator and/or bulldozer) to clear the flood-deposited material and/or realign the channel. Such in-channel works would release mud bound with the riverbed gravels into the river flow, increasing the concentration of mud-grade suspended sediment in the river downstream of the intake and so reducing water clarity for the period of the works. The mud concentration (as against the total concentration of suspended mud and sand) is of primary importance because water clarity is much more sensitive to suspended mud than to suspended sand.

The second is very similar. The road crossing of Macgregor Creek will comprise a "Hynds Driftdeck" structure (i.e., a concrete ford with a raised deck that the creek passes under at baseflows) set within a low causeway formed of in-situ creek-bed gravel. Like at the Scheme intake, floods down Macgregor Creek will sometimes scour and/or deposit gravel and woody debris at the road-crossing, or even relocate the baseflow channels, necessitating maintenance work by earth-moving machinery. Some of this maintenance should be able to be done in the dry, with no impact on water clarity. However, some in-stream works will typically be necessary around the ford structure, and this

[9] Simply as an indication of scale, if undispersed this 250 m^3 volume would amount to an 8 cm thick sand drape over a 100 m span of the 30 m wide boulder bed channel below the tailrace.

will release embedded mud into the Macgregor Creek flow, which will then impact water clarity in the Waitaha River, some 400 m downstream of the road-crossing.

The third involves a transient reduction in water clarity of the Waitaha River below the tailrace during desander flushes due to mud embedded with the sand in the desander.

A fourth water clarity issue could result from efforts to flush fine sediment deposits from the abstraction reach during extended baseflow periods, should that be regarded as necessary to maintain the channel physical environment.

The fifth relates to the effect of emergency Power Station shutdowns (as described in **Appendix A**).

Investigations: The impact of intake maintenance works on downstream water clarity was assessed by simulating the increase in suspended mud concentration and associated reduction in water clarity during example maintenance events. The analysis steps were as follows:

- A relationship was developed between laboratory measured turbidity (T_L, nephelometric turbidity units, NTU) and black-disk field-measured water visual clarity (VC, m) from an 18-year (2004–2022) dataset of monthly measurements from the Haast River at the Roaring Billy site (**Figure D-9**). Of the available water quality data from Westland rivers (LAWA 2024), the Haast site with its pristine, schist-formed mountainous catchment, is the best proxy for the Waitaha River at Kiwi Flat. This relation (adjusted for logarithmic bias) is: $VC = 4.0\ T_L^{-0.876}$.

- This relationship was adjusted to provide a relation between water clarity and the turbidity recorded by the FTS turbidity instrument that was deployed at Kiwi Flat between 2013 and 2015. This adjustment made use of a relation comparing the laboratory-measured turbidity of the samples collected from Kiwi Flat in May 2015 with the matching turbidity values recorded by the field instrument at Kiwi Flat (T_F), $T_F = 1.65T_L$. This adjustment was necessary because different models of turbidity instrument can return different readings from river water samples, even if both are calibrated to the same reference suspension (typically Formazin). The same laboratory instrument was used for both the Haast and Waitaha samples.

- The latter relationship ($VC = 6.20T_F^{-0.876}$) was used to generate a 2013–2015 water clarity record at Kiwi Flat from the turbidity record collected there.

- The same Kiwi Flat turbidity record was used to generate a record of suspended mud concentration (C_m), using the relation in **Figure D-1** and estimating that the mud content of the total suspended load was 61%. This figure is based on suspended sediment size-grading data from the Hokitika and Haast Rivers (Hicks et al. 2012), which are reasonable proxies for the Waitaha River.

- An equation was developed that predicted the suspended mud concentration (g/m^3) added into the river by in-water shifting/excavation of gravels (C_{me}). This is: $C_{me} = k \cdot m_b \cdot R \cdot \rho_b / Q$, where k is a unit conversion factor, m_b is the mud content of the deposited riverbed gravels, ρ_b is the bulk density of the riverbed gravels (estimated at 1.8 t/m^3), R is the gravel turnover rate (estimated as 30–60 m^3/hr), and Q (m^3/s) is the water discharge. m_b was estimated at 0.52% mud based on sieved analysis of riverbed gravels in the nearby Whataroa River by Hicks et al. (2012). This shows that the increase in suspended mud concentration depends directly on the rate of gravel working but is inversely related to the river discharge.

- The reduced visual clarity associated with the excavation (VC_e) was then derived as $VC_e = VC \cdot ((C_m + C_{me})/C_m)^{-0.876}$, where it is assumed that turbidity and suspended mud concentration are linearly related so that proportional changes in concentration produce the same proportional changes in turbidity. Thus, the relative reduction in visual clarity increases with the gravel excavation rate but decreases as the ambient mud concentration and discharge increase.

This procedure enabled estimates of altered water clarity entering Morgan Gorge during hypothetical channel works over the 2013–2015 period of turbidity record. It was assumed that excavations would be undertaken as soon as practical on flood recessions to minimise downtime of the intake. The relative increase in suspended mud concentration, and associated reduction in water clarity, from the in-channel works will diminish downstream due to diffusion and settling processes.

The same approach and assumptions were used to estimate the effects on water clarity caused by maintenance works at the Macgregor Creek road-crossing. The main difference being that since the Macgregor Creek confluence is further downstream, the receiving flow of the Waitaha River (**Q**) is higher and its dilution potential greater.

Again, a similar approach was used to estimate the change in water clarity of the Waitaha River below the tailrace during desander flushes due to mud embedded with the sand in the desander. In this case, the suspended mud concentration added to the river by the flush (**C_{mf}**) is $C_{mf} = k \cdot M_f \cdot m_b/(Q \cdot T_f)$, where **k** is a unit conversion factor (16,666), **M_f** is the mass of sand flushed from the desander (375 t), **m_b** is the mud content of the flushed sand mass (estimated at 0.52% as a most likely value but possibly as high as 2% as a sensitivity exercise), **Q** is the river discharge (e.g., 75 m^3/s), and **T_f** is the time taken to flush the desander (30 minutes). As above, the proportional change in visual clarity associated with the flush (VC_f) was then derived as $VC_f / VC = ((C_m + C_{mf})/C_m)^{-0.876}$, where C_m and VC are the ambient mud concentration and visual clarity in the river, respectively.

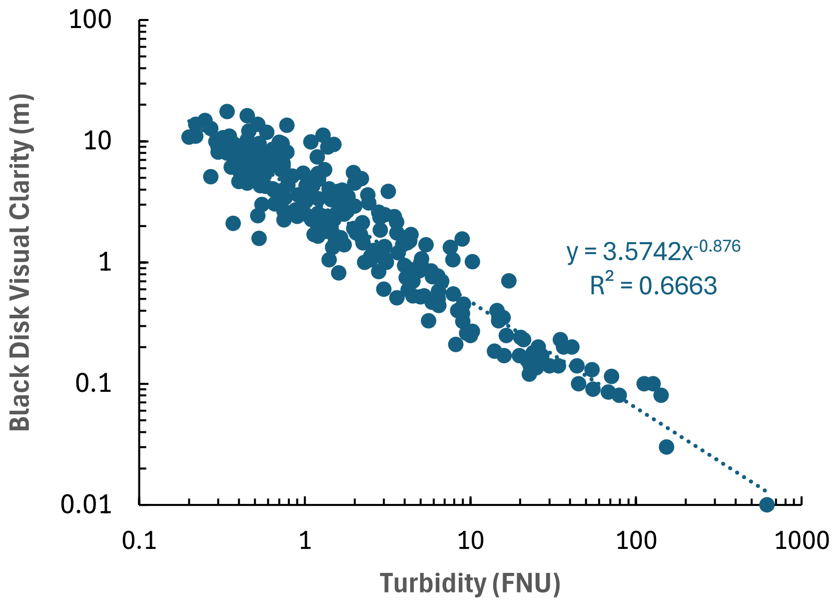

Figure D-9: Relationship between visual clarity (as measured with black disk) and turbidity in Haast River at Roaring Billy from monthly measurements 2004–2022. Data from LAWA (2024).

A similar simulation procedure was also followed to estimate the change in water clarity of the Waitaha River downstream of the powerhouse arising from any flushing flow releases (i.e., passing the full flow of the river into the abstraction reach), and made use of the estimates of sediment masses deposited in the abstraction reach during minimum residual flow events derived during the 2013–2015 period of Kiwi Flat turbidity record (see above). With this, a worst-case scenario (at least regarding downstream water clarity) was assumed in which all the fine sediment deposited prior to the flush was remobilised by the flush, with the re-suspended load declining exponentially through an assumed 12-hour flush period. This re-suspended sediment load was added to the ambient suspended load, and the change in total suspended load immediately below the Power Station relative to the ambient load was used to estimate the change in water clarity (as above).

The same approach was used to assess the effect on fine sediment entrainment and associated decreased water clarity of a sudden increase in flow down the abstraction reach associated with an emergency shutdown of the Power Station, since this would be the equivalent of an engineered flush. Further calculations with results from the **Downstream Flow Modelling Report** showed that the worst-case acceleration of flow associated with an emergency shutdown with the 10 m^3/s bypass valve operating (4.3 m^3/s/minute in the abstraction reach and 2.1 m^3/s/minute immediately downstream of the Power Station) would not much alter the flow's bed shear stress (and hence sediment entrainment capability) in the lower part of the abstraction reach and below the Power Station beyond what would occur under steady flow conditions[10].

The effect of emergency shutdown flow transients on the entrainment and deposition of coarse bedload (i.e., gravel, cobbles, boulders) was assessed by logical reasoning. At the intake, a shutdown would simply pass the full river flow and bedload into the abstraction reach as occurs naturally. Under normal Power Station operation, the reach downstream of the Power Station will be under-supplied with bed material (since the transport capacity through the abstraction reach will be less than it is downstream of the Power Station by virtue of reduced flows), so reducing the flows further downstream will simply help rebalance the bed-material supply and transport capacity. Given that, and the limited (approximately 30 minute) duration of the flow transient, then the impact on bedload transfer and bed-material deposition/entrainment of an emergency shutdown should be negligible.

[10] The bed shear stress in unsteady flow, τ, was derived as defined by Pathirana et al. (2008): $\tau = \rho gys + \rho gy(1/c)dy/dt - \rho(ydu/dt(1-u/c))$, where ρ is water density, g is the gravitational acceleration, y is mean water depth, u is mean velocity, s is channel slope, dy/dt is rate of change in depth, du/dt is acceleration, and c is wave celerity ($c = u + (gy)^{0.5}$). s, and u and y as a function of discharge, along the lower part of the abstraction reach and downstream of the Power Station were derived from the instream flow habitat surveys of Allen and Hay (2013). The first shear stress term is the steady-state shear stress (i.e., without any flow change with time), the second is the stress increase due to the steepened water surface slope associated with the rapidly-changing flow, and the third is the stress due to the acceleration with time. Even with ramping rates of 5 m^3/s/min, the steady-state term dominates the total shear stress because of the very high channel slope (s = 0.017), thus the shear stress is relatively insensitive to the flow ramping rates.

D.5 Potential aggradation of Kiwi Flat

Problem: While Kiwi Flat experiences substantial geomorphic activity associated with floods and varying sediment deliveries from upstream, superimposed on this the Scheme's weir has the potential to cause permanent aggradation along Kiwi Flat if it significantly affects the hydraulics of the river flow along Kiwi Flat. A potential concern is that it will cause aggradation along the whole length of Kiwi Flat (i.e., the entire Flat might lift by several metres, parallel to its existing grade, to match the change in the height of the control at Morgan Gorge). This could also cause the bed of Whirling Waters to rise. This is indeed how an ideal and simple alluvial reach of river is expected to respond.

Investigation: To assess this, Hicks (2013) made field observations along Kiwi Flat, including surveying the Waitaha River channel, and built a one-dimensional hydraulic model of the Waitaha channel that extended from upstream of Kiwi Flat to the bottom of Morgan Gorge. The model was built using topographic data from channel surveys along Kiwi Flat (of 22 February 2013 by Hicks 2013), from Coastwide Surveys for the vicinity of the intake weir, and from LINZ *Topomap* contours for upstream of Kiwi Flat, and estimating the hydraulic roughness. The model was run at discharges of 10 m^3/s and 1000 m^3/s with and without the intake weir present. The former flow is a typical baseflow while the latter corresponds to somewhere between a 5 and 10-year recurrence interval flood (Doyle 2013, Table 8). The weir crest elevation (238 m on project datum) and location were as supplied by Westpower in 2013, but these remain current. Without the weir, the model-predicted water level profile along Kiwi Flat at 10 m^3/s aligned with those surveyed on 22 February 2013, when the gauged flow was 9.5 m^3/s, while the modelled profile at 1000 m^3/s aligned with the level of recent silt banks inferred to have been deposited from the flood in December 2012 that exceeded 1000 m^3/s at the Kiwi Flat gauge, thus confirming reasonable hydraulic calibration of the model over the flow range of interest.

D.6 Likelihood of bank erosion opposite the Power Station

Problem 1: The Scheme involves building the powerhouse on the short span of low, tussock-and scrub-covered terrace on the Waitaha River right bank immediately upstream from Alpha Creek (**Figure D-10**). Currently, the Waitaha River runs in a boulder-lined channel to the left of this terrace, but the terrace, only 5–6 m above the river, has a flood-overflow channel that drains into Alpha Creek. A flood-protection wall is required to keep flood spill from the powerhouse infrastructure area. However, this will force more flood flow down the Waitaha main channel, potentially causing its left bank to erode (the right bank will be stabilised by the armoured floodwall). Currently, the left bank is cut into a forested terrace formed of material that ranges in size from sand through boulders. Its upper part is near-vertical and shows signs of recent erosion, but the lower bank is armoured by boulders left as a lag as the bank has retreated over time. Thus, the left bank opposite the powerhouse site is already prone to erosion, but its rate of erosion appears limited by natural armouring. The question is: how much further erosion could be caused by the floodwall?

Figure D-10: Waitaha bank at Power Station site. Left: the left bank with a boulder lag on its lower slope. Right: schematic showing natural flood-spill channel and floodwall on the terrace where the Power Station is proposed to be located.

Investigation: The investigation (Hicks 2014), undertaken with NIWA colleague Richard Measures, used a hydraulic model that predicts water levels and calculates the lateral distribution of flow velocity and shear stress (i.e., current drag) on the banks. It used data from surveys of channel cross-section and long profile and bank-material size and was calibrated hydraulically by matching predicted water surface profiles to flood trash lines from an estimated 1400 m^3/s flood that occurred in December 2013. This flood had an estimated 100-year recurrence interval (Martin Doyle, pers. comm.). The model was run to estimate the potential erosion extent of the left bank, without and with the floodwall, at discharges of 1400 and 812 m^3/s, where the latter is the estimated mean annual flood size at Kiwi Flat (which has a 2.3-year recurrence interval). The erosion extent was estimated in two ways. First, the left bank was shifted laterally (i.e., eroded) until the water level fell back to the level without the floodwall. Second, the left bank was shifted until the shear stress at the left bank toe fell back to that without the floodwall. The shear stresses over the left bank were also compared to the threshold-of-motion stresses of the natural bank armour.

Problem 2: The proposed bypass valve to mitigate river flow transients during emergency Power Station shutdowns would discharge up to 10 m^3/s as an aerated water plume approximately 100 m long, 40 m high, and 36 m wide that would fall on the river downstream of the tailrace. This could potentially erode the opposite riverbank if directed more across-river than down-river.

Investigation: The **Project Description** and **Project Overview Report** provide, however, that this plume will be directed down-river to avoid erosion on the opposite riverbank, thus no investigations were considered necessary.

D.7 Potential geomorphic effects of gravel extraction on Waitaha braidplain

Problem: The proposal is to permanently remove up to 23,000 m^3 of gravel from the Waitaha braidplain for use in access road construction. This has the potential to affect geomorphic form and processes both at the extraction localities and further downstream including the coast adjacent to the Waitaha River mouth.

Investigation: Investigations involved:

- Inspecting historical satellite imagery to (i) compare the borrow area sizes, shapes, and locations with those of the bars, braids, and bends of the natural channels, and (ii) to gauge the extent and frequency of bar and channel migrations at the borrow areas.
- Comparing the proposed total gravel extraction volume of 23,000 m^3 with the estimated average annual Waitaha River bedload transport rate downstream of the Macgregor Creek confluence.
- Assessing if the total extracted volume would be sufficient to induce any significant downstream impacts on channel stability and coastal stability north of the Waitaha mouth using the Hicks (2017) guidelines.

Appendix E Potential effects of the scheme

E.1 Overall effect on sediment transport and channel morphology

The Waitaha channel at Kiwi Flat naturally exhibits considerable instability due to frequent large floods, high but variable fluxes of bed-material, the choking of Morgan Gorge during floods, and transient deposition and re-working of sediment in response to these drivers. This is evident from abandoned branches (typically perched above the existing channel), terraces and banks of deposited sand and gravel, armoured segments of bed and bank, and places where the channel margins have eroded or are eroding. The Scheme will not alter this suite of natural processes and fluvial features, nor their frequencies of occurrence or physical characteristics. The only potential long-term effect on average riverbed level is limited to the lower few 100 m of Kiwi Flat and is small in the context of the natural variability experienced there.

Along the abstraction reach, the Waitaha River falls through the bedrock-lined Morgan Gorge then flows along a still relatively steep boulder lined reach. Bed material transport and channel morphology there are also dominated by the frequent flood regime. Since the Scheme will have minimal impact on the flood regime (i.e., bypassing all flows exceeding 250 m^3/s and diverting only up to 23 m^3/s from lesser flood flows), its effect on bed material transport through this reach will be **less than minor**. The only potential effects are transient fine sediment deposition during baseflow periods, and potential bank erosion stemming from reduced channel conveyance past the Power Station.

Downstream of the powerhouse, the Waitaha River will always have its natural flow regime and supply of bedload and suspended load. This is because (i) there is no water storage in the Scheme, so hydrographs will not change, (ii) any fine sediment and gravelly bedload deposited in the abstraction reach between floods will be flushed during subsequent floods, (iii) diverted suspended fine sand and mud will pass directly through the Power Station to the tailrace, and (iv) the sand intercepted by the sander will be sluiced directly to the tailrace. Thus, no downstream effects relating to interruptions of sediment transport continuity (such as typically occur downstream of a large dam that stores both water and sediment) are anticipated.

It is concluded that broadly, the Scheme will have **less than minor** effects on sediment transport processes and channel characteristics along the Waitaha channel, except perhaps for the potential localised exceptions that are further considered below:

- transient sediment deposition in the abstraction reach;
- transient sand deposition downstream of the Power Station;
- effect of maintenance operations and emergency shutdowns on water clarity;
- aggradation along Kiwi Flat; and
- bank erosion opposite the Power Station.

E.2 Transient sediment deposition in abstraction reach

In the abstraction reach, the potential concern is that during normal scheme operations, the incidence and extent of fine-suspended and coarse-bedload deposition will increase in the abstraction reach, particularly during extended baseflow periods when the residual flow will be steady at its minimum value of 3.5 m^3/s.

In regard to fine sediment, as noted in **Appendix C** deposits of fine sediment already naturally accumulate along the Waitaha channel margin during baseflows, and it is possible that this might worsen along the abstraction reach because: (i) the lowered, steady flow in the abstraction reach will have less bankside turbulence, promoting enhanced sediment deposition compared with what would occur without the diversion, and (ii) the marginal zones prone to sedimentation may widen if the reduced flow covers only the flatter base of the channel bed.

The investigations, detailed in **Appendix D**, focussed on the periods of steady minimum residual flow when the risk of this sediment deposition should be greatest. Using the simulated flows assuming the scheme operated over the 1973–2012 period, there would have been 33 events/year on average when the residual discharge into Morgan Gorge was steady at 3.5 m^3/s for longer than a day (**Figure E-1**). Most of these events (22 events/year) lasted from 1–7 days, with only 11 events/year lasting longer than one week. These longer events typically, but not always, occurred during the winter months. The longest event (June–August 1996) spanned just over 10 weeks.

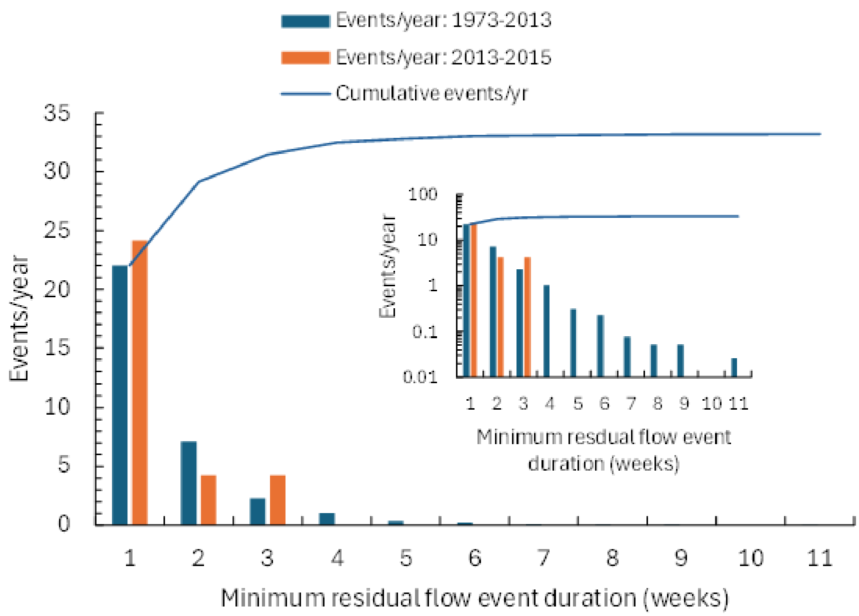

Figure E-1: Frequency and cumulative distributions of duration of events when residual flow into the abstraction reach would be steady at 3.5 m^3/s minimum (events lasting less than 1 day excluded). Blue bars and line show the period 1973–2012 and orange bars show the period 2013–2015. Inset graph plots the same data with event-count on log-scale, highlighting data for events of longer duration.

The short, 8.6-month period of useful turbidity record over 2013–2015 showed a similar frequency-distribution of steady-at-3.5 m^3/s event durations to the longer period (**Figure E-1**). Also, for the same period, estimating SSC off the rating curve and from the turbidity record yielded very similar cumulative distributions of suspended load and associated littoral margin deposit thickness for these events (**Figure E-2**). So, the short period appears reasonably representative of the longer one, and the rating curve approach, while not capturing the short-term variability in SSC that the turbidity record did, appears to give a reliable rendering of the statistics of the sediment loads into the abstraction reach during the steady-at-3.5 m^3/s residual flow events.

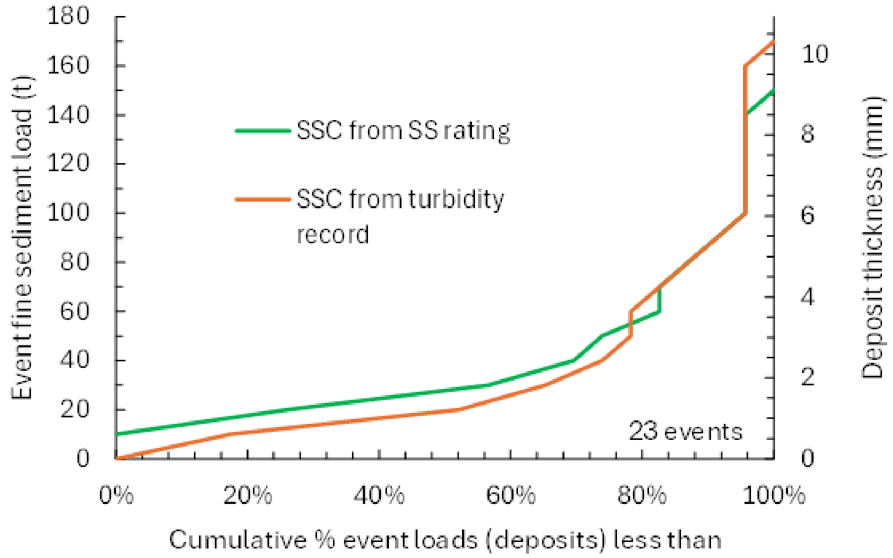

Figure E-2: Cumulative distributions of suspended load passed into the abstraction reach during minimum residual flow events exceeding one day and associated fine sediment deposit thickness along littoral margins. Derived over 2013–2015 period using SSC proxied from turbidity record and from discharge via SS rating curve.

Based on the above, focus was directed to results from the longer 1973–2012 period and those minimum residual flow events that last longer than one week. While ultimately arbitrary, the one-week cutoff is based on two considerations. First, fine sediment deposits in the abstraction reach are expected to be flushed by high-flow events, so the ecological impact of a fine sediment drape existing only a few days (as against several weeks) should be minimal. Second, the minimum residual flow event suspended load generally increases with event duration (**Figure E-3**), although it also depends on the size of the flow arriving at the Scheme intake.

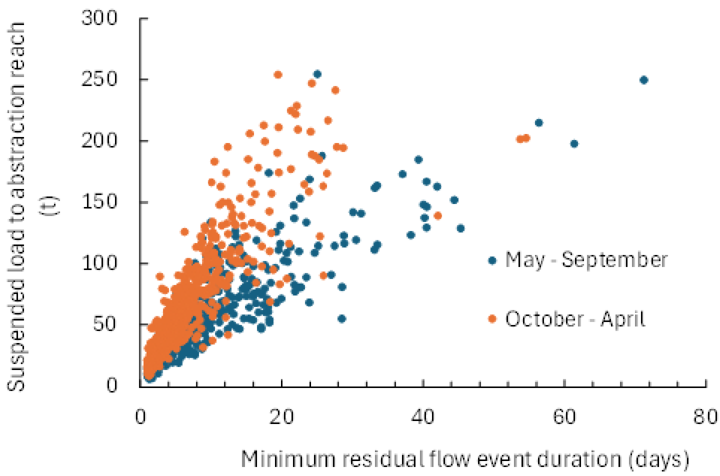

Figure E-3: Suspended load discharged to abstraction reach during minimum residual flow events vs duration of minimum residual flow events for 1973–2012 period, distinguished by season. Scatter stems from the varying discharge arriving at the intake during the minimum residual flow event.

Over this 1973–2012 period, the simulations showed that the suspended sediment load entering the abstraction reach during the minimum flow events would have ranged from 25–254 tonnes and would have deposited sediment drapes 2–14 mm thick (assuming all the incoming sediment was deposited uniformly along the abstraction reach). Half the events (i.e., 5.5 events/yr) would deposit drapes over 5 mm thick but only ¼ (less than 3 events/year) would deposit drapes over 7 mm thick (**Figure E-4**).

As noted above, the amount of sediment entering the abstraction reach during each event depended on both the minimum flow event duration and the discharge from Kiwi Flat over the event, both of which are seasonally influenced (**Figure E-3**). In winter months (May through September), such event durations tended to be longer but their associated loads were typically lower by virtue of lower river baseflows. In contrast, over summer months (October–April), such event durations tended to be shorter but their sediment loads could be as high as occurred in winter by virtue of the greater summer baseflows. Thus, the risk of measurable fine sediment deposits persists regardless of season.

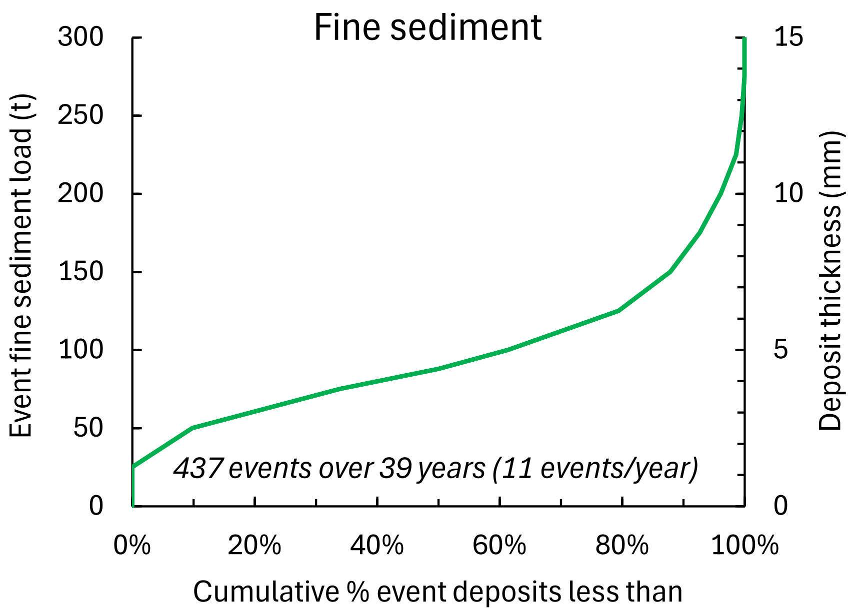

Figure E-4: Cumulative distribution of suspended sediment loads passed into abstraction reach and associated average deposit thicknesses along channel margins. The plotted sediment loads are for minimum residual flow events longer than one week over period 1973–2013 (when there were 437 such events).

Repeating the analysis assuming, as a sensitivity exercise, that diversions to the power-station would cease whenever the natural flow fell below 8.5 m^3/s (rather than below 3.5 m^3/s) made minimal difference to the above figures:

- the average frequency of steady-at-3.5 m^3/s events in the abstraction reach lasting 1-7 days would be 25/year (compared with 22/year above), with 10 events/year lasting longer than one week (compared with 11 events/year above); and
- sediment drapes would be 2–15 mm thick (compared with 2–14 mm above), with 5 events/year depositing over 5 mm (compared with 5 mm from 5.5 events/year above), and less than 3 events/year would deposit over 7 mm (the same as above).

The thicknesses of the potential, albeit transient, fine sediment drapes derived above are likely to be upper-bound estimates because of the conservative assumptions made: that the abstraction reach will trap all the incoming suspended load, that it will be deposited over only a portion of the channel width, and that increases in discharge above 3.5 m^3/s by the tributaries entering the along abstraction reach have been ignored.

The effect of the fine sediment drapes on biota is addressed in the **Freshwater Ecology Report**. Acknowledging the uncertainty of what fine sediment deposits may accumulate under the Scheme, the **Freshwater Ecology Report** concludes that there is the potential for **more than minor** adverse effects on biota. Thus, it would be prudent to monitor fine sediment accumulation in the lower part of the abstraction reach and to flush any excessive accumulations by temporarily reducing the take to the Power Station. A strategy for this management regime is developed in **Appendix F**. The effect of such flushes on water clarity are considered below.

Considering the gravelly bedload discharge into Morgan Gorge, the bedloads during steady-at-3.5 m^3/s residual flow events range from zero to 3.2 tonnes, which would deposit a layer 0-3 mm thick in the first pool downstream of the gorge, with half the events depositing less than 1 mm (**Figure E-5**). These figures are small because the bedload carried out of Kiwi Flat by discharges less than 26.5 m^3/s (which are required for a 3.5 m^3/s residual flow) is very small – by virtue of bed-armouring (which limits the gravel supply) and the threshold of motion effect (which limits the flow's transport capacity) at these common discharges. And while the bedload has only been estimated as a proportion of the suspended load, even a factor-of-10 underestimate of the bedload would produce an only 30 mm thick transient deposit in the first pool.

As for fine sediment, repeating this gravel deposition analysis supposing that diversions to the Power Station would cease whenever the natural flow fell below 8.5 m^3/s (rather than below 3.5 m^3/s) made minimal difference to the above figures.

Therefore, it is concluded that gravelly bedload deposition downstream of Morgan Gorge during steady-at-3.5 m^3/s residual flow events should be a **less than minor** effect.

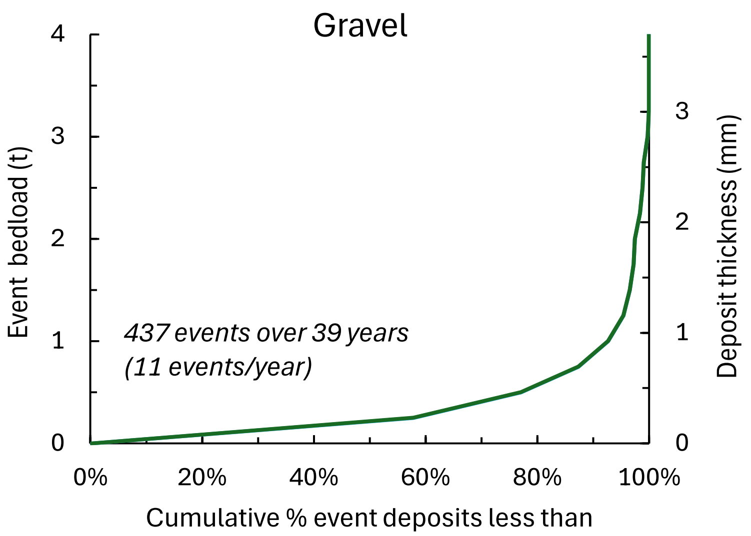

Figure E-5: Cumulative distribution of gravelly bedload passed into abstraction reach and associated average deposit thickness in first pool encountered. The plotted bedloads are for minimum residual flow events longer than one week over period 1973–2013 (when there were 437 such events).

E.3 Sand deposition downstream of Power Station from desander flushing

As described in **Appendix D**, the sand mass to be flushed as necessary from the desander (375 t) was compared with the natural sand load carried by the Waitaha River during a runoff event of the same frequency.

The desander sand entrapment analysis indicated that on average, the desander would collect 3160 t/yr, which would therefore require an average 8.4 flushes/year (i.e., every 6.2 weeks) at 375 t per flush.

In comparison, the analysis of natural event sand loads showed that "qualifying" natural river events (i.e., exceeding 75 m^3/s and 1 hour) recurring at the same average frequency as the flushes would carry a sand load of at least 4120 t (over 10 times the flushed sand mass). Even events recurring 18.3 times/year (every 2.8 weeks on average) would carry a sand load at least twice the flush mass. Moreover, such additions to the sand load by desander flushing would be well inside the natural factor of at least 10 (possibly 100) variation in suspended sediment load observed at Kiwi flat amongst runoff events (**Figures D-3, D-4**) and not beyond the Waitaha River's sand transport capacity at the powerhouse site as evidenced by the absence of a sand-covered riverbed there.

It is concluded that providing desander flushes are scheduled with natural runoff events as proposed, desander flushing should not overload the Waitaha River at the Power Station in regard to its natural sand load, and any effects of transient accumulations of sand immediately downstream of the powerhouse due to desander flushing should be **minor**.

E.4 Effects of channel maintenance operations at intake on water clarity

As described in **Appendix D**, the relative change in clarity of the water flowing into Morgan Gorge was estimated for example instances when in-channel works would be needed to reform the training wall and/or clear flood-deposited gravel and woody debris from around the intake structure. The relative reduction in clarity would be greater the higher the rate of gravel working (i.e., m^3/hour), the lower the river discharge, and the lower the background turbidity and SSC.

Figure E-6 illustrates the estimated changes in water clarity downstream of Morgan Gorge associated with a hypothetical intake maintenance event following the 390 m^3/s flood on 26 January 2014, assuming gravel excavation/turnover rates of 30 m^3/hour and 60 m^3/hour. The ambient visual clarity was ~ 1.6 m before the flood, dropped to <0.1 m over the flood, then recovered to exceed the monitoring-period-averaged median clarity of 0.78 m after several days. Commencing on 26 December, when the discharge had receded below 50 m^3/s (an assumed safe working threshold), the channel works at 30 m^3/hour would have reduced the visual clarity by ~ 0.1 m on average over the four-day work period, while this average reduction increases to ~ 0.2 m at a 60 m^3/hour work rate. The divergence between the ambient and with-works clarity records over time reflects the increasing "signal" of the works-stirred mud relative to the ambient suspended mud as the discharge and ambient turbidity wane on the flood recession. Even at 60 m^3/hour, however, the clarity reduction due to the channel maintenance works would have been much less than that associated with the preceding flood.

It is concluded that (i) the impact of such transient channel works on water clarity will be small relative to the clarity reductions associated with natural freshes and floods, and (ii) the effect of such works could be mitigated by limiting the rate of gravel shifting/excavation, working if safe and practical at higher river flows, and minimising machine operation in-channel when possible. Under such conditions the impact on water clarity would be reduced from **minor to less than minor**.

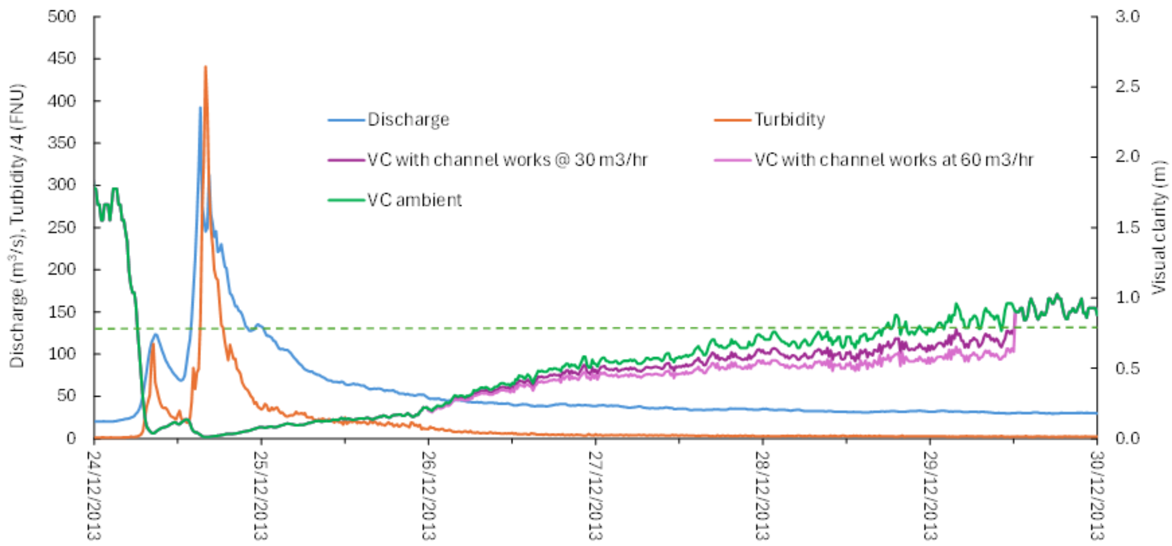

Figure E-6: Changes in visual clarity associated with in-channel gravel shifting/excavation at intake for hypothetical maintenance event following 390 m^3/s flood. Occurring on 24 December 2013. Works commenced on 26 January and continued through 29 December, turning over gravel at a rate of 30 m^3/hour or 60 m^3/hr. Dashed green line shows median clarity over 2013–2015 turbidity monitoring period. Note recorded turbidity is four times the plotted value.

E.5 Effects of Macgregor Creek road-crossing maintenance operations on water clarity

The relative change in clarity of the Waitaha River downstream of the Macgregor Creek confluence due to maintenance work on the Macgregor Creek road-crossing was assessed as above, allowing for a higher Waitaha discharge at MacGregor Creek which would dilute the impact of the mud resuspension. The same conclusions as above apply: in the context of the greatly reduced water clarity that occurs naturally during frequent runoff events, the impact of the road-crossing maintenance works would be **minor**.

E.6 Effects of abstraction reach flushes on water clarity

Using the approach described in **Appendix D**, the relative change in clarity of the Waitaha River immediately downstream of the powerhouse was simulated for a hypothetical flush of deposited fine sediment from the abstraction reach. As illustrated in **Figure E-7**, the hypothetical flush involved passing the full flow of the river (approximately 14 m^3/s) into the abstraction reach for 12 hours on 15 February 2014, 16 days into an event when the abstraction reach discharge would have been steady at 3.5 m^3/s and an estimated 68 t of fine sediment was deposited in the abstraction reach. Assuming the extreme case of all these 68 t being remobilised, and most early during the flush, the visual clarity downstream of the powerhouse would fall from ~ 2.0 m to <0.1 m for several hours. However, and in comparison, the clarity fell to similarly low levels for a longer period during the preceding flood on 24 January (peak discharge 330 m^3/s and peak turbidity 1048 FNU at Scheme intake), and even during the small fresh on 12 February (peak discharge 22 m^3/s and peak turbidity

113 FNU at Scheme intake) the clarity fell to 0.1 m. Moreover, the reduction in clarity due to the flush would attenuate downstream from the Power Station due to diffusion processes. It is concluded that, while visible, the effect of such flushes on downstream water clarity in the Waitaha River would be well within the bounds of water clarity changes experienced more frequently during natural runoff events and would therefore be **minor**.

Figure E-7 also demonstrates how water clarity in the Waitaha River would improve by around 0.2–0.3 m downstream of the Power Station during normal operation of the Scheme due to fine sediment settling in the abstraction reach.

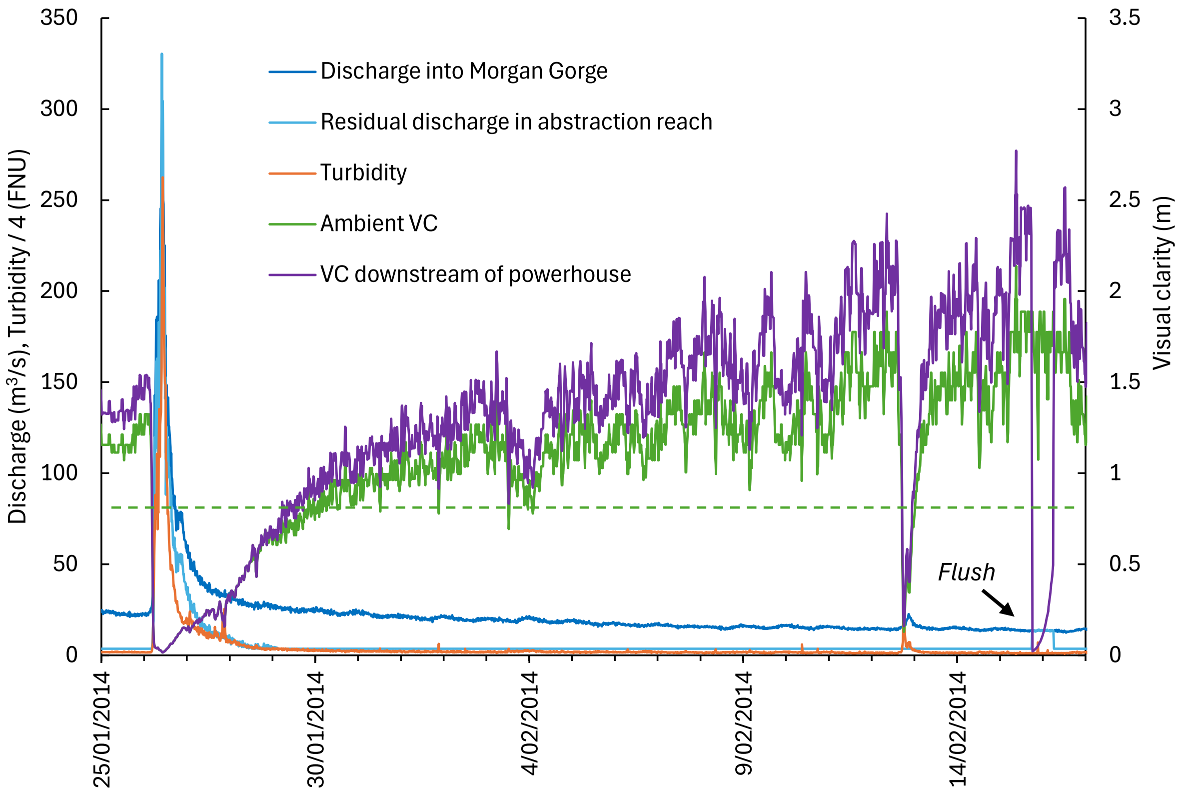

Figure E-7: Changes in water visual clarity (VC) downstream of Power Station associated with normal Scheme operation and with flushing fine sediment deposited in the abstraction reach. Changes are illustrated for a 12-hour flush on 15 February 2014 (arrowed), 16 days into an 18-day period when the natural discharge was 14 m^3/s and the discharge in the abstraction reach was steady at 3.5 m^3/s, with 68 t of fine sediment remobilised. Dashed green line shows median clarity over 2013–2015 turbidity monitoring period. Note recorded turbidity is four times the plotted value.

E.7 Effect of emergency Power Station shutdown on water clarity

Figure E-7 was also used to inform on the relative change in clarity of the Waitaha River due to fine sediment remobilised from the abstraction reach caused by rapidly ramped-up flow associated with an emergency shutdown of the Power Station. As noted in **Appendix D**, this situation is equivalent to an engineered flush of the abstraction reach, and the increase of abstraction reach flow from 3.5 to 14 m^3/s on 15 February 2014 in the hypothetical example shown in **Figure E-7** is much the same as the worst-case (in terms of relative increase in abstraction reach flow) situation for an emergency shutdown with bypass valve operation where the abstraction reach inflow would increase from 3.5 to 16.5 m^3/s. In that context, the effects on water clarity downstream of the Power Station associated with an emergency shutdown would be no worse (and indeed would last for a much shorter time) than experienced during an engineered flush. Thus, the water clarity changes experienced with an emergency shutdown should also be **minor**.

As noted in **Appendix D**, emergency Power Station shutdowns should have negligible impact on bedload transport in the river, given that the shutdowns are likely to occur four times a year on average, are more likely to occur during high-flow conditions when the relative magnitudes of the induced flow transients will be small, and the duration of effects will be limited to around 30 minutes, after which the river will have returned to its natural downstream distribution of flow and bedload transport.

E.8 Effects of desander flushes on water clarity

Sand deposited in the desander is likely to contain small amounts of embedded mud (estimated at 0.52%), which, during desander flushing, will add to the river's suspended mud concentration and turbidity at the tailrace. Under a normal desander flushing scenario in which 375 t of sand is flushed over 30 minutes into a river discharge of 75 m^3/s, when the river's ambient suspended mud concentration is estimated (from the sediment rating curve) to be 216 g/m^3, the flush would increase the suspended mud concentration to 230 g/m^3. This would reduce the ambient water clarity in the river at the tailrace by 6% (or by 18% if the embedded mud proportion was as high as 2%). Such proportional clarity reductions would be difficult to discern visually and would lessen progressively as the river discharge during the flush increased above 75 m^3/s, due to the associated increase in river suspended mud concentration. Therefore, it is concluded that embedded mud should have a **less than minor** effect on instantaneous water clarity during normal desander flushing operations. The flushed sand itself should have low impact on water clarity because the >300 microns sand that is targeted by the desander has much less impact on water clarity than does suspended mud (which is some 10–300 times finer grained and more optically responsive).

E.9 Kiwi Flat aggradation

As detailed in **Appendix D**, an assessment was made of the aggradation that might occur at Kiwi Flat with the weir built at the inlet to Morgan Gorge. A potential concern is that the weir will cause aggradation along the whole length of Kiwi Flat (i.e., the Flat will rise parallel to its existing grade to match the change in the height of the control at Morgan Gorge). This could also cause the bed of Whirling Waters to rise. This is indeed how an ideal and simple alluvial reach of river is expected to respond. However, as explained previously, Kiwi Flat has a more complex hydraulic and sedimentation behaviour than a typical alluvial reach, due mainly to the constricting effect of the narrow entrance to Morgan Gorge which sets the hydraulic control for flood flows along the lower section of Kiwi Flat.

The hydraulic modelling at 1000 m^3/s without the weir in place confirmed this field-based appreciation of the natural situation by showing a choking pond extending some 700 m upstream (almost as far upstream as Whirling Waters) and with a water-surface elevation that aligned with the elevations of recently deposited sand banks. Re-running the model with the weir in place made no difference to this 1000 m^3/s flood profile (**Figure E-8**). This arises because the weir is submerged in the backwater reach upstream of the control point in the gorge throat. Thus, the effects of the weir on river processes during large floods along Kiwi Flat would be **less than minor**.

The weir's only impact would be developed at lower flows when the weir would set the hydraulic control at the Gorge entrance. Under those conditions, the weir would initially create a backwater that would extend about 200 m upstream (**Figure E-8**). The short pond created by the weir would have only a few thousand m^3 of storage, thus it would fill with cobbly-gravel material quickly, possibly over the first small high-flow event or flood recession. At that stage, assuming this deposit formed with a slope of 7.7 m/km (which is the surveyed riverbed slope along the alluvial segments of Kiwi Flat), then the re-graded riverbed profile would intersect the natural riverbed profile about 300 m upstream from the weir (**Figure E-8**). Thus, this would be the likely upstream extent of the weir's influence on channel morphology at flows when the gorge does not choke. Moreover, downstream of Whirling Waters the River at normal flows occupies a relatively narrow (30–60 m wide) channel that wanders between the high, flood-formed gravel bars and sand banks, so the width of the bed-level regrading would be confined to this relatively narrow and incised normal flow channel.

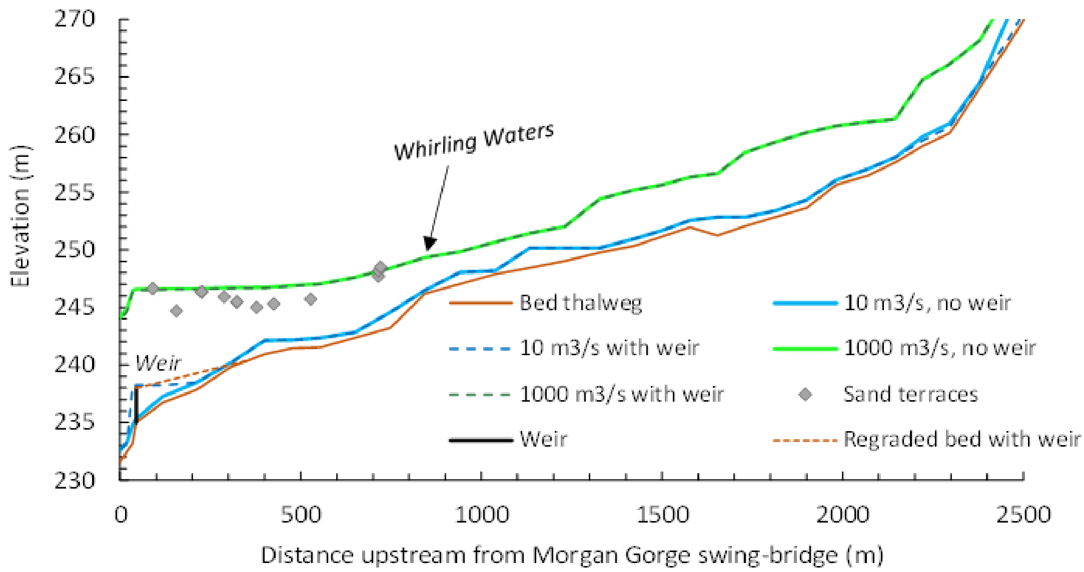

Figure E-8: Modelled water surface profiles along Kiwi Flat at 10 and 1000 m^3/s, without and with weir. Diamonds show elevation of sand terraces formed during recent floods. Dashed brown line shows estimated re-graded bed thalweg profile with weir. Whirling Waters joins the Waitaha some 700 m upstream from Morgan Gorge.

It is concluded that the effects of the weir at the proposed location will be limited spatially and, over time, will be lost in the natural variability experienced at Kiwi Flat during its frequent floods and erratic sediment supplies, thus there should be only **minor** effects on the riverine landscape. Future LiDAR surveys of Kiwi Flat, repeated on a 5–10 yearly basis, would verify this projection when compared with the LiDAR survey of Kiwi Flat scheduled for November 2024.

E.10 Bank erosion opposite powerhouse

As detailed in **Appendix D**, a hydraulic model was used to investigate the likelihood and lateral extent of erosion of the Waitaha River left bank opposite the powerhouse, due to reduced flood conveyance associated with the flood-protection wall to be built alongside the Power Station. The model was run at discharges of 1400 and 812 m^3/s, where the former has an approximately 100-year recurrence interval and the latter is the mean annual flood which has an approximately 2.3-year recurrence interval.

It was found that even at 1400 m^3/s, the floodwall would induce only slight increases in water level (8–17 cm) and shear stress (1-2%) against the left bank. While such an event just has the competence to mobilise the boulders lining the left bank, and so some bank erosion is likely during an event of this size, retreat of only 1–3 m would be all that would be required to recover the hydraulic conditions without the flood-protection wall. At 812 m^3/s, the modelling showed that all the flow would just be contained by the Waitaha channel and would not be concentrated by the floodwall. Thus, the hydraulic effects of the floodwall would only occur with floods with recurrence intervals exceeding ~ 2.3 years, and even during the largest of those events, bank retreat extents would be short and naturally mitigated by self-armouring.

It is concluded that the effect of the floodwall on erosion of the left bank across from the Power Station would be **less than minor**.

In regard to the possibility of the bypass-valve's spray plume eroding the Waitaha riverbank opposite the Power Station, this will be avoided by directing the valve's discharge directly downstream as proposed in the **Project Description** and in the **Project Overview Report**. Westpower have also advised that they operate a 10 m^3/s bypass valve at the Dillman's power station near Kumara without any bank erosion issues (Rodger Griffiths, Westpower, pers. comm., 30/1/2025).

E.11 Geomorphic effects of gravel extraction from the Waitaha braidplain

Near-field effects:

Considering the proposed Waitaha gravel extraction, the minimum average annual bedload estimated at the Waitaha gravel extraction site below Macgregor Creek is 37,500 m^3/yr (based on estimated bedload from Kiwi Flat scaled-up by catchment area and bulk density of 1.8 t/m^3). However, it could easily be twice as large at 75,000 m^3/yr, particularly given the large (albeit unquantified) gravel discharge from Macgregor Creek that is sourced from active slips and gullies along the Alpine Fault trend in the right branch headwaters. By comparison, the active volume of a typical gravel bar at this location on the Waitaha is of the order of 75,000 m^3 (500 m long by 150 m wide by 1 m depth, from Google Earth and LiDAR imagery inspection). Bedload transport in the Waitaha River is manifest by floods transferring gravel from one bar to the next downstream, so the mean annual bedload is equivalent to shunting each gravel bar about 500 m downstream every 1–2 years.

Since the proposed one-off extraction volume of 23,000 m^3 from the Waitaha River borrow areas amounts to at most 61% of the average annual Waitaha bedload, the extraction "hole" can be expected to be smeared-out within several years (depending on what floods occur after the extraction).

Inspection of satellite imagery covering the proposed Waitaha borrow areas over the past decade showed considerable bar activity and lateral shifting of the main Waitaha braids driven by the frequent flooding regime. As illustrated on **Figure E-9**, while the borrow areas identified in earlier proposals were dry and accessible from the northern bank on 29/10/2023, on 2/5/2021 these areas were on the south side of the Waitaha main braid, and on 31/10/2018 they were in the main braid. Thus, the Waitaha braidplain is very active and to meet the Rule 29 requirements of extracting only from dry riverbed (Rule 29c) and avoiding / minimising machinery movement in the wetted riverbed (Rule 29h), the actual borrow-areas will need to be located according to braid and bar locations at the time of extraction, not necessarily as mapped in early versions of the proposal.

Thus, the impact of the proposed extraction from the Waitaha braidplain on the local channel morphology and gravel transport would be **minor**, but the exact location of the borrow areas will need to be selected when it is due to commence. This is recognised in the current proposal.

Figure E-9: Gravel borrow-area 1 and 2 locations (red outlines) on Waitaha active braidplain downstream from Macgregor Creek as originally proposed. While dry and accessible from northern bank on 29/10/2023, on 2/5/2021 these areas were on the south side of the Waitaha main channel and on 31/10/2018 they were in the main channel. Current proposal recognises that borrow-areas will need to be located according to braid and bar locations at the time of extraction. Borrow-areas shown taken from Westpower Plans *Waitaha River proposed new power scheme gravel take areas for the road construction etc, Waitaha Area 1 (Wed Feb 5 11:04:11 2025)* and *Waitaha River proposed new power scheme gravel take areas for the road construction etc, Waitaha Area 2 (Wed Feb 5 11:04:44 2025)*.

Far-field effects

The Hicks (2017) guidance for WCRC included a decision tree for assessing the significance of river gravel extraction on coastal stability. The logic flow of the proposed Waitaha gravel extraction on this decision tree is shown on **Figure E-10** (following the solid red path):

- Most of the gravel bedload passing the extraction site must be assumed to connect to the coast, since there is no evidence of riverbed aggradation along the lower Waitaha.
- The 10-year averaged extraction rate from the Waitaha River (2300 m^3/yr) is not more than 10% of the Waitaha's estimated annual bedload (37,500–75,000 m^3/yr).
- Considering cumulative effects, current (in 2024) consents for other takes of gravel/stones from the beds of the Waitaha River and Macgregor Creek total approximately 13,300 m^3/yr[11], thus with the proposed Westpower take the overall 10-year averaged take from the Waitaha catchment would be 15,600 m^3/yr, equivalent to 21–42% of the annual average Waitaha bedload. However, most (68%) of the existing consents chase boulder-sized stones in the 10–120 cm size range, whereas Westpower seek finer-grade gravel fractions suited for road aggregate. In this context, the combined average take rate for gravel would total 6600 m^3/yr, equivalent to 9–18% of the average Waitaha bedload (which is dominated by gravel, anyway).
- While there is no quantitative information available on the coastal gravel budget about the Waitaha River mouth, the Waitaha cannot be the major sediment source of its littoral compartment which extends south to Jackson's Bay and includes gravel sourced from the Wanganui, Poerua, Whataroa, Waiho, Fox, Haast, and Arawhata Rivers, nor is there evidence of coastal erosion immediately north of the Waitaha Mouth, nor was that coast identified as a Coastal Hazard Area by Measures and Rouse (2022), thus no significant effect on the coast is expected.

This logic flow short-circuits to no significant effect on the coast if only the currently consented gravel takes (as against total gravel and stone takes) from the Waitaha catchment are considered or if the currently consented takes are only being partly utilised (broken red path on **Figure E-10**). It is understood that there may be some opportunity for Westpower to make use of existing underutilised consents to meet some of its gravel needs. If that eventuates, then any cumulative effect would be lessened.

Considering potential degradation of the Waitaha channel downstream, if the Waitaha's 23,000 m^3 gravel deficit was diffused over the 14 km long by 500 m wide active braidplain from Macgregor Creek down to the SH6 bridge, the average degradation amounts to 3 mm, which is **less than minor**.

Therefore, it is concluded that the proposed gravel extraction from the active Waitaha braidplain downstream of Macgregor Creek will have **less than minor** far-field effects.

[11] As shown on LocalMaps, in 2024 there were eleven current resource consents for gravel-extraction/stone-harvesting from the beds of the Waitaha River and Macgregor Creek: RC-2014-0223-01, RC-2014-0033-01, RC-2015-0044-01, RC-2016-0049-01, RC-2018-0084-02, RC-2019-0037-01, RC-2019-0068-01, RC-2019-0068-02, RC-2020-0052-01, RC-2020-0062-01, and RC-N95197-1. All but RC-N95197 specify annual take limits totalling 12,461 m^3/yr, but only 4300 m^3/yr of this is gravel in the size range required by Westpower – the remainder is for selected stones in the size-range 10–120 cm. The annual gravel take associated with RC-N95197, which is held by Westland District Council for the primary purpose of stopbank construction and maintenance, is estimated at 800 m^3/yr, and this, too, is likely to prefer coarser grades.

E.12 Overall conclusion

The only **potentially more than minor** sediment related adverse environmental effect of the proposed Scheme is transient deposition of fine sediment in the abstraction reach downstream from Morgan Gorge. The potential significance of this is addressed in the **Freshwater Ecology Report**. A strategy to manage this potential effect is proposed in **Appendix F**.

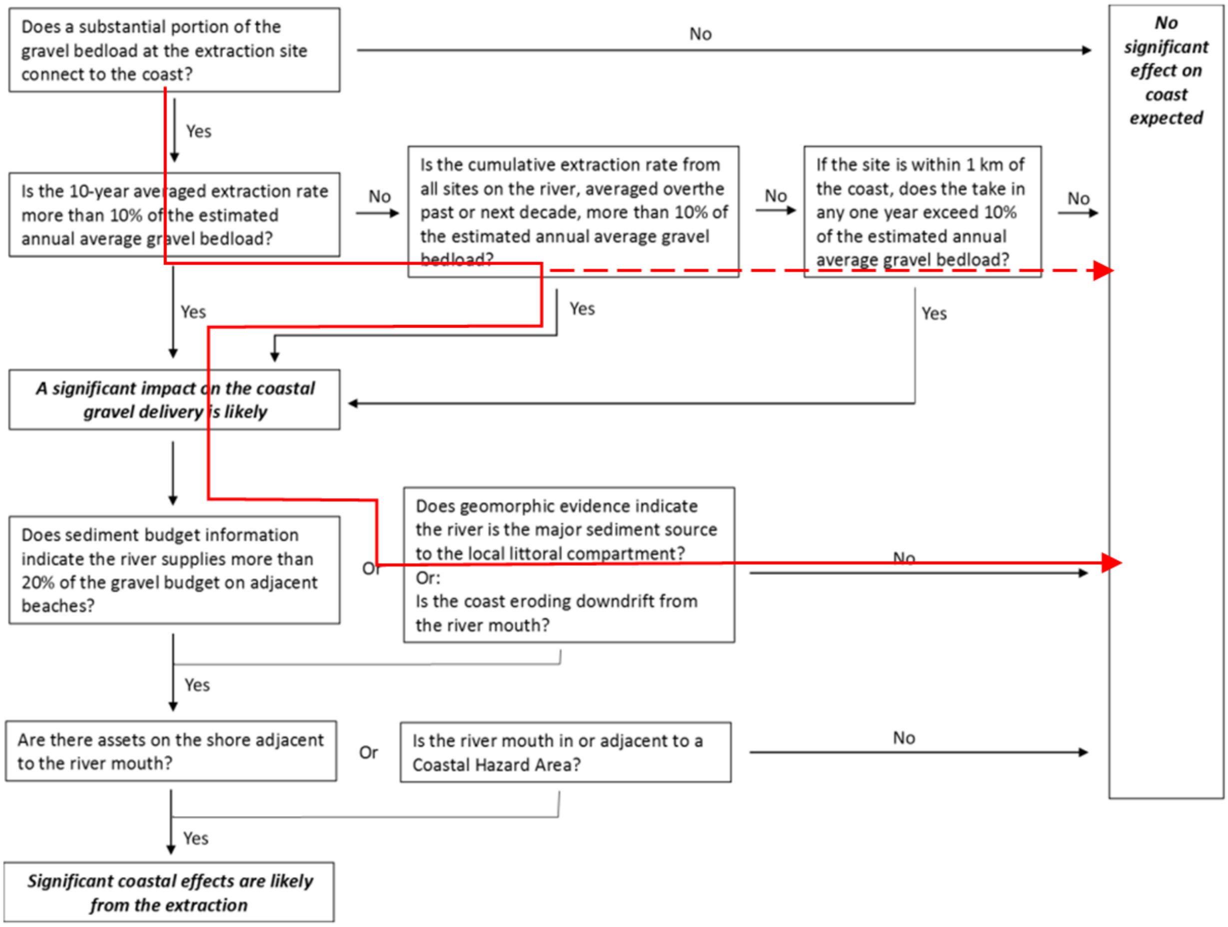

Figure E-10: Decision tree for assessing if the proposed gravel extraction could be expected to have a significant effect on the coast near the Waitaha River mouth (from Hicks 2017).

Appendix F Proposed management of effects

From **Appendix E**, the only sediment effect with potentially meaningful environmental consequences, and therefore requiring management, is transient fine sediment deposition in the abstraction reach downstream from Morgan Gorge during extended periods when the residual flow will be steady at 3.5 m^3/s. This could produce drapes of fine-grained 'sludge' up to two cm thick over and amongst the cobbles and boulders forming the 3.5 m^3/s channel margins. While such thicknesses could accumulate any time of year, they would tend to persist for longer periods during winter months, when longer periods of baseflow and minimum residual flow will tend to occur.

Acknowledging that exact predictions of this effect (and its ecological impacts as addressed in the **Freshwater Ecology Report**) are not possible, the recommended management approach combines monitoring during extended minimum residual flow periods and flushing flow releases if warranted.

Monitoring

Monitoring purpose: The purpose of monitoring would be to assess if a reference state of fine sediment cover and depth was exceeded in the abstraction reach, which would then trigger a flushing flow release.

Monitoring approach. As detailed in Clapcott et al. (2011), fine sediment deposits can be assessed in several ways, ranging from visual estimates to at-a-point measurements. The visual methods include bank-side visual assessment, in-stream visual assessment, and the "shuffle index", which assesses the amount of fine sediment re-suspended by scuffing the bed with your feet. At-a-point measurements include direct measurement of fine sediment drape thickness or measuring the mass of sediment re-suspended inside a cylinder placed over the bed (e.g., Quorer method). With these, spatial variability is managed by sampling a minimum number of points. The re-suspension methods are not well suited for boulder-bed channels (since boulders are often bigger than the quorer tube and can't be "scuffed"); likewise, the in-stream visual approach becomes impractical in boulder-bed channels because a viewer is used. Direct thickness measurements are practical but require at least 20 sampling points over a single habitat type (e.g., a run). The bank-side visual approach focuses on the spatial cover (proportion of wetted channel bed area) of fine sediment at a given habitat type, as well as an assessment of whether this sediment is sand or mud (silt-clay) grade.

In the Waitaha context, where changes in fine sediment aerial extent and thickness are of interest, a combination of methods is recommended, using the visual bankside assessment of fine sediment cover to assess the width of any fine sediment depositional zone, then sampling the sediment thickness within that zone by direct measurement. Both these approaches should be practical at 3.5 m^3/s.

Where to monitor. A pragmatic monitoring reach (in terms of access) would be the nearest slow-run habitat upstream from the powerhouse.

Reference state. For instream biodiversity (which includes native fish and benthic invertebrates), Clapcott et al. (2011) recommend a sediment cover guideline of <20% fine sediment cover OR within 10% cover of a reference cover level. Clapcott et al.'s intended reference cover was based on statistical analysis of national datasets, which indicated different reference values for different river types. However, in the Waitaha context of monitoring the abstraction reach channel, a more useful reference would be the fine sediment cover there that appears at 3.5 m^3/s immediately after natural flushing events (before any deposition commences). Establishing this would require a baseline period of monitoring during the first year of the Scheme's operation and over which an average and range of fine sediment cover would be derived. This baseline monitoring to establish the reference state should aim for about 10 events when the flow released into the abstraction reach drops to 3.5 m^3/s, spaced through the year to capture seasonal variation.

Thereafter, subsequent (operational) monitoring would compare the observed fine sediment deposit cover and local thickness with the reference values. Note that Clapcott et al.'s 10% cover threshold for deviation from the reference value is very "tight", and it is doubtful that any visual assessment would be within this tolerance. Therefore, it is recommended that this threshold be initially relaxed to a 20% cover increase (e.g., from 5% to 25%). This could be reviewed after monitoring data has been collected for five years.

How often to monitor. Visual assessment can be done quickly, so the recommended frequency is every two weeks through minimum residual flow events lasting longer than two weeks. An observed change from the visual cover assessment would prompt a sediment thickness survey and test of the threshold.

How long to monitor. The monitoring should be continued until such time as the monitoring shows no exceedances beyond tolerance level of the reference state over a two-year period. It should be resumed if casual observation indicates obvious fine sediment accumulation (due to a significant increase in fine sediment delivery from the catchment, such as from slips associated with a large future storm and/or earthquake).

Flushing flows

Flushing flows can be released during minimum residual flow periods simply by reducing the Scheme's intake for an adequate time. The added flow, and particularly the additional turbulence associated with the sudden increase in flow, can be expected to re-entrain the fine sediment drape. A flushing duration of less than a day should suffice, but this would best be refined by monitoring the river turbidity past the Power Station during trial flushes.

By design, a flush will temporarily elevate the concentration of suspended sediment (and reduce water clarity) in the abstraction reach and further downstream, but this is expected to be well within the range of what naturally occurs in the river during flood events (e.g., **Figures D-2 to D-5**, **Appendix D**, **Figure E-7, Appendix E**) (and from what the **Freshwater Ecology Report** says, what the biota are adapted to). The fine sediment entrained by the flush will be dispersed in the flow for many kilometres downstream from the abstraction reach, and some will re-settle on channel margins until the next natural high flow event arrives. So effectively, such a flush will disperse any relatively thick deposits in the abstraction reach more thinly over a much greater area of river channel downstream, rendering its environmental impact insignificant. Again, monitoring downstream turbidity during trial flushes and fine sediment cover before/after flushes would inform on the most effective flush design characteristics.

Lastly, a decision to flush should also consider the weather forecast. If the threshold is triggered but a fresh or flood is expected within a week, then the flushing could be left to nature.

Artificial flushes should use the normal operational flow ramping rates of 0.5 m^3/s per minute to avoid any of the issues associated with emergency Power Station shutdowns. There is minimal geomorphic advantage to be gained by using more rapid flow ramping.

Monitoring and flushing protocols

It is recommended that an interim set of monitoring and flushing protocols are included in conditions. The monitoring protocols should cover the operational monitoring (to trigger flushes) and the monitoring of trial flushes (including monitoring water clarity or turbidity and riverbed fine sediment cover) to assess the effectiveness of the flushes. An additional condition would be that the trial-flush monitoring results be used to inform updated, optimised flushing protocols.

Alignment with earlier Department of Conservation sediment management requests

Note that earlier versions of the Scheme design involved flushing the desander into the abstraction reach, and the Department of Conservation's Notified Concession Officer's Report of June 2016 stated that *"The Concessionaire shall establish a programme to monitor any discernible accumulation of fine sediment within the abstraction reach (i.e., between Morgan Gorge and the tailrace discharge point) due to residual flow or flushing of settling basins once the Scheme is operational."* The above proposed monitoring and management protocols address the residual flow issue, while the potential settling basin (i.e., the desander) flushing issue has now gone. This is because the current Scheme design has the desander being flushed directly into the tailrace at the Power Station, whereas the earlier design had it being flushed into the abstraction reach at Morgan Gorge. Providing the desander is flushed to the tailrace during natural high flow events, then any impact on the river channel downstream of the Power Station would be negligible.

Appendix G References

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