Assessment of Floodplain Intervention Options – Dart River

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Otago Regional Council

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Executive Summary

The Issue

The floodplains and delta associated with the Dart and Rees Rivers at the head of Lake Wakatipu are subject to both flooding and erosion hazards. These hazards affect the communities in the area, partly due to disruptions in access via Kinloch Road. The landscape scale geomorphic changes occurring in the area coupled with future climate change effects mean that these hazards are increasing over time.

Kinloch Road can be closed due to inundation by floodwaters from the Dart River overflowing its right bank and consequential flood-related damage. The frequency of flood inundation is expected to increase in the future. The trend is likely to be exacerbated by climate change effects including an increasing magnitude and frequency of storm events and potential increases in sediment supply

The road is also threatened by bank erosion on the right bank. The current westerly migration of the active river channel belt along the right bank is expected to continue in the future due to the transverse slope across the riverbed. Since the 1960s, the long-term bank erosion rate has been greater than 10 m/year in places and could be up to 50 m/year if a series of consecutive large flood events occurred.

The Queenstown Lakes District Council (QLDC) owns and maintains the existing Dart River rockfill protections. The Otago Regional Council (ORC) has provided a one-off contribution to the rockfill works. 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.

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. The workshop was provided a “first-pass” review of possible flood 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 Dart River floodplain and in particular for Kinloch Road to address the flood erosion hazards. The objectives of the assessment were to provide an evidence base to rule out various intervention options and to identify viable options. All options were also tested for their alignment with a Nature-based Solutions (NbS) approach to floodplain management (refer Section 3).

What We Did

We conducted an assessment of the main flood-related hazards on the right bank floodplain of the Dart River, which consist of:

- Flooding of farmland and Kinloch Road.
- Loss of farmland and potential undermining or loss of Kinloch Road due to river migration and scour.

To facilitate the hazard assessment and the development of potential floodplain intervention measures, we created a simple hazard classification system. Each hazard was evaluated based on a set of assessment parameters and classified into four categories of increasing severity. This classification helped in selecting and prioritizing interventions.

Kinloch Road is considered critical infrastructure as it is the only external link for the communities at the head of Lake Wakatipu. No other significant impacts were identified on the Dart River's right floodplain, which primarily consists of low productivity farmland. Mitigating flooding in the farmland between Kinloch Road and the active river channel would require constructing a 6 km long stopbank system, which would be highly vulnerable to lateral erosion. Therefore, intervention options focused on mitigating river migration, preventing the loss of Kinloch Road, and reducing the rate of farmland loss between the road and the river.

The effectiveness of implementing different floodplain intervention options to mitigate bank erosion were investigated, including both “soft” and “hard” solutions.

“Soft” solutions consisted of vegetation buffers of willow plantings. Considering the high bank erosion rates, the buffers were set away from the current active river channel edge. Although it would be possible to use other tree species, including native ones, willows were selected due to their rapid growth rate and extensive tree root system.

“Hard” solutions consisted of rock protection works, including revetment and short groynes. These solutions were selected in the areas of high bank erosion rates where Kinloch Road is close to the active river channel edge.

The effectiveness of these potential floodplain intervention options was assessed against a range of factors:

- Current rates of lateral channel migration and bank retreat.
- The proximity of the existing right bank to Kinloch Road.
- The river flooding and surface erosion hazard to Kinloch Road.
- The previous performance of existing protection works to bank erosion and lateral channel migration hazards.
- The development time for soft bioengineered protections to become effective against bank erosion and lateral channel migration hazards.
- The minimum space required for the establishment of soft bioengineered protections.
- The proximity of new works to existing hard engineered protections.

The intervention options considered are not effective in mitigating flooding or surface erosion of the Dart River right floodplain or Kinloch Road during floods. Although specific road-raising solutions were not developed for Kinloch Road, the sections of the roadway that would need to be raised to address this hazard have been identified.

What We Selected

A concept-level intervention option was selected as a short-to-medium term solution to address the erosion hazards affecting Kinloch Road. This option involves an optimised mix of soft bioengineered (vegetation buffers) and hard engineered (rock revetment) protections.

Soft solutions are vulnerable to erosion during floods and will require significant active maintenance if implemented. The intervention options considered also do not offer a long-term solution, as river aggradation and future climate change effects will lead to increasing hazards over time.

A two-dimensional computational hydraulic model of the Rees-Dart River system was used to assess the effect of the selected vegetation buffers on floodplain flows. There was negligible change in floodplain depths and extents since vegetation buffers do not constitute a continuous flow barrier. However, the increased surface roughness resulted in lower velocities through the buffer area (with a reduction of approximately 50% of the base velocity), which would contribute to reduce surface erosion within the buffer during floods.

The following concept-level design information was developed for the selected intervention option:

- Concept-level drawings (refer to Appendix B).
- Indicative construction costs.
- Preliminary review of design and construction considerations.
- Preliminary review of consenting requirements.
- Issues and further works to prepare for any future detailed design phase.

Refer to Sections 4 and 5 of this report for further detail and discussion on the above.

Model results for a series of flood scenarios in combination with possible future riverbed geometries accounting for aggradation were also used to analyse the current likelihood and severity of Kinloch Road flooding.

Next Steps

It is understood that the information contained in this report, regarding intervention options for protecting Kinloch Road in the short-to medium term, will be reviewed by ORC and QLDC and taken forward as required for community consultation and engagement. Following on from consultation, if Council and the community decide they wish to pursue the concept-level intervention option presented in this report to another stage, then additional work will be required to develop a detailed design for resource consent application and construction purposes.

Contents

1 Introduction ... 8
1.1 Background ... 8
1.2 Purpose of this Report ... 8
1.3 Report Structure ... 9
1.4 Level Datum & Coordinate System ... 9
1.5 Limitations ... 9
1.6 Infrastructure Ownership and Responsibilities ... 10

2 Analysis of the Dart River Floodplain Flood Hazards ... 11
2.1 River Setting and Flood Hazard Overview ... 11
2.2 River Geomorphology ... 12
2.2.1 Migration ... 12
2.2.2 Aggradation ... 16
2.3 Flood Hazard Assessment ... 16
2.3.1 Flood Frequency and Climate Change ... 16
2.3.2 Road Flooding Hazard ... 17
2.3.3 Road Surface Erosion Hazard ... 21
2.3.4 Road Undermining Hazard ... 22
2.4 Hazard Classification ... 22

3 Nature-based Solutions ... 25
3.1 Background ... 25
3.2 NbS Integration to Dart River Floodplain Intervention Options ... 25

4 Assessment of Floodplain Intervention Options ... 26
4.1 Possible Intervention Options Identified in 2022 Adaptation Workshop ... 26
4.2 Selection of Intervention Options ... 26
4.2.1 Scope ... 26
4.2.2 Migration Hazard ... 27
4.2.3 Road Flooding and Surface Erosion Hazard ... 27
4.3 Existing Erosion Protections ... 29
4.3.1 Rockfill Protections ... 29
4.3.2 Vegetation Planting ... 30
4.4 Assessment of Erosion Protection Options ... 34
4.4.1 Overview ... 34
4.4.2 Selection of Protection Type ... 34
4.4.3 Selected Protections and Prioritisation ... 35
4.5 Effects of Selected Option ... 36
4.5.1 Numerical Hydraulic Modelling Overview ... 36
4.5.2 Road Flooding Results ... 37
4.5.3 Effect of Vegetation Buffers ... 38

5 Concept Design ... 40
5.1 Rockfill Protections ... 40
5.1.1 Concept Design Assumptions ... 40

5.1.2 Scope of Works 41
5.1.3 Long-Term Resilience 41
5.2 Vegetation Buffers 42
5.2.1 Concept Design Assumptions 42
5.2.2 Scope of Works 43
5.2.3 Use of Native Species 44
5.2.4 Long-Term Resilience 44
5.3 Potential Environmental Impacts 45
5.4 Consenting Requirements 46
5.5 Indicative Costings 47
5.6 Further Work for Detailed Design Phase 49
6 Conclusions 50
7 References 52

List of figures

Figure 2.1: Flood inundation of Kinloch Road in a 2019 flood event. Dart River floodplain viewed looking upstream. 12
Figure 2.2: Migration of active river channel edge from 1966 to 2023 (road chainages marked for reference). 13
Figure 2.3: Distance from Kinloch Road to active river channel edge from 1966 to 2023. 14
Figure 2.4: Active river channel migration rates and location of existing bank erosion protection works. 15
Figure 2.5: a) Kinloch Road centreline level and water surface level along active river channel for 1:100 AEP flood event assuming a +1.0 m average increase in riverbed elevation due to sediment aggradation; b) Difference between road elevation and water surface elevation. 18
Figure 2.6: Maximum depth of flooding on Dart River floodplain with current riverbed levels. 19
Figure 2.7: Maximum flooding depths on Kinloch Road. 20
Figure 2.8: Maximum depth-averaged water velocities on Kinloch Road. 21
Figure 3.1: Nature-based Solutions for flood risk management functions 25
Figure 4.1: Existing rockfill protection A4 between road chainages 7,800 and 8,030 m. 30
Figure 4.2: Evolution of vegetated earthfill bund at road chainage 2,500 m. 32
Figure 4.3: Evolution of B1 vegetation protection at approximate road chainage 5,350 m. 33
Figure 4.4: Effect of vegetation buffer on floodplain flow velocities. 38
Figure 5.1: Typical rip-rap revetment section. 40
Figure 5.2: Typical groyne section. 41
Figure 5.3: Willow pole planting and debris fences made of biodegradable materials. 43
Figure 5.4: Willow pole planting and bioengineered groynes. 45

List of tables

Table 2.1: Flood peak discharge estimates for Dart and Rees Rivers........ 17
Table 2.2: Peak Lake Wakatipu water level estimates 17
Table 2.3: Hazard classification parameters and categories. 23
Table 2.4: Hazard classification for Kinloch Road. 24
Table 4.1: Approximate volume of fill material required to raise road above maximum water surface levels during various flood scenarios. 28
Table 4.2: Data for existing rockfill protections. 29
Table 4.3: Data for existing vegetation protections. 31
Table 4.4: Selected protections and proposed priority. 36
Table 4.5: Summary of hydraulic model simulations for assessment of floodplain interventions 37
Table 5.1: Preliminary construction cost estimates. 48

Appendices

Appendix A Hydraulic Model of Rees-Dart River

Appendix B Concept Design Drawings

Appendix C Relevant Statutory Planning Provisions

List of abbreviations

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

1 Introduction

1.1 Background

Otago Regional Council (ORC) engaged Damwatch Engineering Ltd (Damwatch)[1] to undertake a high-level assessment of potential floodplain intervention options for the Dart River floodplain and in particular for Kinloch Road.

Kinloch Road can be closed due to inundation by floodwaters from the Dart River overflowing its right bank, and consequential flood-related damage. Anecdotally, the frequency of flood inundation is increasing over time due to ongoing bed aggradation. This a trend is expected to continue in the future and is likely to be exacerbated by climate change effects including an increasing magnitude and frequency of storm events and potential increases in sediment supply.

The road is also threatened by bank erosion on the right bank. The current westerly migration of the active river channel belt along the right bank is expected to continue in the future due to the transverse slope across the riverbed. Since the 1960s, the long-term bank erosion rate has been greater than 10 m/year in places and could be up to 50 m/year if a series of consecutive large flood events occurred. Further detail on these hazards is provided in Section 1.5 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 invited technical experts. The workshop was provided a “first-pass” review of possible flood mitigation and floodplain management options.

This current study builds on the February 2022 workshop, providing an evidence base to assess the pros and cons of various flood intervention options and to identify a viable short to medium term option. The selected intervention option was taken forward to a concept-level design stage.

1.2 Purpose of this Report

This report summarises engineering investigations into potential floodplain intervention options to address the flood and erosion hazards affecting the Dart River floodplain and in particular Kinloch Road on the true right Dart River floodplain. This included investigation of alternatives incorporating Nature-based Solutions (NbS) for flood hazard and erosion mitigation. A viable option to mitigate erosion hazards at Kinloch Road was developed to a concept design level.

This study did not include an analysis of the potential for relocation of Kinloch Road, or the implementation of alternate access methods such as water taxis or helicopters. Non-flood-related hazards such as landslides or debris flows were also not considered.

The information contained in this report is intended to aid community consultation and future decision-making regarding flood and erosion hazards affecting Kinloch Road. If Councils and the community decide they wish to pursue the concept-level intervention option presented in this report to another stage, then

[1] With Vision Planning Consultants Ltd sub-contracted to Damwatch to provide planning review services (as outlined in Section 5.4 of this report).

additional work will be required to develop a detailed design for resource consent application and construction purposes.

1.3 Report Structure

This report is broken down into the following sections:

- Section 1, Introduction
- Section 2, Analysis of Kinloch Road Flood Hazards
- Section 3, Nature Based Solutions
- Section 4, Assessment of Floodplain Intervention Options
- Section 5, Concept Design
- Section 6, Conclusions
- Section 7, References

1.4 Level Datum & Coordinate System

All levels referred to in this report are 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.

1.5 Limitations

- This report provides a high-level assessment of potential floodplain intervention options to reduce erosion and flood hazards at Kinloch Road, including provision of a concept-level design for a viable short to medium term option. Further work will be needed to progress the concept-level design presented in this report to a detailed design stage and to support a resource consent application if a decision is made to proceed with it.
- The assessment used a two-dimensional (2D) computational hydraulic modelling approach to evaluate flood inundation extents for different flood magnitudes, climate change and bed aggradation scenarios. 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.
- Note that these potential floodplain intervention options were not intended to address the backwater flooding hazard to Kinloch and surrounding areas from high lake levels in Lake Wakatipu. The backwater flooding hazard is an entirely separate issue to the flood and erosion hazards associated with the Dart River. However, the rockfill protections and vegetation buffers discussed in this study are well outside of the areas that would be most impacted by lake level flooding.

1.6 Infrastructure Ownership and Responsibilities

The Queenstown Lakes District Council (QLDC) owns and maintains the existing Dart River rockfill protections. The Otago Regional Council (ORC) has provided a one-off contribution to the rockfill works. 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.

2 Analysis of the Dart River Floodplain Flood Hazards

2.1 River Setting and Flood Hazard Overview

The Dart and Rees Rivers flow into Lake Wakatipu at the head of the lake. The floodplains and combined delta of these rivers are subject to both flooding and erosion hazards, impacting the communities at the head of Lake Wakatipu partly due to disruptions in access via Kinloch Road. The landscape scale geomorphic changes occurring in the area, coupled with future climate change effects, will likely causing these hazards to increase over time.

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

- January 1994
- November 1999
- March 2019
- February 2020

The Dart River floodplain is frequently flooded due to high flows in the Dart and Rees River and/or high Lake Wakatipu levels. Figure 2.1 shows an aerial view of the Dart River floodplain during a moderate flood event. Figures A.5 and A.6 in Appendix A show aerial views of the floodplain during the significant March 2019 flood.

Flooding issues can be intensified by the following geomorphic and hydrological processes in the area:

- Actively aggrading riverbed levels.
- Actively migrating braided river channel belts.
- Progradation of the Dart-Rees River delta into the head of Lake Wakatipu.
- Future climate change effects which are likely to increase flood hazards over time.
- Possible increases in the sediment supply to the river system due to future climate change effects or following a major earthquake if it results in widespread co-seismic landslides.

Another critical hazard is the westerly migration of the Dart River's active channel belt towards the roadway due to rapid bank erosion over significant lengths of the right bank. In some locations, the active channel is currently hard against the road, requiring the construction of rockfill protection works. With continued westerly river channel migration and lateral bank retreat, long sections of Kinloch Road could be cut by erosion, resulting in a loss of road access to the Kinloch, Greenstone and Caples areas.

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

Figure 2.1: Flood inundation of Kinloch Road in a 2019 flood event. Dart River floodplain viewed looking upstream.

Source: Supplied by ORC

2.2 River Geomorphology

2.2.1 Migration

The Dart River's active channel belt[2] has progressively migrated westward since at least 1966 in response to major braid channels of the river being on the right side of the channel. Figure 2.2 shows the position of the edge of the active river channel in 1966, 2006, June 2019, October 2022 and November 2023[3]. This highlights the dynamic, changing nature of the Rees-Dart River System over a relatively short geomorphic period.

[2] The "active river channel belt" refers to the area of a river where water normally flows. The active river channel belt within the Rees and Dart River System refers to the constantly shifting and interconnected braided channels that make up this interconnected river system. During flood conditions, water can spill out of the active river channel and onto adjacent floodplains. Floodwaters in the Rees River also crossover into the Dart River via a currently active channel.

[3] 1966, 2006, 2019 and 2022 banklines derived by ORC from analysis of historical aerial photographs. 2023 bankline derived by Damwatch.

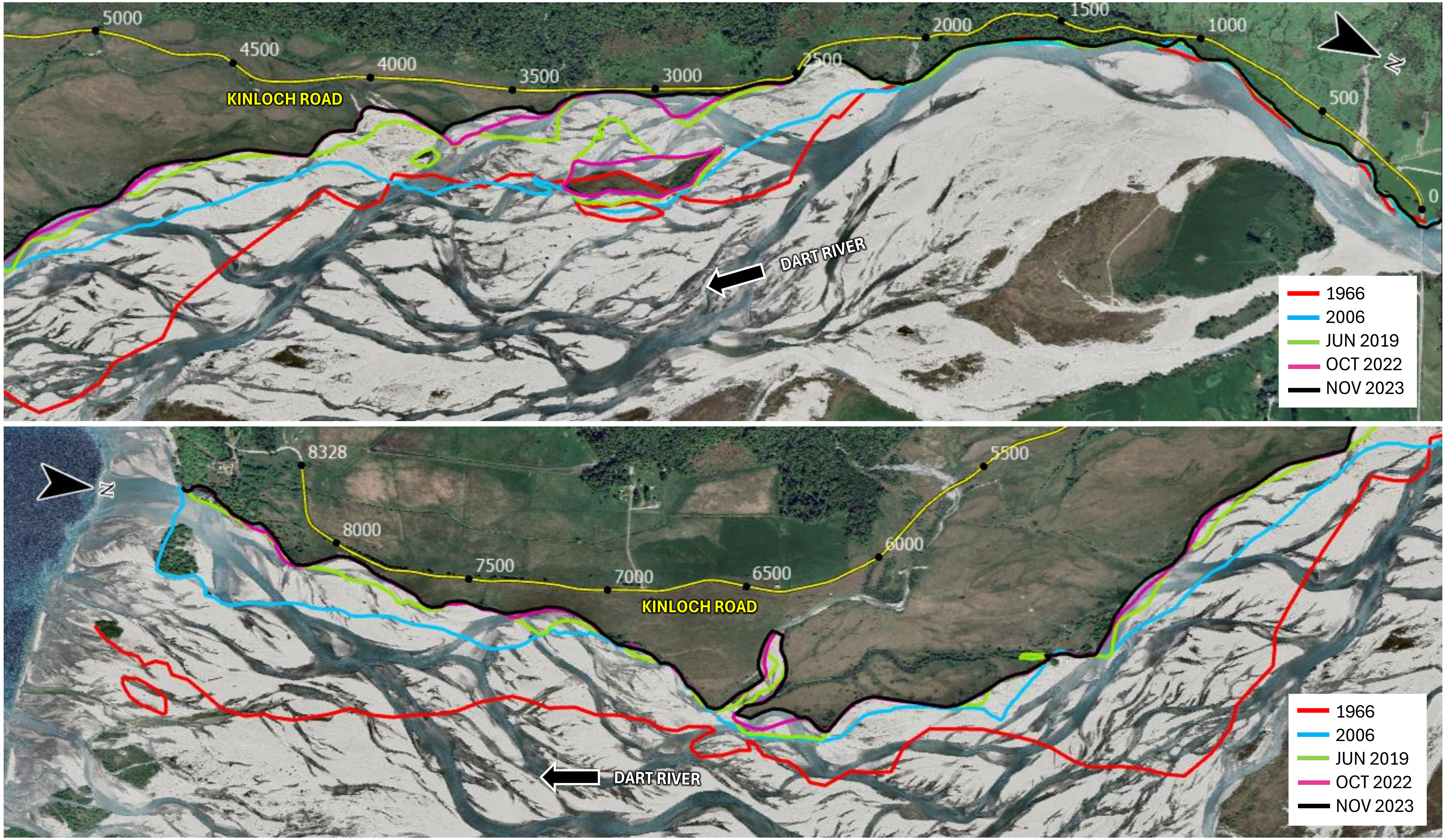


Figure 2.2: Migration of active river channel edge from 1966 to 2023 (road chainages marked for reference).

Source for background image: Google Earth

To evaluate the rates of erosion on the right Dart River floodplain, the approximate distance between Kinloch Road centreline and the active river channel edge was measured according to the banklines in 1966, 2006, 2019, 2022 and 2023. The data are presented in Figure 2.3. Distance was measured perpendicular to the road direction at 100 m intervals and is presented using the chainage system shown in Figure 2.2. Road chainages marked along the length of Kinloch Road were used to provide a longitudinal reference frame for these bankline to roadway distances (chainage 0 was defined at a point 1,230,020 mE 5,031,469 mN according to the NZTM coordinate system).

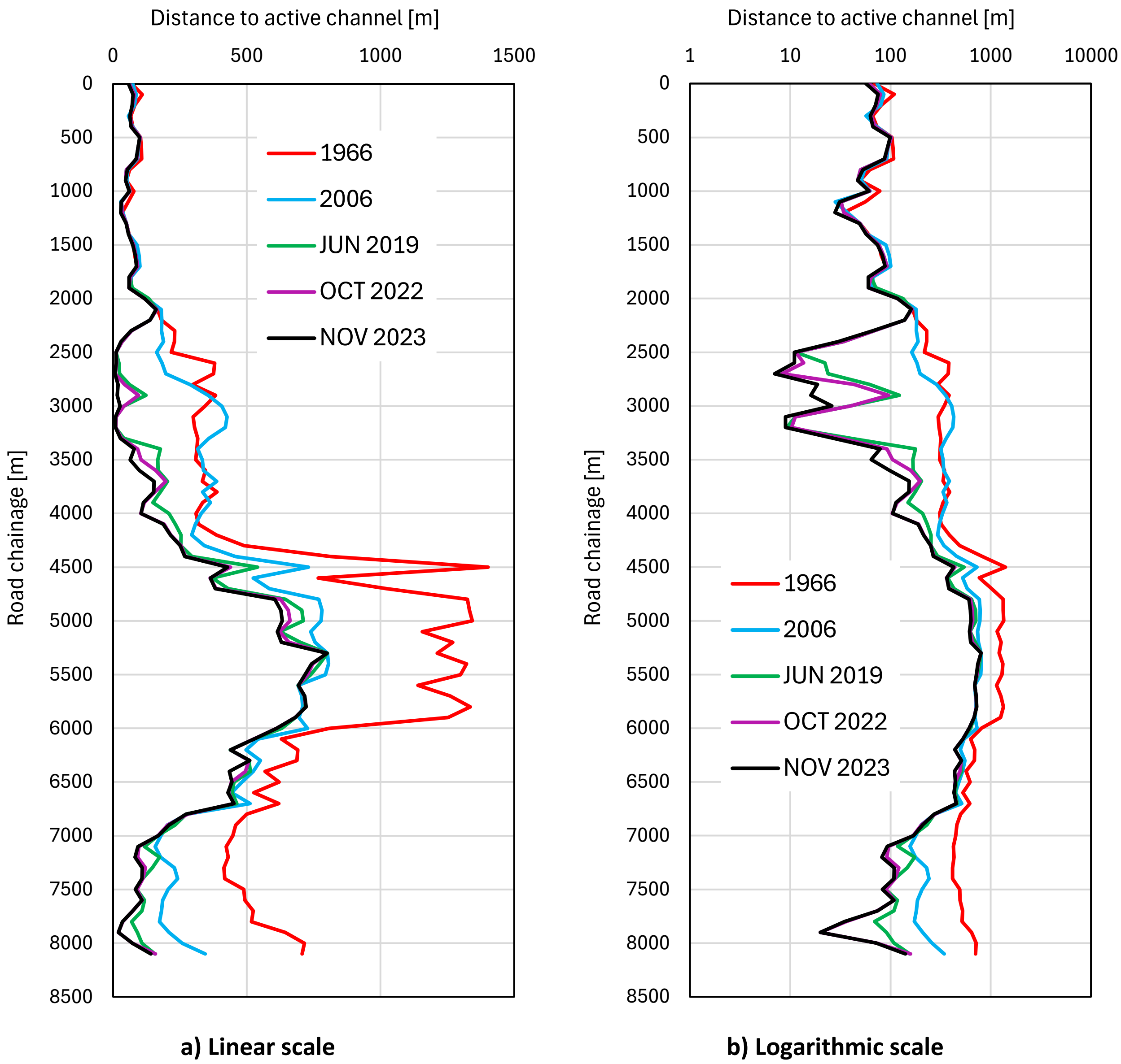


Figure 2.3: Distance from Kinloch Road to active river channel edge from 1966 to 2023.

Based on the distances measured, average migration rates for two periods were calculated:

- Long term rates, from 1966 to 2023.
- Short term rates, from 2006 to 2023.

The average bank migration or erosion rates are shown in Figure 2.4 in metres of lateral migration (in a direction perpendicular to Kinloch Road) per year. The location and construction years of existing scour protections (rip-rap revetments, groynes, and willow plantings), built to arrest erosion and protect Kinloch Road and the right bank floodplain, are also indicated.

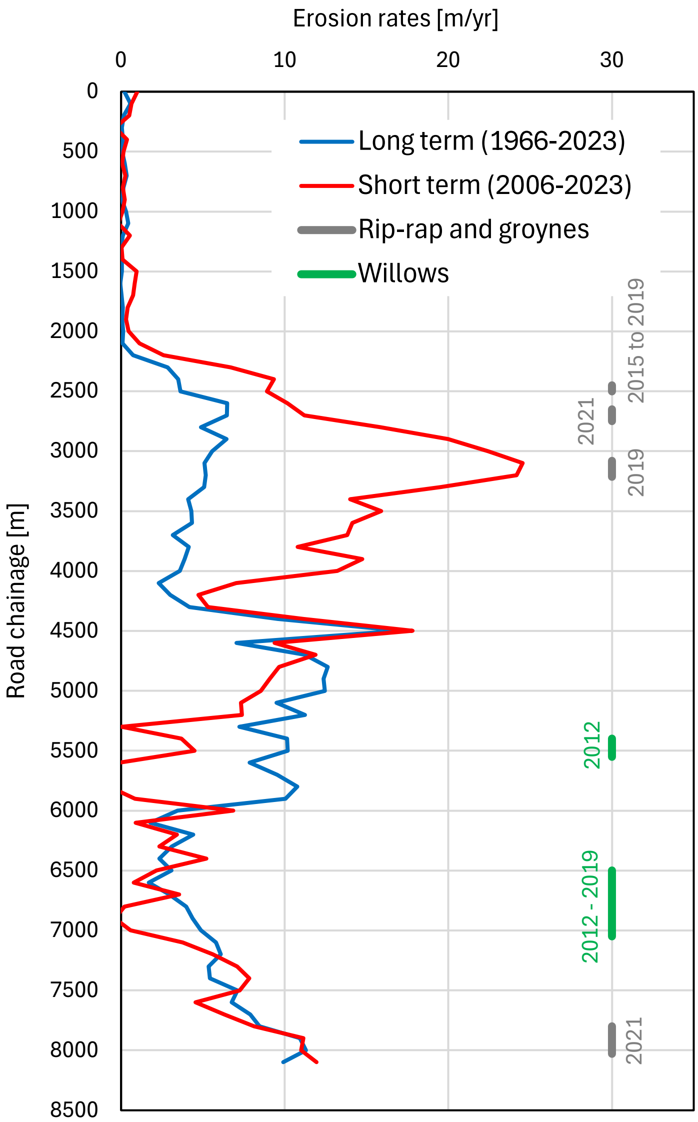


Figure 2.4: Active river channel migration rates and location of existing bank erosion protection works.

The data show that:

- Erosion rates between road chainages 0 and 2,100 m were low to negligible in the 1966-2023 period.
- Erosion rates between road chainages 2,100 and 4,300 m are accelerating. The active river channel edge is close, and in some areas adjacent, to Kinloch Road, which led to the construction of three sections of rip-rap revetment between 2015 and 2021.
- Erosion rates between road chainages 4,700 and 5,900 m are decelerating.
- Distance from Kinloch Road to the active channel edge between road chainages 4,800 and 6,700 m is approximately 500 m, and bank erosion has not progressed significantly since 2006.

- Erosion rates south of road chainage 7,200 m are relatively high, and distance from the road to the active channel edge is less than 100 m. Rapid erosion has led to the construction of a rip-rap revetment between chainages 7,800 and 8,030 m.
- The maximum yearly erosion rate in the analysis period was approximately 70 m/yr, which was measured at road chainage 2,900 m in the 2022-2023 period. Maximum long-term (1966-2023) erosion rates were approximately 17 m/yr. Maximum short-term (2006-2023) erosion rates were approximately 24 m/yr.

2.2.2 Aggradation

Recent river channel bed surveys by ORC have indicated that the active river channel of the Dart River is aggrading[4]. Two high-resolution Light Detection and Ranging (LiDAR) aerial surveys in 2011 and 2019 indicated that the average change in bed level generally increased in the order of 0.1 to 0.3 m over this period[5]. Such aggradation has the potential to exacerbate flooding of the Dart River floodplain and Kinloch Road. This is further discussed in Section 2.3.

2.3 Flood Hazard Assessment

2.3.1 Flood Frequency and Climate Change

The Hillocks flow gauging site on the Dart River (located near the Glenorchy-Routeburn Road crossing) has been maintained since June 1996. The Rees River has a recently installed flow gauging site near the confluence of the Invincible Creek with the Rees River, measured since December 2021.

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. Flood frequency estimates for the Dart River including the 1:100 Annual Exceedance Probability (AEP) flood were obtained using a partial duration analysis of the 150 highest independent peak flood events with a threshold of 612 m^3/s in the June 1996 to December 2021 flow record. An estimate for the 1:100 AEP plus climate change flood given in ORC (2021) was obtained using a rainfall/runoff routing approach.

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

[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.

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

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

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

Table 2.2: Peak Lake Wakatipu water level estimates

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

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

2.3.2 Road Flooding Hazard

As discussed in Section 2.1, Kinloch Road may be flooded during even moderate floods (see Figure 2.1). Kinloch Road currently gets flooded whenever flows in the Dart River reach a threshold of about 500 m^3/s based on the Dart at Hillocks flow gauge (Damwatch, 2022). On-going bed aggradation in the Dart River and climate change effects will likely result in increased flooding frequency in the future.

An assessment of the likelihood and severity of flooding along Kinloch Road was undertaken based on the results of two-dimensional computational hydraulic numerical model simulations. A range of flood, climate change and bed aggradation scenarios for the Dart and Rees River System were considered (refer to Section 4.5.1 and Appendix A for a discussion of the computational hydraulic modelling approach). The following scenarios were considered:

- 1:20 AEP flood, current riverbed surface.
- 1:50 AEP flood, current riverbed surface.
- 1:100 AEP flood, current riverbed surface.
- 1:100 AEP flood, +0.2 m of average riverbed aggradation (simulating the active riverbed surface in approximately 10 years time or c. 2030).

- 1:100 AEP flood, +0.4 m of average riverbed aggradation (simulating the active riverbed surface in approximately 20 years time or c. 2040).
- 1:100 AEP flood, +1.0 m of average riverbed aggradation (simulating the active riverbed surface in approximately 50 years time or c. 2070).

The effect of higher lake levels near the Kinloch township was within the scope of this study.

Figure 2.5 compares Kinloch Road and water surface levels for the 1:100 AEP flood scenario, assuming a +1.0 m average lift in the surface of the active river channel belt due to bed aggradation, using the chainage system shown in Figure 2.2. The road is well above estimated flood levels between chainages 200 and 2,200 m, and therefore the flood risk is negligible in this area. At its highest point at chainage ~1500 m, the road is 32 m above the flood surface level. Over the remaining length of road, estimated flood levels are above road levels for most of the distance except isolated locations (refer to detailed assessment below).

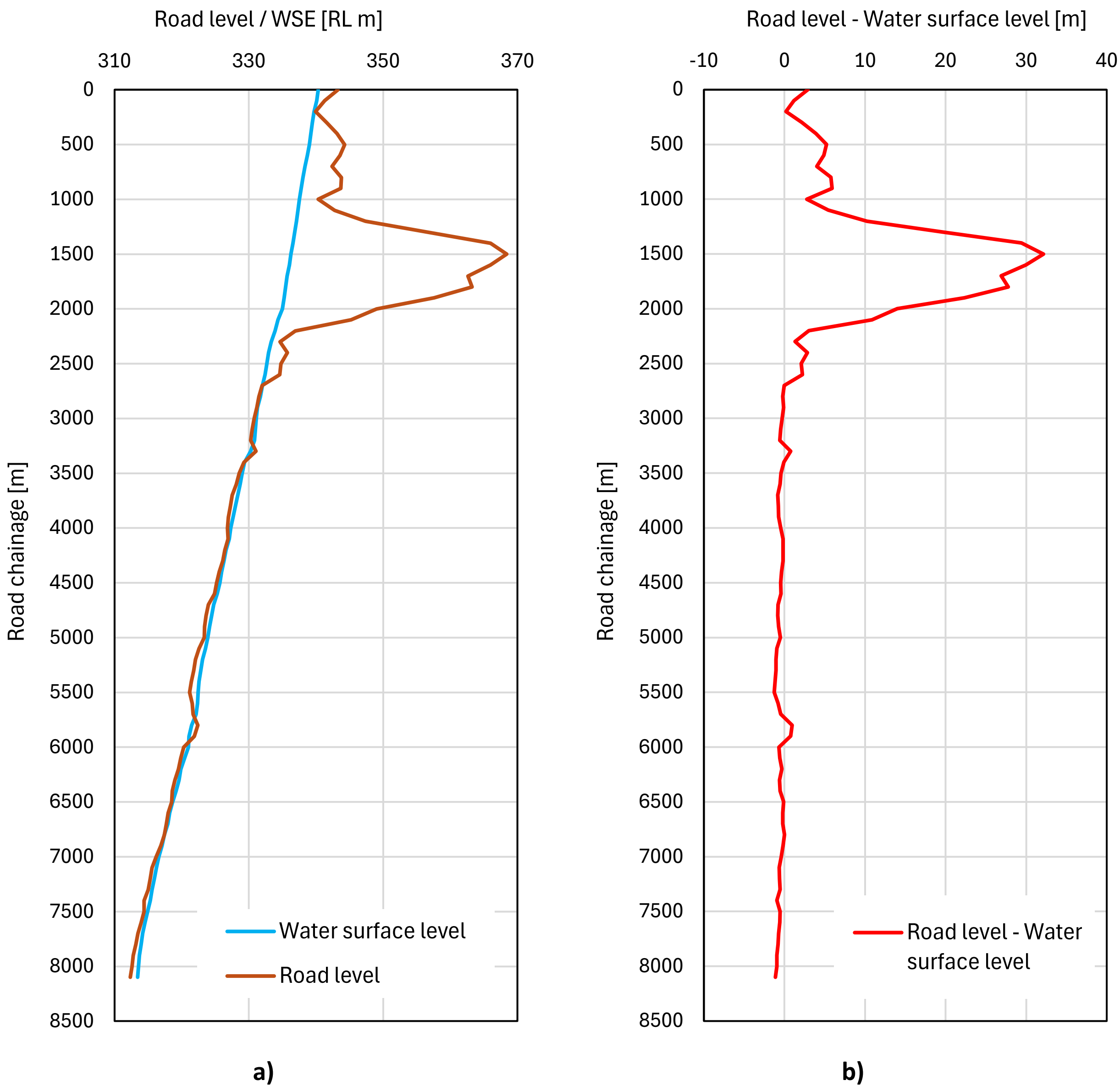
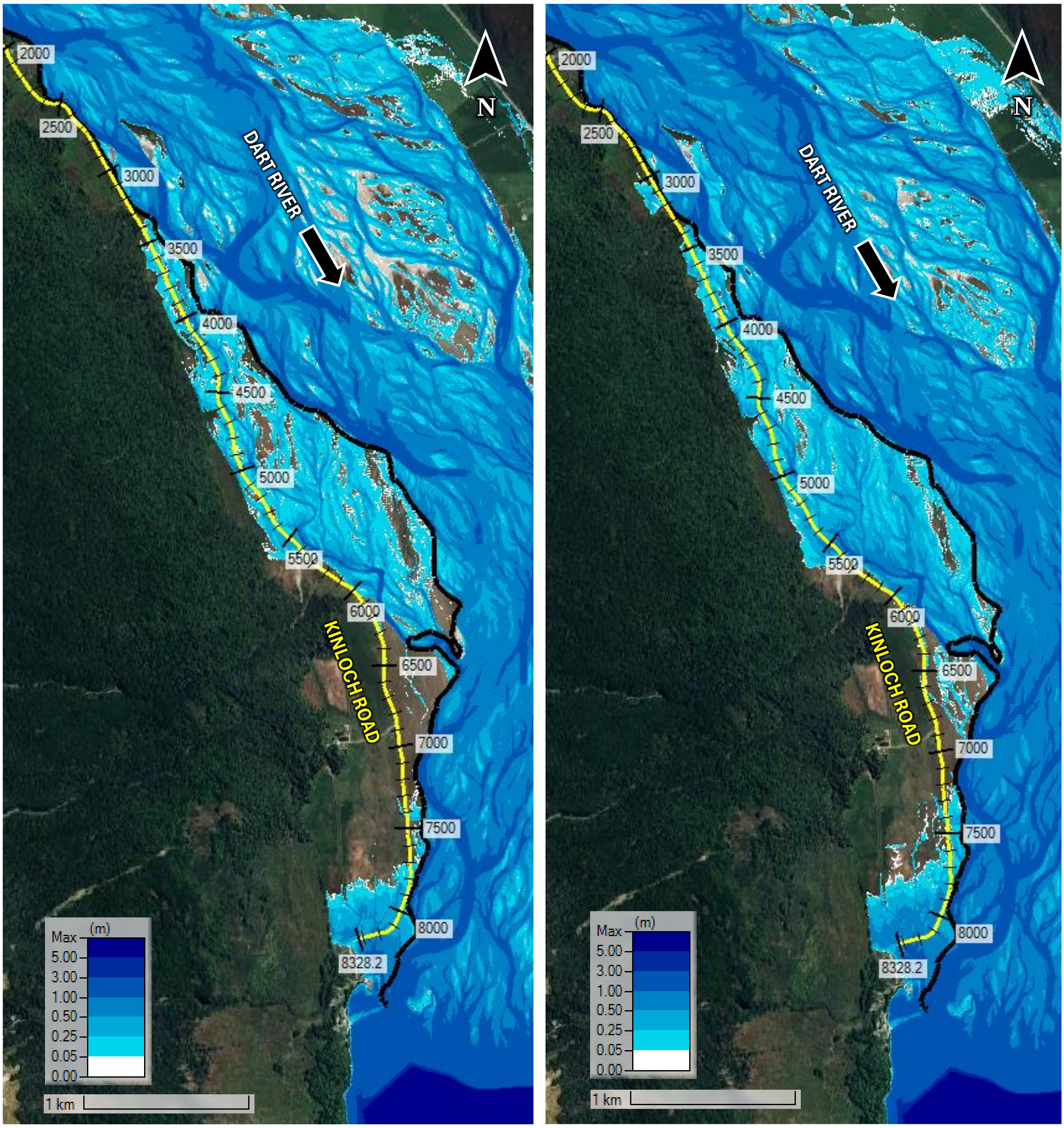


Figure 2.5: a) Kinloch Road centreline level and water surface level along active river channel for 1:100 AEP flood event assuming a +1.0 m average increase in riverbed elevation due to sediment aggradation; b) Difference between road elevation and water surface elevation.

Flooding depths along the road centreline were extracted from the hydraulic numerical model results for all scenarios at 100 m intervals. In some cases, Kinloch Road is set slightly higher than the surrounding floodplain, and is therefore not flooded despite the river breaking out of the active river channel into the floodplain. This is possibly the result of previous road raising efforts to reduce flooding frequency.

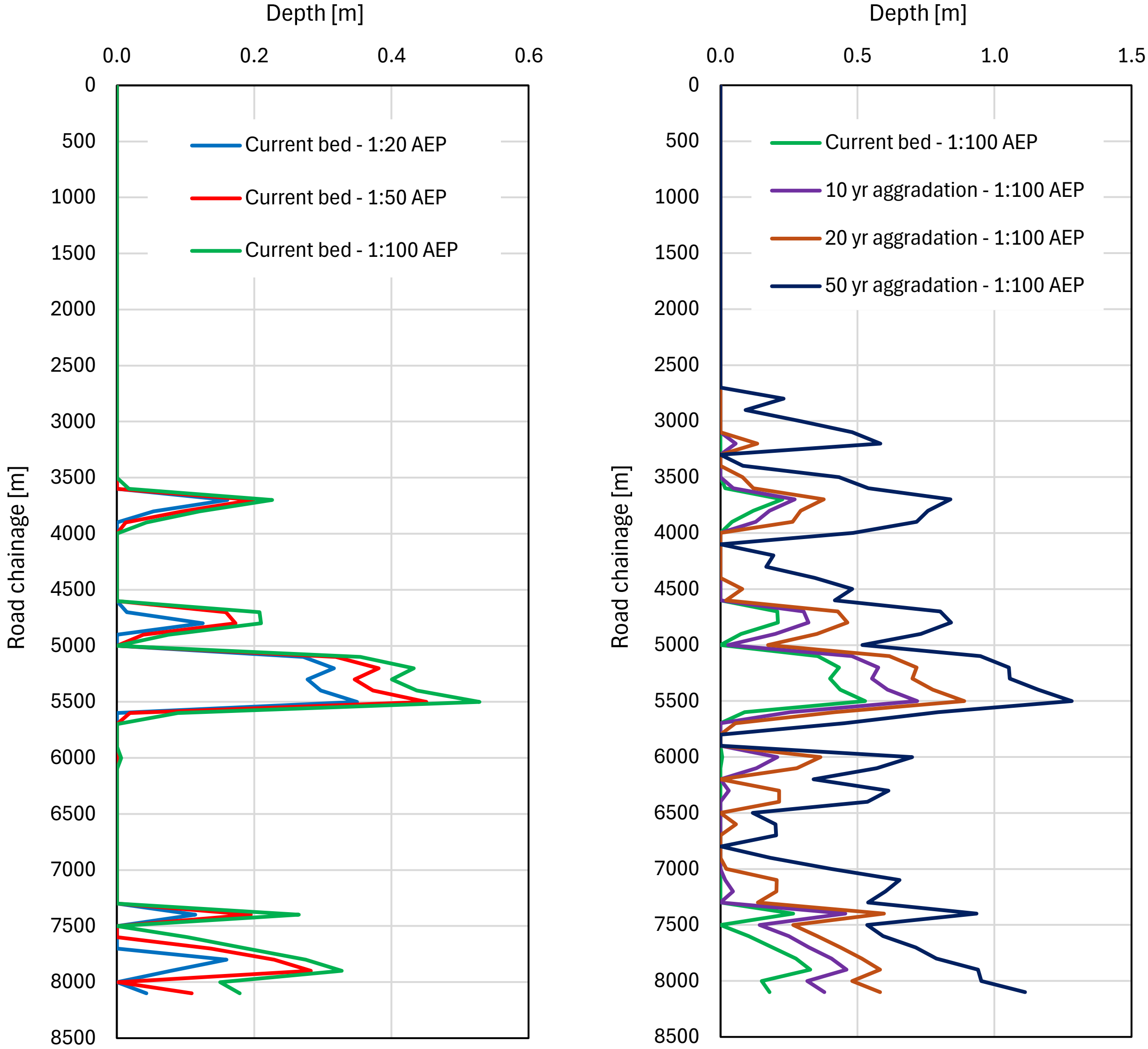
Figure 2.6 shows the maximum flooding depths on the Dart River true right floodplain for two scenarios: a 1:20 AEP flood (Figure 2.6.a) and a 1:100 AEP flood (Figure 2.6.b). In both cases, the current riverbed surface was used.



a) 1:20 AEP flood **b) 1:100 AEP flood**

Figure 2.6: Maximum depth of flooding on Dart River floodplain with current riverbed levels.

Estimated water depths on Kinloch Road, measured at 100 m intervals along the road for all scenarios, are shown in Figure 2.7. Considering the current riverbed surface, flood inundation is limited to three sections: chainages 3,500 to 4,000 m, 4,600 to 5,600 m, and south of chainage 7,300 m. In scenarios with a high degree of riverbed aggradation, the majority of the road south of chainage 2,700 m was flooded.



a) Current riverbed surface **b) Different riverbed aggradation scenarios**

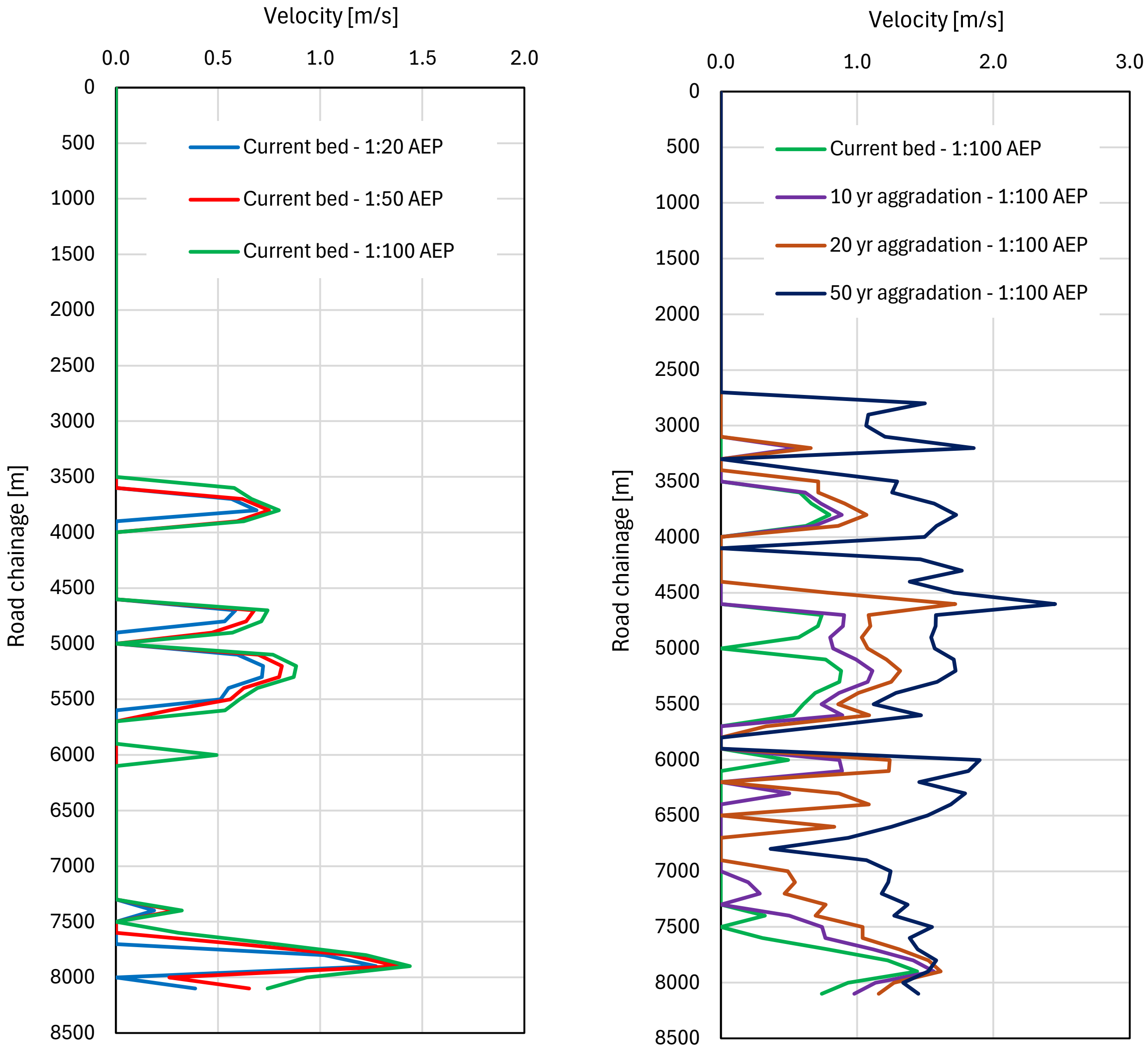
Figure 2.7: Maximum flooding depths on Kinloch Road.

This assessment was based on a Digital Elevation Model (DEM) created using data from the 2019 and 2022 LiDAR surveys (see Figure A.1 in Appendix A). The 2022 survey did not cover the area of the road from chainages 3,720 to 3,950 m, and from 4,600 to 6,200 m. Consequently, it may not reflect any recent road raising carried out since 2019. A new survey of road surface levels would need be conducted to confirm the road flooding hazard.

2.3.3 Road Surface Erosion Hazard

High flow velocities could potentially cause erosion and damage to the road embankments based on typical allowable velocities for gravel channels (USDA, 2007). Flow velocities on Kinloch Road, measured at 100 m intervals along the road for all scenarios, are shown in Figure 2.8.

Although useful for identifying the sections with the highest likelihood of road erosion, this parameter is a partial indicator of the road erosion hazard. In cases where the road is higher than the surrounding terrain, floodwaters may be deflected by the road and the consequential flow adjacent to the road may be faster than on the road. This deflected higher velocity flow could lead to lateral erosion of the road embankment. The assessment of the threshold conditions (flow velocities[6] or shear stresses) for Kinloch Road at which erosion of road embankment materials would be likely to occur would require the characterisation of the road embankment and surface materials, and was outside the scope of this study. However, flow velocities below 0.6 m/s are unlikely to cause significant erosion.



a) Current riverbed surface **b) Different riverbed aggradation scenarios**

Figure 2.8: Maximum depth-averaged water velocities on Kinloch Road.

[6] The *threshold or critical velocity* is the flow velocity below which erosion rates are negligible.

The duration of road inundation may also influence the potential for road erosion. The lowest points on the road may be flooded for over two days during rare floods, increasing the likelihood of damage to the road surface or embankment.

2.3.4 Road Undermining Hazard

As discussed in Section 2.2.1, the Dart River's active channel has rapidly migrated westward since 1966, resulting in the progressive loss of farmland. Additionally, the edge of the active river channel is now close to Kinloch Road in some locations, leading to the ongoing construction of rockfill revetments and groynes (refer to Section 4.3). Failure of these rockfill protections or rapid river migration in unprotected areas during a flood could result in the lateral erosion of the road embankment, potentially undermining Kinloch Road and blocking access to the communities at the head of Lake Wakatipu.

2.4 Hazard Classification

To facilitate the assessment of hazards to Kinloch Road and the development of possible floodplain intervention works, a simple hazard classification system was developed.

Each hazard (e.g., loss of road due to river migration) was evaluated according to a set of assessment parameters (e.g., distance from road to active river channel edge). The assessment parameters were classified into four categories of increasing hazard. In all cases, category 1 (colour coded in red) represents the highest hazard and category 4 (colour coded in green) the lowest.

The hazard classification system used is summarised in Table 2.3.

Note that there is no alternative assessment framework available in the literature that we are aware of to undertake such an assessment.

Table 2.3: Hazard classification parameters and categories.

Hazard	Parameter	Proportional to	Category	
Loss of road due to active channel migration / lateral erosion	Distance to active river channel edge	Time available for effective intervention and availability of space for “soft” solutions	1	< 30 m
			2	> 30 m
			3	> 70 m
			4	> 200 m
	Migration rate (2006 – 2022 period)	Time available for effective intervention	1	> 15 m/yr
			2	> 10 m/yr
			3	> 5 m/yr
			4	< 5 m/yr
Road flooding	Likelihood of most frequent event which floods the road	Vulnerability to flooding and frequency of road closure events	1	Flooded in 1:20 AEP or lesser events, current riverbed
			2	Flooded in 1:50 AEP event, current riverbed
			3	Flooded in 1:100 AEP event, current riverbed
			4	Flooded in 1:100 AEP event, 20-year aggradation or greater
	Water depth on road (1:100 AEP, +1.0 m average bed aggradation scenario)	Hazard to users and magnitude of road raising required to prevent flooding	1	> 0.8 m
			2	> 0.4 m
			3	> 0 m
			4	= 0 m (no flooding)
Road surface erosion	Flow velocity on road (1:100 AEP, +1.0 m average bed aggradation scenario)	Likelihood of road erosion and need for maintenance post flooding	1	> 1.8 m/s
			2	> 1.2 m/s
			3	> 0.6 m/s
			4	< 0.6 m/s

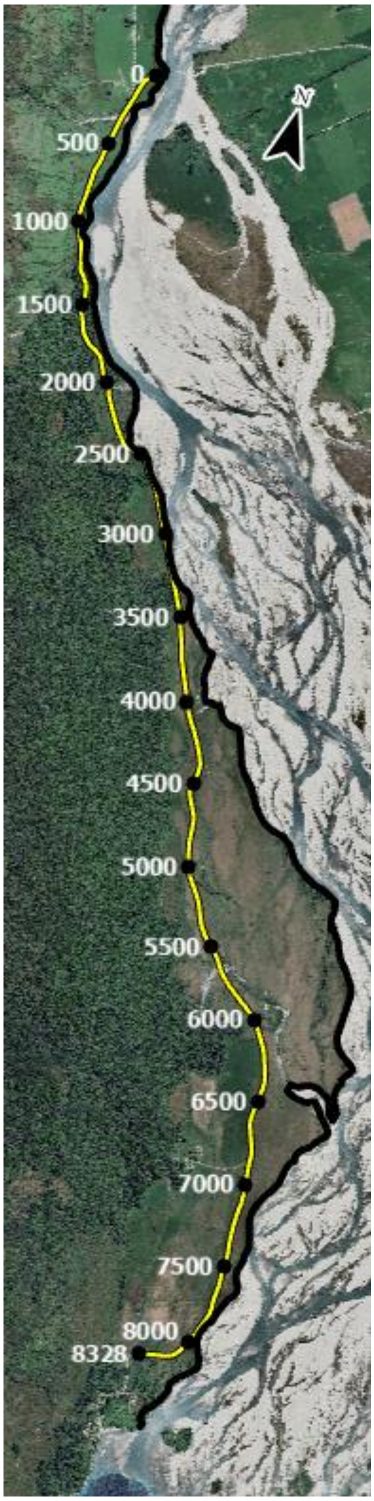
The hazard analysis results are summarised in Table 2.4. Although in some cases the selection of thresholds for each category is based on judgement of a suitable parameter, the assessment serves to illustrate how each hazard varies along the road.

No significant riverbank migration was observed north of chainage 2,100 m since 1966, and Kinloch Road is set well above the maximum water level for a 1:100 AEP flood. This section was therefore excluded from the hazard analysis.

Table 2.4: Hazard classification for Kinloch Road.

CH [m]	Hazard				
	Migration / Lateral erosion		Flooding		Surface erosion
	Distance	Rate	Likelihood	Depth	Velocity
2100	3	4	4	4	4
2200	3	4	4	4	4
2300	2	3	4	4	4
2400	1	3	4	4	4
2500	1	3	4	4	4
2600	1	2	4	4	4
2700	1	2	4	4	4
2800	1	1	4	3	2
2900	1	1	4	3	3
3000	1	1	4	3	3
3100	1	1	4	2	2
3200	1	1	4	2	1
3300	1	1	4	4	4
3400	3	2	4	3	3
3500	2	1	4	2	2
3600	3	2	3	2	2
3700	3	2	1	1	2
3800	3	2	1	2	2
3900	3	2	2	2	2
4000	3	2	4	2	2
4100	3	3	4	4	4
4200	4	4	4	3	2
4300	4	3	4	3	2
4400	4	2	4	3	2
4500	4	1	4	2	2
4600	4	3	4	2	1
4700	4	2	1	1	2
4800	4	3	1	1	2
4900	4	3	2	2	2
5000	4	3	4	2	2
5100	4	3	1	1	2
5200	4	3	1	1	2
5300	4	4	1	1	2
5400	4	4	1	1	2
5500	4	4	1	1	3
5600	4	4	2	2	2
5700	4	4	4	2	3
5800	4	4	4	4	4
5900	4	4	4	4	4
6000	4	3	3	2	1
6100	4	4	4	2	1
6200	4	4	4	3	2
6300	4	4	4	2	2
6400	4	3	4	2	2
6500	4	4	4	3	2
6600	4	4	4	3	2
6700	4	4	4	3	3
6800	4	4	4	3	4
6900	4	4	4	3	3
7000	3	4	4	2	2
7100	3	4	4	2	2
7200	3	3	4	2	3
7300	3	3	4	2	2
7400	3	3	1	1	2
7500	3	3	4	2	2
7600	3	4	3	2	2
7700	3	3	2	2	2
7800	2	3	1	2	2
7900	1	2	1	1	2
8000	3	2	2	1	2
8100	3	2	1	1	2

Road chainage:



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.

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

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

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

Source: ADB (2022)

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

3.2 NbS Integration to Dart River Floodplain Intervention Options

Floodplain intervention options for the Dart River were considered in terms of their alignment with Nature-based Solutions. Where possible, "soft" NbS solutions were developed and tested.

Refer to the following Section 4 of this report for further discussion.

4 Assessment of Floodplain Intervention Options

4.1 Possible Intervention Options Identified in 2022 Adaptation Workshop

The 2022 Adaptation Workshop identified the following possible intervention options (Damwatch, 2022):

- Localised bank protection works and localised road raising.
- Large-scale erosion protection of flood mitigation structures.
- Active river management to keep the river away from the road.
- Temporary 4-wheel drive vehicle access across private land when the existing road is blocked.
- Permanent relocation of the road within the floodplain.
- Permanent relocation of the road to the valley side-slopes.
- Alternative means to road access (e.g., boat and air access).
- Temporary access across the lake as an emergency measure.

The first intervention option represents the current reactive management strategy.

The Workshop noted several significant challenges with the second intervention option:

- Any large-scale structures may only have a limited lifespan due to ongoing bed aggradation.
- The approach would do nothing to address the flood inundation problem.
- The type of intervention would be expensive.

The Workshop also noted several significant challenges with the third intervention option:

- The dynamic behaviour of the river system would make the approach difficult to implement.
- The approach would require large scale and continuous channel modification works which would be environmentally damaging.
- There is high chance that any works would be ineffective in the short term and likely unsustainable in the long-term.
- The ongoing cost would be very high.
- The approach would do nothing to address the flood inundation problem.

While the first two intervention options were of relevance to the current investigation, all other intervention options identified in the Workshop were excluded from consideration.

4.2 Selection of Intervention Options

4.2.1 Scope

Kinloch Road is considered critical infrastructure as it is the only external link for the communities at the head of Lake Wakatipu. No other significant impacts were identified on the Dart River's right floodplain, which primarily consists of low productivity farmland. Mitigating flooding in the farmland between Kinloch Road and the active river channel would require constructing a 6 km long stopbank system, which would be highly vulnerable to lateral erosion. Therefore, intervention options focused on mitigating river migration, preventing the loss of Kinloch Road, and reducing the rate of farmland loss between the road and the river.

The intervention options considered are not effective in mitigating flooding or surface erosion of Kinloch Road during floods. Although specific road-raising solutions were not developed, the sections of the roadway that would need to be raised to address this hazard have been identified (refer to Section 2.3).

4.2.2 Migration Hazard

River channel migration is mainly driven by the combination of riverbank erosion and sediment deposition, particularly during episodic flood events. On shallow banks, such as those at the edge of the Dart River's active braid channels, erosion primarily progresses when shear forces exerted by fast-flowing water exceed the resistance of the bank material, causing it to weaken and detach. Undermining of channel banks by bed scour is a secondary erosion mechanism. Controlling or slowing down river channel migration rates thus requires the protection or stabilisation of the riverbanks.

Erosion protection approaches are typically classified into two broad groups:

- "**Hard solutions**". These involve placing revetments or other structures built using conventional engineering materials (such as rockfill or concrete) on the banks. These protection works are generally sturdy and, as long as they are well founded, have a high capacity to withstand erosion. They form a hard boundary to resist lateral river channel migration if properly designed. However, they are generally costly.
- "**Soft solutions**". These involve managing erosion through bioengineered protections, such as tree or vegetation planting. These protections form a buffer between active river channels and their floodplains. The roots of planted vegetation bind the soil together, stabilising the banks and reducing erosion rates. However, extreme floods can often damage bioengineered solutions, requiring active maintenance. Soft solutions are in line with the principles of nature-based solutions discussed in Section 3.

When developing the concept stage intervention option for the Dart River, we sought to tailor the design to the local conditions along Kinloch Road. The concept design thus features a combination of hard and soft solutions.

The main limiting factor for soft solutions are the availability of space for an effective vegetation buffer and the time required for vegetation to develop. Trees are only capable of binding the soil once their root system has sufficiently developed, and they are thus vulnerable to failure for several years after planting. In highly dynamic rivers such as the Dart River, rapid migration can expose newly planted trees to fast-moving river flows, leading to partial or complete failure of the protection. Hard rockfill protections, including rip-rap revetments and terminal groynes, were thus selected for application on sections of Kinloch Road where the active river channel edge is close to the road. This is further discussed in Section4.4.

4.2.3 Road Flooding and Surface Erosion Hazard

Arresting or slowing down migration rates of the Dart River active channel will not prevent flooding of Kinloch Road. As discussed in Section 2.3, the road may be closed due to flooding several times per year and the frequency of flooding events will likely increase in the future due to climate change effects and ongoing aggradation of the riverbed.

As part of QLDC's response in the past, sections of the road have been raised to try to reduce the frequency of flood inundation. This option was also identified as a possible flood mitigation approach in Geosolve (2018).

Although the extent of road raising has not been documented, it is likely that raising of the roadway has been focused on the areas north of road chainage 3,500 m, and between chainages 4,000 and 4,600 m, which show adequate performance when reviewing the results of the hydraulic numerical model simulations (refer to Section 2.3.2). Our assessment of the numerical hydraulic modelling results indicates that further targeted road-raising could ensure connectivity of the road during frequent to moderate floods, although localised scour in areas subject to high velocity flows could occur during moderate and large flood events.

Table 4.1 shows the approximate volume of fill material required to maintain connectivity of Kinloch Road (i.e., prevent flooding of the road) during a given flood scenario, assuming a road width of 8 m, vertical shoulders and no freeboard.

Table 4.1: Approximate volume of fill material required to raise road above maximum water surface levels during various flood scenarios.

Target flood scenario (no water on road for this event)	Road fill volume required [m^3]
1:20 AEP – Current bed	2,100
1:50 AEP – Current bed	3,200
1:100 AEP – Current bed	4,000
1:100 AEP– +0.2 m bed aggradation	6,700
1:100 AEP – +0.4 m bed aggradation	10,300
1:100 AEP – + 1.0 m bed aggradation	23,400

The hazard classification results presented in Table 2.4 could be used to prioritise sections of the road for raising. We would suggest prioritising works primarily on the basis of likelihood of flooding, with the maximum flooding depth as a secondary consideration.

The analysis of a partial or full relocation of Kinloch Road south of chainage 2,100 m toward the western hills was not considered as part of this investigation. However, we note that the road is already close to the hill toe at the edge of the floodplain between road chainages 2,100 and 6,000 m, with distances to the toe ranging from 40 to 250 m. Considering the high active river channel migration rates in the Dart River (refer to Section 2.2.1), any relocation of the road within the floodplain in that road section would only be a stopgap measure if current river channel migration trends are not mitigated.

4.3 Existing Erosion Protections

4.3.1 Rockfill Protections

In cases where river channel migration previously progressed to the edge of Kinloch Road, QLDC built sections of emergency rock revetment protection works to prevent direct erosion of the road. The approximate position, time of construction (inferred from aerial photographs) and length of each revetment is summarised in Table 4.2. The position of each revetment is also illustrated in Figure 2.4, which shows average river migration rates along the length of the road, and indicated in Drawings DAR2350/30/100 to 104 in Appendix B.

Table 4.2: Data for existing rockfill protections.

ID	Road chainage [m]		Length [m]	Construction date	Description
	From	To			
A1	2,450	2,500	50	2015 to 2019	Rip-rap
A2	2,650	2,750	100	2021	Rip-rap and terminal groyne
A3	3,080	3,215	135	2019	Rip-rap
A4	7,800	8,030	230	2021	Rip-rap and groynes

Design and construction details for these protection works are sparse. Based on a site inspection and photos, it appears that the rip-rap revetments were likely built without a geotextile transition or granular filter between the top riprap layer and the underlying ground material. In some cases, rip-rap was placed up to ground level, while in others, it mounds above ground level (refer to Figure 4.1). It is also unclear whether a buried foundation toe was constructed on each rip-rap revetment. A 2020 inspection of protection A3 (see Figure 2.4) estimated a maximum rockfill diameter of 800 mm (WSP, 2020).

Figure 4.1 shows photos of the A4 rock riprap protection (see Figure 2.4) built between road chainages 7,800 and 8,030 m after the 25 October 2022 flood. A sketch provided by QLDC indicates that the groynes in protection A4 were built by placing rockfill on a gravel bund core, with no granular or geotextile filter (Ben Greenwood, pers. comm., 25 July 2024).

Damwatch did not undertake detailed observations of the rock riprap protection works. However, no evidence of failure of the rockfill protections was observed while reviewing aerial photos. The oldest revetment, built between 2015 and 2019 at chainages 2,450 to 2,500 m, appears to have been effective at preventing further lateral bank erosion despite the occurrence of several minor to moderate floods since (satellite imagery shows flood flows in at least one flood event in contact with this revetment).

a) Looking downstream

b) Looking upstream

Figure 4.1: Existing rockfill protection A4 between road chainages 7,800 and 8,030 m.

Source: ORC

4.3.2 Vegetation Planting

The Dart River features several clumps of trees along the edge of the active river channel belt and along various internal braid channels. In some areas, trees appear to have been planted to prevent further river migration, as evidenced by the narrow planting rows observed in aerial photos. In other areas, trees appear to have grown naturally downstream of the original planting sites.

Although Damwatch did not inspect these planting sites, the trees could possibly consist of crack willows (salix x fragilis), which easily colonises areas downstream of an original planting site when broken twigs and branches are carried by the flow during a flood and take root along the bank. We note that crack willows are an unwanted organism regulated under the National Plan Pest Accord[7]. Any new vegetation buffers applied as a mitigation measure for lateral bank erosion should instead employ sterile willow hybrids (refer to Section 5.2).

The approximate position, time of construction and length of the tree plantings identified is summarised in Table 4.3. Their position is also illustrated in Figure 2.4, which shows average river migration rates along the road., and indicated in Drawings DAR2350/30/100 to 104 in Appendix B. Protection B1 (refer to Table 4.3), approximately located between road chainages 5,400 and 5,550 m, has engendered a significant number of naturally occurring trees, and the extent of the original planting is not clear.

[7] https://www.mpi.govt.nz/biosecurity/about-biosecurity-in-new-zealand/registers-and-lists/

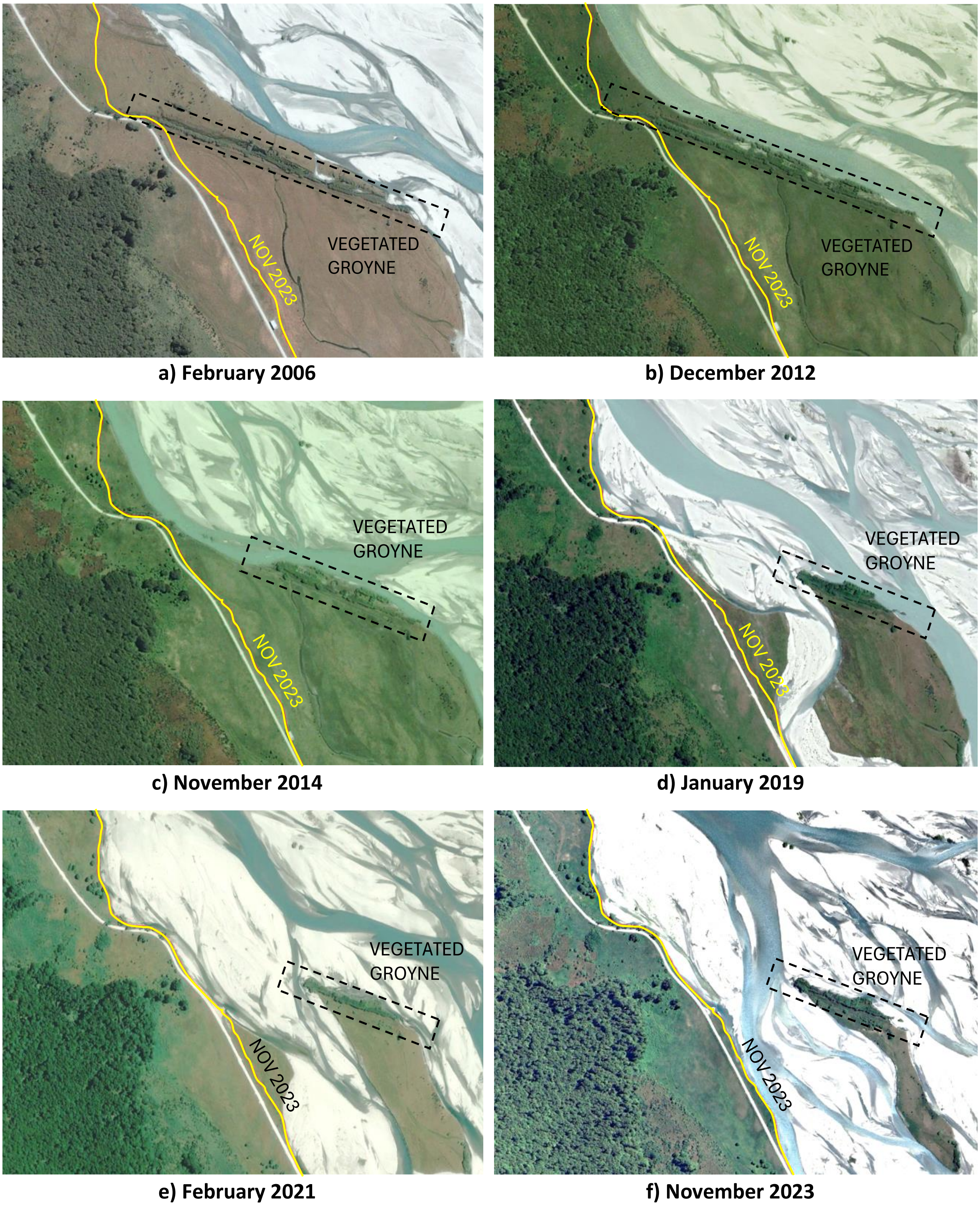
Table 4.3: Data for existing vegetation protections.

ID	Road chainage [m]		Length [m]	Description
	From	To		
B1	5,400	5,550	150	Planted in 1 to 3 rows in 2012.
B2	6,500	7,050	550	Planted in 3 rows progressively between some time before 2012 up to 2019.

The success of vegetation protections in the area varies. Figure 4.2 shows the evolution of a protection constructed in the early 1980s, which abutted Kinloch Road at approximately chainage 2,500 m. It consisted of a long earthfill groyne, likely built with locally sourced materials, with trees planted on the groyne crest and immediately upstream along the groyne axis. The bund was initially constructed away from the active river channel (Figure 4.2(a)) with the likely purpose of deflecting flood flows away from the floodplain and blocking potential overland flow paths.

Figure 4.2 illustrates the progressive erosion of the groyne near the road (Figures 4.2(b) and 4.2(c)). Once most of the groyne was eroded, the river outflanked the rest of the protection, creating a remnant island (Figure 4.2(d)). Although the bund was reinstated in August 2018 as a non-vegetated gravel bund, it quickly failed due to overtopping during a flood in November 2018 (Tim van Woerden, ORC, pers. comm., 24 July 2024). The active river channel flow path was enlarged by successive floods, and only a small section of the remnant island downstream of the original groyne location remained in November 2023 (Figure 4.2(f)).

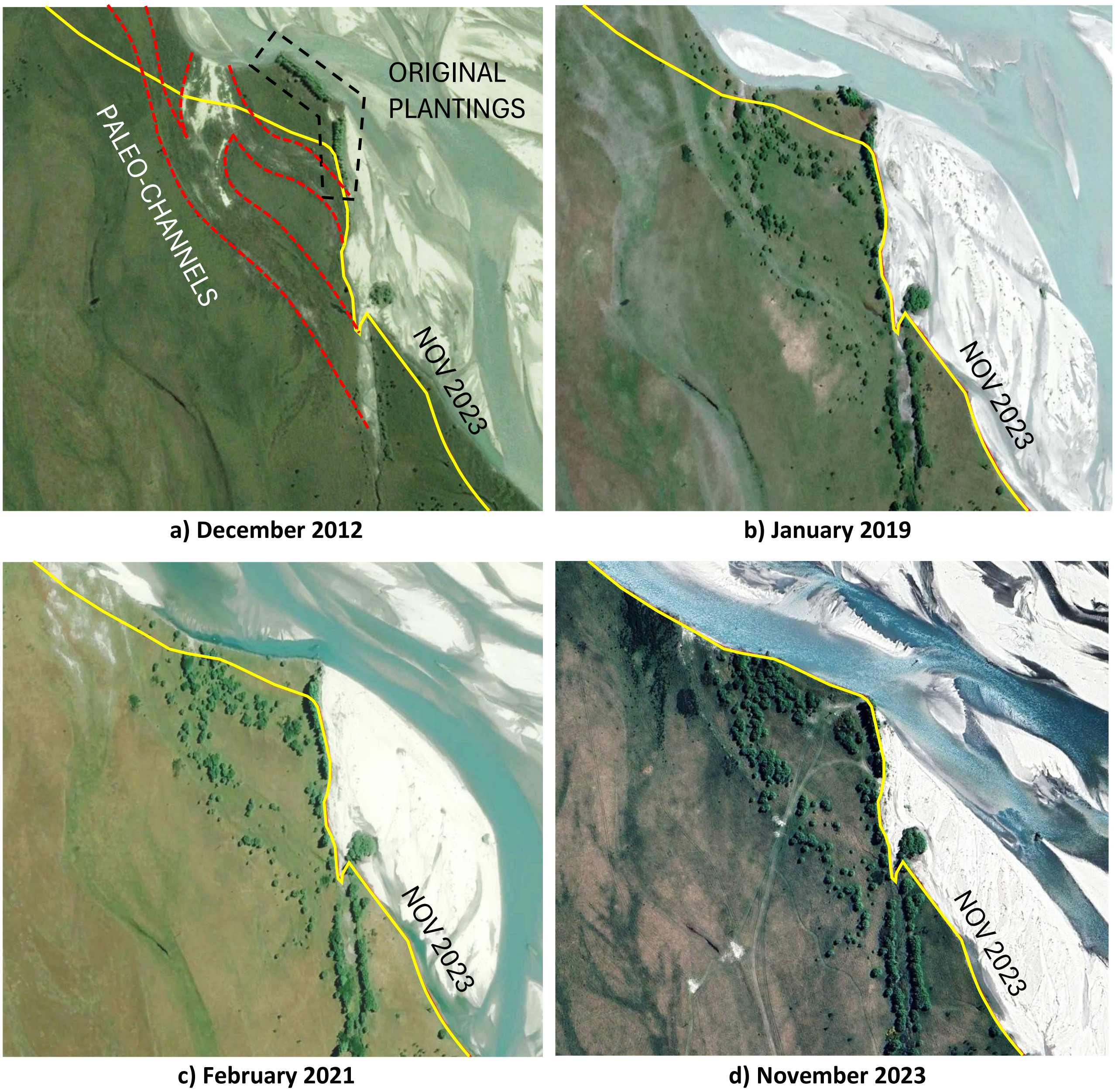
Figure 4.2 highlights the critical importance of continual maintenance when using bioengineered, “soft” protections such as vegetation buffers. As well, it is necessary to maintain the continuity of the protection to avoid outflanking by river flows during flood events. Furthermore, it shows that tree planting can be effective at mitigating bank erosion. This is evidenced by the remnant island remaining in place despite its proximity to one of the main river braid channels.



Note: Yellow line indicates November 2023 bankline

Figure 4.2: Evolution of vegetated earthfill bund at road chainage 2,500 m.

Figure 4.3 shows the evolution since 2012 of protection B1 (approximately between road chainage 5,400 to 5,550 m). Although the protection has been partially effective in stabilising the river channel edge once vegetation was sufficiently established, some erosion has occurred at the upstream end, where it was more exposed to high-velocity flows during flood events. A series of old paleo-channels can be observed in Figure 4.3 to the northwest of protection B1. If high flows overflowed into these channels during a flood event, the protection could be bypassed, generating an island. This also underscores the importance of continuity in vegetation type protections, as well as the risk of losing a vegetation buffer if it is stress-tested soon after planting and before it has become well established.



Note: Yellow line indicates November 2023 bankline

Figure 4.3: Evolution of B1 vegetation protection at approximate road chainage 5,350 m.

4.4 Assessment of Erosion Protection Options

4.4.1 Overview

Given the dynamic behaviour of the Dart and Rees River System with ongoing aggradation of the riverbed and continual lateral bank retreat along the westerly edge of the Dart River, a mix of "hard" and "soft" protection approaches is considered a suitable bank erosion mitigation strategy. Aligning with current floodplain management trends in New Zealand and internationally, as well as the project goal of incorporating Nature-based Solutions, it is preferable to emphasise the "soft" protection approach. The "hard" protection approach should be reserved for smaller areas where the existing riverbank is very close to the road and vulnerable to erosion by an active braid channel.

It should be cautioned that this would not necessarily be a long-term solution as future climate change effects causing an increase in sediment supply and an accelerating rise in average bed levels could still start to threaten any applied mix of "hard" and "soft" protection measures. Furthermore, "soft" protection measures can still fail as evidenced by the sequences of aerial photos in Figures 4.2 and 4.3. For these reasons, we have described this strategy as a short-to-medium term solution only (e.g., 5 to 15 years). Furthermore, "soft" protection measures require significant ongoing maintenance, that requires commitment to attend to.

4.4.2 Selection of Protection Type

As discussed in Section 4.2.2, the selection of bank erosion mitigation options was undertaken considering several factors:

- **Development time for willow protection**.

  Willows were selected for the development of vegetation buffers due to their superior performance in protecting bank edges (refer to Section 5.2). Although willows establish easily and quickly, an initial period of some years is required before a willow protection becomes fully effective. Oplatka & Sutherland (1994) indicate that willow poles planted 2-3 m apart and over 3 years old form networks of interconnected roots. Typical estimates of time required for willows to become well established is 5 to 10 years.

  A 2 m spacing was adopted for willow poles (refer to Section 5.2). Given the high river migration rates, the vegetation buffer was set back at least 50 m away from the active river channel edge to allow time for the willows to grow before being stressed by lateral bank erosion. This coincides with the expected river migration distance in 3 years considering the maximum long term migration rate registered (17 m/yr).

- **Minimum space for vegetation buffer.**

  Selection of a vegetation buffer design width typically requires balancing available space, robustness of the protection, and allowing the river space to naturally widen its active channel. Death (2018) indicates that "*several studies have shown that efficient buffer widths can range from 5 m for bank* *stabilization and stream shading, to 20 m for self-sustaining buffers, to over 50 m for biodiversity gains*". Typical recommended widths range from 20 to 50 m.

Considering the significant length of riverbank along the length of Kinloch Road that requires protection, a 20 m wide buffer was selected as a compromise between cost and resilience (refer to Section Section 5.2). This is in line with other vegetation buffer widths applied recently in New Zealand rivers (e.g., Hutt River, as described in NZTA, GWRC & HCC (2022))[8].

- **Proximity to existing rock revetment protections.**

  Existing rock revetment protections A1, A2 and A3 (refer to Table 4.2) partially protect Kinloch Road between road chainages 2,450 and 3,215 m. The gaps between these protections have quickly eroded, necessitating new rip-rap protections as an emergency response measure. Given the high bank migration rates, limited space for relocating the road within the floodplain, and the short distance between the road and the active river channel edge (see Figure 2.3), we concluded that a vegetation buffer would likely be ineffective in mitigating bank erosion in these areas. Therefore, a continuous rock revetment protection in this area is the most effective strategy.

The hazard classification results presented in Table 2.4 were used to select appropriate protection types along the length of Kinloch Road. The following criteria were adopted:

- Vegetation buffer options were discarded in road sections where the distance from the road centreline to the active river channel edge was less than 30 m. Instead, "hard" rock revetment protections were selected.
- In road sections where the distance to the active river channel edge is between 30 m and approximately 70 m, vegetation buffers were chosen and set as far back from the river as possible. To provide limited protection during floods while the plantings mature, terminal groynes are suggested for application on adjacent rock revetment protections.
- In areas with ample distance between the road and the edge of the active channel, vegetation buffers were selected and set back at least 50 m away from the active river channel edge.
- Debris fences and bioengineered groynes using tree bunches, commonly used in bioengineered protections, have also been suggested to deter surface erosion. Their use is further discussed in Section 5.2.

4.4.3 Selected Protections and Prioritisation

Table 4.4 lists the selected protections, as well as their approximate length. Their location in plan is shown in Drawings DAR2350/30/100 to 104 in Appendix B.

[8] Death (2018) includes an extensive list of articles on the topic of buffer width. However, there is no clear consensus, and in some cases buffers of over 150 m have been built by ECan (e.g. Waimakariri River).

Table 4.4: Selected protections and proposed priority.

Type	Priority	Name	Approx. road CH [m]		Length [m]	Total length [m]	
			From	To			
Hard	1	R1	2,360	2,450	86	768	
		R2	2,480	2,650	173		
		R3	2,750	3,080	333		
		R4	3,210	3,300	99		
		R5	7,750	7,800	77		
Soft	1	W1A	2,250	2,380	122	703	5,098
		W1B	3,310	3,560	254		
		W1C	7,550	7,750	202		
		W1D	7,980	8,100	125		
	2	W2A	2,080	2,250	180	1,424	
		W2B	3,560	4,150	607		
		W2C	6,940	7,550	637		
	3	W3A	4,150	5,350	1,209	1,209	
	4	W4A	5,350	6,400	1,135	1,762	
		W4B	6,240	6,940	627		

Rockfill protection R4 is located near Turner Creek Bridge. A conceptual design for a rockfill protection was previously developed for this area, incorporating short rockfill groynes in both the new and the existing protection upstream (WSP, 2020).

The erosion protections were prioritised as shown in Table 4.4 as a function of river migration rates and distance from the road to the active channel. If possible, adjacent “hard” and “soft” Priority 1 works should be constructed in tandem to ensure continuity of the protection.

4.5 Effects of Selected Option

4.5.1 Numerical Hydraulic Modelling Overview

A HEC-RAS[9] two-dimensional hydraulic model of the Rees-Dart River system was used to:

- Assess the likelihood and severity of flooding along Kinloch Road (refer to Section 2.3).
- Assess the effects of the vegetation buffers.

[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.

An overview of this model is provided in Appendix A. The model was supplied by ORC for the purposes of this assessment and was based on the LRS (LRS, 2022) model previously used for flood hazard assessment at Glenorchy.

The HEC-RAS model was validated against the February 2020 flood and indicated relatively good agreement between model predicted and observed flood levels for this flood event. Although the model results on the Dart River floodplain area were not validated, flooding extents observed in photos during floods appear to approximately match those shown in model results (see Figure 2.6). The model is sufficiently accurate for this study, which aims to characterize flood hazards and evaluate the impact of vegetation buffers.

The model was used to determine maximum flood inundation extents, depths and velocities on the Dart River floodplain for different flood scenarios and riverbed aggradation assumptions. The model simulations used for this study are listed in Table 4.5. For all options assessment simulations using the HEC-RAS model, Lake Wakatipu was assumed to be at a 1 in 10 AEP flood level of RL 311.5 m.

Further detail on model development validation is provided in Appendix A.

Table 4.5: Summary of hydraulic model simulations for assessment of floodplain interventions

Model code	Scenario description	Flood frequency (AEP)	Lake Wakatipu level (AEP)	Active river channel bed aggradation assumption *
A20	**Baseline** – Existing Dart River floodplain and vegetation **	1:20 (5%)	1:10 (10%)	Current (2022)
A50		1:50 (2%)	1:10 (10%)	
A100		1:100 (1%)	1:10 (10%)	
A100-SED1		1:100 (1%)	1:10 (10%)	+0.2 m (c.2030)
A100-SED2		1:100 (1%)	1:10 (10%)	+0.4 m (c.2040)
A100-SED3		1:100 (1%)	1:10 (10%)	+1.0 m (c.2070)
A50-SED1-DEF	**Vegetation Buffers –** Fully developed buffers after 5 to 10 years of growth (simulated in HEC-RAS by increased surface roughness)	1:50 (2%)	1:10 (10%)	+0.2 m (c.2030)

Notes: * Refer to Section 2.3.2 for active river channel bed aggradation assumptions to 2030, 2040 and 2070.
** The model includes modifications of Glenorchy floodbank from current condition which do not affect Dart River floodplain results.

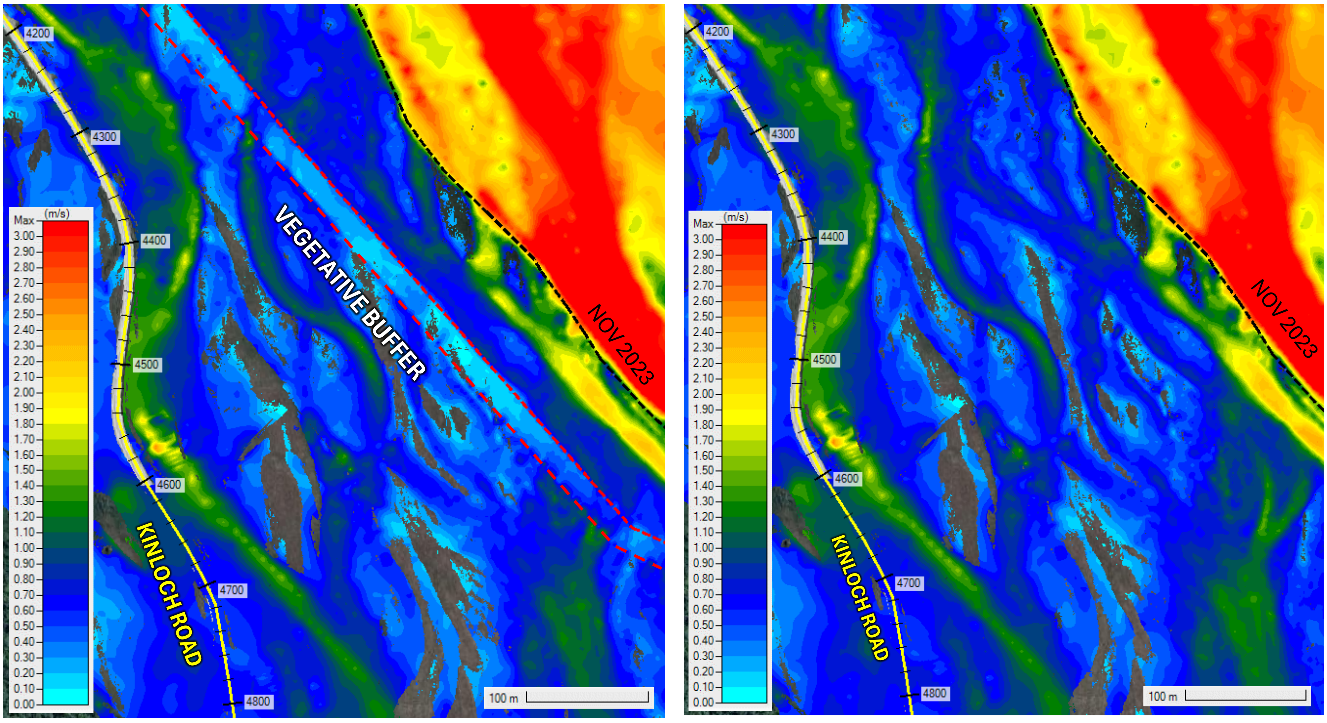
4.5.2 Road Flooding Results

Model results used to assess the road flooding and erosion hazards are presented in Sections 2.3.2 and 2.3.3. The development of vegetation buffers will not significantly affect road flooding. However, river aggradation will result on the majority of the road downstream of chainage 2,700 m being flooded during a 1:100 AEP flood.

The potential effect of potential road raising on flooding extents was not modelled.

4.5.3 Effect of Vegetation Buffers

The effect of vegetation buffers was studied by simulating a 1:50 AEP flood with and without the buffers. The buffers were represented as zones of increased surface roughness represented by an increased Manning's n surface roughness coefficient of 0.12 (relative to n = 0.033 for other grassed floodplain/pasture areas). The results of the model simulations are shown in Figure 4.4.



a) With vegetation buffer **b) Without vegetation buffer**

Note: Maximum flow velocities for 1:50 AEP flood event, considering 10 years of active river channel aggradation.

Figure 4.4: Effect of vegetation buffer on floodplain flow velocities.

There was negligible change in floodplain depths and extents since vegetation buffers do not constitute a continuous flow barrier. However, the increased surface roughness results in lower velocities through the buffer area (with a reduction of approximately 50% of the base velocity), which would contribute to reduced surface erosion at the buffer during floods. Velocities across the right bank floodplain away from the vegetation buffers are largely unchanged.

The vegetation buffers do not significantly alter flow velocities and depths over and along the Kinloch Road embankment. Effectively mitigating flooding or erosion hazards at the road will require raising the road level and potentially installing erosion protections. Road hazards are discussed earlier in Section 2.3.

Since the model used a "fixed bed" assumption, erosion processes (i.e. surface erosion and lateral bank erosion) were not able to be represented. Furthermore, the effectiveness of tree roots to resist erosion and reduce erosion rates was not studied, although available empirical evidence indicates that tree roots would be partially effective at mitigation erosion (refer to Section 4.3.2).

5 Concept Design

5.1 Rockfill Protections

5.1.1 Concept Design Assumptions

The use of rip-rap revetments and rockfill groynes was chosen for sections of Kinloch Road set close to the active river channel edge. Figure 5.1 shows a typical cross section for a rip-rap protection on a river bank.

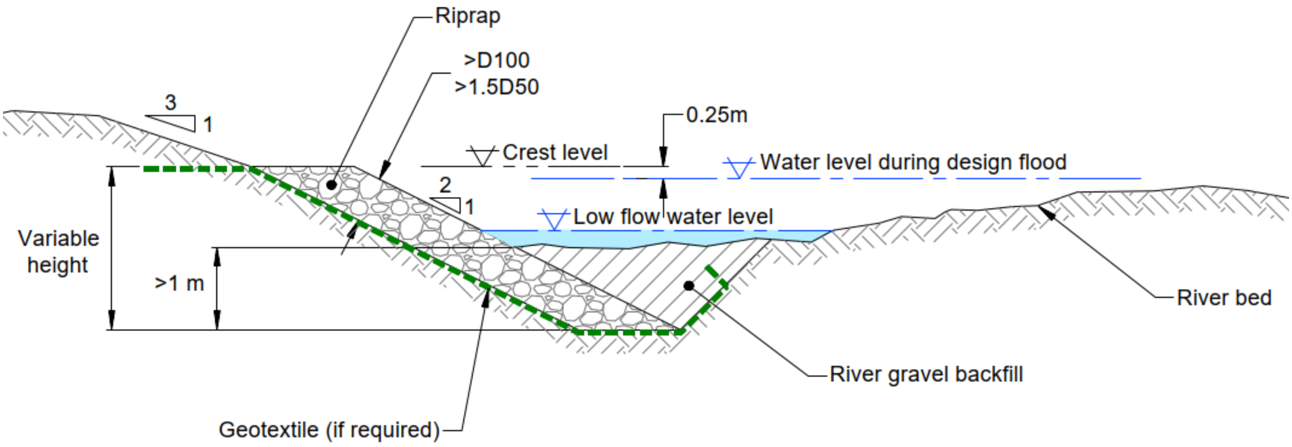


Figure 5.1: Typical rip-rap revetment section.

Although no site-specific design was carried out as part of this study, a concept design was developed to estimate approximate construction costs based on the following assumptions:

- Rip-rap size is selected based on the flow's erosive force, which is in turn a function of flow depth and velocity. In the case of highly dynamic rivers such as the Dart River, lateral erosion will likely progress quickly if one of its main branches moves towards the protection. Considering that model results indicate velocities of up to 4 m/s in the main branches during floods, a median size (D_{50}) of at least 0.6 m was selected for the purposes of preliminary costing. The D_{50} was estimated using the EM-1601 formula (USACE, 1994) assuming a depth-averaged velocity of 4 m/s, a slope of 2H:1V, and the use of angular shaped rock material. Rip-rap size and grading envelopes would need to be confirmed during detailed design.
- The height of the protection will depend on the design flood selected and the topography of the riverbank. This is not accurately represented in the Digital Elevation Model (DEM) used to represent the riverbed geometry in the numerical hydraulic model (which did not include bathymetric data below the water level at the time of the LiDAR bed survey). To estimate rockfill quantities, a height of 2 m and a toe depth of 1 m were assumed, for a total depth of 3 m.
- It was assumed that a geotextile fabric would be placed in between the ground and the riprap material (to prevent the erosion of fine ground material through the voids in the riprap layer). The geotextile could be replaced in the final design by a granular filter if suitably graded material is readily available and reasonably priced. Depending on the grading of the bank material, a filter may not be required.

On the edges of the protection, terminal groynes were included to protect the adjacent vegetation buffers. The height, length and final alignment of the groynes should be reviewed during any detailed design stage when detailed topographical data is available if this option is taken forward. Figure 5.2 shows a typical cross section for rockfill groynes. Depending on the characteristics of the core material, a geotextile filter may not be required although one is shown in this sketch.

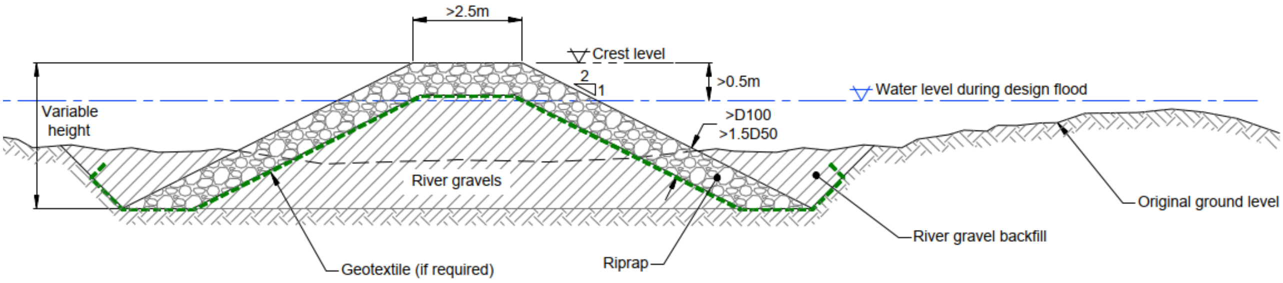


Figure 5.2: Typical groyne section.

The typical cross sections for rockfill protections are presented in Drawing DAR2350/30/200.

5.1.2 Scope of Works

The rockfill protection works are expected to involve:

- Detailed design.
- 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.
- Trimming of river bank below protection crest level to design 2H:1V batter.
- Excavation and shaping of toe section.
- Installation of a non-woven geotextile or granular filter on trimmed surface (if required for soil compatibility purposes).
- Placement and compaction of suitable core material for groynes.
- Placement of rip-rap material. If significant sorting is observed after dumping of rockfill, use excavator to redistribute material. Revetment should be of uniform thickness and size distribution.

5.1.3 Long-Term Resilience

Rockfill protections are generally reliable and durable, but damage or failure may still occur. The most common causes of riprap failure are excessive scour, outflanking, or inadequate design. The detailed design should therefore be conservative and preferably adopt an infrequent flood event (e.g., 1:100 AEP flood) as a minimum design flood standard.

Even properly designed rockfill protections require some maintenance periodically. Maintenance requirements include replacing dislodged riprap, reshaping over-steep or bulging sections, and extending protections where the toe has been undermined. Regular inspection of the protections after floods is critical to avoid major failures and repairs.

As highlighted in Sections 4.3, outflanking and toe scour pose significant risks to rockfill protections in this environment. Ensuring the continuity of these protections is essential for maintaining long-term effectiveness.

5.2 Vegetation Buffers

5.2.1 Concept Design Assumptions

Willows are preferred for riverbank erosion protection due to their fast growth rates, ability to be propagated vegetatively (using rooted cuttings, wands, stakes, or poles from existing stands), and their capacity to be layered[10] when they become old. Following loss of trees during a flood, willows enable a relatively rapid re-establishment of the protection. For these reasons, the use of sterile willow hybrids to develop the vegetation buffers is proposed. The selection of willow species during the final design stage should be based on cost, availability and suitability for the area. However, species with a spreading habit (e.g., salix purpurea) should be chosen if possible. Species with a spreading habit do not develop into large trees, making them more resistant to lateral erosion (Oplatka & Sutherland, 1994). Thicker rather than thinner poles should be planted to ensure adequate early passive resistance until vegetation is established.

As discussed in Section 4.4.2, a 20 m buffer width was selected. Willows should be set in rows at a 45 degree angle to the buffer axis, with a 2 m pole spacing, resulting in 14 willow poles per row. A 2 m distance between rows was also chosen, and willow poles were arranged in a staggered pattern between consecutive rows to reduce flow velocities and limit both general and local scour.

The establishment of willow vegetation buffers generally requires supportive and protective structural measures to manage surface and lateral erosion by slowing down flows during an establishment period. This is usually done by placing fences across and along the buffer to trap debris during floods and act as flow retarders.

These fences can be made from various materials and can be removed after the vegetation is well established. The use of fences made of biodegradable materials is proposed, using untreated wooden poles and natural fibre rope. Fences should be aligned with the willow rows at a 45 degree angle to the buffer axis and set at 23 m intervals.

[10] "Layering" involves partly cutting the trunk so that the tree lays in the active channel edge, protecting the riverbank.

Figure 5.3: Willow pole planting and debris fences made of biodegradable materials.

When riverbank migration progresses to the edge of a vegetation buffer, further reinforcement should be considered in critical areas, such as rockfill toe protections or trenched and anchored tree barriers. This is further discussed in Section 5.2.4.

As indicated in Section 4.3.2, it is likely that crack willows are currently growing along the edge of the active river channel, particularly downstream of road chainage 5,250 m. Although these trees are unwanted species, they currently serve a function in controlling riverbank migration. Removal of these trees is suggested only after the vegetation buffers have become well established.

The soil type surrounding a willow pole, which influences water and nutrient availability, affects its ability to develop an interwoven root network. In no-fines gravel, roots will not form an effective root net, compromising pole stability (Oplatka & Sutherland, 1994). Therefore, soil type and water table depth should be reviewed when selecting the final placement of vegetation buffers during the final design stage.

The typical details for willow vegetation buffers and debris fences are included in Drawing DAR2350/30/201.

5.2.2 Scope of Works

The vegetation buffer works are expected to involve:

- Detailed design.
- Site establishment, including compliance with any resource consent conditions.
- Tree removal and vegetation clearance. Any trees removed can be salvaged to build erosion protections (refer to Section 5.2.4).
- Removal of surface silt layer.
- Planting of poles as deeply as possible.
- Construction of debris fences.

5.2.3 Use of Native Species

There is a consensus among river engineers that no native species are as effective as willows for frontline river protection. Natives are slower to develop, cost more, have to be grown from seed, cannot be managed as easily as willows, and do not provide the same level of protection due to the lack of extensive root systems. Furthermore, the knowledge base on the effectiveness of native plants for erosion and sediment control is limited (Landcare, 2008).

Natives are typically planted away from frontline defences, and their use is driven by biodiversity enhancement concerns. Some councils adopt a multi-tiered approach, combining willows for frontline defences with natives planted further from the active river channel. Once natives are well established, willows can be gradually removed and replaced by larger native species (GWRC, 2021).

Considering the cost-effectiveness and superior attributes of willows for riverbank erosion protection, willow plantings were adopted for the concept stage vegetation buffer design. The use of native vegetation could be reviewed during future detailed design stage if the suggested concept is taken forward.

5.2.4 Long-Term Resilience

Compared to “hard” solutions, vegetation buffers are relatively inexpensive. However, the intentionally sacrificial nature of vegetation buffers must be understood by all stakeholders to ensure adequate long-term management and performance.

Once vegetation is established, the rate and extent of lateral erosion will be less than if there was no vegetation. However, although vegetation buffers increase resilience to surface erosion during flood events, they are vulnerable to lateral erosion due to river channel migration and bank retreat and large floods can result in the loss of part of or the entirety of a vegetation buffer. Effective management of vegetation buffers requires rapid intervention when erosion occurs, both during establishment and once established.

Bank stabilisation projects featuring vegetation buffers typically include hardened toes, either built using traditional “hard” (e.g., rip-rap, concrete blocks, etc.) or degradable materials. The vegetated buffers for the Dart River floodplain were set away from the active river channel, preventing the construction of toe protections. However, if river migration results in lateral erosion reaching the buffer, toe protections could then be installed as part of maintenance works. Possible protections include:

- *Short riprap revetments or groynes*, particularly in critical areas exposed to high velocity flow or close to Kinloch Road.
- *Trenched and anchored tree edge protections*, which involve burying and anchoring of tree trunks into the riverbanks. Crack willow and other unwanted species removed from the shoreline could be salvaged, lashed together with manila fibre rope, secured into the banks with driven untreated timber poles and anchored with concrete blocks back into the bank. Protection can be placed along the riverbank or forming short groynes. An example of a bioengineered groyne is shown in Figure 5.4.

Figure 5.4: Willow pole planting and bioengineered groynes.
Source: ECan

Other possible maintenance requirements may include bolstering the buffers with additional plantings, either to replace trees that were washed out during a flood event or to increase the width of the buffer in critical sections. Debris fences might need to be repaired or reinstated after a flood until the willows become established.

The soil-binding capacity of willows is strongest before the trees reach maturity. Mature willows feature larger, smoother roots with reduced soil reinforcing potential, and are more vulnerable to toppling by windthrow or lateral erosion. As a consequence, willows are typically rejuvenated at least once every 10 to 15 years by layering or lopping (Landcare, 2008).

5.3 Potential Environmental Impacts

As part of any erosion protection works it will be necessary to assess and manage environmental impacts. Erosion control measures are most likely to impact morphological evolution, sedimentation processes, habitat and biological community interactions.

Considering the braided nature and large active river channel width of the Dart River, impacts of rockfill protections and vegetation buffers on the hydrological balance and sedimentation processes will be very localised and negligible overall. Local morphological changes such as reduction of surface erosion and river migration rates are the intended function of the project.

No known significant impacts on habitat and biological processes are expected. If the proposed erosion protection works are taken forward for further development, it is recommended that investigations are carried out to assess the potential environmental impacts and develop conditions for a resource consent.

5.4 Consenting Requirements

A preliminary analysis of the statutory planning documents and provisions is provided in Appendix C. Further detailed statutory analysis of the activities associated with the concept design will be required as part of the resource consent once the detailed design is completed.

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

Queenstown Lakes District Council

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

- A discretionary consent under Rule 30.5.1.16 (Flood Protection Works) for both the planting and the riprap.
- A restricted discretionary consent under Standard 25.5.10A.2 for the volume of earthworks required to construct the sections of riprap outside the road reserve.
- A restricted discretionary consent under Standard 25.5.11 for the area of earthworks.
- A restricted discretionary consent under Standard 25.5.18 to undertake unretained earthworks greater than 0.5 metres in height across site boundaries.
- A restricted discretionary consent under Standard 25.5.19.1 to undertake earthworks within 10m of the bed of a waterbody.
- A restricted discretionary consent under Standard 25.5.21 to transport more than 300 m^3 of cleanfill to the site.
- A discretionary consent under Rule 29.4.13 - Activities that are not listed in the transport activities/ rules Table.

Otago Regional Council

The 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 RPW are:

- A restricted discretionary consent under 12.3.4.1 to construct riprap edge in a manner that will divert floodwaters.
- A restricted discretionary consent under 13.3.2.1 to construct part of the riprap in the bed of the river.
- A discretionary consent under 13.5.3.1 to alter the bed of the river (through the construction of the riprap).
- A discretionary consent under Rule 14.3.2.1 to erect riprap (being a defence against water), other than on the bed of any lake or river, is a discretionary activity.

Consultation and affected persons

The proposed flood protection works are located within a Wāhi Tūpuna area and on various parcels of land, affecting various owners. Consultation and, ideally, procurement of approvals by affected persons, will be integral parts of the consenting process. The landowners and other parties that are likely to be affected by the activities are listed in full in Appendix C.

Regarding land ownership, land boundaries are marked on the drawings. All land is private (owned by a single owner), except for Kinloch Road and very small areas where the works cross Crown land (refer to Table C.1 in Appendix C).

Whether ORC/QLDC would need to purchase land to either construct rock rip-rap for river edge protection or for willow planting purposes is a matter for council policy and how they ordinarily engage with landowners when they need to use private land for infrastructure works. As such, any land acquisition costs have been excluded from the costing given in Table 5.1.

5.5 Indicative Costings

Preliminary cost estimates have been prepared based on the concept-level, flood protection design outlined above. Rates for erosion protection works were sourced from recent and similar construction contracts.

Indicative (i.e., order of magnitude) costs are provided in Table 5.1. Inclusions on the cost estimates are listed in the table. These costs should be considered as a guide only and it is recommended that ORC seeks further professional Quantity Surveying guidance prior to detailed design if this option is taken forward for further development.

Cost estimates exclude items such as:

- Operating and maintenance costs
- 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

Considering construction, contractor and client costs, but excluding contingency costs, the following indicative unit costs per linear metre of riverbank protected were estimated:

- Rockfill protections: $3080/m
- Vegetation buffers: $125 /m (assuming a 20 m wide buffer)

Table 5.1: Preliminary construction cost estimates.

<table>
<tr><th rowspan="2">Description</th><th rowspan="2">Notes / Inclusions</th><th colspan="5">Item</th></tr>
<tr><th>Rockfill protections</th><th>Vegetation buffer (priority 1)</th><th>Vegetation buffer (priority 2)</th><th>Vegetation buffer (priority 3)</th><th>Vegetation buffer (priority 4)</th></tr>
<tr><td>[A] Construction costs</td><td>• Erosion protection construction costs</td><td>$1,816,000</td><td>$73,000</td><td>$148,000</td><td>$126,000</td><td>$183,000</td></tr>
<tr><td>[B] Contractor costs</td><td>• Preliminary and general costs = @ 20% of [A]</td><td>$363,000</td><td>$15,000</td><td>$30,000</td><td>$25,000</td><td>$37,000</td></tr>
<tr><td>[C] Client costs</td><td>• [C1]: Consenting = $70,000 (for publicly notified consent)
• [C2]: Design, tender documentation, peer review and evaluation = 3% of [A] + [B]
• [C3]: Construction monitoring and certification = 1% of [A] + [B]
• [C4]: Management costs = 1% of [A] + [B]
• [C] = [C1] + [C2] + [C3] + [C4]</td><td>$179,000</td><td>$74,000</td><td>$79,000</td><td>$78,000</td><td>$81,000</td></tr>
<tr><td>[D] Contingency</td><td>• Lower estimate: 0%
• Upper estimate: 40% of [A] + [B] + [C]</td><td>$0
$943,000</td><td>$0
$65,000</td><td>$0
$103,000</td><td>$0
$91,000</td><td>$0
$120,000</td></tr>
<tr><td>Indicative cost range</td><td>Sum of [A] to [C] (no contingency)

Sum of [A] to [D] (+40% contingency)</td><td>$2,358,000
to
$3,301,000</td><td>$162,000
to
$227,000</td><td>$257,000
to
$360,000</td><td>$229,000
to
$320,000</td><td>$301,000
to
$421,000</td></tr>
</table>

5.6 Further Work for Detailed Design Phase

This study was intended to provide information to facilitate future decision making by ORC and QLDC. If a decision is made to proceed with the concept-level erosion protection design presented in this report, detailed design will be needed to ensure a robust design. It is also required for consenting and for contracting the construction of the protection works.

Detailed design will include consideration of hydraulic, geotechnical, civil and environmental engineering aspects.

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

- Surveyed locations and characteristics of existing rock revetment protections, including rip-rap size, to determine whether reinforcement or modification is required to form a continuous protection with any new protections.
- Road surface survey along those portions identified as inundated by flooding, if QLDC were to opt to further raise the road.
- Performance of existing rock revetment protections and tree plantings. Performance reviews of rockfill protections should determine design criteria used, including approximate rockfill size, and look for signs of damage, deterioration, or scour in the areas surrounding the protection. Reviews of tree plantings should identify the species planted in the area and evaluate their performance in zones of lateral erosion.
- Soil type and water table depth in areas of vegetation buffers, and evolution of water table depth through the year.
- Nearby availability of suitable rock material for riprap and willow poles.
- Confirm resource consent requirements from QLDC and ORC.
- Confirm land acquisition (if required) from property owners to build vegetation buffers.

6 Conclusions

This study assessed flood and erosion hazards affecting Kinloch Road on the true right Dart River floodplain. The assessment was based on historical aerial photos and the results of numerical hydraulic modelling simulations of a range of flood and bed aggradation scenarios. A series of potential floodplain intervention options were considered, prioritising alternatives incorporating Nature-based Solutions (NbS).

The effectiveness of these potential floodplain intervention options was assessed against a range of factors:

- Current rates of lateral channel migration and bank retreat.
- The proximity of the existing right bank to Kinloch Road.
- The river flooding and surface erosion hazard to Kinloch Road.
- The previous performance of existing protection works to bank erosion and lateral channel migration hazards.
- The development time for soft bioengineered protections to become effective against bank erosion and lateral channel migration hazards.
- The minimum space required for the establishment of soft bioengineered protections.
- The proximity of new works to existing hard engineered protections.

A concept-level intervention design was developed as a short-to-medium term solution to address the erosion hazard affecting Kinloch Road. This concept design involves an optimised mix of soft bioengineered (vegetation buffers) and hard engineered (rock revetment) protections.

Soft solutions are vulnerable to erosion during floods and will require significant active maintenance if implemented. The intervention options considered also do not offer a long-term solution, as large-scale geomorphic changes occurring in the Dart Rees River, along with future climate change effects, will lead to increasing hazards over time.

The intervention options considered are not effective in mitigating flooding or surface erosion of the Dart River right floodplain or Kinloch Road during floods. Although specific road-raising solutions were not developed for Kinloch Road, the sections of the roadway that would need to be raised to address this hazard have been identified.

The following concept-level design information was developed for the selected solution:

- Concept-level drawings (refer to Appendix B).
- Indicative construction costs.
- Preliminary review of design and maintenance considerations.
- Preliminary review of consenting requirements.
- Issues and further works to prepare for any future detailed design phase.

Refer to Sections 4 and 5 of this report for further detail and discussion on the above.

It is understood that the information contained in this report, regarding intervention options for protecting Kinloch Road in the short-to medium term, will be reviewed by ORC and QLDC and taken forward as required for community consultation and engagement. Following on from consultation, if Council and the community decide they wish to pursue the concept-level intervention option presented in this report to another stage, then additional work will be required to develop a detailed design for resource consent application and construction purposes.

7 References

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USACE. (1994). *Hydraulic Design of Flood Control Channels.* US Army Corps of Engineers, EM 1110-2-1601, 30 June 1994.

USDA. (2007). *Stream Restoration Design.* United States Department of Agriculture, Part 654, National Engineering Handbook.

WSP. (2020). *Kinloch Road Erosion.* WSP, Ref. 6-XO009, 23 January 2020.

Appendix A Hydraulic Model of Rees-Dart River

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

Table A.1: Summary of hydraulic model parameters

Parameters	Description
Model type	HEC-RAS 2D (v6.5)
Model extent	Dart-Rees Rivers from Glenorchy-Paradise Road crossing of Rees River and Glenorchy-Routeburn Road crossing of Dart River to head of Lake Wakatipu (refer Figure A.1)
Topographic data	Digital Elevation Model (DEM) used for ground elevations in model derived from: • University of Canterbury 2022 LiDAR aerial survey • Otago Regional Council 2019 LiDAR aerial survey • LRS (2022) terrain modifications to represent Lake Wakatipu and Glenorchy Lagoons bathymetry Data provided as 1 m gridded bare earth digital elevation model (DEM). Refer Figure A.1 for the extent of the topographic data sets used.
Model mesh	An unstructured mesh with an average 15 x 15 m cell dimension for the active river channels and an average 25 x 25 m cell dimension for floodplain areas. Average cell dimension in the vegetated buffers was 4 x 4 m.
Model scenarios	Refer to main report Table 4.5.
Model validation	The model was validated against the February 2020 flood at Glenorchy and the March 2019 flood for the Dart River right-bank floodplain. Refer to section below "HEC-RAS Model Validation" for further detail.
Boundary conditions	• *Upstream*: Refer to Table 2.1 in main report for Rees and Dart River peak discharge estimates. 1 in 100 AEP flood hydrograph shape published in ORC (2021) (refer Figure A.2) scaled based on ratio of flood peak discharge. • *Downstream*: Constant water level boundary, representing Lake Wakatipu flood level. Refer to Table 2.2 in main report for Lake Wakatipu flood level frequency data.
Roughness coefficients	• Manning's "n" surface roughness coefficients listed in Table A.2 and based on those adopted by LRS (2022) for flood hazard modelling.
Simulation Control Parameters	• *Solution Technique*: Both the "diffusion wave" and "shallow water equations" were tested for this model and gave very similar results. The "diffusion wave" solution had the advantage that the run times were significantly less than those for the "shallow water equation" solution, and the former was therefore elected for this study. The model was also validated based on the "diffusion wave" equations and therefore the same approach was used for the option assessment simulations. This was the same approach adopted in the LRS (2022) hydraulic modelling study. • *Computational Time Step*: An adaptive time step between 1 and 25 seconds provided numerical stability and suitable model simulation times.
Model Outputs	• Two-dimensional grids of flood extent, flow depth, water levels and flow velocity

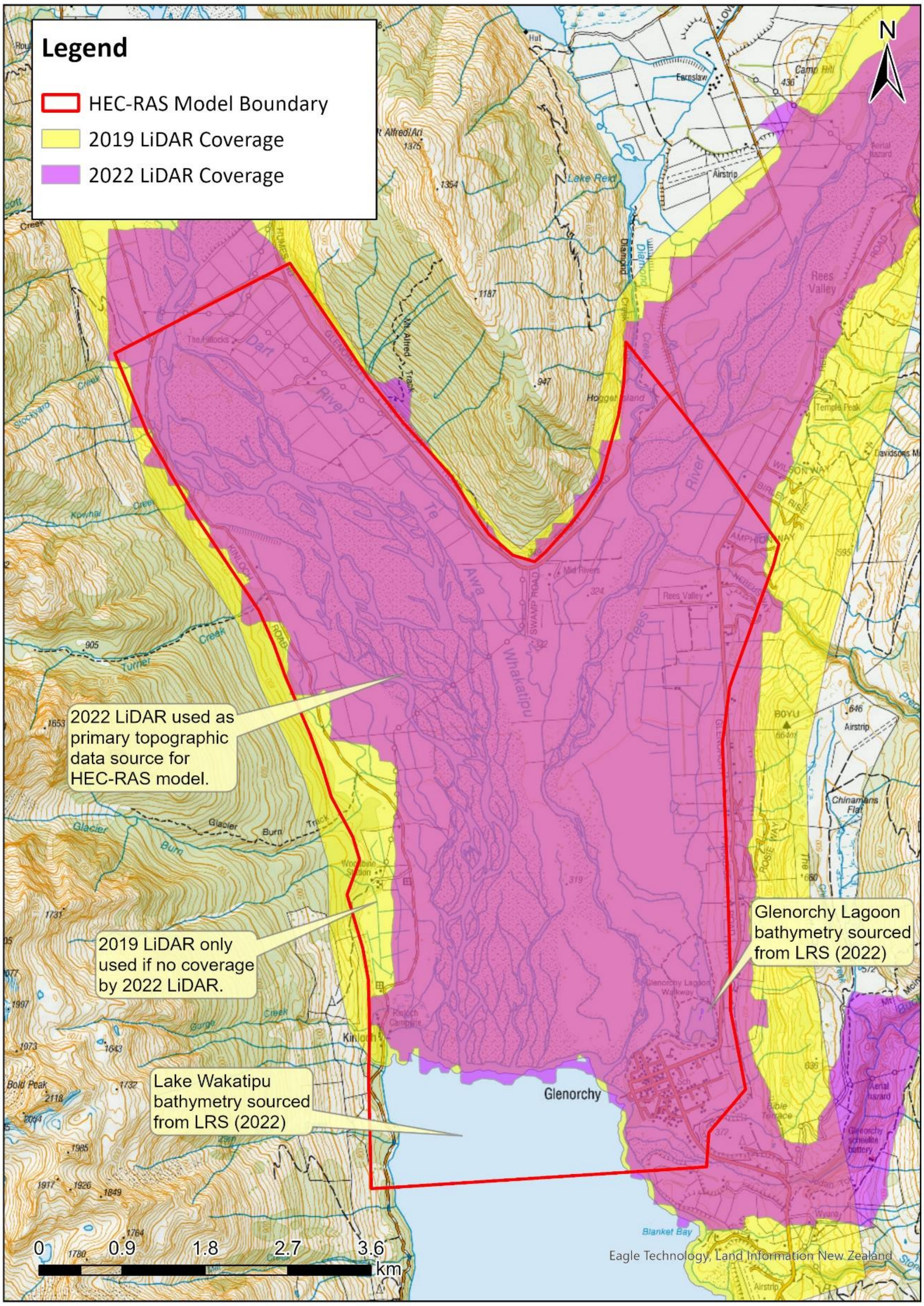


Figure A.1: Extent of HEC-RAS model domain, showing coverage of 2019 and 2022 LiDAR topographic surveys.

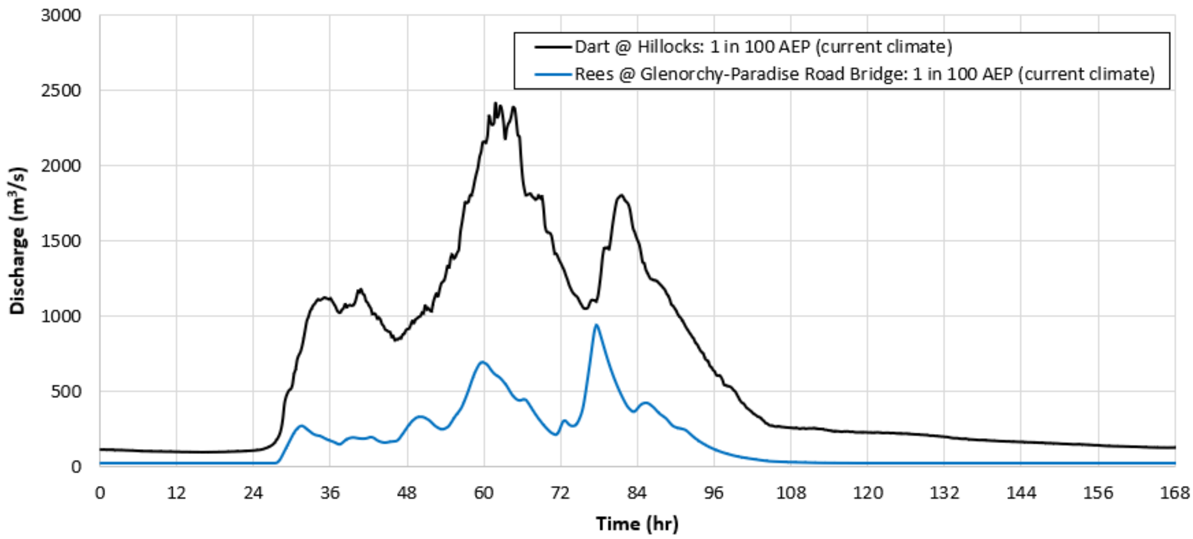


Figure A.2: 1 in 100 AEP (current climate) hydrographs, reproduced from ORC (2021)

Table A.2: Manning's "n" roughness coefficients adopted in HEC-RAS model, reproduced from LRS (2022), except for value adopted for vegetated buffer which was selected by Damwatch.

Land use type	Manning's "n"
Vegetation	0.07 – 0.12
Roads / Concrete	0.02
Grass / Pasture	0.033
Gravel River Bed	0.019
Buildings	1.00
Vegetation buffer	0.12

HEC-RAS Model Validation

- February 2020 flood:

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

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

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

  - Based on observations after the flood event, peak water level at the footbridge crossings Glenorchy Lagoons creek was estimated to be around RL 312.7 to 312.8 m (LRS, 2022). The HEC-RAS model predicted a peak water level of RL 312.67 m.

- Comparison of HEC-RAS model predicted flood extents at Glenorchy with the estimated extent provided by ORC (refer to Figure A.3).
- The general pattern of floodplain overflows matched those visible from infrared satellite imagery captured after the flood event (refer to Figure 6-2 in the LRS (2022) report).

No specific validation was carried out on the Dart River floodplain, but flooding extents appear to approximately match those observed in photos of Kinloch Road during floods.

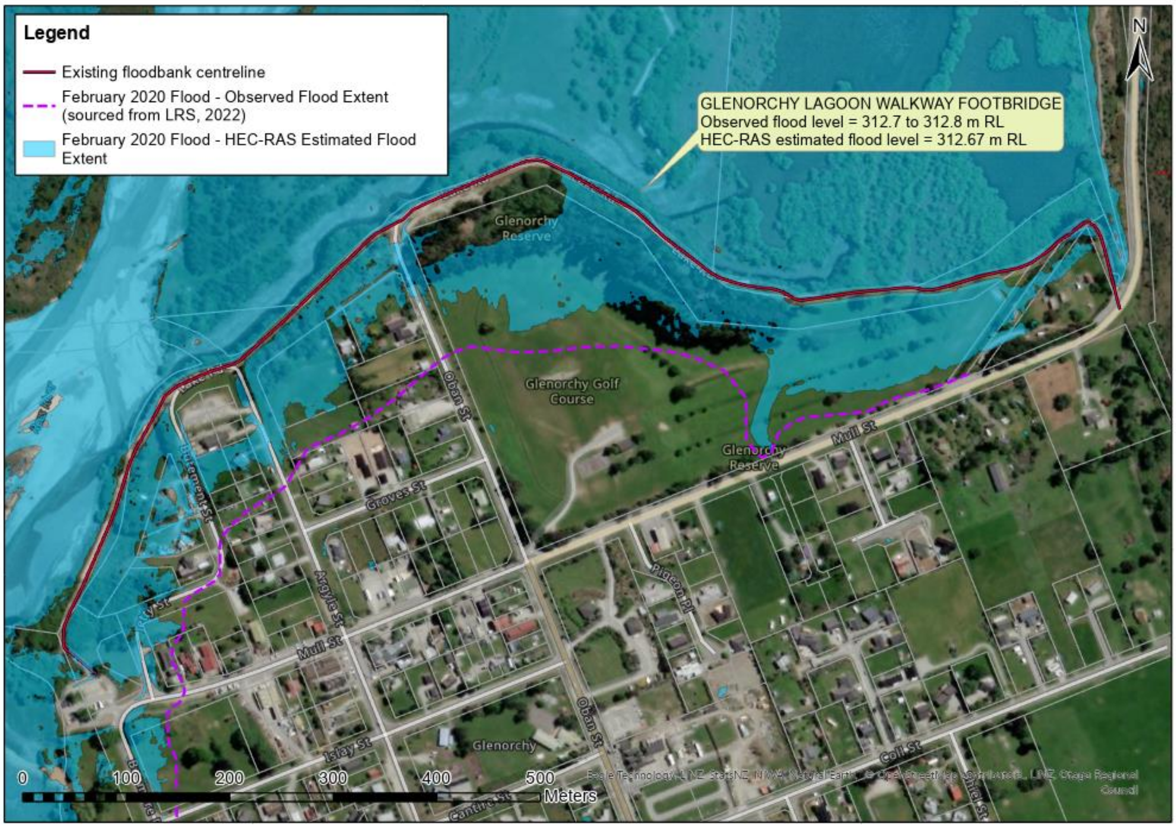


Figure A.3: Comparison of HEC-RAS modelled February 2020 flood extent (blue shading) with estimated actual extent (dashed-purple line). Existing Glenorchy floodbank alignment shown with red line.

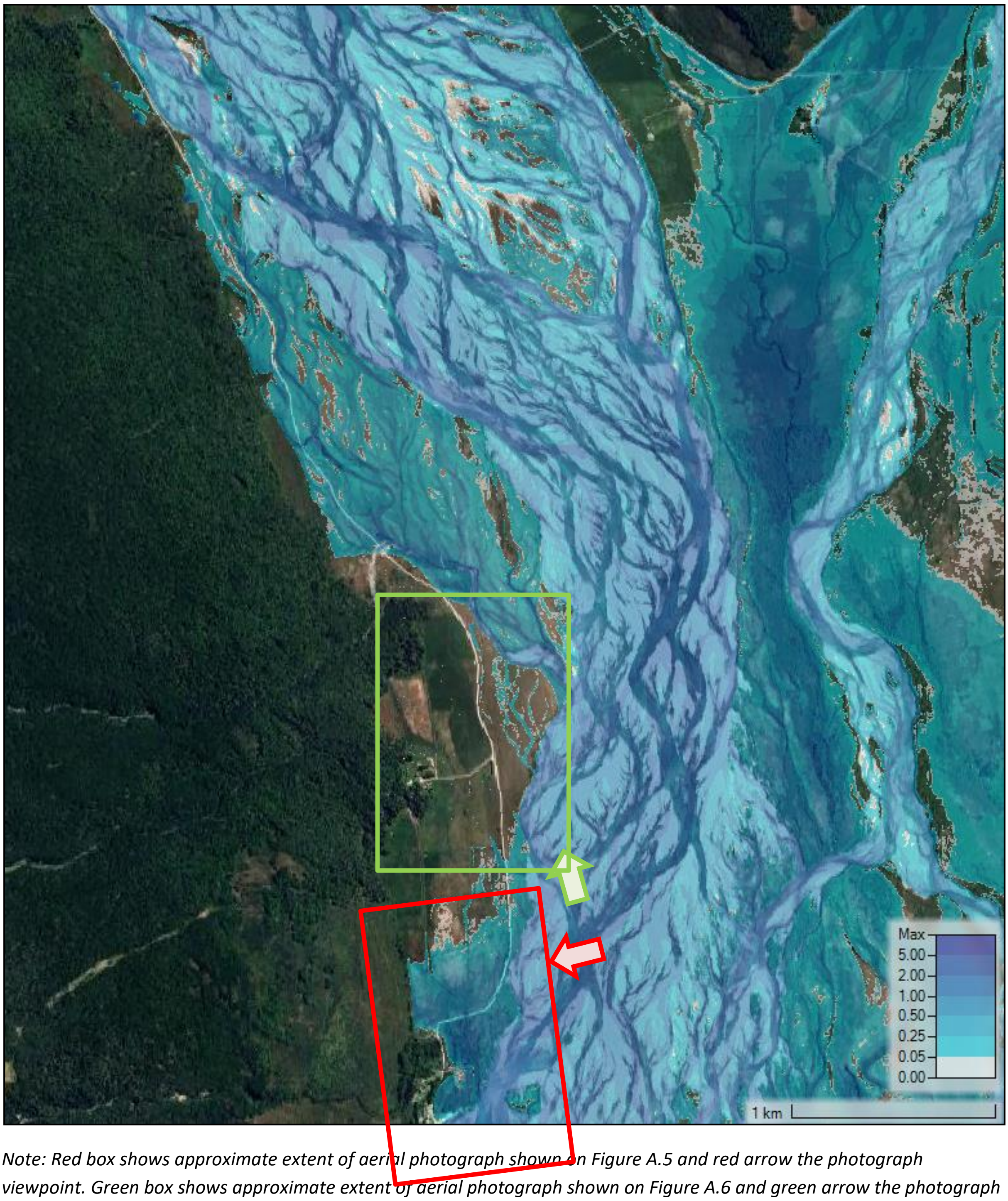
- March 2019 flood:

  The March 2019 flood event was simulated with the HEC-RAS model, using the following model boundary conditions:

  - Flood hydrographs with shape derived from ORC (2021) with a peak recorded flow of 1789 m^3/s in the Dart River at the Hillocks flow gauging site. Rees River peak discharge of 695 m^3/s, scaled based on ratio of Dart River to Rees River February 2020 flood peak.
  - Lake Wakatipu levels were taken from the ORC level gauge at Willow Place.

  No observed water level data was available for this event and which could be used to quantiatvely validate the model. Instead, the HEC-RAS model predicted maximum flood inundation extents (Figure A.4) were qualitatively compared with oblique aerial photographs captured by ORC on 26 March 2019 and near the time of the flood peak (Figures A.5 and A.6).

In general, comparison of Figures A.4 with A.5 and A.6 indicates a reasonable agreement between the flood extents in the right bank floodplain areas predicted by the HEC-RAS model and observed in the photographs.



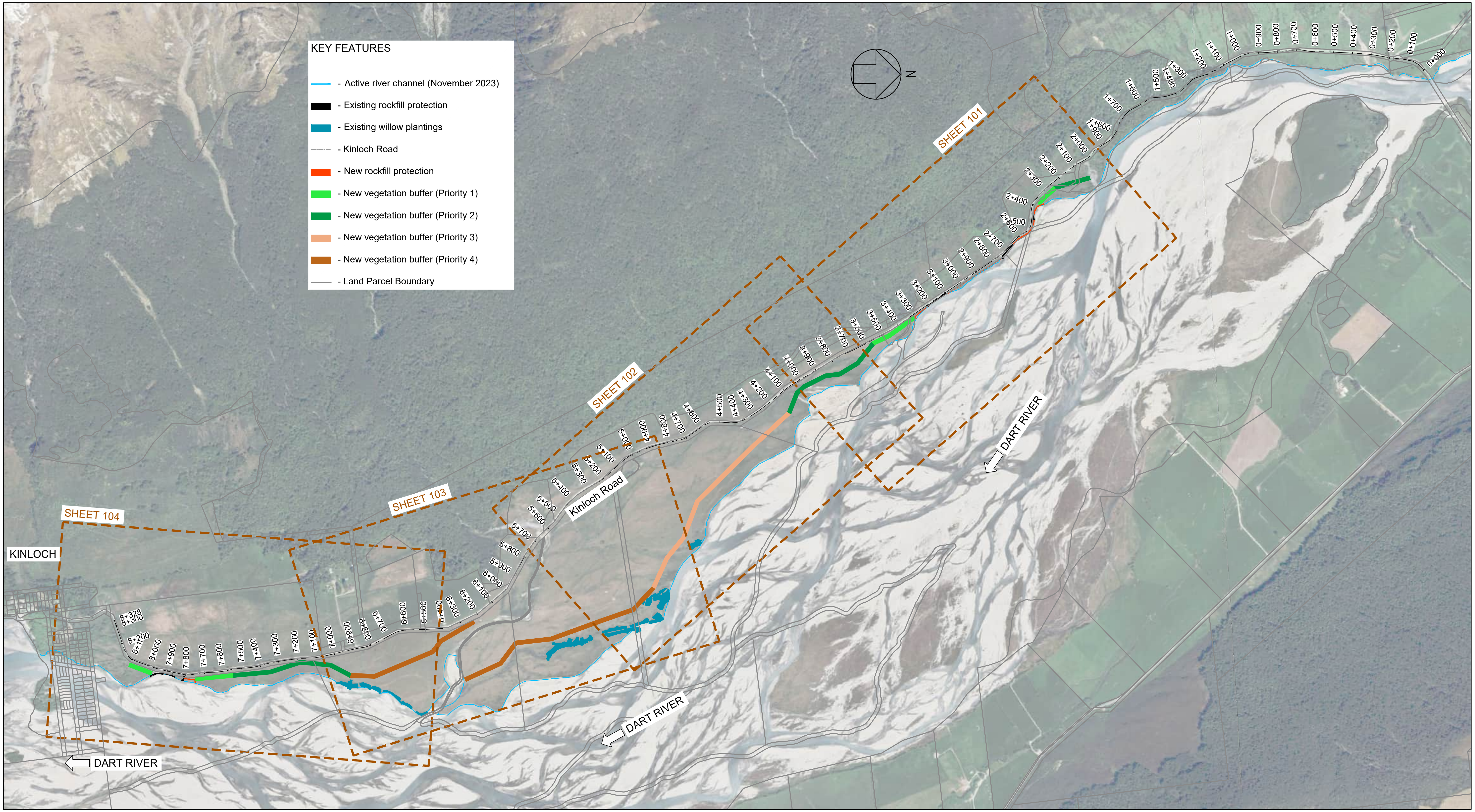
Note: Red box shows approximate extent of aerial photograph shown on Figure A.5 and red arrow the photograph viewpoint. Green box shows approximate extent of aerial photograph shown on Figure A.6 and green arrow the photograph viewpoint.

Figure A.4: Maximum flood depths and extents predicted by HEC-RAS model for March 2019 flood event.

Figure A.5: Aerial view of Kinloch Road flooding during March 2019 flood

Figure A.6: Aerial view of Kinloch Road flooding during March 2019 flood

Appendix B Concept Design Drawings



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Graphic Scales

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DAMWATCH
ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
DART RIVER FLOODPLAIN ASSESSMENT

GENERAL ARRANGEMENT
PLAN

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Original Sheet Size A3 (420x297)

Ⓐ Damwatch Engineering, Wellington Club Building Level 3, 88 The Terrace, PO Box 1549, Wellington 6140, New Zealand Ⓔ info@damwatch.co.nz Ⓟ +64 4 381 1300

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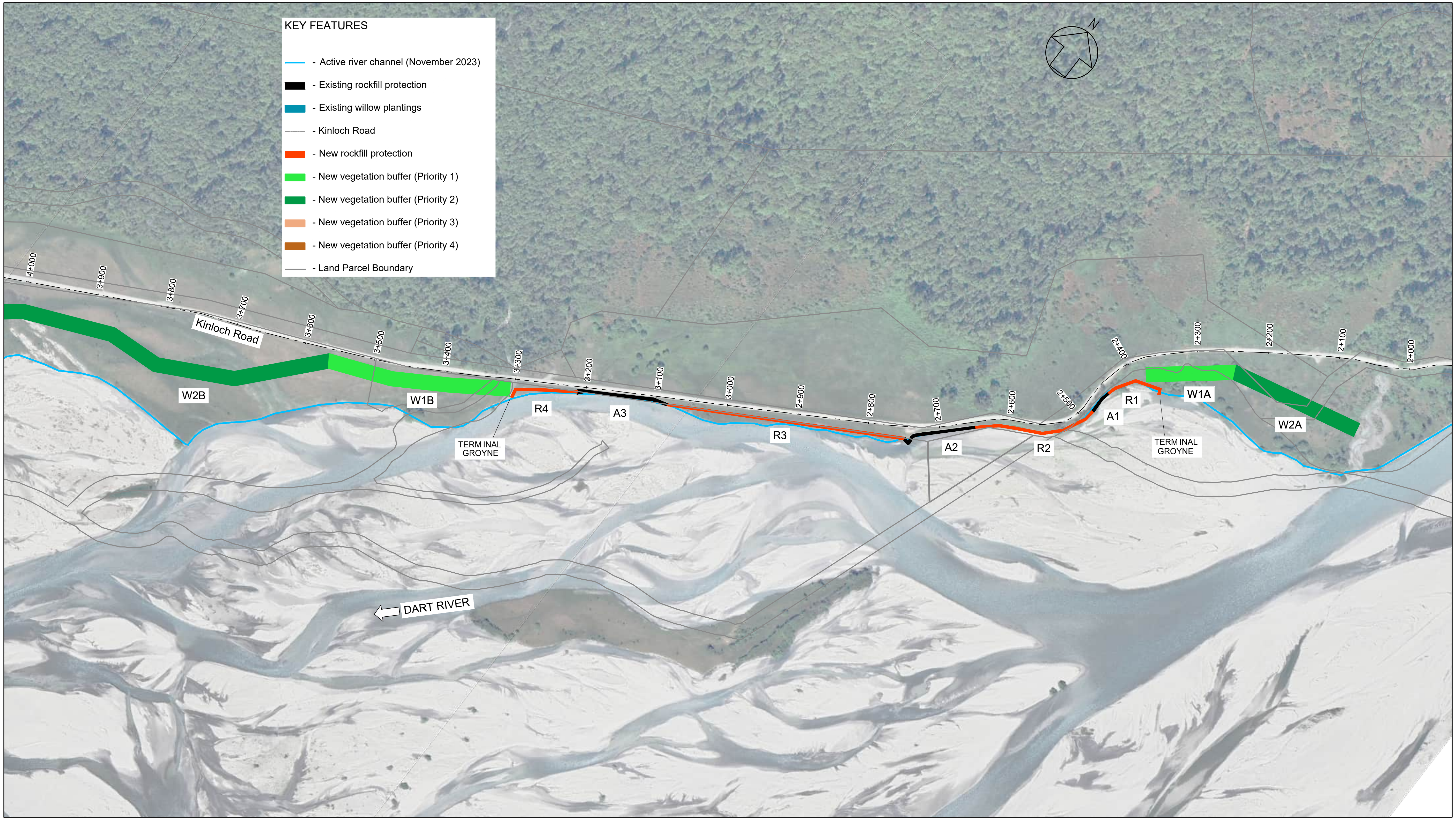

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DAMWATCH
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Title
OTAGO REGIONAL COUNCIL
DART RIVER FLOODPLAIN ASSESSMENT

GENERAL ARRANGEMENT
DETAIL PLAN – 1 OF 4

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GENERAL ARRANGEMENT
DETAIL PLAN – 2 OF 4

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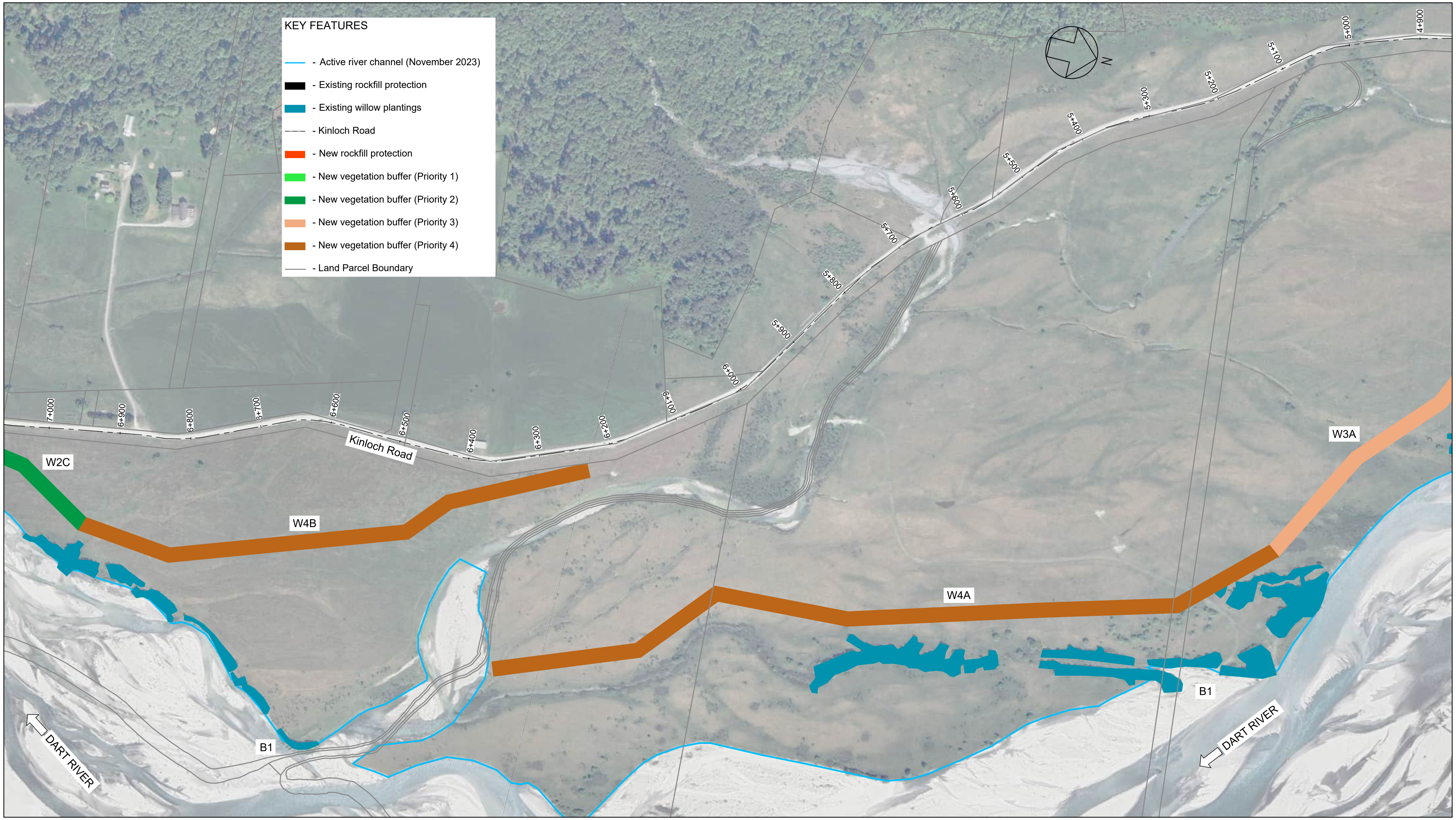

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DAMWATCH ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
DART RIVER FLOODPLAIN ASSESSMENT

GENERAL ARRANGEMENT
DETAIL PLAN – 3 OF 4

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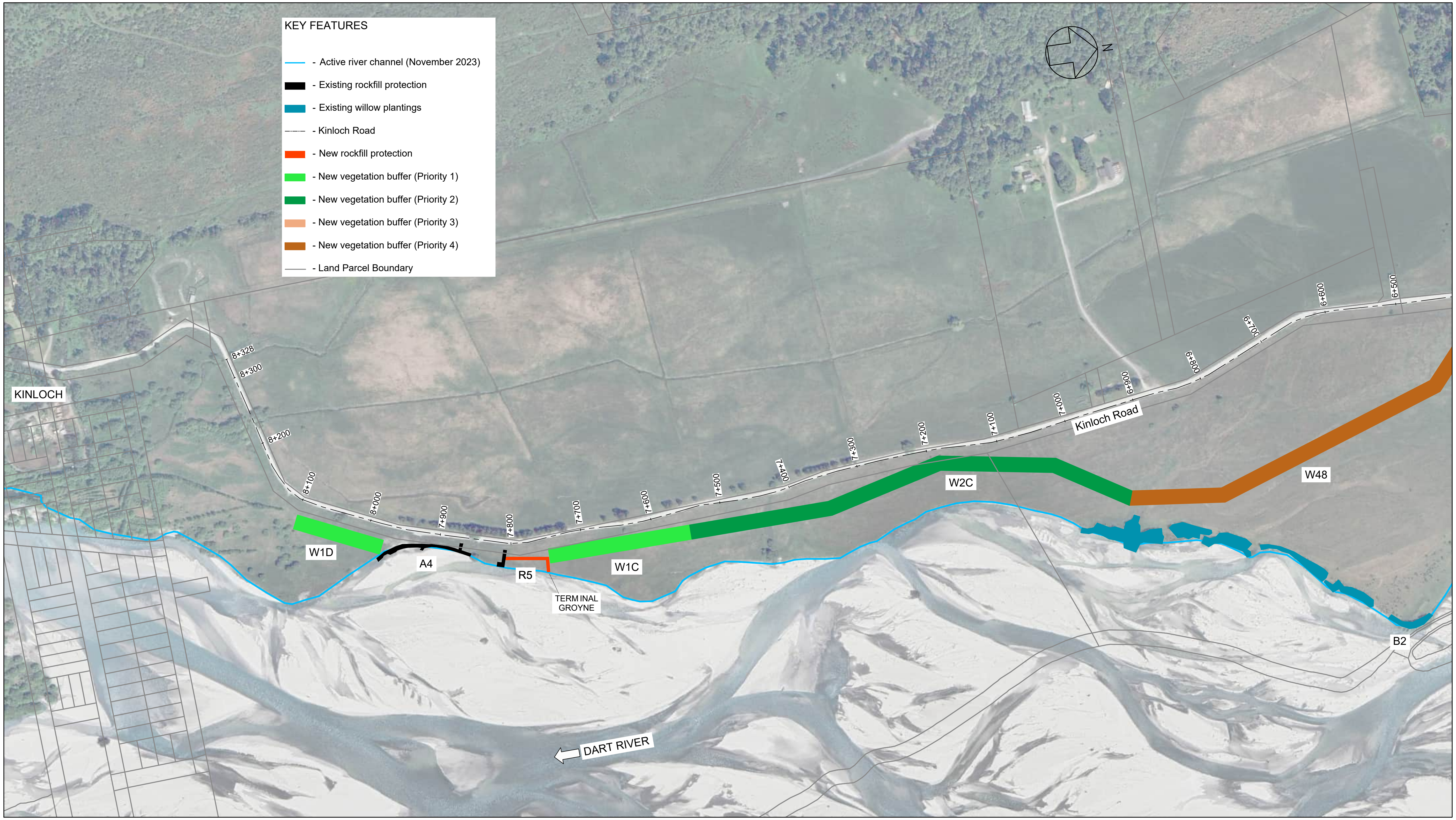

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OTAGO REGIONAL COUNCIL
DART RIVER FLOODPLAIN ASSESSMENT

GENERAL ARRANGEMENT
DETAIL PLAN – 4 OF 4

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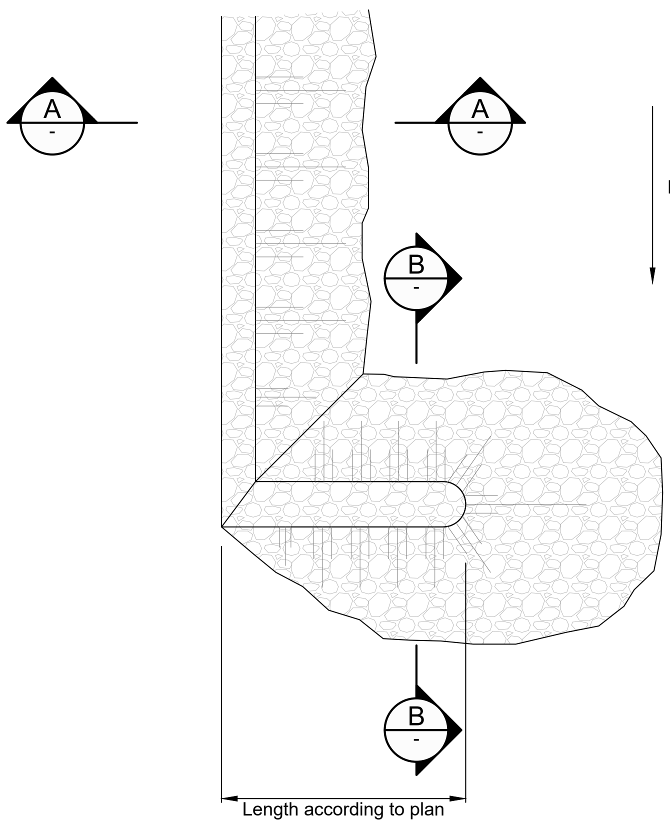

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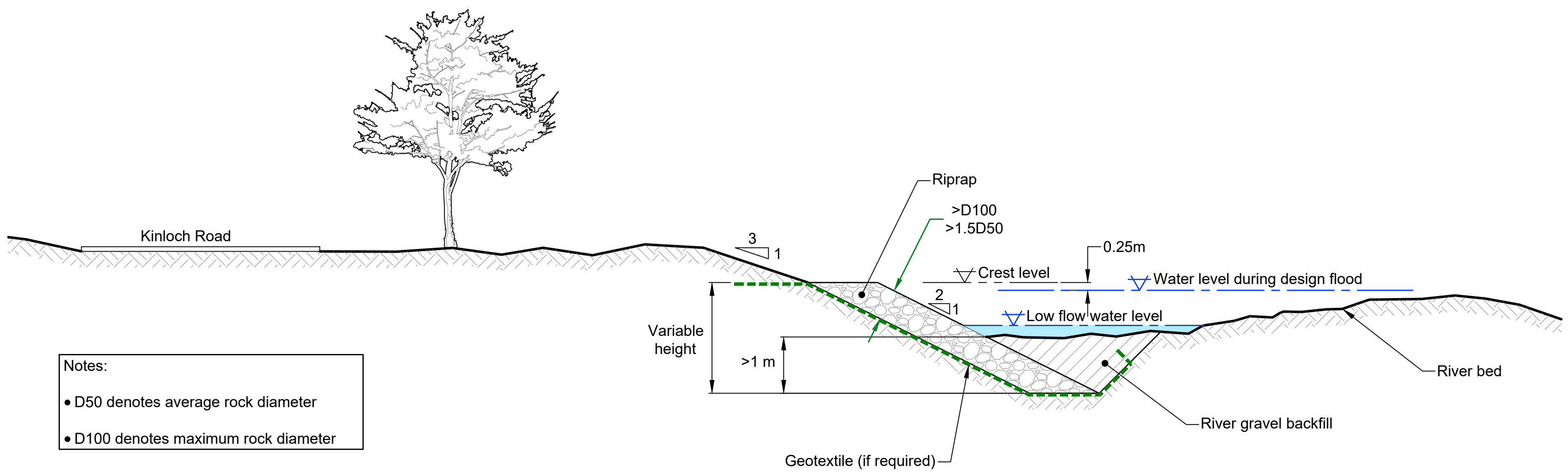

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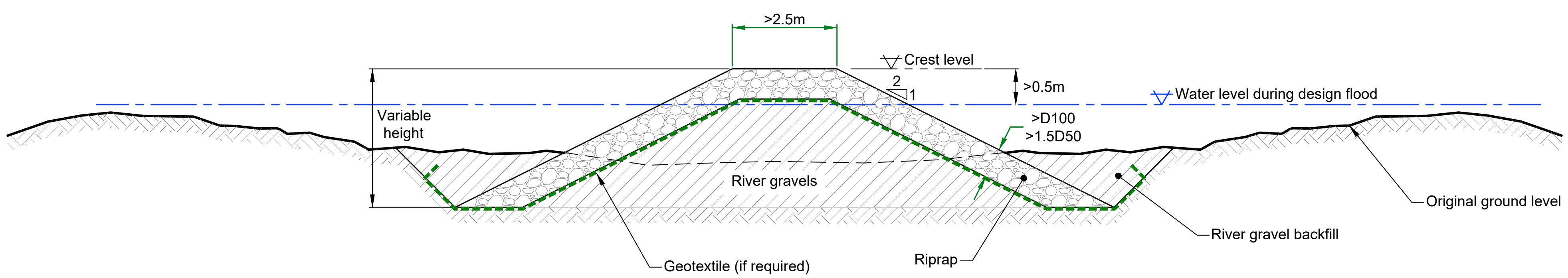
Notes:

- D50 denotes average rock diameter
- D100 denotes maximum rock diameter



SECTION B GROYNE
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Graphic Scales

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Title
OTAGO REGIONAL COUNCIL
DART RIVER FLOODPLAIN ASSESSMENT

TYPICAL DETAILS

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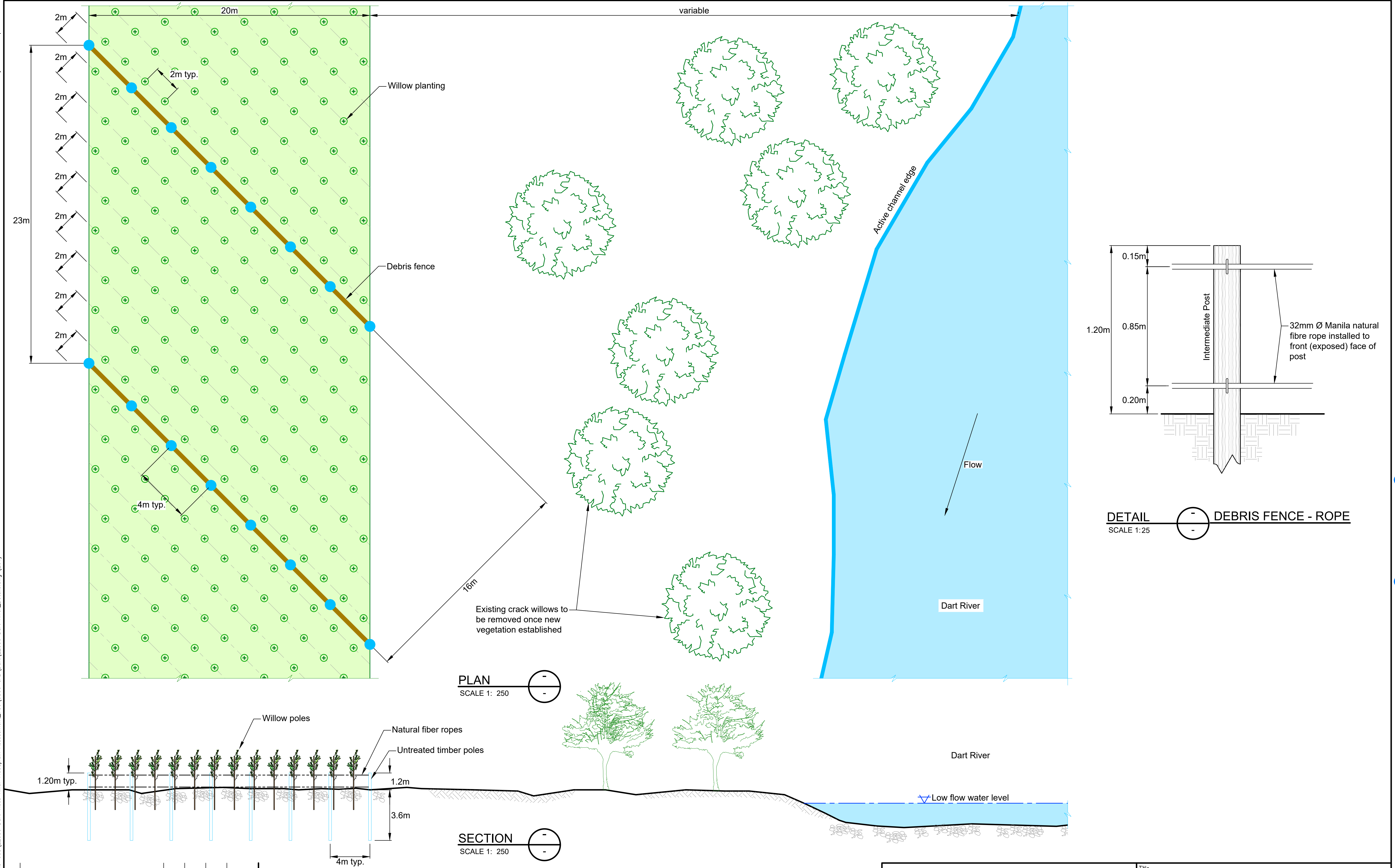

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DAMWATCH ENGINEERING BEYOND THE SURFACE

Title
OTAGO REGIONAL COUNCIL
DART RIVER FLOODPLAIN ASSESSMENT

TYPICAL WILLOW PLANTING DETAILS

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Graphic Scales

Original Sheet Size A3 (420x297)

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Appendix C Relevant Statutory Planning Provisions

C.1 Introduction

This appendix provides a preliminary review of the consent requirements for the concept design. 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.

C.2 Summary of Concept Design & Consenting Requirements

The concept design that is deemed be viable on the Dart River is to plant out the true right of the river in (non pest) willow species forming a vegetation buffer and to construct riprap protection in those places where the active channel of the river is very close to Kinloch Road. Of relevance to the consenting process, none of the wilding species listed in Chapter 34 of the QLDC PDP, including grey willow (Salix cinereal) and crack willow (Salix fragilis) or those listed in the ORC Pest Management Strategy 2009 will be included in the planting plan.

The concept design is located partly on rural zoned land and partly on (formed and unformed) roads. All the works are located within an Outstanding Natural Landscape and the majority of it is located within Wāhi tūpuna Area 14 - Tāhuna (Glenorchy and surrounds).

In summary, under the current regulatory framework the concept design will require resource consent to be obtained from QLDC for the planting, riprap protection structure, and earthworks and from the ORC to erect new lengths of riprap both on and beyond the bed of the river and, in so doing, to permanently divert flood water and alter the bed of the river.

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

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

C.3 Review of Key Higher Order Policy Documents

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

C.3.1 Partially Operative Otago Regional Policy Statement 2019 (PORPS)

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 is likely to be consistent with the relevant objectives and policies of the PORPS. In particular, the preliminary assessment finds that the concept design will:

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

- recognise the values of ecosystems and natural resources of the nearby waterbodies and their margins (including their natural functioning as far as practicable and their landscape values);
- mitigate natural hazard risks to the communities;
- maintain the existing public access to and along the margin of the Dart 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), noting that undertaking only planting was considered as part of the options assessment but was found to not be an effective alternative given the close proximity of the active channel to Kinloch Road.

C.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.

C.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 will be consistent with the relevant policies of the NRMP.

C.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.

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 will be consistent with the relevant policies of the IMP.

C.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 aligns with, and has appropriate regard for, the document (or its replacement).

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

- 2.1 Objective (1)
- The objective of this National Policy Statement is to ensure that natural and physical resources are managed in a way that prioritises:
  (a) first, the health and well-being of water bodies and freshwater ecosystems
  (b) second, the health needs of people (such as drinking water)
  (c) third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.
- Policy 1: Freshwater is managed in a way that gives effect to Te Māna o te Wai;
- Policy 2: Tangata Whenua are actively involved in freshwater management (including decision-making processes), and Māori freshwater values are identified and provided for.
- Policy 3: Freshwater is managed in an integrated way that considers the effects of the use and development of land on a whole-of-catchment basis, including the effects on the receiving environment.
- Policy 7: The loss of river extent and values is avoided to the extent practicable.
- Policy 8: The significant values of outstanding water bodies[11] 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:

[11] Whether the Dart River is an Outstanding Water Body is to be determined in accordance with the PRPS.

- 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[12];
- Consultation will be undertaken with iwi through the consenting process;
- The concept design will not result in a reduction in the extent of the river when at normal flow levels or its values (noting that the works will only affect water level flood conditions and will not affect the normal water level range or hydrological function of the river);
- Based on the values of the Dart 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 Dart River listed in the RWP, it 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

C.3.6 The Water Conservation (Kawarau) Order 1997

Lake Wakatipu and the Dart River mainstem from Lake Wakatipu to the confluence with Beans Burn are listed as watercourses to be protected in Schedule 2 of this order. While no damming is included in the concept design and the braided nature of the watercourses will be maintained it noted for completeness that, Clause 5(b) of the Order provides an exception to allow for river protection works. As such, the activities are not prohibited under the Order.

C.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.

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

C.4 Consenting Requirements for the Concept Design

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

C.4.1 Consenting requirements by the Queenstown Lakes District Council

Queenstown Lakes Proposed District Plan (PDP)

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

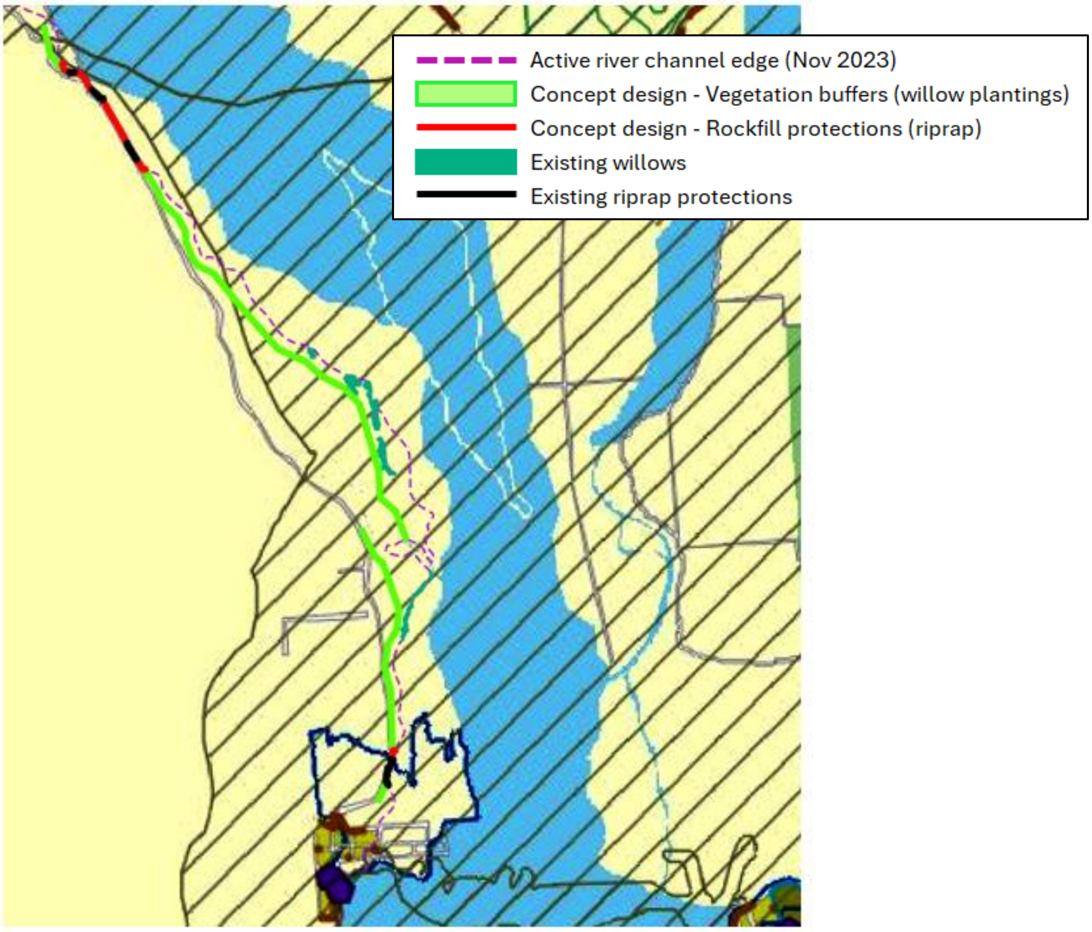

Figure C.1: The concept design overlaid the PDP planning (zone) map.

Based on the preliminary plans, the planting identified in the concept design will be located primarily in the Rural Zone with small areas of planting located on road reserve (i.e. unformed sections of legal road where Kinlock Road has been physically constructed to the west of the road reserve).

Based on the preliminary plans, it is likely that the riprap protection will be located in both in the Rural Zone and within Kinloch Road/ road reserve (but not within the carriageway).

The concept design is wholly located on land classified as Outstanding Natural Landscape and approximately two thirds of it is located within Wāhi tūpuna Area 14 (Tāhuna - Glenorchy and surrounds).

As the plans are not yet to the level of detail that would be required for consenting purposes, the exact location/ extent of the planting and rock riprap and the plant species is 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 is held in a small number of different ownerships. This information is summarised in Table C.1.

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

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

Zone	Location/ description	Ownership
Road	Kinloch Road – Two short stretches of planting in the northern and mid sections of the planting and various sections of the rock riprap.	QLDC
Rural	Very small areas of planting where the planting crosses narrow areas of land that link the road to the river margin.  	Crown Land (variously managed by DOC and LINZ).
Rural	All of the planting and riprap on the land to the east of Kinloch Road (as formed) other than the two small areas shown above.	Private ownership
Outstanding Natural Landscape	All of the concept design.	Various as noted above
Wāhi tūpuna Area 14	The majority of the planting and a small area of rock riprap at the southern end of the concept design.	Various as noted above

Table C.2: QLPDP rules and preliminary assessment consent requirements for proposed works

Rule	Discussion of Consent Requirements
Chapter 30 – Energy and utilities	
30.5.1.16 - Flood Protection Works[13] 30.6.1.2 – Non notification of Applications	Both the planting and rock riprap fall within the definition of Flood Protection Works and therefore require a Discretionary activity consent. Discretionary activities 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). However this is likely to be of little consequence in this instance as the consents that are triggered under other chapters are able to notified.

[13] 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'.

Chapter 25 – Earthworks[14]		
Rule	Road	OSRZ
Table 25.2 Earthworks volumes (able to be notified pursuant to Rule 25.6) 25.5.7.1 - Volumes within Roads 25.5.10A.2 - Wāhi tūpuna areas as identified in Schedule 39.6 but not listed in 25.5.10A.1, where earthworks: a. are located within 20m of the boundary of any wetland, bed of any river or lake.	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.*	**Restricted discretionary** consent as the maximum 10 m^3 will be breached by the riprap protection works within the rural zoned land. The threats for Wāhi tūpuna 14 are listed in Chapter 39. Of relevance to the concept design, these threats include 'activities affecting water quality', 'earthworks', and 'utility activities'.
25.5.11 - Earthworks over a contiguous area of land shall not exceed the following area: - 2,500 m^2 where the slope is 10° or greater. - 10,000 m^2 where the slope is less than 10°. Rule 25.6.1 - Non notified	A **Restricted Discretionary** activity consent is likely to be required based on the preliminary information that the land where the riprap is shown in the concept design is steeper than 10°.	
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 submits 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).**	

[14] The following consent breaches all assume that the riprock protection works will fall within the definition of Earthworks, which is defined in the PDP as 'The disturbance of land by the removal or deposition on or change to the profile of land. Earthworks includes excavation, filling, cuts, root raking and blading, firebreaks, batters and the formation of roads, access, driveways, tracks and the deposition and removal of cleanfill'.

Chapter 25 – Earthworks[14]	
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 submits 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).**
25.5.14 - 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.	This standard may be breached depending on whether the Council considers that only the small amount of excavation required at the toe of the structure falls within the definition of earthworks or whether the placement of the rock on top of the ground is also considered to be earthworks. if it is the latter, then this standard may be breached along the road boundary and a **Restricted Discretionary** consent required.
25.5.19.1 - Earthworks within 10m of the bed [See Note 1] of any water body shall not exceed 5 m³ in total volume, within any consecutive 12-month period. None of the exemptions to the rule apply in this instance	As the intention is to construct the riprap alongside the active channel of the river, earthworks will be undertaken within 10 m of a waterbody and therefore, a **Restricted discretionary** consent will be required.

Chapter 25 – Earthworks[14]	
25.5.20 - Earthworks shall not be undertaken below the water table of any aquifer, or cause artificial drainage of any aquifer.	No earthworks will be below the water table of any aquifer, or cause artificial drainage of any aquifer and therefore no consent is required under this rule (**Permitted**).
25.5.21 - No more than 300 m³ of Cleanfill shall be transported by road to or from an area subject to Earthworks.	More than 300 m³ of 'cleanfill' will be brought to the site via road and, therefore a **Restricted discretionary** consent will be required.
Chapter 29 – Transport - Table 29.2 - Activities within a road	
29.4.13 - Activities that are not listed in this Table.	Planting and the construction of flood protection works is not listed in the Rules table and therefore a **Discretionary** activity consent is required for that part of the concept design located within the road reserve. 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 C.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.

It is noted for completeness that:

- Pursuant to Rule 25.3.2.11, any earthworks associated with planting riparian vegetation[15] is exempt from the earthworks rules in Tables 25.1 – 25.3. As such, any earthworks associated with the planting shown in the concept design is permitted.
- A conservative approach has been taken in the above assessment and it has been assumed that specific earthworks consents will be required under Chapter 25 of the PDP. However, if the QLDC determines that the works associated with the riprap protection do not fall within the definition of 'earthworks' or that those works can be processed as a 'Structure… and associated works including earthworks for the protection of the community from natural hazards' (Rule 30.5.1.14) rather than as Flood Protection Works (Rule 30.5.1.16), then no specific consents will be required under Chapter 25. Under either of these alternative scenarios, it is relevant to note that the overall activity status remains discretionary and matters relating to the effects of earthworks will still need to be thoroughly assessed.

C.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.

C.4.3 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 Dart River:

- A 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.
- An absence of aquatic pest plants (e.g. Lagarosiphon) identified in the Pest Management Strategy for Otago 2009;
- A presence of riparian vegetation of significance to aquatic habitats;
- A significant area for the spawning and development of juvenile fish (trout, salmon, and eel);
- Presence of a breeding population of threatened endemic species (blue duck) above Beans Burn confluence to its source.
- Areas of importance to internationally uncommon species (black fronted tern, wrybill, banded dotterel) in the main stem from Lake Wakatipu to confluence to Beans Burn.
- Has a high level of naturalness.
- Outstanding Natural and physical qualities and characteristics that contribute to people's appreciation of pleasantness of waters, the aesthetic coherence, and cultural attributes;
- Outstanding biological and genetic diversity of ecosystems, essential characteristics that determine the ecosystem's integrity, form, functioning and resilience, and wildlife habitat

[15] While Riparian vegetation is not defined in the PDP, it is defined in the RWP as 'the terrestrial plants growing on the bed or margin of a water body'.

- Outstanding scenic characteristics;
- Outstanding natural characteristics and scientific values (in particular, natural turbidity);
- Outstanding for its significance in accordance with tikanga Maori, in particular sites at the mouth of the river.

Schedule 1AA of the RPW identifies Otago resident native freshwater fish and their threat status. The Dart 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 C.3 below, along with a preliminary assessment of what consents will be required for the concept design.

Table C.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 riprap protection will permanently divert floodwaters, it will require a **Discretionary** Activity consent.
13.3.2.1 - Except as provided for by Rules 13.3.1.1 and 13.3.1.2, the extension, alteration, replacement or reconstruction of any structure, fixed in, on, under or over the bed of any lake or river, or any Regionally Significant Wetland, is a restricted discretionary activity. This is required to be processed on a non-notified basis (unless special circumstances apply).	As the riprap protection will be located partly on the bed of the river it will require a **Restricted Discretionary** Activity consent.
13.5.3.1 - Except as provided for by Rules 13.5.1.1 to 13.5.2.1 the alteration of the bed of any lake or river is a discretionary activity. Note: Alteration of the bed is defined as 'Any bed disturbance, reclamation, or deposition'. Bed disturbance is defined as 'Any activity which affects the bed or bank of a water body and includes any excavation, dredging, drilling, tunnelling, and any widening, deepening or altering of the course of the water body.	As the riprap protection will be located partly on the bed of the river 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.	The riprap protection will require a **Discretionary** Activity consent.

For completeness, it is noted that the planting shown in the concept design requires no resource consents under the RWP, on the basis that:

- There is no planting on the bed of the river, as defined in the RWP.

[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.

- The planting is not included in the definition of a 'Defence Against Water'[17] in the RWP.
- The planting is not considered to be a diversion of water based on the definition of 'Divert'[18] in the RWP.

Overall, construction of the riprap shown in the concept design will require a **Discretionary** activity consent under the RWP.

Resource Management (National Environmental Standards for Freshwater) Regulations 2020

As the works are not considered to fall within the definition of Reclamation[19] under the National Planning Standards 2019 and are not proximate to a natural inland wetland, it is considered that 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 for the concept design under the LWRP at this stage. Rather, that assessment should be undertaken once a decision has been released on the proposed LWRP (at the earliest) and that assessment attached as an addendum to this report.

C.5 Consenting Information Requirements & Costs

C.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 C.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 C.4 into the following categories:

- General information requirements

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[17] *Any dam, weir, bank, carriageway, groyne, or reservoir, and any structure or appliance of any kind which has or may have the effect of stopping, diverting, controlling, restricting, or otherwise regulating the flow or spread or subsidence, in or out of a water body, of water including flood waters, which is specifically established for the purpose of flood hazard mitigation.*

[18] *In relation to the diversion of water, is the process of redirecting the flow of water from its existing course to another.*

[19] *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.

- Consultation and affected parties
- Notification and the need for a hearing

Table C.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 and cross sections, of the rock riprap and a planting plan for the willows and the native succession planting ***[completed to concept-level design stage in this report].*** • A brief Landscape Assessment report (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:
	  ○ an assessment of the need for, and effectiveness of, the defence (riprap protection)
	  ○ 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.
	  ○ the extent to which the defence is likely to create or exacerbate a natural hazard.
	  ○ effects of the riprap protection on the movement of water and sediment and on the existing riprap protection; and
	  ○ any effect of any flow and sediment processes ***[completed to concept-level design stage in this report].***
	• High risk EMP**.
	• 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 showing the footprint and cross sections, of the rock riprap**. ***[completed to concept-level design stage in this report].***

Consultation and affected parties	
Combined consultation process for all district and regional council consents.	It is anticipated that consultation would be undertaken with the following entities as part of preparing the consent applications: • Private land owners • QLDC • DOC • LINZ • Fish and Game NZ • Aukaha • Te Ao Marama 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 road reserve on which extensive sections of riprap protection and small areas of planting are proposed to be located. • Private land owners – As the owners of land on which extensive sections of riprap protection and planting are proposed to be located. • DOC – As owner (agency responsible) of a small area of land on which planting is proposed. • LINZ – As owner (agency responsible) of a small area of land on which planting is proposed. • Aukaha • Te Ao Marama • (Potentially) Fish and Game NZ
Notification and the need for a hearing	
	While Rule 30.6.1.2 of the PDP states that consents for Flood Protection Works will be processed on a non-notified basis, consents for earthworks that breach the PDP standards, as is the case with this project, may be notified. 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 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.

C.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 5.7 of the main report, rather than as a consenting cost.
- Where the information required by the district and regional councils is the same or similar, the same expert report will be submitted to both consenting authority.
- Any effects on recreational values will be covered by the AEE and not require an expert report.
- If both the regional and district council consents are required to be notified, they will be heard jointly.
- Consents would be prepared and lodged by the end of 2025 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:

- $52,000.00 excl. GST (under a non-notified scenario)
- $62,000.00 excl. GST (under a limited notified scenario)
- $70,000.00 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 5.5), 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.