Assessment of Floodplain Interventions Options – Upper Rees River

22/08/2024

Prepared for
Otago Regional Council

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Issue 2

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Executive Summary

The Issue

The Rees River, including the reach upstream of the Rees River Bridge, is subject to ongoing riverbed aggradation. In the 3 km long reach upstream of the bridge, there has been an average increase in riverbed levels of about 0.3 m over the last 10 years (Damwatch, 2022). In places, the aggrading riverbed levels are approaching the crest of floodbanks upstream of the Rees River Bridge.

This aggradation trend has the following implications for existing flood hazards:

- Increased potential for breakout flooding and channel avulsion along the left and right banks of the river, upstream of the Rees River Bridge
- Reduced bridge waterway flood capacity
- Increased potential for scour and erosion damage at the bridge piers and abutments
- Increased potential for structural damage to the bridge from debris rafting and flood overtopping

Future climate change effects are expected to lead to an increase in both the flood hazards (due to an increase in the frequency and intensity of extreme rainfall) and riverbed aggradation (due to increased sediment supply).

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 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 intervention options for the Upper Rees River. The objectives of the review were to provide an evidence base to rule out various floodplain intervention options and to assess the viability of feasible options. All options were also tested for their alignment with a Nature-based Solutions (NbS) approach to floodplain management (refer Section 3). Selected options were then taken forward to a concept level design stage.

The floodbank and groynes on the right bank of the Rees River are privately owned. ORC undertakes some river management activities (planted willow maintenance) in this area. In relation to the above, ORC may inspect and carry out some maintenance activities on structures that are not owned by ORC. This has been determinate on community request and response to weather/flooding events.

What We Did

Based on an understanding of the current rate of active river channel bed aggradation and flood flow paths and extents, the Upper Rees River flood hazards are very challenging to defend against with conventional engineered solutions (e.g. floodbanks). The long-term sustainability of such structures cannot be assured due to outflanking and overtopping during floods in combination with ongoing channel bed aggradation and lateral river channel migration. This is compounded by the hydraulic constriction caused by the existing

Rees River Bridge. Under flood conditions, there is insufficient conveyance capacity through the bridge waterway and the river naturally wants to break-out on the true left and right bank floodplains (but primarily on the right bank floodplain).

The floodplain intervention options considered in the current assessment were therefore focused on meeting the following objectives:

I. Providing managed floodways on the left and/or right bank approaches to the bridge. The intention of the floodways is to guide floodplain flows in defined areas past the bridge, and to reduce flood discharge through the Rees River Bridge waterway.
II. Alignment with NbS strategies that provide “room for the river” through floodplain widening and embankment removal or retreat, rather than construction of new floodbanks or structural (engineering) solutions to mitigate flood hazards.

It should be noted that these objectives are not aimed at reducing the risk of flooding from the Upper Rees River to farmland and road networks. Options to raise and/or lengthen the existing Rees River Bridge were also not considered as they were outside the scope of the current study. However, these bridge options could be considered in the future by ORC and QLDC and as a further step in the floodplain management adaptation strategies.

The following Options A to C were developed from possible floodplain intervention strategies outlined in the February 2022 workshop (refer Damwatch (2022)). These options met objectives I and II listed above, and were investigated with the aid of a two-dimensional computational hydraulic model of the Upper Rees River. The hydraulic model was used to simulate various flood scenarios in combination with the potential floodplain intervention options. An illustration of each of these options is provided in Figure 4.1.

- Option A: Establishment of a floodplain breakout path on the true right abutment of Rees River Bridge; new floodbank to guide flood flows on the true right floodplain, along Priory and Glenorchy-Paradise Roads.
- Option B: Establishment of a floodplain breakout path on the true right abutment of Rees River Bridge; no new floodbanks.
- Option C: Establishment of a floodplain breakout path on true left abutment of Rees River Bridge; new floodbank to guide flows on true left floodplain.

Option B represents a restoration of the original design concept for the Rees River Crossing as indicated by the extract from an original bridge design drawing in Figure 2.4.

Options to raise the existing, approximately 4 km long, floodbank on the right bank floodplain upstream of the bridge were not considered. There is a natural tendency for flood flows to break-out on the right bank floodplain, due to existing river and floodplain levels, and raising floodbanks on this relatively long reach would be counter to NbS strategies. The long-term sustainability of raising the existing floodbank could not be assured under future flood conditions (i.e. primarily due to outflanking during floods and vulnerability to ongoing bed aggradation, lateral river channel migration and scour and erosion processes).

Options A, B and C are intended to relieve the pressure on the Rees River Bridge under flood conditions by allowing excess floodwaters to bypass the bridge waterway. They are not designed to remove the existing flood hazard to farmland and roads.

What We Found

Option C was found not to be viable for the following reason:

- Assessment of Option C found that the floodplain ground elevations upstream of the Rees River Bridge mean that large floods in the Upper Rees River preferentially want to break out onto the right bank floodplain towards Diamond Stream. Lesser volumes of excess floodwaters in large floods were found to break out onto the left bank floodplain compared to the right bank floodplain, even with removal of existing left bank vegetated areas.

Options A and B were both determined to be viable at meeting objectives I and II listed above. The following concept level design information was developed for these options:

- 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

However, both Options A and B increase the frequency of flooding to the section of Glenorchy-Paradise Road between the Priory Road intersection and the approach to the Rees River Bridge and the potential for erosion damage of the road. This is due to Options A and B reducing the flood discharge through the Rees River Bridge waterway but at the expense of increasing the flood discharge across the true right floodplain.

Next Steps

It is understood that the information contained in this report, regarding potential floodplain intervention options for the Upper Rees River, will be considered by both ORC and QLDC and 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
DEM	Digital Elevation Model
DVD1958	Dunedin Vertical Datum 1958
HEC-RAS	Hydrologic Engineering Centre's River Analysis System
LRS	Land River Sea Consulting Limited
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 Upper Rees River in the vicinity of the Rees River Bridge, near Glenorchy, Otago. The Upper Rees River is subject to flooding and erosion hazards which impact on the Rees River Bridge, the Glenorchy-Paradise Road and Priory Road (Figure 1.1). Further detail on these hazards outlined in Section 2 of this report.

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 external technical experts (Damwatch, 2022). The workshop was intended to be a first pass review of possible floodplain mitigation and floodplain management options to address flooding and erosion hazard issues affecting the Dart and Rees Rivers at the head of Lake Wakatipu.

The current study follows on from the February 2022 workshop and provides an evidence base to rule out various floodplain management options and to identify a viable option for addressing flooding issues around the Rees River Bridge. The viable options were taken forward to a concept level design stage.

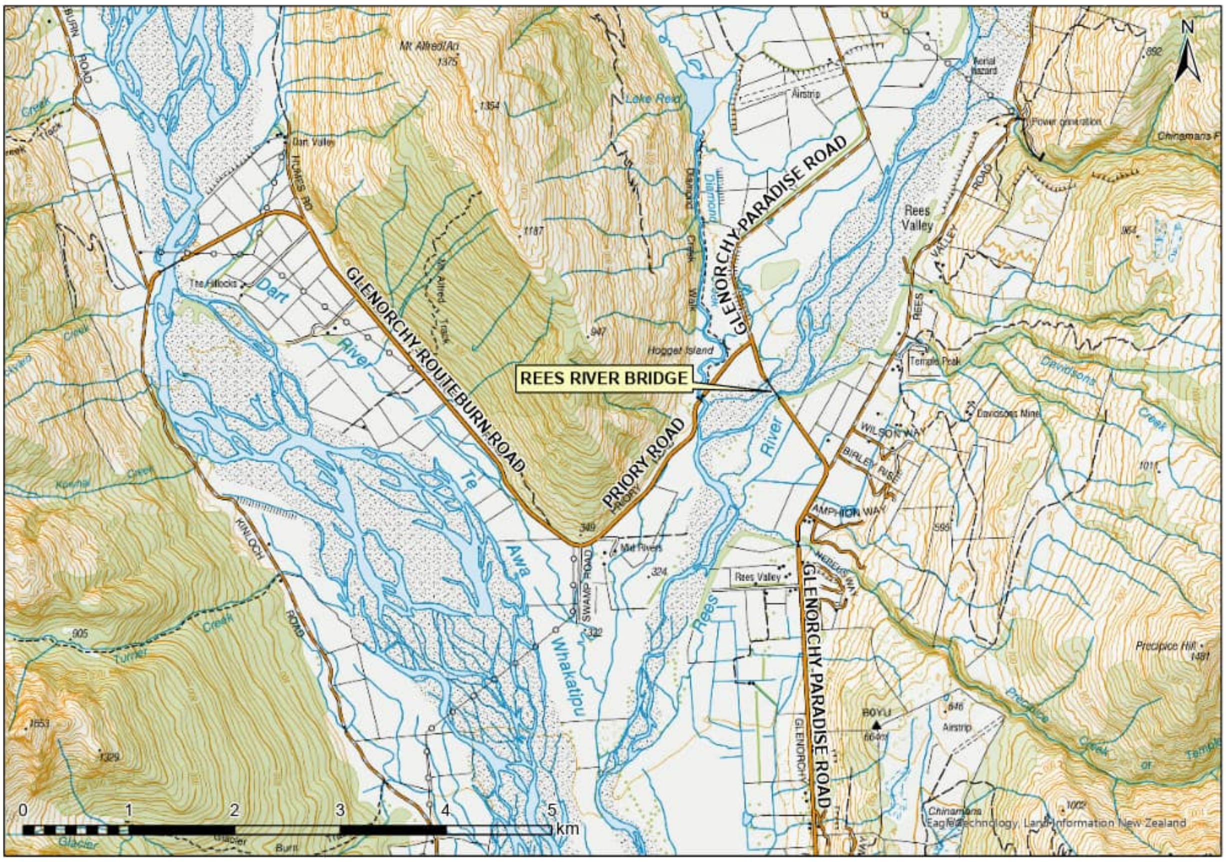


Figure 1.1: Upper Rees River and Dart River valleys at the junction of the two valleys

[1] With Vision Planning Consultants Ltd sub-contracted to Damwatch to provide planning review services (as outlined in Section 5.7 of this report).

1.2 Purpose of Report

This report summarises the engineering investigations into potential floodplain improvement options, including nature-based solutions (NbS), and any fundamental issues associated with each option.

Based on consideration of these options, possible viable options to address flood hazards in the vicinity of the Rees River Bridge are put forward for consideration, including:

- Concept level design drawings
- Indicative budget to construct
- Preliminary analysis of statutory planning provisions
- Description of residual flood risks which would remain if the viable design option was applied
- Description of next steps if viable 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 QLDC and the local community on the potential application of this engineered flood management interventions at the Rees River Bridge.

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 Preferred Option
- Section 6, Conclusions & Recommendations
- Section 7, References

1.4 Limitations

- This report provides a high-level review of potential intervention options to manage floodplain flows in the vicinity of the Glenorchy-Paradise Road crossing of the Upper Rees River (i.e. Rees River Bridge). This includes the development of a concept level design for each viable intervention option. Further work will be needed to progress any concept designs presented in this report to a detailed design stage and to support a resource consent.
- 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 assessed in this report were based on meeting the following objectives:

  - Providing managed floodways on the left and/or right bank approaches to the bridge. These floodways are provided to guide floodplain flows in defined areas and to reduce flood discharge through the Rees River Bridge waterway.
  - Alignment with NbS strategies that provide “room for the river” through floodplain widening and embankment removal or retreat, rather than construction of new floodbanks or structural (engineering) solutions to flood mitigation.
- The options assessed did not consider modification, extension or replacement of the existing Rees River Bridge or reducing the risk of flooding from the Upper Rees River to existing farmland and road networks.
- The options assessed did not consider the potential effects of debris rafts forming at the Rees River Bridge under flood conditions.

1.5 Level Datum and 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 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 floodplain associated with the Rees River is subject to both flooding and erosion hazards which impact on the Rees River Bridge, the Glenorchy-Paradise Road and Priory Road.

In recent years, the Dart and Rees Rivers have experienced several major floods including:

- January 1994 (see Figure 2.2)
- November 1999 (see Figure 2.3)
- February 2020

The January 1994 flood event resulted in extensive flood breakout along the right bank upstream and downstream of the bridge (Figure 2.2). The November 1999 flood event also resulted in flood breakout along the right bank upstream and downstream of the bridge (Figure 2.3), although to a lesser extent than the January 1994 flood. ORC (1999) indicates that in the January 1994 flood there was a "*major break [of the right bank floodbank] that threatened the Glenorchy-Paradise Road*". Inspection of aerial photographs and topographic data indicates that the section of the primary floodbank system marked by the dashed, red line on Figure 2.2 is no longer intact. This could be the section of the primary floodbank system that was damaged in the January 1994 flood.

Flooding and erosion issues on the Upper Rees River are intensified by the following wider geomorphic and hydrological processes in the area:

- Actively aggrading riverbed levels
- Actively migrating braided river channel belts
- Future climate change effects expected to increase flood hazards over time, as well as sediment supply and riverbed level aggradation.

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 Upper Rees River channel currently occupies the eastern side of the river valley upstream of the Rees River Bridge as shown in Figure 2.1 and Figure 2.2. These figures also shows the position of the edge of the active river channel[2] in 1966 and 2019[3]. The movement of the edge of the active river channel highlights the dynamic, changing nature of the Rees-Dart River system over a relatively short geomorphic period.

[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.

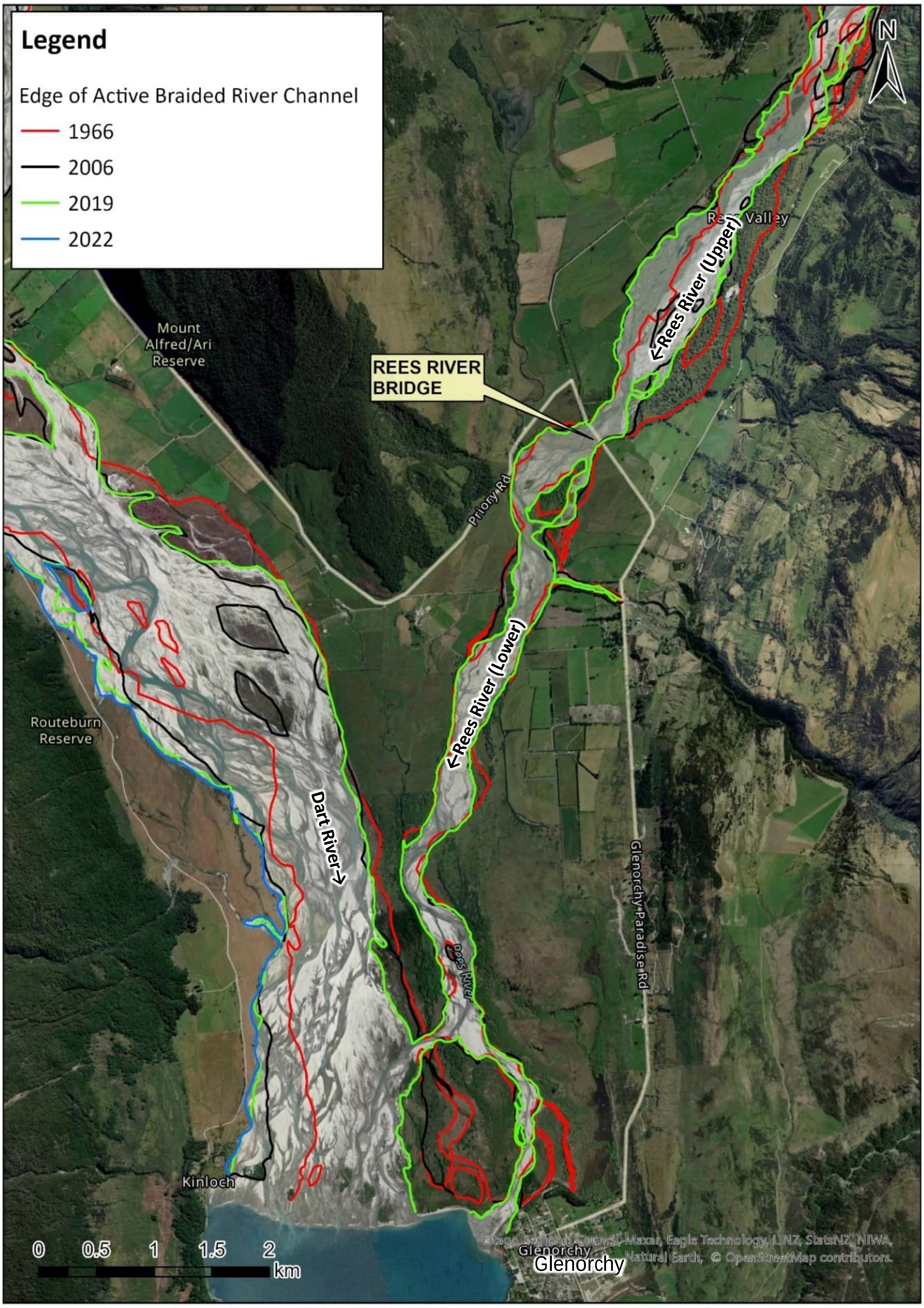
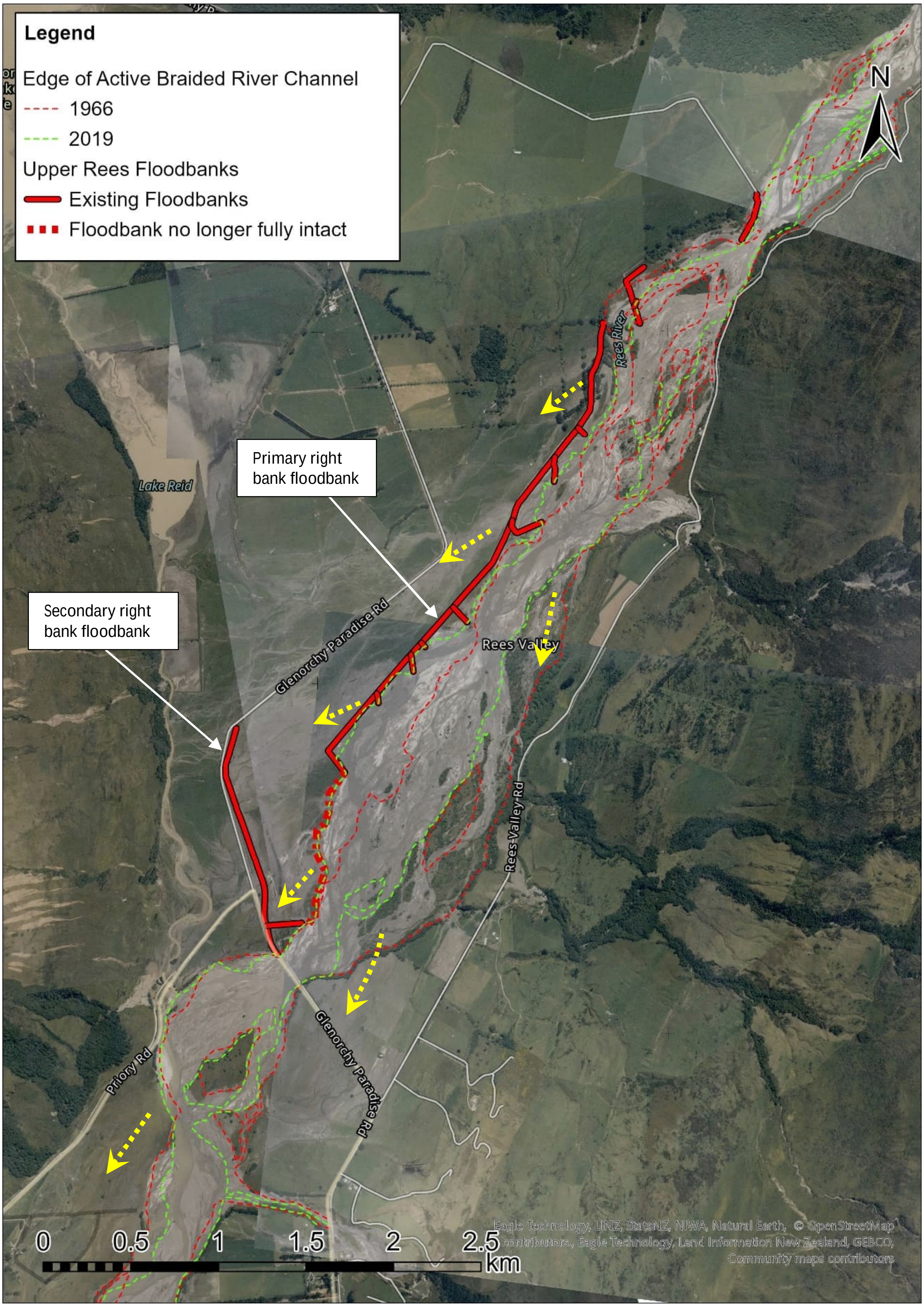


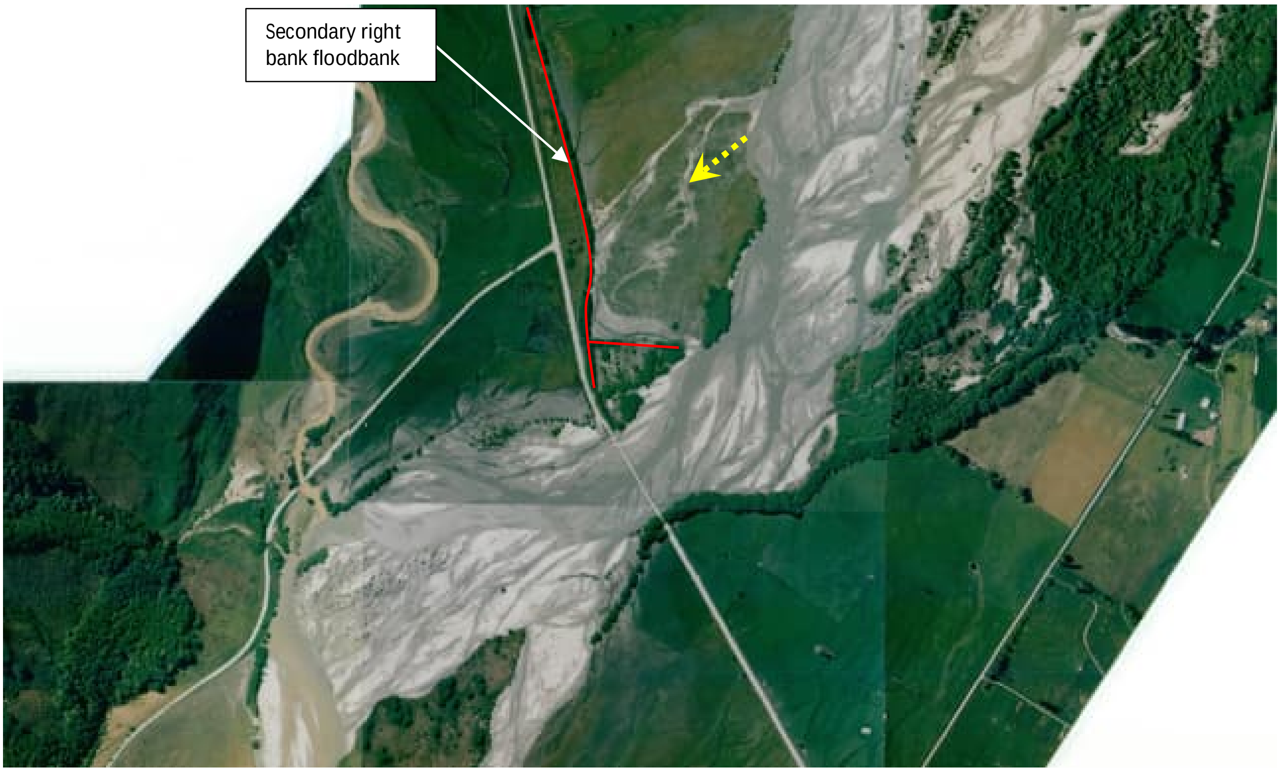
Figure 2.1: Aerial photograph of Dart and Rees Rivers at head of Lake Wakatipu and changes over time in edge of the active river channel



Source: 1994 aerial photograph sourced from ORC

Figure 2.2: 1994 aerial photograph, with grey areas (outside active river channel) showing deposited sediments on floodplains left by January 1994 flood in Upper Rees River in vicinity of Rees River Bridge. Dashed, yellow arrows indicate break-out flow paths from the active river channel.

During flood conditions the Rees River breaks-out from the active river channel and discharges onto adjacent floodplains. The location of the break-out points from the active river channel are marked on Figures 2.2 and 2.3. These figures show aerial photographs of the Rees River Bridge area taken after the January 1994 and November 1999 flood events. The grey areas on these photos indicate where floodwaters have flowed over the floodplains and are characterised by deposited sediments left after the flood.



Source: 1999 aerial photograph sourced from ORC

Figure 2.3: 1999 aerial photograph, with grey areas show deposited sediments left by November 1999 flood in Upper Rees River in vicinity of Rees River Bridge. Aerial photographs taken from 2.30-5 pm on 22 November.

Channel Aggradation

Recent river channel bed surveys by ORC and the University of Canterbury have indicated that the active river channel of the Lower 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 the Lower Rees River bed level (i.e. from the Rees River bridge to the river mouth at Lake Wakatipu) generally increased up to +0.2 to +0.3m[5]. In the 3 km long reach upstream of the bridge, there has been an average increase in riverbed levels of about 0.3 m over the last 10 years (Damwatch, 2022). There is currently no quantitative information on channel aggradation for areas further upstream on the Upper Rees River.

[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.

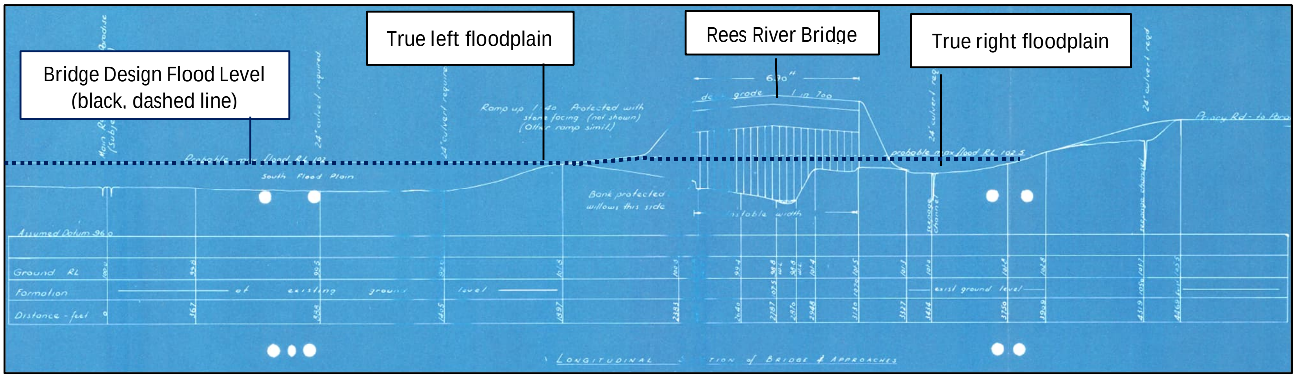
Such aggradation has the potential to exacerbate flooding on the Upper Rees River by raising active river channel bed levels above adjacent floodplain ground levels and pushing a greater proportion of flood flows out of the active river channel and onto the floodplains.

Channel Avulsion Potential

In addition to the potential for greater volumes of flood breakout flow onto adjacent floodplains, riverbed aggradation in the Upper Rees River (described previously) can also lead to an increased risk of channel avulsion[6]. Historical break-out flows from the active river channel and onto floodplain areas are marked with yellow arrows on the aerial photo in Figure 2.2. These indicate possible future channel avulsion paths.

Rees River Bridge Conveyance

The original design drawing for the Rees River Bridge[7], from c.1950, indicates the bridge was designed to for a flood with a peak discharge of 32,000 ft^3/s (906 m^3/s). However, notes on the drawing indicate that in flood conditions, water would be conveyed not only through the bridge waterway but also across floodplains to the south and north of the bridge (Figure 2.4). This highlights that there was acceptance, at the time of bridge design, that the Glenorchy-Paradise Road (which approaches the bridge to the north and south) would be out of service during floods. Since the bridge construction in c.1950, the secondary floodbank on the right bank constructed in c.1980 (refer Figure 2.2 for its location) has modified the right bank floodplain flows. The secondary floodbank guides flood waters on the true right floodplain back into the main river channel just upstream of the Rees River Bridge. This reduces the degree of flood hazard to the Glenorchy-Paradise Road between the right bridge abutment and the intersection with Priory Road. However, it also has the effect of increasing the total flood discharge through the Rees River Bridge waterway.



Source: Lake County Council drawing 1878/2, dated 1953

Figure 2.4: Long-section along Glenorchy-Paradise Road from original Rees River Bridge construction drawing

Since the bridge construction in c.1950, bed aggradation of the Upper Rees River has resulted in riverbed levels at the Rees River Bridge gradually increasing over time (Figure 2.5). Bed aggradation under the bridge is now at levels where it is difficult for a person to stand under the beams supporting the bridge deck. The reduced clearance above bed level to the bridge soffit has the effect of reducing the flood conveyance capacity through the bridge waterway. WSP (2023) estimated that the underside of the bridge deck (at

[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.
[7] Lake City Council drawing 1878/2 (dated March 1953, titled “Proposed New Bridge Rees River”)

335.13 m RL DVD1958) would become surcharged on the upstream side of the bridge deck in a flood event as small as a 1 in 5 Annual Exceedance Probability (AEP) flood. As floods typically transport large volumes of woody debris, the reduced clearance under the bridge significantly increases the potential for debris raft formation upstream of the bridge and consequently the scour risk to the bridge.

WSP (2023) also estimated that, while a 1 in 100 AEP flood would also be surcharged against the upstream side of the bridge deck, it would not overtop the deck.

Queenstown Lakes District Council (QLDC) currently hold a resource consent for extraction of gravel at the bridge up to 20,000 m^3 annually although the actual amount extracted on a yearly basis is constrained by the available budget for this work (Damwatch, 2022).

Figure 2.6 shows aerial photos at the Rees River Bridge from August 2019, just after gravel extraction and from February 2021. The photos in these figures illustrate that the localised area of gravel extraction in the bridge area from 2019 is relatively quickly filled in again after extraction has occurred. This highlights that such a management practice is ineffective at maintaining bridge conveyance capacity. The volume of gravel extracted annually is small relative to the natural supply of sediment material from upstream. Damwatch (2022) indicates that, based of measurements from 2009-2011 field surveys, sediment volumes of 5,000-30,000 m^3 can move past the bridge in relatively small flood events.

Consequences for Rees River Bridge Security

The combination of ongoing riverbed aggradation and future climate change effects mean that there is increased potential for structural damage to the Rees River Bridge during a future large flood event from:

- Flood surcharging against the upstream side of the bridge
- Debris raft formation against the upstream side of the bridge
- Flood overtopping
- Pier and abutment scour

Figure 2.5: View of bed aggradation at the Rees River Bridge in January 2023

Figure 2.6: Aerial photos of riverbed in the vicinity of the Rees River Bridge showing (a) gravel extraction zone upstream and downstream of bridge in August 2019 (indicated by dashed, red box) and (b) same area in February 2021

2.3 Flood Frequency Estimates and Climate Change Effects

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 reinstalled 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)[8].

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.

The peak of the February 2020 flood event in the Rees River at the Rees River Bridge was estimated by means of a calibrated rainfall/runoff model to be 642 m^3/s (ORC, 2021). Comparison with the flood frequency estimates for the Rees River at the Rees River Bridge indicates that this event would have been about a 1 in 10 AEP flood.

[8] Some flow data was also collected as part of a research project in 2009-2010 (refer “Event-by-event” slide in Appendix D of Damwatch (2022)).

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

Site	Catchment Area (km²)	Flood Peak Discharge (m³/s)							
		1 in 2.33 AEP (50%)	1 in 5 AEP (20%)	1 in 10 AEP (10%)	1 in 20 AEP (5%)	1 in 50 AEP (2%)	1 in 100 AEP (1%)	1 in 100 AEP (1%) plus CC [a]	1 in 500 AEP (0.2%)
Dart @ Hillocks	591	NA	1,390	1,623	1,853	2,168	2,420	2,907	3,067
Rees @ Invincible	230	NA	442 [b]	516 [b]	589 [b]	689 [b]	769	929	975 [b]
Rees @ Rees River Bridge	297	420 [d]	540 [c]	631 [c]	721 [c]	843 [c]	941	1,138	1,193 [c]

Notes:
All data sourced from ORC (2021) unless otherwise stated.
[a] 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.
[b] Flood peak discharge estimate not provided in ORC (2021). Estimates therefore scaled from Dart @ Hillocks estimates using a scaling factor of 1/3.147, derived from ratio of Dart / Rees 1 in 100 AEP peak discharge estimates (i.e. 2,420 / 769 = 3.147).
[c] 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).
[d] Flood peak discharge estimate not provided in ORC (2021). The 1 in 2.33 AEP estimate was obtained through linear regression analysis of peak discharge estimates ranging from 1 in 5 to 1 in 20 AEP.
NA = not available.

2.4 Existing Upper Rees Floodbank System

Figure 2.7 shows two images side by side of the Rees River upstream of the Rees River Bridge on which the floodbank system along the right bank of the river has been marked. One image is an aerial photo while the other image is a topographic relief image. The floodbank system is marked by the yellow lines.

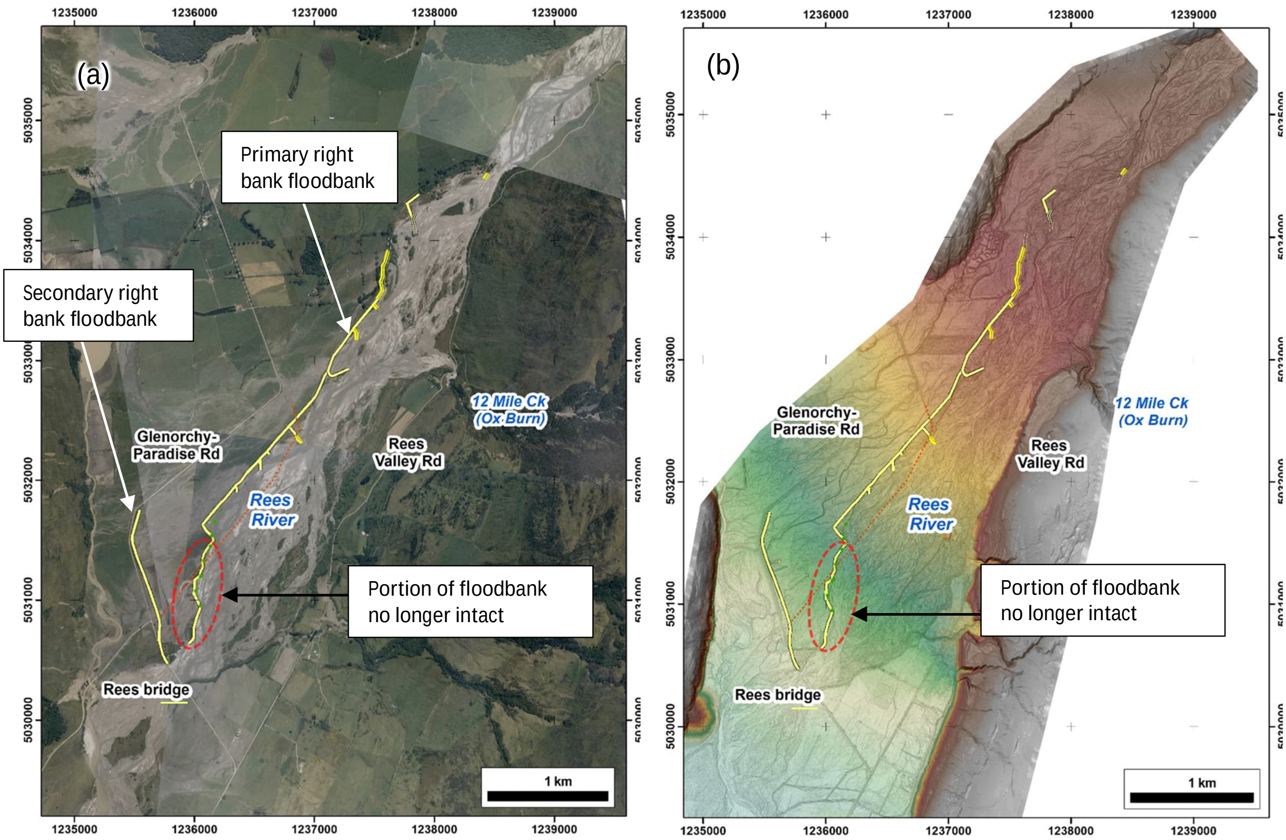
The floodbank system is comprised of:

- A primary floodbank along the edge of the active river channel (constructed in 1984 (ORC, 1999))
- A secondary floodbank running roughly parallel with the Glenorchy-Paradise Road

Figure 2.8(a) shows a photo of a short section of the secondary floodbank.

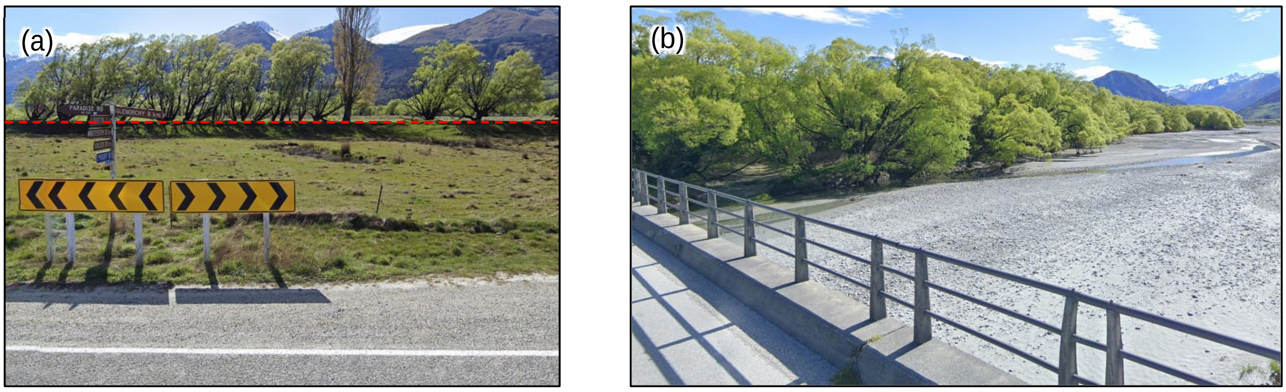
Inspection of the LiDAR data along the edge of the floodplain in this area circled in red on Figure 2.7 indicates that there are only remnants of the original floodbank remaining. Riverbed levels are also perched above adjacent ground levels along the active river channel edge while existing willow trees continue to provide some degree of edge protection (see Figure 2.8(b)).

As previously described in Section 2.2 “Rees River Bridge Conveyance” this secondary floodbank reduces the flood hazard to the section of the Glenorchy-Paradise Road on the floodplain to the true right of the Rees River Bridge. However, it also acts as a guide-bank which turns flood flows back towards the bridge and forces them through the bridge waterway (contrary to the original design intention for the bridge).



Source: Images sourced from ORC presentation contained in Appendix B of (Damwatch, 2022)

Figure 2.7: (a) Aerial photo and (b) topographic relief images showing location of floodbank system on right bank of Rees River upstream of Rees River Bridge



Source: Images sourced from Google Street View

Figure 2.8: (a) Secondary floodbank on right bank of Upper Rees River upstream of Rees River Bridge (photo taken from junction of Glenorchy-Paradise Road and Glenorchy-Routeburn Road). Floodbank crest marked with red-dashed line. (b) Willow trees providing edge protection along right bank of Rees River upstream of right abutment of Rees River Bridge.

2.5 Flood Hazard Assessment

2.5.1 Previous Assessments

A flood hazard assessment for the Lower Rees River and Glenorchy township (refer LRS (2022)) utilised the results from a computational hydraulic model of the river and floodplain system. The model used in the LRS (2022) assessment had its upstream boundary at the Rees River Bridge. It therefore provides no useful information on flood hazards for the purposes of the current assessment.

WSP were engaged by QLDC to carry out a structural options study for the Rees River Bridge (refer WSP (2023)) to help provide direction and guidance towards a long-term asset management strategy for the bridge. This was driven by the bed aggradation trends and threats to the security of the bridge discussed in Section 2.2. Some computational hydraulic modelling was undertaken to support the WSP structural options study. However, this modelling had a different focus and therefore only provided limited information that was useful for this assessment. Section 2.2 summarised the findings from the WSP (2023) modelling study on the hydraulic behaviour at the bridge for the 1 in 5 AEP and 1 in 100 AEP floods.

2.5.2 Further Analysis of Flood Hazards

Computational Hydraulic Model of Upper Rees River

A HEC-RAS[9] two-dimensional computational hydraulic model of the Upper Rees River was developed to provide a better understanding of flood hazards upstream of the Rees River Bridge. An overview of the model is provided in Appendix A. The model extent covered the Upper Rees River and floodplains about 1.5 km downstream and 7.5 km upstream of the Rees River Bridge (refer Figure A.1 in Appendix A).

Ground and riverbed levels in the digital elevation model (DEM) defining the ground topography for the HEC-RAS computational hydraulic model were defined in terms of the DVD1958 level datum. Linear features such as roads raised above natural ground levels and existing floodbanks were carefully delineated within the model DEM.

The HEC-RAS model also incorporated the Rees River Bridge as an internal structure based on the geometry shown on an existing construction drawing and surveyed soffit and deck levels from the WSP structural options assessment report (WSP, 2023).

Simulation of February 2020 Flood

The HEC-RAS model was used to simulate the February 2020 flood event. However, there was a lack of detailed information on actual maximum flood extents to enable the model to be properly validated.

The model was used to estimate maximum flood inundation extents, flow depths and flow velocities for the flood event over the extent of the model domain. Figure 2.9 illustrates the maximum predicted flood extents and depths for the event.

[9] 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.

The following observations were noted about the HEC-RAS model predicted February 2020 flood inundation extents and patterns:

- No significant flood break-outs along the primary right bank floodbank system except for a minor amount of break-out flow about 3.8 km upstream of the Rees River Bridge (and marked with a red dashed arrow on Figure 2.9).
- Backing up of floodwaters upstream of the existing secondary floodbank system (marked with a yellow dashed arrow on Figure 2.9) parallel with Glenorchy-Paradise Road, with outflanking of this secondary floodbank in places.
- Overtopping of Glenorchy-Paradise Road between the right abutment of the Rees River Bridge and the junction with Priory Road.
- Overtopping of Priory Road at the Diamond Stream crossing.
- Moderate flood break-out flows over the left bank floodplain about 3.2 km upstream of the Rees River Bridge with break-out flows returning to the main river channel system immediately upstream of the bridge. These break-out flows are marked with a white dashed arrow on Figure 2.9.
- Backing up of floodwaters upstream of the Glenorchy-Paradise Road to the south-east of the left abutment of the Rees River Bridge. The water backing up behind the road on this true left floodplain would drain through culverts underneath the road (and the locations marked with a star on Figure 2.9) and eventually return to the main river channel.
- Flood flows are passed under the Rees River Bridge without being surcharged on the upstream side of the bridge deck.

Note that the extent of the available DEM, and HEC-RAS model domain, did not capture the full extent of overland flows on the true right floodplain and into Diamond Creek. This area is marked on Figure 2.9 with a caption "Model Boundary (flood extents not available past this line)". Actual flood extents would extend further towards Diamond Creek than shown on Figure 2.9 and subsequent figures illustrating maximum flood extents.

Base Simulations of 1 in 20, 1 in 50 and 1 in 100 AEP Floods

Following simulation of the February 2020 flood event, the HEC-RAS model was then used to estimate maximum flood inundation extents, flow depths and flow velocities for the 1 in 20, 1 in 50 and 1 in 100 AEP floods based on the peak flood discharge estimates summarised in Table 2.1 at the Rees River Bridge.

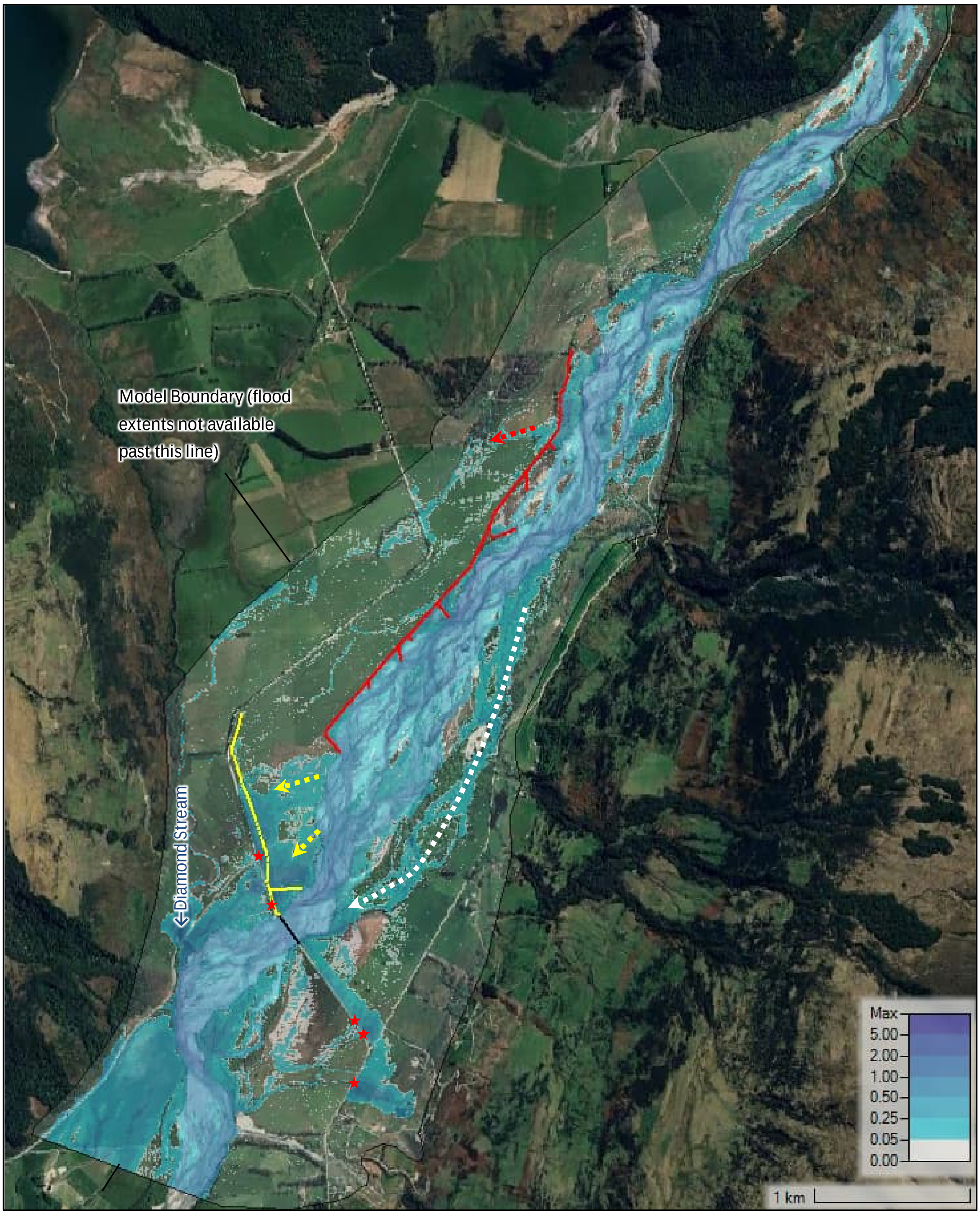


Figure 2.9: Maximum flood extent and depths predicted by HEC-RAS model for February 2020 flood event. Primary floodbank marked with red line, secondary floodbank marked with yellow line. Red stars indicate location of culverts underneath true left and right approaches of the Glenorchy-Paradise Road to the Rees River Bridge.

Figure 2.10(a), (b) and (c) illustrate the maximum predicted flood extents and depths for the 1 in 20, 1 in 50 and 1 in 100 AEP floods respectively. As the size of the flood increases, the following changes in maximum flood extent and patterns are noted:

- Progressively increasing volumes of flood break-out along the right bank upstream of Camp Hill (about 3.8 km upstream of the Rees River Bridge), with the break-out flows flowing overland in a south-westerly direction to enter Diamond Stream.
- Progressively increasing volumes of flood break-out along the right bank over about 2.6 km upstream of the Rees River Bridge with breakout flows intercepted by the road embankment carrying the Glenorchy-Paradise Road and the secondary floodbank running parallel with the road. This includes progressively increasing flood overtopping of the remnant primary right bank floodbank over about 1.4 km upstream of the right abutment of the Rees River Bridge.
- Progressively increasing levels of overtopping of the Glenorchy-Paradise Road between the right abutment of the Rees River Bridge and the junction with Priory Road.
- Progressively increasing levels of overtopping of the secondary floodbank around the junction of Glenorchy-Paradise Road and Priory Road.
- Progressive backing up on the Diamond Lake side of the road embankment carrying Priory Road and road overtopping in the vicinity of the Diamond Stream crossing.
- Progressively increasing volumes of flood breakout over the left bank floodplain about 3.2 km upstream of the Rees River Bridge with breakout flows mostly returning to the main river channel system immediately upstream of the bridge. Some leakage of these flood breakout flows towards the Glenorchy-Paradise Road south of the Rees River Bridge.
- Progressive backing up upstream of the road embankment carrying the Glenorchy-Paradise Road to the south of the Rees River Bridge in conjunction with progressively increasing volumes of flood overtopping of the road.

The flood inundation extents shown in Figure 2.10 generally reflect the sediment deposition pattern left after the January 1994 flood event (refer to the aerial photo in Figure 2.2).

Figure 2.11 illustrates the effect of the Rees River Bridge on the longitudinal flood surface profile with increasing flood magnitudes. The effect of the bridge is to cause a sharp, local increase in the peak flood level profile which extends at least 100 m upstream. Although Figures 2.11 suggests no surcharging of the flood surface profiles on the bridge superstructure would occur, the flood surfaces are within about 20 cm of the underside of the bridge deck so that turbulent wave action is likely to cause floodwaters to intermittently impinge on the superstructure. With large floods transporting significant volumes of woody debris flushed out of the upper catchment, there is a high potential for woody debris to get snagged on the bridge superstructure causing a debris raft to progressively form. This would exacerbate the scour risk to the bridge.

Figure 2.12 illustrates the magnitude of flow velocities and the directions of flow within the main river channel system and on the floodplains for the 1 in 100 AEP flood. This figure indicates that floodwaters at the peak of a flood of this magnitude, based on the current riverbed geometry, are concentrated along the right bank of the active channel where a 1.4 km section of the primary floodbank is no longer fully (refer Figure 2.7(a)).

The flood inundation extents (Figure 2.10) and flow directions (Figure 2.12) provide some direction for the development of suitable floodplain intervention options. These options are outlined and assessed in Section 4 of this report.

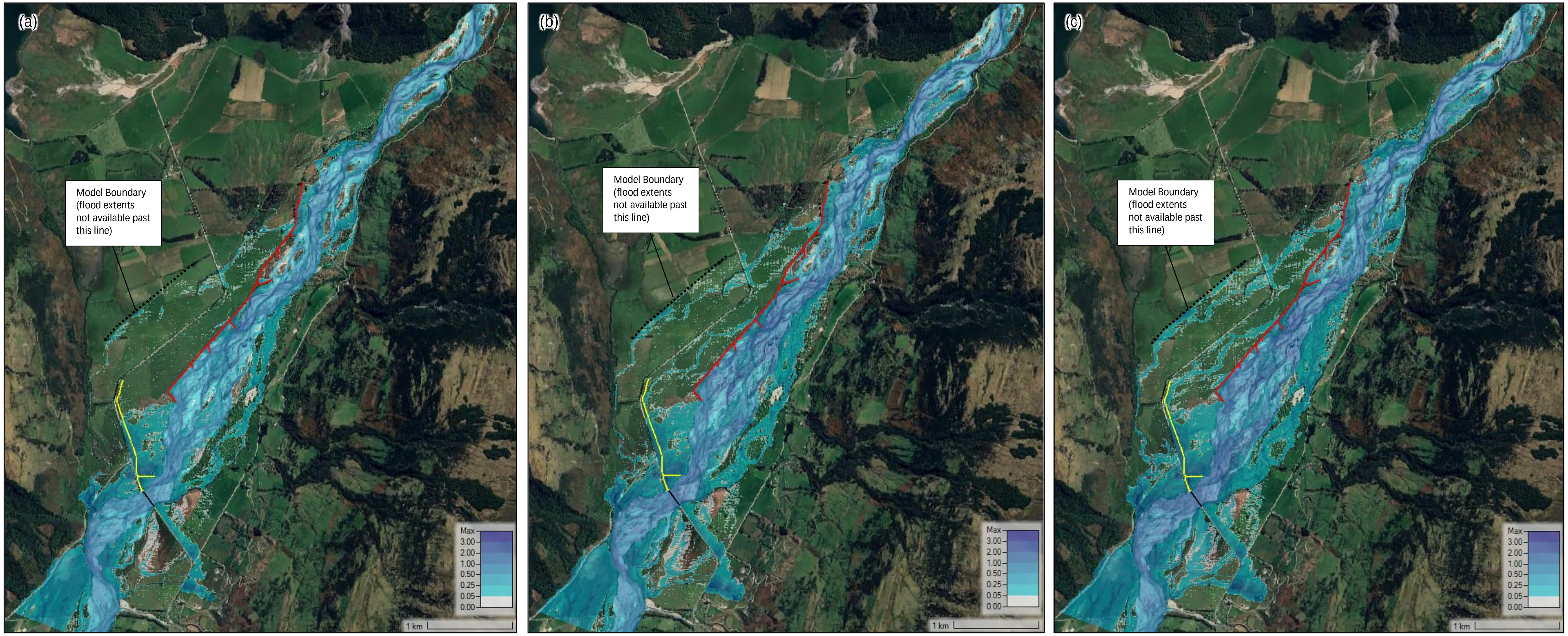


Figure 2.10: HEC-RAS model predicted maximum flood depths and extents for (a) 1 in 20 AEP flood, (b) 1 in 50 AEP flood and (c) 1 in 100 AEP flood for existing river and floodplain geometry on Upper Rees River based on 2022 LiDAR topographic survey.

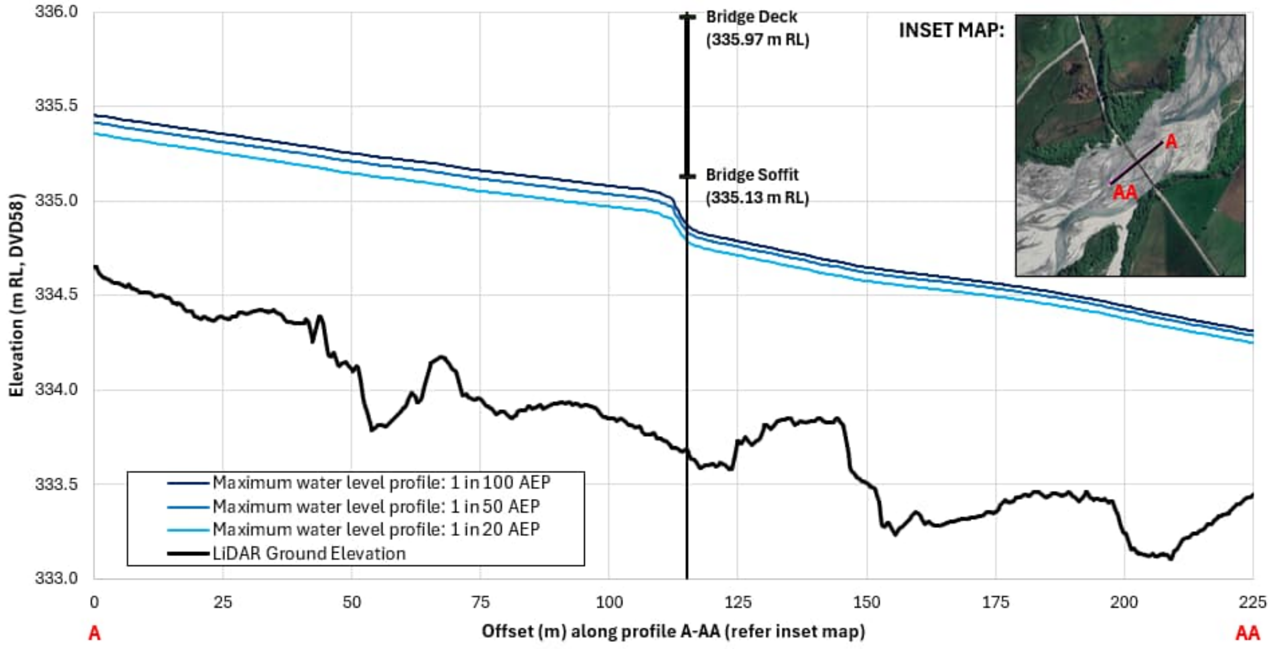


Figure 2.11: Longitudinal peak flood level profiles upstream of the Rees River Bridge showing the extent of the backwater influence of flow surcharging on the bridge deck for the 1 in 20 AEP, 1 in 50 and 1 in 100 AEP floods

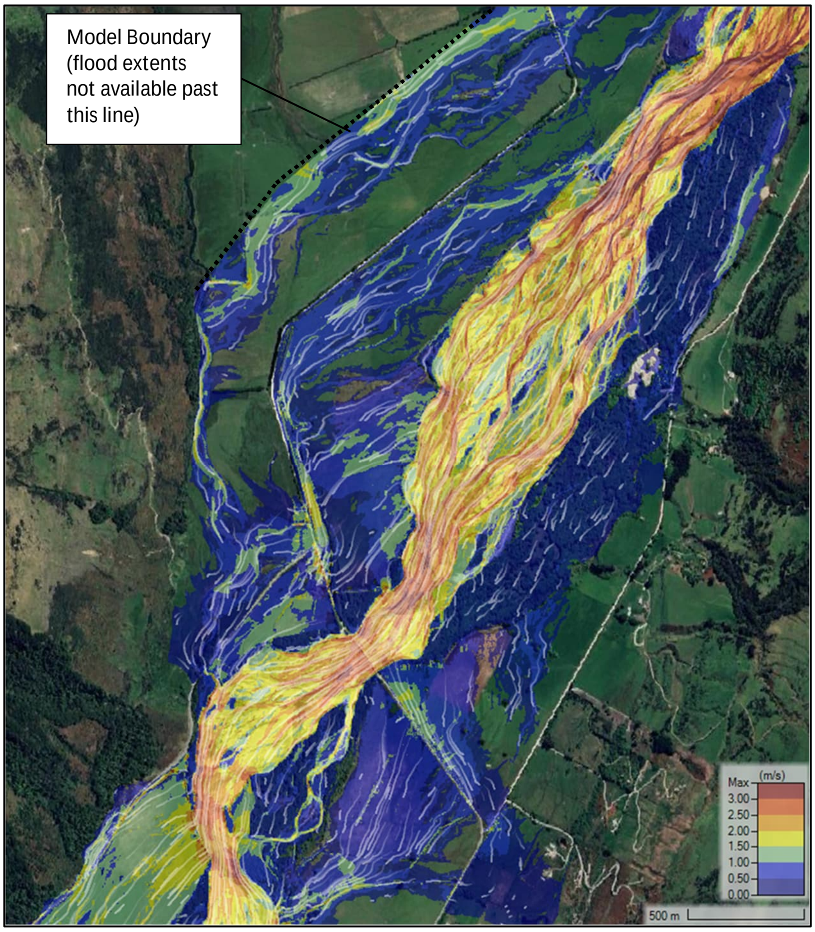


Figure 2.12: Flow velocity (coloured contours) and streamlines (white streaks) at peak of 1 in 100 AEP flood over an area extending 3 km upstream of Rees River Bridge and 1 km downstream

2.6 Infrastructure Ownership and Responsibilities

The floodbank and groynes on the right bank of the Rees River are privately owned. ORC also undertakes some river management activities (planted willow maintenance) in this area. In relation to this, ORC may inspect and carry out some maintenance activities on structures that are not owned by ORC. This has been determinate on community request and response to weather/flooding 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 (2020)

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

3.2 NbS Integration to Upper Rees Floodplain Interventions

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 Options Considered in 2022 Workshop

The following floodplain intervention options were considered in the 2022 workshop (Damwatch, 2022):

(a) Raising the existing primary floodbank on the right bank upstream of the Rees River Bridge
(b) Extending the existing secondary floodbank on the right bank floodplain further upstream
(c) Raising the existing secondary floodbank on the right bank floodplain upstream of the Rees River Bridge
(d) Establishing a left bank flood breakout path upstream of the Rees River Bridge

These options were identified without the benefit of a full understanding of flood flow paths and extents within the active braid channel belt of the river and preferential breakout flow paths along the left and right bank floodplains (refer Section 2.5). Options (a) and (b) listed above are out of the scope of the current assessment based on the February 20220 workshop findings.

4.2 Options Considered in Current Assessment

Based on the understanding of the current rate of active river channel bed aggradation (refer Section 2.2) and flood flow paths and extents (refer Section 2.5), the Upper Rees River flood hazards are very challenging to defend against with conventional structural (engineering) solutions (e.g. floodbanks). The long-term sustainability of such structures could not be assured due to outflanking and overtopping during floods in combination with ongoing channel bed aggradation and lateral river channel migration. This is compounded by the hydraulic constriction caused by the Rees River Bridge. Under flood conditions, there is insufficient conveyance capacity through the bridge and the river naturally wants to break-out on the true left and right floodplains (although primarily on the right bank).

The options considered in the current assessment are therefore focused on meeting the following objectives:

I. Providing managed floodways on the left and/or right bank approaches to the bridge. The intention of the floodways is to guide floodplain flows in defined areas and to reduce flood discharge through the Rees River Bridge waterway.
II. Alignment with NbS strategies that provide “room for the river” through floodplain widening and embankment removal or retreat, rather than construction of new floodbanks or structural (engineering) solutions to flood mitigation.

The first two options considered in the 2022 Workshop (i.e. (a) and (b) listed in Section 4.1) do not meet the above objectives and have not been considered in the current assessment. These first two options would be counter to NbS strategies and their long-term sustainability could not be assured under future flood conditions (i.e. primarily due to outflanking during floods and vulnerability to bed aggradation and lateral river channel migration processes). The second two options considered in the 2022 Workshop (i.e. (c) and (d) listed in Section 4.1) were assessed as described in the following Section 4.5.

However, the options considered in the current assessment do not remove the flood hazard to the existing farmland and road networks. Nor do they consider modification, extension or replacement of the existing

Rees River Bridge which were outside the scope of the current study. These bridge options could be considered in the future by ORC and QLDC and as a further step in the floodplain management adaptation strategies.

4.3 Development of Options

Table 4.1 outlines the range of floodplain intervention options considered. Options A and B were focussed predominately on making 'room for the river' around the right flank of the Rees River Bridge and on the right bank floodplain where existing riverbed levels are already at or nearing adjacent floodplain levels. Option C considered a left bank floodplain intervention option.

Options A to C are illustrated in Figure 4.1.

Options A, B and C are all intended to relieve the pressure on the Rees River Bridge under flood conditions by allowing excess floodwaters to bypass the bridge waterway. They are not designed to remove the existing flood hazard to farmland and roads.

Table 4.1: Summary of floodplain intervention options considered

Option	Floodplain	Floodplain Modifications
A	Right	*Establishment of floodplain breakout path on true right abutment of Rees River Bridge; new floodbank to guide flood flows downstream of the bridge along Priory Road and Glenorchy-Paradise Road to the north-west of the bridge.* • Lower secondary floodbank system between right abutment of bridge and junction of Glenorchy-Paradise Road and Priory Road • Raise Priory Road from junction with Glenorchy-Paradise Road over a distance of about 650 m to south-west (tie into existing vertical alignment of Priory Road immediately to north of Diamond Stream crossing) • Raise Glenorchy-Paradise Road north of junction with Priory Road over a distance of about 930 m • Ramp south of junction with Priory Road over a distance of 100 m (to tie existing Glenorchy-Paradise Road south of junction with new road vertical alignment)
B	Right	*Establishment of floodplain breakout path on true right abutment of Rees River Bridge; no new floodbanks.* • Lower secondary floodbank system between right abutment of bridge and junction of Glenorchy-Paradise Road and Priory Road
C	Left	*Establishment of floodplain breakout path on true left abutment of Rees River Bridge; new floodbank to guide flows upstream of the bridge.* • Clear existing left bank floodplain vegetation over an area of about 352 hectares to form a floodway of reduced surface roughness / retain existing willow edge protection along active riverbed side of this floodway • Form 500 m long floodbank to form a guide bank roughly parallel with the left bank of the active riverbed but set back 440 m from left abutment of bridge

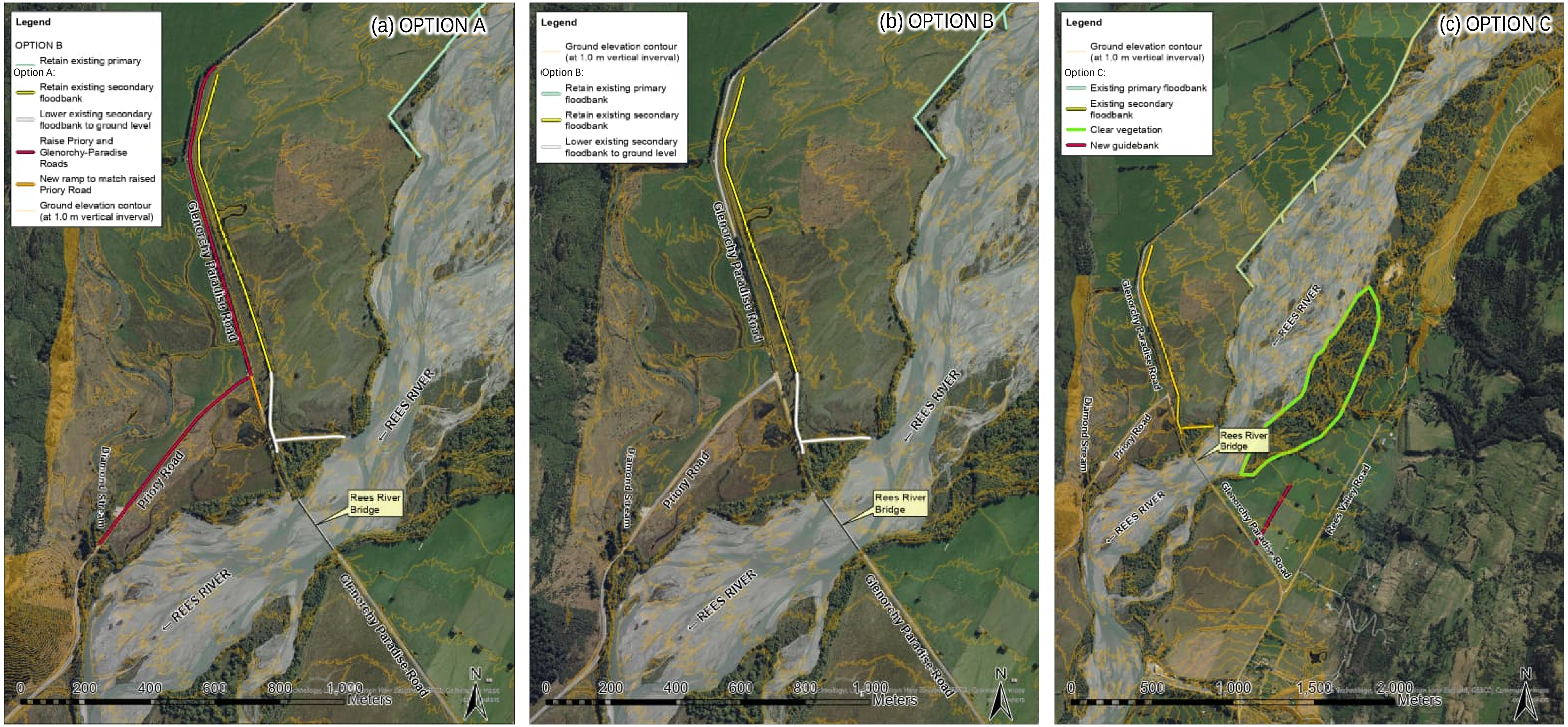


Figure 4.1: Illustration of floodplain interventions for right bank (a) Option A, (b) Option B, and left bank (c) Option C

Development of Options A and B for the right bank floodplain evolved through a trial-and-error approach. The philosophy behind Option A was to provide room for the passage of flood breakout flows over the right bank floodplain. This would relieve pressure on the Rees River Bridge. Raising the existing Priory and Glenorchy-Paradise Roads north of the bridge would act to guide floodwaters but provide the added benefit of mitigating the flood hazard to this section of the roading network. However, it involves an acceptance that the section of road between the right abutment of the bridge and the junction of Glenorchy-Paradise Road and Priory Road, as well as the section of road between the left abutment and Rees Valley Road intersection, would be impassable in floods exceeding a certain threshold due to flood inundation. As a result, some damage to these stretches of road may occur during floods when inundation occurs, requiring subsequent repairs.

Option B is similar to Option A but with minimal intervention and no proposed new floodbank or road raising works. Instead, it uses the right bank floodplain for breakout flows to relieve pressure on the Rees River Bridge but at the expense of allowing flooding across the farmland and Glenorchy-Paradise Road and Priory Road network north and south of the bridge. It represents a restoration of the original design concept for the Rees River Crossing as indicated by the extract from an original bridge design drawing in Figure 2.4.

Option C represented an intervention option on the left bank floodplain. This involved clearance of existing vegetation on the left bank to the north-east of the Rees River Bridge in an effort to promote flood break-out flows on the left bank. A guide bank upstream of the Glenorchy-Paradise Road was included to guide floodplain flows within a defined corridor. Like previous options, this would not prevent flooding across the road network to the north and south of the bridge.

The effectiveness of Options A to C were investigated as outlined in the following Section 4.4.

4.4 Options Investigations Methodology

Options A to C were investigated by implementing each of them into a modified DEM for the HEC-RAS computational hydraulic model of the Upper Rees River. Refer to Section 2.5.2 and Appendix A for further detail on the HEC-RAS model.

The HEC-RAS model was run for each option to determine maximum flood inundation extents, flow depths and flow 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 to whether the proposed option was aligned with an NbS approach.

Table 4.2 lists the scenarios investigated for each option. Baseline scenarios were firstly simulated for 1 in 20, 1 in 50 and 1 in 100 AEP floods on the existing Upper Rees River. The various options were then input to the HEC-RAS model and tested under the same flood conditions, including the following potential future riverbed 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 4.2.

- Ongoing active river channel bed aggradation, assuming a +0.2 m increase in active riverbed levels per decade[10]. These simulations are noted with the following suffixes in Table 4.2:
  - *SED1*: +0.2 m of active river channel aggradation (simulating the active riverbed in 10 years time or c.2030).
  - *SED2*: +0.4 m of active river channel aggradation (simulating the active riverbed in 20 years time or c.2040).

For Options A and B, a "super-design" flood event with a 1 in 500 AEP flood was also simulated (denoted with the suffix '500', in Table 4.2). This was carried out to test the effectiveness of the floodplain interventions included in each option to an extreme flood greater than the 1 in 100 AEP design flood standard commonly adopted for flood defences.

Results from the options investigation are summarised in Appendix B.

4.5 Assessment of Options

Table 4.3, 4.4 and 4.5 summarise the findings regarding assessment of Options A to C respectively. Supporting evidence for the findings is provided in Appendix B and referred to in Tables 4.3 to 4.5 where required.

Based on the assessment of options outlined in Tables 4.3 to 4.5, Options A and B were considered viable in meeting the objectives outlined in Section 4.2 previously. These options were taken forward for concept design considerations, as outlined in Section 5 of this report.

Option C was not considered to be a viable option. Assessment of this option found that the floodplain ground elevations upstream of the Rees River Bridge mean that large floods in the Upper Rees River preferentially want to break out onto the right bank floodplain towards Diamond Stream. Lesser volumes of excess floodwaters in large floods were assessed to break out onto the left bank floodplain than on the right bank floodplain, even with removal of vegetated areas.

[10] 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 to be a simplified approach to testing the various options to riverbed aggradation effects but are not reflective of more complex 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).

Table 4.2: Summary of hydraulic model simulations for assessment of floodplain interventions

Model Code	Scenario Description	Flood Frequency (AEP)	Active River Channel Bed Aggradation Assumption*
X20	Baseline - Existing riverbed geometry and flood protections	1:20 (5%)	Current (2022)
X50		1:50 (2%)	
X100		1:100 (1%)	
A20	Option A – refer to Figure 4.1(a)	1:20 (5%)	Current (2022)
A50		1:50 (2%)	
A100		1:100 (1%)	
A100-SED1		1:100 (1%)	+0.2 m (c.2030)
A100-SED2		1:100 (1%)	+0.4 m (c.2040)
A100-CC		1:100 (1%) + CC**	Current (2022)
A500-SED2		1:500 (0.2%)	+0.4 m (c.2040)
B20	Option B - refer to Figure 4.1(b)	1:20 (5%)	Current (2022)
B50		1:50 (2%)	
B100		1:100 (1%)	
B100-SED1		1:100 (1%)	+0.2 m (c.2040)
B100-SED2		1:100 (1%)	+0.4 m (c.2040)
B100-CC		1:100 (1%) + CC**	Current (2022)
B500-SED2		1:500 (0.2%)	+0.4 m (c.2040)
C100	Option C – refer to Figure 4.1(c)	1:100 (1%)	Current (2022)

* 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.

Table 4.3: Summary of Option A assessment

Option	Flood Improvements	NbS Assessment	Risks	Overall Viability
A – Establishment of floodplain breakout path on true right abutment of Rees River Bridge; new floodbank to guide flood flows downstream of the bridge along Priory Road and Glenorchy-Paradise Road to the north-west of the bridge. (refer to Figure 4.1(a) for an illustrative sketch)	• Lowering existing floodbanks creates a bypass for excess floodwaters and relieves pressure on flood conveyance capacity of existing bridge. • Raised road embankments function as guide banks for excess floodwaters although they elevate floodwaters in specific areas. • The raised road embankments provide the added benefit of mitigating flooding to the raised road sections. • Relatively shallow floodwaters outflank the north end of the raised section of Glenorchy-Paradise Road. NB: Refer Appendix B for discussion of flood modelling results and evidence base to support these statements.	• Significant NbS benefits as this option allows for removal of selected embankment sections and floodplain widening. • Over time, it may also allow for the revival of old channels and recovery of part of the original bed through channel avulsion.	• Elevation of Glenorchy-Paradise Road to north of junction with Priory Road will require a much wider floodbank embankment footprint (to accommodate a dual road carriageway at the crest). • Allowing overtopping of section of the Glenorchy-Paradise road from the right bridge abutment to the Priory Road intersection will result in road closure during flooding and may result in damage to road surfaces and shoulders. • Over time, as further riverbed aggradation occurs, there is a risk of permanent channel avulsion occurring which outflanks the right abutment of the existing bridge. • Long-term resilience of existing Rees River Bridge with rising riverbed levels and potential erosion and scour to right abutment is not addressed.	• Floodplain interventions, including road raising, are considered viable in achieving objectives outlined in Section 4.2.

Table 4.4: Summary of Option B assessment

Option	Flood Improvements	NbS Assessment	Risks	Overall Viability
B – Establishment of floodplain breakout path on true right abutment of Rees River Bridge; no new floodbanks. (refer to Figure 4.1(b) for an illustrative sketch)	• Lowering existing floodbanks creates a bypass for excess floodwaters and relieves pressure on flood conveyance capacity of existing bridge. • Existing Glenorchy-Paradise and Priory Road networks north of Rees River Bridge overtopped in floods with less than 1 in 20 AEP. NB: Refer Appendix B for discussion of flood modelling results and evidence base to support this statement.	• Significant NbS benefits as this option allows for removal of selected embankment sections and floodplain widening. • Over time, it may also allow for the revival of old channels and recovery of part of the original bed through channel avulsion.	• Allowing overtopping of road sections will mean road closures during flooding and may result in damage to road surfaces and shoulders. • Over time, as further riverbed aggradation occurs, there is a risk of permanent channel avulsion occurring which outflanks the right abutment of the existing bridge. • Long-term resilience of existing Rees River Bridge with rising riverbed levels and potential erosion and scour to right abutment is not addressed.	• Floodplain interventions are considered viable in achieving objectives outlined in Section 4.2.

Table 4.5: Summary of Option C assessment

Option	Flood Improvements	NbS Assessment	Risks	Overall Viability
C – Establishment of floodplain breakout path on true left abutment of Rees River Bridge; new floodbank to guide flows upstream of the bridge. (refer to Figure 4.1(c) for an illustrative sketch)	• Formation of floodway on left bank theoretically creates a bypass for excess floodwaters to relieve pressure on flood conveyance capacity of existing bridge. • Additional guide bank upstream of road intended to contain floodwaters conveyed by floodway and allow them to overtop road and outflank bridge. • Floodway formation is not very effective as existing ground contours work against this approach (more discussion under “overall viability” header). • Glenorchy-Paradise Road on left bank floodplain overtopped in floods larger than 1 in 20 AEP flood. NB: Refer Appendix B for discussion of flood modelling results and evidence base to support this statement.	• Theoretically this option would provide significant NbS benefits as it allows for floodplain widening, removal of obstructions to flow (dense willow vegetation) and potential revival of old channels.	• Floodway would need to be maintained with control of recolonising vegetation. • Construction of guide bank would potentially require acquisition of private land. • Allowing overtopping of sections of the roading network on the left and right bank floodplains may result in damage to road surfaces and shoulders. • Long-term resilience of existing Rees River Bridge with rising riverbed levels is not addressed.	• Floodway formation, while feasible, is not very effective as existing ground contours work against this approach. • Large floods in the Upper Rees River preferentially want to break out onto the right bank floodplain towards Diamond Stream. • Lesser volumes of excess floodwaters in large floods will therefore break out onto the left bank floodplain than on the right bank floodplain, even with reduced surface roughness. • This option is therefore not considered viable.

5 Option A & B – Concept Design

5.1 Introduction

The following sections outline the design considerations and assumptions to develop the concept level engineering solution for Options A and B. These options were outlined previously in Section 4.

5.2 Concept Design Overview

Option A involves the following concepts:

- Lower existing secondary floodbank between right abutment of bridge and junction of Glenorchy-Paradise Road and Priory Road
  ⇒ Lowering the existing floodbank creates a bypass for excess floodwaters and relieves pressure on the flood conveyance capacity of the existing Rees River Bridge.
- Raise Priory Road from junction with Glenorchy-Paradise Road over a distance of about 650 m to south-west.
  ⇒ The raised road will serve a dual purpose as both a road and floodbank.
- Raise Glenorchy-Paradise Road north of junction with Priory Road over a distance of about 930 m.
  ⇒ The raised road will serve a dual purpose as both a road and floodbank.

Option B only involves the first item listed above. Option B is considered a minimum intervention version of Option A, with no new floodbank / road raising works involved. Therefore, the following sections describe the work required for Option A (as this includes the works involved in Option B). A separate cost estimate is provided for both Options A and B in Section 5.8.

5.2.1 Floodbank Alignment

Under Option A, it is proposed that the Glenorchy-Paradise and Priory Roads are raised and serve the dual purpose of a road and floodbank.

Alternatives to this approach were considered, which involved raising the existing secondary floodbank (running parallel and just to the east of the Glenorchy-Paradise Road) or construction of a new floodbanks outside of the existing road footprints. However, initial geotechnical review (Section 5.3) identified that the terrain outside of the existing road corridor is intersected by drainage channels which are likely to include areas of soft and organic soils unsuitable for floodbank construction. Ground improvement works prior to floodbank formation would therefore likely be required, as well as additional sediment control and access measures during construction. Refer to Figure 5.1 for an example of the drainage channels near the Glenorchy-Paradise intersection with Priory Road.

Raising sections of the existing Glenorchy-Paradise Road and Priory Roads was therefore proposed as an alternative strategy to implementing Option A. The roading footprints would provide a better foundation on which to form the new floodbank, with the road running along the crest of the floodbank. The existing horizontal alignment of the Glenorchy-Paradise Road and Priory Roads would be retained with filling on both sides of the existing road centreline to raise the road and form the new floodbank.

Figure 5.1: Example of existing drainage channels (marked with blue lines) running parallel with Glenorchy-Paradise and Priory Roads. Existing secondary floodbank marked with dashed, yellow line.

5.2.2 Design Concept Plans

Appendix C provides the concept design plans, which show:

- URR2350/30/100: General arrangement plan
  - Aerial photograph showing proposed raised road / new floodbank footprint (magenta shading), and sections of existing floodbank to be removed (clouded in red).
- URR2350/30/105: Proposed raised road / new floodbank crest levels
  - Long section along the existing Glenorchy-Paradise Road and Priory Road (black lines) and proposed raised road / floodbank crest levels (blue line, corresponding to the road crest level).
- URR2350/30/120: Typical sections
  - Typical cross sections showing the proposed raised road / floodbank.

5.2.3 Design Parameters

The following design parameters were assumed to support the concept drawings.

- 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.
  - The 0.6 m freeboard allows for uncertainties in estimated flood water levels and accounts for wave runup, aggradation effects, and settlement due to new floodbank construction.
- Upstream and downstream floodbank batter at 1V:4H.
  - This slope provides resilience against overtopping erosion, provides a grade that can be mowed by conventional equipment and a safe slope for vehicles (refer Section 5.2.5 “Roading Implications”).
- Floodbank crest width of 9.5 m set by requirements to maintain existing traffic lanes (refer Section 5.2.4 “Roading Implications”).

- Stormwater culverts which penetrate through the existing road to be extended as required. This would maintain the existing stormwater management system in the vicinity of the Glenorchy-Paradise and Priory Roads.

5.2.4 Roading Implications

The concept design involve raising sections of the existing Glenorchy-Paradise and Priory Roads. The following roading considerations have been included in the concept design:

- Floodbank / road crest width set at 9.5 m wide, based on Austroads (2021) recommendations. This consists of a 3.5 m wide traffic lane in each direction and a 1 m wide shoulder on each side.
- Construction of a (nom.) 400 mm thick granular pavement layer within the traffic lanes and surfaced with chipseal.
- Floodbank / road batters set at 1V:4H, based on Austroads (2021) recommendations. This is to provide a safe slope for wayward vehicles and minimise the risk of rollover crashers.
- The concept design floodbank crest level rises above the existing road levels. This requires roads to be raised but also ramped to tie into the existing vertical alignment of the road network outside the works footprint. The grade of these ramps have been set at 5% (or 1V:20H), based on Austroads (2021) recommendations.

It should be noted that the concept design of the road presented does not consider full design requirements to ensure all road safety parameters are met. As such, further refinement of the road design would be necessary as part of any future detailed design stage.

5.2.5 Scope of Works

The concept design works (presented on the plans in Appendix C) 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 (as required within the works footprint).
- Removal of the existing floodbank between the right abutment of the Rees River Bridge and the Glenorchy-Paradise intersection with Priory Road (refer extents shown with red, clouds on Drawing URR2350/30/100). If excavated material is of suitable quality, it could be stockpiled for re-use in the raised road / floodbank. If not, it would be required to be either transported to a disposal area off-site or spread to a shallow depth over a suitable designated area.
- Extension of existing stormwater culverts which penetrate through the existing Glenorchy-Paradise and Priory Roads.
- Stripping of existing road surfaces and topsoil within the works footprint.
- Placement and compaction of suitable fill for floodbank construction (refer to Section 5.3.2 for discussion on fill material sources). Fill placed in 300 mm (loose) layers and compacted until the pavement subgrade level is reached.
- Cutting the batters slope to 1V:4H, allowing for a minimum 9.5 m wide crest.
- Construction of a (nom.) 400 mm thick pavement layer, placed in 200 mm (loose) layers and compacted until the final level is reached.

- Chipsealing the full extent of floodbank / raised road along Glenorchy-Paradise Road and Priory Road. Glenorchy-Paradise Road is currently chipsealed over a length of about 50 m north of the intersection with Priory Road. However, chipsealing of the full length of the raised Glenorchy-Paradise Road is conservatively proposed.
- Placement of a topsoil layer across the new batter slopes.
- Re-vegetation of exposed areas (assumed by grass-seeding the embankment faces).

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 Geotechnical Review

To assess site conditions, and potential constraints on road raising / floodbank construction, a review of available geotechnical data in the vicinity of the site was carried out. No site-specific geotechnical studies or reports were available. The geotechnical data reviewed was therefore restricted to available geological mapping, aerial photography, and assessment of site topography.

The geological information reviewed indicates that the floodbank is underlain by Holocene River Deposits (typically consisting of unconsolidated gravel, sand, silt, clay, and minor peat of modern to postglacial flood plains which may be terraced). Adjacent to the site are several minor swamps, with mapped swamp and peat deposits in the proximity of Diamond Lake. Surface vegetation and topography indicates that near surface fine grained soils (including possible organic soils) are present, particularly along the Glenorchy-Paradise Road, north of the intersection with Priory Road until the alignment turns to the northeast.

Review of the New Zealand Geotechnical Database provides no data in the vicinity (within c. 5 km) of the proposed, and existing, floodbank alignments. No groundwater investigation data is available in the vicinity of the proposed floodbank alignments, although drains either side of the Glenorchy-Paradise Road indicate that groundwater is approximately 1.5 m below the natural surface level , and is likely to vary significantly across the site and seasonally.

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 the Rees River Bridge
- Moonlight north fault zone, approximately 20 km east of the Rees River Bridge
- Alpine fault, approximately 45 km north-west of the Rees River Bridge
- Northwest Cardrona fault, approximately 50 km east of the Rees River Bridge

5.3.2 Design and Construction Risks

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

- Borrow material sources will need to be identified. Excavation of material from the Rees River bed is presently permitted up to 30,000 m^3 annually (under a resource consent held by QLDC), and is considered the most likely source of construction fill. The suitability of this material, and any potential requirement to import low permeability materials, will need to be investigated.

- The floodbank / raised road is founded on Holocene aged sediment of the Dart-Rees River System. Given the deposition environment and age these are likely to be susceptible to liquefaction. 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.
- As noted in Section 5.2.1, sections of the Glenorchy-Paradise Road exhibit surface characteristics that are consistent with swamp deposits, which are likely to include areas of soft and organic soils that will be susceptible to settlement. Settlement is likely to occur following construction of the floodbank / raised road. To ensure long-term 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 removal of the existing floodbank between the right abutment of the Rees River Bridge and the Glenorchy-Paradise intersection with Priory Road will generate excess fill. This fill will need to be tested for suitability for re-use in the raised road / floodbank construction. If it is not suitable for re-use it will need to be disposed of off-site or spread to a shallow depth in a suitable area. These issues 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 5.2.3, the concept design was developed for a 1 in 100 AEP flood (future climate) and included an allowance of +0.6 m freeboard to set the crest levels of the floodbanks / raised Glenorchy-Paradise and Priory Roads. The concept design was also checked against vulnerability to the more extreme floods and active riverbed channel aggradation scenarios listed below:

- 1 in 100 and 1 in 500 AEP flood (current climate conditions) with Rees and Dart active river bed aggradation of +0.4 m (i.e. at approx. 2040)

The results from this assessment are provided in Appendix B.1, and indicate that:

- For Option A, the raised road portions of the Glenorchy-Paradise and Priory Roads are not expected to overtop in the scenarios listed above. However, the +0.6 m freeboard is reduced to about 0.3 m in the 1 in 500 AEP event.
- In Option B, the right bank floodplain is allowed to function naturally without any floodbanks (other than the existing secondary bank north of the Glenorchy-Paradise Road and Priory Road junction). In this respect, the original design intent of the Rees River Bridge crossing when the current bridge was first constructed in c.1950 is being restored. As this option does not significantly constrain flood breakout flows flowing over the right bank floodplain, it offers some degree of resilience.
- If riverbed aggradation continues to follow current trends, then neither option provides long-term resilience for the Rees River Bridge. Other options would need to be considered to address this as a further step in the floodplain management adaptation strategies (bridge modification or replacement options were outside the scope of the current study).
- For Options A and B, removal of the existing floodbank between the right abutment of the Rees River Bridge and the Glenorchy-Paradise intersection with Priory Road may result in more frequent flood inundation of the Glenorchy-Paradise Road. While could be viewed as reducing the resilience of the

road network at this location (i.e. the stretch of road on the right abutment of the Rees River Bridge), the wider road network in the vicinity of the bridge is subject to flood inundation in multiple locations during signficant flood events. Options A and B attempt to balance the resilience of the Rees River Bridge with the resilience of the wider road network in the vicinity of the bridge. This issue is discussed further in Section 5.5. below.

- The removal of the existing floodbank between the right abutment of the Rees River Bridge and the Glenorchy-Paradise intersection with Priory Road may increase erosion hazards to the right abutment of the bridge. Additional rock rip-rap scour protection may be required to mitigate against these risks. This will need to be investigated further if the concept design is taken forward to detailed design stages.

5.5 Impact on Bridge Approach Roads

Removal of the existing floodbank between the right abutment of the Rees River Bridge and the Glenorchy-Paradise intersection with Priory Road would result in increased flood flows and overtopping depths of the roadway approaching the Rees River Bridge. Table 5.1 summarises an assessment of the impact of floods ranging from a 1 in 2.33 AEP (i.e. the mean annual flood) to the 1 in 20 AEP flood in terms of the maximum flood depth at the true right approach road to the Rees River Bridge, the duration of flood overtopping and the estimated percentage damage to roadway. This assessment is based on hydrographs for these floods scaled from the hydrograph for the double-peaked February 2020 flood event (see Figure A.3).

Table 5.1 indicates that Options A and B increase the depth and duration of flood overtopping of the true right approach roadway to the Rees River Bridge, relative to the existing case. This is due to Options A and B reducing the flood discharge through the bridge waterway but at the expense of increasing the flood discharge across the true right floodplain.

Table 5.1 also provides indicative estimates, using the FHWA (1987) empirical damage assessment method, of the amount of damage to the roadway at the location of maximum overtopping depth[11]. For the existing scenario the amount of potential damage to the roadway is relatively low (i.e. in the order of 5% or less of roadway damage for the 1 in 20 AEP flood). However, Options A and B increase the amount of potential damage to a point where repairs of the roadway could be expected post-flood (i.e. in the order of 20 to 30% roadway damage for the 1 in 20 AEP flood).

These findings indicate that if Options A or B are implemented, additional measures to mitigate against the risk of damage to the true right approach roadway to the Rees River Bridge could be considered. Such measures could include provision of scour protection where the roadway is raised above adjacent ground levels. This matter will need to be investigated further if the concept design is taken forward to detailed design stages.

The maximum flood overtopping depth and duration to the true left approach road to the Rees River Bridge was generally unchanged or slightly reduced for Options A and B, relative to the existing case.

[11] The FHWA (1987) damage assessment method expresses damage to the roadway as a percentage loss of roadway embankment cross-section (where 0% is no damage and 100% is complete wash-out).

Table 5.1: Flood overtopping depths, durations and indicative damage estimates to true right Rees River Bridge roadway

Flood Frequency (AEP)	Maximum Overtopping Depth above Road Level (m) [See Note 1]		Duration of Overtopping (hr) [See Note 2]		Percent Loss of Roadway at Location of Max. Overtopping (%) [See Note 3]	
1 in 2.33	Existing	0.20	Existing	1.3	Existing	0.1
	Option A	0.45	Option A	10.5	Option A	2
	Option B	0.35	Option B	10.5	Option B	1
1 in 5	Existing	0.25	Existing	5.5	Existing	1.5
	Option A	0.50	Option A	16.5	Option A	11
	Option B	0.40	Option B	16.5	Option B	8
1 in 10	Existing	0.30	Existing	9.5	Existing	10
	Option A	0.55	Option A	23.8	Option A	25
	Option B	0.45	Option B	23.8	Option B	20
1 in 20	Existing	0.35	Existing	12.0	Existing	5
	Option A	0.60	Option A	26.8	Option A	35
	Option B	0.50	Option B	26.8	Option B	25

Notes:
1. Maximum flood overtopping depth derived from HEC-RAS model simulations along Glenorchy-Paradise Road between intersection with Priory Road and the Rees River Bridge. Note that flood overtopping depth along road is variable, and maximum flood depths listed will not apply everywhere the road is overtopped.
2. Approximate time period during which road is overtopped by depth exceeding 0.15 meters.
3. Percent loss of roadway is an indicative estimate of the amount of roadway cross-section damaged at the location of maximum overtopping depth. Obtained using FHWA (1987) empirical method for estimating roadway embankment damage due to flood overtopping for depths ranging from 0.15 to 1.2 m.

5.6 Potential Environmental Impacts

As part of any proposed 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.
- As part of site establishment, it will be necessary to remove vegetation within the works area. This will require erosion and sediment control measures. Replacement planting may be necessary to offset any vegetation removed.
- Compression of soils, with the resulting impact on permeability, may lead to localised changes in the groundwater regime, which may impact existing surface water bodies.

If a raise of the road alignment is progressed to form the floodbank, it is recommended that investigations are carried out to assess the ground conditions, potential environmental impacts and develop conditions for a resource consent. As a minimum, investigations should:

- Investigate ground conditions along the proposed floodbank / raised road alignment, with particular focus on subgrade conditions and foundation compressibility.
- Assess and classify borrow materials within the Rees River for use in floodbank and pavement 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.
- Assess the suitability of fill, sourced from removal of the existing secondary floodbank, for suitability in road raising / floodbank construction.

5.7 Consenting Requirements

A preliminary analysis of the relevant statutory planning documents and provisions 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, or are likely to, be required from QLDC and ORC as summarised below.

Queenstown Lakes District Council

The concept design will require a Discretionary activity under the Queenstown Lakes Proposed District Plan (PDP). The various consents that will, or are likely to, be required under the PDP are:

- A discretionary consent under Rule 30.5.1.16 (Flood Protection Works) to raise Priory Road and Glenorchy-Paradise Road.
- A restricted discretionary consent under Rule 25.4.2 for a breach of earthworks volume standards 25.5.6 and 25.5.10A.2).
- A restricted discretionary consent under Standard 25.5.11 for the area of earthworks associated with raising Priory Road and Glenorchy-Paradise Road and removing the existing floodbanks.
- A restricted discretionary consent under Standard 25.5.16 as Priory Road is likely to need to be raised by more than 2 m where it intersects with Glenorchy-Paradise Road
- A restricted discretionary consent under Standard 25.5.18 to undertake unretained earthworks greater than 0.5 metres in height in closer proximity to the boundaries of Glenorchy -Paradise Road.
- A restricted discretionary consent under Standard 25.5.19.1 to undertake earthworks within 10 m of the bed of a waterbody.
- A restricted discretionary consent under Standard 25.5.21 to transport more than 300 m³ of cleanfill to the site via road.
- A discretionary consent under Rule 29.4.13 - Activities that are not listed in the transport activities/ rules Table.

Otago Regional Council

The concept design will require a Discretionary activity under the Otago Regional Plan: Water 2004 (RPW).

The various consents that are likely to be required under the RWP are:

- A restricted discretionary consent under 12.3.4.1 to divert floodwaters (through the raising of Priory Road and Glenorchy-Paradise Road).
- A discretionary consent under Rule 14.3.2.1 to raise Priory Road and Glenorchy-Paradise Road; both of which are located outside the bed of the river on the basis that those works fall within the definition of a Defence Against Water.

Consultation and affected persons

As the concept design is located within a Wāhi tūpuna area and is located on various parcels of land and affects various owners, consultation will be an integral part of the consenting process and, ideally, affected persons approvals will be obtained through that 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.

5.8 Indicative Costings

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

Indicative costs are provided in Table 5.3 for Option A and Table 5.3 for Option B. 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 exclude 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

5.9 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:

- Final hydraulic modelling investigations to confirm new floodbank / raised road alignment and crest levels.
- Geotechnical investigations to assess the foundation conditions for the new floodbank / raised roads, along with laboratory soil testing as required.
- Geotechnical investigations to confirm the location of suitable borrow sources for new floodbank / raised roads construction, along with laboratory soil testing as required.
- Geotechnical and/or hydraulic investigations to determine if existing Rees Road Bridge right abutment requires additional erosion and scour protection (e.g. rock-rip rap).
- Confirm resource consent requirements from QLDC and ORC.

- Confirm land acquisition (if required) from property owners to build a raised floodbank.

It should be noted that roading design requirements have not been considered as part of this concept level design. It is expected that the road alignment and geometry will be further developed as part of detailed design and incorporated into any final design requirements.

Table 5.2: Option A – preliminary construction cost estimate

Item	Notes / Inclusions	Cost Estimate
A. Construction Works	• Includes all works items described in Section 5.2.5 • Total earthworks quantities (approx.): - Remove existing secondary floodbank: 5,500 m^3 - Raise Glenorchy-Paradise Road: 44,000 m^3 - Raise Priory Road: 14,200 m^3	$4,300,000
B. Contractor Costs	• Preliminary & General items @ 20% of construction costs	$860,000
C. Client Costs	• Detailed engineering design @ 15% of [A] + [B] • Consenting (refer Appendix D, assuming $72,000 for publicly notified consent) • Construction contract management and monitoring @ 4% of [A] + [B]	$890,000
D. Contingency	• Contingency Range 0% • Contingency Range +40%	+$0 +$2,420,000
INDICATIVE COST RANGE	Sum of [A] to [C] above with [D] @0% contingency Sum of [A] to [C] above with [D] @+40% contingency	$6,050,000 to $8,470,000

Table 5.3: Option B – preliminary construction cost estimate

Item	Notes / Inclusions	Cost Estimate
A. Construction Works	• Only works associated with removal of existing secondary floodbank between Glenorchy-Paradise Road intersection with Priory Road and Rees Road Bridge (shown as red, clouded area on Drawing RUU235-/30/100 in Appendix C). • Total earthworks quantities (approx.): - Remove existing secondary floodbank: 5,500 m^3	$300,000
B. Contractor Costs	• Preliminary & General items @ 20% of construction costs	$60,000
C. Client Costs	• Detailed engineering design @ 10% of [A] + [B] • Consenting (refer Appendix D, assuming $63,000 for limited non-notified consent) • Construction contract management and monitoring @ 4% of [A] + [B]	$110,000
D. Contingency	• Contingency Range 0% • Contingency Range +40%	+$0 +$188,000
INDICATIVE COST RANGE	Sum of [A] to [C] above with [D] @0% contingency Sum of [A] to [C] above with [D] @+40% contingency	$470,000 to $658,000

6 Conclusions

Upper Rees Flood Hazards

The Rees River, including the reach upstream of the Rees River Bridge, is subject to ongoing riverbed aggradation. In the 3 km long reach upstream of the bridge, there has been an average increase in riverbed levels of about 0.3 m over the last 10 years (Damwatch, 2022). In places, the aggrading riverbed levels are approaching the crest of floodbanks upstream of the Rees River Bridge.

This aggradation trend has the following implications for existing flood hazards:

- Increased potential for breakout flooding and channel avulsion along the left and right bank of the river, upstream of the Rees River Bridge
- Reduced bridge waterway flood capacity
- Increased potential for scour and erosion damage at the bridge piers and abutments
- Increased potential for structural damage to the bridge from debris rafting and flood overtopping

Future climate change effects are expected to lead to an increase in both the flood hazards (due to an increase in the frequency and intensity of extreme rainfall) and riverbed aggradation (due to increased sediment supply).

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 (refer Damwatch (2022)). The workshop 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 to undertake the current study which involved a high-level assessment of potential floodplain intervention options for the Upper Rees River. The objectives of the assessment were to provide an evidence base to rule out various floodplain intervention 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). Selected options were then taken forward to a concept level design stage.

The floodbank and groynes on the right bank of the Rees River are privately owned. ORC also undertakes some river management activities (planted willow maintenance) in this area. In relation to this, ORC may inspect and carry out some maintenance activities on structures that are not owned by ORC. This has been determinate on community request and response to weather/flooding events.

Investigation of Potential Flood Improvement Options

Based on an understanding of the current rate of active river channel bed aggradation and flood flow paths and extents, the Upper Rees River flood hazards are very challenging to defend against with conventional engineered solutions (e.g. floodbanks). The long-term sustainability of such structures cannot be assured due to outflanking and overtopping during floods in combination with ongoing channel bed aggradation and lateral river channel migration. This is compounded by the hydraulic constriction caused by the existing Rees River Bridge. Under flood conditions, there is insufficient conveyance capacity through the bridge waterway and the river naturally want to break-out on the true left and right bank floodplains (but primarily on the right bank floodplain).

The floodplain intervention options considered in the current assessment were therefore focused on meeting the following objectives:

III. Providing managed floodways on the left and/or right bank approaches to the bridge. The intention of the floodways is to guide floodplain flows in defined areas past the bridge, and to reduce flood discharge through the Rees River Bridge waterway.
IV. Alignment with NbS strategies that provide "room for the river" through floodplain widening and embankment removal or retreat, rather than construction of new floodbanks or structural (engineering) solutions to mitigate flood hazards.

It should be noted that these objectives are not aimed at reducing the risk of flooding from the Upper Rees River to farmland and road networks. Options to raise and/or lengthen the existing Rees River Bridge were also not considered as they were outside the scope of the current study. However, these bridge options could be considered in the future by ORC and QLDC and as a further step in the floodplain management adaptation strategies.

The following Options A to C were developed from possible floodplain intervention strategies outlined in the February 2022 workshop (refer Damwatch (2022)). These options met objectives I and II listed above, and were investigated with the aid of a two-dimensional computational hydraulic model of the Upper Rees River. The hydraulic model was used to simulate various flood scenarios in combination with the potential floodplain intervention options. An illustration of each of these options is provided in Figure 4.1.

- Option A: Establishment of floodplain breakout path on true right abutment of Rees River Bridge; new floodbank to guide flood flows on true right floodplain, along Priory and Glenorchy-Paradise Roads.
- Option B: Establishment of floodplain breakout path on true right abutment of Rees River Bridge; no new floodbanks.
- Option C: Establishment of floodplain breakout path on true left abutment of Rees River Bridge; new floodbank to guide flows on true left floodplain.

Option B represents a restoration of the original design concept for the Rees River Crossing as indicated by the extract from an original bridge design drawing in Figure 2.4.

Options to raise the existing, approximately 4 km long, floodbank on the right bank floodplain upstream of the bridge were not considered. There is a natural tendency for flood flows to break-out on the right bank floodplain, due to existing river and floodplain levels, and raising floodbanks on this relatively long reach would be counter to NbS strategies. The long-term sustainability of raising the existing floodbank could not be assured under future flood conditions (i.e. primarily due to outflanking during floods and vulnerability to ongoing bed aggradation, lateral river channel migration and scour and erosion processes).

Options A, B and C are intended to relieve the pressure on the Rees River Bridge under flood conditions by allowing excess floodwaters to bypass the bridge waterway. They are not designed to remove the existing flood hazard to farmland and roads.

Findings from Investigation of Potential Flood Improvement Options

Option C was found not to be viable for the following reason:

- Assessment of Option C found that the floodplain ground elevations in the vicinity of the Rees River Bridge mean that large floods in the Upper Rees River preferentially want to break out onto the right bank floodplain towards Diamond Stream. Lesser volumes of excess floodwaters in large floods were found to break out onto the left bank floodplain compared to the right bank floodplain, even with removal of existing vegetated areas.

Options A and B were both determined to be viable at meeting objectives I and II listed above. The following concept level design information was developed for these options:

- 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

However, both Options A and B increase the frequency of flooding to the section of Glenorchy-Paradise Road between the Priory Road intersection and the approach to the Rees River Bridge and the potential for erosion damage of the road. This is due to Options A and B reducing the flood discharge through the bridge waterway but at the expense of increasing the flood discharge across the true right floodplain.

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

7 References

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Appendix A Hydraulic Model of Upper Rees River

A.1 Description of HEC-RAS Model

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

Figure A.1 shows the extent of the model superimposed on the extents of the LiDAR topographic survey data used to develop the DEM defining ground elevations within the model domain. The model extended from about 10.5 km upstream of the Rees River Bridge (Glenorchy- Paradise Road) to about 2.1 km downstream of the bridge. The DEM for the model was defined in terms of the DVD1958 level datum.

The Rees River Bridge was defined as a bridge structure in the HEC-RAS model (refer to Figure A.2). For consistency with the DEM for the model, the bridge superstructure levels were also defined in terms of the DVD1958 level datum based on levels sourced from (WSP, 2023)[12].

The upstream boundary condition for the HEC-RAS model was defined as an inflow hydrograph. Figure A.3 shows range of inflow hydrographs estimated at the bridge which were used for the different model simulations:

- February 2020 flood
- 1:20 AEP flood
- 1:50 AEP flood
- 1:100 AEP flood
- 1:100 AEP + CC flood
- 1:500 AEP flood

The location of the downstream boundary was located close to the southern end of the base of Mt Alfred where the Dart and Rees Valleys converge together (refer to Figure A.1). The boundary ran across the width of the active riverbed and left and right bank floodplains. The boundary condition applied on this boundary was a normal depth one (i.e. uniform flow depth) based on the outflow from each grid cell and the local bed slope. For a hydraulically steep gravel-bed river, this type of boundary condition is considered suitable. The downstream boundary was located well downstream of the Rees River Bridge so that the applied condition would have no influence on model-predicted flood levels at the bridge.

Table A.1 summarises the Manning's n surface roughness coefficient values applied in the HEC-RAS model to different types of surfaces to represent the effects of surface friction on river and floodplain flows. These n values are the same values as used for the combined model of the Lower Rees and Dart Rivers except that the n value for the gravel riverbed surface has been set at 0.027. This reflects the value given 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).

[12] Note that levels in the WSP (2023) report were in terms of New Zealand Vertical Datum 2016. These levels were converted to Dunedin Vertical Datum 1958 using the Land Information New Zealand online conversion tool (https://www.geodesy.linz.govt.nz/concord/).

Table A.1: Summary of hydraulic model parameters

Parameters	Description
Model type	HEC-RAS 2D (version 6.3)
Model extent	Upper Rees River from about 10.5 km upstream of the Glenorchy-Paradise Road crossing to about 2.1 km downstream (refer Figure A.1).
Topographic data	Digital Elevation Model (DEM) used for ground elevations in model derived from: ● Otago Regional Council 2022 LiDAR aerial survey ● Otago Regional Council 2019 LiDAR aerial survey● Data provided as 1m gridded bare earth digital elevation model (DEM) in terms of DVD1958 vertical datum. Refer Figure A.1 for the extent of the topographic data sets used.
Model mesh	An unstructured mesh with an average 5 x 5 m cell dimension for the active river channels and an average 10 x 10 m cell dimension for floodplain areas.
Model scenarios	Refer to Table 4.2 in main report.
Model validation	No historical flood data available to quantitatively validate the model. However, the model performance was checked by simulation of the February 2020 flood event. Refer to section below "HEC-RAS Model Check" for further detail.
Boundary conditions	● Upstream: Refer to Table 2.1 in main report for Rees River peak discharge estimates at Invincible Creek and at bridge. Refer to Figure A.2 for flood hydrographs, scaled from 1 in 100 AEP design flow hydrographs provided in ORC (2021). ● Downstream: normal (uniform) flow depth based on average riverbed slope.
Roughness coefficients	● Manning's "n" surface roughness coefficients listed in Table A.1 and generally based on values adopted by LRS (2022) for flood hazard modelling. ● Manning's "n" surface roughness coefficient value of 0.027 adopted for riverbed reflecting results of Strickler equation for median grain size of sediment material of 50-100 mm.
Hydraulic structures	● Glenorchy-Paradise Road crossing inserted as bridge structure in model with soffit and deck levels of 353.13 m RL and 335.97 m RL respectively (DVD1958). ● Existing floodbanks and road embankments incorporated in model as a "dike" feature which allowed these elements to be modeled as a broad-crested weir with LiDAR survey spot 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 selected 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 hydraulic modelling investigations for the Lower Rees River. ● *Computational Time Step*: An adaptive time step between 0.25 and 4 seconds provided numerical stability and suitable model simulation times.
Model Outputs	● Two-dimensional grids of flood extent, flow depths, water levels and flow velocities.

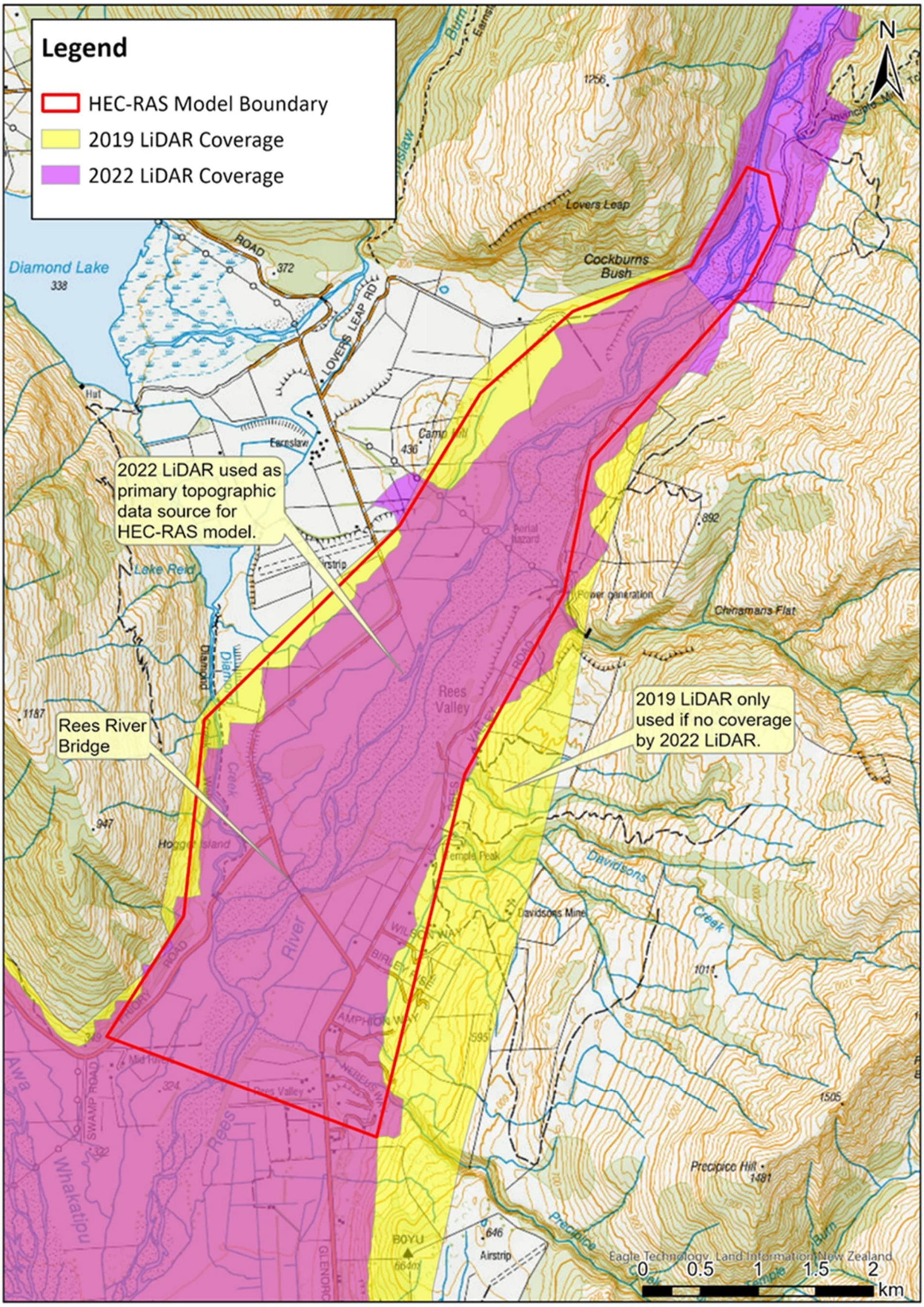


Figure A.1: Extent of HEC-RAS model domain, showing coverage of 2019 and 2022 LiDAR topographic surveys

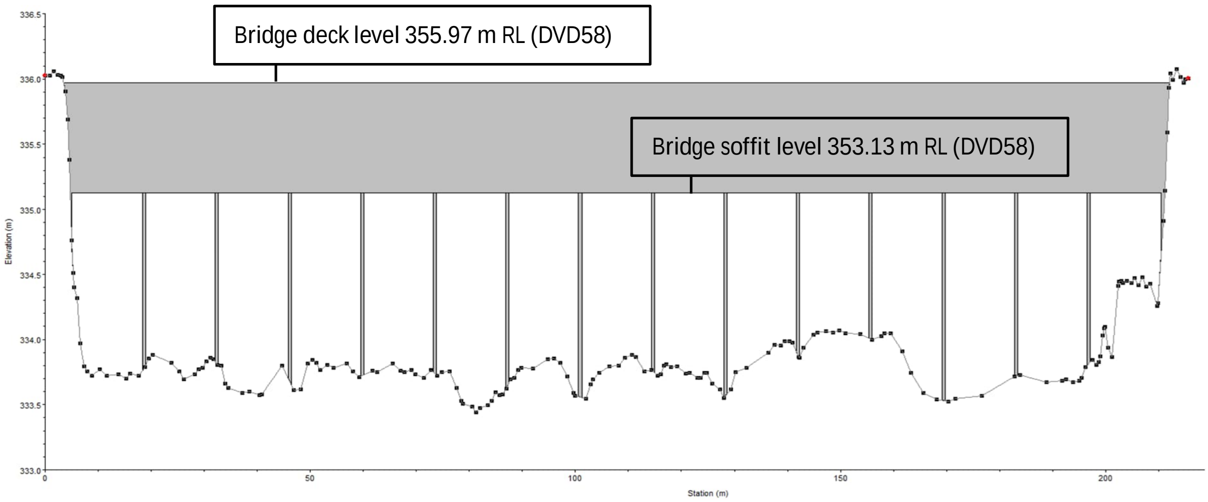


Figure A.2: Representation of Rees River Bridge on Glenorchy-Paradise Road in HEC-RAS model

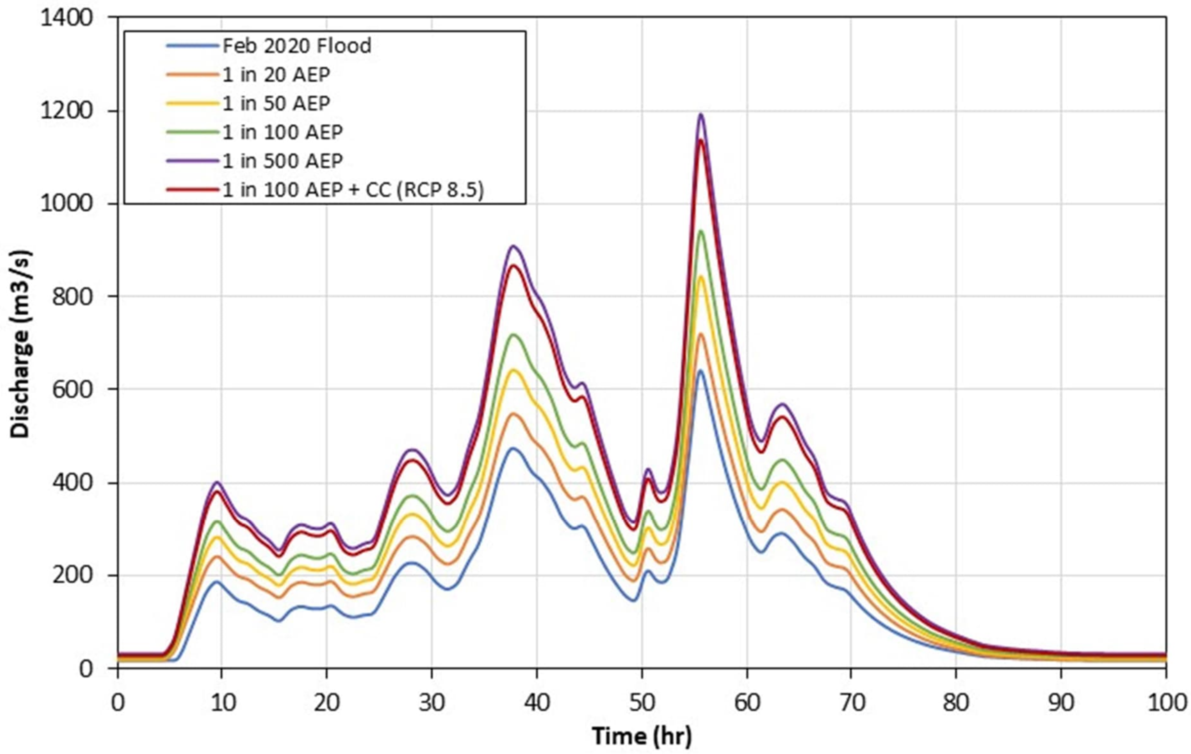


Figure A.3: February 2020, 1 in 20 AEP, 1 in 50 AEP, 1 in 100 AEP, 1 in 100 AEP + CC and 1 in 500 AEP flood hydrographs for Upper Rees River at Glenorchy-Paradise Rd Crossing

Table A.1 - Manning's "n" roughness coefficients adopted din 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 Riverbed	0.019 (LRS, 2022), 0.027 (this investigation)
Buildings	1.000

A.2 HEC-RAS Model Check

Two-dimensional computational hydraulic models are typically validated by comparing maximum predicted flood extents with observed maximum flood extents for recent or historic large flood events. The model validation may also be complemented by anecdotal observations of peak flood levels or extents where available.

For the Upper Rees River, there was no available photographic evidence of maximum flood extents from the recent February 2020 flood event which was used to validate the HEC-RAS model of the Lower Rees and Dart Rivers.

In lieu of such evidence, the Upper Rees HEC-RAS model predictions of flood extents for the 1 in 100 AEP flood were compared with the pattern of sediment depostion arising from the January 1994 flood from a post-flood aerial photograph in Figure A.4. The January 1994 flood occurred before the Dart River at Hillocks flow gauging site was established (June 1996) and long before the Rees River at Invincible Creek was first established (October 2009). Therefore it is not possible to say what the magnitude of the January 1994 flood peak was relative to the estimate of a 1 in 100 AEP flood at the ReesRiver Bridge (941 m^3/s, refer Table 2.1)[13]. However, the pattern of sediment deposition resulting from the January 1994 flood event shown in Figure A.4(a) broadly seems to reflect the maximum flood extent for a 1 in 100 AEP flood in Figure A.4(b) and lesser floods in Figures 2.10(a) and (b).

Figure A.5 provides a photograph taken during a September 2023 high-flow event which provides evidence of floodplain flows at the location marked with a red arrow on Figure 2.4(b).

[13] It would be possible to make some estimate of the magnitude of the January 1994 flood by deriving an historic total inflow record for Lake Wakatipu from lake level and outflow records, establishing a correlation between historic Dart River flood peaks and to total lake catchment inflow peaks and then using the approximate relationship between Dart River and Rees River flood peaks for Dart River flows greater than 850 m^3/s given in (ORC, 2021). However, this would require extensive analysis of available hydrological records.

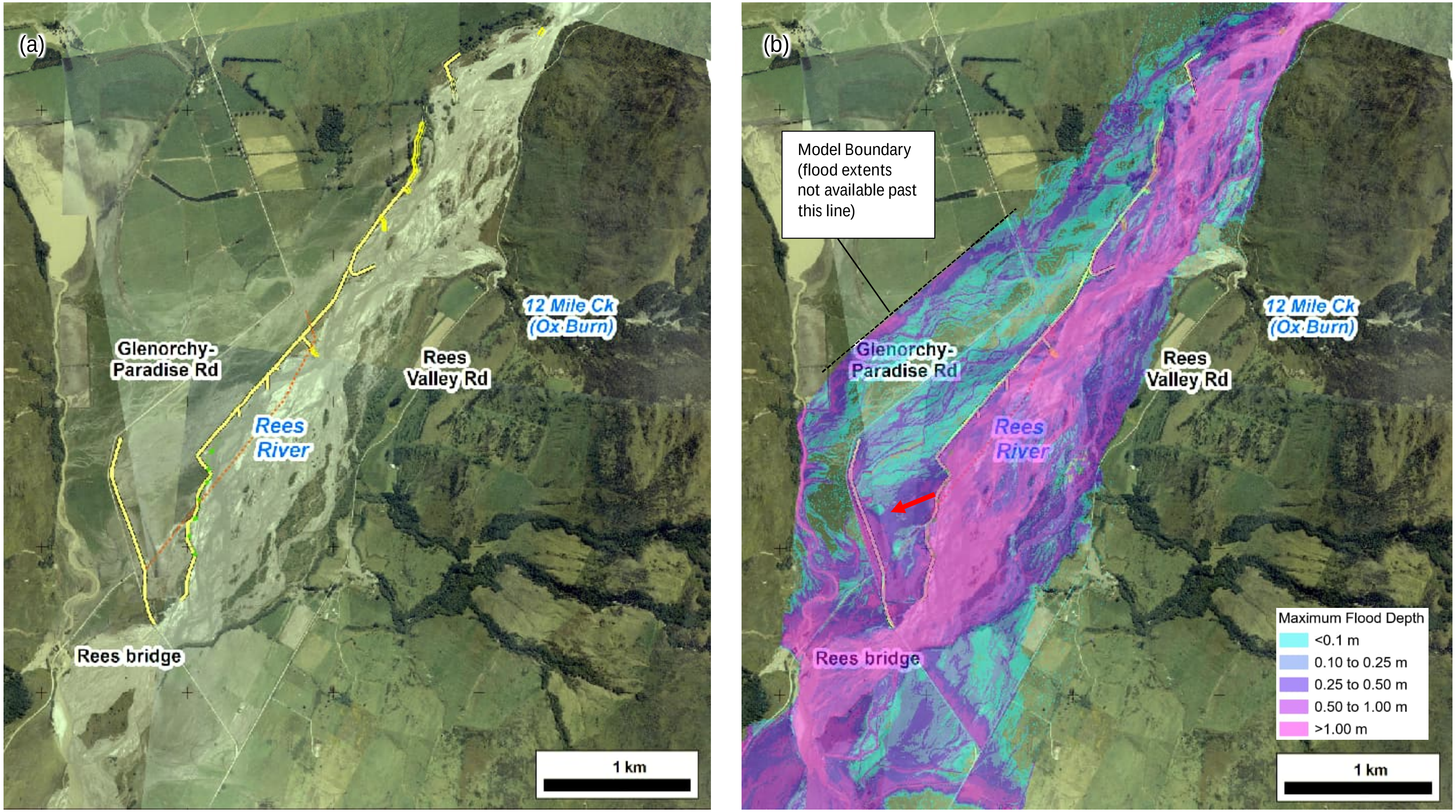


Figure A.4: Comparison of (a) sediment deposition pattern remaining after January 1994 flood event with (b) HEC-RAS model predicted flood extents for 1 in 100 AEP flood

Source: Image provided by ORC

Figure A.5: Photograph of floodplain flows on true right bank of Rees River during September 2023 high-flow event.

A.4 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[14]:

- the Diffusion Wave equation set (DWE)
- the original Shallow Water equation set using an Eulerian-Lagrangian solution method (SWE-ELM)
- a newer Shallow Water equation set solution 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

[14] Refer HEC-RAS User Manual, available: https://www.hec.usace.army.mil/confluence/rasdocs/r2dum/6.2/running-a-model-with-2d-flow-areas/shallow-water-or-diffusion-wave-equations

- 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 DWE 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 Upper Rees River, 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 maximum flood extents and depths at the flood peak for the two solutions are compared in Figures A.5(a) and (b). A long-section of the peak water level profile across the Rees River Bridge is shown on Figure A.6.

Figure A.5 indicates that use of the DWE provides near identical maximum flood inundation extents and depths to the full SWE set. Figure A.6 indicates the water levels predicted across the Rees River Bridge by the two equation sets are very similar. However, the DWE equation set produces a smoother water level profile due to the omission of higher order terms (such as the local and convective acceleration).

Figures A.5 and A.6 indicate that there are not signficant difference between the two solutions that would warrant use of the SWE set. Accordingly, the DWE equation set was used for all other model simulation scenarios.

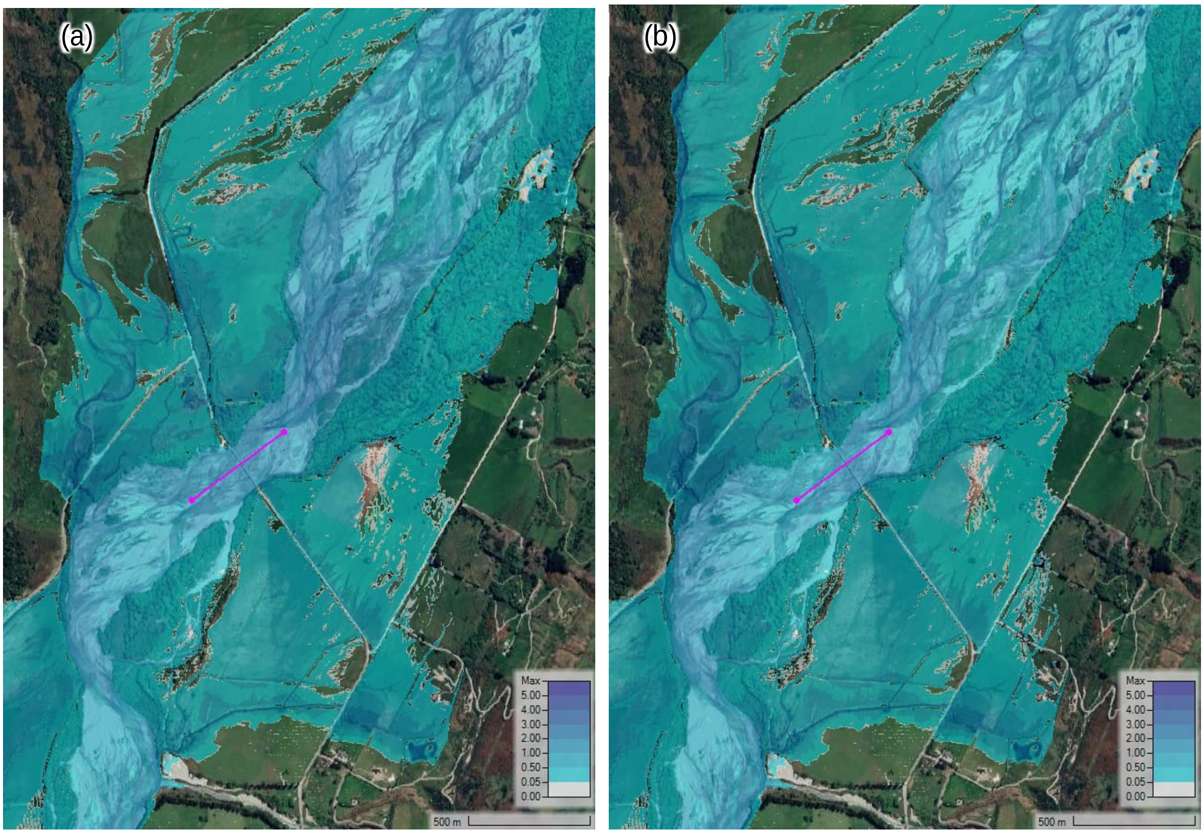


Figure A.5: Comparison of predicted flood extents and depths at peak of 1 in 100 AEP (historic climate) flood for existing river and floodplain geometry with (a) DWE solution and (b) full SWE solution

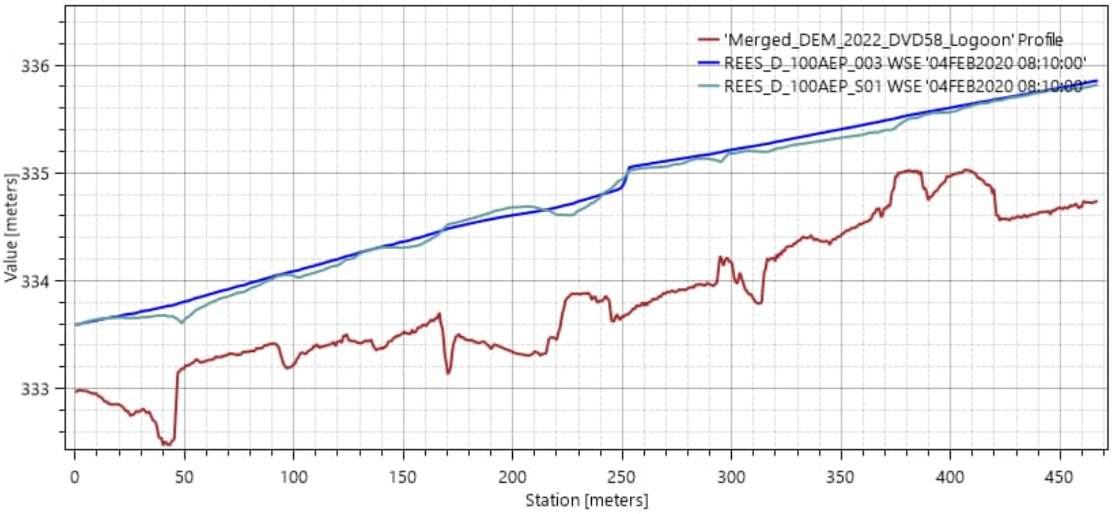


Figure A.6: Water level profile across Rees River bridge at peak of 1 in 100 AEP (historic climate) flood for DWE solution (blue line) and full SWE solution (light blue line). Riverbed elevation shown with brown line. Refer to pink line on Figure A.5 for profile take-off location.

Appendix B Options Assessment Findings

B.1 Option A – Development of Right Bank Secondary Flow Path with Floodbanks

Option Summary

The objective of this option was to form a secondary flow path over the right bank floodplain between the true right bridge abutment and the intersection of Glenorchy-Paradise and Priory Roads. Due to ground elevations, this is an area where flood breakout flows from the main river naturally want to flow. New floodbanks would be formed by raising sections of the existing of Glenorchy-Paradise and Priory Roads. These floodbanks would guide flood flows back into the main river channel downstream of the Rees River Bridge.

This option would involve the following floodplain modifications (and illustrated on Figure 4.1(b) in Section 4.3 of the main report):

- Lowering the existing secondary floodbank running parallel with Glenorchy-Paradise Road between the right abutment of the Rees River Bridge and the junction with Priory Road.
- Raising Glenorchy-Paradise Road north of the junction with Priory Road over about 930 m.
- Raising Glenorchy-Paradise Road south of the junction with Priory Road over about 100 m to tie the raised roadway to the north into the existing vertical alignment of the roadway to the south.
- Raising Priory Road from the junction with Glenorchy-Paradise Road over about 650 m to the south-west with the end to tie into the existing vertical alignment of the roadway immediately to the north of the Diamond Stream crossing.

Model Simulation Results – Comparison of Existing Situation and Option A

Table 4.2 (Section 4.4 of the main report) lists the range of flood and riverbed geometry scenarios simulated with Option A.

Figures B.1 to B.3 provide a side-by-side comparison of the respective 1 in 20, 1 in 50 and 1 in 100 AEP predicted maximum flood extents for the existing river and floodplain geometry and proposed Option A floodplain modifications. These figures show that the implementation of Option A reduces flooding around land to the north-west of the Priory Road intersection with the Glenorchy-Paradise Road, due to the raising of these roads above flood inundation levels. However, portions of these roads are still flooded in areas around Diamond Stream and north of the Rees River bridge abutment to the Priory Road intersection. Flooding on the left bank floodplain is also reduced under the proposed Option A due to the additional conveyance provided by the right bank floodway.

Table B.1 provides the peak discharges through the Rees River Bridge waterway and left and right bank overflow paths for the 1 in 20, 1 in 50 and 1 in 100 AEP floods for the existing river and floodplain geometry and proposed Option A floodplain modifications (Figure B.4 indicates the cross-section locations from where these discharges were obtained). This table indicates that Option A results in a modest increase in flows across the right bank floodplain and decreases in flow through the Rees River Bridge waterway and left bank floodplain.

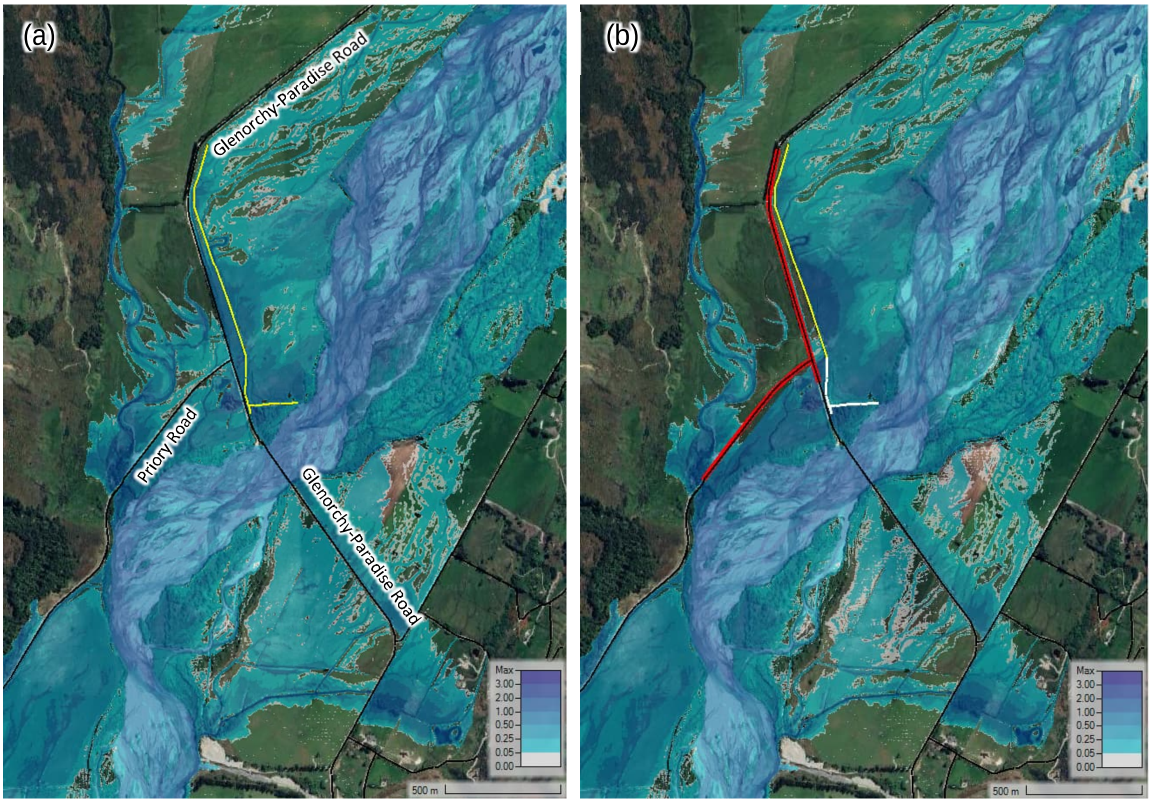


Figure B.1: Comparison of predicted maximum flood extents for 1 in 20 AEP flood (historic climate) for (a) existing river and floodplain geometry and (b) Option A floodplain modifications

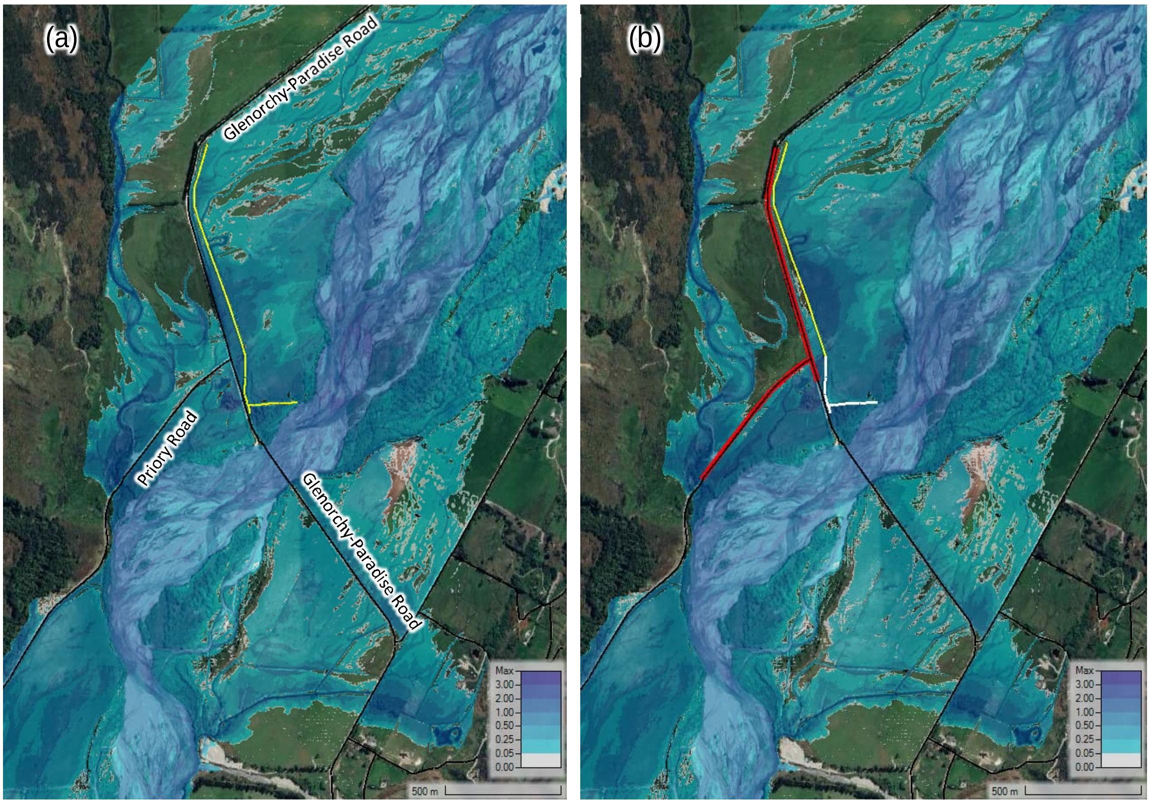


Figure B.2: Comparison of predicted maximum flood extents for 1 in 50 AEP flood (historic climate) for (a) existing river and floodplain geometry and (b) Option A floodplain modifications

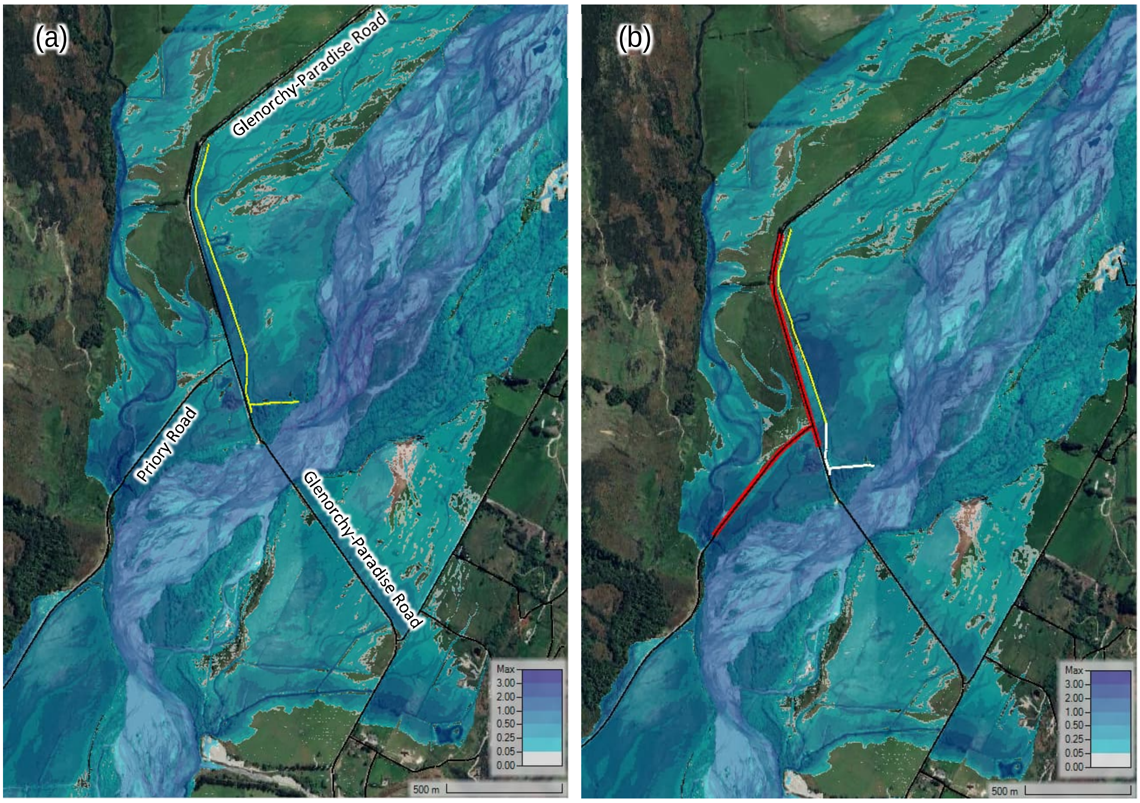


Figure B.3: Comparison of predicted maximum flood extents for 1 in 100 AEP flood (historic climate) for (a) existing river and floodplain geometry and (b) Option A floodplain modifications

Table B.1: Comparison of peak flood discharge through Rees River Bridge waterway and left and right bank floodplains (refer Figure B.4) for existing river and floodplain geometry (existing) and Option A floodplain modifications (Option A).

Flood Frequency (historic climate)	Peak Discharge (m^3/s) Right Bank Floodplain			Peak Discharge (m^3/s) Rees River Bridge Waterway			Peak Discharge (m^3/s) Left Bank Floodplain		
	Existing	Option A	Change in Peak Discharge*	Existing	Option A	Change in Peak Discharge*	Existing	Option A	Change in Peak Discharge*
1 in 20	124	179	+55	547	474	-73	34	14	-24
1 in 50	158	202	+44	595	525	-70	57	32	-29
1 in 100	184	223	+39	627	566	-61	75	46	-33
Notes:									
** Change in peak flow between "Option A" and "Existing"*									

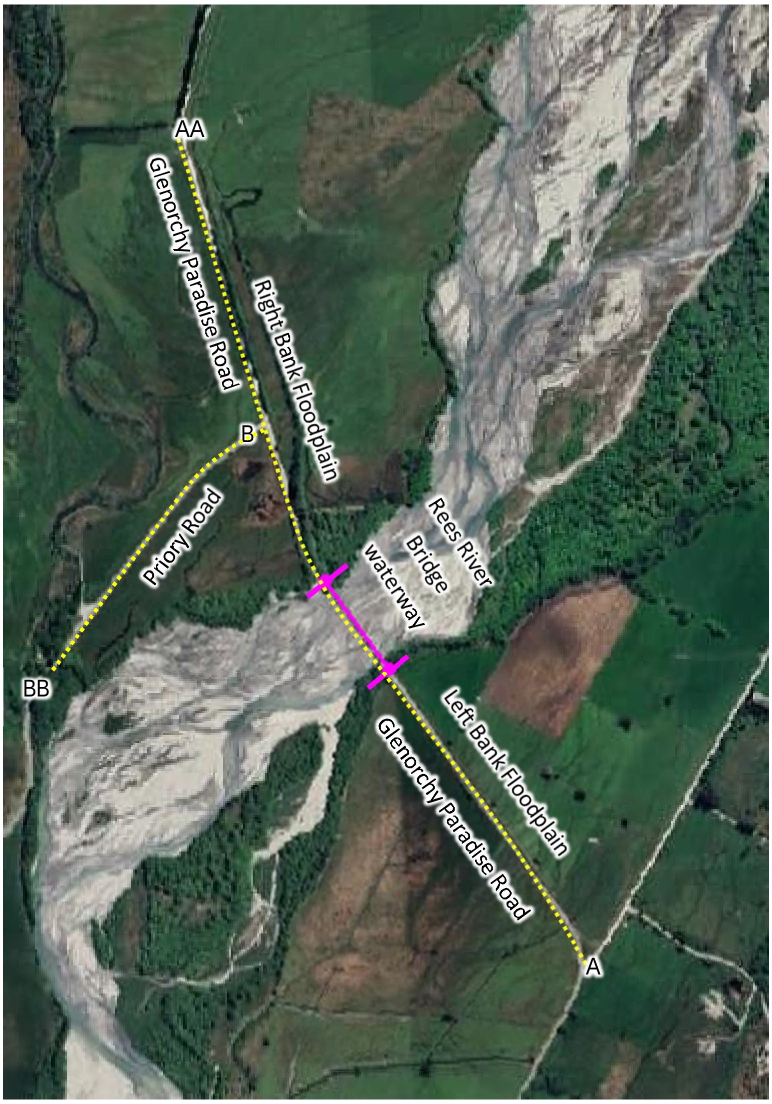


Figure B.4: Aerial photograph showing right bank floodplain, Rees River Bridge waterway and left bank floodplain locations and where flows listed in Table B.1 were extracted. Also shown are locations of long-section profiles A-AA shown on Figure B.5 and B-BB shown on Figure B.6.

Figure B.5 plots a long-section along Glenorchy-Paradise Road showing road crest levels relative to peak 1 in 100 AEP flood levels estimated with the HEC-RAS model for the existing river and floodplain geometry and Option A floodplain modifications. The same information is shown on Figure B.6 along Priory Road. Refer to Figure B.4 for the long-section locations.

Figure B.5 indicates that Option A floodplain modifications change the water level profile on the right bank Rees River Bridge. Flood waters back-up behind the raised Glenorchy-Paradise Road and flow through the new floodway provided by removing the secondary floodbank between the right abutment of the Rees River Bridge. Peak flood levels through the Rees River Bridge waterway and the left bank floodplain are not changed significantly, but do reduce in the order of 5 to 10 cm with the Option A floodplain modifications relative to the existing situation.

Figure B.6 indicates that Option A increases peak 1 in 100 AEP flood levels along the profile of Priory Road, and in the order of 0.2 to 0.4 m, relative to the existing river and floodplain geometry. Under Option A the introduction of additional discharge through the new floodway, and running parallel with Priory Road, acts to increase peak flood levels.

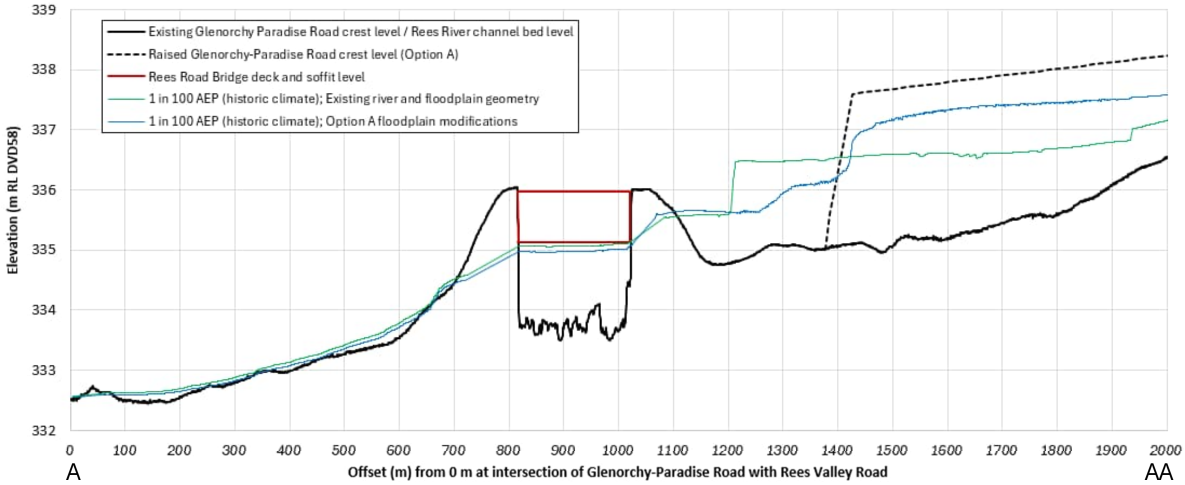


Figure B.5: Comparison of predicted maximum flood levels along Glenorchy-Paradise Road (long section A-AA) for 1 in 100 AEP flood for existing river and floodplain geometry and Option A floodplain modifications

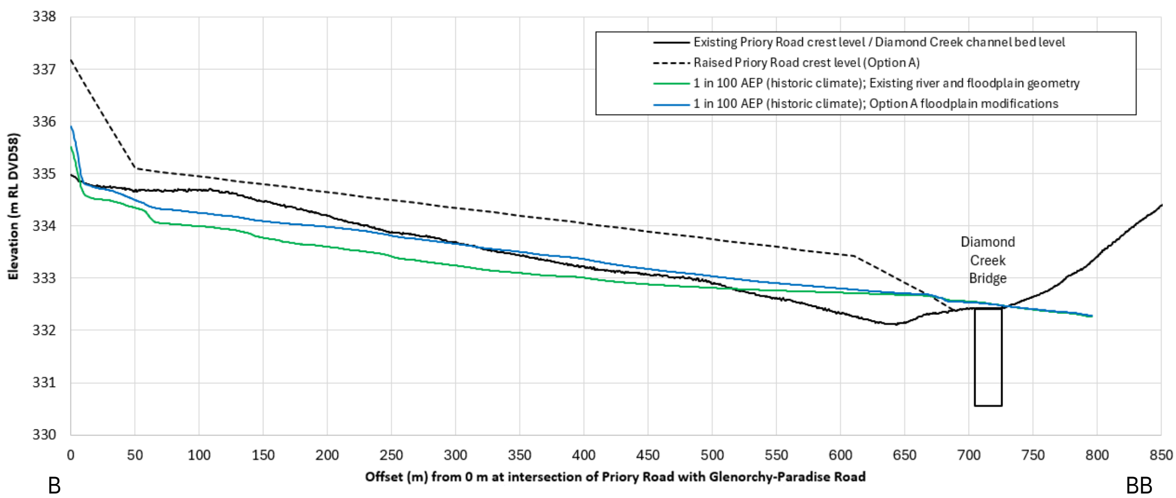


Figure B.6: Comparison of predicted maximum flood levels along Priory Road (long-section B-BB) for 1 in 100 AEP flood for existing river and floodplain geometry and Option A floodplain modifications

Model Simulation Results – Long-Term Resilience of Option A

The following scenarios were simulated with the HEC-RAS model to understand the sensitivity of Option A to the:

- 1 in 100 AEP flood including future climate change effects
- 1 in 100 AEP flood (historic climate) with +0.4 m average riverbed aggradation
- 1 in 500 AEP flood (historic climate) +0.4 m average riverbed aggradation

Figure B.7 provides a side-by-side comparison of the maximum flood inundation extents and depths for the Option A floodplain modifications for the 1 in 100 AEP flood (historic climate) and the three additional cases listed above. Figures B.7a and B.7b show relatively similar maximum flood extents and depths, but with additional flooding observable in the 1 in 100 AEP (future climate) case to the north of Priory Road. This is due to additional break-out flows occurring upstream of the Rees River Bridge at the location shown with a yellow arrow on Figure B.8. Figures B.7c and B.7d illustrate that, when the entire active riverbed is increased by +0.4 m in elevation, even larger amounts of flood flow break out down the path indicated with a yellow arrow on Figure B.8 and re-enter the Rees River via Diamond Creek to the north of Priory Road.

Figure B.9 plots a long-section along Glenorchy-Paradise Road showing road crest levels relative to peak 1 in 100 AEP flood levels (historic climate) estimated with the HEC-RAS model for Option A floodplain modifications, as well as the three additional cases listed above. Figure B.10 provides the same information along Priory Road. Figures B.9 and B.10 indicate that the raised road levels are not estimated to be overtopped in any of the sensitivity cases listed above. However, the 0.6 m of freeboard provided above the 1 in 100 AEP (future climate) flood levels is reduced in all the sensitivity testing cases.

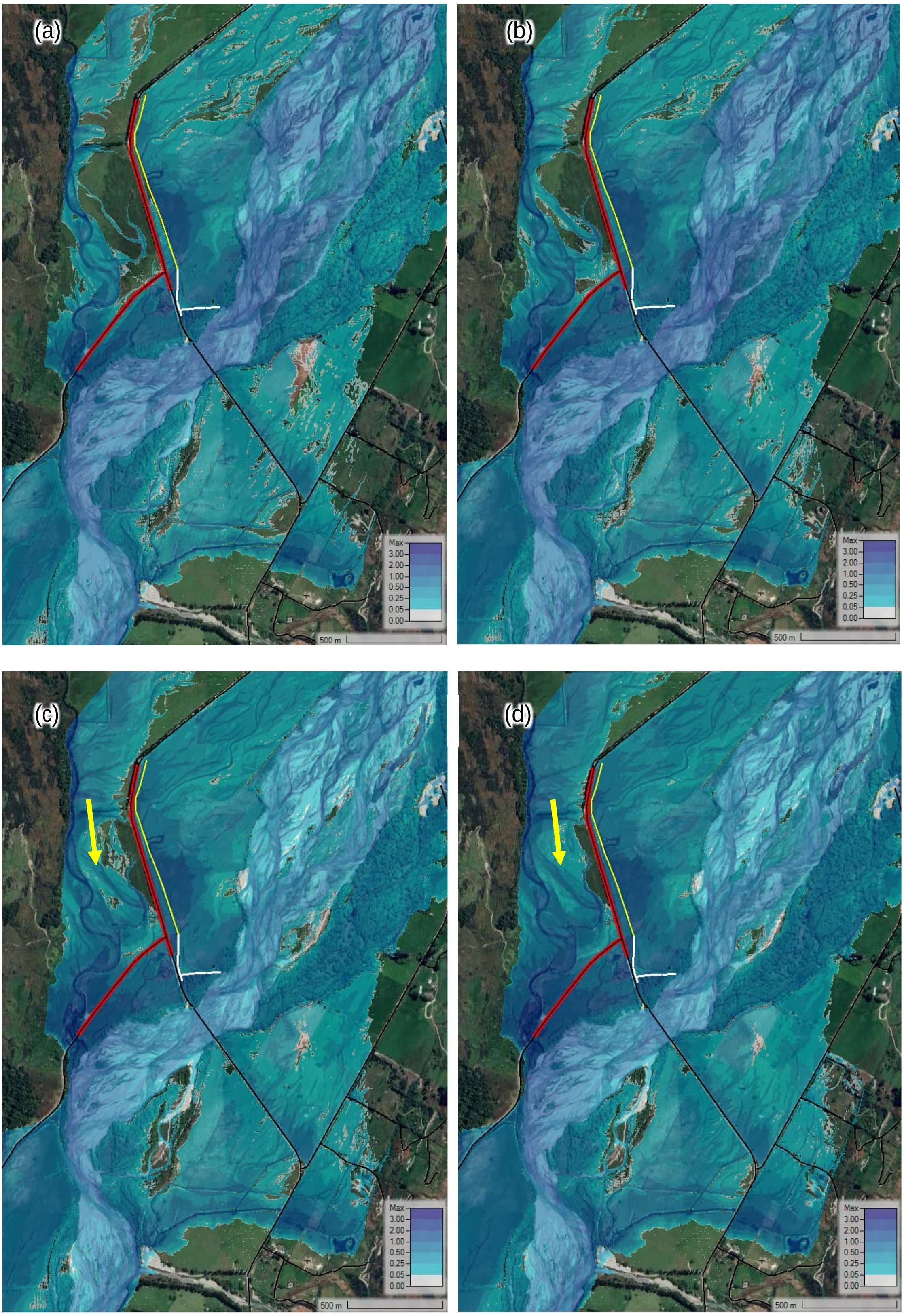


Figure B.7: Comparison of predicted maximum flood extents for Option A floodplain modifications for (a) 1 in 100 AEP flood (historic climate) (b) 1 in 100 AEP flood (future climate) (c) 1 in 100 AEP flood (historic climate) with +0.4 m average riverbed aggradation (d) 1 in 500 AEP flood (historic climate) with +0.4 m average riverbed aggradation

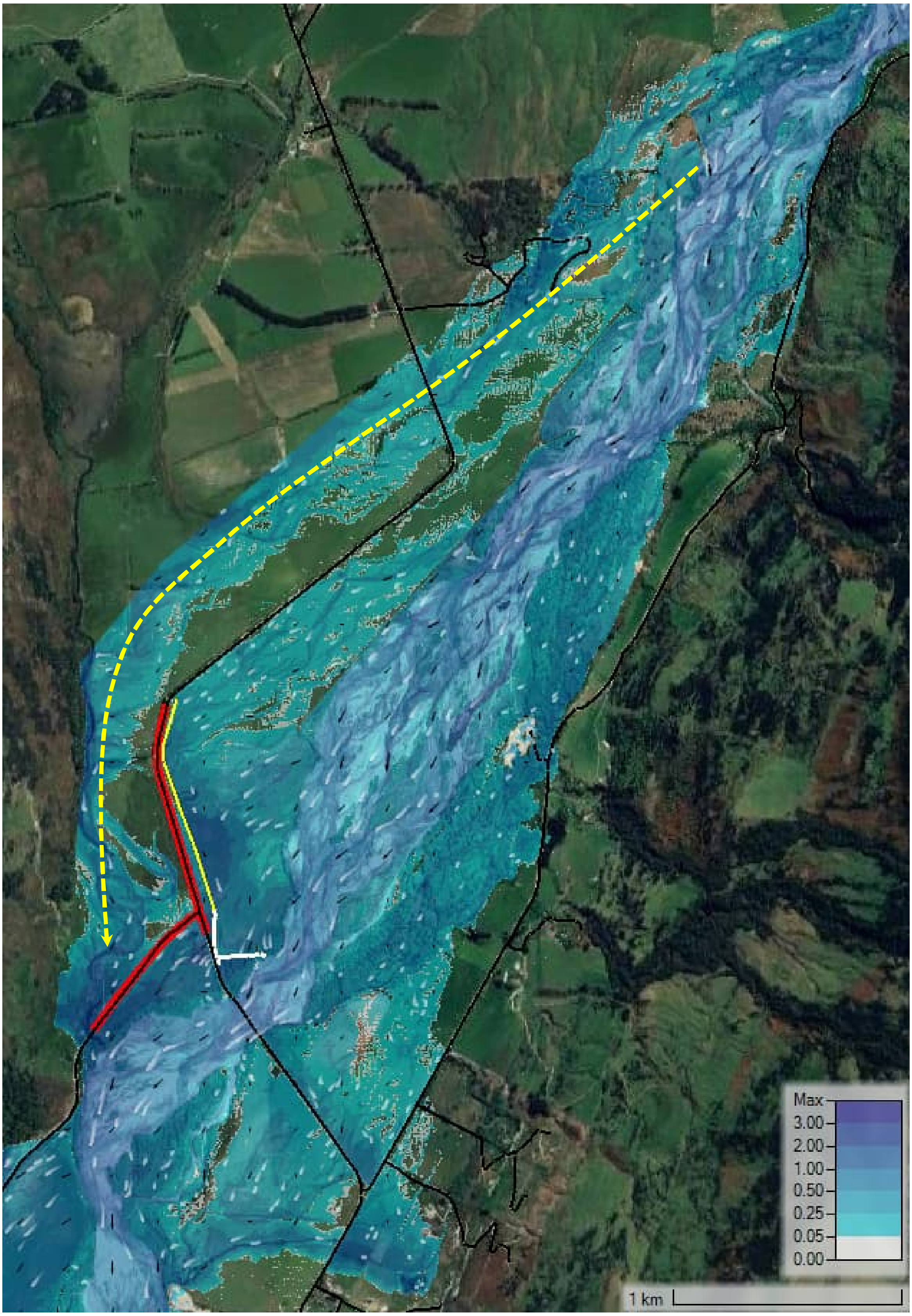


Figure B.8: Maximum flood extents for Option A floodplain modifications for in 100 AEP flood (future climate) case. Yellow arrows indicate break-out flow paths on true-right floodplain and to the north of Glenorchy-Paradise Road.

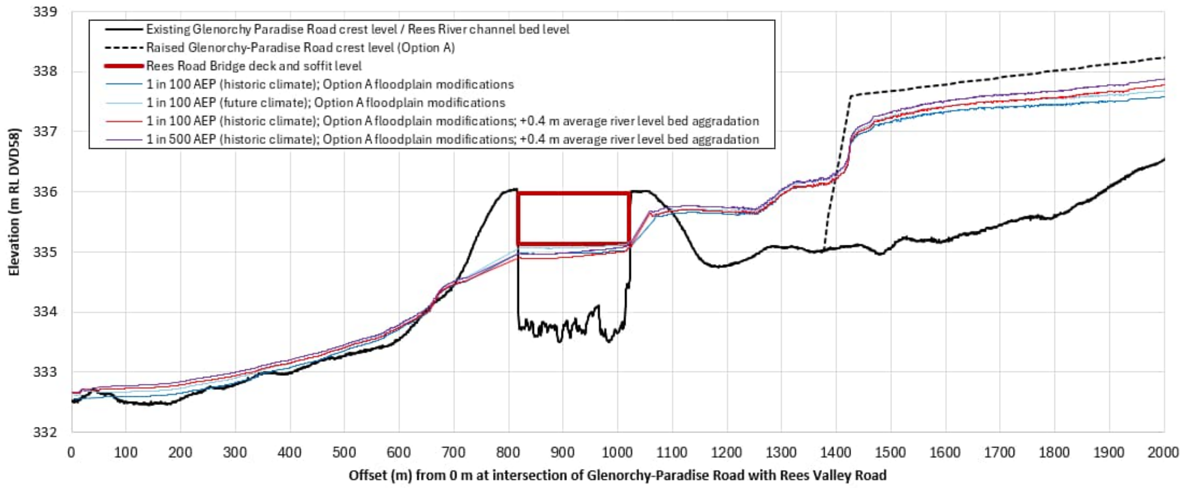


Figure B.9: Comparison of predicted maximum flood levels along Glenorchy-Paradise Road (long section A-AA) for Option A floodplain modifications for simulations of 1 in 100 AEP flood (historic and future climate) and 1 in 100 AEP and 1 in 500 AEP floods (with +0.4 m average riverbed aggradation).

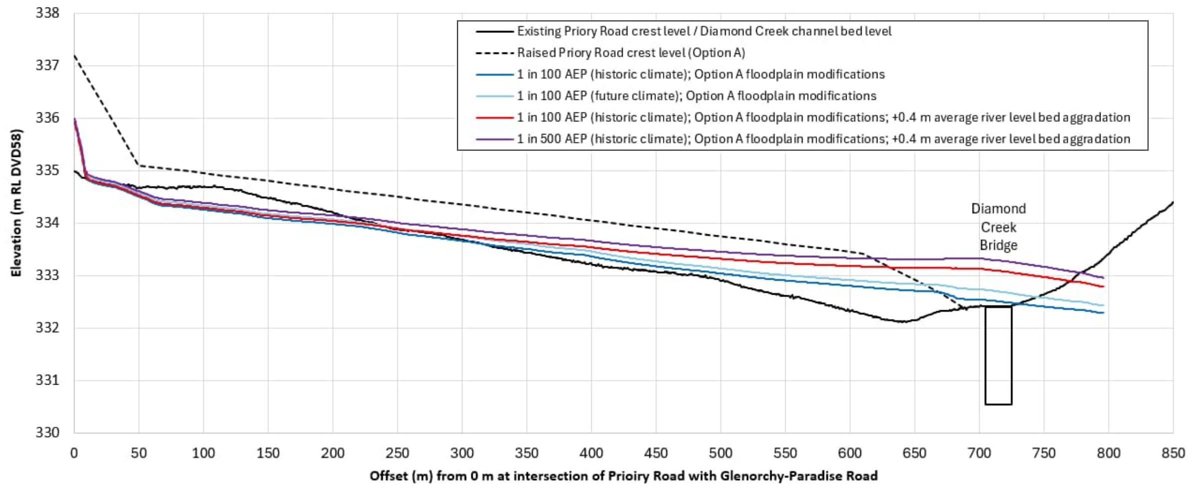


Figure B.10: Comparison of predicted maximum flood levels along Priory Road (long-section B-BB) for Option A floodplain modifications for simulations of 1 in 100 AEP flood (historic and future climate) and 1 in 100 AEP and 1 in 500 AEP floods (with +0.4 m average riverbed aggradation).

B.2 Option B – Development of Right Bank Secondary Flow Path without Floodbanks

Option Summary

Option B was a variation on Option A. The objective of this option was again to form a secondary flow path over the right bank floodplain to the west of the Rees River Bridge. However, the secondary flow path was allowed to be unconstrained by guide banks except for one residual floodbank (i.e. no additional guide banks would be constructed). It represents a restoration of the original design concept for the Rees River Bridge (refer to Figure 2.4 in Section 2 of the main report}.

This option would involve the following floodplain modifications (and illustrated on Figure 4.1(c) in Section 4.3 of the main report):

- Lowering the existing secondary floodbank running parallel with Glenorchy-Paradise Road between right abutment of Rees River Bridge and junction with Priory Road.

Model Simulation Results

Table 4.2 (Section 4.4 of the main report) lists the range of flood and riverbed geometry scenarios simulated with Option B.

Figures B.11 provides a side-by-side comparison of the respective 1 in 100 AEP predicted maximum flood extents for the existing river and floodplain geometry and proposed Option B floodplain modifications. This figure shows that implementation of Option B has no discernible impact on maximum flood extents relative to the existing river and floodplain geometry.

Table B.2 provides the peak discharges through the Rees River Bridge waterway and left and right bank overflow paths for the 1 in 20, 1 in 50 and 1 in 100 AEP floods for the existing river and floodplain geometry and proposed Option B floodplain modifications. This table indicates that Option B results in a signficant increase in flows across the right bank floodplain as well as a decrease in flow through the Rees River Bridge waterway and left bank floodplain.

Figure B.12 plots a long-section along Glenorchy-Paradise Road showing road crest levels relative to peak 1 in 100 AEP flood levels estimated with the HEC-RAS model for the existing river and floodplain geometry and Option B floodplain modifications. The same information is shown on Figure B.13 along Priory Road. Refer to Figure B.4 for the long-section locations.

Figure B.12 indicates that the Option B floodplain modifications change the water level profile on the right bank Rees River Bridge. Flood waters are more evenly distributed across the true right bank with removal of the secondary floodbank between the right abutment of the Rees River Bridge. Water levels through the Rees River Bridge waterway and the left bank floodplain are reduced slightly, in the order of 10 cm, with the Option B floodplain modifications relative to the existing situation.

Figure B.13 indicates that Option B increases peak 1 in 100 AEP flood levels in the right bank floodway, alongside Priory Road, in the order of 0.2 m, relative to the existing river and floodplain geometry. This is due to the introduction of additional discharge through the new wider floodway provided by Option B.

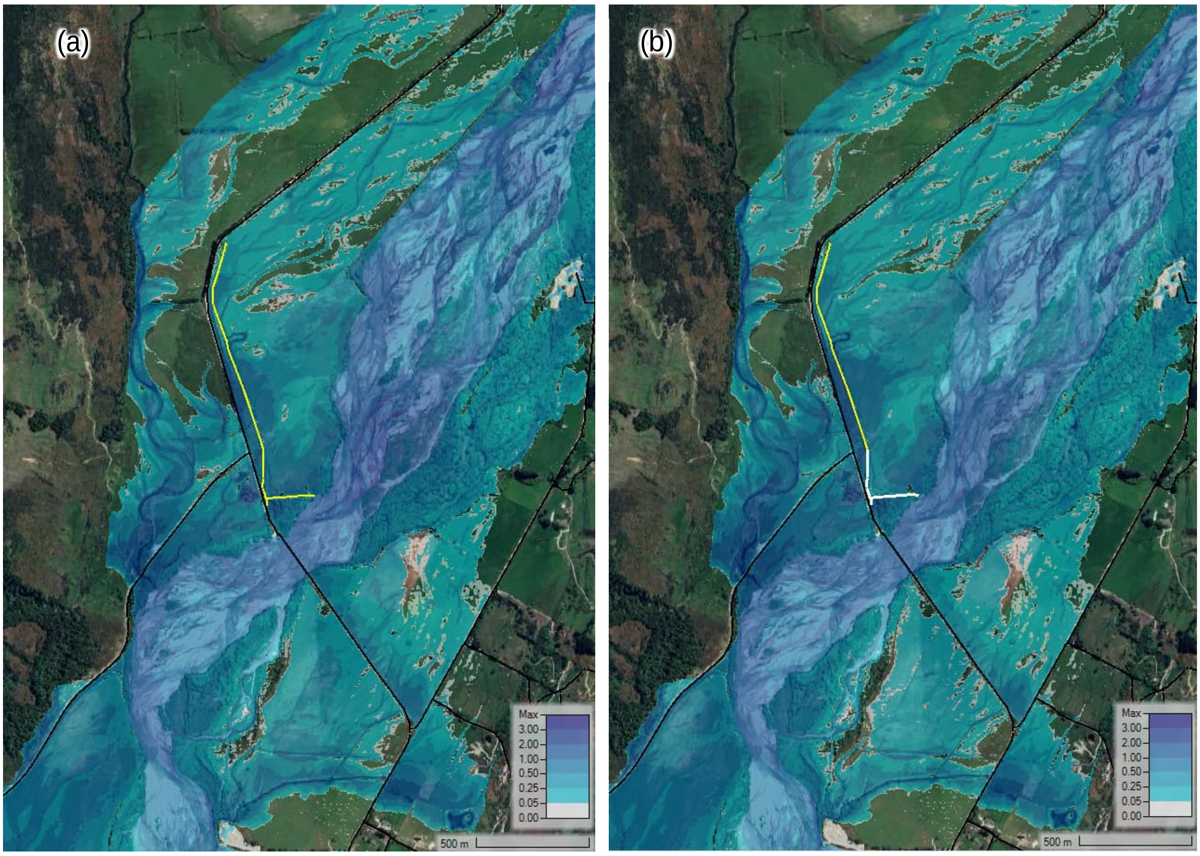


Figure B.11: Comparison of predicted maximum flood extents for 1 in 100 AEP flood (historic climate) for (a) existing river and floodplain geometry and (b) Option B floodplain modifications

Table B.2: Comparison of peak flood discharge through Rees River Bridge waterway and left and right bank floodplains (refer Figure B.4) for existing river and floodplain geometry (existing) and Option B floodplain modifications.

Flood Frequency (historic climate)	Peak Discharge (m^3/s) Right Bank Floodplain			Peak Discharge (m^3/s) Rees River Bridge Waterway			Peak Discharge (m^3/s) Left Bank Floodplain		
	Existing	Option B	Change in Peak Discharge*	Existing	Option B	Change in Peak Discharge*	Existing	Option B	Change in Peak Discharge*
1 in 20	124	262	+138	547	514	-33	56	26	-30
1 in 50	158	313	+155	592	479	-113	82	46	-36
1 in 100	183	360	+177	627	519	-108	104	62	-41

Notes:
** Change in peak flow between “Option B” and “Existing”*

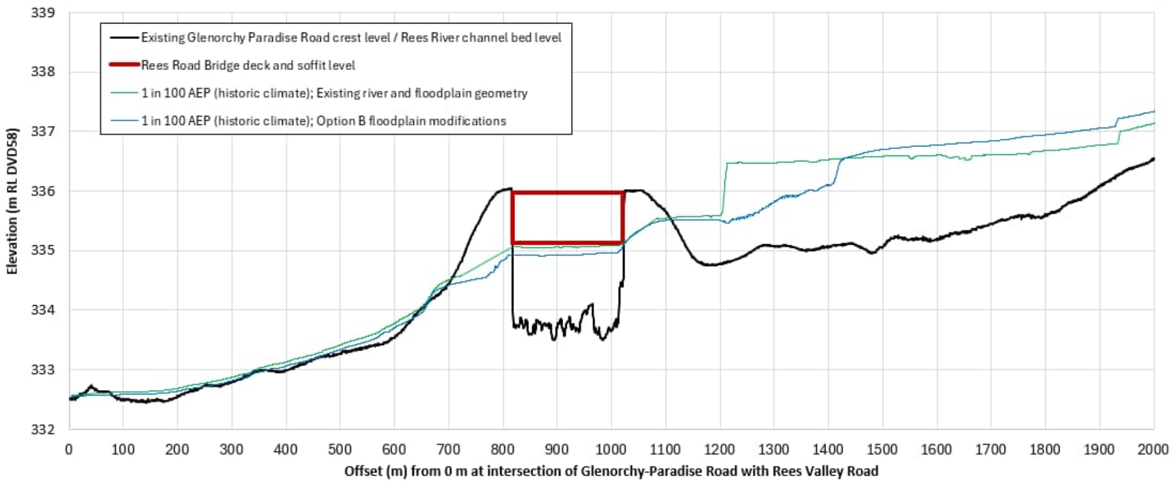


Figure B.12: Comparison of predicted maximum flood levels along Glenorchy-Paradise Road (long-section A-AA) for 1 in 100 AEP flood for existing river and floodplain geometry and Option B floodplain modifications

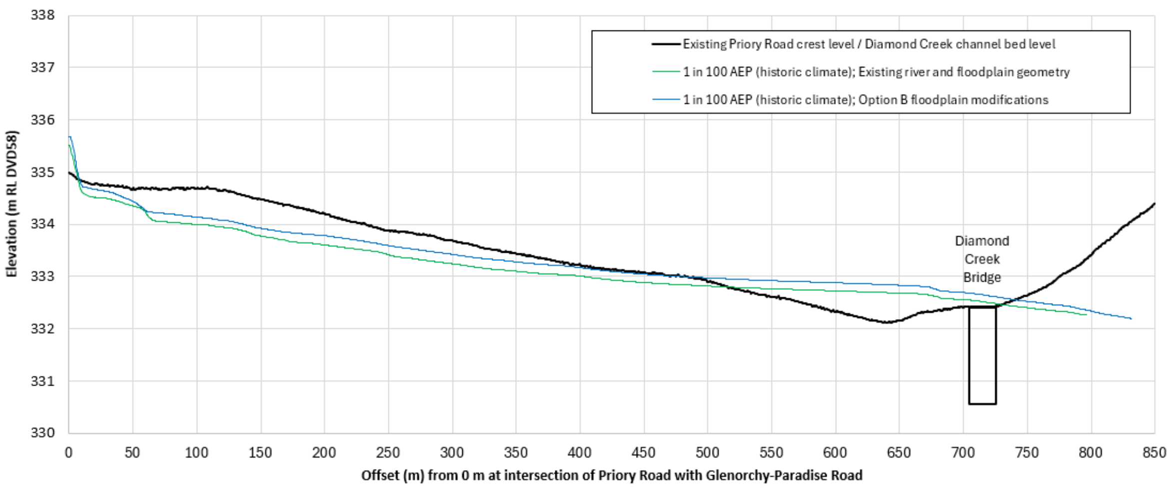


Figure B.13: Comparison of predicted maximum flood levels along Priory Road (long-section B-BB) for 1 in 100 AEP flood for existing river and floodplain geometry and Option B floodplain modifications

B.3 Option C – Left Bank Secondary Flow Path with Guide Bank

Option Summary

Option C explored the viability of forming a secondary flow path along the left bank floodplain following the route that flood breakout flows follow on that bank in large enough floods. However, this route is currently heavily congested by colonising vegetation which increases the resistance to flood flows.

The objective of this option was to form a lower resistance secondary flow path over the left bank floodplain upstream of the Rees River Bridge. However, some of the flood breakout flows over the left bank floodplain in the February 2020 flood were predicted to not return to the river but were trapped by the road embankment across the floodplain to the east of the bridge. In a large enough flood, it is expected that the road embankment would be overtopped. Option C proposed that this overtopping flow would be constrained by a guide bank extending upstream of the road.

As described in Table 4.1, Option C would involve the following floodplain modifications (and illustrated on Figure 4.1(d) in Section 4.3 of the main report):

- Clearing the existing left bank floodplain vegetation over an area of about 352 hectares to form a floodway of reduced surface roughness.
- Retaining the existing willow protection along the left edge of the active channel belt upstream of the Rees River Bridge where the left bank floodway is formed.
- Constructing a 500 m long flood bank to function as a guide bank – roughly parallel with the left bank of the active riverbed but set back from the edge by about 440 m.

Model Simulation Results

Table 4.2 (Section 4.4 of the main report) lists the range of flood and riverbed geometry scenarios simulated with Option C.

Figures B.14 provides a side-by-side comparison of the respective 1 in 100 AEP predicted maximum flood extents for the existing river and floodplain geometry and proposed Option C floodplain modifications. This figure shows that implementation of Option C has some effect at reducing maximum flood extents across the left bank floodplain. This is largely due to the addition of the 500 m long guide bank which acts to limit flood inundation areas to the east of the Rees Valley Road.

Table B.3 provides the peak discharge through the Rees River Bridge waterway and left and right bank overflow paths for the 1 in 100 AEP floods for the existing river and floodplain geometry and proposer Option C floodplain modifications. This table indicates that Option C results in a modest increase (~26 m^3/s) in discharge across the left bank floodplain with a corresponding decrease in flow through the Rees River Bridge waterway and right bank floodplain. However, the majority of the flood flow still passes through the Rees River Bridge waterway and true right bank floodplain.

This finding indicates that, while clearing the left bank floodplain vegetation and adding the guide bank provides some additional increase in flood flow over the left bank floodplain of the Rees River bridge, it is not particularly effective. Even with a reduction in the left bank floodplain vegetation, the Upper Rees River preferentially wants to break out on the true right floodplain. This is illustrated in Figure B.15 which shows shallower water depths on the left bank (refer area circled in purple on Figure B.15), relative to the right bank (refer area circled in black on Figure B.15), at the peak of a 1 in 100 AEP flood (historic climate).

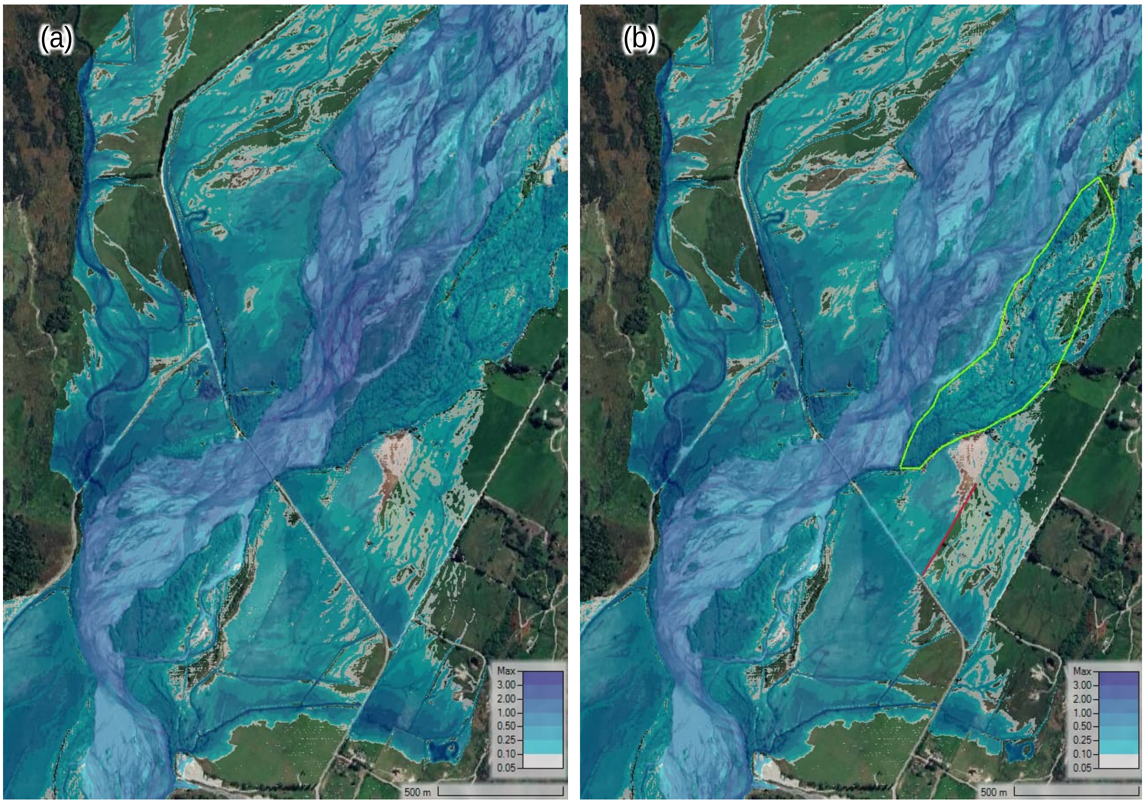


Figure B.14: Comparison of predicted maximum flood extents for 1 in 100 AEP flood (historic climate) for (a) existing river and floodplain geometry and (b) Option C floodplain modifications

Table B.3: Comparison of peak flood discharge through Rees River Bridge waterway and left and right bank floodplains (refer Figure B.4) for existing river and floodplain geometry (existing) and Option C floodplain modifications.

Flood Frequency (historic climate)	Peak Discharge (m^3/s) Right Bank Floodplain			Peak Discharge (m^3/s) Rees River Bridge Waterway			Peak Discharge (m^3/s) Left Bank Floodplain		
	Existing	Option B	Change in Peak Discharge*	Existing	Option B	Change in Peak Discharge*	Existing	Option B	Change in Peak Discharge*
1 in 100	183	176	-7	627	612	-15	104	130	+26
Notes: ** Change in peak flow between “Option B” and “Existing”*									

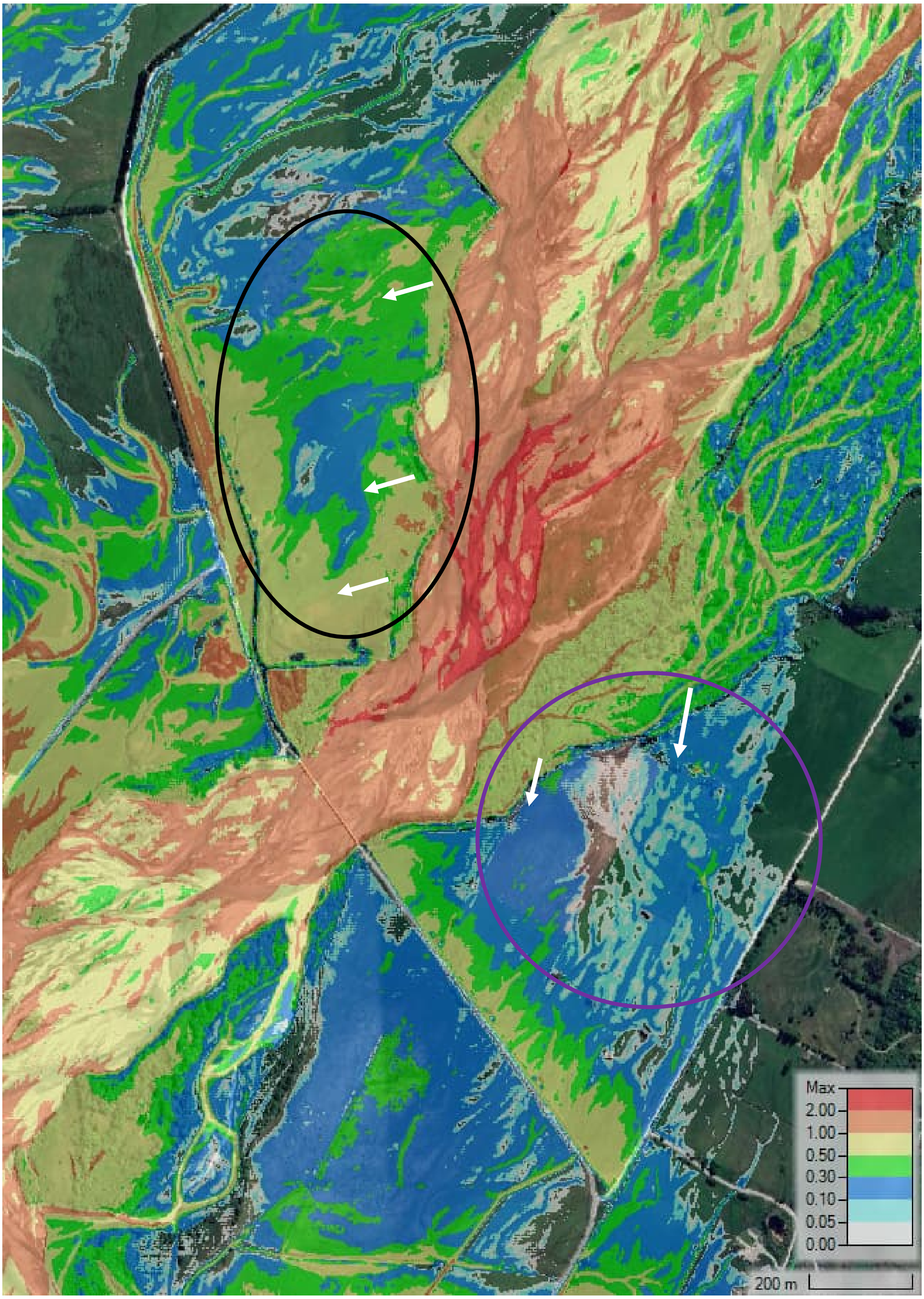
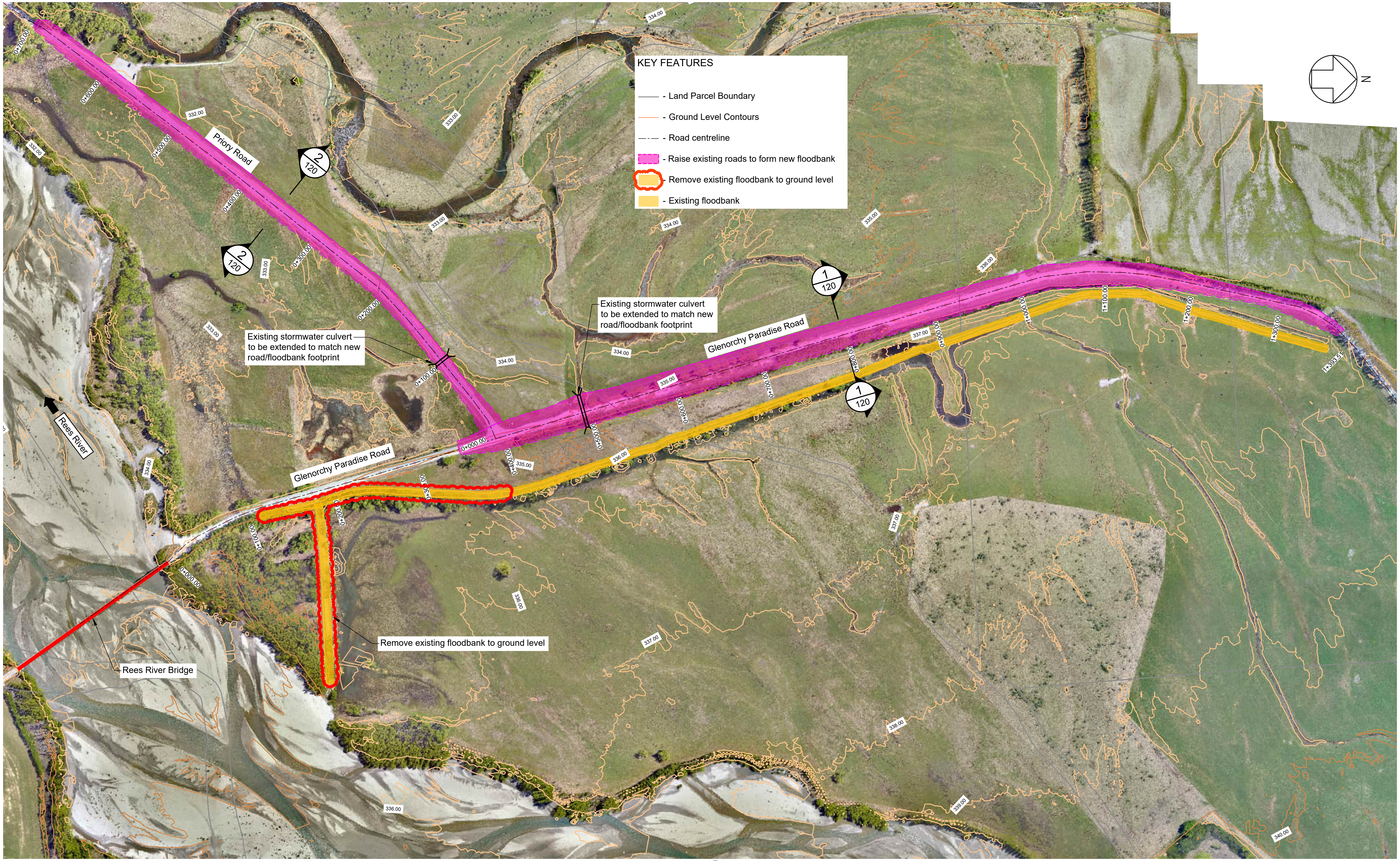


Figure B.15: Maximum flood depth for 1 in 100 AEP flood (historic climate) for existing river and floodplain geometry showing break-out flow paths from the main river channel with white arrows. Black and purple circles indicates break-out flow inundation on true right and true left banks respectively upstream of the Rees River Bridge

Appendix C Option B - Concept Design Plans



PLAN
SCALE 1: 4000

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
A	FOR INFORMATION	JA	RG/BV	Dr GW	12.06.24

Graphic Scales

DAMWATCH ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
UPPER REES RIVER FLOODPLAIN ASSESSMENT

UPPER REES RIVER
GENERAL ARRANGEMENT
PLAN

Scale	Project	Drawing Number	Revision
1:4000	E2350	URR2350/30/100	A

Original Sheet Size A3 (420x297)

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19 June 2024 5:08pm
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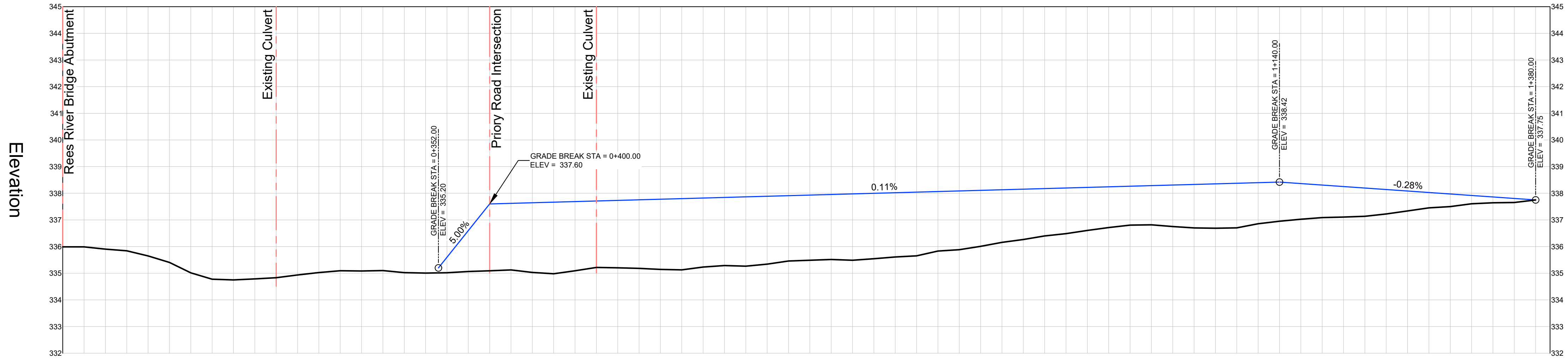
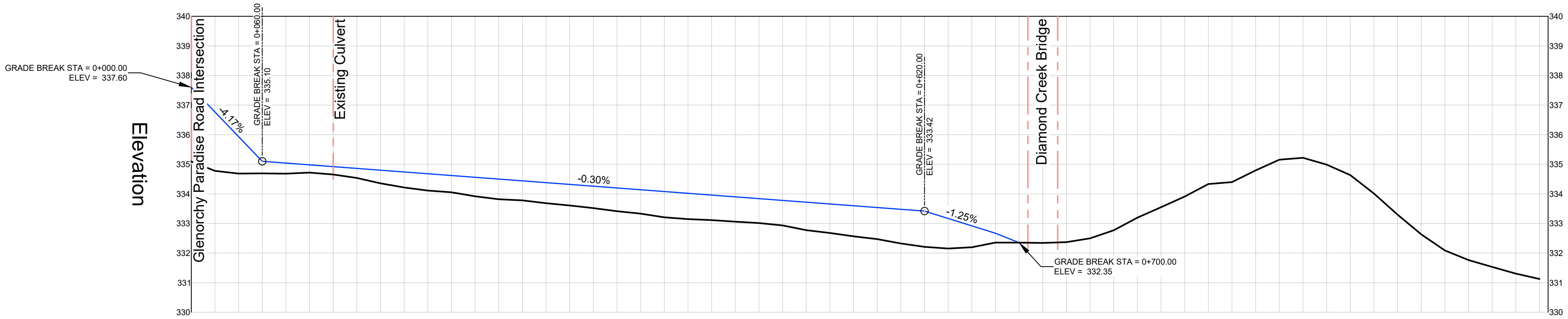
Elevation



Chainage	Proposed Road Crest / Floodbank Crest Level	Existing Ground Level along Road CL
0+000		335.99
0+020		335.99
0+040		335.90
0+060		335.84
0+080		335.65
0+100		335.41
0+120		335.02
0+140		334.78
0+160		334.75
0+180		334.79
0+200		334.83
0+220		334.94
0+240		335.03
0+260		335.09
0+280		335.08
0+300		335.10
0+320		335.02
0+340		335.01
0+360	335.60	335.02
0+380	336.60	335.06
0+400	337.60	335.09
0+420	337.62	335.12
0+440	337.64	335.03
0+460	337.67	334.98
0+480	337.69	335.09
0+500	337.71	335.22
0+520	337.73	335.20
0+540	337.76	335.18
0+560	337.78	335.14
0+580	337.80	335.13
0+600	337.82	335.23
0+620	337.84	335.29
0+640	337.87	335.26
0+660	337.89	335.34
0+680	337.91	335.46
0+700	337.93	335.49
0+720	337.95	335.52
0+740	337.98	335.49
0+760	338.00	335.54
0+780	338.02	335.61
0+800	338.04	335.65
0+820	338.07	335.83
0+840	338.09	335.88
0+860	338.11	336.01
0+880	338.13	336.16
0+900	338.15	336.26
0+920	338.18	336.40
0+940	338.20	336.49
0+960	338.22	336.61
0+980	338.24	336.71
1+000	338.26	336.80
1+020	338.29	336.82
1+040	338.31	336.75
1+060	338.33	336.70
1+080	338.35	336.69
1+100	338.38	336.70
1+120	338.40	336.86
1+140	338.42	336.95
1+160	338.36	337.03
1+180	338.31	337.09
1+200	338.25	337.11
1+220	338.20	337.14
1+240	338.14	337.22
1+260	338.08	337.34
1+280	338.03	337.45
1+300	337.97	337.50
1+320	337.92	337.61
1+340	337.86	337.64
1+360	337.81	337.65
1+380	337.75	337.75
1+394		

LONG-SECTION - GLENORCHY PARADISE ROAD

Elevation



Chainage	Proposed Road Crest / Floodbank Crest Level	Existing Ground Level along Road CL
0+000	337.60	335.09
0+020	336.77	334.78
0+040	335.93	334.69
0+060	335.10	334.69
0+080	335.04	334.68
0+100	334.98	334.72
0+120	334.92	334.65
0+140	334.86	334.54
0+160	334.80	334.36
0+180	334.74	334.22
0+200	334.68	334.11
0+220	334.62	334.05
0+240	334.56	333.92
0+260	334.50	333.82
0+280	334.44	333.78
0+300	334.38	333.68
0+320	334.32	333.61
0+340	334.26	333.52
0+360	334.20	333.41
0+380	334.14	333.33
0+400	334.08	333.21
0+420	334.02	333.15
0+440	333.96	333.11
0+460	333.90	333.06
0+480	333.84	333.01
0+500	333.78	332.93
0+520	333.72	332.77
0+540	333.66	332.68
0+560	333.60	332.56
0+580	333.54	332.47
0+600	333.48	332.32
0+620	333.42	332.21
0+640	333.17	332.15
0+660	332.92	332.20
0+680	332.67	332.35
0+700	332.35	332.35
0+720		332.34
0+740		332.37
0+760		332.50
0+780		332.77
0+800		333.20
0+820		333.55
0+840		333.91
0+860		334.33
0+880		334.40
0+900		334.79
0+920		335.15
0+940		335.22
0+960		334.99
0+980		334.64
1+000		334.01
1+020		333.30
1+040		332.63
1+060		332.09
1+080		331.76
1+100		331.53
1+120		331.30
1+140		331.12
1+147		

LONG-SECTION - PRIORY ROAD

NOTES

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

Rev	Comments	Drawn	Chk'd	Appr'd	Date
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DAMWATCH
ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
UPPER REES RIVER FLOODPLAIN ASSESSMENT

GLENORCHY-PARADISE ROAD & PRIORY ROAD
PROPOSED FLOODBANK CREST LEVEL

Scale 1:10V ; 1:250H | Project E2350 | Drawing Number URR2350/30/105 | Revision A

Graphic Scales 0 10 mm 50 100 200 mm

Original Sheet Size A3 (420x297)

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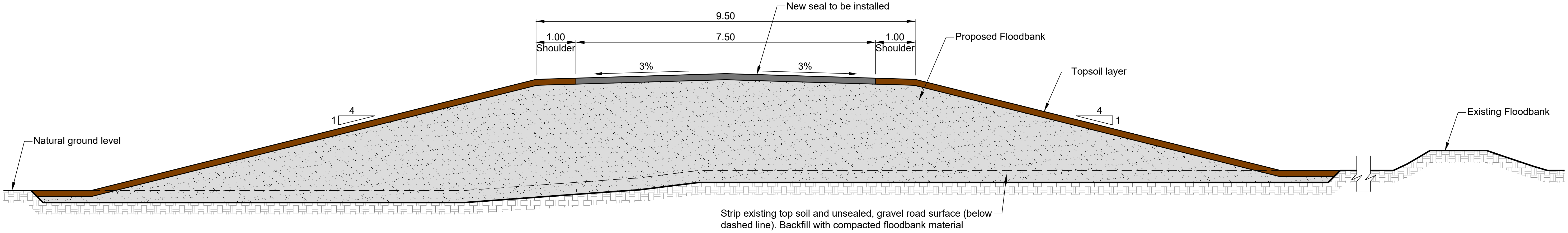
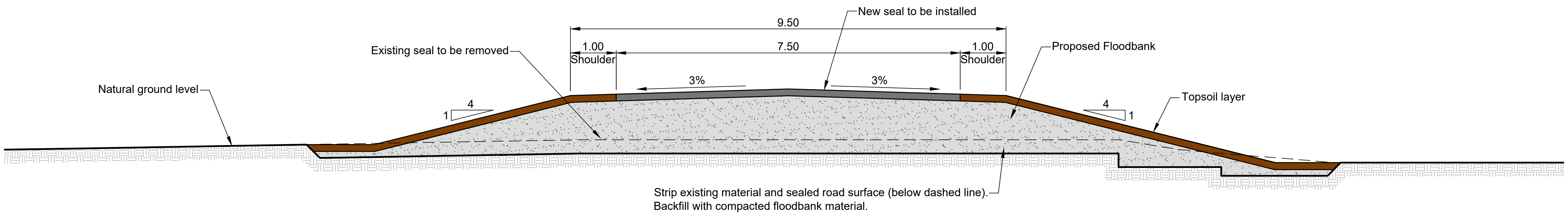


TYPICAL SECTION 1/100 GLENORCHY PARADISE ROAD

SCALE 1: 100



TYPICAL SECTION 2/100 PRIORY ROAD

SCALE 1: 100

Rev	Comments	Drawn	Chk'd	Appr'd	Date
A	FOR INFORMATION	JA	RG/BV	Dr GW	12.06.24

Graphic Scales

DAMWATCH ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
UPPER REES RIVER FLOODPLAIN ASSESSMENT

TYPICAL SECTIONS

Scale	Project	Drawing Number	Revision
1:100	E2350	URR2350/30/120	A

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. It also provides indicative costings to prepare and obtain the necessary consents.

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 at the time of preparing this report.

Further detailed statutory analysis of the concept design 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 the Concept Design & Consenting Requirements

The concept design involves partial removal of existing floodbanks in the vicinity of the Rees River Bridge and raising Priory Road and Glenorchy-Paradise Road to enable them to function as effective floodbanks. No new culverts beneath the roads are included in the concept design but existing culverts may need to be extended.

The removal of the existing floodbanks and the earthworks required to raise Priory Road is located on Rural zoned land and the earthworks required to raise Glenorchy-Paradise Road is land zoned as Road. All the works are located within an Outstanding Natural Landscape and within Wāhi tūpuna Area 13 - Ōturu (Diamond Lake, Mount Alfred and surrounds).

In summary, under the current regulatory framework the concept design will require resource consent to be obtained from both the QLDC and ORC to raise the roads (to enable them to also function as new flood protection works) and to remove the existing floodbanks and, in so doing, create new defences against water and permanently divert flood waters.

A more detailed review of these consenting requirements 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 and Non-Statutory 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 likely to be relevant and an assessment of the concept design 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 available information and plans, it is considered that the concept design are likely to be consistent with the relevant objectives and policies of the ORPS. 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 design of the concept design takes into account climate change effects until the end of the century.
- maintain the existing public access to and along the margin of the Rees River;
- likely be consistent with the policy direction set by policies 4.1.10 and 4.1.11 (relating to the use of hard protection structures).

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 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, through appropriate design and conditions of consent, 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.
- 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.
- 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.

It is recommended that iwi are consulted with as part of the preparation of the resource consent applications. However, the preliminary view is that, through appropriate design and conditions of consent, the concept design outlined in this report 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 once that occurs to check that the concept design still align with, and have 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 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 10: The habitat of trout and salmon is protected, insofar as this is consistent with Policy 9.
- 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.

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 ;
- Consultation will be undertaken with iwi through the consenting process;
- The concept design is not expected to result in a reduction in the extent of the river when at normal flow levels or its values, noting that the concept is to modify the floodplain rather than the active river channel;
- Based on the values of the Rees River listed in the RWP, it is anticipated that the significant values of the River (should it be identified as an outstanding water body) will be protected, as will the trout and salmon habitat that it provides;
- Based on the values of the Rees River listed in the RWP, the Rees River is not a known habitat for indigenous freshwater species;
- On the basis that the concept design will be effective at mitigating flood risks to the community and property they will 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 listed as watercourses to be protected in Schedule 2 of this order. No damming is included in the concept design and the braided nature of the watercourses will be maintained. Notwithstanding 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.

D.3.7 Other Higher Order Documents

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 flood mitigation interventions 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 flood mitigation interventions 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 flood mitigation interventions 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 of 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.

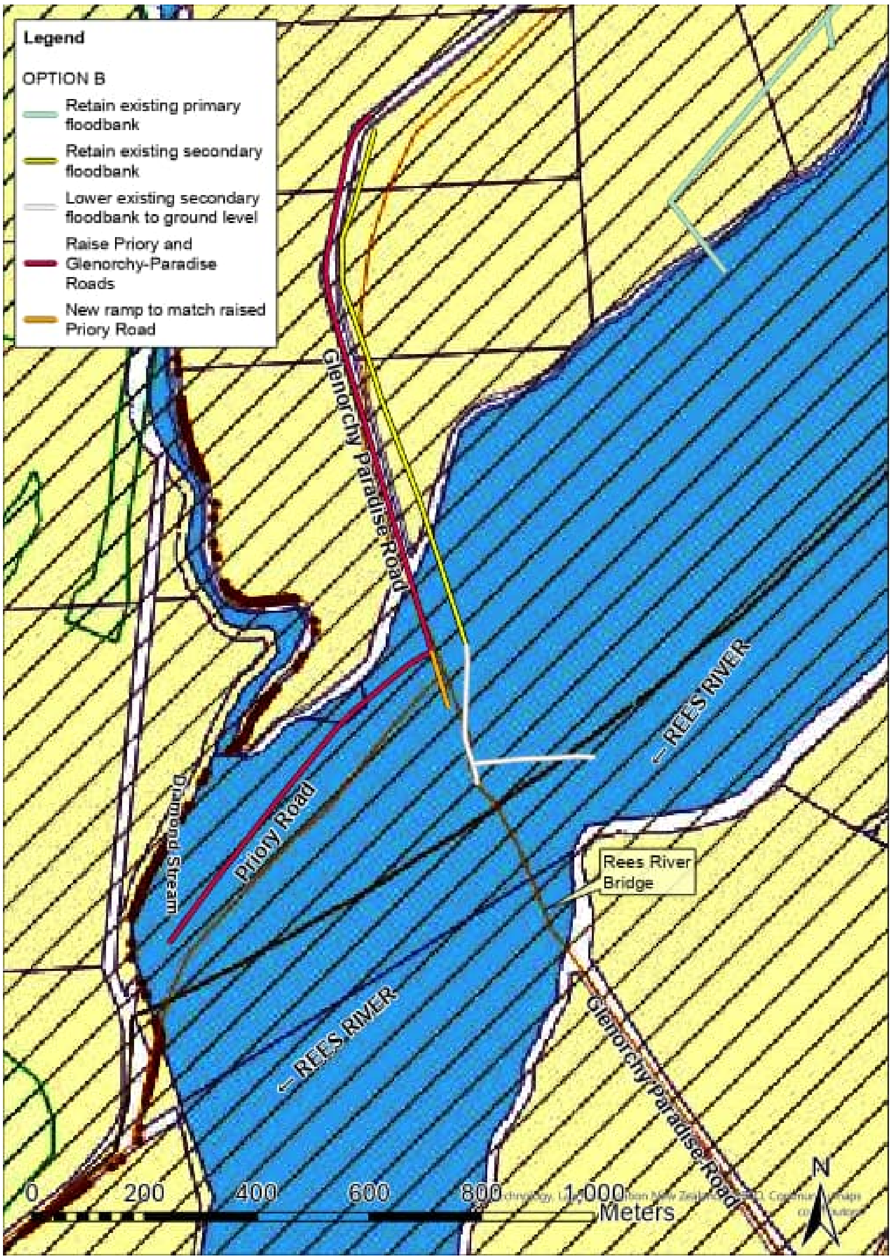

Figure D.1: The concept design overlaid the PDP planning (zone) map

Based on the preliminary plans, the removal of the existing floodbanks and the earthworks required to raise Priory Road is located on Rural zoned land and the earthworks required to raise Glenorchy-Paradise Road is primarily on land zoned as Road. All the works are located within an Outstanding Natural Landscape and within Wāhi tūpuna Area 13 - Ōturu (Diamond Lake, Mount Alfred and surrounds).

As the plans are not yet to the level of detail that would be required for consenting purposes, the exact location and scale of the earthworks/ flood protection works may be subject to minor changes. As such, a conservative approach has been taken in all instances and if there is a reasonable chance that a planning rule will be breached and consent required, this has been included in the below review and indicative costings.

The land on which the concept design is held in a small number of different ownerships. This information is summarised in Table D.1.

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 the PDP zoning and land ownership

Zone	Location/ description	Ownership
Road	Road (New Zealand Gazette 2013 p 1262) The raising of Glenorchy-Paradise Road.	Vested in Queenstown Lakes District Council
Rural	All that land shown in blue in Figure D.1 above. The raising of Priory Road and removal of the existing floodbanks.	Crown Land
Rural	5091 Glenorchy-Paradise Road, being that land on either side of the road. The earthworks associated with raising the road could potentially extend slightly beyond the road reserve in some places.	In private ownership
Outstanding Natural Landscape	All of the concept design.	Various as noted above
Wāhi tūpuna Area 14	All of the concept design.	Various as noted above

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[15] 30.6.1.2 – Non notification of Applications	Raising Glenorchy-Paradise Road and Priory Road fall within the definition of Flood Protection Works and therefore require a discretionary activity consent. While applications for Flood Protection Works are required to be processed on a non-notified basis and without the written approval of other persons (unless special circumstances apply), the concept design will also require consents for earthworks and, as such, the council is able to notify the application if it determines that to be appropriate.	
Chapter 25 – Earthworks –		
Rule	**Roads**	**Rural**
Table 25.2 Earthworks volumes (able to be notified pursuant to Rule 25.6) 25.5.6 – Volumes in the Rural Zone – 1000 m^3 25.5.7.1 - Volumes within Roads 25.5.10A.2 – Volumes in 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 – 10 m^3.	No limit and therefore no consent is required under this rule (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.*	As the concept plans indicate that the volume of earthworks in the Rural Zone will be well in excess of the 1,000m^3 permitted, a restricted discretionary consent will be required. Furthermore, as the earthworks associated with the removal of one of the existing floodbanks will be within 20 m of the bed of the river [See Note 1], a restricted discretionary consent will be required under 25.5.10A.2.

[15] Defined in the PDP as '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'.

Rule	Discussion of Consent Requirements	
	Roads	Rural
25.5.15 - Maximum depth of any cut	This rule does not apply to roads so permitted	2.4 metres. There is no cut included in the concept design and therefore no consent is required under this rule (permitted).
25.5.16 - Maximum height of any fill (2m)	This rule does not apply to roads so permitted	As the concept plans indicate that the height of fill for the first approximately 20 m of Priory Road (which is not a designated road) may be higher than 2 m, a restricted discretionary consent may be required.
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°. Rule 25.6.1 - Non notified	As the concept plans indicate that an estimated 25,000 m² of earthworks will be associated with the removal of the existing floodbanks and raising of the two stretches of road, a restricted discretionary consent will be required.	
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 is 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 is 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 is 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 concept plans indicate that the earthworks will extend close to or slightly over the boundary between the Glenorchy-Paradise road and adjoining sites, this standard may be breached and a restricted discretionary consent required.
25.5.19.1 - Earthworks within 10m of the bed 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	As the earthworks associated with the removal of one of the floodbanks may extend to within 10 m of the bed of the river, it is possible that 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.	While this will need to be confirmed if the concept progresses to the detailed design stage, it is expected that no earthworks occur 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.	A restricted discretionary consent will be required.

Rule	Discussion of Consent Requirements
Chapter 29 – Transport - Table 29.2 - Activities within a road	
29.4.13 Activities that are not listed in this Table.	While transport infrastructure (which includes the roading corridor) is a permitted activity, as the primary purpose of the works within the road reserve is to enable the road to also function as a flood protection works and this is not listed in the Rules table, a discretionary activity consent is required to raise the section of Glenorchy-Paradise Road. While these works are utilities, 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.

Notes to Table D.2:
1. 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;

Overall, a Discretionary activity consent will be required under the PDP.

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 following natural and ecosystem values are identified for the Rees River:

- 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 listed 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.

Overall, the concept design will require a Discretionary activity consent under the RWP.

Table D.3: Relevant rules related to RPW

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 the proposed raising of the roads 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[16], 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.	As the proposed raising of the roads will act as a defence against water and are located beyond the bed of the river, those works will require a Discretionary Activity consent.

[16] It is permitted if there 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 the works are not considered to fall within the definition of Reclamation[17] under the National Planning Standards 2019 and are not proximate to a natural inland wetland, no consents are required under the NPSFM.

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 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 will be required to support 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

[17] *Means the manmade formation of permanent dry land by the positioning of material into or onto any part of a waterbody, bed of a lake or river or the coastal marine area, and:*
(a) includes the construction of any causeway; but
(b) excludes the construction of natural hazard protection structures such as seawalls, breakwaters or groynes except where the purpose of those structures is to form dry land.

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) • Detailed plans, including plans showing the footprint, cross sections, and long sections of the floodbanks/ raised roads and the extent of earth being removed from the existing floodbanks *[completed to concept level design stage in this report].* • Traffic engineering assessment/ report detailing the temporary and permanent effects on the safety and efficiency of the roads and recommending conditions of consent. • Potentially a brief Landscape Assessment report but it is likely this will not be necessary (addressing Policies 25.2.1.2, 30.2.7.1, and 30.2.9.5). • Potentially a brief Cultural Impact Assessment (or evidence of consultation and/ or affected person approval).
Discretionary Consents under the Regional Plan: Water.	** = *Items that will be the same or similar to that required by the QLDC.* • AEE**, covering all relevant matters listed in Rule 13.3.2.1 and Clause 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 raised roads/ floodbanks on the movement of water and sediment and on the existing road/ floodbanks; and o any effect of any flow and sediment processes *[completed to concept level design stage in this report].* • High risk EMP**. • Potentially a brief Landscape Assessment report** (addressing the values of the water body listed in Schedule 1 and the effects on natural character, amenity values, and any heritage values). • 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 plans, including plans showing the footprint, cross sections, and long sections of the floodbanks/ raised roads and the extent of earth being removed from the existing floodbanks** *[completed to concept level design stage in this report].*

<table>
<tr><th colspan="2">Consultation and affected parties</th></tr>
<tr><td>Combined consultation process for all district and regional council consents.</td><td>It is anticipated that consultation would be undertaken with the following entities as part of preparing the consent applications:
The owners of 5091 Glenorchy-Paradise Road, which adjoins the concept design)
QLDC
The Crown (via DOC and/ or LINZ)
Aukaha
Te Ao Marama
Fish and Game NZ
It is anticipated that Affected Person Approvals (APA) would be required from the following (and, if not obtained, that the application would likely be limited notified):
QLDC, as the owner of Glenorchy-Paradise Road
The Crown (via DOC and/ or LINZ), as the owner of the river and its margins, including the land on which Priory Road is located.
Aukaha
Te Ao Marama
The owners of 5091 Glenorchy-Paradise Road
Potentially Fish and Game NZ</td></tr>
<tr><th colspan="2">Notification and the need for a hearing</th></tr>
<tr><td></td><td>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.

Similarly, while Rule 13.3.2.1 of the RWP states that consents for the alteration, replacement or reconstruction of any structure on the bed of a river will be processed on a non-notified basis, the other consents required under the RWP for this project may be notified.

Therefore the ORC and QLDC are able to notify the consents if that is deemed necessary.

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 APAs outlined above are not obtained, it is likely that the consents will be limited notified to those persons whose APAs have not been obtained.</td></tr>
</table>

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 Section 5.8 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 and at current hourly charge out rates.
- 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 cost range for obtaining the necessary consents are as follows:

- $54,000.00 excl. GST (under a non-notified scenario)
- $63,000.00 excl. GST (under a limited notified scenario)
- $72,000.00 excl. GST (under a publicly notified scenario).

The cost 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 5.8), stakeholder engagement, obtaining APAs, and project management
- QLDC processing costs
- ORC processing costs
- The drafting of S 42A reports and consent decisions.

The cost estimates do not include any appeal costs following the issuing of the decisions.