DAMWATCH
ENGINEERING BEYOND THE SURFACE

Assessment of Floodplain Intervention Options – Lower Rees River & Glenorchy

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Prepared for
Otago Regional Council

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Issue 3

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Executive Summary

The Issue

The Lower Rees River is subject to flooding and erosion hazards which impact on the township of Glenorchy in the Queenstown-Lakes District. There is an existing floodbank to partly manage flood risks at Glenorchy. It runs from the eastern end of Mull Street to Lake Wakatipu (refer Figure 2.4). However, the floodbank overtopped in a February 2020 flood event. A recent flood hazard assessment by Land River Sea Consulting Ltd (LRS, 2022) estimated the existing Glenorchy floodbank, will be overtopped in events upwards of a 1 in 20 AEP (5%) flood. Flooding issues are aggravated by the following wider geomorphic and hydrological processes in the area:

- Actively aggrading river bed levels
- Actively migrating braided river channel belts
- Propagation of Dart-Rees delta into the head of Lake Wakatipu
- Future climate change effects expected to increase flood hazards over time
- Future climate effects likely to increase sediment supply and riverbed level aggradation which will further exacerbate flood hazards.

Background

A floodplain adaptation workshop was held on 23-24 February 2022 which involved staff from both Otago Regional Council (ORC) and Queenstown Lakes District Council (QLDC) as well as a small number of invited technical experts (refer Damwatch (2022)). The workshop was provided a “first-pass” review of possible floodplain mitigation and floodplain management options.

Following on from the February 2022 workshop, Otago Regional Council (ORC) engaged Damwatch Engineering Ltd (Damwatch) to undertake the current study which involved a high-level assessment of potential floodplain improvement options for the Lower Rees River. The objectives of the assessment were to provide an evidence base to rule out various floodplain management options and assess the feasibility of viable options. All options were also tested for their alignment with a Nature-based Solutions (NbS) approach to floodplain management (refer Section 3). Viable options were then taken forward to a concept level design stage.

QLDC owns and maintains the existing Glenorchy floodbank. ORC undertakes some river management activities (channel clearance and obstruction removal) in this area in liaison with the Department of Conservation and QLDC. In relation to this, ORC may inspect and carry out some maintenance activities on structures that are not owned by ORC. This is determined based on community request and response to weather/flooding related events.

What We Did

The following potential floodplain intervention options to mitigate the flooding hazard were investigated with the aid of a two-dimensional computational hydraulic model of the Rees-Dart River system. The model was validated against the February 2020 flood. The model was used to simulate various flood scenarios in combination with the potential floodplain intervention options.

- Option A: Raising or modifying the existing Glenorchy floodbank
- Option B: Construction of bunding or new structures to reduce overland flood flow paths on the left bank floodplain and into the Glenorchy Lagoon
- Option C: Vegetative buffers to modify overland flow paths on the left bank floodplain and into the Glenorchy Lagoon

An illustration of each of these options is provided in Figure 4.1.

Note that these potential floodplain intervention options were not intended to address the backwater flooding hazard to Glenorchy from high lake levels in Lake Wakatipu. The backwater flooding hazard is an entirely separate issue to the flood and erosion hazards associated with the Lower Rees River.

What We Found

Options B and C were not found to be viable or effective:

- Option B required construction of new and relatively long (1.5 to 5 km long) floodbanks, between 1 to 3 m high above natural ground on the true left floodplain of the Rees River, downstream of the Glenorchy-Paradise Road bridge crossing the Rees River. Such new floodbanks were counter to NbS practices and their long-term sustainability could not be assured under future flood conditions. They would be susceptible to outflanking, overtopping and erosion from lateral river bed migration.
- Option C had good alignment with NbS practices, but was not effective at reducing flood hazards to Glenorchy.

Option A was determined to be viable and effective for mitigating flood hazards at Glenorchy. This option involved raising the existing floodbank between Argyle Street and the eastern end of Mull Street. The following concept level design information was developed for this option:

- Concept level drawings (refer Appendix C)
- Indicative construction costs
- Preliminary review of design and construction considerations
- Preliminary review of consenting requirements
- Long-term resilience of the proposed floodbank
- Issues and further works to prepare for any future detailed design phase

Refer to Section 5 of this report for further detail and discussion on the above.

Next Steps

It is understood that the information contained in this report, regarding potential floodplain intervention options for the Lower Rees River and to mitigate flood hazards at Glenorchy, will be considered by ORC and QLDC taken forward as required for community consultation and engagement.

Contents

Appendices

List of abbreviations

Abbreviation	Meaning
2D	Two-dimensional
AEP	Annual Exceedance Probability
CC	Climate Change
Damwatch	Damwatch Engineering Limited
DVD1958 or DVD58	Dunedin Vertical Datum 1958
HEC-RAS	Hydrologic Engineering Center's River Analysis System
LRS	Land River Sea Consulting Ltd
LINZ	Land Information New Zealand
NbS	Nature-based Solutions
NZTM	New Zealand Transverse Mercator
ORC	Otago Regional Council
QLDC	Queenstown Lakes District Council

1 Introduction

1.1 Background

Otago Regional Council (ORC) engaged Damwatch Engineering Ltd (Damwatch)[1] to undertake a high-level assessment of potential floodplain intervention options for the Lower Rees River, near Glenorchy, Otago. The Lower Rees River is subject to flooding and erosion hazards which impact on the township of Glenorchy. Further detail on these hazards is provided in Section 2 of this report.

A floodplain adaptation workshop was held on 23-24 February 2022 which involved staff from both ORC and QLDC as well as a small number of external technical experts (Damwatch, 2022). The workshop was intended to be a first pass review of possible floodplain mitigation and floodplain management options.

The current study follows on from the February 2022 workshop and provides an evidence base to rule out various flood intervention options and to identify a viable option. The preferred intervention option was taken forward to a concept level design stage.

1.2 Purpose of this Report

This report summarises engineering investigations into potential floodplain intervention options to address the flood and erosion hazards affecting the township of Glenorchy at the head of Lake Wakatipu. This included investigation of options incorporating Nature-based Solutions (NbS), and any fundamental issues associated with each option.

Based on consideration of these options, a viable option to mitigate flood hazards at the township of Glenorchy was developed to a concept design level. The following information to support the concept design is provided:

- Concept level design drawings
- An indicative budget to construct
- Preliminary analysis of statutory planning provisions
- A description of residual flood risks which would remain if the preferred design option was applied
- A description of the next steps if the preferred design option is taken forward to further design stages

It is understood that ORC will use the information provided in this report to consult with Queenstown Lakes District Council (QLDC), key stakeholders and the local community on the feasibility of potential floodplain intervention options for Glenorchy.

Note that the potential floodplain intervention options considered were not intended to address the backwater flooding hazard to Glenorchy from high lake levels in Lake Wakatipu. The backwater flooding hazard is an entirely separate issue to the flood and erosion hazards associated with the Lower Rees River.

[1] With Vision Planning Consultants Ltd sub-contracted to Damwatch to provide planning review services (as outlined in Section 5.6 of this report).

1.3 Report Structure

This report is broken down into the following sections:

- Section 1, Introduction
- Section 2, Flood Hazard Background
- Section 3, Nature Based Solutions
- Section 4, Assessment of Floodplain Intervention Options
- Section 5, Concept Design of Viable Option
- Section 6, Conclusions & Recommendations
- Section 7, References

1.4 Limitations

- This report provides a high-level assessment of potential floodplain intervention options to reduce flood hazards at the township of Glenorchy, including provision of a concept level design for a viable option. Further work will be needed to progress the concept level design presented in this report to a detailed design stage and to support a resource consent application.
- The assessment used a two-dimensional (2D) computational hydraulic modelling approach to evaluate the effectiveness of potential floodplain intervention options. The 2D model 'fixed bed' developed for this purpose was based primarily on 2022 LiDAR survey data for the bed surface profile of the Dart-Rees river system. Fixed bed models reflect the braid channel pattern imprinted into the bed surface profile of the river system at the time of the survey and are not able to simulate the future evolution of the bed surface, something that is impossible to predict. The results of the 2D modelling simulations presented in this report are therefore indicative only although they are considered adequate for the purposes of the assessment.
- The floodplain intervention options presented in this report only provide mitigation against flooding directly from the Lower Rees River. Glenorchy, and its surrounds, are also vulnerable to flooding from:
  - High water levels in Lake Wakatipu (such as occurred in November 1999).
  - Flooding from the Buckler Burn (refer LRS (2023)) and Bible Stream as well as surface water runoff during heavy rainfall events.

  Options to mitigate against flooding from these sources are not considered.

1.5 Level Datum & Coordinate System

All levels referred to in this report are in terms in terms of Dunedin Vertical Datum 1958 (DVD1958) mean sea level datum unless otherwise stated. Any topographic data supplied by others for the purposes of this project have been converted to the DVD1958 vertical datum using conversion values provided by Land Information New Zealand (LINZ).

All coordinates are in terms of New Zealand Transverse Mercator (NZTM) projection unless otherwise stated.

2 Glenorchy Flood Hazard Background

2.1 River Setting and Flood Hazard Overview

The Dart and Rees Rivers flow into Lake Wakatipu at the head of the lake (see Figure 2.1). The floodplains and combined delta associated with these rivers are subject to both flooding and erosion hazards which impact on the township of Glenorchy.

In recent years, the Rees River has experienced several major floods including:

- January 1994: Prior to construction of the Glenorchy floodbank in 2000
- November 1999 (Figure 2.2): Combination of Lake Wakatipu flooding (highest lake level on record) and Rees River flooding
- February 2020 (Figure 2.3): Resulting in overtopping of the existing Glenorchy floodbank

Flooding of the Glenorchy township and the Lower Rees River floodplain is caused primarily by high flows in the Lower Rees River and/or high flood levels in Lake Wakatipu. Parts of the township are also affected by flooding from the Buckler Burn and the Bible Stream as well as surface water runoff during heavy rainfall events. Flooding issues are intensified by the following wider geomorphic and hydrological processes in the area:

- Actively aggrading river bed levels
- Actively migrating braided river channel belts
- Propagation of the Dart-Rees river delta into the head of Lake Wakatipu
- Future climate change effects expected to increase flood hazards over time
- Future climate effects likely to increase sediment supply and riverbed level aggradation which will further exacerbate flood hazards.

Further discussion on these issues can be found in Damwatch (2022) with a summary provided in the following sections.

2.2 River Geomorphology

Channel Migration

The Rees River channel currently occupies the eastern side of the Dart-Rees River floodplain as shown in Figure 2.1. This figure also shows the position of the edge of the active river channel[2] in 1966, 2006, 2019 and 2022[3]. This highlights the dynamic, changing nature of the Rees-Dart River system over a relatively short geomorphic period. ORC (2010) indicates that prior to the 1990's a large proportion of flow in the Lower Rees River was in the branch labelled (A) in Figure 2.1. However, changes in channel position have diverted much of this flow into the eastern branch which enters Lake Wakatipu adjacent to Glenorchy (refer branch labelled (B) in Figure 2.1).

[2] The "active river channel" refers to the area of a river where water normally flows. The active river channel within the Rees and Dart Rivers refers to the constantly shifting and interconnected braided channels that make up these river systems. During flood conditions, water can spill out of the active river channel and onto adjacent floodplains.
[3] Derived by ORC from analysis of historical aerial photographs.

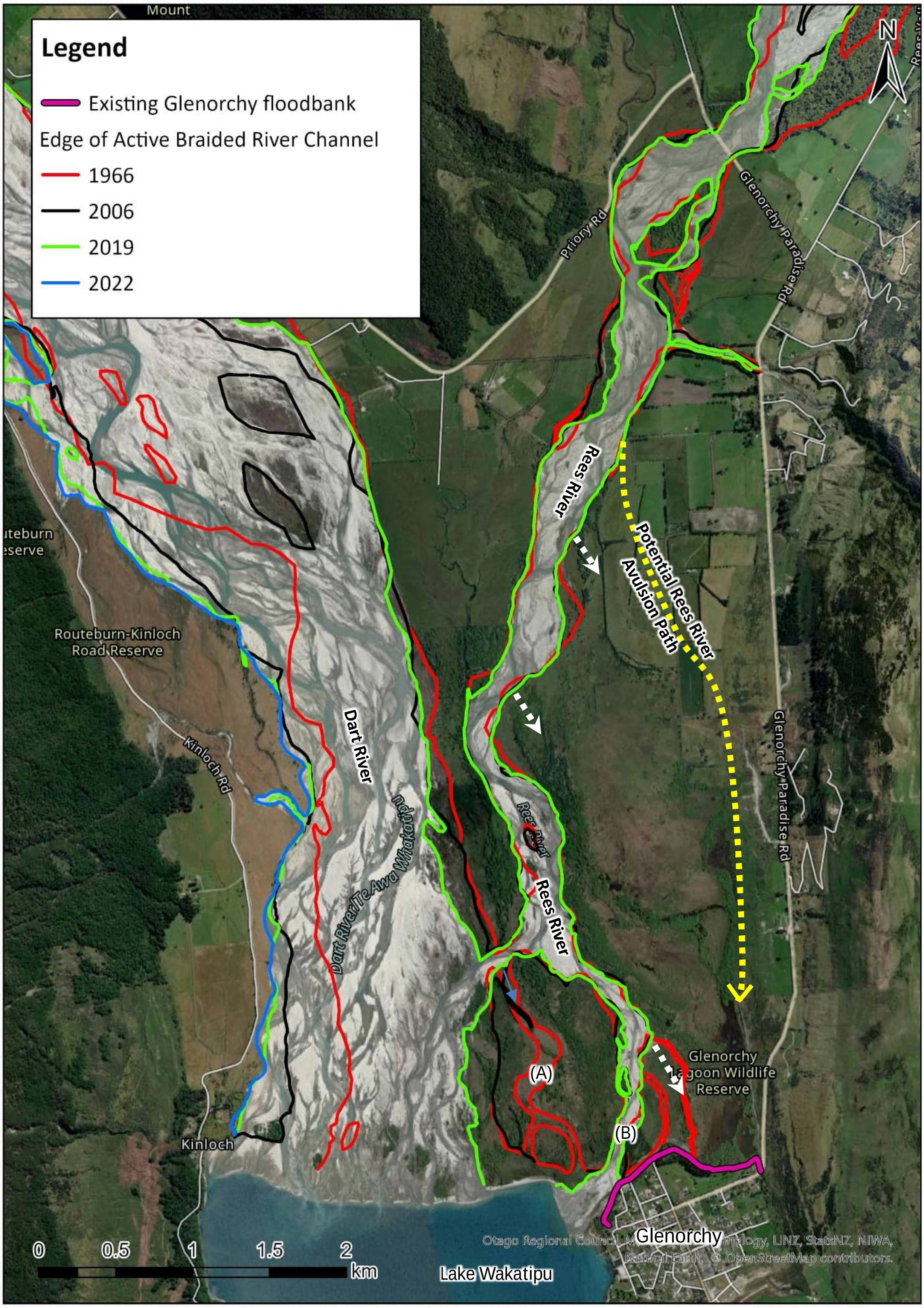
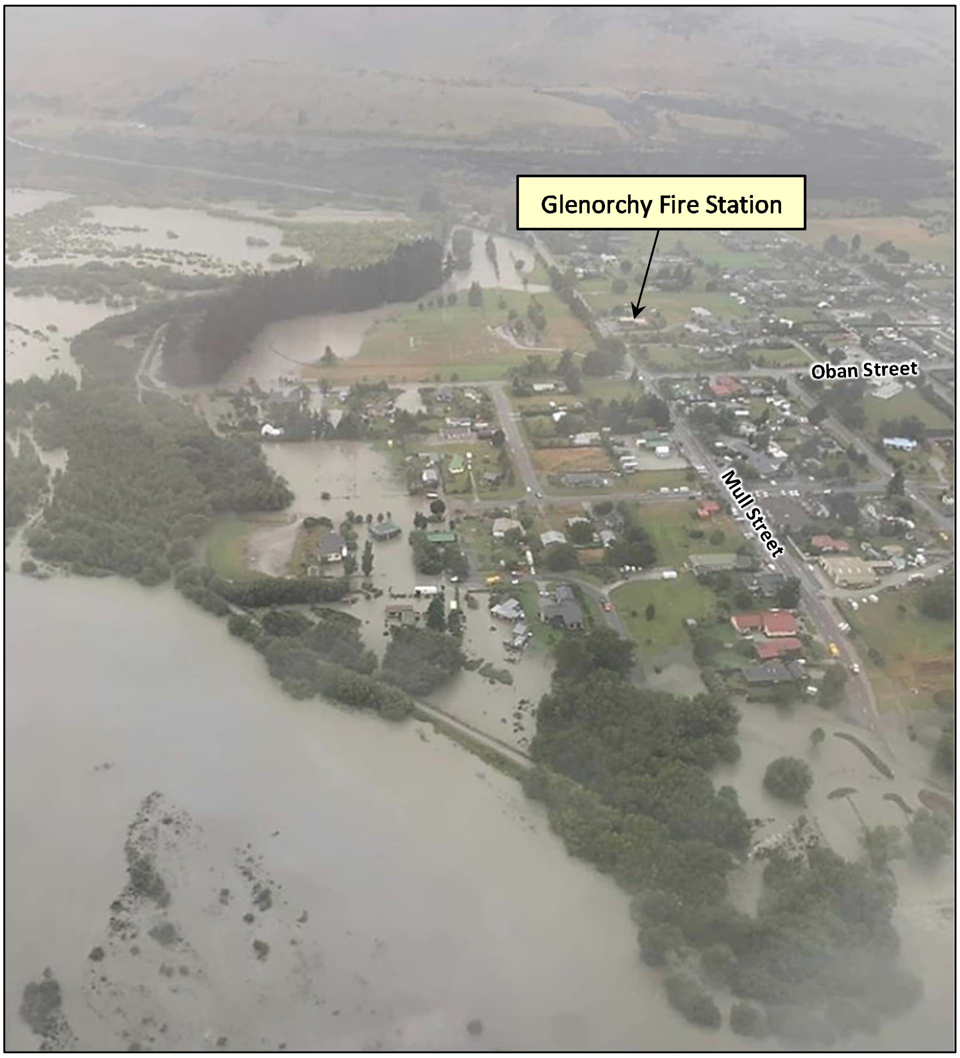


Figure 2.1: Aerial photograph of Dart and Rees Rivers at head of Lake Wakatipu

Source: https://www.glenorchycommunity.nz/community/emergency-services/civil-defence/

Figure 2.2: January 1999 flooding at Glenorchy, looking south-east



Source: Supplied by ORC, photo credit to Luke Hunter.

Figure 2.3: February 2020 flooding at Glenorchy, looking north-east along Mull Street

Channel Aggradation

Recent river channel bed surveys by ORC have indicated that the active river channel of the Rees River is aggrading[4]. Two high-resolution Light Detection and Ranging (LiDAR) aerial surveys between 2011 and 2019 indicated that the average change in bed level generally increased in the order of 0.1 to 0.3 m over this period[5]. Such aggradation has the potential to exacerbate flooding and lower the existing level of service of existing floodbank protection at Glenorchy.

Channel Avulsion Potential

Riverbed aggradation in the Lower Rees River (described previously) can also lead to increased risk of breakout flooding and channel avulsion[6]. A potential channel avulsion path was identified in the LSR (2022) study on the true left river bank as marked by the yellow arrow on Figure 2.1.

Additional left bank floodplain break-out locations and potential channel avulsion paths are also indicated with white arrows on Figure 2.1. These were identified from observations of satellite imagery following the February 2020 flood event (refer Appendix D of Damwatch, 2022).

2.3 Existing Glenorchy Floodbank

In response to large flood events in 1994 and 1999, and the shift in location of the active branch of the Lower Rees River near Glenorchy (refer Section 2.2), the Glenorchy-Rees floodbank was constructed in 2000 to mitigate the effects of flooding and to train the Rees River away from the township (URS, 2007).

The 1999 resource consent application for the floodbank (Imtech (1999)) indicates the floodbank is a homogeneous earthfill structure, composed of river gravels won from Buckler Burn immediately to the south of Glenorchy township. The construction of the floodbank involved compaction of the river gravels in 300 mm layers, with a maximum aggregate size of 150 mm in diameter. A topsoil layer, composed of material stripped from the floodbank foundation, was placed over the compacted gravels.

Figure 2.4 is a plan showing the horizontal alignment of the existing floodbank, including distances along the floodbank centreline (in metres).

A long-section showing the 1999 design floodbank crest levels was supplied by ORC (refer Imtech (1999)). Topographic survey of the crest level of the floodbank was carried out by ORC in 2020 as well as LiDAR aerial survey of the wider Rees-Dart River areas in 2022. Figure 2.5 provides a long-section comparing floodbank crest levels from the 1999 design, 2020 topographic survey and 2022 LiDAR surveys. This figure indicates that the original design floodbank crest level of 313 m RL, tapering to 312 m RL at the western end. The original floodbank crest level was higher than the current low points on the floodbank crest at about 312.64 m RL at the eastern end of the floodbank. The observed floodbank crest level profile being lower than the design profile is believed to result from post-construction settlement caused by underlying soft soils (also refer to further discussion in Section 5.3.3).

[4] Aggradation is a geomorphological term used to describe the increase in land elevation, typically in a river system, due to the deposition of sediment over time. Aggradation occurs in areas in which the supply of sediment is greater than the amount of material that the system is able to transport by means of intermittent flood events.
[5] Refer to Appendix D of Damwatch (2022) for an interpretation of river channel bed survey data with respect to river channel bed aggradation by Professor James Brasington of the University of Canterbury.
6 River avulsion occurs where sediment material accumulates on a river bed, elevating it above the surrounding floodplain. In this situation, flows can spill out of the established river channel into a new course at a lower elevation on the adjacent floodplain.

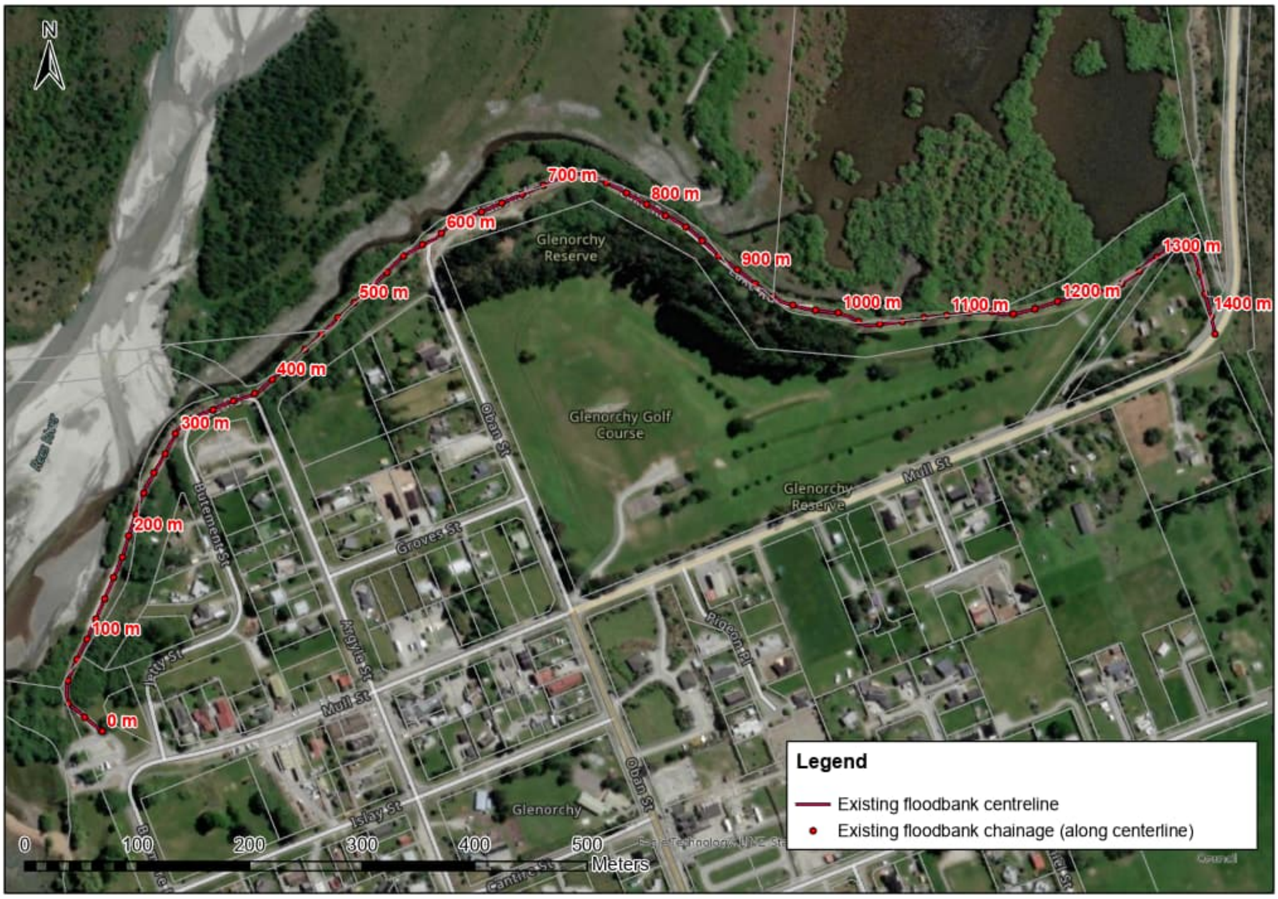


Figure 2.4: Plan showing alignment existing Glenorchy floodbank. Chainage (in metres) along the crest centreline is provided at 100 m intervals, with 0 m starting at the western end of the Glenorchy Lagoon Scenic Walkway.

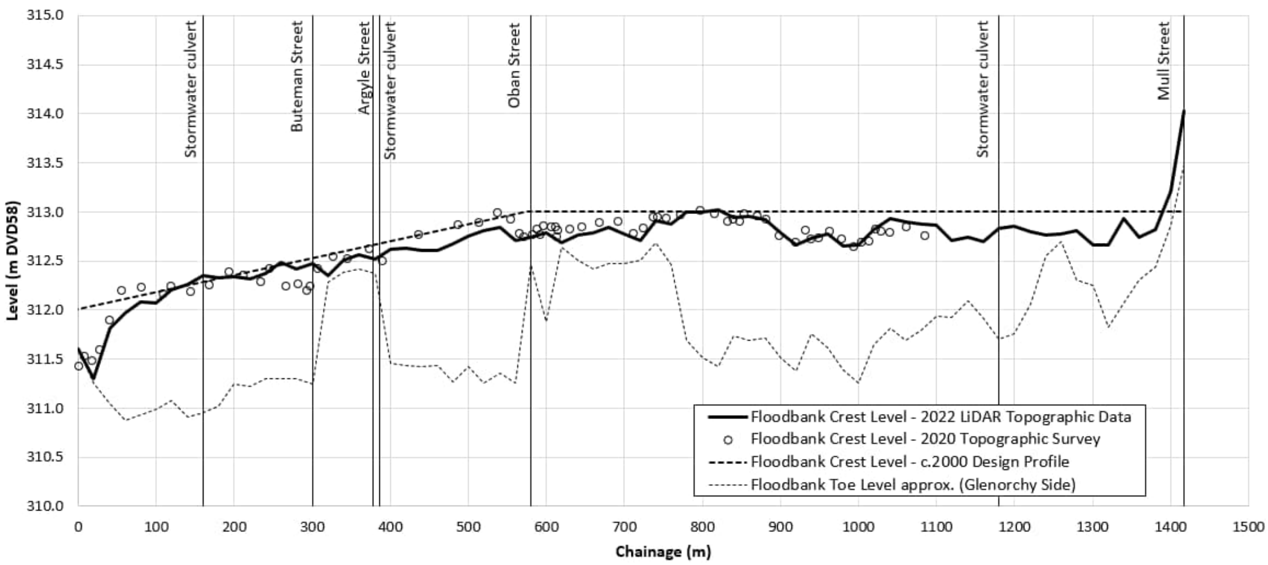
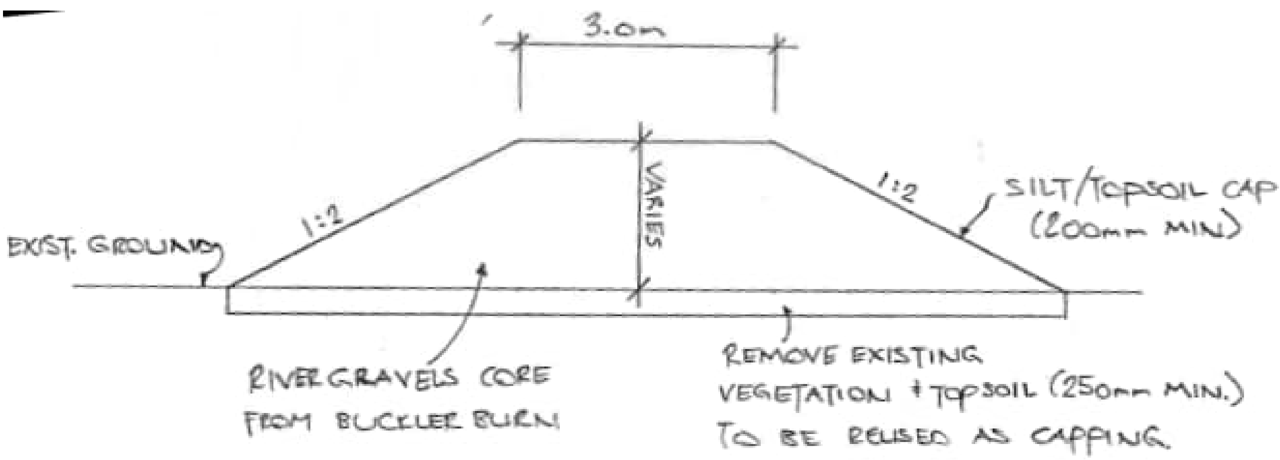


Figure 2.5: Long-section along Glenorchy floodbank showing crest levels

Figure 2.6 provides site photographs of the floodbank and Figure 2.7 shows a schematic cross-section profile based on the design details provided in the resource consent application (refer Imtech (1999)).

Figure 2.6: Photographs of the Glenorchy floodbank at (a) near Arglye Street and (b) adjacent to Glenorchy Golf Course



Source: Imtech (1999)

Figure 2.7: Schematic cross-section for Glenorchy floodbank as proposed in 1999

Assessments of the floodbank conditions were carried out by in 2020 (refer WSP (2020)) and in 2021 as part of a walk-over visual inspection by an engineer (refer T&T (2021)). The WSP (2020) assessment noted the main channel of the Rees River flows against the toe of the floodbank at the Lake Wakatipu end. Installation of rock armouring was recommended, along the northern length of the bank downstream of the Lagoon confluence, to mitigate against erosion occurring at the northern/river side floodbank toe.

Following the WSP (2020) assessment, and in about 2021, QLDC undertook improvement works to the Glenorchy floodbank which included:

- The supply and placement of 1,200 tonnes of rock to protect vulnerable sections of the floodbank along the western end of the embankment (i.e. from Buteman Street towards Lake Wakatipu)
- The repair of some over-steep sections of the floodbank
- Localised and minor raising of a short section of the floodbank near the golf course where the crest was low

In addition to these works, ORC completed works in July 2020 to clear willows from along the banks of Lagoon Creek. These works were to improve the discharge capacity of the creek and to lower water levels in the lagoon under flood conditions.

2.4 Flood Hazard Assessment

A flood hazard assessment of the Lower Rees River was carried out in 2022 by Land River Sea Consulting Ltd (LRS) using a two-dimensional computational hydraulic modelling approach (refer LRS (2022)). This study provided flood inundation maps for the Glenorchy township for 1 in 100 Annual Exceedance Probability (AEP) floods on the Rees River in combination with Lake Wakatipu at 1 in 10 and 1 in 100 AEP lake levels. Flood hazard maps were also developed for climate change, floodbank breach and channel avulsion scenarios.

The predicted extent of flooding at Glenorchy by LRS (2022) for the 1 in 100 AEP Rees River flood in combination with a 1 in 10 AEP level of Lake Wakatipu is shown with blue shading on Figure 2.8. This figure also indicates the approximate extent of flooding from the February 2020 flood with a dashed, purple line. This line was provided by ORC and approximately interpreted from flood photographs.

Further detail on the flood hazard assessment can be found in the LRS (2022) report. However, the main findings from this assessment were:

- The existing Glenorchy floodbank will be overtopped in events upwards of a 1 in 20 AEP flood. However, the extent of flooding is controlled by the topography of the town (i.e. the town is sited on an alluvial fan, with higher ground to the south of the existing floodbank as indicated on Figure 2.8).
- The impacts of increased flows due to climate change as well as the potential for channel avulsion are likely to increase the depth and extent of flooding at the eastern end of the floodbank. However, the flood extent closer to the lake remains largely unchanged.

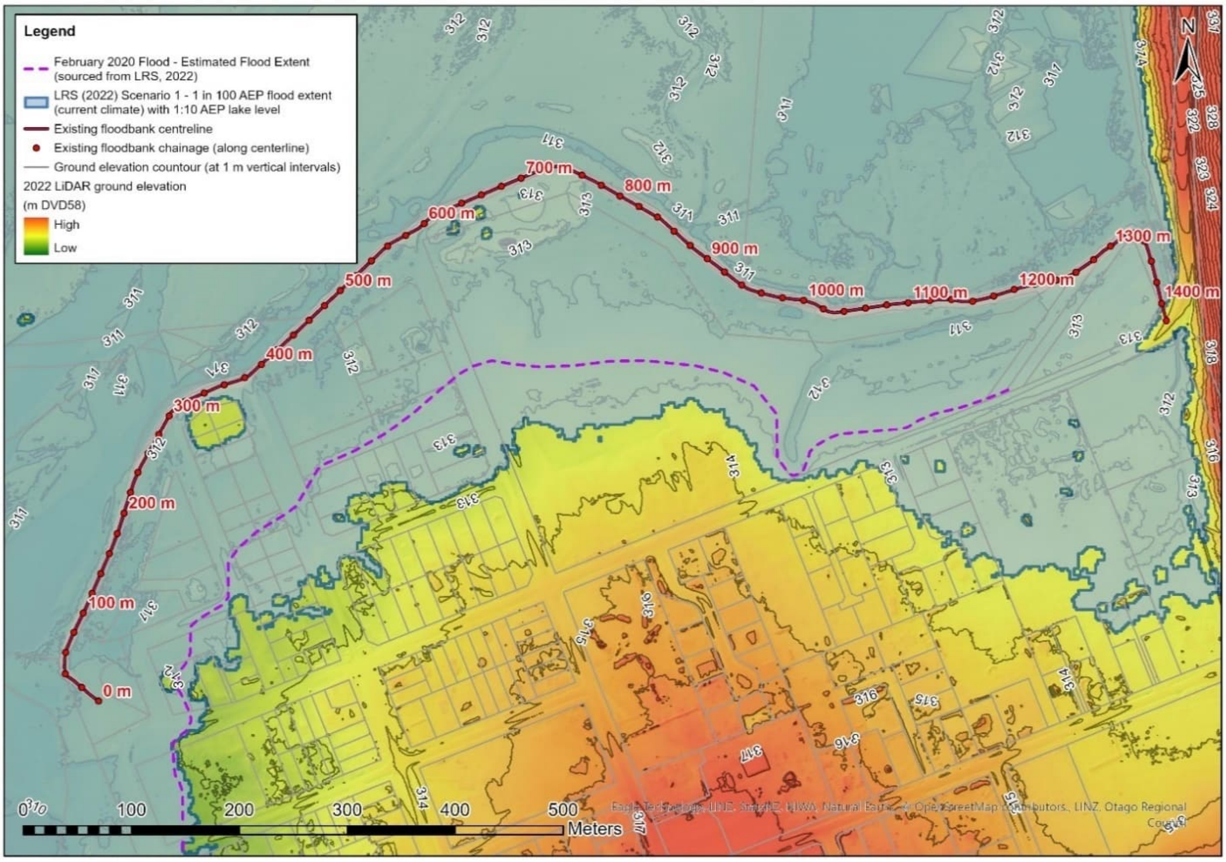


Figure 2.8: 1 in 100 AEP Rees River flood extent at Glenorchy in combination with 1 in 10 AEP Lake Wakatipu water level.

2.5 Flood Frequency and Climate Change

The Hillocks flow gauging site on the Dart River (located near the Glenorchy-Routeburn Road crossing) has been maintained since June 1996. However, the Rees River has only had a flow gauging site installed recently in December 2021 (located near the confluence of the Invincible Creek with the Rees River, and about 7 km upstream of the Glenorchy-Paradise Road crossing of the Rees River).

ORC (2021) provides estimates of flood peak discharge frequency for the Dart River at Hillocks and Rees River at the Glenorchy-Paradise Road Bridge sites. The results from this assessment are provided in Table 2.1. The Rees River flood frequency estimates for the 1 in 100 AEP and 1 in 100 AEP plus climate change floods given in ORC (2021) were obtained using a rainfall/runoff routing approach. Other flood frequency estimates for the Rees River in Table 2.1 were scaled, for the purposes of this study, from the ratio of the 1 in 100 AEP estimates for the Rees and Dart Rivers.

ORC (2021) also provides estimates of peak Lake Wakatipu water level frequencies, based on analysis of the Willow Place hydrological gauging station. This station has an available record from November 1962 onwards. The peak lake level results are provided in Table 2.2.

Table 2.1: Flood peak discharge estimates for Dart and Rees Rivers

Site	Catchment Area (km^2)	Flood Peak Discharge (m^3/s)				
		1 in 20 AEP (5%)	1 in 50 AEP (2%)	1 in 100 AEP (1%)	1 in 100 AEP (1%) plus CC*	1 in 500 AEP (0.2%)
Dart @ Hillocks	591	1,853	2,168	2,420	2,907	3,067
Rees @ Glenorchy-Paradise Road Bridge	295	487**	843**	941	1,138	1,193**

Notes:
All data sourced from ORC (2021) unless otherwise stated.
* CC = inclusion of climate change impacts to 2081-2100 based on Representative Concentration Pathway (RCP) 8.5. RCP8.5 represents a future climate scenario where greenhouse gas emissions continue to rise throughout the 21st century.
** Flood peak discharge estimate not provided in ORC (2021). Estimates therefore scaled from Dart @ Hillocks estimates using a scaling factor of 1/2.572, derived from ratio of Dart / Rees 1 in 100 AEP peak discharge estimates (i.e. 2,420 / 941 = 2.572).

Table 2.2: Peak Lake Wakatipu water level estimates

Site	Peak Lake Wakatipu Water Level (m RL)			
	1 in 10 AEP (10%)	1 in 20 AEP (5%)	1 in 50 AEP (2%)	1 in 100 AEP (1%)
Lake Wakatipu @ Willow Place	311.5	311.9	312.3	312.6

Notes:
All data sourced from ORC (2021) based on the Generalised Pareto (GPareto) distribution.

2.6 Infrastructure Ownership and Responsibilities

QLDC owns and maintains the existing Glenorchy floodbank. ORC undertakes some river management activities (channel clearance and obstruction removal) in this area in liaison with the Department of Conservation and QLDC. In relation to this, ORC may inspect and carry out some maintenance activities on structures that are not owned by ORC. This is determined based on community request and response to weather/flooding related events.

3 Nature Based Solutions

3.1 Background

Nature-based solutions (NbS) are strategies that utilize natural processes and ecosystems to address environmental challenges, such as climate change and disaster risk reduction. In the context of flood risk management, NbS can be used to enhance natural processes while simultaneously providing flood mitigation improvements.

Examples of NbS with respect to flood management are outlined in Table 3.1. In general, NbS solutions for floodplain management depart from a reliance on “hard” infrastructure (e.g. floodbanks and flood control structures) and promote “green” interventions that respect river dynamics and ecosystem functions (e.g. providing “room for the river” through floodplain widening and setback of floodbanks).

Further information on NbS with respect to floodplain management can be found in the “*International Guidelines on Natural and Nature-Based Features for Flood Risk Management*” (Bridges, et al., 2021). In the New Zealand context, the “*Nature-based solutions for flood management*” (NIWA, 2023) and “*Application of Room for the River for NZ Rivers and Streams*” (Christensen, 2023) reports also provide further information on NbS practices.

	Room for Flood Conveyance	Room for Water Retention	Room for Bank Erosion	Impact Reduction
Floodplain widening	✓		✓	
Retention areas		✓		
Wetland restoration	✓	✓	✓	
Embankment removal	✓		✓	
Meander restoration			✓	
Zonation/ Building codes				✓
Elevating houses				✓
Reviving old channels	✓		✓	
Removing obstacles	✓		✓	
Early-warning system				✓

Source: ADB (2022)

Figure 3.1: Nature-based Solutions for flood risk management functions

3.2 NbS Integration to Lower Rees Floodplain Intervention Options

All floodplain intervention options for the Lower Rees were considered in terms of their alignment with Nature-based Solutions. Refer to the following Section 4 of this report for further discussion.

4 Assessment of Floodplain Intervention Options

4.1 Summary of Options

The following options were considered to mitigate flood hazards at Glenorchy:

- Option A: Raising or modifying the existing Glenorchy floodbank
- Option B: Construction of bunding or new structures to reduce overland flood flow paths on the left bank floodplain and into the Glenorchy Lagoon
- Option C: Vegetative buffers to modify overland flow paths on the left bank floodplain and into the Glenorchy Lagoon

An illustration of each of these options is provided in Figure 4.1.

These options were developed based on discussion with ORC staff, discussion with community members at an engagement session in April 2021 (refer NIWA (2021)) and from feedback on the Rees-Dart River floodplain adaptation workshop in 23-24 February 2022 (refer Damwatch (2022)).

The following Section 4.2 describes how these options were investigated to determine their effectiveness at reducing Rees River flood hazards at Glenorchy and their alignment with Nature-based Solutions. Section 4.3 compares the options and provides a rationale for the option selected for further consideration at a concept design level.

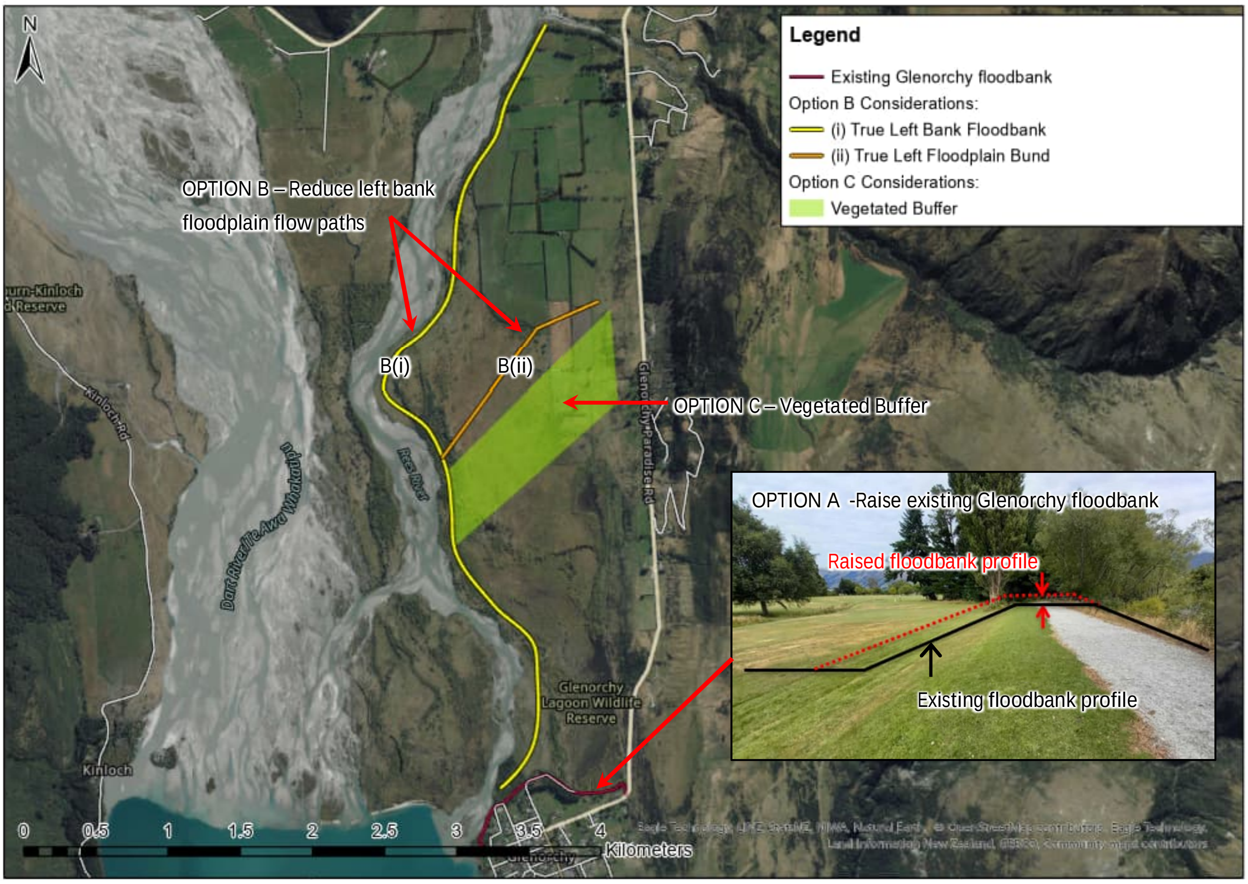


Figure 4.1: Illustration of Options A, B and C

4.2 Options Investigation Methodology

Options A to C were investigated by implementing them into a HEC-RAS[7] two-dimensional hydraulic model of the Rees-Dart River system. An overview of this model is provided in Appendix A. The model was supplied by ORC for the purposes of this assessment and was based on the LRS (2022) model used for flood hazard assessment at Glenorchy (refer Section 2.4).

The HEC-RAS model was validated against the February 2020 flood and indicated relatively good agreement between model predicted and observed flood levels for this flood event. Further detail on model validation is provided in Appendix A.

The model was used to determine maximum flood inundation extents, depths and velocities. These data were then analysed to determine the flood mitigation effectiveness of each option.

The options were also qualitatively evaluated with respect to Nature-based Solutions (NbS) for flood management (refer Section 3). This involved applying judgement on whether the proposed option was aligned with an NbS approach.

Table 4.1 lists the scenarios investigated for each option. Baseline scenarios were firstly modelled for 1 in 20, 1 in 50 and 1 in 100 AEP floods on the existing Rees River system. The various options were then input to the model and tested under the same flood conditions, including the following potential future river bed aggradation and climate situations:

- Climate change impacts to the end of the century (i.e. 2080-2100 period). These simulations are noted with the suffix "*CC*" in Table 4.1.
- Ongoing active river channel bed aggradation, assuming a +0.2 m increase in active river bed levels per decade[8]. These simulations are noted with the following suffixes in Table 4.1:
  - *SED1*: +0.2 m of active river channel aggradation (simulating the active river bed channel in 10 years time or c.2030).
  - *SED2*: +0.4 m of active river channel aggradation (simulating the active river bed channel in 20 years time or c.2030).
  - *SED3*: +1.0 m of active river channel aggradation (simulating the active river bed channel in 50 years time or c.2070).

For all options assessment simulations using the HEC-RAS model, Lake Wakatipu was assumed to be at a 1 in 10 AEP flood level of 311.5 m RL. A sensitivity test to a 1 in 50 AEP lake level was also tested for Option A.

For Option A, a "super-design" flood event with a 1 in 500 AEP was also simulated (denoted with the suffix A500, in Table 4.1). This was carried out to test the effectiveness of the proposed Glenorchy floodbank raising to an extreme flood greater than the 1 in 100 AEP design criteria commonly adopted for flood defences.

[7] HEC-RAS is a computer program developed by the United States Army Corps of Engineers that solves the shallow water wave equations to simulate the flow of water through natural rivers and other channels. It is widely used internationally for modelling of river and floodplain systems.
[8] Based on interpretation of the river channel bed survey information (refer Section 2.2), and for the purposes of this study, an average rate of active river channel aggradation of +0.2 m per decade has been assumed. This approach provides a way to test the sensitivity of active riverbed aggradation at current rates. This helps to highlight the location and sensitivity of local breakout points from the active river channel, as well as potential impacts on any proposed flood intervention options. The sensitivity tests are considered a simplified approach to testing the various options to riverbed aggradation effects but are not reflective of more complicated geomorphological processes (i.e. the river system will respond to sedimentation processes with the locus of aggradation shifting over time rather than a uniform increase in riverbed levels globally).

Results from the options investigation are summarised in the following Section 4.3.

Table 4.1: Summary of hydraulic model simulations for assessment of floodplain interventions

Model Code	Scenario Descitpion	Flood Frequency (AEP)	Lake Wakatipu Level (AEP)	Active River Channel Bed Aggradation Assumption*
X20	Baseline - Existing river channels and flood protections	1:20 (5%)	1:10 (10%)	Current (2022)
X50		1:50 (2%)	1:10 (10%)	
X100		1:100 (1%)	1:10 (10%)	
A20	Option A - Raising or modifying existing Glenorchy floodbank (simulated in HEC-RAS through modification of terrain model)	1:20 (5%)	1:10 (10%)	Current (2022)
A50		1:50 (2%)	1:10 (10%)	
A100		1:100 (1%)	1:10 (10%)	
A100-SED1		1:100 (1%)	1:10 (10%)	+0.2 m (c.2030)
A100-SED2		1:100 (1%)	1:10 (10%)	+0.4 m (c.2040)
A100-SED3		1:100 (1%)	1:10 (10%)	+1.0 m (c.2070)
A100-SED3-LL		1:100 (1%)	1:50 (0.2%)	+1.0 m (c.2070)
A100-CC		1:100 (1%) + CC**	1:10 (10%)	Current (2022)
A100-SED3-CC		1:100 (1%) + CC**	1:10 (10%)	+1.0 m (c.2070)
A500-SED1		1:500 (0.2%)	1:10 (10%)	+0.2 m (c.2030)
A500-SED2		1:500 (0.2%)	1:10 (10%)	+0.4 m (c.2040)
A500-SED3		1:500 (0.2%)	1:10 (10%)	+1.0 m (c.2070)
B20	Option B - Bunding to reduce overland flood flow paths (simulated in HEC-RAS through modification of terrain model)	1:20 (5%)	1:10 (10%)	Current (2022)
B50		1:50 (2%)	1:10 (10%)	
B100		1:100 (1%)	1:10 (10%)	
B100-SED1		1:100 (1%)	1:10 (10%)	+0.2 m (c.2030)
B100-SED2		1:100 (1%)	1:10 (10%)	+0.4 m (c.2040)
B100-SED3		1:100 (1%)	1:10 (10%)	+1.0 m (c.2070)
C20	Option C - Vegetative buffers to modify overland flow paths (simulated in HEC-RAS by increased roughness distribution over proposed vegetated buffer area)	1:20 (5%)	1:10 (10%)	Current (2022)
C50		1:50 (2%)	1:10 (10%)	
C100		1:100 (1%)	1:10 (10%)	
C100-SED1		1:100 (1%)	1:10 (10%)	+0.2 m (c.2030)
C100-SED2		1:100 (1%)	1:10 (10%)	+0.4 m (c.2040)
C100-SED3		1:100 (1%)	1:10 (10%)	+1.0 m (c.2070)

* Refer Section 4.2 for active river channel bed aggradation assumptions to 2030, 2040 and 2070.

** CC = inclusion of climate change impacts to 2081-2100 based on Representative Concentration Pathway (RCP) 8.5. RCP8.5 represents a future climate scenario where greenhouse gas emissions continue to rise throughout the 21st century.

4.3 Assessment of Options

Table 4.2, 4.3 and 4.4 summarise the findings regarding assessment of Options A, B and C respectively. Supporting evidence for the findings is provided in Appendix B and referred to in Tables 4.2 to 4.4 where required.

The following points were noted as part of the options assessment:

- Option A would involve raising of the existing Glenorchy floodbank crest to reduce flood hazards to properties at the northern end of Glenorchy. Refer to Figure 4.1 for an illustrative sketch of this option. Option A was considered viable, subject to resolution of resource consenting issues and further design considerations. However, the flood protection benefits of this option are limited to properties at the northern end of Glenorchy township as indicated on Figure B.2 (Appendix B). Properties behind the western end of the floodbank are low-lying and vulnerable to flooding from Lake Wakatipu which outflanks the floodbank at high lake levels.

- Options B would require significant new floodbank works along left bank of the Rees River (refer yellow line labelled B(i) on Figure 4.1). A bund across the left-bank floodplain was also investigated (refer white line labelled B(ii) on Figure 4.1) but not found to be effective as it was outflanked by breakout flows from the left bank of the Rees River downstream of the bund. In both cases, the floodbanks would be in the order of 2 to 5 km long and between 1 to 3 m high above existing ground levels. However, the long-term sustainability of such floodbanks could not be assured as, during flood conditions, they would be susceptible to outflanking, overtopping and erosion from lateral river channel migration. Such works would also be counter to an NbS “room for the river” approach as they would involve construction of significant new floodbanks which would restrict lateral migration of the active river channel belt. Therefore, Option B was <u>not</u> considered viable based on expected costs, long-term performance and non-alignment with an NbS approach for floodplain management.

- Option C would involve large-scale planting on the left bank floodplain of the Rees River in an attempt to reduce left bank overflows. Refer to Figure 4.1 for an illustrative sketch of this option. However, this option was not effective at reducing left bank floodplain overflows or reducing the existing flood hazard to properties at the northern end of Glenorchy township. Planting of a vegetative buffer alone would not significantly divert or disrupt breakout flows from the left bank of the Rees River during flood conditions. Therefore, Option C was <u>not</u> considered viable or effective.

  An alternative to Option C could involve planting along the left bank of the Rees River in an effort to mitigate against lateral migration of the active river channel. Such planting could extend along all or parts of the yellow line shown on Figure 4.1. Whilst such planting may improve riverbank stability (e.g. by developing strong root systems to stabilise the riverbank) they would also not be effective at reducing left bank floodplain overflows or reducing the existing flood hazard to properties at the northern end of Glenorchy township.

Based on these findings, Option A was taken forward for concept design considerations, as outlined in Section 5 of this report.

Table 4.2: Summary of Option A assessment

Option	Flood Improvements	NbS Assessment	Risks	Overall Feasibility
A – Raising or modifying existing Glenorchy floodbank *(refer to Figure 4.1 for an illustrative sketch)*	• Raising existing floodbank is effective at reducing floodbank overflow and increases level of flood protection for properties at northern end of Glenorchy. NB: Refer Appendix B for discussion of flood modelling results and evidence base to support this statement.	• No significant NbS benefits as this option relies on a floodbank which is considered a "hard" engineering structure. It modifies the natural river processes during flood conditions. • However, it does utilise the left bank floodplain as an overland flow path for floodwaters from Rees River and Glenorchy Lagoon as a flood storage facility. Both functions are aligned with NbS approach. • Note this option does not affect the status quo of the river system, which already includes the Glenorchy floodbank.	• Difficult to raise floodbank on northern/river side due to proximity to Glenorchy Lagoon outflow channel. • Existing floodbank is heavily vegetated. Such vegetation will require removal if option adopted. • Structural and geotechnical performance of existing floodbank is unknown. Raising or full rebuild of existing floodbank would require geotechnical investigations (i.e. part of further design stages). • Properties at the western end of the floodbank are low-lying and vulnerable to flooding from Lake Wakitipu which outflanks the floodbank at high lake levels.	• Raising existing floodbank is a viable option. • It has been taken forward for concept design consideration (refer Section 5).

Table 4.3: Summary of Option B assessment

Option	Flood Improvements	NbS Assessment	Risks	Overall Feasibility
B – Construction of bunding or new structures to reduce overland flood flow paths on the left bank floodplain *(refer to Figure 4.1 for an illustrative sketch)*	Two sub-options were considered: • Option B(i) (refer yellow line on Figure 4.1) considered a new floodbank about 5 km long, 30 to 50 m from the true left bank of the current active river channel belt and about 1 to 2 m high above natural ground levels. This was effective at reducing left bank flood discharges and peak water levels into the Glenorchy Lagoons and flooding at Glenorchy. • Option B(ii) (refer orange line on Figure 4.1) considered a new floodbank about 1.5 km long and 2 to 3 m high above natural ground levels. This had little to no effectiveness at reducing flooding at Glenorchy as the bund was outflanked from the left bank downstream of the bund. NB: Refer Appendix B for discussion of flood modelling results and evidence base to support these statements.	• No NbS benefits as this option (either B(i) or B(ii)) relies on a floodbank approach which is considered a "hard" engineering structure. It modifies the natural river processes during flood conditions. The options are counter to NbS such as floodplain widening and providing "room for the river" for natural floodplain processes to occur.	• Significant costs of construction due to large length of floodbank (e.g. 5 km for Option B(i)) and 1.5 km for Option B(ii)). • Significant risk to long-term durability of floodbank (either Option B(i) or B(ii)) as structure vulnerable to erosion, bed aggradation and lateral river channel migration processes.	• For the reasons outlined in this table, this option is not considered viable and has not been taken forward for concept design consideration.

Table 4.4: Summary of Option C assessment

Option	Flood Improvements	NbS Assessment	Risks	Overall Feasibility
C – Vegetative buffer to modify overland flow paths on the left bank floodplain and into Glenorchy Lagoon *(refer to Figure 4.1 for an illustrative sketch)*	• Vegetative buffer on left bank floodplain (500 m width and 1,000 m long) was not effective at reducing break-out flood flows from the true left bank of the Rees River. • No reduction in flood flows or peak water levels into Glenorchy Lagoon or flood hazard to Glenorchy. NB: Refer Appendix B for discussion of flood modelling results to support these statements.	• This option would align with NbS to flood management. Use of forest and tree-planting (either exotic or native species) is a potential solution to limit floodplain overflows and floodplain erosion whilst simultaneously providing ecosystem benefits such as habitat creation, controlling erosion and filtering runoff.	• Not effective at floodplain reduction. • Intermittent flooding could wash-out tree-planting before trees get established.	• For the reasons outlined in this table, this option is not considered viable and has not been taken forward for concept design consideration.

5 Option A – Concept Design

5.1 Introduction

The existing Glenorchy floodbank is currently estimated to overtop in floods exceeding a 1 in 20 AEP flood (refer Section 2.4). Glenorchy is listed as a "settlement" zone (i.e. a low-density residential living area) in the QLDC Proposed District Plan[9]. The floodbank design standard for such residential zones is not specified by ORC or QLDC but it is generally recommended to provide protection against a 1 in 100 AEP flood in these areas (refer HBRC (2021))[10].

To improve flood resilience, the concept design considered a scenario where the existing floodbank was raised to meet a 1 in 100 AEP flood standard of protection (including a climate change allowance).

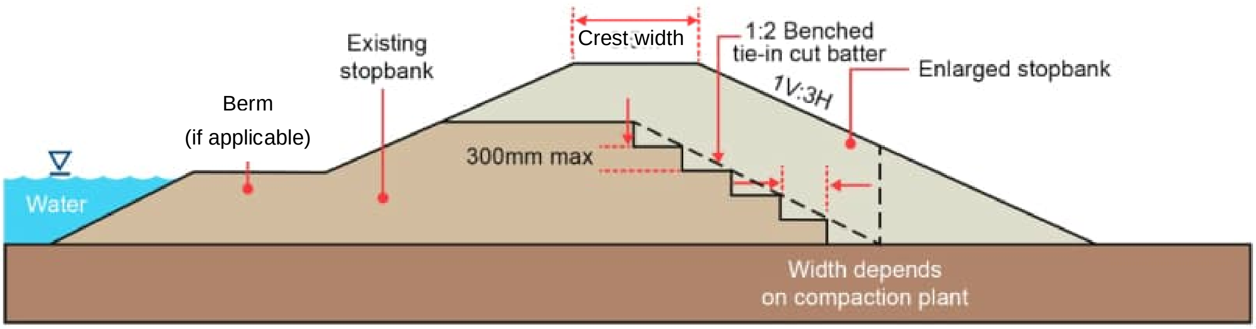
A series of concept level plans showing the raised floodbank option are presented in Appendix C. The concept design assumptions adopted for developing these plans are outlined in the following sub-sections.

5.2 Floodbank Raising Overview

5.2.1 Floodbank Raising Approach

A description of the existing Glenorchy floodbank was provided previously in Section 2.3 . The raised floodbank alignment follows the existing floodbank, along the Glenorchy Walkway (refer Figure 2.4 in Section 2).

The floodbank raise is considered viable using a southern/township side enlargement approach (refer Figure 5.1). This approach is considered best suited as it removes the need for works on the northern/river side of the floodbank which would require re-alignment of the Glenorchy Lagoon outflow channel. This watercourse runs hard-up against the northern/river side of the existing floodbank in places.



Source: HBRC (2021)
Figure 5.1: Illustration of existing floodbank raising by enlargement on landward (non-river) side

[9] *https://districtplan.qldc.govt.nz/proposed/rules/0/34/0/22207/0/99*
[10] Note that the Building Regulations 1992, Clause E1.3.2 "Surface Water" sets out a minimum performance standard for buildings with respect to floods: "*E1.3.2 Surface water, resulting from an event having a 2% probability of occurring annually, shall not enter buildings (being limited to housing, communal residential and communal non-residential buildings*". The Building Code only applies to new building work undertaken after 1991. However, this minimum flood performance standard relates to individual buildings and not district or regional level flood protection schemes.

5.2.2 Design Concept Plans

Appendix C provides the concept design plans which show:

- DRR2350/30/100: General arrangement plan
  - Aerial photograph showing concept for raised floodbank footprint (purple shading) overlaid on existing floodbank footprint (with yellow shading)

- DRR2350/30/105: Long-Section and Cross-Sections
  - Long-section along floodbank crest centreline showing existing floodbank crest levels (red line) and concept for raised floodbank crest levels (blue line)
  - Typical cross-sections showing concept for raising of floodbank by the southern/township side enlargement approach.

5.2.3 Geometric Design Parameters

The following design parameters have been assumed to support the concept design:

- Floodbank crest level set based on estimated water levels for the 1 in 100 AEP flood, including climate change effects to the end-of-century, with additional 0.6 m allowance for freeboard.
  - Based on the results of the computational hydraulic modelling (refer Appendix B), this corresponds to a raised floodbank crest level of 313.75 m RL, tapering to 312.5 m RL from Oban Street to Argyle Street (refer Drawing DRR2350/30/105 in Appendix C). This represents an approximately 0.75 to 1.1 m increase in floodbank height above the existing floodbank crest level (which varies between approximately 312.64 to 313.00 m RL).
  - The 0.6 m freeboard allowance allows for uncertainties in estimated flood water levels and accounts for wave runup, aggradation effects, and settlement due to new floodbank construction.
- Southern/township side floodbank batter at 1V:3H.
  - This slope provides resilience against overtopping erosion and provides a grade that is able to be mowed by conventional equipment.
- Floodbank crest to be 3 m wide to maintain the existing crest width.
- Stormwater culverts which penetrate through existing floodbank to be extended on the southern/township side as required. These culverts are understood to currently be fitted with a non-return flap gate at their northern/river side outlet.

5.2.4 Scope of Works

To raise the existing floodbank, the works are expected to involve:

- Site establishment, including compliance with any resource consent conditions (e.g. mitigation against construction erosion, sediment control, public safety barriers, etc).
- Tree removal and vegetation clearance
- Stripping and stockpiling of topsoil within the works footprint.
- Benching the existing floodbank profile to approximately 300 mm step heights.
- Extension of existing stormwater culverts which penetrate through the existing floodbank.

- Installation of a flap-gate on the southern/township side of the existing stormwater culvert which passes under Glenorchy-Paradise Road, just outside the eastern end of the existing floodbank[11].
- Installing a non-woven geotextile filter on fill surface (if required for soil compatibility purposes).
- Placement and compaction of suitable fill for floodbank construction (refer to Section 5.3.3 for discussion on fill material sources). Fill placed in 300 mm (loose) layers and compacted until the new crest level is reached.
- Cutting the northern/river side batter slope to match existing slopes (1V:2H), and the southern/township side batter at 1V:3H, allowing for a minimum 3.0 m wide crest.
- Placement of a topsoil layer across the area influenced by the works, including a gravel surface on the dam crest (to match the existing floodbank crest walkway surface).
- For re-vegetation of exposed areas, it is assumed that grass seed will be placed on the southern/township side batter.

A series of concept level plans showing the raised floodbank option are presented in Appendix C. The design parameters assumed to develop these plans are outlined in the following Section 5.3.

5.3 Design and Construction Considerations

A desktop review of site conditions and construction requirements was carried out to prepare the concept design drawings presented in Appendix C. Findings from this review are outlined in the following sub-sections.

5.3.1 Existing Floodbank Condition

A review of site data indicates that the existing floodbank has performed generally within expectations. However, the floodbank is heavily overgrown with vegetation and the crest level is lower than designed (refer Section 2.3).

It is assumed, for this concept stage design, that no signficant repair or rebuild work is required to raise the existing floodbank. However, this assumption will need to be confirmed, through a geotechnical assessment, if the concept design is taken forward to more detailed design stages.

5.3.2 Geotechnical Review

To assess site conditions, and potential constraints on floodbank construction, a review of available geotechnical data in the vicinity of the site was carried out. This data included geological mapping (GNS, 2000) and earlier geotechnical studies in the area (e.g. URS (2007)).

The geological information reviewed indicates that the floodbank is underlain by Holocene River Deposits (typically consisting of consolidated gravel, sand, silt, clay, and minor peat of modern to postglacial flood plains which may be terraced). Adjacent to the site, to the south, are Holocene Fan Deposits associated with Buckler Burn (loose, commonly angular, boulders, gravel, sand, and silt forming alluvial fans) and to the north is an active wetland (likely underlain by unconsolidated clays, silts, and localised peat). The site gently slopes down to the north, with the alignment of the floodbank within a local low point.

[11] Installation of a new flap gate on this culvert will prevent the potential for flood waters from the Glenorchy Lagoon backing-up into low-lying areas upstream of the culvert.

The 2022 Glenorchy Liquefaction Vulnerability Assessment (refer T&T (2022)) indicates the eastern end of the floodbank is located over an area described as "backwater fine sediments" and the remaining floodbank located on "fan-top braided river type channel deposits". This report indicated the floodbank is sited on a zone of "high" vulnerability to liquefaction and lateral spreading damage. This means that the land could experience significant vertical subsidence and deformation during large earthquakes (e.g. in the order of a 1 in 25 to 1 in 100 AEP seismic event).

Geotechnical investigation data contained in the New Zealand Geotechnical Database[12] were available at locations within approximately 500 m of the concept floodbank alignment. These data generally found that the site consists of a surface layer of medium dense to dense granular materials underlain by loose to medium dense, layered, fine and coarse-grained soils. Groundwater was typically noted at 3 to 4 m below ground surface level and is likely to vary significantly across the site and seasonally. This is generally consistent with findings of groundwater levels indicated in the 2022 Glenorchy Liquefaction Vulnerability Assessment (refer T&T (2022)).

The site is within a seismically active area, and located near the following active faults (refer GNS (2019)):

- West Wakatipu fault, approximately 5 km west of Glenorchy
- Moonlight north fault zone, approximately 20 km east of Glenorchy
- Alpine fault, approximately 50 km north-west of Glenorchy
- Northwest Cardrona fault, approximately 50 km east of Glenorchy

5.3.3 Design and Construction Risks

Potential risks to the construction of the raised floodbank identified as part of the desktop review of site conditions include:

- Construction of the existing floodbank was carried out using material from Buckler Burn (assumed to be a mix of reworked Caples Terrane schist and alluvium). Such borrow materials may be suitable for the concept floodbank raising works but will need to be investigated and reviewed for suitability.
- Depending on the material sourced for the concept floodbank raising works, a filter layer may be required between the existing floodbank surface and the raised floodbank material. This is to ensure material compatibility and ongoing performance. This filter layer would likely consist of a geosynthetic layer, extending along the interface of existing and new embankment layers.
- The existing floodbank is founded on Holocene aged sediment of the Dart-Rees River System and sediment contributions from the Buckler Burn alluvial fan. Given the deposition environment and age these are susceptible to liquefaction as outlined in the Glenorchy Liquefaction Vulnerability Assessment report (refer T&T, 2022). Such seismic related risks will need to be mitigated as part of the detailed design (e.g. provision of an operation and maintenance plan that requires prompt repair of any seismic-induced damage to the floodbank). Other seismic risks, such as deformations due to extreme ground shaking during earthquakes will also need to be mitigated as part of the detailed design.
- Approximately 0.5 m of crest settlement has occurred to the existing floodbank in the vicinity of Glenorchy Lagoons (refer Figure 2.5, Section 2). This could be attributed to underlying soft soils (with settlement corresponding to approximately 25-50% of the original embankment height over 25 years).

12 https://www.nzgd.org.nz

Further settlement is likely to continue, and to ensure ongoing performance, construction of additional embankment height, above the design level may be required. This will need to be investigated further if the concept design is taken forward to detailed design stages.

- The riverside/northern floodbank is currently heavily vegetated. External floodbank surfaces are often kept clear of vegetation as their root systems may contribute to seepage paths developing in the floodbank and increase the risk of internal erosion (HBRC, 2021). However, some vegetation may also be incorporated into a floodbank as long as it does not dimmish the integrity and functionality of the floodbank system (USACE, 2000). How to treat vegetation of the northern/riverside slope of the existing floodbank will need to be considered if the concept design is taken forward to detailed design stages.
- The northern/riverside floodbank is adjacent to the Glenorchy Lagoon outflow channel. Additional rock rip-rap protection may be required in places to mitigate against erosion and scour risks during extreme flood events. This will need to be investigated further if the concept design is taken forward to detailed design stages.

5.4 Long-Term Resilience

As outlined in Section 5.2.2, the concept design involved raising the existing Glenorchy floodbank crest level to 313.75 m RL to defend against a 1 in 100 AEP flood (including a future climate change allowance). This includes a 0.6 m freeboard provision and assumes based on an assumption of a concurrent 1 in 10 AEP Lake Wakatipu water level with a 1 in 100 AEP flood on the Rees River.

The concept for floodbank raising was checked against vulnerability to overtopping in a 1 in 500 AEP flood (based on the current climate conditions) potential future riverbed aggradation scenarios and a more extreme Lake Wakatipu lake level scenario. These scenarios are as listed below:

- 1 in 100 AEP flood (with climate change allowance); 1 in 50 AEP Lake Wakatipu level
- 1 in 500 AEP flood (current climate conditions); 1 in 10 AEP Lake Wakatipu level
- Rees and Dart active river bed aggradation of +0.2 m (i.e. at approx. 2030); 1 in 10 AEP Lake Wakatipu level
- Rees and Dart active river bed aggradation of +0.4 m (i.e. at approx. 2040); 1 in 10 AEP Lake Wakatipu water level
- Rees and Dart active river bed aggradation of +1.0 m (i.e. at approx. 2070); 1 in 10 AEP Lake Wakatipu level
- Sensitivity test that considers a Rees River avulsion scenario where all flood discharge downstream of the Rees River bridge conveyed via left bank floodplain. Refer Appendix B.1, under heading “Additional Sensitivity Testing” for further information on this sensitivity test.

The results from this assessment are presented in Table 5.1. This table lists the peak water level adjacent to the floodbank at Glenorchy Lagoon, relative to the concept design floodbank crest level of 317.5 m RL. The table indicates that the concept design floodbank crest, if raised to 313.75 m RL is expected to be resistant to overtopping in all scenarios considered, except for the sensitivity test case A100-SED4-CC. This indicates effective long-term resilience of the concept design floodbank upgrade works, with further discussion on the sensitivity test case A100-SED4-CC provided below.

Table 5.1: Summary of results from hydraulic modelling to test long-term resiliance of Option A - Raising or modifying existing Glenorchy floodbank

Model Code	Flood Frequency (AEP)	Lake Wakatipu Level (AEP)	Active River Channel Bed Aggradation Assumption*	Floodbank Crest Level (m RL)	Peak Water Level at Glenorchy Lagoon*** (m RL)	Floodbank Crest Overtopping Depth (m) †
A20	1:20 (5%)	1:10 (10%)	Current (2022)	Concept for floodbank crest level at 313.75, reducing to 312.5 between Oban and Argyle Streets (refer Figure B.1)	312.80	-0.95
A50	1:50 (2%)	1:10 (10%)	Current (2022)		312.92	-0.83
A100	1:100 (1%)	1:10 (10%)	Current (2022)		313.00	-0.75
A100-SED1	1:100 (1%)	1:10 (10%)	+0.2 m (c.2030)		313.06	-0.69
A100-SED2	1:100 (1%)	1:10 (10%)	+0.4 m (c.2040)		313.08	-0.67
A100-SED3	1:100 (1%)	1:10 (10%)	+1.0 m (c.2070)		313.12	-0.63
A100-SED3-LL	1:100 (1%)	1:50 (0.2%)	+1.0 m (c.2070)		313.13	-0.64
A100-CC +	*1:100 (1%) + CC***	*1:10 (10%)*	*Current (2022)*		*313.15*	*-0.60*
A100-SED3-CC	1:100 (1%) + CC**	1:10 (10%)	+1.0 m (c.2070)		313.27	-0.48
A100-SED4-CC	1:100 (1%) + CC**	1:10 (10%)	See Note [1]		313.80	+0.05
A500-SED1	1:500 (0.2%)	1:10 (10%)	+0.2 m (c.2030)		313.22	-0.53
A500-SED2	1:500 (0.2%)	1:10 (10%)	+0.4 m (c.2040)		313.26	-0.49
A500-SED3	1:500 (0.2%)	1:10 (10%)	+1.0 m (c.2070)		313.31	-0.44

Notes:
* Refer Section 4.2 for active river channel bed aggradation assumptions to 2030, 2040 and 2070.
** CC = inclusion of climate change impacts to 2081-2100 based on Representative Concentration Pathway (RCP) 8.5. RCP8.5 represents a future climate scenario where greenhouse gas emissions continue to rise throughout the 21st century.
*** Peak water level estimated from HEC-RAS hydraulic model (refer Appendix B)
† Overtopping depth = Peak Water Level minus Floodbank Crest Level at Glenorchy Lagoon. Positive values indicate floodbank crest overtopping at Glenorchy Lagoon, negative values indicate no floodbank crest overtopping.
[1] Refer Appendix B.1 "Additional Sensitivity Testing" for description of this scenario, which assumes all flood discharge on Reer River, downstream of Rees River bridge, is conveyed down left bank floodplain.

Table 5.1 also indicates that the peak water level at Glenorchy Lagoon, and adjacent to the concept design floodbank is not particularly sensitive to the different active river channel bed aggradation scenarios considered (i.e. SED1, SED2, SED3). The HEC-RAS modelling indicates that the floodplain flows spread out of the active river channel and onto the true left and right floodplains of the Rees-Dart River system. However, this effect does not significantly influence peak flood levels at Glenorchy. Active river channel bed aggradation of +0.2 m (SED1), +0.4 m (SED2) and +1.0 m (SED3) results in increases in flood level in the Glenorchy Lagoon above the A100 base case of 0.06 m, 0.12 m and 0.15 m respectively.

The case A100-SED4-CC, listed in Table 5.1, was simulated to test an extreme potential future situation, where all flood flows are directed down the true left floodplain. Further detail on this case is provided in Appendix B.1 under the "Additional Sensitivity Testing" header. This case raised the peak water level at Glenorchy Lagoon to about +0.05 m (5 cm) over the proposed Option A floodbank crest level and would result in marginal overtopping. A small amount of additional freeboard could be considered in any future detailed design phase for the Option A floodbank to mitigate against the potential for this extreme scenario to occur.

5.5 Potential Environmental Impacts

As part of any floodbank upgrades it will be necessary to assess and manage environmental impacts. As part of construction, environmental effects that should be addressed and managed include:

- Surface disturbance and sedimentation resulting from the establishment of borrow areas to facilitate construction.
- Erosion and sedimentation following vegetation stripping of the existing floodbank, particularly in the vicinity of the Glenorchy Lagoon.
- As part of site establishment, it will be necessary to remove vegetation from the existing floodbank including trees and shrubs. This will require localised surface treatment, and likely necessitate offset by remedial planting.
- Confirmation that the raised floodbank would not impact on the Glenorchy Lagoon water levels or hydraulic characteristics.

Compression of soils, with the resulting impact on permeability, may lead to localised changes in the groundwater regime. Preliminary review of site topography indicates that these effects will be limited to the area of the golf course. If a raise of the floodbank crest is progressed, it is recommended that investigations are carried out to assess the potential environmental impacts and develop conditions for a resource consent. As a minimum, investigations should:

- Identify borrow sources suitable for use in floodbank construction.
- Assess the extent of topsoil stripping and vegetation required to facilitate floodbank and borrow area construction.
- Assess groundwater flows in the vicinity of the floodbank, and confirm any effects that may result from floodbank construction.

5.6 Consenting Requirements

A preliminary analysis of the relevant statutory planning documents and provisions for the concept design option is provided in Appendix D. Further detailed statutory analysis of the activities associated with the concept design will be required as part of the resource consent process once the final design is confirmed.

In summary, resource consent for the concept design will be required from QLDC and ORC as summarised below:

Queenstown Lakes District Council

Consents will, or are likely to, be required under the following rules of the Queenstown Lakes Proposed District Plan (PDP) and, overall, it will be assessed as a Discretionary activity:

- A discretionary consent under Rule 30.5.1.16 - Flood Protection Works.
- A restricted discretionary consent under Table 25.2 Earthworks volumes.
- A restricted discretionary consent under Standard 25.5.10A.2 Wāhi Tūpuna Areas - earthworks area.
- A restricted discretionary consent under Standard 25.5.11 - Earthworks area.
- A restricted discretionary consent under Standard 25.5.18- Setbacks from site boundaries for earthworks not supported by retaining walls greater than 0.5 metres in height or depth.

- A restricted discretionary consent under Standard 25.5.19.1 - Earthworks within 10m of the bed of a waterbody.
- A restricted discretionary consent under Standard 25.5.21 - No more than 300m³ of cleanfill transported to the site.
- A discretionary consent under Rule 29.4.13 - Activities that are not listed in the transport activities/ rules Table.

Otago Regional Council

The following consents will, or are likely to be, required under the Otago Regional Plan: Water 2004 (RPW) and, overall, it will be assessed as a Discretionary activity:

- A discretionary activity under Rule 12.3.4.1 of the Otago Regional Plan: Water 2004 *(RPW)* for the diversion of water.
- A discretionary activity under Rule 14.3.2.1 of the RPW for erecting/ altering a defence against water.
- A discretionary activity consent is likely to be required under Clause 45(2) of the Resource Management (National Environmental Standards for Freshwater) Regulations 2020 *(NESF)* for those parts of the works located in close proximity to the Glenorchy Lagoon.

The Glenorchy Lagoon is listed as a regionally significant wetland in Schedule 9 of that Plan (Figure D.1) and is identified in Section F of the maps contained in the RPW. However, as the concept design is not expected to alter the wetland in any way, consent is not required under Rule 13.5.3.2.

Consultation and affected persons

As the concept design is located within a Wāhi Tūpuna area, is located on various parcels of land and affects various land owners, consultation and, ideally obtaining affected persons approvals, will be an integral part of the consenting process. The landowners and other parties that are likely to be considered to be affected by the activities are listed in full in Appendix D.

5.7 Indicative Costings

Preliminary cost estimates have been prepared based on the concept-level design outlined above. Rates for floodbank construction were summarised based on recent and similar floodbank construction contracts.

Indicative costs are provided in Table 5.2. Inclusions on the cost estimates are listed in the table. These costs should be considered as a guide only and it is recommended that further professional Quantity Surveying guidance is sought prior to detailed design.

Cost estimates <u>exclude</u> items such as:

- Operating and maintenance costs
- Planting or vegetation works (other than grassing of disturbed surfaces)
- Land purchase (if required)
- Iwi engagement
- Community consultation
- Legal fees (as required)
- Costs associated with any appeals, or other legal action taken, on resource consent decisions

Table 5.2: Preliminary construction cost estimate

Item	Notes / Inclusions	Cost Estimate
A. Floodbank construction	• Includes all works items described in Section 5.2.3 • Total quantity of fill required to raise existing floodbank = approx. 13,000 m^3	$1,100,000
B. Contractor Costs	• Preliminary & General items @ 20% of floodbank construction costs	$220,000
C. Client Costs	• Detailed engineering design @ 15% of [A] + [B] • Consenting (refer Appendix D, assuming $75,000 for publicly notified consent) • Construction contract management and monitoring @ 4% of [A] + [B]	$330,000
D. Contingency	• Contingency Range -5% • Contingency Rang +40%	-$82,500 +$660,000
INDICATIVE COST RANGE	Sum of [A] to [C] above with [D] @-5% contingency Sum of [A] to [C] above with [D] @+40% contingency	$1,567,500 to $2,310,000

5.8 Further Studies Prior to Detailed Design Phase

The following works have been identified to confirm assumptions made as part of this concept design and to prepare for the detailed engineering design phase:

- Existing floodbank hydraulic performance, including but not limited to northern/riverside erosion and scour risks and existing vegetation removal options (also refer discussion under Section 5.3.3).
- Geotechnical investigations to assess the foundations and the existing floodbank condition, along with laboratory soil testing as required.
- Geotechnical investigations to confirm the location of suitable borrow sources for floodbank construction, along with laboratory soil testing as required. It is envisaged that the Buckler Burn borrow site would be utilised, as was understood to have been done for original floodbank construction. However, other borrow sources should be considered (e.g. from the Rees River delta).
- Confirm resource consent requirements from QLDC and ORC.
- Confirm land acquisition (if required) from property owners to build a raised floodbank.

6 Conclusions

Lower Rees Flood Hazards

The Lower Rees River is subject to flooding and erosion hazards which impact on the township of Glenorchy in the Queenstown-Lakes District. There is an existing floodbank to manage flood risks at Glenorchy. It runs from the eastern end of Mull Street to Lake Wakatipu (refer Figure 2.4). However, the floodbank overtopped in a February 2020 flood event and a recent flood hazard assessment (LRS, 2022) estimated the existing Glenorchy floodbank, will be overtopped in events upwards of a 1 in 20 AEP (5%) flood. Future flooding issues are anticipated to be intensified by the following wider geomorphic and hydrological processes in the area:

- Actively aggrading river bed levels
- Actively migrating braided river channel belts
- Progradation of the Dart-Rees river delta into the head of Lake Wakatipu
- Future climate change effects which are expected to increase flood hazards over time

Background & Scope of Current Assessment

A floodplain adaptation workshop was held on 23-24 February 2022 which involved staff from both Otago Regional Council (ORC) and Queenstown Lakes District Council (QLDC) as well as a small number of invited technical experts. The workshop provided a “first-pass” review of possible flood mitigation and floodplain intervention options.

Following on from the February 2022 workshop, Otago Regional Council (ORC) engaged Damwatch Engineering Ltd (Damwatch) to undertake the current study which involved a high-level assessment of potential floodplain intervention options for the Lower Rees River to mitigate flood hazards. The objectives of the review were to provide an evidence-base to rule out various floodplain intervention options and identify a viable option. All options were also tested for their alignment with Nature-based Solutions to floodplain management (refer Section 3). The viable option was then taken forward to a concept level design stage.

QLDC owns and maintains the existing Glenorchy floodbank. ORC undertakes some river management activities (channel clearance and obstruction removal) in this area in liaison with the Department of Conservation and QLDC. In relation to this, ORC may inspect and carry out some maintenance activities on structure that are not owned by ORC. This is determined based on community request and response to weather/flooding related events.

Investigation of Potential Flood Improvement Options

The following potential floodplain intervention options were investigated with the aid of a two-dimensional computational hydraulic model of the Rees-Dart River system. The model was validated against the February 2020 flood. The model was used to simulate various flood scenarios in combination with the potential flood improvement options.

- Option A: Raising or modifying the existing Glenorchy floodbank
- Option B: Construction of bunding or new structures to reduce overland flood flow paths on the left bank floodplain and into the Glenorchy Lagoon

- Option C: Vegetative buffers to modify overland flow paths on the left bank floodplain and into the Glenorchy Lagoon

An illustration of each of these options is provided in Figure 4.1.

Findings from Investigation of Potential Flood Improvement Options

Options B and C were found not to be viable:

- Option B required construction of new and relatively long (1.5 to 5 km long) floodbanks, between 1 to 3 m high above natural ground on the true left floodplain of the Rees River, downstream of the Glenorchy-Paradise Road bridge crossing the Rees River. Such new floodbanks were not aligned with NbS practices and their long-term sustainability could not be assured during future flood conditions. They would be susceptible to outflanking, overtopping and erosion from lateral river channel migration.
- Option C had good alignment with NbS practices, but was not effective at reducing flood hazards to Glenorchy.

Option A was determined to be viable and effective at mitigating flood hazards at Glenorchy. This option involved raising the existing floodbank between Argyle Street and the eastern end of Mull Street. The following concept level design information was developed for this option:

- Concept level drawings (refer Appendix C)
- Indicative construction costs
- Preliminary review of design and construction considerations
- Preliminary review of consenting requirements
- Long-term resilience of the concept design floodbank
- Issues and further works to prepare for any future detailed design phase

It is understood that the information contained in this report, regarding potential floodplain intervention options for the Lower Rees River and to mitigate flood hazards at Glenorchy, will be considered by both ORC and QLDC and taken forward as required for community consultation and engagement.

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Appendix A Hydraulic Model of Rees-Dart River

Table A.1 provides a summary of the HEC-RAS hydraulic model used for the purposes of this study.

Table A.1: Summary of hydraulic model parameters

Parameters	Description
Model type	HEC-RAS 2D
Model extent	Dart-Rees Rivers from Glenorchy-Paradise Road crossing of Rees River and Glenorchy-Routeburn Road crossing of Dart River to head of Lake Wakatipu (refer Figure A.1)
Topographic data	Digital Elevation Model (DEM) used for ground elevations in model derived from: ● 2022 LiDAR aerial survey captured by the University of Canterbury ● Otago Regional Council 2019 LiDAR aerial survey ● LRS (2022) terrain modifications to represent Lake Wakatipu and Glenorchy Lagoons bathymetry Data provided as 1m gridded bare earth digital elevation model (DEM). Refer Figure A.1 for the extent of the topographic data sets used.
Model mesh	An unstructured mesh with, an average 15 x 15 m cell dimension for the active river channels and an average 25 x 25 m cell dimension for floodplain areas.
Model scenarios	Refer to main report Table 4.1.
Model validation	The model was validated against the February 2020 flood. Refer section below "HEC-RAS Model Validation" for further detail.
Boundary conditions	● Upstream: Refer to Table 2.1 in main report for Rees and Dart River peak discharge estimates. 1 in 100 AEP flood hydrograph shape published in ORC (2021) (refer Figure A.2) scaled based on ratio of flood peak discharge. ● Downstream: Constant water level boundary, representing Lake Wakatipu flood level. Refer to Table 2.2 in main report for Lake Wakatipu flood level frequency data.
Roughness coefficients	● Manning's "n" surface roughness coefficients listed in Table A.2 and based on those adopted by LRS (2022) for flood hazard modelling.
Hydraulic structures	● Glenorchy floodbank incorporated in model as a "dike" feature which allowed this feature to be modeled as a broad-crested weir with surveyed floodbank crest levels assigned to the weir crest.
Simulation Control Parameters	● *Solution Technique*: Both the "diffusion wave" and "shallow water equations" were tested for this model and gave very similar results. The "diffusion wave" solution had the advantage that the run times were significantly less than those for the "shallow water equation" solution, and the former was therefore elected for this study. The model was also validated based on the "diffusion wave" equations and therefore the same approach was used for the option assessment simulations. This was the same approach adopted in the LRS (2022) hydraulic modelling study. Refer sub-section "Selection of HEC-RAS Model Solution Techniques" below for further detail. ● *Computational Time Step*: An adaptive time step between 1 and 25 seconds provided numerical stability and suitable model simulation times.
Model Outputs	● Two-dimensional grids of flood extent, flow depth, water levels and flow velocity

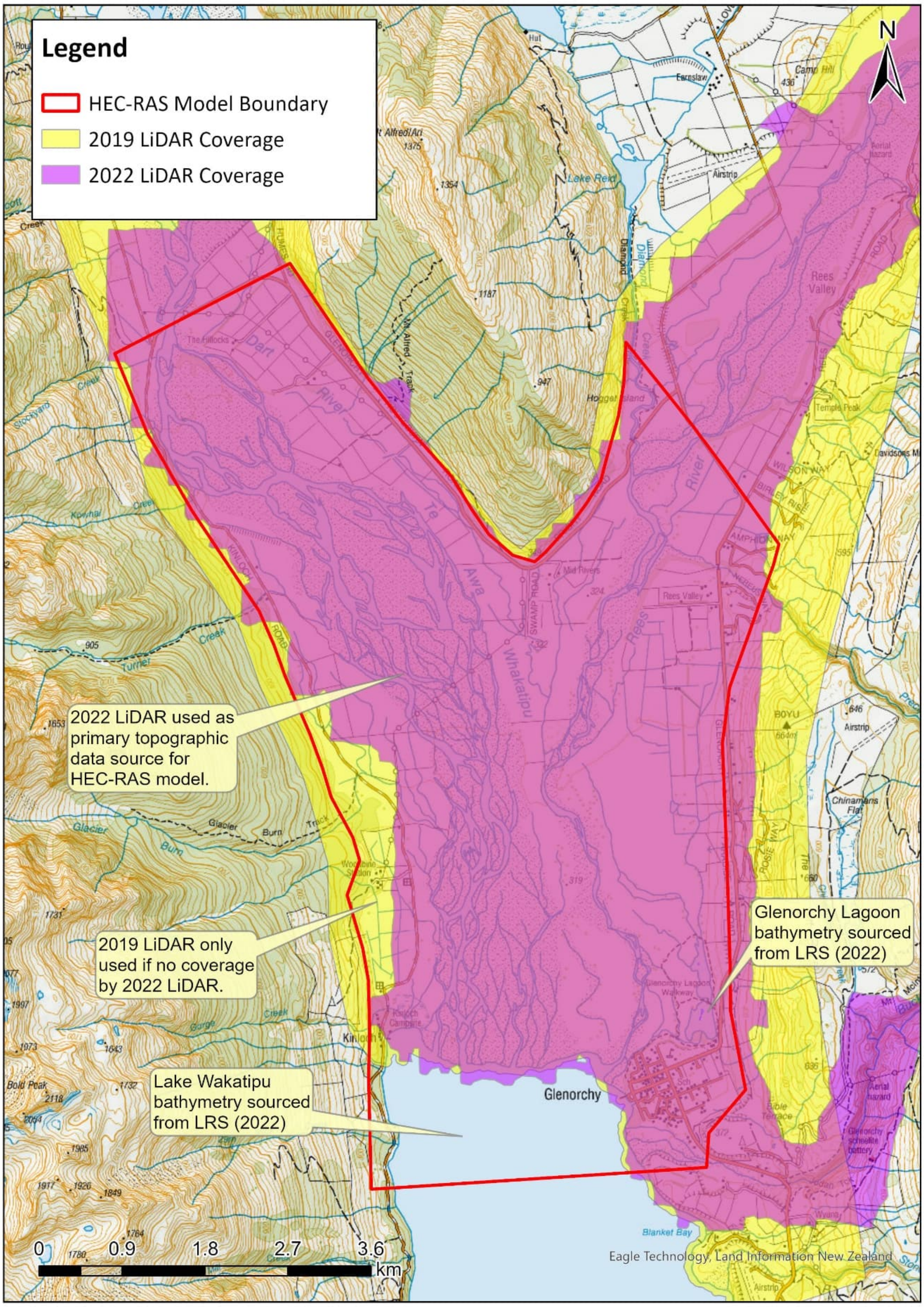


Figure A.1: Extent of HEC-RAS model domain, showing coverage of 2019 and 2022 LiDAR topographic surveys.

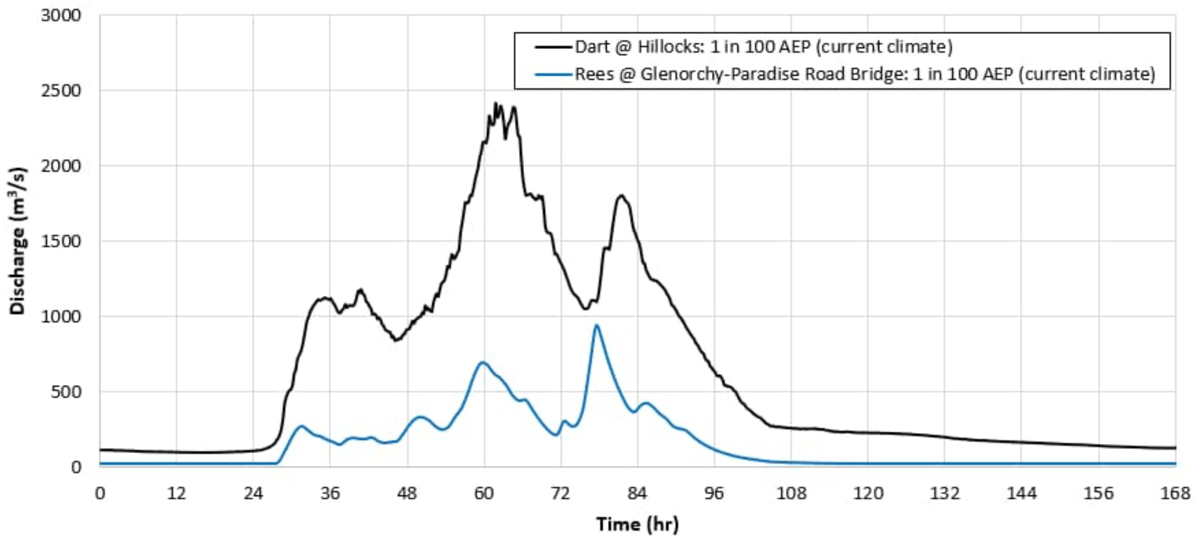


Figure A.2: 1 in 100 AEP (current climate) hydrographs, reproduced from ORC (2021)

Table A.2 - Manning's "n" roughness coefficients adopted in HEC-RAS model, reproduced from LRS (2022)

Land use type	Manning's "n"
Vegetation	0.07 – 0.12
Roads / Concrete	0.02
Grass / Pasture	0.033
Gravel River Bed	0.019
Buildings	1.000

HEC-RAS Model Validation

The February 2020 flood event was simluated with the HEC-RAS model, using the same model bournday conditions outlined in LRS (2022), which adopted:

- Flood hydrographs (with shape derived from ORC (2021) and a peak flow of 642 m^3/s in the Rees River and 1792 m^3/s in the Dart River
- Lake Wakatipu levels were taken from the ORC level gauge at Willow Place

The model was found to validate reasonably well with the February 2020 flood event based on the following findings:

- Based on observations after the flood event, peak water level at the footbridge crossings Glenorchy Lagoons creek was esimated to be around 312.7 to 312.8 m RL (LRS, 2022). The HEC-RAS model predicted a peak water level of 312.67 m RL.
- Comparison of HEC-RAS model predicted flood extents at Glenorchy with the estimated extent provided by ORC (refer Figure A.3)
- The general pattern of floodplain overflows matched those visible from infrared satellite imagery captured after the flood event (refer Figure 6-2 in the LRS (2022) report).

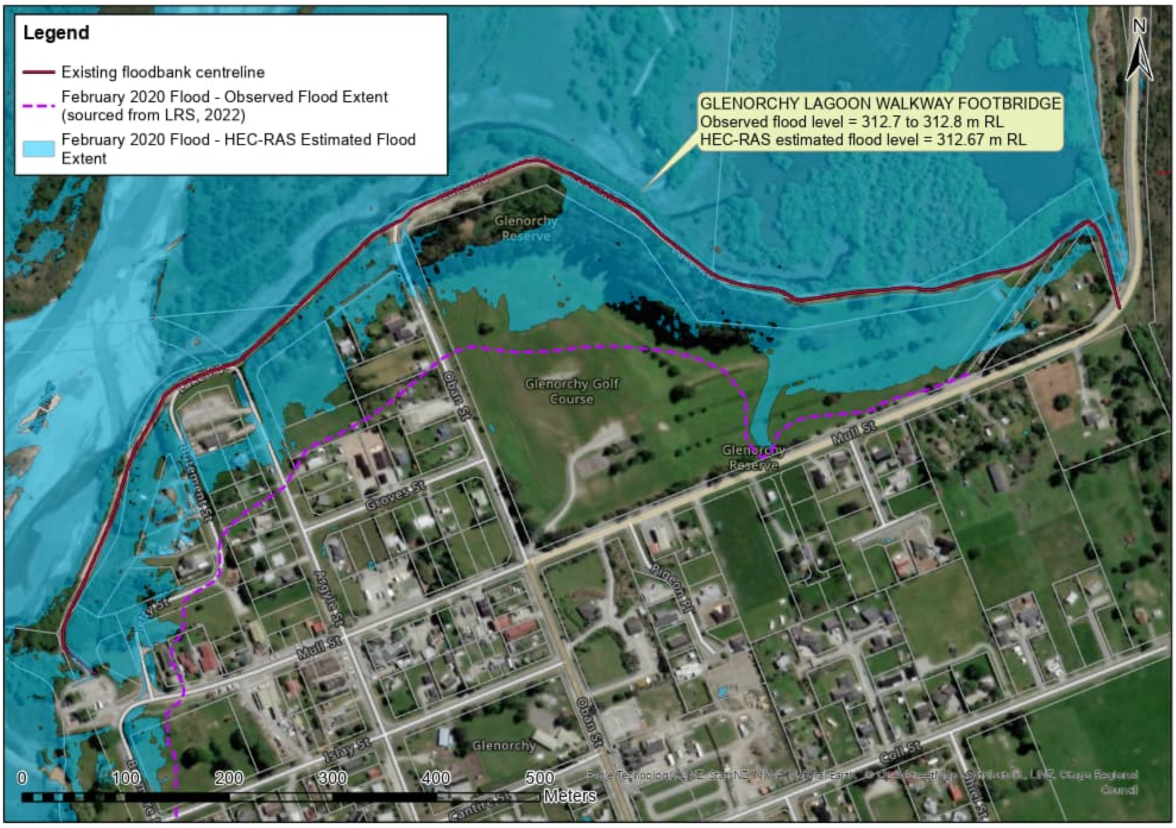


Figure A.3: Comparison of HEC-RAS modelled February 2020 flood extent (blue shading) with estimated actual extent (dashed-purple line). Existing Glenorchy floodbank alignment shown with red line.

Selection of HEC-RAS Model Solution Techniques

The HEC-RAS software package incorporates three different equation sets for solving for flow moving over the two-dimensional (2D) surface defined by the computational domain :

- the Diffusion Wave equation set (DWE)
- the original Shallow Water wave equation set using an Eulerian-Lagrangian solution method (SWE-ELM)
- a newer Shallow Water wave equation set that is more momentum-conservative and which uses an Eulerian solution method (SWE-EM)

The DWE set omits several terms from the momentum equation in the full set of shallow water equations to give a simplified version. This considerably reduces the computational effort required when using the DWE set to solve for flow moving over a 2D surface. However, there are a number of situations where the full SWE set should be used to more accurately predict flow patterns:

- flash flood situations
- situations involving very abrupt expansions and contractions
- very flat sloping river situations
- tidally influenced situations
- wave propagation due to rapid opening or closing of gates in structures

- bend situations involving flow superelevation
- situations where accurate knowledge of flow velocity distributions and water surface elevation profiles is required around structures
- situations involving mixed sub-critical and supercritical flow regimes

Within the software, the DWE equations are set as the default. The HEC-RAS User Manual recommends using the Diffusion Wave equations when developing a model and then, once all problems with the model are resolved, repeating the final model simulation with the SWE set using the full set of Shallow Water equations. If there are significant differences between the two solutions, then the solution using SWE set should be assumed to be more accurate.

For the HEC-RAS model of the Rees-Dart River system, the DWE equation set was primarily used to predict flood inundation patterns across the river and floodplain system within the model domain. However, the model was re-run for the 1 in 100 AEP flood for the existing river and floodplain geometry using the full SWE set. The predicted peak flood level at the Glenorchy Lagoon footbridge was 313.13 m RL for the model using the DWE equation set and 313.20 m RL for the model using the full SWE equation set (i.e. a difference of 7 cm).

This indicates that there are not signficant differences between the two solutions that would warrant use of the full SWE equation set. Accordingly, the DWE equation set was used for all other model simulation scenarios.

Appendix B Options Assessment Findings

B.1 Option A – Raising Existing Glenorchy Floodbank

Option Summary

The objective of this option was to raise the existing Glenorchy floodbank to mitigate flooding at Glenorchy from the Rees River. This option was simulated in the HEC-RAS model (described in Appendix A) by setting an artificial “glass wall” on the existing floodbank crest centreline. This prevented overtopping of the existing floodbank and allowed peak water levels upstream of the floodbank to be determined.

Results Discussion

Table B.1 lists the HEC-RAS model predicted peak flood levels at Glenorchy Lagoon for the various model scenarios considered. For all model scenarios, the Lake Wakatipu water level equivalent to a 1 in 10 AEP lake level was adopted as a downstream boundary condition, except for scenario “A100-SED3-LL” listed in Table B.1 where a sensitivity test to a 1 in 50 AEP lake level was simulated.

The Glenorchy floodbank crest level is nominally at 313.0 m RL but with low points at about 312.64 m RL (refer Section 2.3). The peak water levels predicted by the HEC-RAS model, and listed in Table B.1, indicate the crest level of the existing Glenorchy floodbank would require raising to prevent overtopping in all scenarios considered.

If the existing floodbank was raised to 313.75 m RL (i.e. raising the existing floodbank in the order of 0.75 to 1.10 m above existing crest levels) it would provide protection against the 1 in 100 AEP flood (with climate change allowance) with a 0.6 m of freeboard allowance (refer Model “A100-CC” in Table B.1). This simulation is highlighted with bold, italic text in Table B.1.

The floodbank would not need to be raised to 313.75 m RL along the full length of the existing floodbank. Figure B.1 shows the HEC-RAS model predicted peak water level profile, just upstream of the floodbank, for the 1 in 100 AEP flood (with climate change allowance) assuming the floodbank is raised to 313.75 m RL east of Oban Street and tapering to 312.5 m RL at Argyle Street. This figure illustrates how the HEC-RAS model predicted peak water profile drops down towards Lake Wakatipu as flows are returned from the Glenorchy Lagoon floodplain area back to the Rees River.

It should be noted that low-lying properties behind the foodbank between Oban Street and Lake Wakatipu are still vulnerable to flooding from high Lake Wakatipu water levels. This is illustrated in Figure B.2 which shows the HEC-RAS model predicted 1 in 100 AEP flood maximum inundation extent with the existing floodbank crest level raised to 313.75 m RL and a combined Lake Wakatipu water level at 1 in 10 AEP (refer Model “A100-SED3”) and 1 in 50 AEP (refer Model “A100-SED3-LL”).

The option of raising the existing Glenorchy floodbank was considered a viable option to mitigate Rees River flooding (but not flooding from Lake Wakatipu) and was taken forward to further concept design considerations as outlined in Section 5 of this report.

Table B.1: Summary of selected computational hydraulic model simulation results for assessment of effectiveness of floodplain interventions

Model Code	Flood Frequency (AEP)	Lake Wakatipu Level (AEP)	Active River Channel Bed Aggradation Assumption*	Floodbank Crest Level (m RL)	Peak Water Level at Glenorchy Lagoon*** (m RL)	Floodbank Crest Overtopping Depth (m) †
X20	1:20 (5%)	1:10 (10%)	Current (2022)	Existing floodbank low point at 312.6	312.62	+0.00
X50	1:50 (2%)	1:10 (10%)	Current (2022)		312.74	+0.11
X100	1:100 (1%)	1:10 (10%)	Current (2022)		312.81	+0.21
A20	1:20 (5%)	1:10 (10%)	Current (2022)	Concept design floodbank crest level 313.75, reducing to 312.5 between Oban and Argyle Streets (refer Figure B.1)	312.80	-0.95
A50	1:50 (2%)	1:10 (10%)	Current (2022)		312.92	-0.83
A100	1:100 (1%)	1:10 (10%)	Current (2022)		313.00	-0.75
A100-SED1	1:100 (1%)	1:10 (10%)	+0.2 m (c.2030)		313.06	-0.69
A100-SED2	1:100 (1%)	1:10 (10%)	+0.4 m (c.2040)		313.08	-0.67
A100-SED3	1:100 (1%)	1:10 (10%)	+1.0 m (c.2070)		313.12	-0.63
A100-SED3-LL	1:100 (1%)	1:50 (0.2%)	+1.0 m (c.2070)		313.13	-0.64
A100-CC +	*1:100 (1%) + CC***	*1:10 (10%)*	*Current (2022)*		*313.15*	*-0.60*
A100-SED3-CC	1:100 (1%) + CC**	1:10 (10%)	+1.0 m (c.2070)		313.27	-0.48
A500-SED1	1:500 (0.2%)	1:10 (10%)	+0.2 m (c.2030)		313.22	-0.53
A500-SED2	1:500 (0.2%)	1:10 (10%)	+0.4 m (c.2040)		313.26	-0.49
A500-SED3	1:500 (0.2%)	1:10 (10%)	+1.0 m (c.2070)		313.31	-0.44

Notes:

* Refer Section 4.2 for active river channel bed aggradation assumptions to 2030, 2040 and 2070.

** CC = inclusion of climate change impacts to 2081-2100 based on Representative Concentration Pathway (RCP) 8.5. RCP8.5 represents a future climate scenario where greenhouse gas emissions continue to rise throughout the 21st century.

*** Peak water level estimated from HEC-RAS hydraulic model (refer Appendix B)

† Overtopping depth = Peak Water Level minus Floodbank Crest Level at Glenorchy Lagoon. Positive values indicate floodbank crest overtopping at Glenorchy Lagoon, negative values indicate no floodbank crest overtopping.

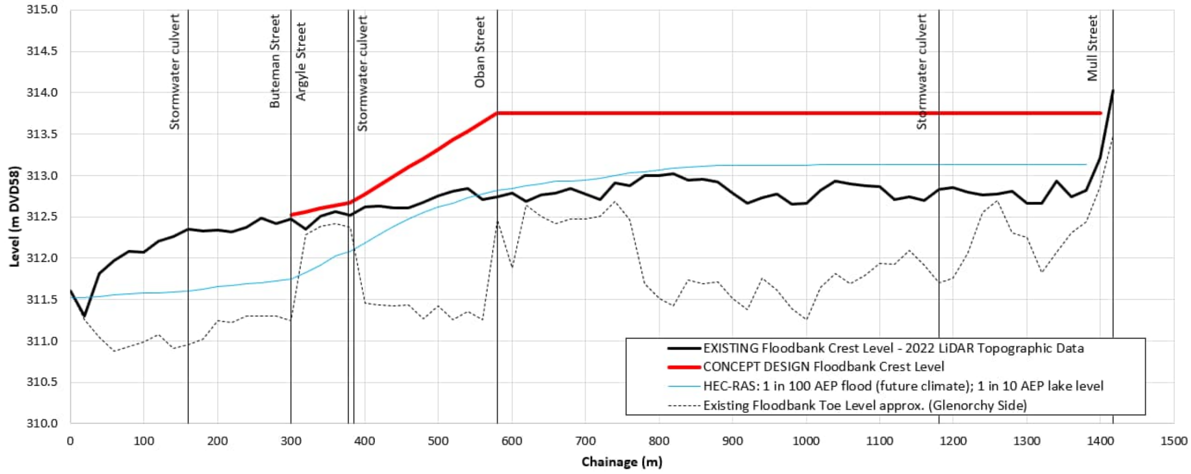


Figure B.1: Long-section along Glenorchy floodbank existing and concept design showing crest levels and HEC-RAS modelled peak water levels upstream of the floodbank for 1 in 100 AEP flood (future climate) with 1 in 10 AEP Lake Wakatipu level

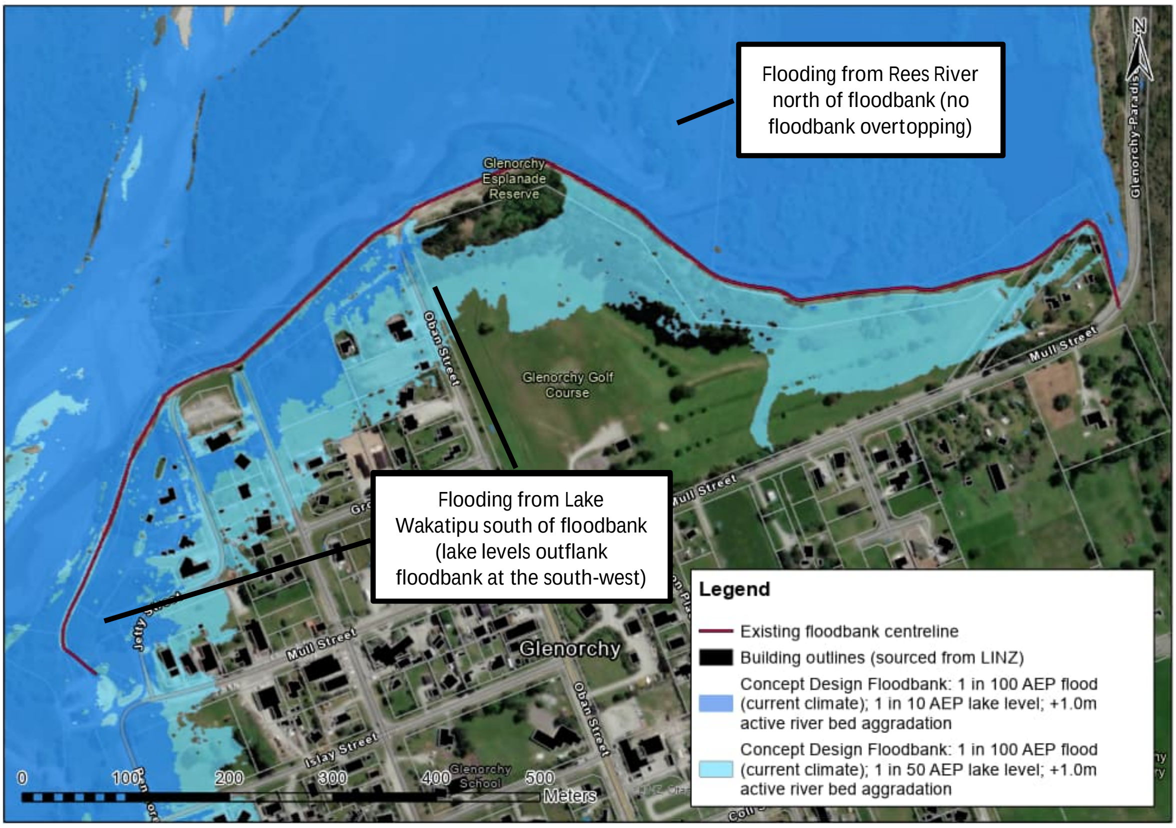


Figure B.2: Maximum flood inundation at Glenorchy for case with concept design raised floodbank and 1 in 100 AEP flood (current climate), assuming +1.0 m active river channel bed aggradation and Lake Wakatipu lake level at 1 in 10 AEP (dark blue shading) and 1 in 50 AEP (light blue shading).

Alternative Option Consideration - Retreat of Existing Floodbank

As part of the development of the concept design of Option A, an alternative floodbank modification option was identified. This involved retreating the existing floodbank along the length of the Glenorchy Golf Course and construction of a new floodbank parallel to Oban Street. A new floodbank would also be needed along Mull Street to prevent flooding to the south of this street. Refer to Figure B.3 for a sketch of this option.

However, this option was determined not to be viable based on discussions with ORC, as it would:

- Reduce the existing level of flood protection to the golf course area and the private property at 1 Glenorchy-Paradise Road
- Require construction of additional floodbank works (the cost of which are likely to exceed those for Option A)
- Provide limited to no NbS benefits relative to Option A)

Effect of River Bed Aggradation on Floodbank Performance

Figure B.4(a) shows the HEC-RAS predicted maximum flood depths and inundation extents for the 1 in 100 AEP flood (current climate) for the concept design floodbank Option A with the Rees-Dart River bed levels derived from the 2022 LiDAR topographic survey. Figure B.4(b) and (c) provide the same information btu with an assumed +0.2 m and +1.0 m of active river bed aggradation. The peak water level at Glenorchy Lagoon is also shown on these plans.

Figure B.4 indicates that an increase in active river bed aggradation (i.e. Figure B.4(b) and (c)) results in a shift in floodplain flow paths with greater flow occurring on the current floodplain areas and reduced flow in the current active river bed channel. Red arrows on Figures B.4(b) and (c) indicate the location of the increased flows on the current floodplain areas. However, the increase in active river bed aggradation does not significantly increase peak flood water levels at Glenorchy Lagoon.

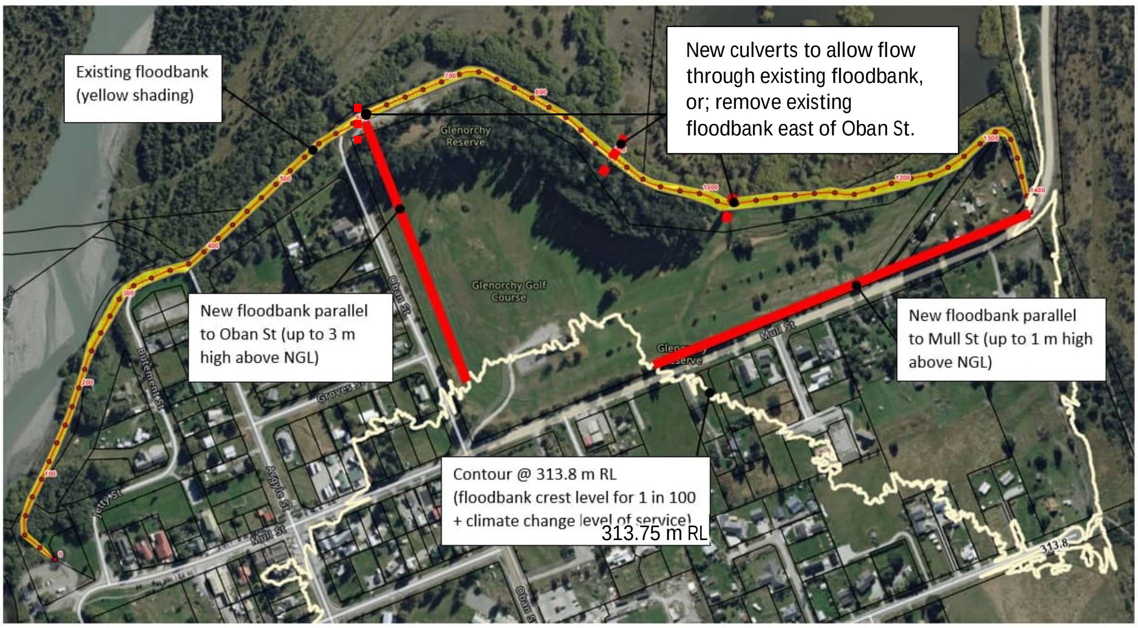


Figure B.3: Illustration of alternative (and discontinued) floodbank alignment option

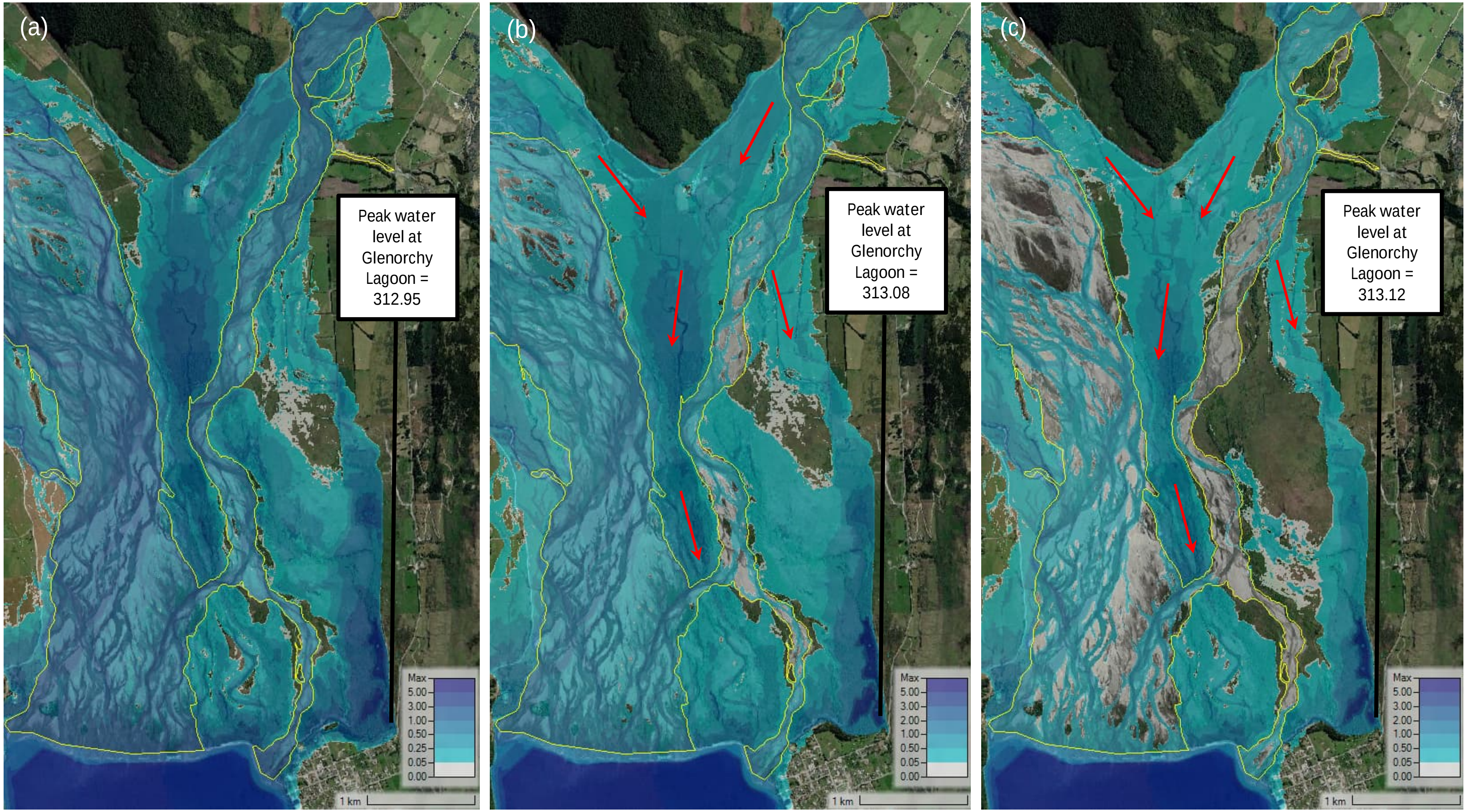


Figure B.4: HEC-RAS model predicted maximum water depths and extents for 1 in 100 AEP (current climate) with 1 in 10 AEP Lake Wakatipu level for Option A with (a) current (2022 LiDAR) Rees-Dart River and floodplain topography and (b) with +0.4 m and (c) +1.0 m of active river channel bed aggradation. Edge of active river channels (c. 2019) shown with yellow lines.

Additional Sensitivity Testing

Table B.2 summarises additional sensitivty tests carried out for the HEC-RAS model of the Rees-Dart River system.

Test A100-CC-S01, listed in Table B.2, was carried out to identify if a change in the Manning's n roughness coefficient from the adopted value of n = 0.019 f(refer Table A.2) for the active river channel to n = 0.027 had a significant impact on the model's prediction of peak water levels at Glenorchy Lagoon. The n = 0.027 value reflects that predicted by the Manning-Strickler relationship (Henderson, 1966) for a median sediment grain size d_{50} of between 50 and 100 mm (assessed from site observations to be a typical bed material size at the Rees River Bridge). Table B.2 indicates that water levels at Glenorchy Lagoon would increase in the order of 0.06m (6 cm) as a result of this change in the model Manning's n value for the river channel. The model is therefore not signficantly affected by this change, but this result should be considered for modelling in any future detailed design phase.

Test A100-CC-S02, listed in Table B.2, was carried out as a long-term resiliance test, assuming a hypothetical future case where the Lower Rees river avulses so that all flow is diverted onto the true left floodplain as illustrated in Figure B.5. Inspection of the model results indicated that this change resulted in an increase in flow paths and the volume of water onto the true left floodplain (refer Figure B.5). As indicated in Table B.2, this raised the peak water level at Glenorchy Lagoon to about 0.65 m above the baseline model scenario. This would result in marginal overtopping of the crest of the Option A floodbank, which is 0.60 m above the baseline model predicted peak water level (refer Table B.1). This senstivity test represents an extreme potential future situation, where all flood flows are directed down the true left floodplain. A small amount of additional freeboard could be considered in any future detailed design phase for the Option A floodbank to mitigate against the potential for this extreme scenario to occur.

Table B.2 – Sensitivity testing summary

Model Code	Sensitivity Test	Difference in Peak Water Level Relative to Baseline Model
A100-CC	Baseline Model (refer model A100-CC in Table B.1)	0.00 m
A100-CC-S01	Same as baseline model, but; increase Manning's n from 0.019 to 0.027 on active river channel (refer yellow lines on Figure B.5).	+0.06 m
A100-CC-S02	Same as baseline model, but; add "glass-wall" across Rees River at location shown in Figure B.5. This is to simulate a hypothetical case scenario where future river avulsion diverts all Rees River flows across the true left floodplain.	+0.65 m

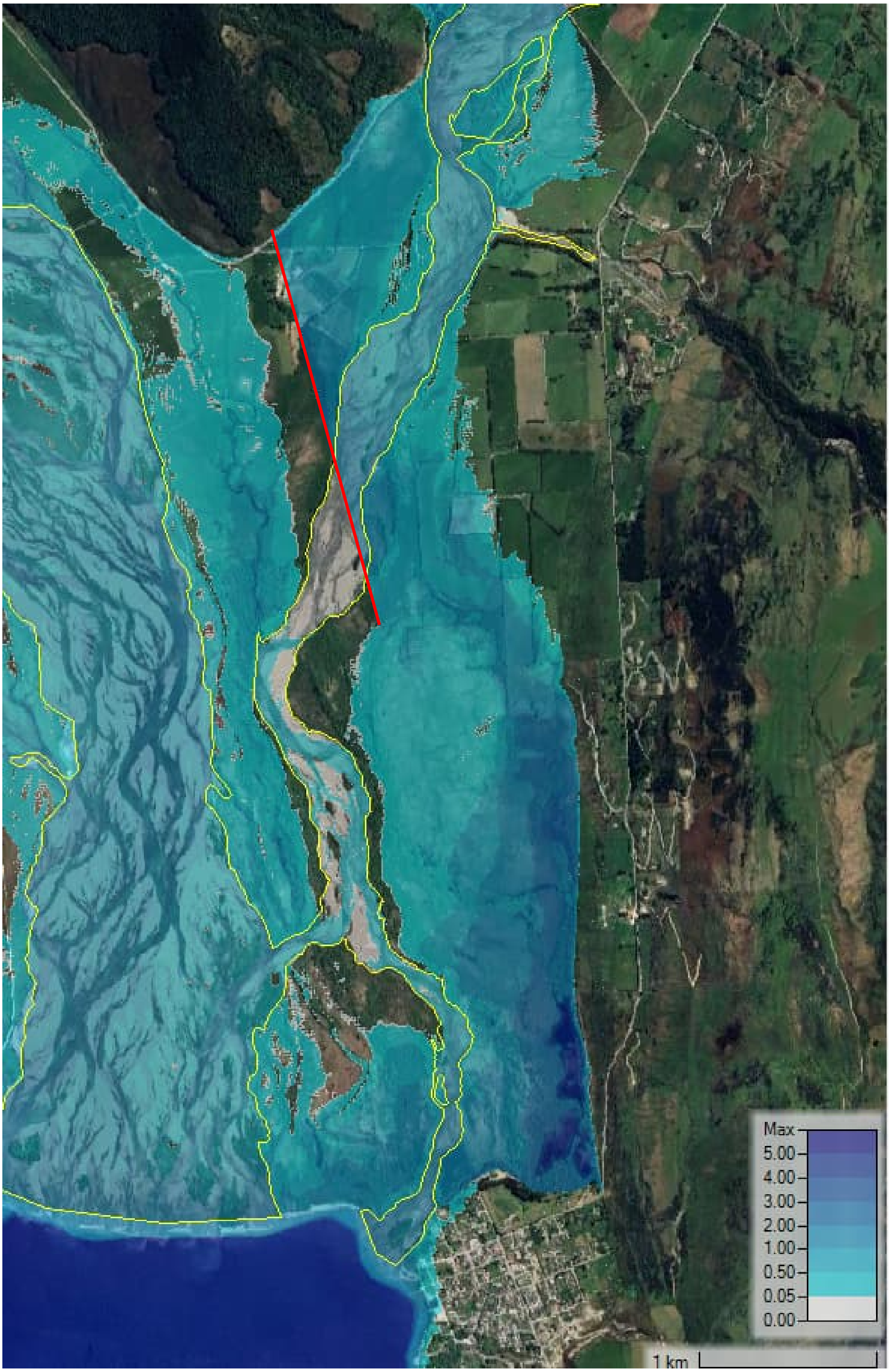


Figure B.5: HEC-RAS model predicted maximum water depths and extents for simulation A100-CC-S02 (refer Table B.2). Yellow lines indicate extents of active river channel. Red line indicates "glass wall" applied in model simulation A100-CC-S02 to direct flood flows onto true left floodplain.

B.2 Option B – Bunding to reduce overland flood flow paths

Results Discussion

Option B involved consideration of new bunding/floodbank works along the left bank of the Rees River to limit or prevent floodplain overflows and flooding at Glenorchy. Two different bund/floodbank alignments were considered:

- Option B(i): A new bund/floodbank along the left bank of the Rees River, extending approximately 5 km from the Glenorchy Lagoon outflow channel confluence with the Rees River to the Precipice Creek confluence (refer red line on Figure B.5b).

  This option was simulated in the HEC-RAS model (described in Appendix A) by setting an artificial "glass wall" along the new bund/floodbank alignment. The new bund/floodbank was offset about 20 m from the edge of the active river channel. This prevented overflow from the active river channel onto the true left floodplain.

- Option B(ii) A bund across the left bank floodplain (refer red line on Figure B.5c).

  This option was simulated in the HEC-RAS model (described in Appendix A) by setting an artificial "glass wall" along the new bund/floodbank alignment. This prevented floodplain flows from overtopping the bund in an attempt to migrate them back into the active river channel.

Figure B.5 show the HEC-RAS predicted maximum flood depths and inundation extents for the 1 in 100 AEP flood (current climate) for the current floodplain topography and for the concept design Option B(i) and Option B(ii) bunds. The peak water level at Glenorchy Lagoon is also shown on these plans.

Summary of Findings

Figure B.5 indicates that:

- Option B(i) is effective at reducing outflows from the Lower Rees River and onto the true left floodplain. Further discussion on this option is provided in Section 4.3 of the main report.
- Option B(ii) is not effective at reducing outflows from the Rees River and onto the true left floodplain. The bund is outflanked to the south. Further discussion on this option is provided in Section 4.3 of the main report.

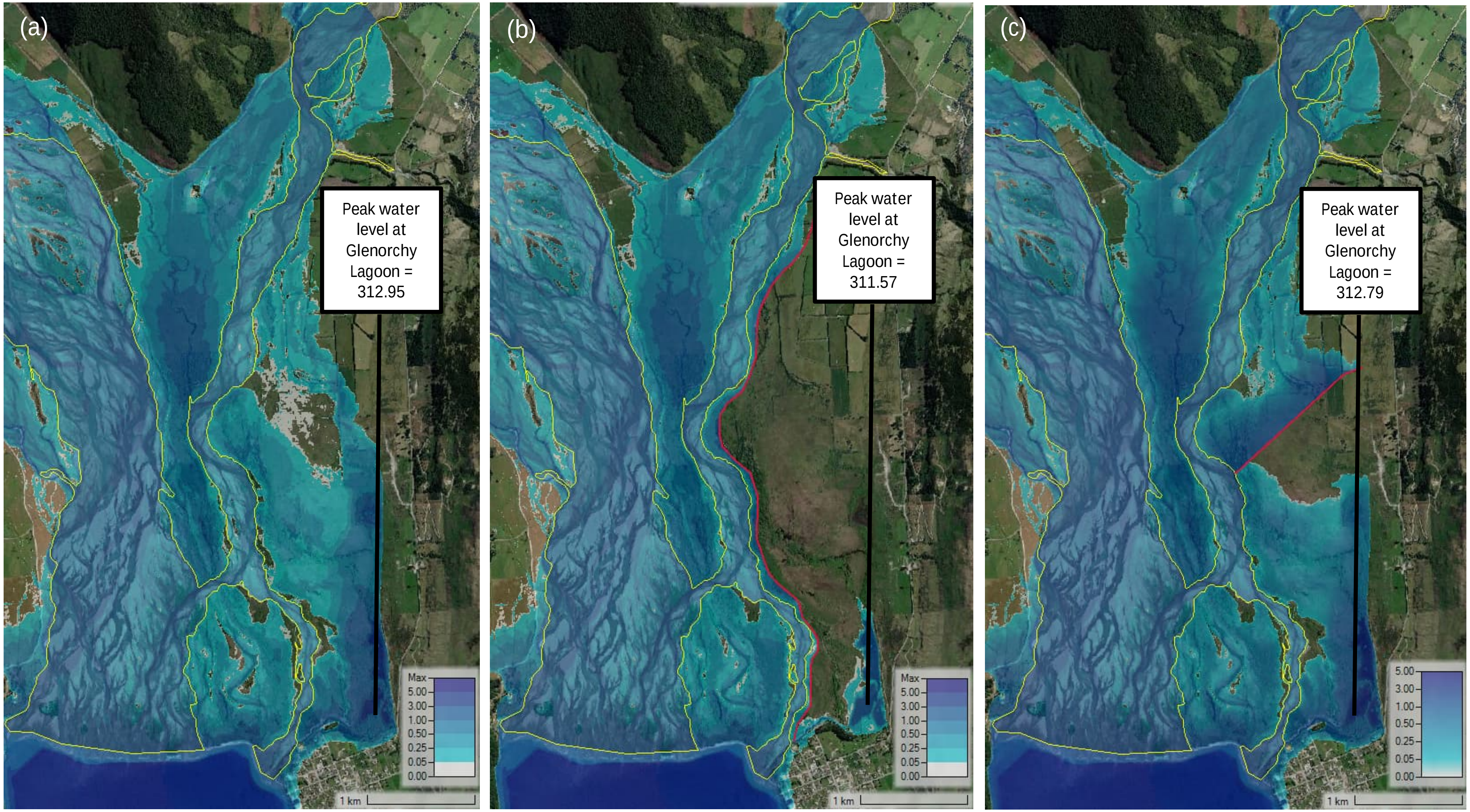


Figure B.5: HEC-RAS model predicted maximum water depths and extents for 1 in 100 AEP flood (current climate) with 1 in 10 AEP Lake Wakatipu level for (a) current (2022 LiDAR) Rees-Dart River and floodplain topography and (b) with Option B(i) bund along true left bank of Lower Rees River and (c) with Option B(ii) bund along Lower Rees River true left floodplain. Extent of Option Bi and Bii bunds shown with red lines. Edge of active river channels (c. 2019) shown with yellow lines.

B.3 Option C– Vegetative buffers to modify overland flow paths

Results Discussion

Option C involved consideration of vegetation works along the left bank of the Lower Rees River to prevent floodplain overflows and flooding at Glenorchy.

A single vegetative buffer was simulated in the HEC-RAS model as illustrated on Figure B.6(b). This vegetative buffer was modelled with an increased Manning's n value of n = 0.125, relative to n = 0.033 for other grassed floodplain/pasture areas. Based on recommendation from ARR (2019), a Manning's n value of 0.125 represents the upper bound for a floodplain area with thick vegetation/trees.

Figure B.6 show the HEC-RAS predicted maximum flood depths and inundation extents for the 1 in 100 AEP flood (current climate) for the current floodplain topography and for the concept Option C vegetative buffer bunds. The peak water level at Glenorchy Lagoon is also shown on these plans.

Summary of Findings

Figure B.6 indicates that:

- Option C is not effective at reducing outflows from the Rees River and onto the true left floodplain. There is negligible change in floodplain outflow depths and extents and the peak water level at Glenorchy Lagoon relative to the same scenario without the vegetative buffer Further discussion on this option is provided in Section 4.3 of the main report.

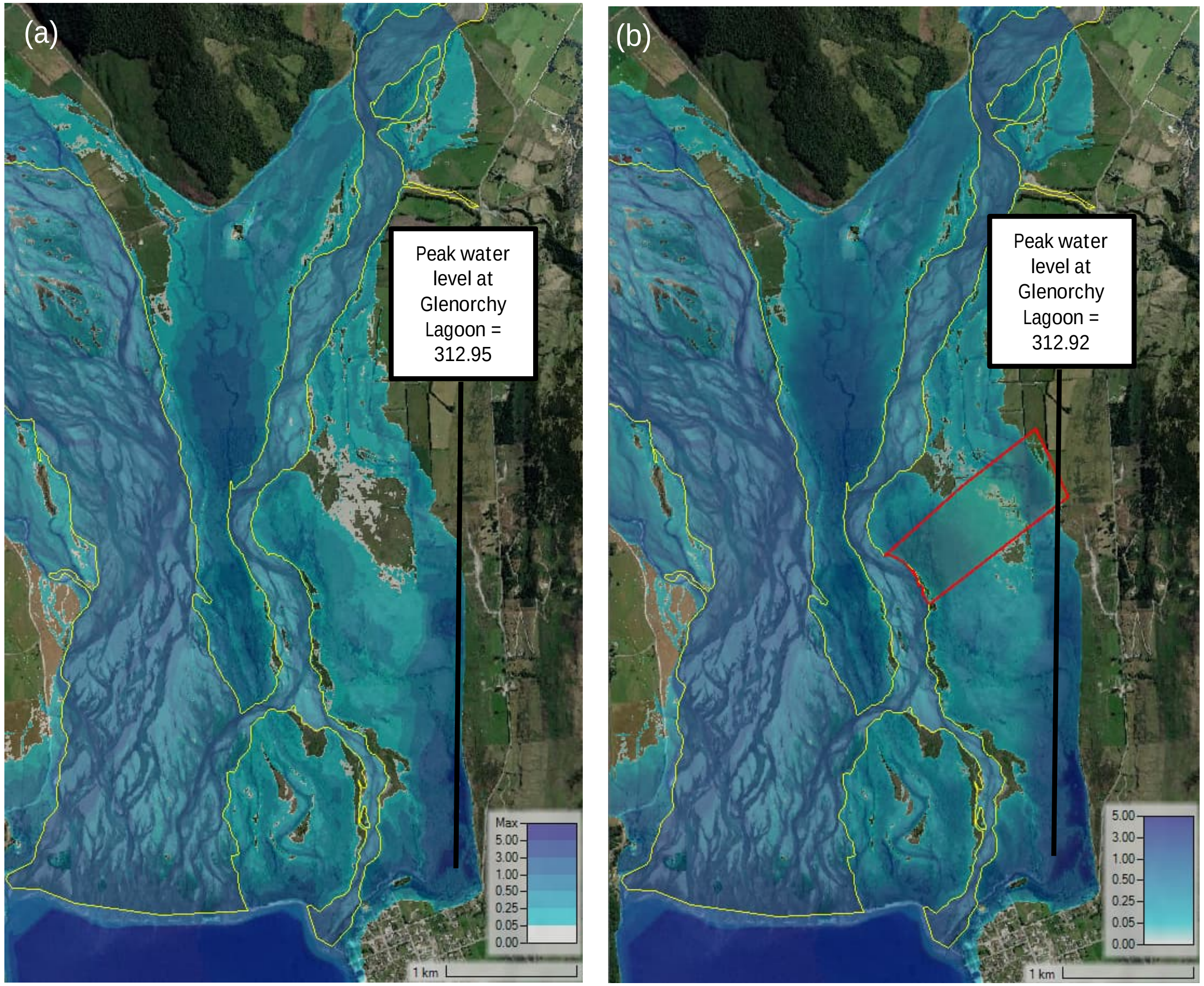
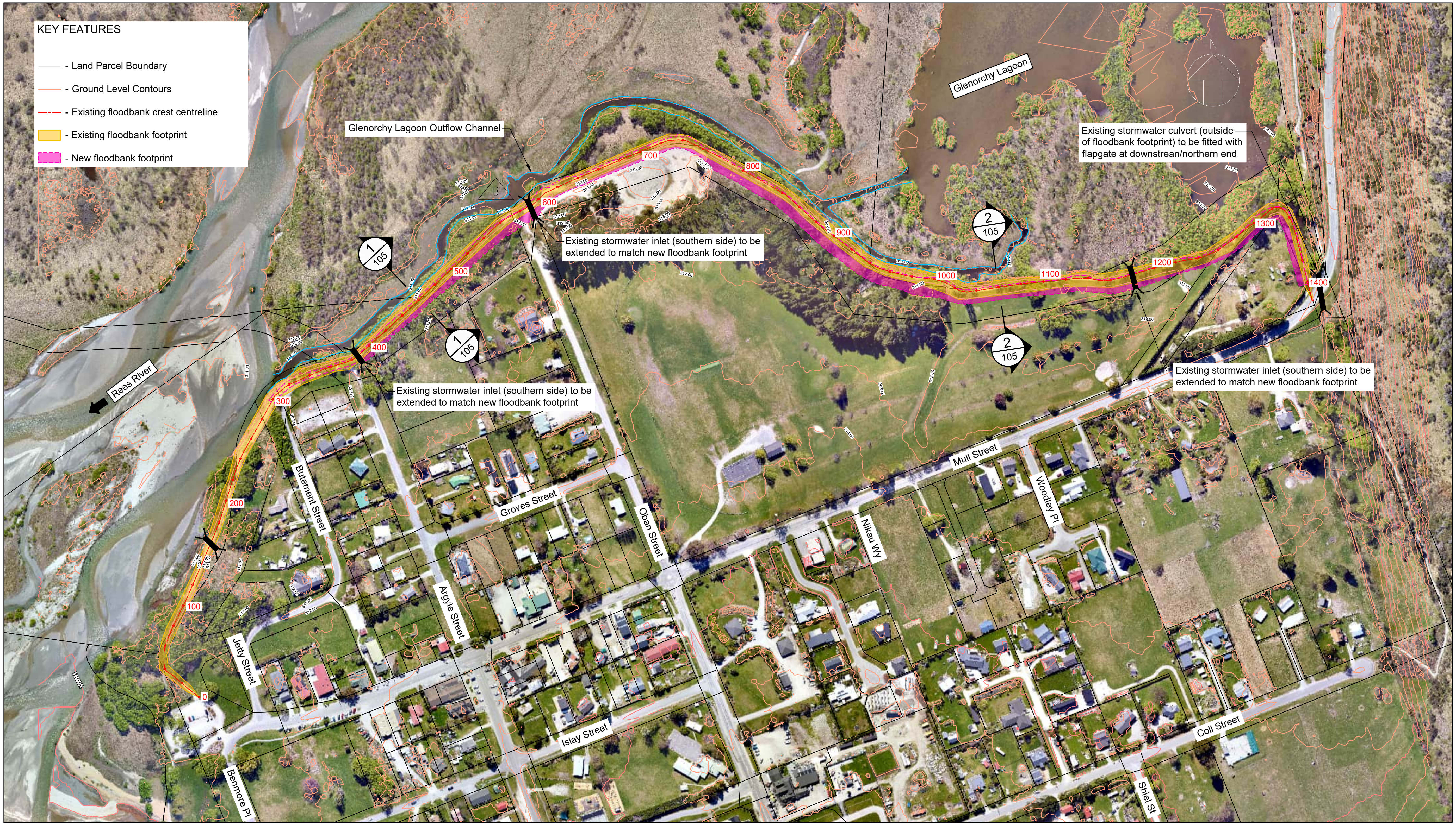


Figure B.6: HEC-RAS model predicted maximum water depths and extents for 1 in 100 AEP flood (current climate) with 1 in 10 AEP Lake Wakatipu level for (a) current (2022 LiDAR) Rees-Dart River and floodplain topography and (b) with Option C vegetative buffer (indicated with red boundary) on true left floodplain of Lower Rees River. Edge of active river channels (c. 2019) shown with yellow lines.

Appendix C Option A – Concept Design Drawings



PLAN
SCALE 1: 3500

NOTES

1. Aerial photograph from 2022 and supplied by ORC.
2. Chainage along existing floodbank crest centreline shown in metres.

Rev	Comments	Drawn	Chk'd	Appr'd	Date
B	DRAWING UPDATED	JA	BV	GW	09-24
A	FOR INFORMATION	JA	BV	GW	05-24

Graphic Scales

0 10 mm 50 100 200 mm

DAMWATCH ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
DART-REES RIVER FLOODPLAIN ASSESSMENT

OPTION A
GENERAL ARRANGEMENT
PLAN

Scale	Project	Drawing Number	Revision
1:3500	E2350	DRR2350/30/100	B

Original Sheet Size A3 (420x297)

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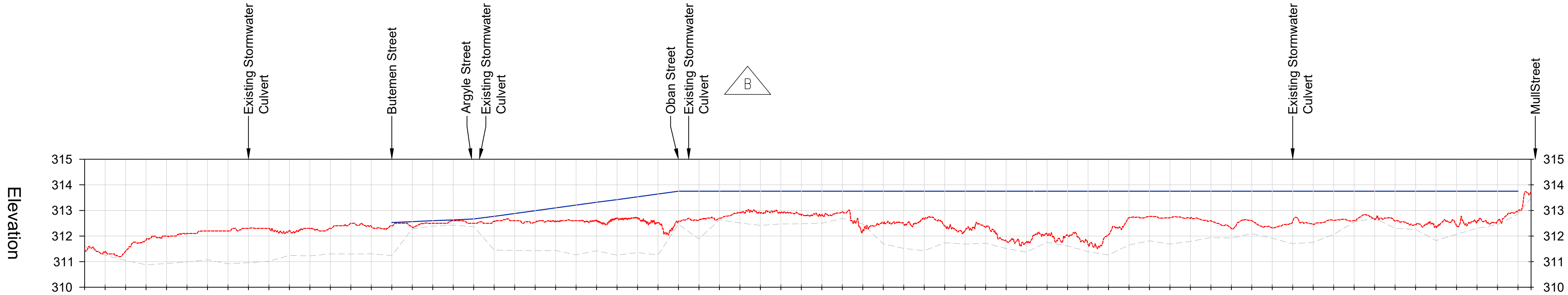
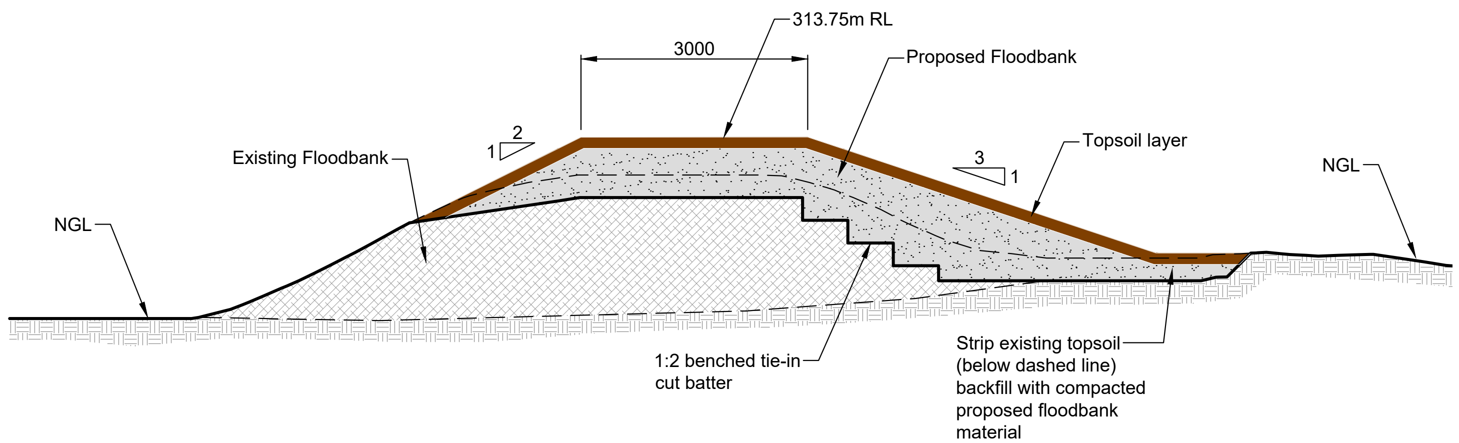
27 September 2024 4:22pm



Chainage	New Floodbank Crest Level	Existing Floodbank Level along CL	Existing Floodbank NGL at Glenorchy Side toe
0+000		311.49	311.60
0+020		311.36	311.25
0+040		311.41	311.05
0+060		311.84	310.88
0+080		312.00	310.93
0+100		312.10	310.99
0+120		312.20	311.08
0+140		312.20	310.91
0+160		312.30	310.96
0+180		312.30	311.02
0+200		312.22	311.24
0+220		312.30	311.23
0+240		312.30	311.30
0+260		312.50	311.30
0+280		312.38	311.31
0+300	312.53	312.40	311.24
0+320	312.56	312.35	312.28
0+340	312.60	312.50	312.39
0+360	312.63	312.60	312.42
0+380	312.67	312.50	312.37
0+400	312.77	312.57	311.45
0+420	312.88	312.60	311.44
0+440	312.99	312.53	311.43
0+460	313.10	312.60	311.44
0+480	313.21	312.60	311.27
0+500	313.32	312.62	311.42
0+520	313.42	312.69	311.25
0+540	313.53	312.70	311.36
0+560	313.64	312.52	311.26
0+580	313.75	312.57	312.46
0+600	313.75	312.62	311.88
0+620	313.75	312.70	312.64
0+640	313.75	312.92	312.51
0+660	313.75	312.89	312.42
0+680	313.75	312.92	312.47
0+700	313.75	312.82	312.48
0+720	313.75	312.83	312.50
0+740	313.75	312.94	312.69
0+760	313.75	312.22	312.47
0+780	313.75	312.49	311.70
0+800	313.75	312.45	311.52
0+820	313.75	312.66	311.43
0+840	313.75	312.39	311.74
0+860	313.75	312.20	311.69
0+880	313.75	312.33	311.72
0+900	313.75	311.81	311.51
0+920	313.75	311.77	311.37
0+940	313.75	312.08	311.76
0+960	313.75	312.03	311.61
0+980	313.75	311.68	311.39
1+000	313.75	312.05	311.26
1+020	313.75	312.71	311.65
1+040	313.75	312.76	311.81
1+060	313.75	312.72	311.69
1+080	313.75	312.69	311.79
1+100	313.75	312.60	311.94
1+120	313.75	312.30	311.92
1+140	313.75	312.60	312.09
1+160	313.75	312.32	311.91
1+180	313.75	312.58	311.70
1+200	313.75	312.46	311.75
1+220	313.75	312.61	312.06
1+240	313.75	312.61	312.55
1+260	313.75	312.65	312.70
1+280	313.75	312.59	312.31
1+300	313.75	312.45	312.26
1+320	313.75	312.36	311.83
1+340	313.75	312.40	312.07
1+360	313.75	312.56	312.30
1+380	313.75	312.58	312.44
1+400	313.75	312.98	312.86
1+413		313.75	313.48

LONG-SECTION - OPTION A



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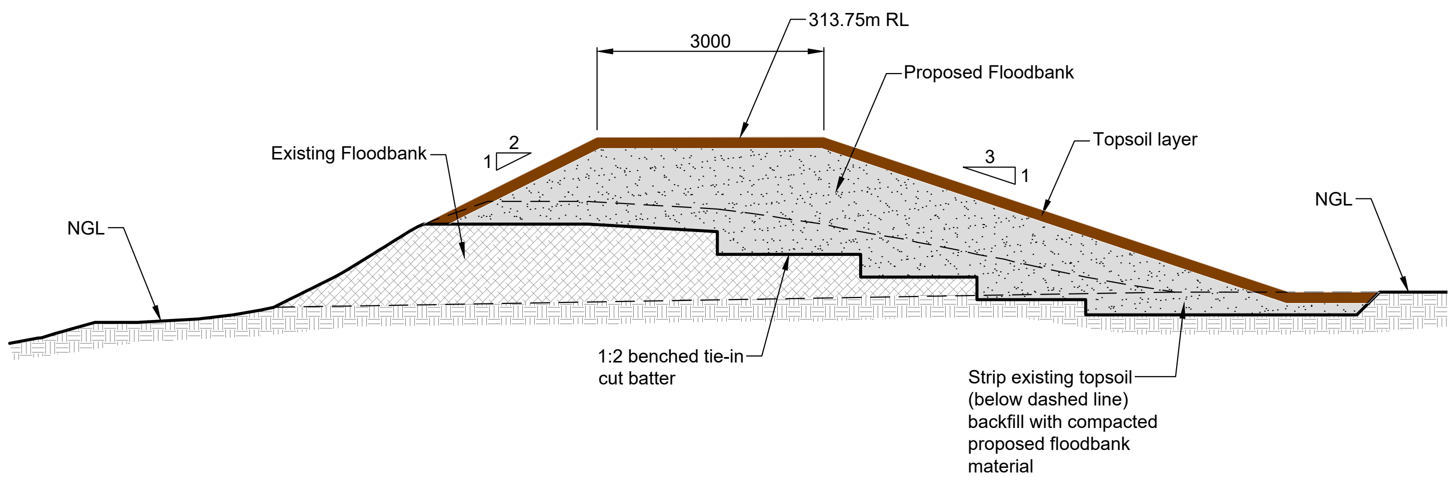
SCALE 1:100



SECTION 2/100 1+060
SCALE 1:100

A3 SCALE 1:100
0 1 2 3 4 5 (m)

NOTES

1. All levels in terms of Dunedin Vertical Datum 1958.

Rev	Comments	Drawn	Chk'd	Appr'd	Date
B	DRAWING UPDATED	JA	BV	GW	09-24
A	FOR INFORMATION	JA	BV	GW	05-24

DAMWATCH
ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
DART-REES RIVER FLOODPLAIN ASSESSMENT

OPTION A
LONG-SECTION & TYPICAL CROSS-SECTIONS

Scale 1:5000H 1:10V | Project E2350 | Drawing Number DRR2350/30/105 | Revision B

Graphic Scales

Original Sheet Size A3 (420x297)

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Appendix D Relevant Statutory Planning Provisions

D.1 Introduction

This appendix provides a preliminary review of the consent requirements for the concept design described in the main report.

The following information represents preliminary planning advice only and is based on the information currently available and the operative national, regional, and local regulatory framework that exists at the time of preparing this report. It also provides indicative costings to prepare and obtain those consents.

Further detailed statutory analysis of the proposed activities will be required once the final design is confirmed and as part of the resource consent and Assessment of Effects on the Environment (AEE) report preparation process.

D.2 Summary of Concept Design & Consenting Requirements

The concept design deemed viable for the Lower Rees River Floodplain and Glenorchy Village is to raise and extend the footprint of the existing Glenorchy floodbank. Of relevance to the consenting process, the cocncept design flood protection works involves placing approximately 13,000 to 20,000 m^3 of cleanfill over approximately 15,000 m^2 of land. The earthworks are primarily located on the road but also extends into small areas of the Settlement, Rural, and Open Space and Recreation zones of the Queenstown Lakes Proposed District Plan (PDP). It is also proposed to increase the height of the existing floodbank, with the maximum height of fill being approximately 2.5 m.

In summary, under the current regulatory framework the concept design will require resource consent to be obtained from Queenstown Lakes District Council (QLDC) for flood protection works and earthworks and from the Otago Regional Council (ORC) to alter the existing defence against water, permanently divert flood water, and to undertake earthworks within 10 m of a natural inland wetland.

A more detailed review to support this summary is provided in the following Sections D.3 and D.4.

Preliminary cost estimates have been prepared for the consenting process and are provided in Section D.5.

D.3 Review of Key Higher Order Policy Documents

Pursuant to Section 104 of the RMA, the consent authorities will need to have regard to the following higher order documents when assessing the various resource consents required. It is therefore prudent to consider, based on the information available at this time, whether the concept design is likely to be contrary to the direction set by those documents, which could cause issues at the consenting stage.

D.3.1 Operative Otago Regional Policy Statement 2019 (ORPS)

The following provisions are considered relevant and an assessment of the concept design against these will need to be included in subsequent resource consent applications:

- Objective 1.1 - Otago's resources are used sustainably to promote economic, social and cultural wellbeing for its people and communities;
- Objective 1.2 - Recognise and provide for the integrated management of natural and physical resources to support the well-being of people and communities in Otago;
- Objective 2.1 - The principles of Te Tiriti o Waitangi are taken into account in resource management processes and decisions;
- Objective 2.2 - Kai Tahu values, interests and customary resources are recognised and provided for;
- Objective 3.1 - The values (including intrinsic values) of ecosystems and natural resources are recognised and maintained, or enhanced where degraded;
- Policy 3.1.1 - Fresh water;
- Policy 3.1.2 - Beds of rivers, lakes, wetlands and their margins;
- Objective 3.2 - Otago's significant and highly-valued natural resources are identified and protected, or enhanced where degraded
- Policy 3.2.4 - Managing outstanding natural features, landscapes and seascapes … Protect, enhance or restore outstanding natural features, landscapes and seascapes…
- Policy 3.2.16 - Managing the values of wetlands
- Objective 4.1 - Risks that natural hazards pose to Otago's communities are minimised;
- Policy 4.1.5 - Natural hazard risk - Manage natural hazard risk to people, property and communities
- Policy 4.1.6 - Minimising increase in natural hazard risk.
- Policy 4.1.8 - Precautionary approach to natural hazard risk - Where natural hazard risk to people and communities is uncertain or unknown, but potentially significant or irreversible, apply a precautionary approach to identifying, assessing and managing that risk.
- Policy 4.1.10 - Mitigating natural hazards - Give preference to risk management approaches that reduce the need for hard protection structures or similar engineering interventions, and provide for hard protection structures [in certain circumstances].
- Policy 4.1.11 - Hard protection structures - Enable the location of hard protection structures or similar engineering interventions on public land only when either or both of the following apply:
  a) There is significant public or environmental benefit in doing so;
  b) The work relates to the functioning ability of a lifeline utility, or a facility for essential or emergency services.
- Policy 4.2.2 - Climate change - Ensure Otago's people and communities are able to mitigate and adapt to the effects of climate change, over no less than 100 years, by… (various methods)
- Objective 4.3 - Infrastructure is managed and developed in a sustainable way;
- Objective 5.1 - Public access to areas of values to the community is maintain or enhanced;
- Policy 5.1.1 - Public access

Based on the information and plans available at this time, it is considered that the concept design is likely to be consistent with the relevant objectives and policies of the PORPS. In particular, the preliminary assessment finds that the concept design will:

- Promote the wellbeing of the community;
- Take into account the principles of Te Tiriti o Waitangi and recognise and provide for Kai Tahu values and interests;

- Recognise the values of ecosystems and natural resources of the nearby waterbodies and their margins (including their natural functioning as far as practicable and their landscape values);
- Mitigate natural hazard risks to the communities, noting that the crest level of the floodbank has been determined taking into account climate change effects until the end of the century.
- In relation to the Lower Rees floodbank:
  - maintain the existing public access along the length of the floodbank
  - likely to be consistent with the policy direction set by policies 4.1.10 and 4.1.11 (relating to the use of hard protection structures).found to

D.3.2 Proposed Otago Regional Policy Statement 2021 (PRPS)

ORC's decision on the PRPS was notified on 30 March 2024. The appeal period for lodging appeals to the High Court on the freshwater planning instrument parts of the PRPS ended on 24 April 2024 and the period for lodging appeals on the non freshwater parts of the PRPS ended on 16 May 2024. Appeals have been lodged on both parts of the PRPS. Given the uncertainty of the eventual content of the PRPS it is recommended that an assessment of the concept design against it be undertaken once the decisions on appeals have been made.

D.3.3 The Kai Tahu ki Otago Natural Resource Management Plan 2005 (NRMP)

The following objectives and policies are considered to be of most relevance to the concept design:

- Require that work be undertaken when water levels are naturally low or dry.
- Require that works are not undertaken during spawning season of certain fish species and fish passage is provided for at all times.
- Require that any visual impacts at the site of the activity are minimal.
- Require that all practical measures are undertaken to minimise sediment or other contaminant discharge and that wet concrete does not enter active flow channels.
- Require that machinery only enters the dry bed of the waterway to the extent necessary to undertake the work, and that it is kept clean and well-maintained, with refuelling occurring away from the waterway. Machinery operating in flowing water is to be discouraged.
- Require that buffer zones are established and agreed upon with the Papatipu Runaka between the flowing water and the site of any river or instream work.

It is recommended that iwi are consulted with as part of the preparation of the resource consent applications. However, the preliminary view is that, with the inclusion of any conditions that are deemed necessary, the concept design outlined in this report will be consistent with the relevant policies of the NRMP.

D.3.4 The Ngāi Tahu ki Murihiku Natural Resource and Environmental Iwi Management Plan 2008 - The Cry of the People, Te Tangi a Tauira (IMP)

The following objectives and policies are considered to be of most relevance to the concept design:

- Require that placement of culverts and other flood works activities in the beds or on the margins of waterways occurs at times of low or no flow and in a manner that does not impede the passage of native fish and other stream life and minimises disturbance to the streambed.

- Recommend that culvert pipes are buried in the streambed, so that gravel can lie in the bottom third of the pipe, thus providing natural habitat in the culvert so that fish can migrate through them.
- Recommend that tracks leading to culverts are designed (e.g. contoured) so that stormwater run-off and any effluent on the track is directed away from the stream. Such discharges should be to land and not directly to water.
- Require that short term effects on water quality and appearance are mitigated during culvert or flood works construction, and for a settling period following. For example, straw bales may be used to minimise turbidity, and contain discolouration and sedimentation.
- Avoid the direct or indirect modification of any existing wetland area.
- Ensure that all native fish species have uninhibited passage from the river to the sea at all times, through ensuring continuity of flow.

It is recommended that iwi are consulted with as part of the preparation of the resource consent applications. However, the preliminary view is that, with the inclusion of any conditions that are deemed necessary, the concept design will be consistent with the relevant policies of the IMP.

D.3.5 National Policy Statement on Freshwater Management 2020 (NPSFM)

The government has signalled it will amend or repeal the NPSFM in the foreseeable future and therefore the following should be reviewed/ revised once that occurs to check that the concept design still aligns with, and has appropriate regard for the document (or its replacement).

Any resource consent application for the concept design outlined in this report will need to have regard to the following relevant provisions of the NPSFM:

- 2.1 Objective (1)
- The objective of this National Policy Statement is to ensure that natural and physical resources are managed in a way that prioritises:
  (a) first, the health and well-being of water bodies and freshwater ecosystems
  (b) second, the health needs of people (such as drinking water)
  (c) third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.
- Policy 1: Freshwater is managed in a way that gives effect to Te Māna o te Wai;
- Policy 2: Tangata Whenua are actively involved in freshwater management (including decision-making processes), and Māori freshwater values are identified and provided for.
- Policy 3: Freshwater is managed in an integrated way that considers the effects of the use and development of land on a whole-of-catchment basis, including the effects on the receiving environment.
- Policy 6: There is no further loss of extent of natural inland wetlands, their values are protected, and their restoration is promoted.
- Policy 7: The loss of river extent and values is avoided to the extent practicable.
- Policy 8: The significant values of outstanding water bodies are protected.
- Policy 9: The habitats of indigenous freshwater species are protected.
- Policy 15: Communities are enabled to provide for their social, economic, and cultural wellbeing in a way that is consistent with this National Policy Statement.

Relevantly, the definition of specified infrastructure in the NPSFM includes "*any public flood control, flood* protection*, or drainage works carried out: (i) by or on behalf of a local authority…"*

While it is considered unlikely that the values of the adjoining wetland will be adversely affected by the alterations to the floodbank, it is noted that Part 3.22 of the NPSFM requires that regional councils include policy in their plans to the following effect, which provides for some reduction in values as a result of the construction of Specified Infrastructure provided certain criteria are met, as follows:

- *"The loss of extent of natural inland wetlands is avoided, their values are protected, and their restoration is promoted, except where:*
  the loss of extent or values arises from any of the following:
  …
  (b) the regional council is satisfied that:
  (i) the activity is necessary for the purpose of the construction or upgrade of specified infrastructure; and 26 National Policy Statement for Freshwater Management 2020
  (ii) the specified infrastructure will provide significant national or regional benefits; and
  (iii) there is a functional need for the specified infrastructure in that location; and
  (iv) the effects of the activity are managed through applying the effects management hierarchy; or

Based on the current NPSFM and available information and plans, it is considered that the concept design is likely to be consistent with the relevant objective and policies of the NPSFM for the following reasons:

- Through careful design and construction management, the interventions can be undertaken in a way that will give effect to Te Māna o te Wai, including protecting the significant values of the outstanding water bodies in the immediate vicinity[13];
- Consultation will be undertaken with iwi through the consenting process;
- The concept design will not result in a reduction in the extent of the river when at normal flow levels or its values, (noting that it will only affect water level flood conditions and will not affect the normal water level range or hydrological function of the river or wetland and, as such, the habitats of indigenous freshwater species are not likely to be adversely affected; and
- On the basis that the concept design will be effective at mitigating flood risks to the community and property they will all enable the community to provide for its wellbeing while being consistent with the NPSFM.

D.3.6 The Water Conservation (Kawarau) Order 1997

Lake Wakatipu and the Rees River mainstem from Lake Wakatipu to confluence with Hunter Stream are all listed as watercourses to be protected in Schedule 2 of this order. No damming is proposed in this application and the braided nature of the watercourses will be maintained. Notwithstanding

[13] Policy LF–FW–P11 of the decision version of the Proposed Otago Regional Policy Statement states the Kawarau River and tributaries described in the Water Conservation (Kawarau) Order 1997are outstanding water bodies. Schedule 2 of that Order lists Lake Wakatipu and the parts of the Dart and Rees Rivers affected by this proposal.

this, Clause 5(b) provides an exception to allow for river protection works in the order. As such, the activities are not prohibited under the order.

Also of note:

- The National Environmental Standards for Freshwater 2020 (NESF) is outlined in the ‘Consents required’ section below.
- The Proposed National Policy Statement for Natural Hazard Decision-Making 2023 (NPSNHD) was considered in the drafting of this report and is not considered to be relevant to the consenting of the floodplain intervention options outlined in this report.
- The Heritage New Zealand Pouhere Taonga Act 2014 was considered in the drafting of this report and is not considered to be relevant to the consenting of the floodplain intervention options outlined in this report.
- The Wildlife Act 1953 was considered in the drafting of this report and is not considered to be relevant to the consenting of the floodplain intervention options outlined in this report.

D.4 Consenting Requirements for the Concept Design

The following sub-sections outline the likely consents that will be required from QLDC (Section D.4.1) and ORC (Section D.4.2) for the concept design.

D.4.1 Consenting requirements by the Queenstown Lakes District Council

Queenstown Lakes Proposed District Plan (PDP)

The concept design is overlaid on the PDP planning maps in Figure D.1.

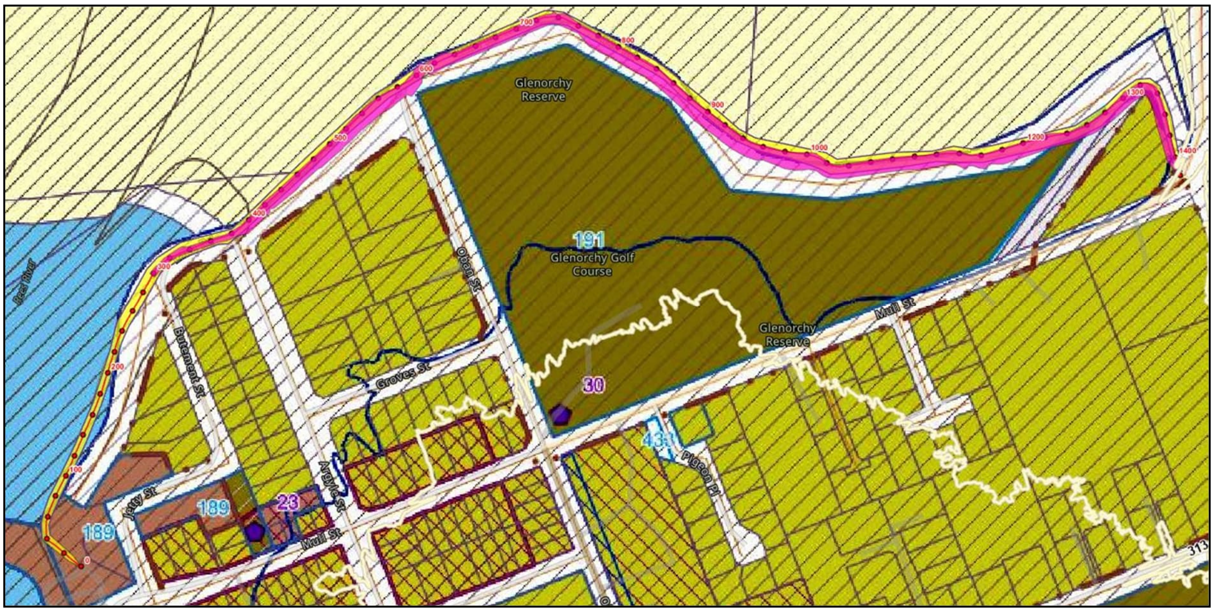

Figure D.1: The modified floodbank footprint (pink shading) overlaid the PDP planning (zone) map

The concept design traverses a number of different zones and the land is held in a number of different ownerships. This information is summarised in Table D.1.

As the plans are not yet to the level of detail that would be required for consenting purposes, the height of the structure, the volume, area, and extent of earthworks are all approximate. In all instances, a conservative approach has been taken and if there is a reasonable chance that a standard/ rule will be breached and consent required, this has been included in the below review and indicative costings.

The relevant rules of the PDP are outlined in Table D.2 below, along with a preliminary assessment of the consents that are likely to be required for the concept design.

Table D.1: Interface of the concept design with PDP Planning Zones and land ownership

Zone	Location/ description	Ownership
Road	The majority of the length of the floodbank runs along an unformed road (Lake Road).	The majority is owned by QLDC and two small portions of stopped road at the far eastern end are owned by the New Zealand Motor Caravan Association.
Rural	Small sections midway along the floodbank (totalling approximately 1,352m^2 in area and 1,000 m^3 in volume)	Reserves for Conservation purposes Wildlife management purposes. Owned by the Crown (managed by LINZ and DOC respectively)
Open Space and Recreation Zone: Community Purpose - Golf Course Subzone and Designation 189	A small section of the floodbank at the far eastern end (approximately 180 m^2 in area and 200 m^3 in volume)	Recreation reserve [Glenorchy Domain] New Zealand Gazette 1910. Vested in/ owned by Queenstown Lakes District Council (Source: QLDC's rates database)
Settlement (residential zoning)	A relatively small section of the floodbank at the far eastern end (maximum depth of approximately 1 m and 763 m^2 in area and 650 m^3 in volume)	New Zealand Motor Caravan Association.
Outstanding Natural Landscape	The entire floodbank, other than the small portion within the Settlement Zone.	As above
Glenorchy Flood Zone	The entire floodbank	As above
Wāhi tūpuna 33	The section of the floodbank west of Argyle Street	As above
Wāhi tūpuna 14	The entire floodbank	As above

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Table D.2: PDP rules and preliminary assessment of the consent requirements

Rule	Discussion of Consent Requirements			
Chapter 30 – Energy and utilities				
30.5.1.16 - Flood Protection Works (see Note 1 at end of table) 30.6.1.2 – non notification of Applications	The works fall within the definition of Flood Protection Works and, in turn, within the definition of a Utility. Flood Protection Works not otherwise provided for in Rule 30.5.1.2 (which permits maintenance and repair etc.) require a Discretionary activity consent. Discretionary activities for Flood Protection Works do not require the written approval of other persons and cannot be notified or limited-notified (unless special circumstances apply).			
Chapter 25 – Earthworks				
Rule	Road	OSRZ	Settlement	Rural
Table 25.2 Earthworks volumes (able to be notified pursuant to Rule 25.6)	25.5.7.1Roads No limit on volume – Permitted *Interpretation note: The reference to 'roads' in this rule relates to earthworks for any purpose within land shown as 'road' on the planning maps.*	25.5.1 OSRZ 100m^3. Restricted discretionary consent required as this standard is likely to be breached.	25.5.3 – 300m^3 Restricted discretionary consent required as this standard is likely to be breached.	25.5.6 – 1000m Restricted discretionary consent likely to be required as this standard is likely to be breached.
25.5.15 - Maximum depth of any cut	This rule does not apply to roads so permitted	2.4 metres. This standard will be met so no consent is required under this rule (permitted).		
25.5.16 - Maximum height of any fill	This rule does not apply to roads so permitted	2 metres. This standard will be met as the highest area of fill outside of the road reserve will be less than 2 metres. Therefore, no consent is required under this rule (permitted).		

Rule	Discussion of Consent Requirements
25.5.10A.2 Wāhi Tūpuna areas as identified in Schedule 39.6 but not listed in 25.5.10A.1, where earthworks: a. are located within 20m of the boundary of any wetland, bed of any river or lake (see Note 2 at end of table).	A Restricted discretionary consent is likely to be required as there will be earthworks within 20 m of the boundary of a waterbody. Notes: - While earthworks in the urban environment are exempt from this rule, as the urban environment is deemed to include only those zones contained in Part 3 of the PDP and the OSRZ, it appears that roads are not considered urban and it is possible that earthworks in the rural zone may be within 20 m a waterbody. As such it is likely that the standard will apply and be breached in this instance. - The threats for Wāhi tūpuna 14 are listed in Chapter 39. Of relevance to the concept design, these threats include 'activities affecting water quality', 'earthworks', and 'utility activities'.
25.5.11 - Earthworks over a contiguous area of land shall not exceed the following area: - 2,500m² where the slope is 10° or greater. - 10,000m² where the slope is less than 10°. - 2,500m2 at any one time for the construction of a trail. Rule 25.6.1 - Non notified	A Restricted Discretionary activity consent will be required based on the scale of the alterations to the floodbank. While a breach of this standard shall not be limited or publicly notified, this is of no real consequence given the other consents that are triggered can be notified if the effects are, or are likely to be, more than minor.
25.5.12 - Erosion and sediment control measures must be implemented and maintained during earthworks to minimise the amount of sediment exiting the site, entering water bodies, and stormwater networks.	Provided ORC provides a comprehensive Environmental Management Plan in general accordance with the 'Erosion and Sediment Control Guide for Land Disturbing Activities in the Auckland region' Auckland Council Guideline Document GD2016/005 no consent will be required under this rule (Permitted)..
25.5.13 - Dust from earthworks shall be managed through appropriate dust control measures so that dust it does not cause nuisance effects beyond the boundary of the site	Provided ORC provides a comprehensive Environmental Management Plan in general accordance with the 'Erosion and Sediment Control Guide for Land Disturbing Activities in the Auckland region' Auckland Council Guideline Document GD2016/005 no consent will be required under this rule (Permitted).

Rule	Discussion of Consent Requirements
25.5.14 Earthworks that discovers any of the following: kōiwi tangata, wāhi taoka, wāhi tapu or other Māori artefact material, or any feature or archaeological material that predates 1900, or evidence of contaminated land… shall comply with the standards and procedures in Schedule 25.10 'Accidental Discovery Protocol'.	Provided a condition requiring that the standards and procedures in Schedule 25.10 'Accidental Discovery Protocol' be adhered to is volunteered no consent will be required under this rule (Permitted).
25.5.18 Earthworks not supported by retaining walls greater than 0.5 metres in height or depth shall be set back from the site boundary at least a) a distance at least equal to the maximum height of the fill, as measured from the toe of the fill, with a maximum batter slope angle of 1:3 (vertical: horizontal); or b. 300mm plus a batter slope angle of a maximum of 1:3 (vertical: horizontal), as measured from the crest of the cut. See diagram.	As the footprint of the floodbank will extend beyond the boundaries of the road reserve in a number of locations and that earthworks will be unretained and greater than 0.5 m in height, this standard will be breached. Therefore, a Restricted Discretionary consent will be required. It is noted for completeness that the earthworks proposed west of Oban Street is set back at least 9.5 metres at the closest point and, therefore, there is no breach of this rule in respect of the adjoining residential (Settlement) properties.
25.5.19.1 - Earthworks within 10m of the bed [See Note 1] of any water body shall not exceed 5m3 in total volume, within any consecutive 12-month period. None of the exemptions to the rule apply in this instance	While the extent of the bed of the wetland will need to be accurately defined as part of the consent process, based on the preliminary design drawings, it appears likely that earthworks will be undertaken within 10 m of the bed of the wetland (for short stretches generally in the area between Oban and Buteman streets. Therefore, a Restricted discretionary consent will be required.
25.5.20 - Earthworks shall not be undertaken below the water table of any aquifer, or cause artificial drainage of any aquifer.	No earthworks will be below the water table of any aquifer, or cause artificial drainage of any aquifer and therefore no consent is required under this rule (Permitted).
25.5.21 - No more than 300m³ of Cleanfill shall be transported by road to or from an area subject to Earthworks.	More than 300m³ of 'cleanfill' will be brought to the site via road and, therefore a Restricted discretionary consent will be required.

Rule	Discussion of Consent Requirements
Chapter 20 -Settlement Zone	
20.4.17 - Any activity not listed in this Table	No consent required as the discretionary utility rules prevail over the rules in this chapter.
Chapter 21 – Rural Zone	
21.4.37 - Any activity not otherwise provided for in Tables 1, 9, 10, 12 or 14.	No consent required as the discretionary utility rules prevail over the rules in this chapter.
Chapter 38 - Open Space and Recreation Zones	
38.9.1 Any activity not listed in Table 38.1	No consent required as the discretionary utility rules prevail over the rules in this chapter.
Chapter 29 – Transport - Table 29.2 - Activities within a road	
29.4.13 Activities that are not listed in this Table.	The construction of a floodbank is not listed in the Rules table and therefore a Discretionary activity consent is required for the proposed floodbank within the road reserve. While the floodbank is a Utility, Rule 30.3.3.4 means that the 'use of roads' is governed by the rules in Chapter 29 rather than those in the Utilities chapter. The fact that a floodbank is already located on, and consumes most of, this unformed road is an unusual situation and, as such, the PDP does not specifically anticipate, or provide for, this use.
Chapter 37 - Designation 191	
Designation 191 – Recreation Reserve, Glenorchy Domain, Oban Street (Showgrounds, racecourse, golf course, rugby)	As the floodbank is not for recreation purposes, it is not in accordance with the designation. Therefore the prior written consent of the requiring authority (in this case QLDC) will be required before the works can proceed.

Notes to Table D.2:

1. Means: Works, structures and plantings for the protection of property and people from flood fairways or lakes, the clearance of vegetation and debris from flood fairways, stop banks, access tracks, rockwork, anchored trees, wire rope and other structures.

2. As defined in the RMA, *bed* means:

(a)in relation to any river—

(i) for the purposes of esplanade reserves, esplanade strips, and subdivision, the space of land which the waters of the river cover at its annual fullest flow without overtopping its banks:

(ii) in all other cases, the space of land which the waters of the river cover at its fullest flow without overtopping its banks; and

(b) in relation to any lake, except a lake controlled by artificial means,—

(i) for the purposes of esplanade reserves, esplanade strips, and subdivision, the space of land which the waters of the lake cover at its annual highest level without exceeding its margin:

(ii) in all other cases, the space of land which the waters of the lake cover at its highest level without exceeding its margin;

In summary, consents will be required for the concept design under the following rules of the PDP and, overall, it will be assessed as a Discretionary activity:

- A discretionary consent under Rule 30.5.1.16 - Flood Protection Works.
- A restricted discretionary consent under Table 25.2 Earthworks volumes.
- A restricted discretionary consent under Standard 25.5.10A.2 Wāhi Tūpuna Areas - earthworks area.
- A restricted discretionary consent under Standard 25.5.11 - Earthworks area.
- A restricted discretionary consent under Standard 25.5.18- Setbacks from site boundaries for earthworks not supported by retaining walls greater than 0.5 metres in height or depth.
- A restricted discretionary consent under Standard 25.5.19.1 - Earthworks within 10m of the bed of a waterbody.
- A restricted discretionary consent under Standard 25.5.21 - No more than 300m³ of cleanfill transported to the site.
- A discretionary consent under Rule 29.4.13 - Activities that are not listed in the transport activities/ rules Table.

D.4.2 The Queenstown Lakes Operative District Plan (ODP)

As the relevant provisions of the PDP outlined above are beyond appeal, no rules in the ODP are relevant to the concept design.

D.4.2 Consents required by the Otago Regional Council

Otago Regional Plan: Water 2004 (RPW)

The RPW outlines the natural and human use values of various watercourses throughout the Otago Region. Of relevance, the Rees River is identified for the following natural and ecosystem values:

- Large water body supporting high numbers of particular species, or habitat variety, which can provide for diverse life cycle requirements of a particular species, or a range of species.
- Access within the main stem of the catchment through to the sea or lake unimpeded by artificial means such as weirs and culverts.
- Presence of significant fish spawning areas for trout.
- Presence of significant areas for development of juvenile trout.
- Significant presence of trout, salmon and eel.
- Presence of indigenous waterfowl threatened with extinction.

Schedule 1AA of the RPW identifies Otago resident native freshwater fish and their threat status. The Rees River is not known to provide habitat for any of the freshwater fish species within this schedule.

The relevant rules of the RWP are outlined in Table D.3 below, along with a preliminary assessment of what consents will be required for the concept design.. In summary, the proposed alterations to the existing Glenorchy floodbank will require a Discretionary activity consent under the RPW.

Table D.3: RWP rules and preliminary assessment of the consent requirements

Relevant rules	Preliminary Assessment
12.3.4.1 - Diversion of water (i) Except as provided for by Rules 12.3.1.1 to 12.3.3.1 and except in the Waitaki catchment, the damming or diversion of water is a discretionary activity.	As this option will permanently divert floodwaters, it will require a Discretionary Activity consent.
14.3.2.1 - Except as provided for in Rule 14.3.1.1[14]*, the erection, placement, extension, alteration, replacement, reconstruction, demolition or removal, of any defence against water, other than on the bed of any lake or river, is a discretionary activity.*	This option will require a Discretionary Activity consent.

For completeness, it is noted that the Glenorchy Lagoon is listed as a regionally significant wetland in Schedule 9 of that Plan (Figure D.2) and is identified as follows in Section F of the maps contained in the RPW. As the concept design is not expected to alter the wetland in any way, consent is not considered to be required under Rule 13.5.3.2.

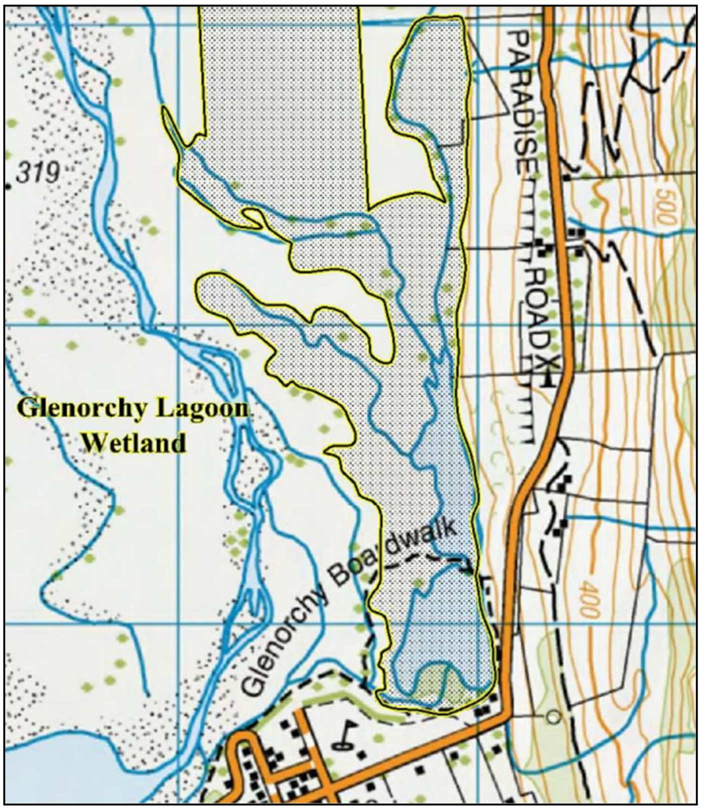

Figure D.2: Extract from the RWP at Glenorchy Lagoon Wetland

[14] It is permitted if there is here is no permanent change to the scale, nature or function of the defence against water – in this case, there would be a permanent change

Resource Management (National Environmental Standards for Freshwater) Regulations 2020

As outlined earlier, the works included in the concept design meet the definition of Specified Infrastructure under the NPSFM and therefore Section 45 of the NESF is applicable. Of relevance to the concept design, Section 45 makes:

- Earthworks within a 10 m setback from a natural inland wetland[15] a discretionary activity (s 45(2));
- Earthworks within 100 m of a natural inland wetland a discretionary activity if it will result in the complete or partial drainage of all or part of the natural inland wetland (s45(3));
- The diversion of water within 100 m of a natural inland wetland a discretionary activity if it is for the purpose of constructing or upgrading specified infrastructure and there is a hydrological connection between the diversion and the wetland, which is likely to change the water level range or hydrological function of the wetland(s 45(4);
- The discharge water into water within 100 m of a natural inland wetland a discretionary activity if it is for the purpose of constructing or upgrading specified infrastructure and there is a hydrological connection between the discharge and the wetland and the discharge will enter the wetland and change, or is likely to change, the water level range or hydrological function of the wetland (s45(5).

Based on the plans and information currently available:

- The earthworks will be within 10 m of the Glenorchy Lagoon (which meets the definition of a 'natural inland wetland');
- The earthworks will be within 100 m of the Glenorchy Lagoon but will not result in the partial drainage of the wetland;
- Under normal flow conditions there is no hydrological connection between the floodbank and the wetland. While there will be a hydrological connection between the floodbank and the wetland in flood conditions, this would be the case with or without the presence of the floodbank; and
- There will be no discharge of water into water within 100 m setback from the Glenorchy Lagoon

As such, a Discretionary Activity consent is likely to be required under Clause 45(2) of NESF for those parts of the concept design located in close proximity to the Glenorchy Lagoon.

In order to assess whether consent should be granted under the NESF, the decision makers will need to decide whether there is a functional need for the proposed alterations to the Lower Rees floodbank and whether they will have regional benefit. This report cannot provide a definitive view on whether those two tests will be deemed to have been met but it does provide useful information that can inform that the resource consent application in respect of those two matters.

3.2.3 Draft Land and Water Regional Plan (LWRPL)

At the time of preparing this report, the LWRP is only in draft form and there is no certainty regarding a notification date. As it is likely to change considerably before it has any legal weight, it is considered premature and of little use to provide advice regarding what consents might be required

[15] In this case, the Glenorchy Lagoon

for the concept design under the LWRP at this stage. Rather, that assessment should be undertaken once a decision has been released on the proposed LWRP (at the earliest) and that assessment attached as an addendum to this report.

D.5 Consenting Information Requirements & Costs

D.5.1 Determining Factors & Consenting Information Requirements

The main determinants of the consenting costs are:

- The activity status of the application.
- The depth and breadth of information that will be required to support the application.
- Whether there are affected parties whose approval will need to be obtained and/ or whether the application is likely to need to be limited notified or publicly notified.
- Whether there is likely to be opposition to the proposal and the extent of that opposition.
- Whether a hearing is likely to be required.

Table D.4 lists the likely scope of work that is required to accompany the necessary consent applications for the concept design. The scope of work is broken-down in Table D.4 into the following categories:

- General information requirements
- Consultation and affected parties
- Notification and the need for a hearing

Table D.4: Preliminary assessment of scope of works required for consenting purposes

General Information Requirements	
Discretionary Consent under the Queenstown Lakes PDP	AEE, including the following attached reports/ plans: • Record of consultation undertaken. • Hydrology report/effects on natural hazards *[completed to concept level design stage in this report].* • High Risk Environmental Management Plan (EMP). • . • Plans, including detailed site plans showing the footprint relative to the planning maps, cross sections, , long sections, and potentially a basic landscape plan *[completed to concept level design stage in this report].* • Potentially an ecological report, if there is deemed to be any potential effects on the Glenorchy Lagoon. • Potentially a brief landscape assessment report • Potentially a brief Cultural Impact Assessment (or evidence of consultation and/ or affected person approval).

Discretionary Consents under the Regional Plan: Water and the NESF	*** = Items that will be the same or similar to that required by the QLDC.*
	• AEE**, covering all relevant matters listed in s 16.3.13 of the RWP.
	• Engineering design report**, including:
	  o an assessment of the need for, and effectiveness of, the proposed defence
	  o a description of the defence against water's dimensions, (existing and proposed), including an assessment of any percentage change in size of the defence against water.
	  o the extent to which the defence is likely to create or exacerbate a natural hazard.
	  o effects of the floodbank on the movement of water and sediment and the existing defence/ floodbank; and
	  o any effect of any flow/ sediment processes *[completed to concept level design stage in this report].*
	• High risk EMP**.
	• Landscape report** (addressing the values of the water body and effects on natural character, amenity, and any heritage values).
	• Potentially an ecological report (under the NESF)**.
	• A construction plan and the expected construction period.
	• A description of the proposed method of construction including the materials and equipment to be used. *[completed to concept level design stage in this report].*
	• A maintenance and repair plan.
	• Detailed site plans showing the footprint, cross sections, long sections, and potentially landscape plan. *[completed to concept level design stage in this report].*

Consultation and affected parties	

General Information Requirements	
Combined consultation process for all district and regional council consents.	It is anticipated that consultation would be undertaken with the following entities as part of preparing the consent applications: • QLDC • The New Zealand Motor Caravan Association • Fish and Game • DOC • LINZ • Users of the reserve – The Glenorchy Community Golf Club, the Lakeside Rugby Club, and potentially the entities responsible for the showgrounds and the Glenorchy horse races • Fish and Game • Aukaha • Te Ao Marama It is anticipated that Affected Person Approvals would be required from the following (and, if not obtained, that the application would likely be limited notified): • QLDC - As the owner of the majority of the land on which the floodbank is proposed • The New Zealand Motor Caravan Association – As the owner of land on which the floodbank is proposed. NB: The fill is up to 1.5 m in height on the Association's land. The Association owns both Settlement Zoned land and areas of stopped road and approximately 259 m^2 of earthworks is on Settlement zoned land and approximately 504 m^2 is on stopped road. • DOC – As owner (agency responsible) of small areas of land on which the floodbank is proposed. • LINZ – As owner (agency responsible) of small areas of land on which the floodbank is proposed. Note: Other than that owned by the New Zealand Motor Caravan Association, the earthworks will be at least 9.5 m from the nearest private property and is reasonably low at that point.
Notification and the need for a hearing	
	While Rule 30.6.1.2 of the PDP states that consents for Flood Protection Works will be processed on a non-notified basis, consents for earthworks that breach the PDP standards, as is the case with this project, may be notified. There are no non-notification rules in the RWP or NESF. Until the consent application is further advanced, it is not possible to determine with certainty what persons will be deemed affected, whether the approvals will be forthcoming, and whether the effects on the environment will be no more than minor. However, based on the information available at this time and for costing purposes: • It is considered unlikely that public notification will be necessary unless the technical reports prepared for the consent indicate that the effects on the environment will be no more than minor. If the Affected Party Approvals (APAs) outlined above are not obtained, it is likely that it will be limited notified to those persons who's APAs have not been obtained.

D.5.2 Estimated Consenting Costs

The following assumptions have been made in determining the below preliminary costings:

- The breadth of information required for the regional council consents is informed by s 16.3.13 of the RWP.
- The costs of preparing the detailed design plans and engineering assessment work are included in the Section 5.7 of the main report, rather than as a consenting cost.
- Where the information required by the district and regional councils is the same or similar, the same expert report will be submitted to both consenting authority.
- Any effects on recreational values will be covered by the AEE and not require an expert report.
- If both the regional and district council consents are required to be notified, they will be heard jointly.
- Consents would be prepared and lodged by the end of 2025, noting that increases in hourly charge out rates beyond that have not been factored in.
- The EMP elements of the district and regional consents will be processed together.
- If limited notified, a half day hearing will be required and if it is publicly notified, a full day hearing will be required. Until submissions are received it is difficult to predict the length of any such hearing.

It is very difficult to estimate the costs of consenting the concept design at this early stage. However, based on the information available, the estimated costs of obtaining the necessary consents range from between:

- $57,000 excl. GST (under a non-notified scenario)
- $66,000 excl. GST (under a limited notified scenario)
- $75,000 excl. GST (under a publicly notified scenario).

The costs estimates include:

- Preparation of both the ORC and QLDC consent applications, including all necessary expert reports (outside of engineering reports which are costed separately in Section 5.6), stakeholder engagement, obtaining APAs, and project management
- QLDC processing costs
- ORC processing costs
- The drafting of S 42A reports and consent decisions
- Hearing costs (consultant team, processing planner, and commissioner decision) assuming a joint hearing and decision.
-
- The cost estimates do not include any costs associated with any appeals.

Assumptions in the cost estimates above:

- It is assumed consents would be prepared and lodged by the end of 2025, noting that increases in hourly charge out rates beyond that have not been factored in. For budgeting purposes, a contingency should be added to the above to account for foreseeable increases in rates should the timing require that.

- It is assumed the EMP elements of the district and regional consents will be processed together.
- It is assumed that there will be a half day hearing if the application(s) are limited notified and a full day hearing if the application(s) are publicly notified. Until submissions are received it is difficult to predict the length of any such hearing.