Science and Resilience Committee
3 September 2025

Meeting will be held in the Council Chamber at Level 2, Philip Laing House
144 Rattray Street, Dunedin

This meeting will be livestreamed to the ORC Official YouTube Channel

Members:
Cr Gary Kelliher (Co-Chair)
Cr Alan Somerville (Co-Chair)
Cr Alexa Forbes
Cr Michael Laws
Cr Kevin Malcolm
Cr Lloyd McCall
Cr Tim Mepham
Cr Andrew Noone
Cr Gretchen Robertson
Cr Elliot Weir
Cr Kate Wilson

Senior Officer: Richard Saunders, Chief Executive
Meeting Support: Cara Jordan, Governance Support Officer

03 September 2025 01:00 PM

Agenda Topic — Page

Agenda 1

1. WELCOME

2. APOLOGIES

No apologies were submitted prior to publication of the agenda.

3. PUBLIC FORUM

At the time of publishing bo requests to speak had been received.

4. CONFIRMATION OF AGENDA

Note: Any additions must be approved by resolution with an explanation as to why they cannot be delayed until a future meeting.

5. DECLARATION OF INTERESTS

Members are reminded of the need to stand aside from decision-making when a conflict arises between their role as an elected representative and any private or other external interest they might have. Councillor interests are published on the ORC website.

6. PRESENTATIONS

There are no presentations scheduled.

7. CONFIRMATION OF MINUTES 4

That the minutes of the Science and Resilience Committee 4 June 2025 be confirmed as a true and accurate record.

7.1 Draft Minutes - Science and Resilience Committee Meeting 4 June 2025 4

8. OPEN ACTIONS FROM THE RESOLUTIONS OF THE COMMITTEE 10

Review of open Committee actions

8.1 Action Register 10

9. MATTERS FOR CONSIDERATION 11

9.1 Roxburgh Debris Flow Hazard Management Update 11

Update on the Roxburgh Debris Flow Hazard Management Programme progress, engagement and programme planning.

9.2 Clutha Delta Natural Hazards Adaptation 23

To update the Committee on progress with the Clutha Delta natural hazards adaptation work programme, including to present the findings of investigations into seismic hazard risks, and an assessment of river morphology (bed levels) trends at Balclutha.

9.2.1 Clutha Delta liquefaction vulnerability study 43

9.2.2 Clutha Delta qualitative risk assessment (seismic) 98

9.2.3 Clutha River morphology trends at Balclutha 157

9.2.4 Plain language report on river bed changes at Balclutha 219

9.2.5 Drop- In Session Posters - Natural Hazards - Balclutha 270

9.3 Communication and Disclosure of Natural Hazards Information 273

To brief the Committee on how natural hazard information is disclosed and communicated by Otago Regional Council and on recent legislative changes.

9.3.1 Guidance for Natural Hazard Information in LIMs - July 2025 280

9.3.2 LGOIMA amendments (LIM) - Workshop Presentation 297

9.4 Otago Active Fault Mapping and Fault Awareness Areas 310

This report reviews active fault mapping for Otago and the development of a fault awareness area dataset.

9.4.1 Review and update of active geological fault and fold characterisation in the Otago region. 319

9.5 Operations and Maintenance Annual Work Plan Update 381

To provide a summary of performance against the 2024/25 annual maintenance programme, and the proposed 2025/26 annual maintenance programme, for the flood protection schemes in Lower Clutha, and Lower Taieri, as well as the drainage schemes in Tokomairiro, East Taieri, and West Taieri.

9.5.1 Scheme and Channel Maintenance 2024/25 388

9.6 Freshwater Biodiversity Science Programme Update 390

This report provides an overview of the freshwater biodiversity science work programme.

9.7 Wetland Programme Update 407

To update the Committee on the wetland mapping and monitoring programme.

9.7.1 Wetland Programme Update 422

9.8 Artificial Lakes and Water Storage in Otago 425

This report is a stocktake of artificial water storage and was prepared to provide Council with insight into the status of water storage in the region.

9.9 An overview of the Envirolink scheme and ORC's involvement 443

This paper provides an overview of Envirolink, a regional council driven scheme with funds administered by the Ministry of Business, Innovation & Employment – Science and Innovation. The paper outlines how the scheme funds research organisations to transfer scientific knowledge to regional councils, and outlines the projects ORC has been successful in having funded.

9.10 Nature Based Solutions 453

This report provides a summary of the findings from the Ministry for the Environment (MfE) funded Nature-based Solutions (NbS) studies to complete "Modelling of Te Hakapupu Catchment to Investigate Flood Mitigation".

9.10.1 Te Hakapupu Nature-based Solutions Feasibility Study 463

9.10.2 Appendix 1 Nb S Technical Specification 566

9.10.3 Appendix 2 GH D- Te Hakapupu Model Build Report Final 580

9.10.4 Appendix 3 Maps 603

9.10.5 Appendix 4 Biodiversity 614

9.10.6 Appendix 5 Landscape 618

9.10.7 Appendix 6 Planning 623

9.10.8 ORC Beca Natura-based Solutions Engagement Study 632

10. CLOSURE

Otago Regional Council

Science and Resilience Committee
MINUTES

Minutes of an ordinary meeting of the Science and Resilience Committee held in the Council Chamber, Level 2 Philip Laing House, 144 Rattray Street, Dunedin on Wednesday 4 June 2025, commencing at 1:00 pm.

DRAFT

PRESENT

Cr Gary Kelliher	*(Co-Chairperson)*
Cr Alan Somerville	*(Co-Chairperson)*
Cr Alexa Forbes	
Cr Michael Laws	*(Online)*
Cr Kevin Malcolm	
Cr Lloyd McCall	
Cr Tim Mepham	
Cr Andrew Noone	
Cr Gretchen Robertson	
Cr Elliot Weir	
Cr Kate Wilson	

1. WELCOME

Chair Kelliher welcomed Councillors, members of the public and staff to the meeting at 1:00 pm. Cr Somerville opened the meeting with a karakia. Tom Dyer (GM Science and Resilience) gave an overview of the Committee restructure from Safety and Resilience to Science and Resilience.

Staff present included Tom Dyer (GM Science and Resilience), Richard Saunders (Chief Executive), Anita Dawe (GM Regional Planning and Transport), Joanna Gilroy (GM Environmental Delivery), Amanda Vercoe (GM Strategy and Customer, Deputy CE), Cara Jordan (Governance Support), Ben Mackey (Manager Science), Jason Augspurger (Principal Scientist), Sarah Harrison (Scientist - Air Quality), Pete Ravenscroft (Team Leader Biodiversity), Erik Button (Scientist - Land and Soil,) Mark Crawford (Scientist - Land and Soil), Sam Thomas (Senior Scientist - Coast), Helen Trotter (Scientist - Water Quality), Tim van Woerden (Senior Natural Hazards Analyst), Andrew Welsh (Spatial Analyst) and Jean-Luc Payan (Manager Natural Hazards). Staff online were Nick Donnelly (GM Finance) and Scott Jarvie (Senior Scientist - Terrestrial Ecology). External guests included Dr Marc Schallenberg (University of Otago), Dr Dean Olsen (Freestone Freshwater) and Ben Youngman (WAI Wanaka). Dr Clive Howard-Williams (NIWA) was online.

2. APOLOGIES

There were no apologies for the meeting.

3. PUBLIC FORUM

No requests to address the Committee under Public Forum were received.

4. CONFIRMATION OF AGENDA

The agenda was confirmed as published.

5. DECLARATIONS OF INTERESTS

No changes to Councillor Declarations of Interests were noted.

6. PRESENTATIONS

No presentations were held.

7. CONFIRMATION OF MINUTES

Resolution: Cr Somerville Moved, Cr Weir Seconded

That the minutes of the Safety and Resilience Committee meeting held on 6 March 2025 be received and confirmed as a true and accurate record.

MOTION CARRIED

8. OPEN ACTIONS FROM RESOLUTIONS OF THE COMMITTEE

There are no open actions for this Committee.

9. MATTERS FOR CONSIDERATION

Cr Laws joined the meeting online at 1:19 pm.
Cr Wilson left the meeting at 1:28 pm.
Cr Laws left the meeting at 1:53 pm.
Cr Laws returned to the meeting at 1:56 pm.
Cr Noone left the meeting at 2:03 pm.

DRAFT

9.1. Otago Deep Water Lakes Technical Advisory Group update

[YouTube 11:30] The paper provided an update on the progress of the Otago Deep Water Lakes Technical Advisory Group. Feedback from the Committee was requested to nominate a preferred funding level for proposed deep lake monitoring and research programmes from which to base a more developed proposal. Ben Mackey (Manager Science), Jason Augspurger (Principal Scientist), Dr Marc Schallenberg (University of Otago), Dr Dean Olsen (Freestone Freshwater), Dr Clive Howard-Williams (NIWA) and Ben Youngman (WAI Wanaka) were available for questions.

Resolution SRC25-101: Cr Forbes Moved, Cr Laws Seconded

That the Committee:

1) ***Notes** this report.*
2) ***Requests** the Technical Advisory Group to develop a more detailed research and monitoring plan at a funding level aligned with Proposal 1.*
3) ***Requests** that the Technical Advisory Group works to identify funding opportunities from external sources.*

MOTION CARRIED

Cr Noone returned to the meeting at 2:06 pm.
Cr Malcolm left the meeting at 2:07 pm.
Cr Malcolm returned to the meeting at 2:08 pm.

9.2. Annual Air Quality Report 2024

[YouTube 1:11:30] The report presented the results of the State of the Environment monitoring for air quality for the calendar year 2024. Sarah Harrison (Scientist Air Quality) and Ben Mackey (Manager Science) were available for questions.

Resolution SRC25-102: Cr McCall Moved, Cr Somerville Seconded

That the Committee:

1) ***Notes** this report.*

MOTION CARRIED

Cr Somerville left the meeting at 2:14 pm.
Cr Somerville returned to the meeting at 2:15 pm.
Cr Noone left the meeting at 2:16 pm.
Cr Wilson returned to the meeting at 2:19 pm.
Cr Noone returned to the meeting at 2:23 pm.

9.3. Update on Regional Indigenous Biodiversity Monitoring

[YouTube 1:20:20] The paper provided an update on the development of monitoring programmes for indigenous biodiversity. Pete Ravenscroft (Team Leader Biodiversity) and Ben Mackey (Manager Science) were available for questions.

Resolution SRC25-103: Cr Kelliher Moved, Cr Forbes Seconded

That the Committee:

1) ***Notes** this report*

MOTION CARRIED

DRAFT

9.4. Land and Soil Monitoring Update

[YouTube 1:33:45] The report provided an annual update on the Land and Soil work programme. Erik Button (Scientist - Land and Soil), Mark Crawford (Scientist - Land and Soil) and Ben Mackey (Manager Science) were available for questions.

Resolution SRC25-104: Cr Malcolm Moved, Cr Wilson Seconded

That the Committee:

*1) **Notes** this report.*

MOTION CARRIED

9.5. Coast and Estuaries Monitoring Programmes

[YouTube 1:43:40] The report provided an update on the current state of estuary sedimentation in Otago estuaries and the next steps in the estuary programme. The report also highlighted the current monitoring occurring in the coastal space and the next steps for the impending coast plan. Sam Thomas (Senior Scientist - Coast) and Ben Mackey (Manager Science) were available for questions.

Resolution SRC25-105: Cr Malcolm Moved, Cr Noone Seconded

That the Committee:

*1) **Notes** this report.*

*2) **Notes** that next steps include a comprehensive estuary and coastal state of the environment report for the coast plan, including catchment threats, habitat threats and issues to provide not only information for the coast plan, but also for targeted management. These reports will be presented to the Council.*

MOTION CARRIED

9.6. Type Localities of Terrestrial Animals, Plants and Fungi in the Otago Region

[YouTube 1:55:08] The paper provided an overview of the type localities for terrestrial species found in Otago, which are those species formally described in the scientific literature from type specimens collected in the Region. Scott Jarvie (Senior Scientist - Terrestrial Ecology) and Ben Mackey (Manager Science) were available for questions.

Resolution SRC25-106: Cr Noone Moved, Cr Weir Seconded

That the Committee:

*1) **Notes** this report.*

*2) **Notes** this work is part of a broader programme to inform management of biodiversity in the Otago Region.*

MOTION CARRIED

Cr Wilson left the meeting at 2:58 pm.

9.7. Regionally Endemic Species in Otago

[YouTube 2:04:26] The paper provided an overview of regionally endemic species in the Otago Region, meaning they do not occur naturally anywhere else on Earth. Scott Jarvie (Senior Scientist - Terrestrial Ecology) and Ben Mackey (Manager Science) were available for questions.

DRAFT

Resolution SRC25-107: Cr Forbes Moved, Cr Weir Seconded
That the Committee:
1) ***Notes*** *this report.*
2) ***Notes*** *this work is part of a broader programme to inform management of biodiversity in the Otago Region.*
MOTION CARRIED

At 3:03 pm Cr Noone Moved, Cr Malcom Seconded
That the Committee adjourn for 15 minutes.
MOTION CARRIED

9.8. Recreational Water Quality Annual Report
[YouTube 2:23:20] The report provided an overview of the contact recreation programme that monitors faecal bacteria and potentially toxic cyanobacteria across 16 freshwater and 16 coastal sites in the Otago Region to assess risks to human health during the summer bathing period. The report also summarised the results of weekly monitoring undertaken during the 2024-25 season. Helen Trotter (Scientist - Water Quality) and Ben Mackey (Manager Science) were available for questions.

Resolution SRC25-108: Cr Kelliher Moved, Cr Weir Seconded
That the Committee:
1) ***Notes*** *this report.*
MOTION CARRIED

9.9. CDEM Partnership Report
[YouTube 2:31:40] The report outlined the delivery of Otago Regional Council's responsibilities under the Otago Civil Defence and Emergency Management Agreement for the second half of 2024-2025. Tom Dyer (General Manager Science and Resilience) was available for questions.

Resolution SRC25-109: Cr Noone Moved, Cr Mepham Seconded
That the Committee
1) ***Notes*** *this report.*
MOTION CARRIED

Cr Noone left the meeting at 3:52 pm.

9.10. Otago Region Natural Hazards Exposure
[YouTube 2:39:38] The report updated the Committee on a region-wide natural hazards assessment programme, including presenting a report analysing natural hazards exposure within the Otago region. Tim van Woerden (Senior Natural Hazards Analyst), Andrew Welsh, (Spatial Analyst) and Jean-Luc Payan (Manager Natural Hazards) were available for questions.

Resolution SRC25-110: Cr Robertson Moved, Cr Weir Seconded
That the Committee:
1) ***Notes*** *this report.*
2) ***Endorses*** *the report Otago Region Natural Hazards Exposure Analysis.*
3) ***Notes*** *the next steps in the work programme including commencement of the natural hazards prioritisation workstream.*
MOTION CARRIED

DRAFT

10. CLOSURE

There was no further business and Cr Somerville ended proceedings with a karakia. Chair Kelliher declared the meeting closed at 4:03 pm.

_____ _____

Chairperson Date

DRAFT

ACTION REGISTER

Meeting Date	Item	Status	Action Required	Assignee/s	Action Taken	Due Date
4-06-2025	GOV2545 Otago Deep Water Lakes TAG update	In progress	Resolution SRC25-101: Requests that the Technical Advisory Group works to identify funding opportunities from external sources.	Manager Science		28-02-2026
4-06-2025	GOV2545 Otago Deep Water Lakes TAG update	In progress	Resolution SRC25-101: Requests the Technical Advisory Group to develop a more detailed research and monitoring plan at a funding level aligned with Proposal 1.	Manager Science		28-02-2026
4-06-2025	GOV2550 Coast and Estuaries Monitoring Programmes	In progress	Resolution SRC25-105: Notes that next steps include a comprehensive estuary and coastal state of the environment report for the coast plan, including catchment threats, habitat threats and issues to provide not only information for the coast plan, but also for targeted management. These reports will be presented to the Council.	Manager Science		30-06-2026

9.1. Roxburgh Debris Flow Hazard Management Update

Prepared for:	Science and Resilience Committee
Report No.	HAZ2507
Activity:	Safety & Hazards: Natural Hazards
Author:	Ann Conroy (Team Leader Natural Hazards Adaptation), Jean-Luc Payan (Manager Natural Hazards), Julion Wright (Natural Hazards Analyst), Toan Nguyen (Senior Natural Hazards Adaptation Specialist), Tim van Woerden (Senior Natural Hazards Analyst), Pete Weir (Team Leader Natural Hazards)
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] To update the Council on the Roxburgh Debris Flow Hazard Management Programme progress, engagement and programme planning.

EXECUTIVE SUMMARY

[2] The Roxburgh area is highly exposed to alluvial fan hazards, including debris flows. The Otago Regional Council (ORC) has a specific work programme to investigate and manage the debris flow hazard and risk in Roxburgh.

[3] The Roxburgh Debris Flow Hazard Management Programme has two concurrent technical projects: 1) the interim creek monitoring and maintenance plan, and 2) the Roxburgh debris flows detailed hazard and risk assessment. A programme of regular engagement with the community, Central Otago District Council (CODC), and other stakeholders/partners underpins the technical work programme.

[4] The interim creek monitoring and maintenance plan is progressing. LiDAR acquired in late 2024 has allowed for geomorphic analysis of the lower reaches of the Roxburgh creeks. These results were utilised by ORC Natural Hazards and ORC Engineering to identify areas requiring channel maintenance.

[5] Information gathering stages of the detailed debris flow hazard and risk assessment are now complete. However, the qualitative risk assessment has identified that more alluvial fans than originally scoped require a quantitative risk assessment. The final results of this investigation will be ready to present to Council in a briefing likely in November/December 2025.

[6] Engagement planning is also underway. Engagement activities, which aim to share and discuss the technical findings and implications with the community are planned for September to December 2025 using a variety of mechanisms to allow for maximum

inclusion. Engagement planning and activities are a collaboration with other ORC teams as well as CODC staff.

[7] The Roxburgh Debris Flow Hazard Management Programme aligns with Council's Strategic Directions, "*Otago builds resilience in a way that contributes to community and environmental wellbeing through planned and well-managed responses to shocks and stresses, including natural hazards*" and "*Plans are in place to ensure that the region's most vulnerable communities (geographic and demographic) and ecosystems are resilient in the face of natural hazards*".

RECOMMENDATION

That the Committee:

1) ***Notes** this report and the work programme update.*
2) ***Endorses** the next steps and engagement activities for the next 6 months described below.*

BACKGROUND

[8] The Roxburgh area, from Coal Creek Flat to north of Ettrick (Figure 1), is exposed to alluvial fan[1] hazards, including debris flows[2], where steep creek catchments exit the Old Man Range towards the Clutha River[3].

[9] Debris flows are a rapidly moving slurry of water, sediment, and debris that may occur on alluvial fans with a high impact force. The geological and geomorphic characteristics of the catchments in the Roxburgh area allow for the high sediment yields required for debris flow generation[4]. In conjunction, debris flows are initiated by high-intensity rainfall events driven by thunderstorms, so typically provide little warning time.

[10] A number of debris flow events have been recorded in Roxburgh since at least 1938. Most of these recorded events have resulted in direct impact of debris to either infrastructure or property.[5]

[11] The debris flow events of November 2017 highlighted the significance of the hazard to the Roxburgh community and prompted the contemporary hazard management response. This included channel maintenance, debris flow investigations, and monitoring (installation of a new rain gauge, LiDAR and aerial imagery capture) of the catchments, as well as a New Zealand Transport Agency Waka Kotahi (NZTA) Response.

[12] Preliminary risk assessments conducted by Golder Associates for the Otago Regional Council (ORC) in 2019 indicated that the risk to life is 'significant' at Pumpstation,

[1] Also referred to as debris fans depending on their dominant process regime.
[2] For this update paper, we refer to "debris flows" as a generic term for flows containing a sediment concentration greater than typical flood flows (i.e. also including debris floods and hyper-concentrated flows).
[3] Woods, R. 2011. Otago Alluvial Fans: High Hazard Fan Investigation. Report prepared by the ORC Natural Hazards team as part of the Alluvial Fans project. 69-75pp.
[4] Golder. 2019a. Management and reduction of debris flow risk in Roxburgh, Otago – geomorphological assessment report. Report prepared for Otago Regional Council.
[5] Wright and van Woerden. 2024. Roxburgh Naturals Hazards Management. Report to the ORC Safety and Resilience Committee, 7 November 2024.

Reservoir, and Golfcourse Creeks[6,7]. These reports also recommended that ORC implement an interim channel monitoring and maintenance plan and conduct a more detailed and spatially comprehensive hazard and risk assessment.

[13] The ORC Natural Hazards team has also identified additional catchments in the Roxburgh area where a debris flow hazard may be present, in addition to those active in November 2017. This identification process included a prioritisation based on a catchment's geomorphic characteristics, history of debris flows, and the exposure of infrastructure and property to potential flows. These additional catchments have been included in the work programme scope[8] (Figure 1).

[14] The previous update (November 2024) to the Safety and Resilience Committee described the Roxburgh Debris Flow Hazard Management Programme (the Programme), which has two parallel works that implement the key recommendations of the Golder reports:

- An interim channel maintenance and monitoring plan to manage the hazard whilst we conduct further investigations and,
- The detailed hazard and risk assessment for debris flows in the Roxburgh area, which is the key technical study that will inform future management options, including potential Central Otago District Council (CODC) spatial planning.

[6] Golder. 2019a. Management and reduction of debris flow risk in Roxburgh, Otago – geomorphological assessment report. Report prepared for Otago Regional Council.

[7] Golder. 2019b. Management and reduction of debris flow risk in Roxburgh, Otago – Engineering options report (conceptual design). Report prepared for Otago Regional Council.

[8] Wright, J. 2024. Roxburgh debris flow catchments prioritisation using morphometrics and hazard exposure analysis. June 2024. Internal Otago Regional Council report.

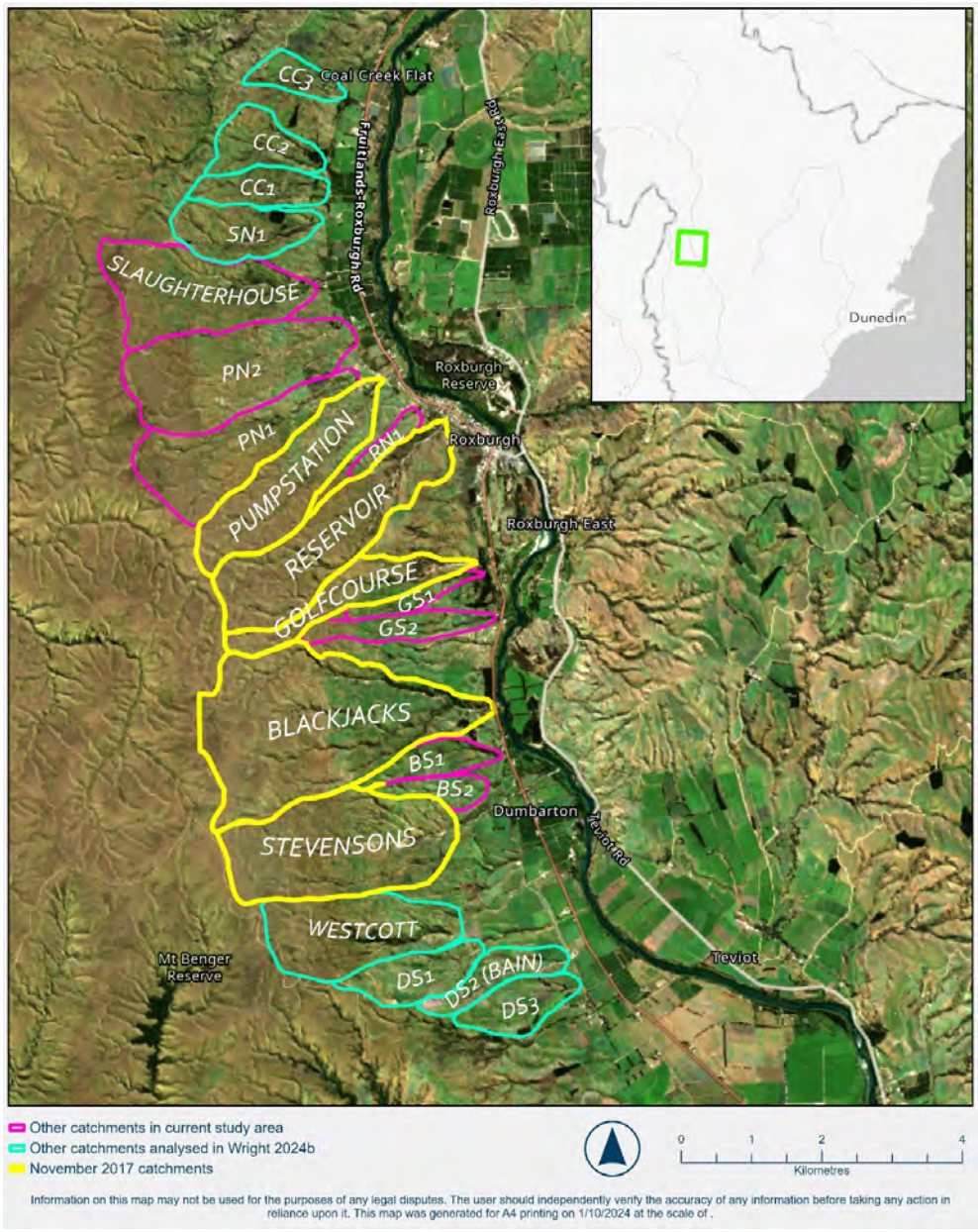


Figure 1: Map of the catchments susceptible to debris flows in the Roxburgh area. Yellow indicates the catchments active during the November 2017 events (these are analysed as part of the interim management plan), pink indicates the additional catchments incorporated in the detailed debris flow hazard and risk assessment, and blue indicates the other catchments assessed during the prioritisation process but not included within the scope of the current investigations.

CURRENT WORK PROGRAMME PROGRESS (TECHNICAL PROJECTS)

[15] To provide recent detailed topographic information to inform both the interim channel maintenance and monitoring plan and the detailed hazard and risk assessment, an updated LiDAR survey and capture of high-resolution aerial imagery were delivered in December 2024 to provide topographic data for the full Roxburgh debris flow/alluvial fan hazard area (Figure 2). This LiDAR acquisition also acted as a survey of recent channel morphology to inform potential channel maintenance.

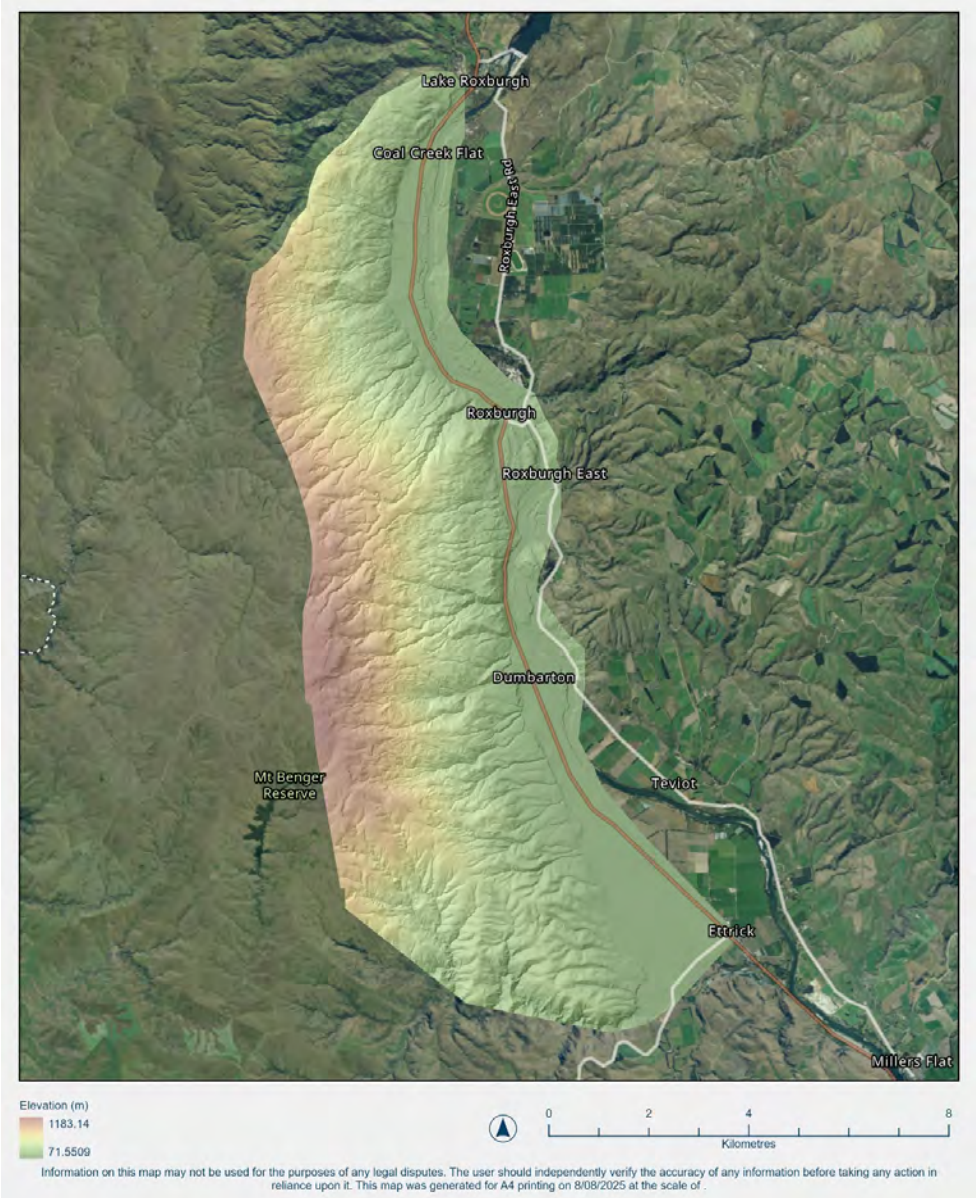


Figure 2: 'Hillshade' Digital Elevation Model (DEM) from the 2024 LiDAR acquisition of the Roxburgh debris flow hazard area of interest.

Interim channel monitoring and maintenance plan

[16] As described in the November 2024 update to the Safety and Resilience Committee paper, the purpose of this plan is to maintain the capacity of the channels to convey high flows during a debris flow event to limit the avulsion of the creeks and any subsequent debris inundation of infrastructure or property. This plan is designed to inform the ORC Engineering team's river management activities and act as an interim measure whilst detailed hazard and risk assessments are completed.

[17] By comparing the new 2024 LiDAR to a LiDAR survey from 2022, the ORC Natural Hazards Team conducted a Geomorphic Change Detection (GCD) analysis for the lower reaches of Pumpstation, Reservoir, Golfcourse, Blackjacks, and Stevensons Creeks. GCD is a tool that enables a systematic assessment of changes to channel bed and land levels (geomorphic changes) between two periods. Minor geomorphic changes were found in the last two years; the greatest magnitude of change was ~ 1 m of channel aggradation in Stevensons Creek downstream of the State Highway 8 bridge.

[18] The results of this analysis, complemented with site visits, were then used to identify and plan ORC creek maintenance activities.

[19] To address the geomorphic changes that may impact creek capacity, minor creek maintenance works are planned to be completed by November 2025, for the sediment deposition lobe in the Clutha River downstream of the concrete chute in Reservoir Creek (Figure 3) and the reach of Stevensons Creek, downstream of the State Highway 8 bridge.

Figure 3: The Reservoir Creek sediment deposition lobe at the Clutha River (background) confluence. Image date 26/03/25.

Detailed debris flow hazard and risk assessment

[20] As described in the previous update paper, a detailed natural hazard and risk assessment will be carried out to inform the community, potential CODC spatial planning measures, as well as possible physical mitigation options. This risk assessment includes developing an understanding of potential debris flow runouts and a comprehensive, spatial understanding of the natural hazard risk characteristics. In addition, climate change impacts will be considered. Study findings will be of value to a range of stakeholders (e.g., community members, ORC, Otago Civil Defence Emergency Management (CDEM), CODC, and NZTA).

[21] The investigation focuses on debris flow hazard and risk from 13 of the 22 catchments in the Roxburgh area (Figure 1). These catchments have been identified and prioritised based on factors including their known history of debris flow occurrences, geomorphic indices which indicate susceptibility to debris flow generation, and the exposure of buildings and infrastructure[9].

[22] In late November 2024, ORC contracted WSP New Zealand Limited to undertake the detailed debris flow hazard and risk assessment. Beca Limited was also contracted by ORC as the external peer review for this project. Beca has provided a review at the end of each stage completed to date.

[23] WSP is undertaking the detailed debris flow hazard and risk assessment investigation in five technical stages:

1. Gap analysis, to identify data and knowledge gaps for the remainder of the investigation.
2. Geomorphic assessment, to provide the necessary background information on the physical processes to allow for hydrogeomorphic modelling and risk assessment.
3. Hydrogeomorphic modelling, to model debris flow runouts (inundation depth and velocity) under three hazard magnitude/frequency scenarios.
4. Qualitative risk assessment, to provide knowledge on the debris flow hazard risk characteristics and to 'screen' which alluvial fans require quantitative risk assessment as per APP6 of the ORC Regional Policy Statement[10].
5. Quantitative risk assessment, to provide a quantitative and detailed spatial understanding of the debris flow hazard risk (risk to life and risk to property).

[24] Stages 1 – 3 are complete. Preliminary qualitative risk assessment results (Stage 4) were presented to the ORC Natural Hazards Team in July 2025. More alluvial fans than originally scoped required a quantitative risk assessment because the qualitative risk assessment indicates that the risk may be 'significant', or other factors have highlighted the need for a quantitative understanding of risk.

[25] Quantitative risk assessment (Stage 5) is underway; due to the scope change, the results are not yet available. Note that the scope change is not surprising, given that one of the purposes of the qualitative risk assessment is to allow for a well-informed and robust decision on which alluvial fans should undergo a quantitative risk assessment.

[9] Wright, J. 2024. Roxburgh debris flow catchments prioritisation using morphometrics and hazard exposure analysis. June 2024. Internal Otago Regional Council report.
[10] ORC. 2021. Proposed Otago Regional Council Policy Statement June 2021. Track Appeals Version.

[26] The results from the full completed study will be shared with the Science and Resilience Committee members in a briefing, likely in November – December 2025.

OVERVIEW OF ENGAGEMENT PLANNING

[27] ORC's Natural Hazards team is working closely with internal teams, including Partnerships and Engagement, and Communications, as well as with Central Otago District Council (CODC) staff from Policy and Community Engagement teams to develop a coordinated engagement plan.

[28] The primary goal of the engagement plan is to share and discuss the technical findings and implications of the Roxburgh detailed hazard and risk assessment.

[29] The plan establishes six objectives:

1. Present the key findings of the technical investigations clearly and share key messages through various channels (social media, media release or new Roxburgh page on ORC website) before the in-person engagement.
2. Provide ways for the community to connect with technical experts and key agencies.
3. Build understanding and awareness of the debris flow hazards and risks for the community and organisations.
4. Understand reactions and implications of the new technical findings and listen to concerns of the community and organisations.
5. Gather feedback from the community and organisations on the results.
6. Strengthen relationships and build trust with community members, organisations and stakeholders.

[30] Engagement planning will use a multi-channel approach to:

- Ensure the technical information is accessible and shared widely
- Hear a range of perspectives to inform the next steps of the Programme
- Build understanding and awareness of debris flow hazards within the community and among key partners

[31] Planned engagement activities include:

- Technical findings workshops (for ORC staff and Councillors, and stakeholders, staff from CODC, NZTA, and CDEM)
- Meetings with mana whenua representatives
- Community engagement event (in-person) in the Roxburgh area
- Community presentation and Q&A (online) with the Roxburgh residents and associated local organisations

[32] Planned communications activities include:

- A plain-language summary of the technical findings report
- Technical finding documents published on the ORC website and Natural Hazards Portal
- ORC media releases
- New Roxburgh Programme webpage- featuring the background, hazards history, new technical findings and feedback channels

[33] These engagement and communications activities will involve both external and internal stakeholders and partners.

[34] Key external stakeholders and partners include:

- Roxburgh and surrounds community members
- Local social, economic and educational organisations
- Iwi Māori residents and mana whenua representatives
- CODC, NZTA and CDEM Otago

[35] Key internal stakeholders include:

- ORC Councillors, and ORC Executive Leadership Team
- ORC Engineering, Catchment Advisors, Engagement and Partnership, Policy, and Communications teams

[36] Engagement and communication activities associated with the detailed debris flow hazard and risk assessment are scheduled to occur from September to December 2025. They will be delivered by the ORC Natural Hazards team in close collaboration with ORC's Partnerships and Engagement and Communications teams, and with CODC's Community and Engagement team.

DISCUSSION

[37] The debris flow hazard has high potential consequences for the Roxburgh area. This is due to the immediate exposure of property and infrastructure to rapid and dense debris flows that occur with little warning.

[38] The detailed debris flow hazard and risk assessment is near completion, with many of the key stages finished. Whilst preliminary qualitative risk assessment results have indicated the need for more quantitative risk assessment than previously scoped, taking the time to complete the additional work will deliver important spatial details on the debris flow hazard risk for alluvial fans where this is necessary.

[39] The detailed hazard and risk assessment will inform an assessment of the need for and the nature of natural hazard management for the Roxburgh area, including any potential CODC land use planning responses. The work to investigate potential management options will be scoped in the latter half of the 25/26 financial year. This work will inform the preparation of the next ORC Long-Term Plan and Infrastructure Strategy.

[40] The purpose of this Roxburgh natural hazards work programme is to identify, assess, and potentially implement, natural hazard risk management responses for debris flow hazards in the Roxburgh area. A range of complementary hazard mitigation responses may be required, which can be summarised and explained using the PARA framework;[11]

- **Protect:** Remain in existing high-risk locations by effectively managing the hazard through the building of protection measures, e.g. floodbanks or other structural defences.

[11] Ministry for the Environment. 2023. Community-led retreat and adaptation funding: Issues and options. Ministry for the Environment, August 2023.

- **Avoid:** Staying away from areas where the risks are considered too high, e.g. restricting or preventing the placement of new assets or activities in higher-risk locations.
- **Retreat:** Purposefully moving people, assets, and activities away from areas where the risks are considered too high, to safer locations.
- **Accommodate:** Support people, assets and activities to remain in existing higher-risk locations by making changes to the infrastructure and buildings to improve resilience, e.g. river management activities, flood warning systems, or modification of existing buildings or assets.

[41] The interim monitoring and maintenance plan is underway, which enables ORC to progress in-channel management whilst the technical investigations and engagement planning are conducted.

[42] Engagement is a vital part of ORC's work and will play an important role throughout the Programme. It will help ensure the community, stakeholders and partners are well informed, able to provide input, and supported to understand and manage risks. The Engagement Plan will be revised and updated as the work programme progresses.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[43] This natural hazards investigation programme aligns with Council's Strategic Directions, where the 'Resilience' focus area has the aspiration that "*Otago builds resilience in a way that contributes to community and environmental wellbeing through planned and well-managed responses to shocks and stresses, including natural hazards*".

[44] The programme contributes to achieving the following goal of the Strategic Directions: "*Plans are in place to ensure that the region's most vulnerable communities (geographic and demographic) and ecosystems are resilient in the face of natural hazards*".

Financial Considerations

[45] The work is funded and is specified in the ORC Long-Term Plan 2024-2034 as key natural hazards work for years 1 to 3 of the Long-Term Plan.

Significance and Engagement

[46] A preliminary Engagement Plan for the Roxburgh Debris Flow Hazard Management Programme has been developed in collaboration with CODC.

[47] The Engagement Plan will be revised and updated as the work programme progresses.

Legislative and Risk Considerations

[48] The work described in this paper helps ORC fulfil its responsibilities under sections 30 and 35 of the RMA and the Soil Conservation and Rivers Control Act 1941.

Climate Change Considerations

[49] Climate change is a factor potentially influencing debris flow hazard and risk, and is being considered in natural hazard and risk assessments.

Communications Considerations

[50] ORC will make all findings from the debris flow hazard and risk investigation available to the Roxburgh area community and other stakeholders. Including through the approaches/channels specified in paragraph 31.

NEXT STEPS

[51] The key next steps of the work programme over the next 6 months are focused on:

- Completion of the detailed debris flow hazard and risk assessment, including peer review.
- Consideration of the implications of the new findings by staff in key work areas at ORC (Natural Hazards, Engineering, Policy, CDEM), and at CODC (Planning) and NZTA. This step will include implications for the next stages of the programme and how to inform the preparation of the next ORC Long-Term Plan and Infrastructure Strategy.
- Briefing to ORC councillors on the new findings.
- Briefing of CODC councillors, if requested.
- Publishing the new findings on multiple communication channels.
- Community engagement activities (in-person and online) to share the new findings, answer questions, and listen to community concerns and feedback.

[52] A high-level timeline for key programme and engagement activities over the next 6 months is given in Table 1.

Table 1: High-level timeline for key programme and engagement activities over the next 6 months

Approximate timing	Programme Activity	Community and stakeholder engagement
September	Progress update to S&R committee	Go-live new webpage
September-December	Staff in ORC, CDEM, CODC, and NZTA teams consider the implications of new findings from the Detailed Hazard and Risk Assessment	
November/December	Briefing to ORC councillors on new findings Briefing to CODC councillors on new findings if required	
October-December	Advertising and engagement activities delivery Public and community information	In-person and online community engagement activities (mid-October) Publish findings in various formats and multiple channels Update webpage

ATTACHMENTS

Nil

9.2. Clutha Delta Natural Hazards Adaptation

Prepared for:	Science and Resilience Committee
Report No.	HAZ2505
Activity:	Safety & Hazards: Natural Hazards
Author:	Tim van Woerden, Senior Natural Hazards Analyst Ariane Bray, Natural Hazards Adaptation Specialist Ann Conroy, Team Leader Natural Hazards Adaptation Jean-Luc Payan, Manager Natural Hazards
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] To update the Committee on progress with the Clutha Delta natural hazards adaptation work programme, including to present the findings of investigations into seismic hazard risks, and an assessment of river morphology (bed levels) trends at Balclutha.

EXECUTIVE SUMMARY

[2] The low-lying plains of the Clutha Delta are exposed to a range of coastal, fluvial, and seismic natural hazard risks. Coastal hazard and flooding hazard risks are projected to be exacerbated by potential impacts of ongoing or projected geomorphic (land and river forms) and climatic changes.

[3] Otago Regional Council (ORC) is leading a natural hazards adaptation programme for the Clutha Delta, which aims to develop a long-term hazards management plan. The programme is currently in a phase of gathering technical data on natural hazards and risk, and planning for engagement activities.

[4] The natural hazards adaptation work programme is aligned with Council's Strategic Directions, "*Otago builds resilience in a way that contributes to community and environmental wellbeing through planned and well-managed responses to shocks and stresses, including natural hazards*" and "*Otago is a climate-resilient region that plans for and invests in initiatives that reduce emissions and help us adapt to our changing climate*".

[5] This paper presents the findings of two natural hazards investigations recently completed:
a. Liquefaction hazards analysis and seismic risk assessment
b. Assessment of Clutha River/Mata-Au bed level trends at Balclutha

[6] The paper also provides an update on recent engagement activities (5 August 2025 community drop-in session) and gives a high-level overview of programme and engagement planning for the next 6 months.

RECOMMENDATION

That the Committee:

1) ***Notes** this report.*
2) ***Notes** the reports by Tonkin + Taylor Ltd; Clutha Delta Liquefaction Vulnerability Study, dated 23 June 2025, and Clutha Delta seismic risk assessment, dated 20 August 2025.*
3) ***Notes** the reports by NIWA; Clutha River morphology trends at Balclutha, dated 12 May 2025, and Plain language report on river bed changes at Balclutha, dated 30 June 2025.*

BACKGROUND

[7] The Otago Regional Council (ORC) is leading a programme of work to develop a natural hazard adaptation strategy for the Clutha Delta area. The natural hazards context, proposed natural hazards adaptation work programme, and investigations underway for the Clutha Delta were summarised in previous update papers to the Safety and Resilience Committee.[1]

[8] The work programme is currently in the first phase of the adaptation planning[2] cycle ("what is happening?"), with progress on investigations to increase our understanding of the key natural hazards on the delta, and early engagement planning.

[9] Two natural hazards investigations have been recently completed and are presented in this paper:

a. A liquefaction hazard analysis and seismic risk assessment for the Clutha Delta.
b. A review of Clutha River/Mata-Au bed levels at Balclutha and trends in how these have changed over time.

[10] The background to each study, their key findings and next steps are summarised in the sections below.

NATURAL HAZARDS INVESTIGATIONS

Liquefaction hazard and seismic risk analysis

[11] Regional-scale liquefaction hazard assessments[3] and other studies[4] [5] indicate that the delta area comprises geologically young, saturated, poorly consolidated, fine-grained sediments, and therefore has the potential for the occurrence of liquefaction and lateral spreading triggered by major earthquake shaking.

[12] Liquefaction hazard and associated lateral spreading triggered by earthquake shaking may pose a significant hazard to the built environment and have occurred during >10 New Zealand earthquakes since European settlement,[6] with some of these events having notable impacts to flooding vulnerability[7] and flood protection infrastructure.[8]

---

[1] Update papers presented on 9 November 2023, 8 February 2024, 8 May 2024, 7 August 2024, 6 March 2025.
[2] The DAPP (Dynamic Adaptation Planning Pathways) cycle, developed by MfE (Coastal hazards and climate change guidance, 2024).
[3] Barrell DJA, 2019. Assessment of liquefaction hazards in the Queenstown Lakes, Central Otago, Clutha and Waitaki districts of the Otago Region. GNS Science Consultancy Report 2018/67, prepared for Otago Regional Council.
[4] Barrell DJA and Crundwell MP, 2022. Radiocarbon dating and geological assessment of sediments associated with the Clutha Delta, Otago. GNS Science Consultancy Report 2022/108, prepared for Otago Regional Council.
[5] Tonkin + Taylor, 2018. Floodbank Condition and Structural Integrity Assessment. Prepared for Otago Regional Council.
[6] Bastin S, van Ballegooy S, and Ogden M, 2021. The past is key to the future; Collating historical cases of liquefaction to supplement liquefaction hazard assessments. In Proceedings of the 21st New Zealand Geotechnical Society Symposium.

[13] In order to improve the understanding of the risks of liquefaction and other potential seismic hazards at the Clutha Delta, ORC engaged Tonkin + Taylor Ltd (T+T) to undertake a liquefaction hazard analysis[9] and a seismic risk assessment.[10] Separate technical reports were completed for each phase of the investigation, and these are attached as Attachments 1 and 2.

[14] The investigations were externally reviewed for ORC by Jacobs Ltd, and review comments have been addressed and incorporated into the final reports.

Liquefaction hazard analysis approach

[15] Liquefaction hazard analysis was completed in accordance with the MBIE/MfE national guidance,[11] achieving Level B[12] (calibrated desktop assessment) for the Balclutha township area, and Level A[13] (basic desktop assessment) for the wider delta area.

[16] The purpose of a Level A assessment is to provide a broad scale understanding of liquefaction vulnerability. The additional detail in the Level B investigation for Balclutha township reduces the residual uncertainty, providing a better understanding of liquefaction susceptibility and triggering.

[17] The investigation made use of 30 new geotechnical investigations collected for this study, and existing data from previous geotechnical investigations for ORC and others, for a total of >130 CPT tests[14] in the delta area.

[18] The liquefaction vulnerability categorisation of the MBIE/MfE guidance is shown in Table 1. For a Level A or B study, three vulnerability categories are applied:

1. Liquefaction damage is unlikely,
2. Liquefaction damage is possible, or
3. Liquefaction category is undetermined.

[19] More detailed geotechnical assessments (Level C or D) are required to assign the more specific liquefaction categories of Very Low, Low, Medium or Very High liquefaction vulnerability.

[7] e.g. the effects of the 2010-2011 Canterbury Earthquake sequence on flooding vulnerability in Christchurch (Fisher T, Taylor M, Ng K and Pennington M, 2014. Assessment of increased flood vulnerability due to the Canterbury Earthquake Sequence. Paper to the 2014 NZ Stormwater Conference).

[8] e.g. the effects of the 1987 Edgecumbe Earthquake on the Rangitaiki flood protection system (de Gale Price CH and Christensen KJ, 2019. The legacy of the 1987 Edgecumbe earthquake, New Zealand),

[9] Ogden M, 2025. Clutha Delta Liquefaction Vulnerability Study. Prepared by Tonkin + Taylor Ltd for Otago Regional Council.

[10] Waugh M and Ogden M, 2025. Clutha Delta Qualitative Risk Assessment (Seismic). Prepared by Tonkin + Taylor Ltd for Otago Regional Council.

[11] Ministry of Business, Innovation and Employment (MBIE) and the Ministry for the Environment (MfE) (2017). Planning and engineering guidance for potentially liquefaction-prone land.

[12] Level B studies include high-level 'calibration' of geological/geomorphic maps. where subsurface investigations provide a better understanding of liquefaction susceptibility and triggering for the mapped deposits and underlying ground profile.

[13] Level A studies consider basic information about geology, groundwater and seismic hazard to assess the potential for liquefaction to occur.

[14] Cone Penetrometer Test – a subsurface test using a probe to determine geotechnical soil properties.

Table 1: Performance criteria for determining liquefaction vulnerability category (MBIE/MfE, 2017).

LIQUEFACTION CATEGORY IS UNDETERMINED			
A liquefaction vulnerability category has not been assigned at this stage, either because a liquefaction assessment has not been undertaken for this area, or there is not enough information to determine the appropriate category with the required level of confidence.			
LIQUEFACTION DAMAGE IS UNLIKELY There is a probability of more than 85 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking. At this stage there is not enough information to distinguish between ***Very Low*** and ***Low***. More detailed assessment would be required to assign a more specific liquefaction category.		**LIQUEFACTION DAMAGE IS POSSIBLE** There is a probability of more than 15 percent that liquefaction-induced ground damage will be ***Minor to Moderate*** (or more) for 500-year shaking. At this stage there is not enough information to distinguish between ***Medium*** and ***High***. More detailed assessment would be required to assign a more specific liquefaction category.	
Very Low Liquefaction Vulnerability There is a probability of more than 99 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking.	**Low Liquefaction Vulnerability** There is a probability of more than 85 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking.	**Medium Liquefaction Vulnerability** There is a probability of more than 50 percent that liquefaction-induced ground damage will be: ***Minor to Moderate*** (or less) for 500-year shaking, and ***None to Minor*** for 100-year shaking.	**High Liquefaction Vulnerability** There is a probability of more than 50 percent that liquefaction-induced ground damage will be: ***Moderate to Severe*** for 500-year shaking; and/or ***Minor to Moderate*** (or more) for 100-year shaking.

Liquefaction hazard analysis findings

[20] The liquefaction vulnerability map developed by T+T is shown in Figure 1. This map shows the majority of the delta floodplain area categorised as 'Liquefaction Damage is Possible', and the surrounding areas (e.g. hillslopes) as 'Liquefaction Damage is Unlikely'. To represent the residual uncertainty in geomorphic mapping, the boundary between these two categories is represented as 'Liquefaction Category is Undetermined'.

[21] Lateral spreading typically occurs in liquefiable soils near a free face (e.g. riverbank or drain). As a preliminary screen for areas with potential for lateral spreading to occur, the map identifies areas within 200 metres of the Clutha River channels. The map does not specify all areas where lateral spreading may occur, which may also include areas adjacent to ORC drains or other stream channels.

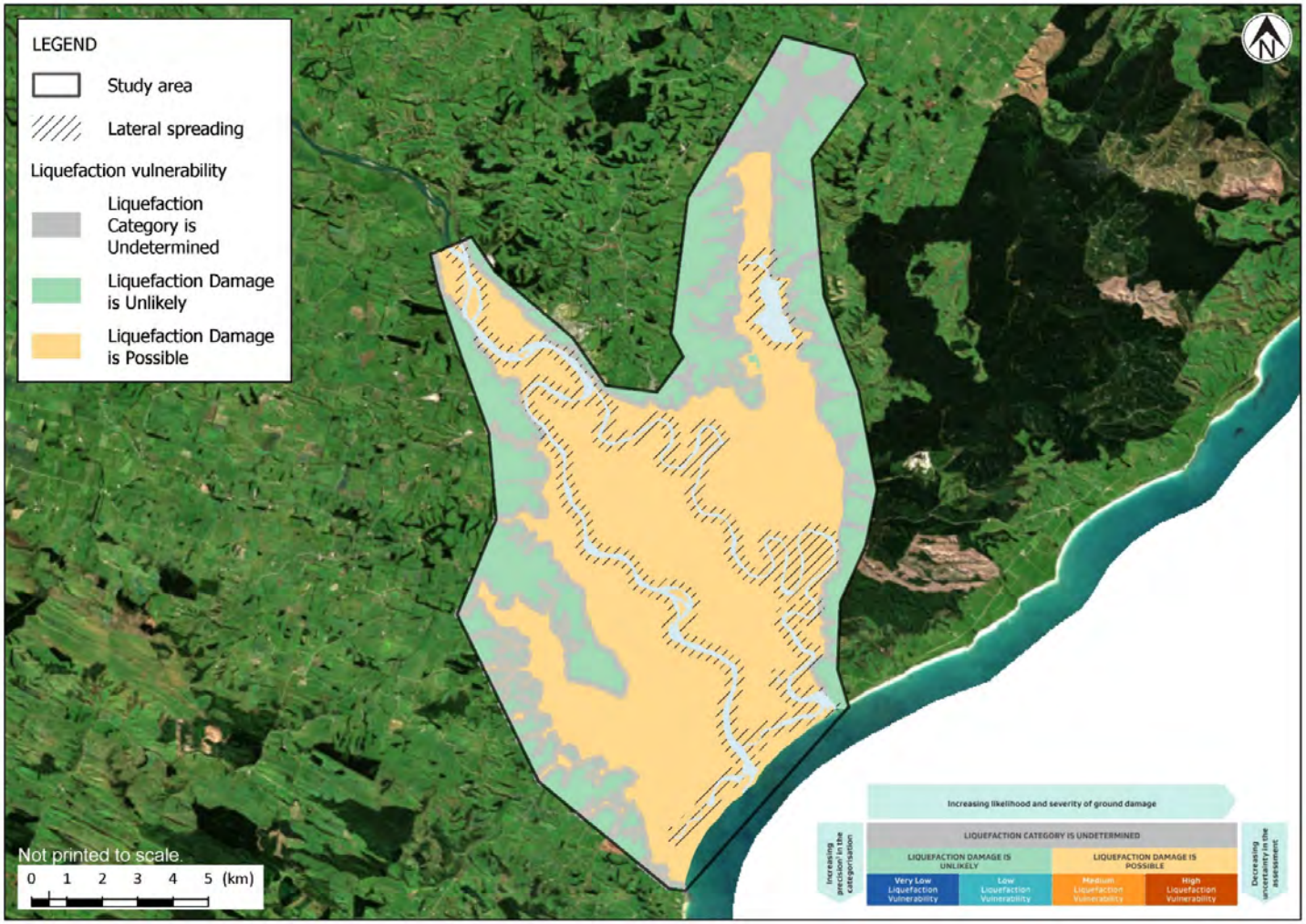


Figure 1: Clutha Delta liquefaction vulnerability classification, developed by T+T (2025).

Seismic risk assessment

[22] An assessment of seismic risks for the delta has been completed to provide a systematic understanding and characterisation of these risks, including their likelihood, types of damages expected and their severity.

[23] Assessments cover a range of seismic hazard events (seismic shaking, fault rupture, liquefaction and lateral spreading), and potential risks to asset types including health and safety, buildings, lifelines infrastructure (e.g. 3-waters, transport, electricity and telecommunications), and ORC's flood protection and drainage infrastructure.

[24] The damage descriptions developed for each hazard type and likelihood scenario are summarised in Table 2. A total of 120 individual risks are assessed, across four hazard types, three likelihood scenarios, and three asset groupings (health and safety, buildings and lifelines). Risk assessments use a qualitative (risk matrix) assessment approach, following the guidance of the proposed Otago Regional Policy Statement.[1]

[25] In addition to the direct impacts of these seismic hazards, potential sequences of cascading hazard events can also occur, for example:

a. Damages to the electricity network causing disruption to interdependent infrastructure systems such as wastewater systems, telecommunications and fuel.
b. Impacts to flood protection, drainage and stormwater networks, can result in an increased flood risk.

[1] https://www.orc.govt.nz/media/10027/proposed-otago-regional-policy-statement-june-2021.pdf

Table 2: Summary of damage descriptions for each hazard and likelihood scenario (T+T, 2025).

Hazard	Likely	Possible	Rare
Seismic shaking	• Hairline cracks in buildings and infrastructure • Minor displacements of fittings and joints in pipes, culverts, bridges and mechanical systems • Electrical and telecommunications equipment may require reset/ inspection • Temporary service outages (generally up to 1 day).	• Structural cracking and misalignment of components (pipes, cables, bridges, tanks) • Mechanical failure in pump stations and treatment plants • Temporary loss of sealing capacity e.g., flood gates and intake structures • Service disruption generally up to 1-week.	• Structural failure, and potential collapse of buildings, bridges and tanks • Rupture of pipes, and displacement of culverts • Widespread disruption to electricity, telecommunications and transport corridors • Service disruption likely to exceed 1-month in most cases.
Liquefaction	• Minor ground deformation, with limited structural impact • Slight settlement possible • Service disruption is limited to inspections and minor repairs.	• Localised liquefaction causing differential settlement and misalignment of assets e.g., pipes, culverts, drains, flood gates etc. • Ejected material may block culverts, drains, and outfalls, reducing flow capacity • Service disruption is likely up to 1-week.	• Widespread liquefaction causing severe ground deformation and structural failure • Rupture or uplift of buried infrastructure • Service disruption is likely to exceed 1-month.
Lateral spreading	• Limited horizontal movement near river margins • Minor displacement of foundations and buried infrastructure • Service disruption is limited to inspections and minor repairs.	• Localised lateral spreading may result in localised deformation • Misalignment and cracking of structures • Damage to embankments, bridges and pipe networks • Service disruption of up to 1-week.	• Extensive lateral spreading causing structural failure of bridges, and buildings • Severance of buried infrastructure, and potential collapse of containment systems • Service disruption is likely to exceed 1-month.
Surface rupture	-	-	• Surface rupture intersecting asset footprints can cause complete structural failure • Severance of buried infrastructure, transport corridors and flood protection assets • Total loss of function of schemes from ground deformation • Service disruption likely to exceed 1-month.

Seismic risk assessment findings

[26] Risk assessment findings are summarised in the technical report by T+T (Attachment 2) and detailed in the accompanying Risk Register spreadsheet. The risk register in the attachment of the T+T report provides full details for all 120 risks assessed.

[27] Figure 2 summarises the distribution of the risks assessed, across the four hazard types and event scenarios in three likelihood classes. This shows that the highest risks are classified as *Tolerable*, based on their likelihood and consequences:

a. For a 'likely' (100-year ARI) event scenario, expected damages are relatively minor and risk levels are classed as *Acceptable*.

b. For a 'possible' (500-year ARI) event scenario, most consequences are assessed as being 'Moderate' or 'Major', and many risks are classed as *Tolerable*.

c. For the lowest-likelihood scenario assessed ('rare', >2500-year ARI), the majority of consequences are rated as 'Catastrophic' and risk levels are classed as *Tolerable*. In this scenario, impacts are expected to include widespread, severe damages.

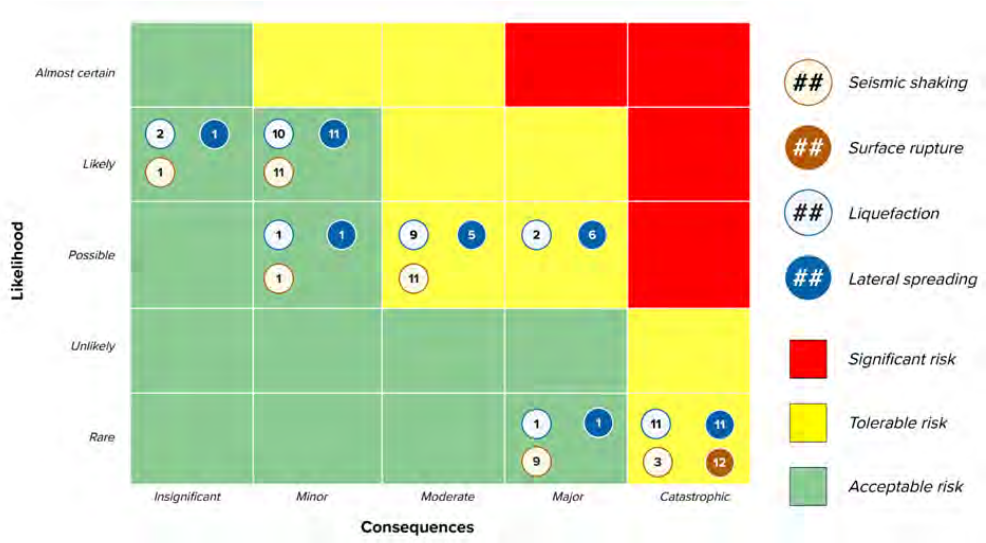


Figure 2: Summary risk matrix showing risk classification for seismic risks at the Clutha Delta. The matrix shows the categorisation of the 120 individual risks assessed, with circles coloured by hazard type, and numbered with count of risks in that category. Green cells represent *Acceptable* risk, yellow *Tolerable* risk, and red cells *Significant* risk.

Communications

[28] The liquefaction vulnerability mapping and technical reports will be added to ORC Natural Hazards portal.

[29] The ORC Engineering and Emergency Management teams have been briefed on the findings of this study.

[30] The liquefaction vulnerability mapping and associated reports will be provided to the Clutha District Council and other stakeholders (e.g. lifelines infrastructure owners) and a briefing offered.

[31] Findings of the liquefaction vulnerability assessment were discussed with community members at the 5 August 2025 drop-in session in Balclutha.

Discussion

[32] The investigation confirms vulnerability of the Clutha Delta to liquefaction hazard and refines previous liquefaction mapping.

[33] Previous assessments[16] of liquefaction vulnerability for the delta were based largely on surficial geological and geomorphic interpretations, and focused on the susceptibility of those sediment deposits to liquefaction processes. This new study has included analysis of >120 subsurface geotechnical tests,[17] enabling estimation of liquefaction triggering and severity. The analysis findings then allow for estimation of consequences for events over a range of recurrence intervals, which was used to inform assessment of liquefaction and lateral spreading risks.

[34] The seismic hazards risk assessment categorises seismic risks as *Tolerable*. Although classed as *Tolerable*, the event consequences are potentially very severe for larger magnitude (i.e. lower likelihood) events. It is prudent for seismic resilience for these risks to be considered in land use planning and infrastructure design and management.

[35] The findings of this seismic risk investigation are expected to be of use for a range of purposes, including for emergency management planning and for infrastructure managers.

Clutha River bed level trends analysis

[36] ORC regularly monitors and reports[18] on the bed level condition of the Clutha River/Mata-Au through cross section surveys, particularly in the area of the Lower Clutha Flood Protection and Drainage Scheme (LCFPDS), which includes Balclutha township.

[37] To provide updated analysis of the Clutha's river bed levels and ensure any capacity potential issues are identified and understood, ORC engaged NIWA (now Earth Sciences New Zealand) to undertake an updated riverbed level assessment. The NIWA assessment is presented in two complementary documents, a technical report[19] and a plain-language version of the same report,[20] these are attached as Attachment 3 and 4.

Scope and methods

[38] The scope of the NIWA investigation was to analyse and compare cross section survey data and monitoring for the Clutha River in the vicinity of Balclutha to provide a comprehensive review of bed level trends.

[16] Barrell D, 2019. Assessment of liquefaction hazards in the Queenstown Lakes, Central Otago, Clutha and Waitaki districts of the Otago Region. GNS Science Consultancy Report 2018/67, June 2019.
[17] Cone Penetrometer Test (CPT)
[18] e.g. ORC, 2008. Channel morphology and sedimentation in the Lower Clutha River, published July 2008.
[19] Haddadchi A and Smart G, 2025. Clutha River morphology trends at Balclutha. Prepared by NIWA (National Institute of Water & Atmospheric Research Ltd) for Otago Regional Council.
[20] Smart G and Haddadchi A, 2025. Plain language report on river bed changes at Balclutha. Prepared by NIWA (National Institute of Water & Atmospheric Research Ltd) for Otago Regional Council.

[39] The approach for the analysis was the review of all available cross sections surveyed of the river channel, and the calculation of measures such as minimum and mean bed levels for each survey profile.

[40] In the Balclutha area, ORC has regularly collected survey data at a series of survey profile locations since 1994 (Figure 3). A small number of historical surveys[21] are also available at the location of the Balclutha railway bridge, providing a record of changes over nearly 150 years at this location.

[41] Additional analysis was also carried out using water level and river flow records from NIWA's monitoring station 'Clutha at Balclutha' (location shown in Figure 3), which has been operating since 1952 (73 years). This includes review of minimum bed levels at the times of flow gauging measurements, and analysis of changes to water level-flow relationships through time.

Figure 3: Locations of Clutha River cross section survey locations at Balclutha, and the NIWA flow monitoring station 'Clutha at Balclutha'.

[21] Dated to 1878, 1893, and 1939.

Key findings

[42] The key results figures from the NIWA bed level analysis are reproduced as Figures 4, 5 and 6.

[43] There was a noticeable raising of river bed levels from the first survey (1878) to the late 1800's, seen as a rise in mean bed level of about 1 metre at the railway bridge (cross section C2, Figure 6). This corresponds to an increase in alluvial sediment produced by gold mining and sluicing in the late 1800's.

[44] There is little bed level data available for the early 1900's, then there was a long-term trend of lowering bed levels from the 1950's, following a severe reduction in sediment supply after commissioning of the Roxburgh hydro dam in 1954.

[45] In the three decades since regular cross section surveys commenced, a general lowering trend can be seen, where the average bed level[22] of ten of the eleven studied cross-sections are stable or lowering (Figure 6). Although the bed levels at cross section C4 show a weak rising trend, the mean bed level at this location remains lower than at adjacent survey locations up and downstream (Figure 4).

[46] Both the trends seen in survey data, and analysis of water level monitoring dataset, indicate that flood capacity at Balclutha has not reduced during the assessment period.

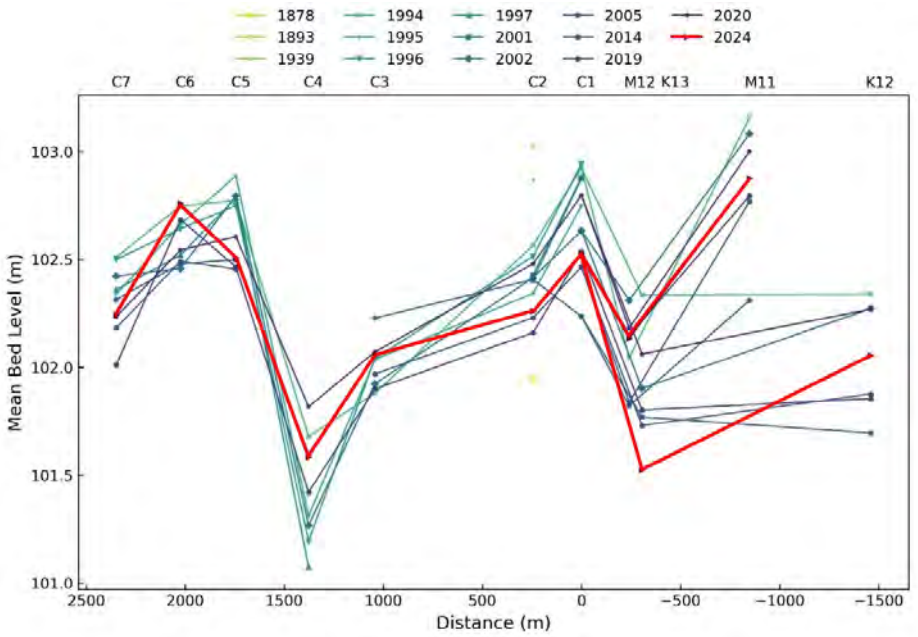


Figure 4: Historical changes in the mean bed level (MBL) of the Clutha River near Balclutha township. The x-axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross sections and negative distances downstream. Cross-section locations are shown in Figure 3. Mean bed levels from the most recent cross section survey (2024) are highlighted red for ease of comparison with data from previous years.

[22] Mean bed level is calculated as the average level of the river channel, analysed between consistent start and end points.

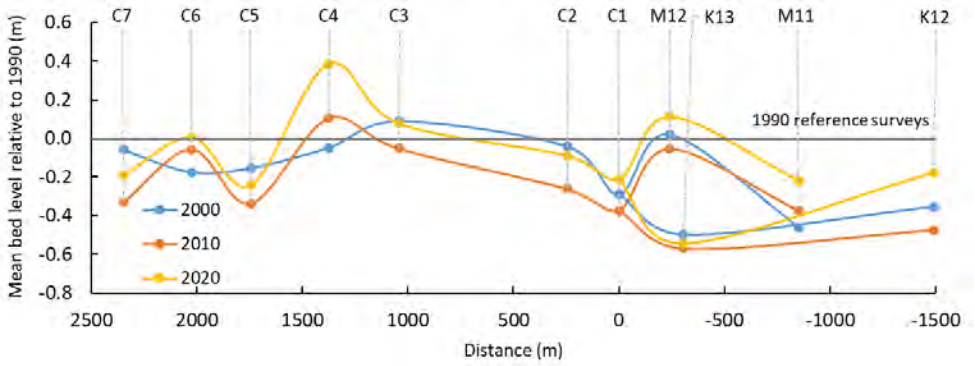


Figure 5: Mean bed level change relative to 1990 in the Clutha River near Balclutha, with surveys grouped by decade. The graph shows that for most cross-section locations, riverbed levels are now lower or very similar to where they were in the 1990's, the only exception is site C4 where the average riverbed level is now ~0.4m higher than the 1990's average bed level, but remains lower than the current level of adjacent bed level profiles located up- and downstream (see Figure 4).

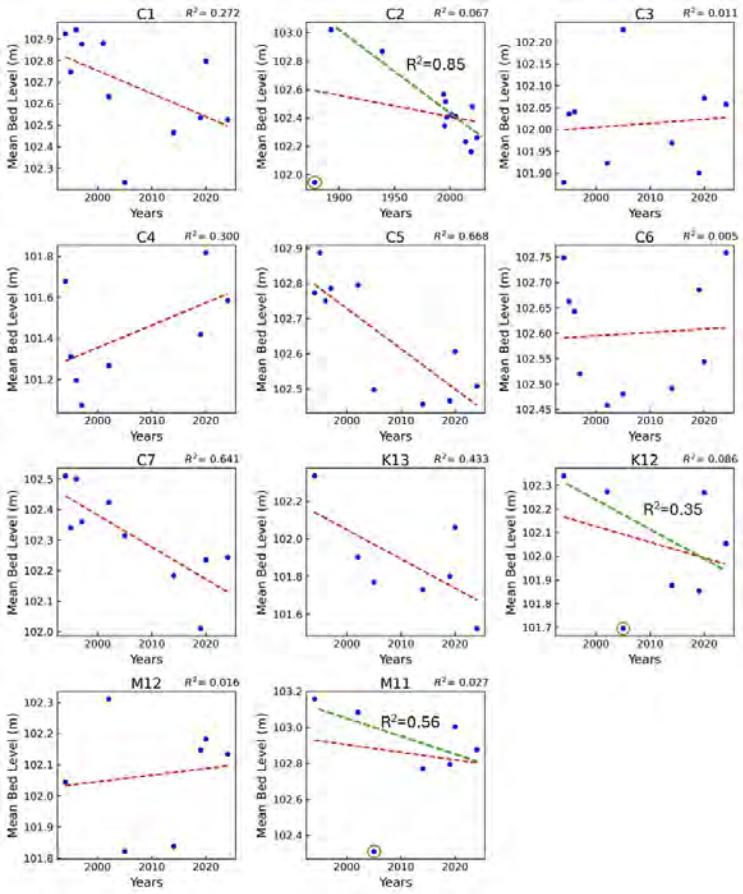


Figure 6: Changes in the mean bed level over years at each Clutha River cross section. The red and green trend lines indicate a linear regression trend for the years observed. These graphs show that bed levels at most locations have a clear lowering trend, some are stable (C3, C6, M12), and one has a weak rising trend (C4).

Communication of findings

[47] There have been concerns from community members that bed levels may be building up, particularly in the Balclutha township area, and that there may be a potential impact on channel capacity, on the level of service provided by the LCFPDS and on flood hazard. This analysis provides assurance that there is no evidence for a widespread or substantial trend of rising bed levels or 'gravel buildup' at Balclutha impacting the channel flood capacity.

[48] The findings from this NIWA investigation have been shared with the community and key stakeholders using a range of approaches, these include:

a. Creation of a dedicated webpage,[23] which includes a link to the NIWA reports, and a recorded video presentation summarising the study findings.

b. An ORC media release was used as the basis for articles in both the Clutha Leader[24] and Otago Daily Times.[25]

[23] https://www.orc.govt.nz/managing-natural-hazards/natural-hazards-adaptation/clutha-river/

[24] Clutha Leader, 17 July 2025. Rising gravel flood risk concerns allayed by new assessment.

c. Natural Hazards staff attended the Lower Clutha community drop-in session in Balclutha on 5 August 2025, where they discussed these findings with community members.
d. Findings were presented to and discussed with CDC staff in early August 2025.

Next steps

[49] ORC will continue to monitor and assess changes to the riverbed levels and channel capacity. River surveys for the lower Clutha at Balclutha are typically carried out around every two years or after major flood events, with the last survey being in June 2024.

[50] If gravel builds up and did present an impact on the flood hazard, ORC will investigate the targeted removal of gravel from the river bed. Any potential gravel removal would need to be considered carefully, as removing gravel starves locations downstream from sediment input which can then cause erosion, including at the coastline and may affect flood protection infrastructure such as floodbanks.

COMMUNITY ENGAGEMENT

[51] An adaptation programme webpage[26] on the ORC website was launched in late July. The webpages cover information on the natural hazards of the Clutha Delta, links to investigations and reports, introduces the adaptation programme, answers FAQs, and sets out how to get involved. The page will be updated as more information becomes available.

[52] On 5 August 2025, the ORC Engineering team hosted the Lower Clutha Scheme community drop-in. Natural Hazards staff were also on hand to share information about new technical findings and build awareness of the adaptation programme. Posters on the liquefaction vulnerability assessment, Clutha River bed level trends at Balclutha, and the adaptation programme were presented (Attachment 5).

[53] The drop-in was attended by about 25-30 community members. Attendees were mostly older adults and included farmers and residents of Balclutha, Inch Clutha, Paretai and Kaitangata.

[54] The community engagement session was successful, with many discussions about ORC's Natural Hazards information, particularly the recent Clutha bed levels investigation.

[55] A 3D printed model of the lower Clutha Delta was displayed, capturing the delta's land elevations, rivers, and flooding and drainage infrastructure (Figure 7). The model was produced by the ORC Science team using the ORC's 3D printer, and is a valuable resource for visualising and communicating the topography and geographic features of the delta area.

[25] ODT, 18 July 2025. ORC reassurance over river gravel levels.
[26] https://www.orc.govt.nz/get-involved/projects-in-your-area/clutha-delta-natural-hazards-adaptation/

Figure 7: 3D printed model of the Clutha Delta at approximately 1:30,000 scale (1 cm ≈ 300 m), measuring 66 x 44 cm. Water bodies (rivers, lakes and sea) are coloured blue, ORC floodbanks as orange lines, the ORC drainage network as pale green lines, land within 1 metre of sea level as dark green, and all other land areas as pale green.

PROGRAMME PLANNING

[56] A high level programme plan is shown in Table 3. Typically, key technical findings are delivered and then community engagement follows to share the results. Approximately twice-yearly engagement is expected to be required through to delivery of the first iteration of the natural hazards adaptation strategy.

[57] Technical investigations will continue over the next 6 months, with an aim to complete the updated flood and erosion hazard assessment, Koau Mouth/Puerua outfall investigations, and to complete scoping for risk assessments and any supporting studies required.

[58] Engagement over the next 6 months will seek to build awareness of the adaptation programme with the community and key stakeholders and build relationships. Upcoming relevant events offer opportunities for joint engagement, including:

- Establishment of the Lower Clutha Liaison Group
- South Otago A&P show

[59] Articles[27] and/or advertising in the Clutha Leader will be the main channel to inform and update the community on progress. Updates and new information will also be published on the programme webpage. CDC communication channels, including their website will also be utilised to inform and update the community.

[27] https://www.rnz.co.nz/news/national/569101/south-otago-residents-keen-for-flood-prevention-action

[60] Programme planning is integrating ORC work programmes from different teams (e.g. Natural Hazard, Engineering, Environmental Monitoring and Science) as well as Emergency Management Otago, Clutha District Council, and mana whenua representatives. The integrated plan will also consider key drivers, adaptation focus areas and how the work will be phased to address the most immediate needs first.

[61] A key step of programme planning is the development of strategic and operational objectives to guide the direction of the programme and integration of ORC workstreams. This will be informed by engagement with partners including iwi, communities and stakeholders.

[62] The first iteration of a natural hazards adaptation strategy for the Clutha Delta is proposed to be completed by December 2027 for initial focus areas.

Table 3: High level programme timeline showing sequence of key activities and associated community engagement to share the findings

Key activities	Technical Delivery Timeline	Associated Community Engagement
Natural Hazard Investigations • Liquefaction hazard • Clutha bed levels trend at Balclutha	completed	• scheme drop-in August 2025 • Lower Clutha Liaison Group (once established) • South A&P Show Spring 2025
Natural Hazard Investigations • Flood and erosion hazard assessments • Koau Mouth and Puerua outfall investigations **Other supporting studies may include:** • Groundwater analysis • Environmental, social and economic baselines • Cultural values • Engineering / scheme supporting studies • Review of environmental monitoring network	late 2025	early 2026
Risk Assessment • Qualitative (for delta) • Detailed for focus areas	mid 2026	late 2026*
Adaptation approaches for focus areas	late 2026	late 2026*
Draft Strategy (including adaptation for focus areas)	mid 2027	mid 2027
First Iteration Strategy (timing depends on feedback on draft)	end 2027	early 2028

*Late 2026 community engagement may include both risk assessment findings and adaptation approaches

DISCUSSION

[63] ORC's Natural Hazards work programme for the Clutha Delta area is in the early stages. The current focus for the technical work is gathering natural hazards and risk information to increase our understanding of the key natural hazards on the delta, as part of the "what is happening?" phase of the adaptation planning cycle (Figure 8). The new natural hazards studies presented in this paper provide updates which will contribute towards development of a natural hazards adaptation strategy for the Clutha Delta.

[64] Seismic hazards are one of the three main natural hazard types at the Clutha Delta – alongside flooding and coastal hazards. The liquefaction hazard analysis and seismic risk assessment improves on the existing liquefaction hazards information for the Clutha Delta, and for the first time systematically classifies the level of those risks. The risk assessment was completed in general accordance with the risk assessment guidance of the proposed RPS, so enables comparison of risks with other studies which were also based on that guidance.[28]

[65] The NIWA study regarding changes to the Clutha River bed levels and channel capacity is a comprehensive review, and is useful for ORC in management of the LCFPDS, and helps to address specific community concerns.

[66] Engagement to share and discuss natural hazards information and community perspectives is a critical step in the success of any adaptation programme. Since the previous update papers, we have advanced the communications and engagement aspects of the programme, including creation of a project webpage, and attendance at a community update drop-in meeting.

[28] e.g. Beca Ltd, 2024. Glenorchy and Kinloch Natural Hazards Risk Analysis Report. Report prepared for Otago Regional Council.

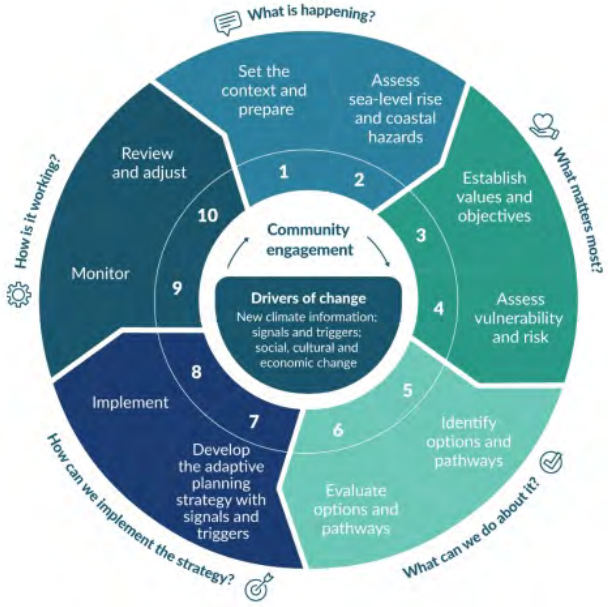


Figure 8: Overview of the 10-step decision cycle from Ministry for Environment (2024) guidance on coastal hazards and climate change. The Clutha Delta natural hazards programme is currently in the first stage of this cycle, "What is happening".

CONSIDERATIONS

Strategic Framework and Policy Considerations

[67] The information presented in this paper reflects Council's Strategic Directions, "*Otago builds resilience in a way that contributes to community and environmental wellbeing through planned and well-managed responses to shocks and stresses, including natural hazards*" and "*Otago is a climate-resilient region that plans for and invests in initiatives that reduce emissions and help us adapt to our changing climate*".[29]

[68] It contributes to achieving the following goals of the Strategic Directions:

- "*Plans are in place to ensure that the region's most vulnerable communities (geographic and demographic) and ecosystems are resilient in the face of natural hazards.*
- *Our infrastructure is designed and built to accommodate variability and uncertainty associated with changing weather patterns and sea level rise*".

[69] The proposed Otago Regional Policy Statement June 2021, notified in late March 2024, states that ORC and territorial authorities are both responsible for specifying objectives, policies and methods in regional and district plans for managing land subject to natural hazard risk. ORC specifically is responsible for "*identifying areas in the region subject to hazards and describing their characteristics as required by Policy HAZ–NH–P1, mapping the extent of those areas in the relevant regional plan(s) and including those maps on a natural hazard register or database.*"[30]

[29] ORC Strategic Directions: https://www.orc.govt.nz/your-council/our-team/strategic-directions
[30] https://www.orc.govt.nz/media/bcvh4vee/clean-appeals-version-porps-21-2001.pdf

[70] The ORC Infrastructure Strategy 2024-2054 was adopted in June 2024, together with 2024-2034 Long-Term Plan adoption.[31] Diagram 3 of the Infrastructure Strategy outlines the timeline of proposed management activities for the Lower Clutha Flood Protection and Drainage Scheme over the coming three decades. The natural hazards adaptation work programme will complement and help guide these activities.

Financial Considerations

[71] The forward work programme is included in the 2024-34 Long-Term Plan budget, which provides funding towards delivery, implementation and monitoring of the Clutha Delta natural hazards adaptation strategy.

[72] The work programme is to be funded by the Kuriwao Endowment Reserve for the current 2025/26 financial year. This reserve represents the accumulation of sale proceeds and net income from Kuriwao Endowment land. The reserve is available to fund works for the benefit of the Lower Clutha District as defined by the Otago Regional Council (Kuriwao Endowment Lands) Act 1994.

Significance and Engagement

[73] Engagement planning considers and is designed to be consistent with organisational commitments made through He Mahi Rau Rika: ORC Significance, Engagement and Māori Participation Policy. The engagement approach for the Clutha Delta natural hazards programme was outlined in the May 2024 and August 2024 update reports.

Legislative and Risk Considerations

[74] The work described in this paper helps ORC fulfil its responsibilities under sections 30 and 35 of the RMA and the Soil Conservation and Rivers Control Act 1941.

[75] Engagement planning will include a risk management plan for engagement related activities throughout the delivery of the programme.

[76] The Government's Resource Management Act reform programme includes development of a National Direction for Natural Hazards.[32] Consultation on the proposed provisions of the new National Policy Statement for Natural Hazards closed in late July 2025.

Climate Change Considerations

[77] Climate change and sea level rise are key factors influencing natural hazards in the Clutha Delta area. These factors will be considered in natural hazard and risk assessments, particularly for flooding and coastal hazards.

Communications Considerations

[78] The Natural Hazards team are continuing to work with the ORC Communications team to ensure communications and engagement planning are integrated, complementary and build off each other.

[31] ORC Long-Term Plan (LTP) 2024-2034: https://www.orc.govt.nz/your-council/plans-and-strategies/long-termplan-ltp/long-term-plan-ltp-2024-2034/

[32] https://environment.govt.nz/assets/publications/RMA/attachment-1.8-national-policy-statement-for-natural-hazards.pdf

NEXT STEPS

[79] The remaining natural hazards investigations (Koau Mouth and Puerua investigations, flood and erosion hazard assessment) are scheduled to be completed by late-2025. Scoping of additional supporting technical studies, including natural hazard risk assessments, will commence later in 2025. It is expected that risk assessments would include detailed assessments of the main natural hazard risks in the delta area, and include consideration of the changing future risk profile, and of residual risks for the scheme areas.

[80] Progress to develop strategic and operational objectives of the programme and an integrated work programme across Council and with project partners is ongoing.

[81] Engagement planning is continuing, and engagement will include sharing and discussion of key findings from all technical studies with community members and other stakeholders.

ATTACHMENTS

1. Clutha Delta liquefaction vulnerability study [**9.2.1** - 55 pages]
2. Clutha Delta qualitative risk assessment (seismic) [**9.2.2** - 59 pages]
3. Clutha River morphology trends at Balclutha [**9.2.3** - 62 pages]
4. Plain language report on river bed changes at Balclutha [**9.2.4** - 51 pages]
5. Drop- In Session Posters - Natural Hazards - Balclutha [**9.2.5** - 3 pages]

REPORT

Tonkin+Taylor

Clutha Delta Liquefaction Vulnerability Study

Prepared for
Otago Regional Council
Prepared by
Tonkin & Taylor Ltd
Date
June 2025
Job Number
1093960 v1.0

Together we create and sustain a better world
www.tonkintaylor.co.nz

Document control

Title: Clutha Delta Liquefaction Vulnerability Study					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
30/04/2025	0.1	Draft for Client and peer review	M Ogden	M Jacka	J Russell
23/06/2025	1.0	Final	M Ogden	M Jacka	J Russell

Distribution:

Otago Regional Council	1 PDF copy
Tonkin & Taylor Ltd (FILE)	1 PDF copy

Table of contents

1 Introduction 1

2 Context 3

2.1 MBIE/MfE Guidance (2017) 3

2.2 Background to this project 3

2.3 Liquefaction hazard 4

2.4 Previous liquefaction studies 6

3 Risk identification 8

3.1 Level of detail 8

3.1.1 Level of detail hierarchy 8

3.1.2 Level of detail required for intended purposes 10

3.2 Base information 11

3.2.1 Ground surface levels 11

3.2.2 Geology and geomorphology 12

3.2.3 Geotechnical investigations 15

3.2.4 Groundwater information 18

3.2.5 Seismic hazard 20

3.2.6 Historical observations of liquefaction 20

3.3 Uncertainty assessment 22

3.3.1 Ground surface levels 22

3.3.2 Geology and geomorphology 22

3.3.3 Geotechnical investigations 23

3.3.4 Groundwater 23

3.3.5 Seismic hazard 25

3.3.6 Assess ground damage response against performance criteria 26

3.4 Level of detail achieved in this assessment 27

4 Risk analysis 29

4.1 Groundwater levels for analysis 29

4.2 Earthquake scenarios for analysis 29

4.3 Liquefaction vulnerability assessment 30

4.4 Sub areas of similar expected performance 30

4.5 Liquefaction vulnerability assessed against performance criteria 32

4.5.1 Assigned liquefaction vulnerability categories 32

4.5.2 Alluvial fans 33

4.5.3 Older marine and river terraces 33

4.5.4 Hills, ranges and mountains 33

4.5.5 Holocene river plains 33

4.5.6 Balclutha township 35

5 Discussion and recommendations 37

5.1 Application to planning and consenting 37

6 Applicability 39

Appendix A Risk identification maps

Appendix B Risk analysis maps

LIQUEFACTION ASSESSMENT SUMMARY	
This liquefaction assessment has been undertaken in general accordance with the guidance document 'Planning and engineering guidance for potentially liquefaction-prone land' published by the Ministry for the Environment and the Ministry of Business, Innovation and Employment in 2017. https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction-land/	
Client	Otago Regional Council (ORC)
Assessment undertaken by	Tonkin & Taylor Ltd, PO Box 13055, Christchurch 8140
Extent of the Study Area	The Study Area aligns with the boundary defined in Figure 1.1.
Intended RMA planning and consenting purposes	To provide ORC with a catchment-wide liquefaction vulnerability assessment to identify areas of land susceptible to liquefaction. The technical report and resulting map outputs will be used to inform land use planning, subdivision consenting, and to identify areas where more detailed, site-specific liquefaction assessments (Level C or D) are likely to be required for building consent applications, in accordance with MBIE/MfE Guidance (2017).
Other intended purposes	To assess the potential impact on infrastructure, particularly the ORC's flood protection and drainage scheme.
Level of detail	Level A/B (basic/calibrated desktop assessment).
Notes regarding base information	The available base information, extended through the course of this project, provides enough information for a Level A (basic desktop assessment) level of detail across the majority of the Study Area. The main factor controlling this level of detail is the spatial extent of the available geotechnical investigations, groundwater information, and high-resolution elevation data. Level B (calibrated desktop assessment) is supported by the base information for the township of Balclutha.
Other notes	This assessment has been made at a broad scale across the entire study area and is intended to approximately describe the typical range of liquefaction vulnerability across neighbourhood-sized areas. It is not intended to precisely describe liquefaction vulnerability at individual property scale. This information is general in nature, and more detailed site-specific liquefaction assessment may be required for some purposes (e.g., for design of building foundations). A key consideration of the liquefaction vulnerability categorisation undertaken in accordance with the MBIE/MfE Guidelines (2017) is the degree of uncertainty in the assessment. Discussion about the key uncertainties in this assessment is provided in Section 3.3 of this report.

1 Introduction

Otago Regional Council (ORC) engaged Tonkin & Taylor Ltd (T+T) to improve the understanding of liquefaction vulnerability across the Clutha Delta. This work builds on previous assessments by incorporating additional geotechnical data collected during this study.

The scope for improving the liquefaction assessment was outlined in T+T (2023a)[1], where a Hybrid Level A/B approach was recommended and subsequently adopted by ORC. This hybrid method applies Level A assessment techniques, supplemented by Level B methods where sufficient data is available.

Existing geotechnical and geological information was previously summarised in T+T (2023b)[2]. Key elements have been reproduced or updated in this report as new data has become available. A primary outcome of the current assessment is a reduction in uncertainty related to ground conditions, which was identified in T+T (2023a) as the main residual uncertainty due to lack of information about the ground conditions.

Figure 1.1 shows the extent of the Study Area, including the townships of Balclutha and Kaitangata.

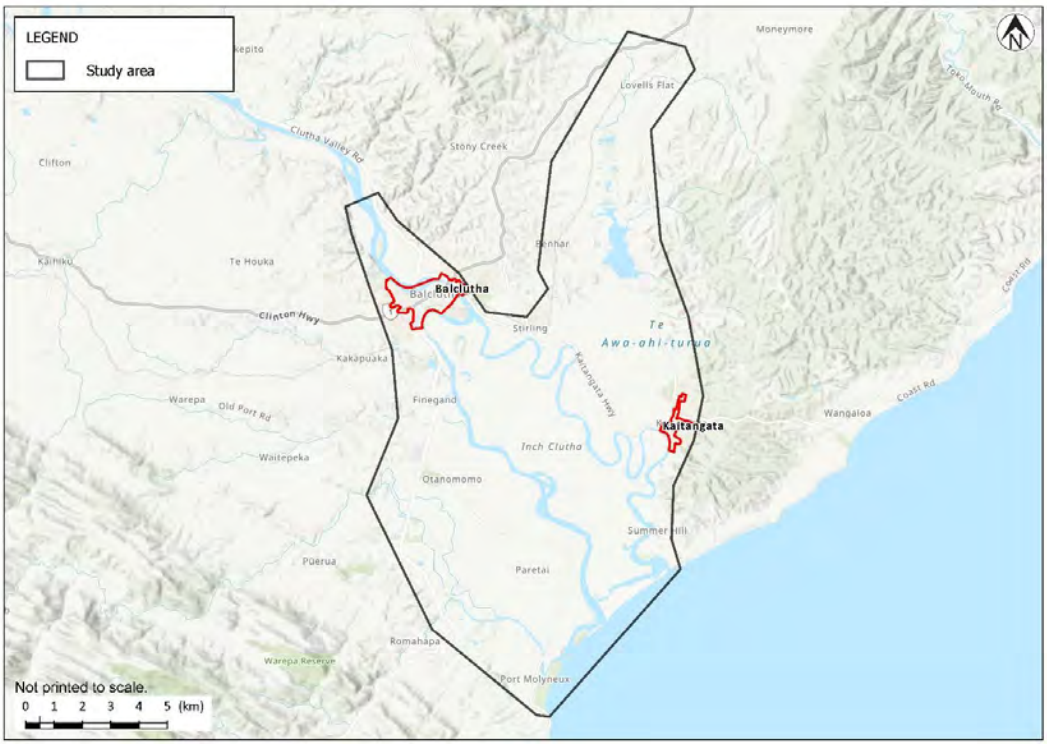


Figure 1.1: Map showing the extent of the Study Area and the townships of Balclutha and Kaitangata.

[1] Tonkin & Taylor Ltd (2023a). Potential scope for the assessment of liquefaction. Job Number: 1090955.0000.
[2] Tonkin & Taylor Ltd (2023b). Evaluation of base information available for the Clutha Delta – Future liquefaction vulnerability assessments. Job Number: 1090955.0000.

This report includes:

- An overview of the project context, the intended use of the findings, and a summary of the compiled liquefaction hazard information (Section 2).
- Liquefaction risk identification (Section 3), including:
  - Discussion regarding appropriate level of detail for the intended purpose (Section 3.1);
  - Summary of relevant base information (Section 3.2); and
  - Assessment of uncertainty in the available data (Section 3.3).
- Liquefaction risk analysis (Section 4), including:
  - Evaluation of groundwater conditions and earthquake scenarios, and sub-area delineation based on expected ground behaviour (Sections 4.1 to 4.3);
  - Assessment of liquefaction vulnerability using MBIE/MfE (2017) guidance (Section 4.4).
- Discussion of the results and key conclusions (Section 5).

The structure of this assessment follows the ISO 31000:2018 risk management process, as shown in Figure 1.2.

It is noted that this report focuses solely on liquefaction hazards. Other natural hazards and geotechnical constraints should also be considered in any future land development or building activity.

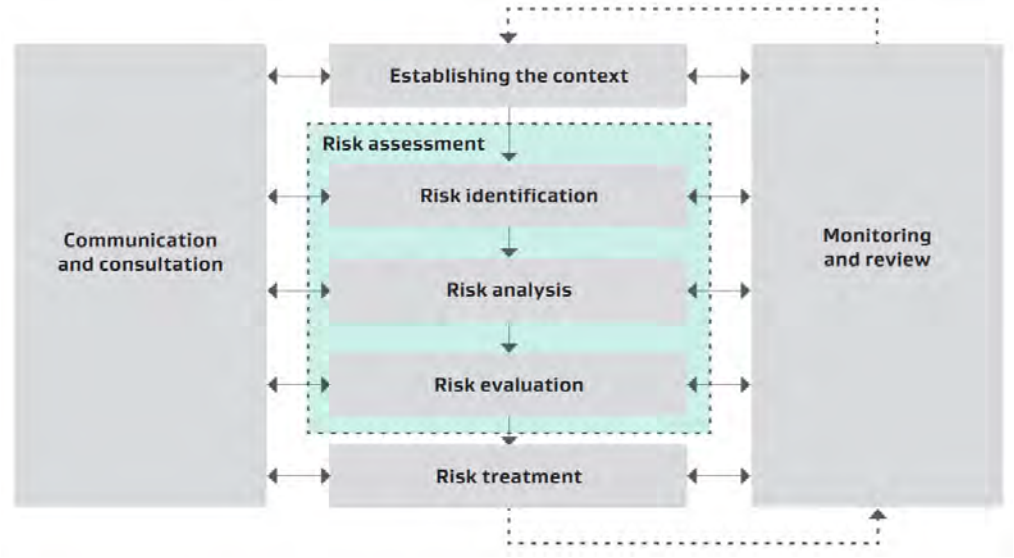


Figure 1.2: Risk management process defined in ISO 31000:2009, which has been used to guide the liquefaction vulnerability assessment and the layout of this report – reproduced from MBIE/MfE Guidance (2017). Note, this figure has been slightly modified in the ISO 31000:2018 standard, however the general concepts remain unchanged.

2 Context

2.1 MBIE/MfE Guidance (2017)

The MBIE/MfE Guidance (2017)[3] sets out a risk-based approach to managing liquefaction-related risk in land use planning and land development decision-making. It was developed in response to the 2010–2011 Canterbury Earthquake Sequence, following recommendations from the Royal Commission of Inquiry into Building Failure caused by the Canterbury Earthquakes.

The guidance aims to support assessments of liquefaction-induced ground damage within the context of the Resource Management Act (RMA) and Building Act. In addition to its role in planning and consenting, liquefaction hazard information may be used in a range of other applications. As outlined in Section 1.2 of the guidance, these include:

- Long-term strategic land use planning
- Development of natural hazard management processes
- Design of land development, buildings, and infrastructure
- Earthquake-prone building assessments
- Enhancing infrastructure and lifelines resilience
- Civil defence and emergency management planning
- Catastrophe loss modelling for insurance and disaster risk reduction

Further detail on the risk-based approach to managing liquefaction hazard is provided in Section 3 of the MBIE/MfE Guidance (2017).

2.2 Background to this project

ORC commissioned this assessment to identify and delineate areas within the Study Area that have the potential for liquefaction-induced ground damage.

The Study Area encompasses a range of landscapes with varying susceptibility to liquefaction hazards. This assessment aims to improve the understanding of liquefaction vulnerability across the area and produce a liquefaction vulnerability map for use by a range of stakeholders.

The study findings are anticipated to be of value to a range of stakeholders and are intended to:

- Inform landowners and residents of the potential risks posed by liquefaction/lateral spreading.
- As an input to the Clutha Delta natural hazards adaptation programme, particularly to inform assessments of seismic risks.
- For the ORC Engineering team, as a high-level assessment of potential liquefaction impacts on scheme infrastructure, and the potential cascading impacts on the performance of the Lower Clutha Drainage and Flood Protection Scheme.
- For Clutha District Council (CDC), to build their awareness of the potential hazard, and to identify areas where this hazard may need to be considered more closely in building consent processes and infrastructure management.
- For Emergency Management Otago, to build their understanding of potential event consequences for a major earthquake.

[3] Ministry of Business, Innovation and Employment (MBIE) and the Ministry for the Environment (MfE) (2017). Planning and engineering guidance for potentially liquefaction-prone land.

2.3 Liquefaction hazard

Liquefaction is a natural process where earthquake shaking increases the water pressure in certain types of ground conditions, resulting in temporary loss of soil strength.

The following three key elements are all required for liquefaction to occur:

1 Loose non-cohesive or weakly cohesive soil (typically sands and silts, sometimes gravels, or fine-grained soils with low plasticity).

2 Saturated or near-saturated soil (e.g. below the groundwater table or in zones influenced by capillary rise).

3 Sufficient ground shaking (a combination of the duration and intensity of shaking).

Figure 2.1 and Figure 2.2 summarises the process of liquefaction through a schematic representation.

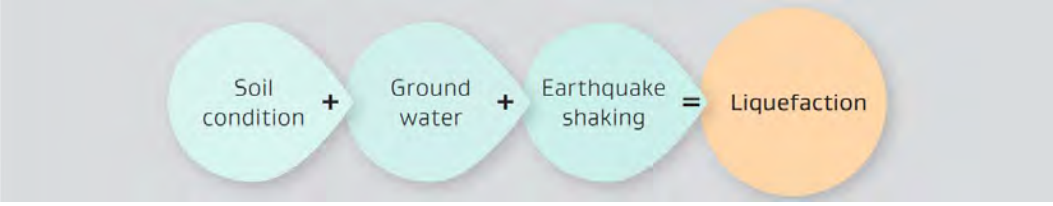


Figure 2.1: Three key elements required for liquefaction to occur - reproduced from MBIE/MfE Guidance (2017).

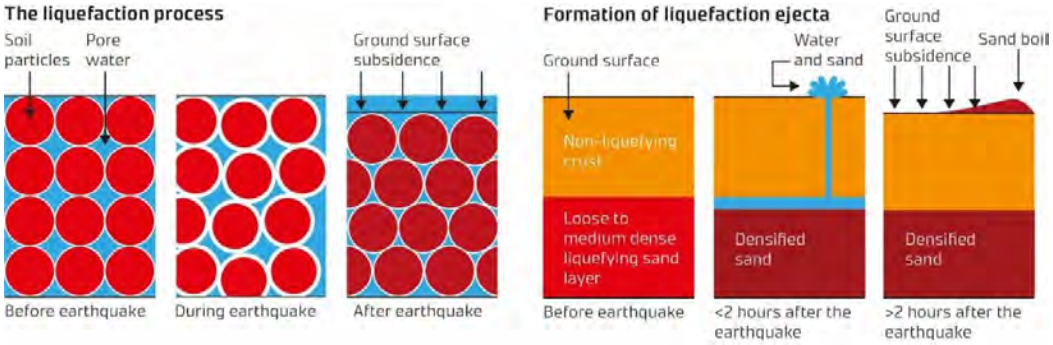


Figure 2.2: Schematic representation of the process of liquefaction and the manifestation of liquefaction ejecta - reproduced from MBIE/MfE Guidance (2017).

Liquefaction can result in significant damage to land and structures. Common manifestations include the ejection of sediment to the ground surface, differential settlement due to volume loss in liquefied soils, and lateral ground movement (lateral spreading). These effects are summarised in Table 2.1.

The consequences of liquefaction can be severe, ranging from land damage to widespread social and economic disruption, as observed during the 2010–2011 Canterbury Earthquake Sequence.

Table 2.1: Overview of potential consequences of liquefaction (reproduced from MBIE/MfE Guidance (2017))

Land	• Sand boils, where pressurised liquefied material is ejected to the surface (ejecta). • Ground settlement and undulation, due to consolidation and ejection of liquefied soil. • Ground cracking from lateral spreading, where the ground moves downslope towards an unsupported face (e.g., a river channel or terrace edge).
Environment	• Discharge of sediment into waterways, impacting water quality and habitat. • Fine airborne dust from dried ejecta, impacting air quality. • Potential contamination issues from ejected soil. • Potential alteration of groundwater flow paths and formation of new springs.
Buildings	• Distortion of the structure due to differential settlement of the underlying ground, impacting the amenity and weather tightness of the building. • Loss of foundation-bearing capacity, resulting in settlement of the structure. • Stretch of the foundation due to lateral spreading, pulling the structure apart. • Damage to piles due to lateral ground movements, and settlement of piles due to downdrag from ground settlement. • Damage to service connections due to ground and building deformations.
Infrastructure	• Damage to road, rail, and port infrastructure (settlement, cracking, sinkholes, ejecta). • Damage to underground services due to ground deformations (e.g., 'three waters', power, and gas networks). • Ongoing issues with sediment blocking pipes and chambers. • Uplift of buoyant buried structures (e.g., pipes, pump stations, manholes and tanks). • Damage to port facilities. • Sedimentation and 'squeezing' of waterway channels, reducing drainage capacity. • Deformation of embankments and bridge abutments (causing damage to bridge foundations and superstructure). • Settlement and cracking of flood stopbanks, resulting in leakage and loss of freeboard. • Disruption of stormwater drainage and increased flooding due to ground settlement.
Economic	• Lost productivity due to damage to commercial facilities, and disruption to the utilities, transport networks, and other businesses that are relied upon. • Absence of staff who are displaced due to damage to their homes or are unable to travel due to transport disruption. • Cost of repairing damage.
Social	• Community disruption and displacement – initially due to damage to buildings and infrastructure, then the complex and lengthy process of repairing and rebuilding. • Potential ongoing health issues (e.g., respiratory and psychological health issues).

The consequences of liquefaction at any location can vary depending on several factors, including:

- **Soil conditions** – Liquefaction is most likely to occur in loose non-cohesive or weakly cohesive soil (typically sands and silts, sometimes gravels, or fine-grained soils with low plasticity). It is unlikely to occur in plastic soils (e.g. clays), dense gravels, or rock. The depositional environment (e.g. river, estuarine, or marine) also influences the soil layering. Thick, continuous layers of liquefiable soil tend to result in more severe consequences than thin, isolated layers interbedded with non-liquefiable material.
- **Depth to groundwater** – Liquefaction occurs in saturated soils. A deeper groundwater table results in a thicker surface crust of non-liquefied material, which can reduce surface manifestation and mitigate overall ground damage.
- **Intensity of earthquake shaking** – More severe shaking can cause a greater thickness of the soil profile to liquefy, increasing the potential for damage.
- **Proximity to free faces or sloping ground** – Lateral spreading typically occurs in liquefiable soils near a free face (e.g. riverbank, channel, or road cut) or sloping terrain. The closer the site is to these features, the more severe the likely consequences.

2.4 Previous liquefaction studies

In 2019, GNS completed a liquefaction hazard assessment for the Queenstown Lakes, Central Otago, Clutha, and Waitaki Districts[4]. The report describes the work as an "office-based evaluation of existing available information", equivalent to a basic desktop assessment as defined in the MBIE/MfE (2017) guidance on liquefaction-prone land.

The GNS study was based on the following information sources:

- Geological, landform, and soil maps
- Topographic data from maps, LiDAR, aerial imagery, and ground photography
- Borehole records and groundwater depth measurements

The assessment differentiated areas underlain by rock or firm sediments, which are unlikely to liquefy, from those underlain by other geologic units that may be susceptible to liquefaction under strong ground shaking.

As part of the assessment, GNS developed a map classifying liquefaction susceptibility using a three-domain system:

- Domain A – Areas predominantly underlain by rock or firm sediments. GNS state that "*it is unlikely that damaging liquefaction could occur*" in these areas.
- Domain B – Areas predominantly underlain by poorly consolidated fluvial sediments with shallow groundwater. GNS consider a "*low to moderate likelihood of liquefaction-susceptible materials being present in some parts*" of this domain. A sub-classification, Domain B1, was applied where geotechnical data indicated the localised presence of susceptible materials.
- Domain C – Areas underlain by poorly consolidated marine or estuarine sediments with shallow groundwater. GNS identify a "*moderate to high likelihood of liquefaction-susceptible material being present in some parts*" of this domain and note that associated ground damage could range from moderate to severe.

[4] Barrell, D. J. A. (2019). Assessment of liquefaction hazards in the Queenstown Lakes, Central Otago, Clutha and Waitaki districts of the Otago Region. Lower Hutt (NZ): GNS Science. Consultancy Report 2018/67. Prepared for Otago Regional Council.

The GNS report links the three domains to liquefaction vulnerability categories from the MBIE/MfE Guidance (2017). Domain A corresponds to ***Liquefaction Damage is Unlikely***, while Domains B, B1, and C correspond to ***Liquefaction Damage is Possible***.

The GNS-derived liquefaction susceptibility domains for the Study Area are shown in Figure 2.3.

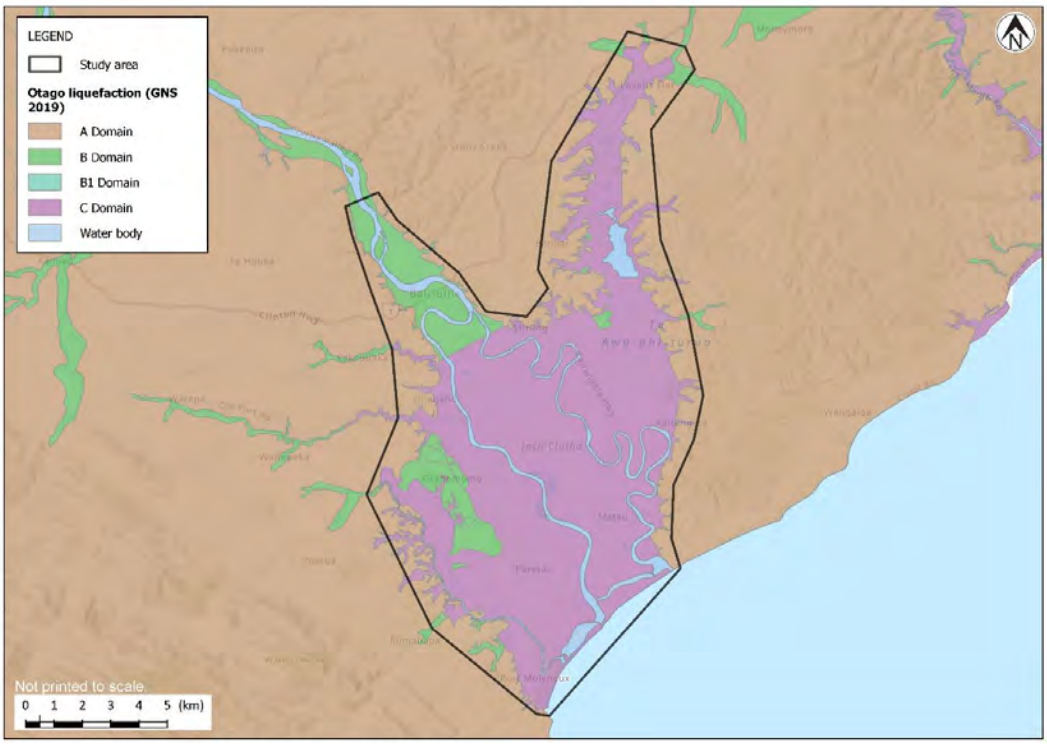


Figure 2.3: GNS liquefaction susceptibility domains within the Study Area (GNS, 2019).

3 Risk identification

3.1 Level of detail

This section outlines the risk identification process undertaken for the liquefaction vulnerability assessment of the Study Area.

The first step was to determine the level of detail required for the intended purpose of the assessment (refer to Section 3.1.2). This involved evaluating the key features associated with each level of detail, as defined in the MBIE/MfE Guidance (2017), and considering ORC's intended applications of the assessment outcomes.

The second step was a review of the base information available for the Study Area (refer to Section 3.2). This included:

- Ground surface levels (refer to Section 3.2.1).
- Geology and geomorphology (refer to Section 3.2.2).
- Geotechnical investigations (refer to Section 3.2.3).
- Groundwater information (refer to Section 3.2.4).
- Seismic hazard (refer to Section 3.2.5).
- Historical observations of liquefaction (refer to Section 3.2.6).

3.1.1 Level of detail hierarchy

The MBIE/MfE Guidance (2017) outlines four levels of assessment detail, from Level A (least detailed) to Level D (most detailed). Figure 3.1 presents the key features of each level.

A core principle of the level of detail hierarchy is the concept of residual uncertainty—the uncertainty that remains after all available information has been considered. This residual uncertainty is a critical factor in determining whether the assessment is suitable for its intended purpose and helps to guide subsequent risk evaluation and treatment.

Two components inform the determination of the appropriate level of detail:

- The level of detail required for the intended purpose, based on stakeholder consultation and the specific planning and development applications (refer to Section 3.1.2).
- The level of detail supported by the available base information, considering both data quality and the level of uncertainty (refer to Sections 3.2 and 3.3).

LEVEL OF DETAIL	KEY FEATURES
Level A **Basic desktop assessment**	Considers only the most basic information about geology, groundwater and seismic hazard to assess the potential for liquefaction to occur. This can typically be completed as a simple 'desktop study', based on existing information (eg geological and topographic maps) and local knowledge. **Residual uncertainty:** The primary focus is identifying land where there is a ***High*** degree of certainty that ***Liquefaction Damage is Unlikely*** (so it can be 'taken off the table' without further assessment). For other areas, substantial uncertainty will likely remain regarding the level of risk.
Level B **Calibrated desktop assessment**	Includes high-level 'calibration' of geological/geomorphic maps. Qualitative (or possibly quantitative) assessment of a small number of subsurface investigations provides a better understanding of liquefaction susceptibility and triggering for the mapped deposits and underlying ground profile. For example, the calibration might indicate the ground performance within a broad area is likely to fall within a particular range. It may be possible to extrapolate the calibration results to other nearby areas of similar geology and geomorphology, however care should be taken not to over-extrapolate (particularly in highly variable ground such as alluvial deposits), and the associated uncertainties (and potential consequences) should be clearly communicated. Targeted collection of new information may be very useful in areas where existing information is sparse and reducing the uncertainty could have a significant impact on objectives and decision-making. **Residual uncertainty:** Because of the limited amount of subsurface ground information, significant uncertainty is likely to remain regarding the level of liquefaction-related risk, how it varies across each mapped area, and the delineation of boundaries between different areas.
Level C **Detailed area-wide assessment**	Includes quantitative assessment based on a moderate density of subsurface investigations, with other information (eg geomorphology and groundwater) also assessed in finer detail. May require significant investment in additional ground investigations and more complex engineering analysis. **Residual uncertainty:** The information analysed is sufficient to determine with a moderate degree of confidence the typical range of liquefaction-related risk within an area and delineation of boundaries between areas, but is insufficient to confidently determine the risk more precisely at a specific location.
Level D **Site-specific assessment**	Draws on a high density of subsurface investigations (eg on or very close to the site being assessed), and takes into account the specific details of the proposed site development (eg location, size and foundation type of building). **Residual uncertainty:** The information and analysis is sufficient to determine with a ***High*** degree of confidence the level of liquefaction-related risk at a specific location. However, the scientific understanding of liquefaction and seismic hazard is imperfect, so there remains a risk that actual land performance could differ from expectations even with a high level of site-specific detail in the assessment.

Increasing level of detail and decreasing degree of uncertainty

Figure 3.1: Levels of detail for liquefaction assessment studies and the defining key features - from MBIE/MfE Guidance (2017).

3.1.2 Level of detail required for intended purposes

Section 3.5 of the MBIE/MfE Guidance (2017) provides recommendations on the appropriate level of detail for liquefaction assessments, based on development intensity, expected ground damage, and the intended use of the outputs.

ORC selected a target level of detail of Level A across the wider district, with Level B applied in areas of higher development focus—specifically Balclutha and Kaitangata.

This decision considered:

- The range of intended uses for the liquefaction vulnerability assessment.
- The minimum level of detail required for those uses.
- The availability, spatial density, and extent of supporting data.
- Whether adopting a higher level of detail than the minimum would improve overall outcomes.

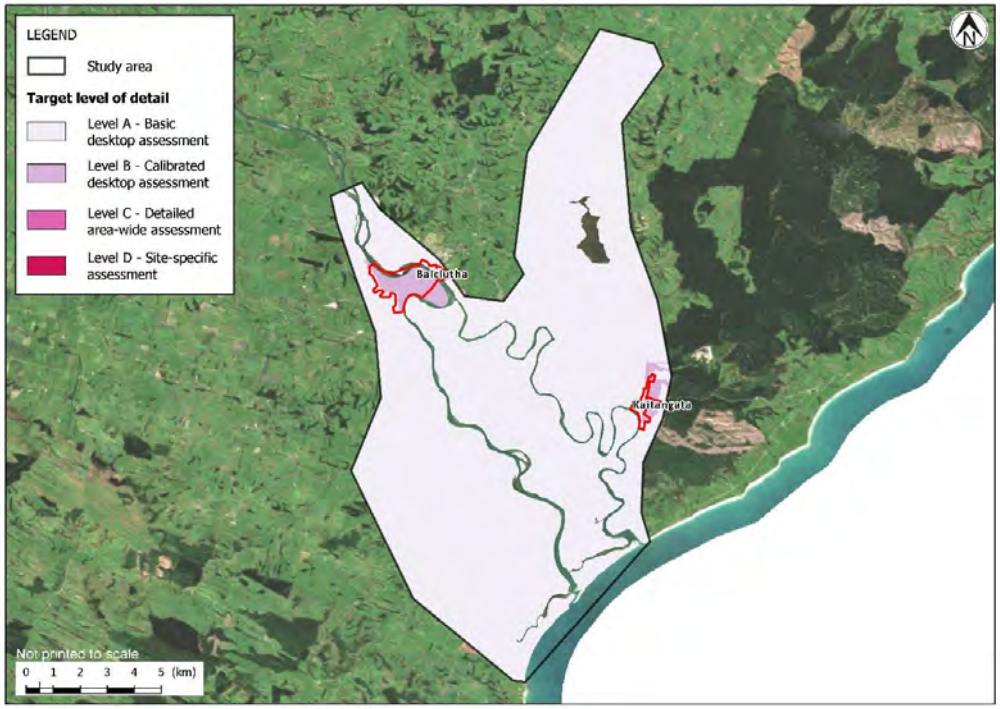


Figure 3.2: Target level of detail for the Study Area – Level A (Basic Desktop Assessment) and Level B (Calibrated Desktop Assessment). Refer to Appendix A for a larger map.

3.2 Base information

This section summarises the base information available for the liquefaction vulnerability assessment and outlines how it has been applied within the risk identification process. The information reviewed includes:

- Ground surface levels
- Geology and geomorphology
- Geotechnical investigations
- Groundwater information
- Seismic hazard
- Historical observations of liquefaction

A high-level assessment of the quality and suitability of each data source has been undertaken to determine its appropriateness for use in this study.

3.2.1 Ground surface levels

The ground surface levels of the entire Study Area are well characterised by LiDAR-derived Digital Elevation Models (DEM). Table 3.1 provides information about the most recent LiDAR data acquisitions.

The extent of coverage and level of resolution of this LiDAR data is considered suitable for the purposes of liquefaction vulnerability assessments.

Table 3.1: Recent LiDAR data acquisitions for the Study Area

Commissioning agency	Year of acquisition	Acquisition by	DEM Resolution (m)	Coverage of Study Area
Otago Regional Council	2024	Landpro	0.25	Balclutha
Otago Regional Council	2021	AAM Ltd	1.0	Otago coastal catchments
Otago Regional Council	2020	Landpro	1.0	Clutha Delta
Otago Regional Council	2016	Aerial Surveys	1.0	Clutha coastal margin

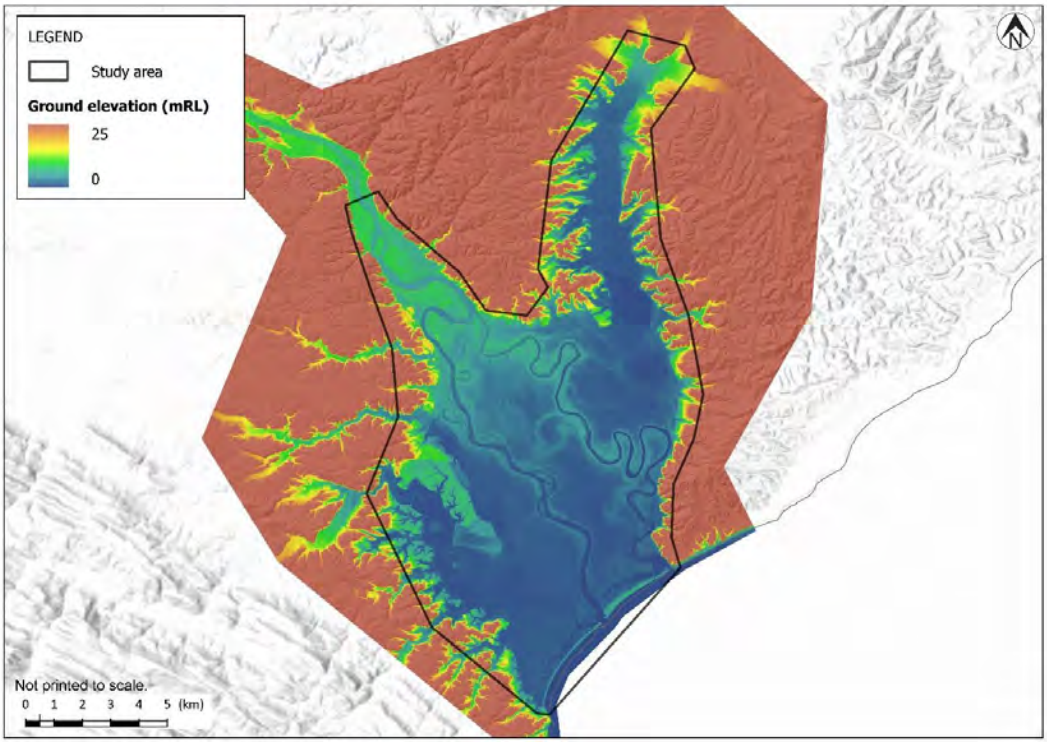


Figure 3.3: Ground surface elevation for the Clutha Delta, 1m LiDAR-derived DEM (2021). Refer to Appendix A for a larger map.

3.2.2 Geology and geomorphology

The Clutha Delta has formed at the mouth of the Clutha River, where the river discharges into the Pacific Ocean near Molyneux Bay. The delta is characterised by extensive alluvial sediments deposited over time by fluvial and coastal processes. These unconsolidated Holocene and Pleistocene sediments are depositional environments like those known to have experienced liquefaction in past New Zealand earthquake events.

The geological and soil information used to inform this study is summarised in Table 3.2.

Table 3.2: Available geological and soil maps in the Study Area

Title	Authors	Published date	Scale	Comments
Geology of the Murihiku area	Turnbull, I.M & Allibone, A.H (Compilers)	2003	1:250,000	Georeferenced
Geology of the Dunedin area	Bishop, D.G & Turnbull, I.M. (Compilers)	1996	1:250,000	Georeferenced
S-MAP Online	Manaaki Whenua Landcare Research	2021	1:20,000 – 1:50,000	Georeferenced

A high-level classification of lithological units across the Study Area has been developed from the QMAP 1:250,000 series. The geology map is shown in Figure 3.4. Table 3.3 summarises the

approximate land area associated with each unit, along with an indication of typical liquefaction susceptibility for these types of deposits.

Table 3.3: Description of high-level lithology and the land area within Study Area

Lithology type	Description	Typical liquefaction susceptibility for this type of deposit	Area (km^2)	Proportion of study area (%)
Basement and sedimentary rock	Cretaceous to Paleogene-aged bedrock	Less likely to be susceptible	35	22
Pleistocene gravel, sand, silt, clay	River and shoreline deposits	More likely to be susceptible	15	9
Holocene gravel, sand, silt, clay	River, shoreline, swamp, and windblown deposits	Most likely to be susceptible	111	69

Additional geomorphic context is provided in a GNS Science report by Barrell & Crundwell (2022)[5], which includes a geomorphic map of the Clutha Delta. This map categorises the delta into four main terrain types (with expected liquefaction susceptibility):

- **Holocene river plains** – The active, low-lying floodplain of the Clutha River. These areas are expected to be more susceptible to liquefaction due to typical shallow groundwater and prevalence of liquefiable sands and silts.
- **Alluvial fans** – Broad, fan-shaped sediment deposits from tributary streams at the valley margins. While potentially containing some susceptible materials, these are generally expected to have deeper groundwater and less fine grained non-cohesive soils making them less susceptible overall.
- **River terraces** – Deposits from older river systems, generally 2–8 m above the Holocene river plain. Because of their age and deeper groundwater these deposits are considered less susceptible to liquefaction.
- **Marine terraces** – Sediment accumulations overlying wave-cut erosion surfaces, typically elevated above current sea level. Because of their age and deeper groundwater these deposits are considered less susceptible to liquefaction.

For this project, an additional geomorphic terrain—**Hills, ranges and mountains**—has been incorporated to capture terrain outside of these four categories. This unit includes elevated and rolling terrain generally underlain by older, more consolidated geological materials and is considered the least susceptible to liquefaction of all these geomorphic terrains.

The geomorphic map is shown in Figure 3.5. T+T obtained a digital copy of this dataset from GNS under licence solely for use in this assessment.

[5] Barrell, D. J. A. & Crundwell, M. P. (2022). Radiocarbon dating and geological assessment of sediments associated with the Clutha River delta, South Otago. GNS Science Consultancy Report 2022/108.

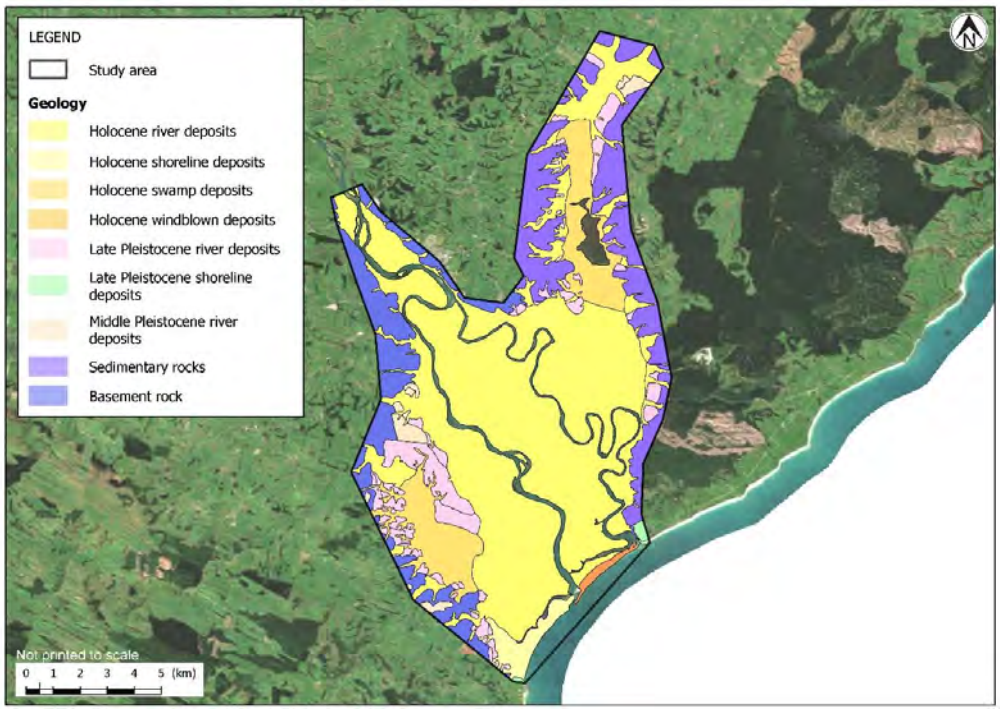


Figure 3.4: Geology of the Clutha Delta (derived from QMAP with boundaries defined in GNS (2022)). Refer to Appendix A for a larger map.

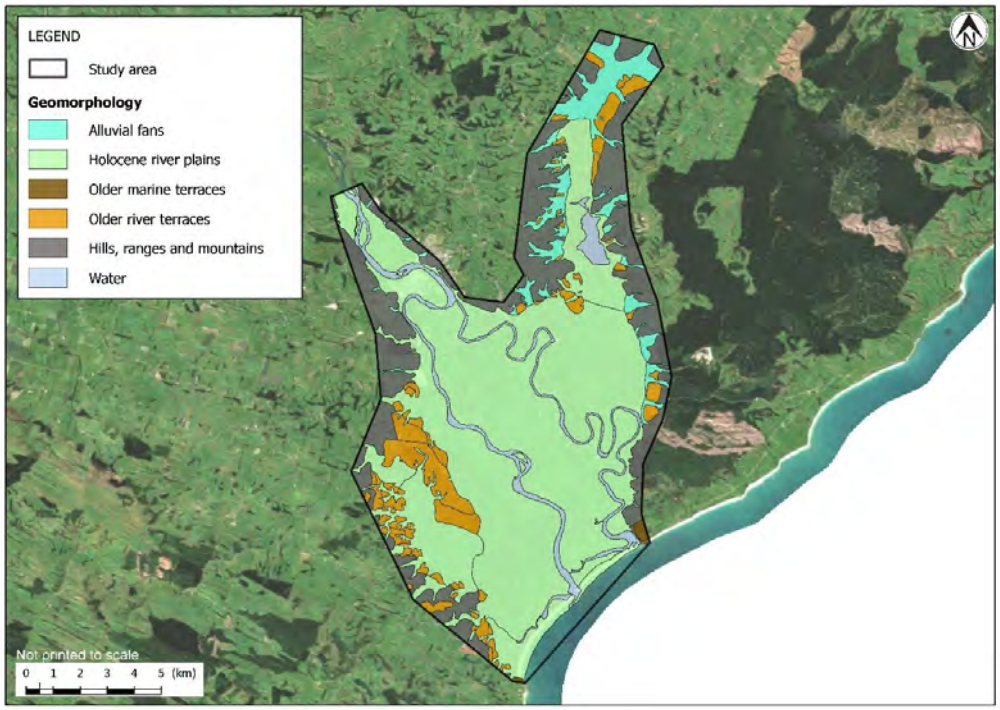


Figure 3.5: Geomorphology of the Clutha Delta (GNS, 2022). Refer to Appendix A for a larger map.

3.2.3 Geotechnical investigations

Geotechnical investigation data from the New Zealand Geotechnical Database (NZGD) were reviewed for this assessment. The available investigations include Cone Penetration Tests (CPTs), machine boreholes, and hand augers.

As part of this project, an additional 29 CPTs were undertaken across the Clutha Delta to increase the availability of ground investigations. These CPTs were carried out by Geotechnics over a three-week period in November 2024. Target investigation depths were 20 m, unless practical refusal was encountered at a shallower depth. Locations were selected to provide broad spatial coverage across the Study Area.

Table 3.4 presents the total number of geotechnical investigations available as of 1 March 2025. Figure 3.6 shows the spatial distribution of all investigations, with the CPTs completed as part of this project highlighted. Figure 3.7 illustrates the spatial density of CPT coverage across the Study Area.

Table 3.4: Summary of geotechnical investigation information within the Study Area as of 1 March 2025

Investigation type	NZGD count (No.)		
	Clutha Delta (including Balclutha and Kaitangata)	Balclutha	Kaitangata
CPT	123	61	3
SCPT	0	0	0
Machine drilled borehole	17	5	0
Hand auger borehole	3	0	0
Machine excavated trial pit	1	0	0

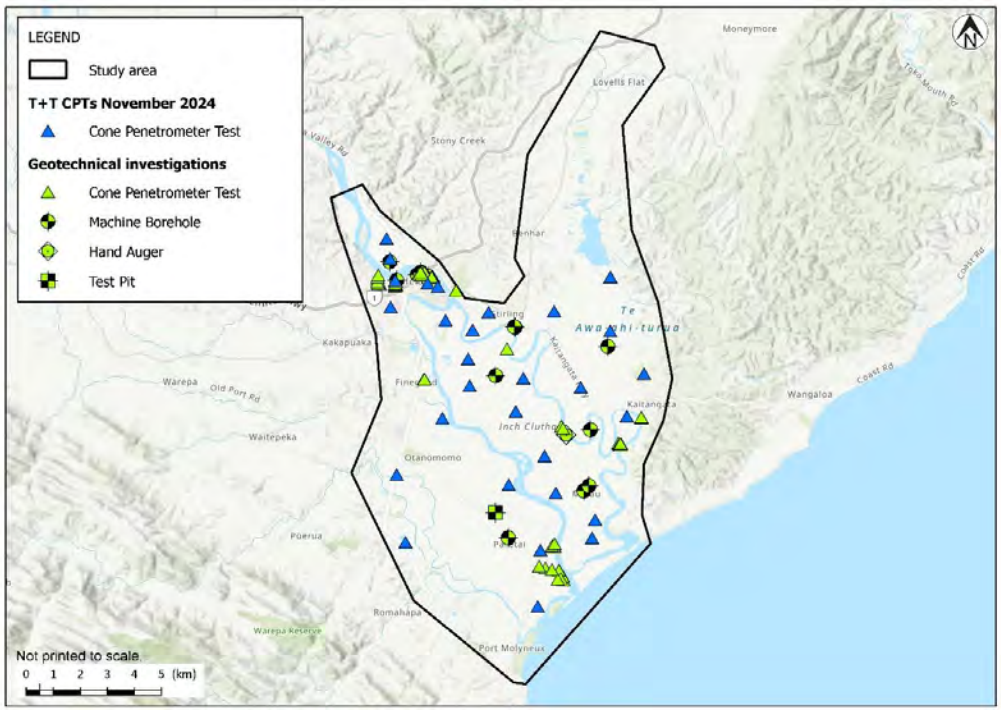


Figure 3.6: Geotechnical investigations in the Clutha Delta available on NZGD as of 1 March 2025, with the new CPTs undertaken as part of this project shown in blue. Refer to Appendix A for a larger map.

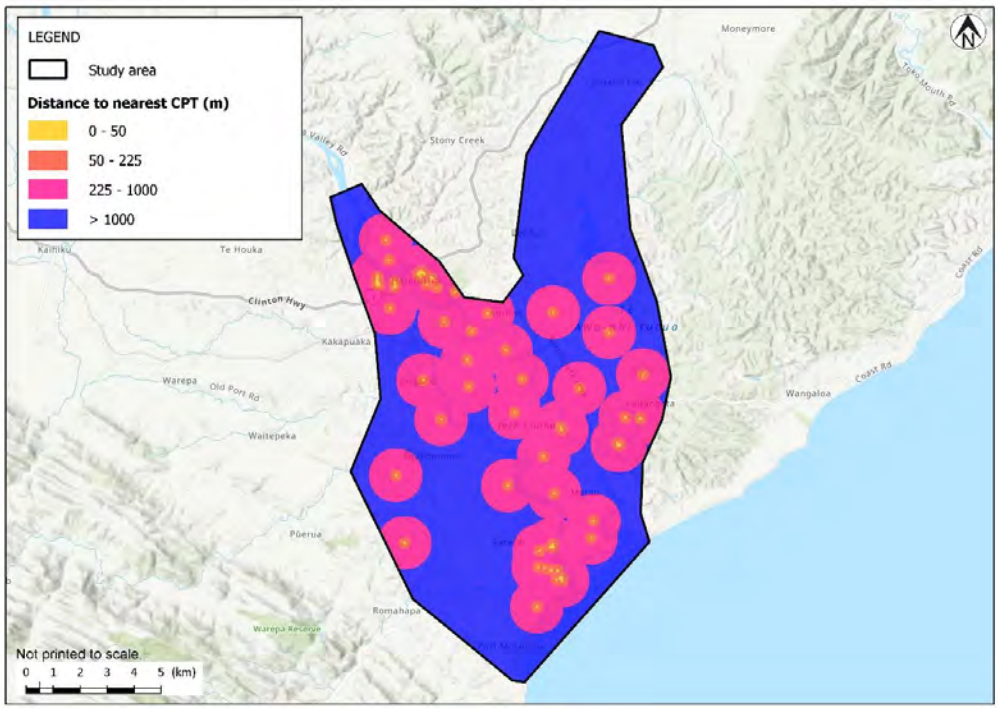


Figure 3.7: Spatial density of CPT investigations. Refer to Appendix A for a larger map.

Table 3.5: Summary of CPTs undertaken for this project

Investigation ID[1]	Easting (m NZTM2000)	Northing (m NZTM2000)	Depth of investigation (m)	Depth of predrill (m)	Depth to groundwater (inferred from CPT trace)
CPT01	1347808	4874233	7.18	0	1.9
CPT02	1349005	4874126	7.16	0	2.2
CPT03	1349383	4874006	20.2	0	2.1
CPT04	1347635	4873253	4.18	0	Null
CPT05	1347618	4875036	20.6	0	2.6
CPT06	1347487	4875777	20.59	0	0.8
CPT07	1351260	4873058	1.5	0	Null
CPT08	1350667	4872403	6.68	0	1.9
CPT09	1349668	4872754	16.3	0.3	1.8
CPT10	1350501	4871331	22.11	0	1.6
CPT11	1352541	4870620	20.6	0	0.4
CPT12	1350557	4870339	23.6	0	0.6
CPT14	1352263	4869385	19.39	0	0.6
CPT15	1353329	4867741	20.1	0	0.6
CPT16	1353743	4866372	20.6	0	0.8
CPT17	1355198	4865388	12.16	0	0.6
CPT18	1355086	4864716	13.2	0	0.9
CPT19	1349549	4869135	5.74	0	1.6
CPT21	1347860	4867048	13.82	0	1.4
CPT22	1352002	4866673	20.58	0	0.4
CPT24	1348186	4864556	1.46	0	Null
CPT26	1353175	4864260	11.94	0	0.7
CPT27	1353075	4862186	10.09	0	0.8
CPT29	1353684	4873093	20.13	0	1
CPT30	1355757	4872360	10.06	0	0.9
CPT31	1356372	4869208	20.24	0.15	1.8
CPT32	1354667	4870276	6.86	0	0.9
CPT33	1357006	4870786	10.66	0	0.8
CPT34	1355764	4874359	7.54	0	1

Notes:

1. Originally 35 investigations were targeted, but 6 were abandoned due to land access constraints.

3.2.4 Groundwater information

Soils must be saturated or nearly fully saturated for liquefaction to occur. In typical liquefaction assessments, the groundwater table is assumed to occur at some depth below the ground surface, below which soils are considered to be fully saturated.

Within the Study Area, ORC operates eight groundwater monitoring wells that provide continuous groundwater level data. These are summarised in Table 3.6.

Table 3.6: Groundwater bores monitored by ORC within the Study Area

Well number	Type	Depth (m)	Screen depth (m)	Data capture start	Recording interval	Location
CF15/0105	Piezometer	6.3	3.3 – 6.3	18/08/2022	1 hour	Centre Road, Inch Clutha
CF15/0106	Piezometer	38	35 – 38	18/08/2022	1 hour	Centre Road, Inch Clutha
CF15/0107	Piezometer	6	3 – 6	18/08/2022	1 hour	Centre Road, Inch Clutha
CF15/0108	Piezometer	6	3 – 6	18/08/2022	1 hour	Lawson Road, Inch Clutha
CF15/0109	Piezometer	39.4	36.4 – 39.4	18/08/2022	1 hour	Lawson Road, Inch Clutha
CF15/0110	Piezometer	6	3 – 6	18/08/2022	1 hour	Kaitangata
CG15/0101	Piezometer	6.3	3 – 6	18/08/2022	1 hour	Settlement Road, Paretai
CG15/0102	Piezometer	35	16.75 – 19.75	18/08/2022	1 hour	Settlement Road, Paretai

Of these eight wells, five are screened to monitor the shallow groundwater table, while the remaining three are screened at depth (which may not reflect the near-surface groundwater aquifers most relevant for liquefaction assessment). The locations of the shallow groundwater wells are shown in Figure 3.8.

In addition to the continuous monitoring network, ORC holds drilling records that include static water level observations made during or shortly after drilling. Of the 59 boreholes reviewed, 56 contain usable water level data.

Further relevant groundwater datasets, which are shown in Figure 3.8, include mapped surface water bodies, flood banks, and drainage networks. Groundwater levels inferred from the geotechnical investigations described in Section 3.2.3 have also been considered in this assessment.

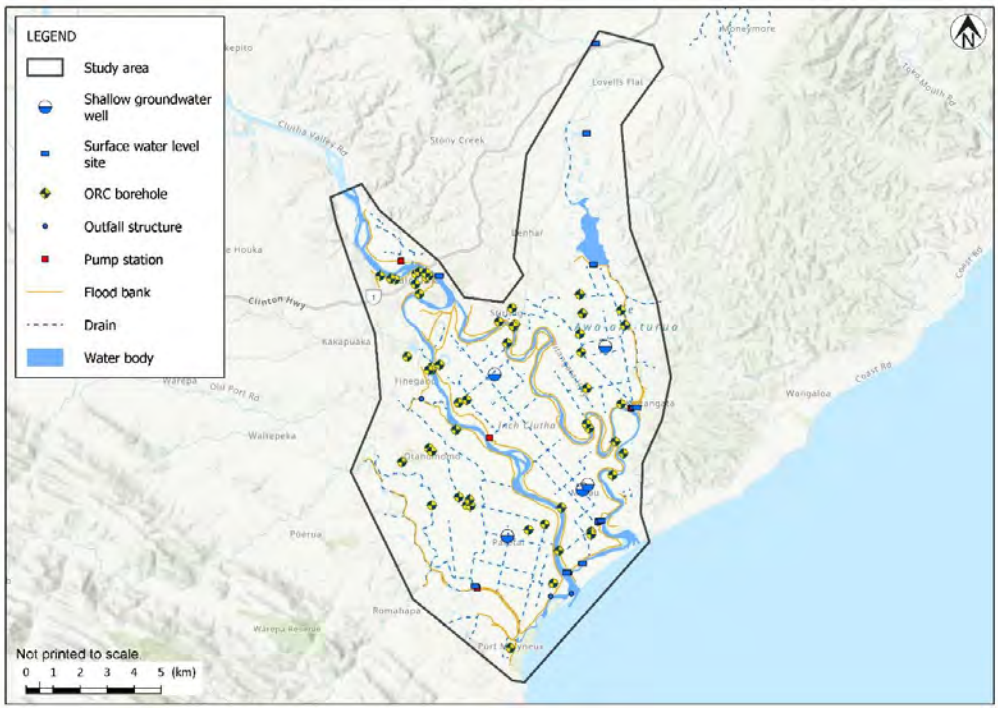


Figure 3.8: Surface groundwater level sites and mapped drains and flood banks in the Clutha Delta. Refer to Appendix A for a larger map.

3.2.5 Seismic hazard

Soils that are susceptible to liquefaction require a sufficient level of ground shaking—both in intensity and duration—to initiate liquefaction. The level of seismic shaking used in a liquefaction assessment is typically selected based on return period events relevant to the performance objectives of the project (e.g. serviceability or ultimate limit states).

Several information sources were reviewed to characterise the seismic hazard for the Study Area:

- New Zealand Transport Agency (2018). Bridge Manual.
- NZGS/MBIE (2021). Earthquake Geotechnical Engineering Practice Series – Module 1: Overview of the Guidelines.
- Barrell, D.J.A. (2021). General Distribution and Characteristics of Active Faults and Folds in the Clutha and Dunedin City Districts, Otago. GNS Science Consultancy Report 2020/88.
- GNS Science (2023). New Zealand Active Faults Database, 1:250,000 scale https://data.gns.cri.nz/af/.
- ORC – Otago Active Faults and Folds, ORC Natural Hazards Earthquakes Otago Active Faults and Folds.
- New Zealand National Seismic Hazard Model (NSHM) – 2022 update (GNS Science).

Ground motion parameters for Balclutha Township, sourced from Module 1 (NZGS/MBIE, 2021), are provided in Table 3.7. These parameters give an indication of expected Peak Ground Accelerations (PGA) and Moment Magnitudes (M) for different return period events and are considered representative for the Study Area. For the broad-scale nature of this Level A/B assessment, the regional variation in seismic hazard across the Clutha Delta is not considered significant enough to warrant distinct hazard parameters for every sub-area. The estimated ground motion parameters generally align with values from the 2022 National Seismic Hazard Model (NSHM) for a NZS 1170.5 Class D (Deep Soil) site classification, which typically corresponds to an average shear wave velocity (Vs30) in the range of 180 to 360 m/s (assumed 200 m/s). The NSHM incorporates updated seismic source modelling and ground motion predictions across New Zealand.

Table 3.7: Ground motion parameters adopted for this study (sourced from MBIE/NZGS 2021 Module 1 for Balclutha), compared to 2022 NSHM estimates (in square brackets)

Return period					
25-year (SLS[1])		100-year		500-year (ULS[2])	
PGA (g)	M	PGA (g)	M	PGA (g)	M
0.06 *[0.05]*[3]	6.0	0.11 *[0.13]*[3]	6.0	0.23 *[0.27]*[3]	6.0

1 SLS: Serviceable limit state event for Importance Level 2 buildings (refer to NZS 1170:2004).

2 ULS: Ultimate limit state event for Importance Level 2 buildings (refer to NZS 1170:2004).

3 2022 NSHM ground motion parameters for centre of the study area assuming Vs30 of 200 m/s.

3.2.6 Historical observations of liquefaction

There are no known historical records of liquefaction occurring within the Study Area. This conclusion is based on a review by Bastin et al. (2021)[6]. No other recent scientific publications were identified that provide evidence of historical liquefaction within the Clutha District. This does not mean that liquefaction has not occurred, simply that there is no historical evidence.

[6] Bastin, S.H., van Ballegooy, S., & Ogden, M. (2021). The past is key to the future: Collating historical cases of liquefaction to supplement liquefaction hazard assessments. In Proceedings of the 21st New Zealand Geotechnical Society Symposium.

While no major earthquake has struck the Clutha Delta in recorded history, the area has experienced strong shaking from distant large events (such as the 2009 Mw 7.8 Fiordland earthquake) and local earthquakes (notably the 1974 Mw 5.0 Dunedin event), with geological evidence indicating that nearby faults, including the Akatore and Settlement faults, have generated powerful prehistoric earthquakes (approximately Mw 7+) capable of significantly impacting the region.

3.3 Uncertainty assessment

This section presents an assessment of the uncertainty associated with the base information available for the Study Area. The key outcome from this is the determination of the level of detail that can be supported by the available information.

In accordance with the MBIE/MfE Guidance (2017), uncertainty can be managed by assigning broader or less precise liquefaction vulnerability categories in areas where residual uncertainty remains high. This section also highlights where specific steps have been taken to reduce or manage key sources of uncertainty.

3.3.1 Ground surface levels

Uncertainty due to accuracy and limitations of the LiDAR-derived DEM

The 1.0 m resolution LiDAR-derived digital elevation model (DEM) is considered fit for the purposes of this assessment. However, typical limitations of LiDAR surveys should be acknowledged, including:

- Measurement error associated with the LiDAR point cloud collection method.
- Localised error due to interpolation in areas with low point density.
- Limitations in spatial resolution when representing fine-scale elevation variation.

In general, these limitations are expected to have a minor influence on the representation of ground surface features relevant to liquefaction. However, specific applications—such as identifying free-face heights near water bodies—are more sensitive to these limitations. ORC has made available bathymetric data for the section of the Clutha River immediately around Balclutha which enables a more accurate estimate of free-face heights, leading to improved prediction of lateral-spreading severity.

Uncertainty due to temporal changes in ground surface elevation

Ground surfaces are subject to change due to natural processes (e.g. tectonic uplift, erosion, or earthquake-induced deformation) and anthropogenic activity (e.g. land development, earthworks, flood protection infrastructure). These changes introduce temporal uncertainty that cannot be precisely accounted for in a static dataset. Future studies should consider the most current topographic datasets and the proposed finished landform in areas subject to significant change. It is also noted that the current estimated rate of vertical land movement[7] at the coast is small and therefore not likely to introduce additional uncertainty.

3.3.2 Geology and geomorphology

Uncertainty due to mapping precision and terrain boundary accuracy

As discussed in Section 3.2.2, geological and geomorphic boundaries are based on maps with a typical scale of 1:250,000. At this scale, there is inherent uncertainty in the exact position of terrain boundaries. This has been accounted for in the liquefaction vulnerability classification by introducing zones where adjacent landform types differ in susceptibility (e.g. areas classified as ***Liquefaction Category is Undetermined*** between ***Liquefaction Damage is Unlikely*** and ***Liquefaction Damage is Possible***).

Uncertainty due to anthropogenic landform modification

Landform changes due to drainage, river realignment, stopbanks, or development may not be reflected in existing maps. In the Clutha Delta, extensive historical river engineering has altered natural channels and depositional environments. These modifications can affect the current soil

[7] https://www.searise.nz/maps-2

profile and local susceptibility to liquefaction, introducing uncertainty when interpreting historical mapping in these areas.

3.3.3 Geotechnical investigations

Uncertainty due to variability within geomorphic terrains

The Clutha Delta is characterised by complex depositional environments, leading to significant variability in subsurface conditions. This includes interbedded layers and discontinuous lenses of sands, silts, and clays with varying densities and consistencies, even within the same geomorphic terrain.

For a Level A (basic desktop) assessment, this inherent subsurface variability means that broad assumptions about liquefaction susceptibility based on geomorphology carry a high degree of uncertainty. Without very dense subsurface investigations, it is not possible to confidently delineate specific zones or assign more precise liquefaction vulnerability categories (e.g. 'Very Low' or 'Low') beyond ***Liquefaction Damage is Unlikely*** or ***Liquefaction Damage is Possible***.

For a Level B (calibrated desktop) assessment, as undertaken in Balclutha, while additional geotechnical investigations provide calibration points, the spatial density of these investigations is still insufficient to fully capture all localised variations in these heterogeneous soils. This limits the ability to confidently assign more precise vulnerability categories (e.g. Medium or High Liquefaction Vulnerability) or to more accurately delineate smaller areas of distinct liquefaction performance across the entire township.

Uncertainty due to data quality

Geotechnical data quality varies depending on the investigation method, execution, and reporting. Known sources of uncertainty include:

- Interpretation limitations from predrilled CPTs or post-ground improvement testing.
- Logging errors or ambiguous borehole descriptions.
- Missing or partial records (e.g. PDF-only logs without digital data).

A significant portion of this uncertainty has been addressed by selecting a reputable contractor (Geotechnics Ltd) to carry out the additional CPT investigations completed for this project. The contractor's established methodologies and quality control processes help ensure consistency and reliability in the data collected.

Where legacy data was of uncertain quality or unverifiable, engineering judgement was applied to assess its suitability for use in the liquefaction assessment.

3.3.4 Groundwater

Uncertainty due to spatial data coverage

While several groundwater measurements are available, the data is spatially sparse. The majority of data points are individual observations taken during drilling, with limited continuous monitoring coverage. This makes interpolation of groundwater depth across the Study Area uncertain, particularly in areas distant from known data points.

Uncertainty due to climate change impacts

Long-term changes to the groundwater regime may result from climate change effects. Potential impacts include:

- Altered recharge patterns due to changes in rainfall intensity and distribution.

- Sea level rise, which may lead to higher groundwater tables in low-lying coastal areas.

These changes could increase the depth or duration of soil saturation in the future, potentially influencing liquefaction vulnerability over long planning horizons.

3.3.5 Seismic hazard

Uncertainty due to variability in earthquake shaking scenarios

Liquefaction triggering depends on both the intensity and duration of ground shaking. While this assessment uses representative peak ground accelerations (PGAs) based on standard return periods (as per MBIE/NZGS guidance), the actual shaking experienced at a site during a future earthquake may differ due to:

- Site-specific amplification effects.
- Variability in earthquake source characteristics (e.g. rupture direction, depth, distance).
- Limitations in the resolution of the National Seismic Hazard Model (NSHM) for local-scale applications.

Uncertainty introduced by unmapped or unknown faults

An additional source of uncertainty arises from the presence of unmapped or poorly characterised faults. While the 2022 NSHM includes known active faults and distributed seismicity, it cannot fully capture the hazard posed by faults that have not yet been identified or whose behaviour is not well understood. This residual uncertainty may result in underestimation of localised seismic hazard in some parts of the Study Area.

Uncertainty in selecting representative seismic parameters

The return period ground motions used in this assessment were selected to represent serviceability and ultimate limit state performance levels. These are standard inputs but remain subject to both epistemic (model) and aleatory (random) uncertainties inherent in seismic hazard modelling.

3.3.6 Assess ground damage response against performance criteria

The MBIE/MfE Guidance (2017) provides performance criteria for determining the liquefaction vulnerability category of land, reproduced in Figure 3.9.

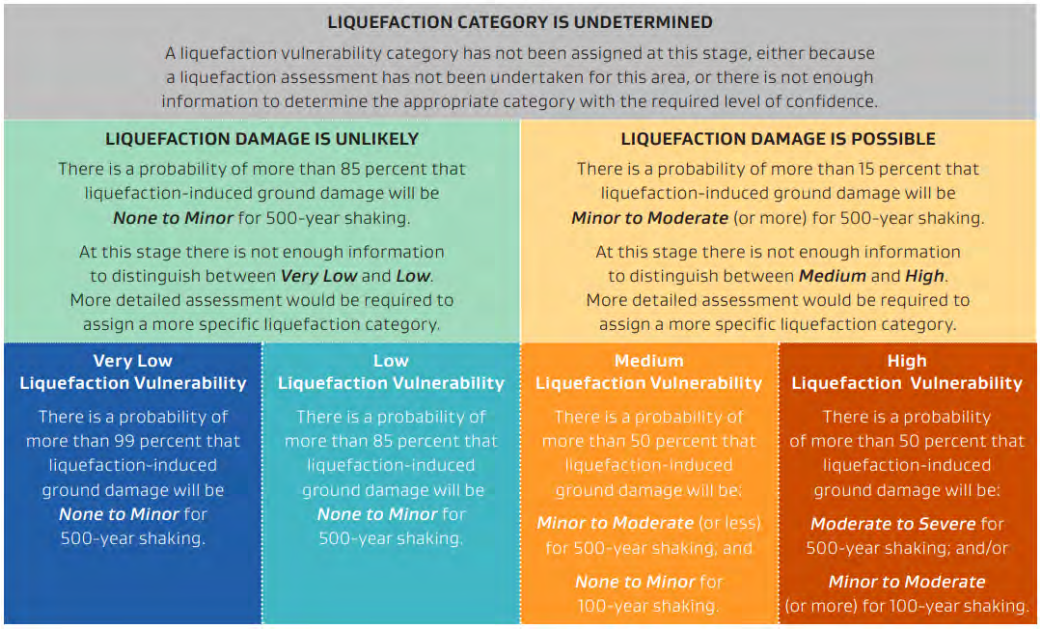


Figure 3.9: Performance criteria for determining the liquefaction vulnerability category – reproduced from MBIE/MfE Guidance (2017).

These criteria are expressed in terms of the expected severity of ground damage during future earthquakes, based on available information about the site's susceptibility to liquefaction. The MBIE/MfE Guidance (2017) includes indicative probabilities of damage occurring at various levels of severity. These probabilities are not intended to serve as fixed numerical thresholds to be calculated, but rather as a qualitative guide to the level of confidence required to assign a given vulnerability category.

It is also important to note that these probabilities relate to the cumulative effect of all uncertainties within the assessment. As a result, direct probabilistic calculation is rarely feasible, and judgement must be applied when assigning categories—particularly in desktop-level assessments such as this one.

In this study, the expected ground performance within each area has been assessed against the MBIE/MfE Guidance (2017) performance criteria using a combination of:

- Geotechnical investigation results (where available)
- Soil type and geomorphic unit
- Groundwater depth
- Proximity to free faces or sloping ground
- Estimated earthquake shaking levels

The level of confidence in assigning each vulnerability category has been evaluated qualitatively, with the indicative probabilities from the guidance used to support this process. As with any

assessment, expert judgement is required to weigh the available evidence and determine the most appropriate categorisation for each area.

Where significant uncertainty remains—either due to limited data, conflicting information, or high natural variability—a less precise category has been assigned. In some locations, the ***Liquefaction Damage is Undetermined*** category has been applied to reflect insufficient confidence in the available information to support a more specific classification.

This approach is consistent with MBIE/MfE Guidance (2017) and ensures that the vulnerability assessment remains fit-for-purpose for informing land use planning and development decisions.

3.4 Level of detail achieved in this assessment

As shown in Figure 3.10, a Level A (basic desktop assessment) has been achieved across the majority of the Study Area. This was driven by the spatially sparse geotechnical data across much of the Clutha Delta, as illustrated in Figure 3.7. Extending a calibrated desktop assessment across such a large area would not have sufficiently reduced residual uncertainty to meet the objectives of a Level B assessment as defined in the MBIE/MfE Guidance (2017).

A Level B (calibrated desktop assessment) has been achieved in the township of Balclutha, where additional geotechnical investigations have reduced residual uncertainty to a level consistent with the requirements of the MBIE/MfE Guidance (2017). While the density of investigations in Balclutha approaches the indicative spatial densities that might support a Level C assessment, the scope and intended outcome of this study for Balclutha remained a calibrated desktop assessment. The analysis performed aimed to provide a more confident understanding of the general liquefaction vulnerability of the township at a broad scale, rather than the precise quantitative delineation of damage categories across every property that would be characteristic of a full Level C assessment. This is reflected in the assignment of a broad ***Liquefaction Damage is Possible*** category for the township, as discussed in Section 4.5.6, rather than a finer breakdown into Medium or High vulnerability.

In contrast, although Kaitangata was initially identified as a target area for Level B assessment, the available data was insufficient to meet the criteria for this higher level of detail. As a result, the assessment in Kaitangata has been undertaken at Level A. This achieved level of detail across the Study Area reflects the current availability, spatial density, and quality of base information, as discussed in Section 3.3.

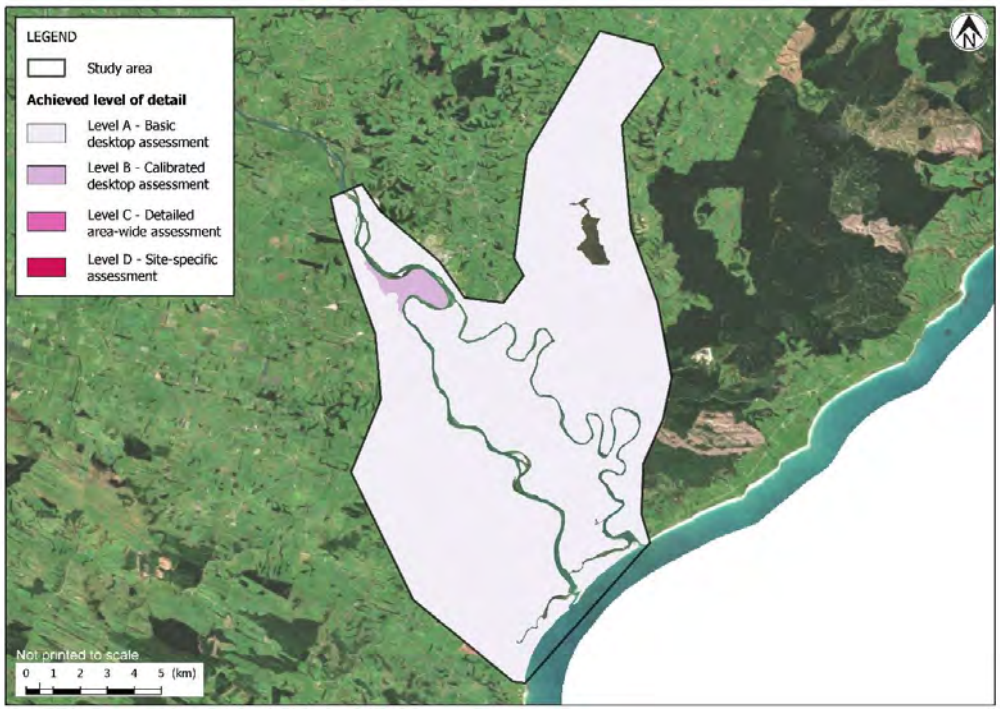


Figure 3.10: Achieved level of detail in this assessment (Level A and Level B).

4 Risk analysis

This section outlines how the base information has been analysed to categorise the liquefaction vulnerability of land within the Study Area. The key tasks in this process include:

- Selecting groundwater levels to support the analysis.
- Selecting earthquake scenarios to support the analysis.
- Delineating sub-areas of similar expected performance.
- Evaluating the expected degree of liquefaction-induced ground damage.
- Assessing liquefaction vulnerability against MBIE/MfE performance criteria.

Each task is discussed in further detail below.

4.1 Groundwater levels for analysis

As described in Section 3.2.4, groundwater data within the Study Area is spatially limited, with most measurements comprising single observations. Due to the limited coverage and the generally flat topography, representative groundwater depths have been assumed for each geomorphic terrain. These assumptions were developed using engineering judgement and are presented in Table 4.1, along with a qualitative assessment of potential climate change effects. It is noted that groundwater levels are highly dependent on rainfall patterns which will also be affected by climate change. These changes are much harder to estimate.

Table 4.1: Assumed groundwater depths and potential influence of climate change

Geomorphic terrain	Elevation summary 5th, 50th, 95th percentile (mRL)	Assumed depth to groundwater (m)	Potential influence of climate change on groundwater
Alluvial fans	0.8, **3.6**, 14.7	0 – 3	Likely to become shallower due to proximity to the coast.
Holocene river plains	0.1, **1.1**, 7.2	0 – 2	Likely to become shallower due to proximity to the coast.
Older river terraces	1.4, **7.0**, 20.6	> 5	Limited influence expected.
Older marine terraces	1.5, **27.6**, 34.4	> 5	Limited influence expected.
Hills, ranges and mountains	5.5, **24.1**, 34.4	> 5	Only lower-elevation valleys may be affected; high ground unaffected.

Notes:

1. Elevation summary calculated from the 2020 LiDAR survey of the Clutha Delta. See Section 3.2.1.

4.2 Earthquake scenarios for analysis

The 500-year return period earthquake scenario is the recommended minimum for Level A and B assessments, as outlined in MBIE/MfE Guidance (2017). For this study, the 500-year scenario was used as the primary basis for evaluating liquefaction vulnerability, as the associated ground motions exceed the threshold required to trigger liquefaction in most susceptible soils.

Additional earthquake scenarios, including 25-year and 100-year events, were also considered to provide a broader understanding of potential liquefaction response across varying levels of seismic shaking.

4.3 Liquefaction vulnerability assessment

A comprehensive suite of liquefaction analyses was undertaken for each CPT profile using a range of groundwater depths (GWD) and peak ground accelerations (PGA). The input ranges used were:

- GWD: 0.1 m increments from 0.1 to 3.0 m
- PGA: 0.05 g increments from 0.0 to 0.6 g, plus discrete return period cases from Table 3.7

The Boulanger and Idriss (2014) simplified method was applied using the following parameters:

- Moment magnitude (Mw): 6 (representative of return period events considered)
- Probability of liquefaction (P_L): 15% (in line with industry practice for geotechnical design)
- Depth of analysis: 10 m (this depth is considered to encompass the most critical layers contributing to liquefaction-induced damage at the ground surface, such as settlement and ejecta, which are of primary concern for typical shallow foundations and infrastructure performance). Adopting this depth cutoff also helps manage differences in termination depth between CPTs (e.g. if a 20 m analysis depth was adopted, then CPTs which were shorter than this would need to be corrected to account for potentially liquefiable soils below the termination depth).

Computed liquefaction parameters included:

- Cumulative Thickness of Liquefaction (CTL)[8]
- One-dimensional Volumetric Settlement (Sv1D)[9]
- Liquefaction Severity Number (LSN)[10]

These parameters were used comparatively to assess spatial patterns and sensitivity across inputs.

For a terrain to be classified as ***Liquefaction Damage is Unlikely*** under the MBIE/MfE Guidance (2017), it is required to meet the performance criteria of 'a probability of more than 85 percent that liquefaction-induced ground damage will be None to Minor for 500-year shaking'. Quantitatively, this has been interpreted for this study to mean that less than 15% of the terrain area exhibits damage exceeding minor – specifically, where calculated Sv1D <15 mm and LSN <5 for 85% of the terrain area. Additionally, this classification can be applied to terrains which have a sufficient groundwater depth, defined as >8 m for Holocene deposits and >4 m for Pleistocene deposits, as specifically outlined in Table 4.3 of the MBIE/MfE Guidance (2017).

In addition, a threshold of 50 mm for Sv1D was considered to assist in identifying areas with the potential for moderate to severe volumetric settlement.

4.4 Sub areas of similar expected performance

Sub-areas of similar expected liquefaction performance were delineated based on the following features:

- **Geomorphology**: Provided the primary basis for delineating expected soil behaviour (Section 3.2.2) – emphasis on the Holocene river plains.
- **Broad delta position**: General position within the Clutha Delta and with respect to the various branches of the Clutha river.

[8] CTL represents the total thickness of soil layers predicted to liquefy during a seismic event.
[9] Sv1D relates to the vertical settlement resulting from the densification of liquefied soil layers as they reconsolidate post-earthquake.
[10] LSN is an index used to quantify the severity of liquefaction-induced ground damage based on the cumulative effects of excess pore water pressure and soil resistance over a subsoil profile.

The sub areas in this assessment are presented in Figure 4.1 and represent geographically distinct zones where a combination of geology, geomorphic features, and anticipated soil and groundwater conditions lead broadly to comparable seismic response and liquefaction vulnerability.

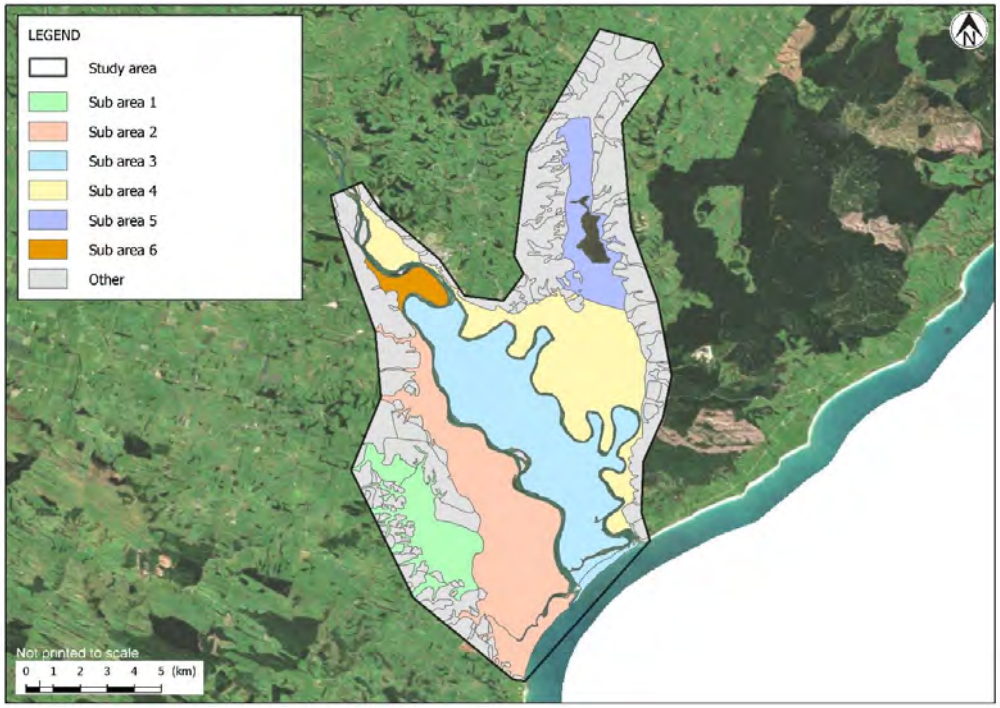


Figure 4.1: Sub-areas of similar expected performance.

4.5 Liquefaction vulnerability assessed against performance criteria

4.5.1 Assigned liquefaction vulnerability categories

Using the available information, the liquefaction vulnerability of each geomorphic terrain has been assessed against the performance criteria. Each terrain is then assigned one of the corresponding liquefaction vulnerability categories shown in Figure 4.2. The resulting liquefaction vulnerability map of the Study Area is shown in Figure 4.3 and Appendix B. Subsequent sections (4.5.2 – 4.5.6) provide discussion on how each of the vulnerability categories were determined.

A polyline categorised as ***Liquefaction Category is Undetermined*** is used between any areas of ***Liquefaction Damage is Unlikely*** and ***Liquefaction Damage is Possible***. This polyline represents the residual uncertainty from the geomorphic mapping and should be interpreted with a width of 50 m.

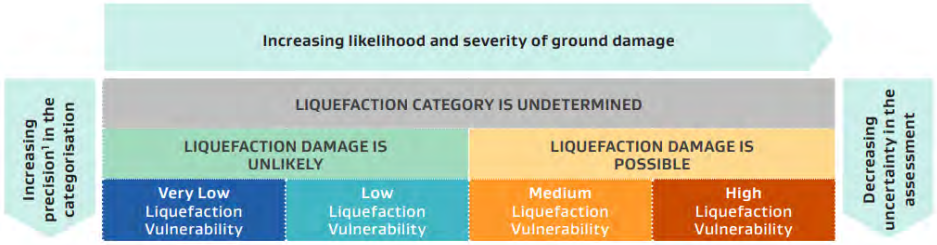


Figure 4.2: Recommended liquefaction vulnerability categories – from MBIE/MfE Guidance (2017).

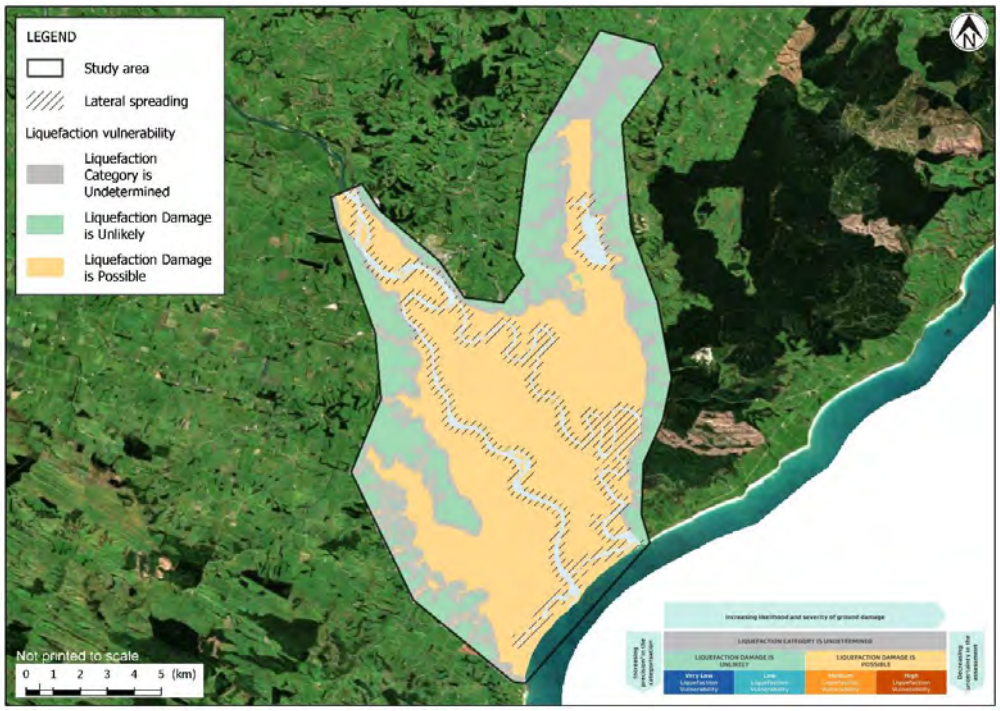


Figure 4.3: Liquefaction vulnerability classification assessed against performance criteria. Refer to Appendix B for a larger map.

4.5.2 Alluvial fans

While the geologic context suggests that alluvial fans are likely to have deeper groundwater and plastic, fine-grained soils that are generally less susceptible to liquefaction, there is limited geotechnical investigation data available to confirm these conditions. Due to this uncertainty, the liquefaction vulnerability of this terrain has been classified as ***Liquefaction Category is Undetermined***.

4.5.3 Older marine and river terraces

The older marine and river terraces typically consist of dense, well-consolidated Pleistocene-aged soils with a groundwater table deeper than 5 m. The combination of soil age, density, and elevation suggests a low likelihood of liquefaction.

In accordance with MBIE/MfE Guidance (2017), specifically Table 4.3, Pleistocene-aged soils can be classified as ***Liquefaction Damage is Unlikely*** if the 500-year PGA is less than 0.3 g (magnitude 7.5 equivalent), or if seasonal higher groundwater levels are deeper than 4 m below ground. For the Study Area, the 500-year PGA of 0.23 g at magnitude 6.0 is equivalent to a PGA of 0.16 g at magnitude 7.5. This satisfies the PGA < 0.3 g criterion by a substantial margin.

While site-specific groundwater measurements are not available for this terrain, the general topographic setting and regional groundwater models indicate that groundwater levels are likely to be deeper than 4m. This criterion is not relied upon to determine the liquefaction vulnerability categorisation, however it provides a degree of reassurance that the categorisation is reasonable.

Based on these characteristics and in accordance with MBIE/MfE Guidance (2017), these terrains have been classified as ***Liquefaction Damage is Unlikely***.

4.5.4 Hills, ranges and mountains

This terrain is characterised by dissected hills, gullies, and elevated ridgelines underlain primarily by Eastern Province basement rock and residual soils. In most locations, the soils are typically not susceptible to liquefaction due to plasticity and consolidation, and the groundwater depth is generally > 5 m.

However, in minor valleys and incised gullies, the presence of younger alluvial deposits and variable groundwater conditions introduces uncertainty (comparable to the alluvial fans discussed in Section 4.5.2).

- Minor valleys: Due to limited data and uncertainty in soil susceptibility and groundwater, these areas are classified as ***Liquefaction Category is Undetermined***.
- Elevated areas: Based on engineering judgement and MBIE/MfE Guidance (2017), these areas are classified as ***Liquefaction Damage is Unlikely***.

4.5.5 Holocene river plains

Holocene river plains are composed of loose, young alluvial sediments, typically deposited in low-energy environments. These soils range from non-plastic sands and silts to plastic clays and are known to include liquefaction-susceptible layers. The depth to groundwater is generally shallow (< 3 m), and the terrain is often adjacent to active or historic river channels/drains.

The analysis of the CPT information to support the liquefaction vulnerability categorisation is summarised in Figure 4.4. The comparison of performance expected across the different sub areas within the Holocene river plains is captured in Figure 4.5. Based on engineering judgement, the analysis of geotechnical information, and the MBIE/MfE Guidance (2017), the Holocene river plains have been classified as ***Liquefaction Damage is Possible.***

Section 4.4.3 of the MBIE/MfE Guidance (2017) recommends that particular attention should be given to the potential for lateral spreading where liquefiable soils are located within 200 m of free faces more than 2 m high (marked with hatched areas in Figure 4.3). The current assessment does not specifically capture all free faces across the study area. Lateral spreading might still be possible outside of the hatched area in Figure 4.3, especially with the free faces which are created by numerous drains across the Clutha Delta. The 200 m buffer has been used as a preliminary screen to identify the most obvious areas where particular attention should be given to the potential for lateral spreading to occur. As part of future development activities or more detailed hazard assessments, site-specific assessment should be undertaken to identify any relevant free faces and assess the lateral spreading hazard.

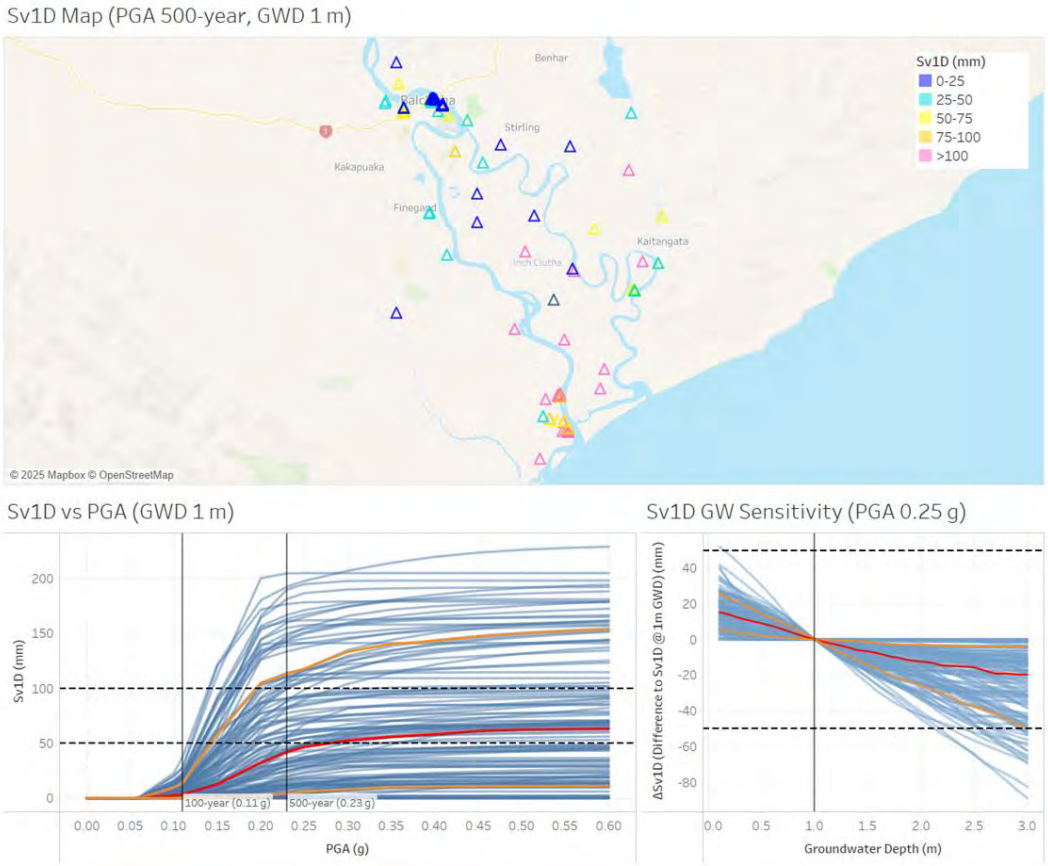


Figure 4.4: Liquefaction vulnerability assessment for Holocene river plains. The figure has 3 components – The top map plots Sv1D (mm) results for a 500-year seismic and 1 m GWD case. The bottom left figure shows the Sv1D (mm) vs PGA response curve for 1 m GWD, with 15th, 50th, and 85th percentile trends identified. The bottom right figure shows the change in Sv1D vs groundwater depth for 0.25 g seismic event, relative to a GWD of 1 m, also with 15th, 50th, and 85th percentile trends identified.

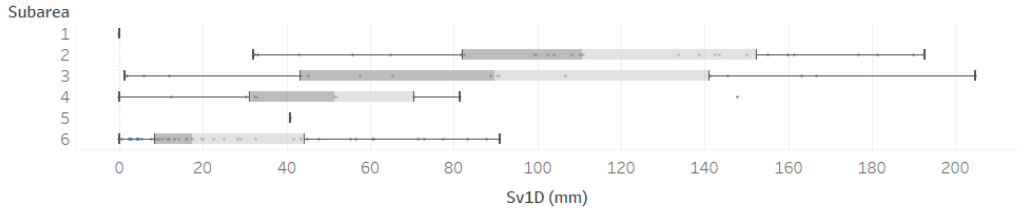


Figure 4.5: Comparison of Sv1D by sub area, for a 500-year seismic and 1 m GWD case. Refer to Figure 4.1 for definition of the sub areas. Note that sub area 1 and 5 only have 1 CPT each and therefore do not support statistical analysis. For the other regions, box and whisker plots show the range of Sv1D (mm) values – the box limits are 25th and 75th percentiles and the boundary between dark and light grey is the 50th percentile.

4.5.6 Balclutha township

A more detailed analysis was undertaken for Balclutha township (subarea 6) given the higher level of detail achieved (as outlined in Section 3.4). Figure 4.6 shows the results of the analysis – there are a significant number of CPTs showing Sv1D > 15 mm at 500-year shaking levels. With no obvious spatial trend that would support further delineation into smaller areas of similar performance, the subarea was categorised as ***Liquefaction Damage is Possible,*** consistent with the other areas of the Holocene river plains.

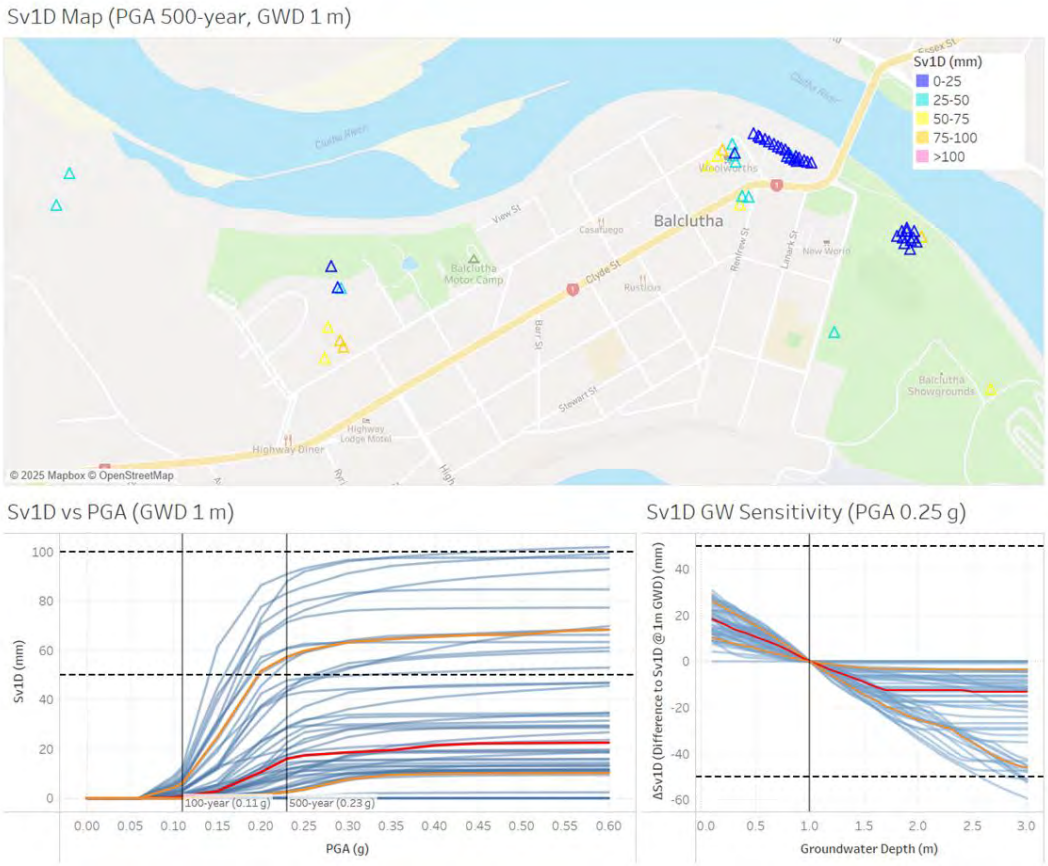


Figure 4.6: Liquefaction vulnerability assessment for Balclutha (subarea 6). The figure has 3 components – The top map plots Sv1D (mm) results for a 500-year seismic and 1 m GWD case. The bottom left figure shows the Sv1D (mm) vs PGA response curve for 1 m GWD, with 15th, 50th, and 85th percentile trends identified. The bottom right figure shows the change in Sv1D vs groundwater depth for 0.25 g seismic event, referenced to a GWD of 1 m, also with 15th, 50th, and 85th percentile trends identified.

5 Discussion and recommendations

Tonkin & Taylor Ltd (T+T) has completed a liquefaction vulnerability assessment of the Clutha Delta in accordance with the MBIE/MfE Guidance (2017). This included a **Level A – Basic Desktop Assessment** across the wider Study Area and a **Level B – Calibrated Desktop Assessment** within the Balclutha township, where additional geotechnical and groundwater information was available to support a higher level of detail.

Based on the results of this assessment, the following conclusions and recommendations are made:

- The land within the Study Area has been classified into one of three liquefaction vulnerability categories:
  - ***Liquefaction Damage is Unlikely***
  - ***Liquefaction Damage is Possible***
  - ***Liquefaction Category is Undetermined***

The classification reflects the spatial variability of ground conditions, groundwater depths, and the degree of uncertainty in each area. The currently available information does not support the use of the more detailed vulnerability categories defined in the MBIE/MfE Guidance (i.e. Very Low, Low, Medium, or High). This is consistent with the expected outcomes of a regional-scale assessment undertaken at Level A or B.

- The liquefaction mapping outputs provide a district-wide base layer that can inform land use planning, infrastructure development, and natural hazard management. These outputs are expected to assist with Resource Consent and Building Consent processes by identifying areas where liquefaction may need to be considered further.
- In most cases, particularly for more sensitive developments or those located in areas classified as ***Liquefaction Damage is Possible*** or ***Liquefaction Category is Undetermined***, additional site-specific investigations will be required to support planning or consenting outcomes. These investigations should be undertaken in accordance with MBIE/MfE Guidance (2017) and the Earthquake Geotechnical Engineering Practice Series, progressing to Level C or D where appropriate.
- The liquefaction classification does not address other geotechnical or natural hazards that may affect land development, such as slope instability, erosion, or flooding. These hazards should be assessed separately as part of future site-specific studies.

5.1 Application to planning and consenting

The liquefaction vulnerability maps produced in this study provide a valuable initial screening tool for land use planning, subdivision, and building consent processes. It is important to reiterate that due to the Level A/B nature of this assessment, the maps are not intended to provide a definitive site-specific assessment of liquefaction hazard for individual properties. Instead, they serve to:

- Inform strategic planning – Guide regional and district councils in long-term strategic land use planning and the development of natural hazard management processes.
- Trigger further investigations – Identify areas where potential liquefaction hazards warrant more detailed, site-specific geotechnical investigations (Level C or Level D assessments). This is particularly critical for proposed building foundations and more sensitive developments within areas classified as ***Liquefaction Damage is Possible*** or ***Liquefaction Category is Undetermined***.
- Streamline consenting – Facilitate the initial stages of Resource Consent and Building Consent applications by clearly indicating the likely requirement for further geotechnical assessment.

This aligns with the hierarchical approach outlined in the MBIE/MfE Guidance (2017) and aims to ensure appropriate consideration of liquefaction risk at all stages of development.

6 Applicability

This report has been prepared for the exclusive use of our client Otago Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Recommendations and opinions in this report are based on data from individual geotechnical investigation locations. The nature and continuity of subsoil away from these locations are inferred and it must be appreciated that the actual conditions could vary from the assumed model.

This assessment has been made at a broad scale across the defined Study Area and is intended to describe the typical range of liquefaction vulnerability across areas of similar ground conditions in an approximate way only. It is not intended to precisely describe liquefaction vulnerability at individual property scale. This information is general in nature, and more detailed site-specific liquefaction assessment may be required for some purposes (e.g., for design of building foundations).

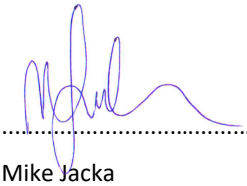
Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:

.....

Matt Ogden
Data Scientist – Geotechnical

Reviewed by:



.....

Mike Jacka
Technical Director – Earthquake Geotechnical Engineering

Authorised for Tonkin & Taylor Ltd by:

.....

James Russell
Project Director

MLO
t:\tauranga\projects\1093960\issueddocuments\2025-03-30 draft report\orc_cluthadeltaliquefactionvulnerabilitystudy_draft_30-apr-2025.docx

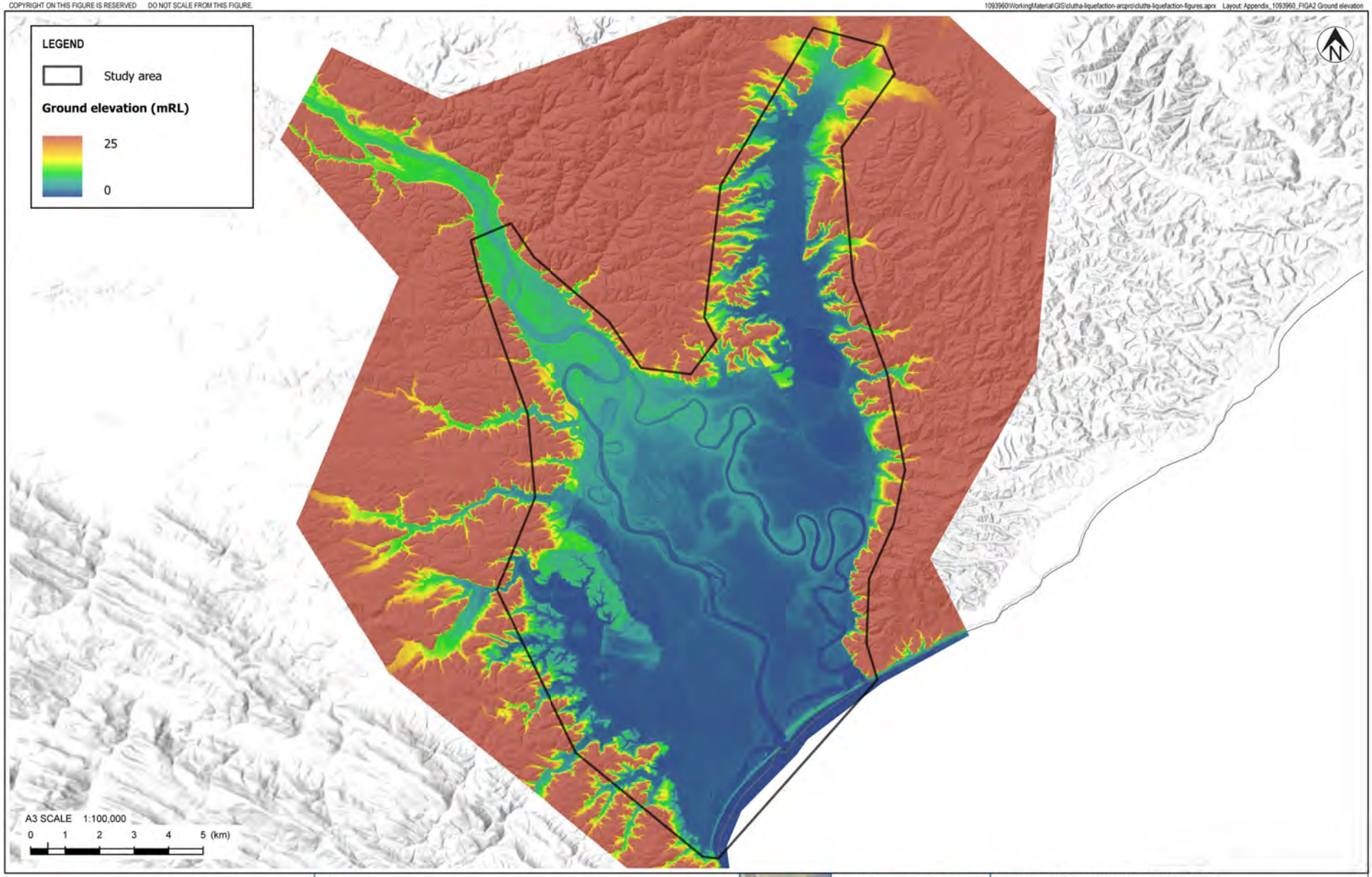
Appendix A Risk identification maps

- **Figure A1 – Target level of detail**
- **Figure A2 – Ground surface elevation**
- **Figure A3 – Geology**
- **Figure A4 – Geomorphology**
- **Figure A5 – Geotechnical investigations**
- **Figure A6 – CPT investigation density**
- **Figure A7 – Groundwater information**
- **Figure A8 – Achieved level of detail**

COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.
1093960\Working Material\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGA1 Level of detail target
LEGEND
Study area
Target level of detail
Level A - Basic desktop assessment
Level B - Calibrated desktop assessment
Level C - Detailed area-wide assessment
Level D - Site-specific assessment
Balclutha
Kaitangata
A3 SCALE 1:100,000
0 1 2 3 4 5 (km)
Tonkin+Taylor
Exceptional thinking together www.tonkintaylor.co.nz
NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.
REV DESCRIPTION GIS CHK DATE
1.0 First version MLO ANDO 19/06/25
LOCATION PLAN
PROJECT No. 1093960.0000
DESIGNED MLO JUN.25
DRAWN MLO JUN.25
CHECKED ANDO JUN.25
APPROVED DATE
CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE TARGET LEVEL OF DETAIL IN THE LIQUEFACTION ASSESSMENT
SCALE (A3) 1:100,000 FIG No. FIGURE A1 REV 1.0

COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.

1093960\WorkingMaterial\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGA2 Ground elevation



Tonkin+Taylor

Exceptional thinking together www.tonkintaylor.co.nz

NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.

REV	DESCRIPTION	GIS	CHK	DATE
1.0	First version	MLO	ANDO	19/06/25

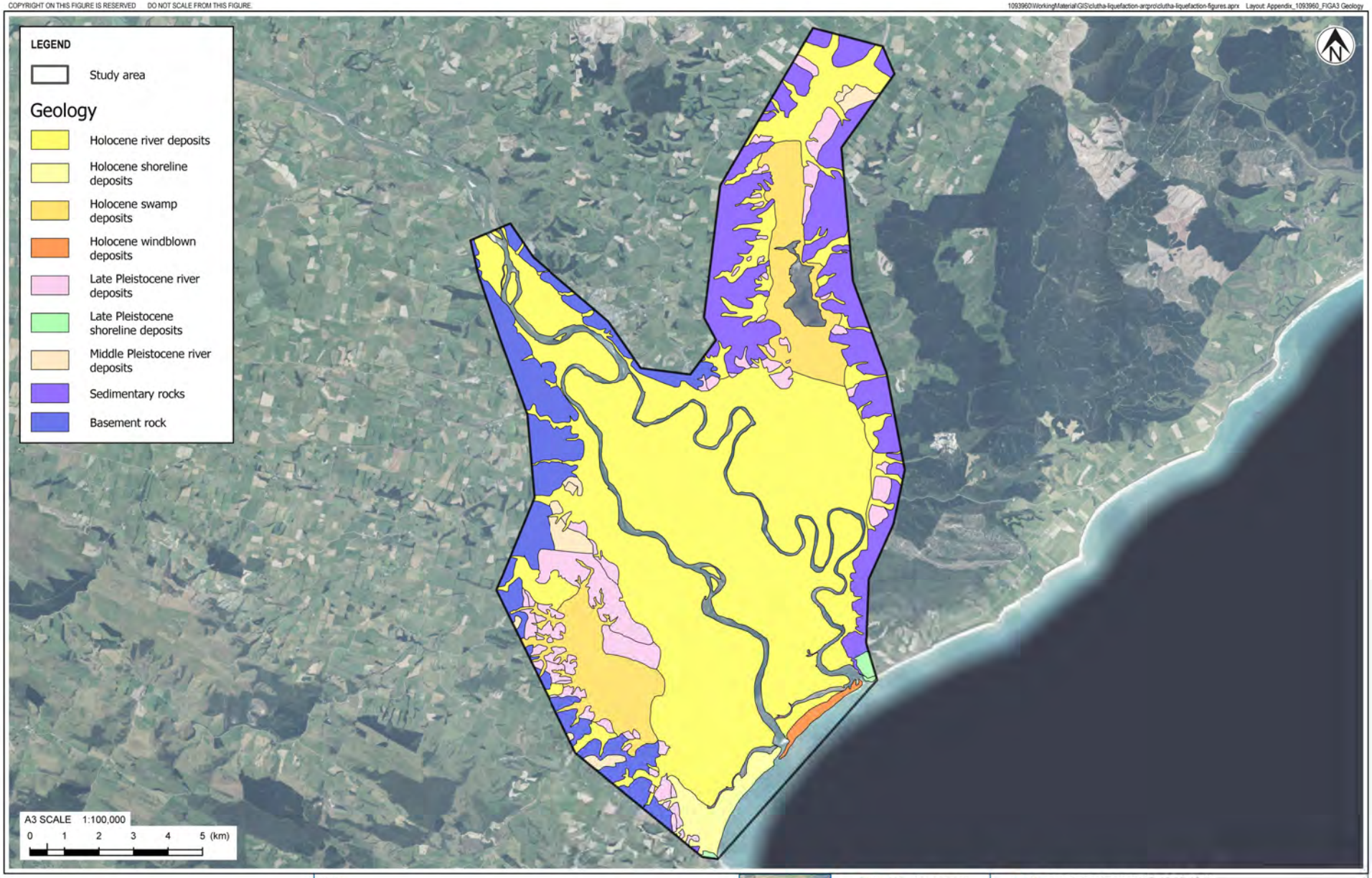
LOCATION PLAN

PROJECT No.	1016765.000		
DESIGNED	MLO	JUN.25	
DRAWN	MLO	JUN.25	
CHECKED	ANDO	JUN.25	
APPROVED		DATE	

CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE GROUND SURFACE ELEVATION
SCALE (A3) 1:100,000 FIG No. FIGURE A2 REV 1.0

COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.

1093960\Working\Material\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGA3 Geology



Tonkin+Taylor

Exceptional thinking together www.tonkintaylor.co.nz

NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.

REV	DESCRIPTION	GIS	CHK	DATE
1.0	First version	MLO	ANDO	19/06/25

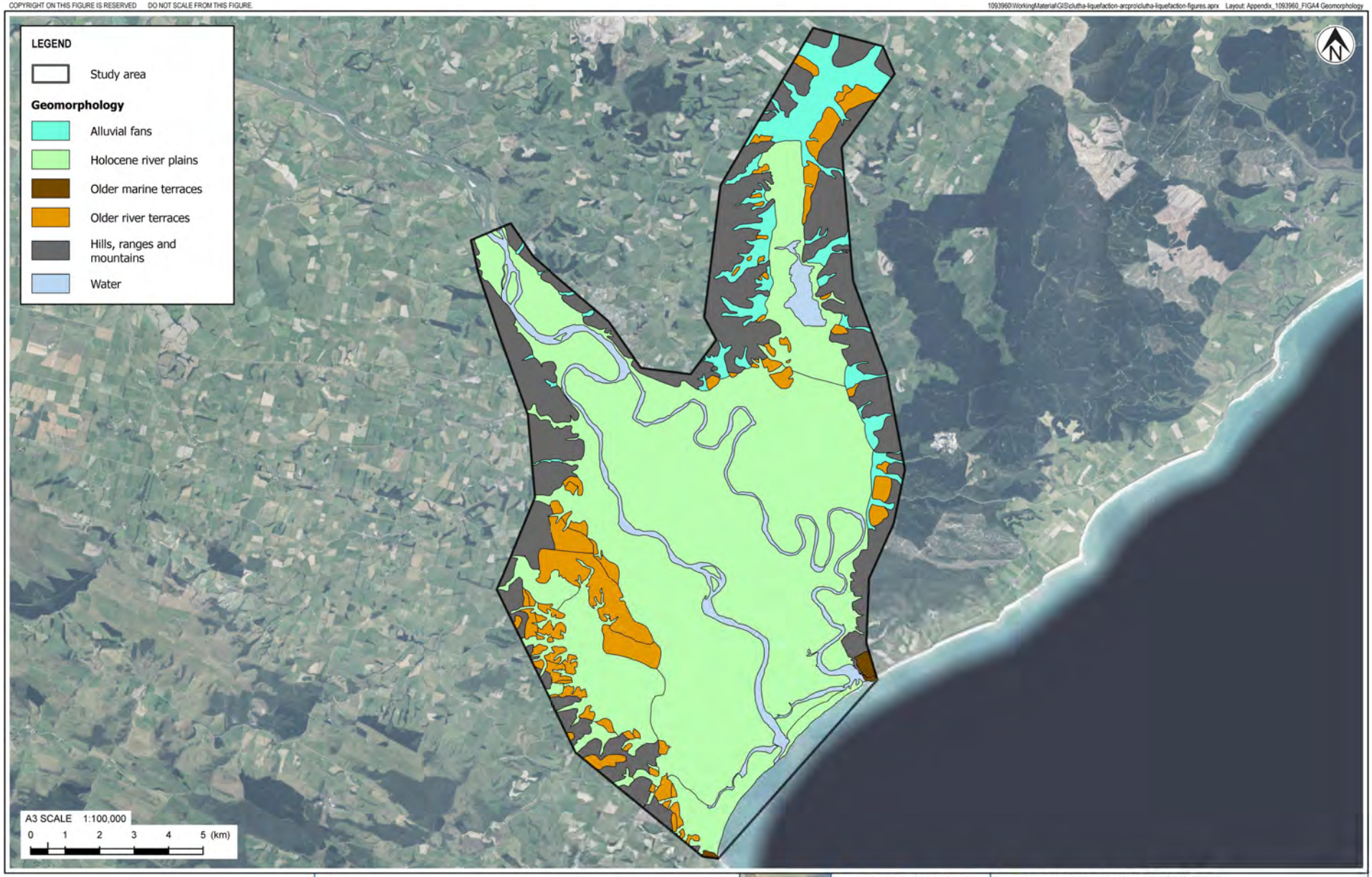
LOCATION PLAN

PROJECT No.	1093960.0000		
DESIGNED	MLO	JUN.25	
DRAWN	MLO	JUN.25	
CHECKED	ANDO	JUN.25	
APPROVED		DATE	

CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE GEOLOGY
SCALE (A3) 1:100,000 FIG No. FIGURE A3 REV 1.0

COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.

1093960\Working\Material\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGA4 Geomorphology



Tonkin+Taylor
Exceptional thinking together www.tonkintaylor.co.nz

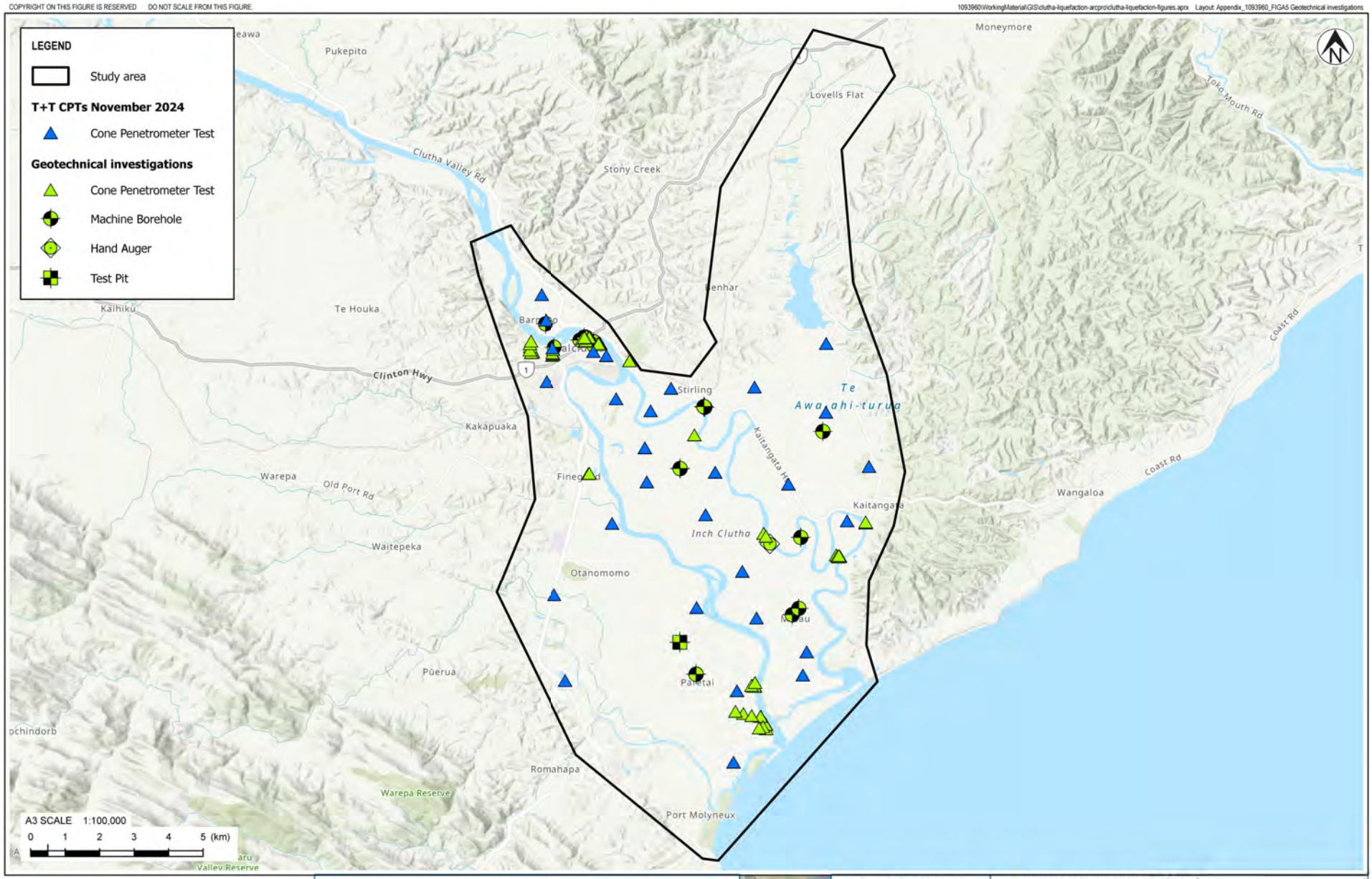
NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.

REV	DESCRIPTION	GIS	CHK	DATE
1.0	First version	MLO	ANDO	19/06/25

LOCATION PLAN

PROJECT No.	1093960.0000		
DESIGNED	MLO	JUN.25	
DRAWN	MLO	JUN.25	
CHECKED	ANDO	JUN.25	
APPROVED		DATE	

CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE GEOMORPHOLOGY
SCALE (A3) 1:100,000 FIG No. FIGURE A4 REV 1.0



Tonkin+Taylor

Exceptional thinking together www.tonkintaylor.co.nz

NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.

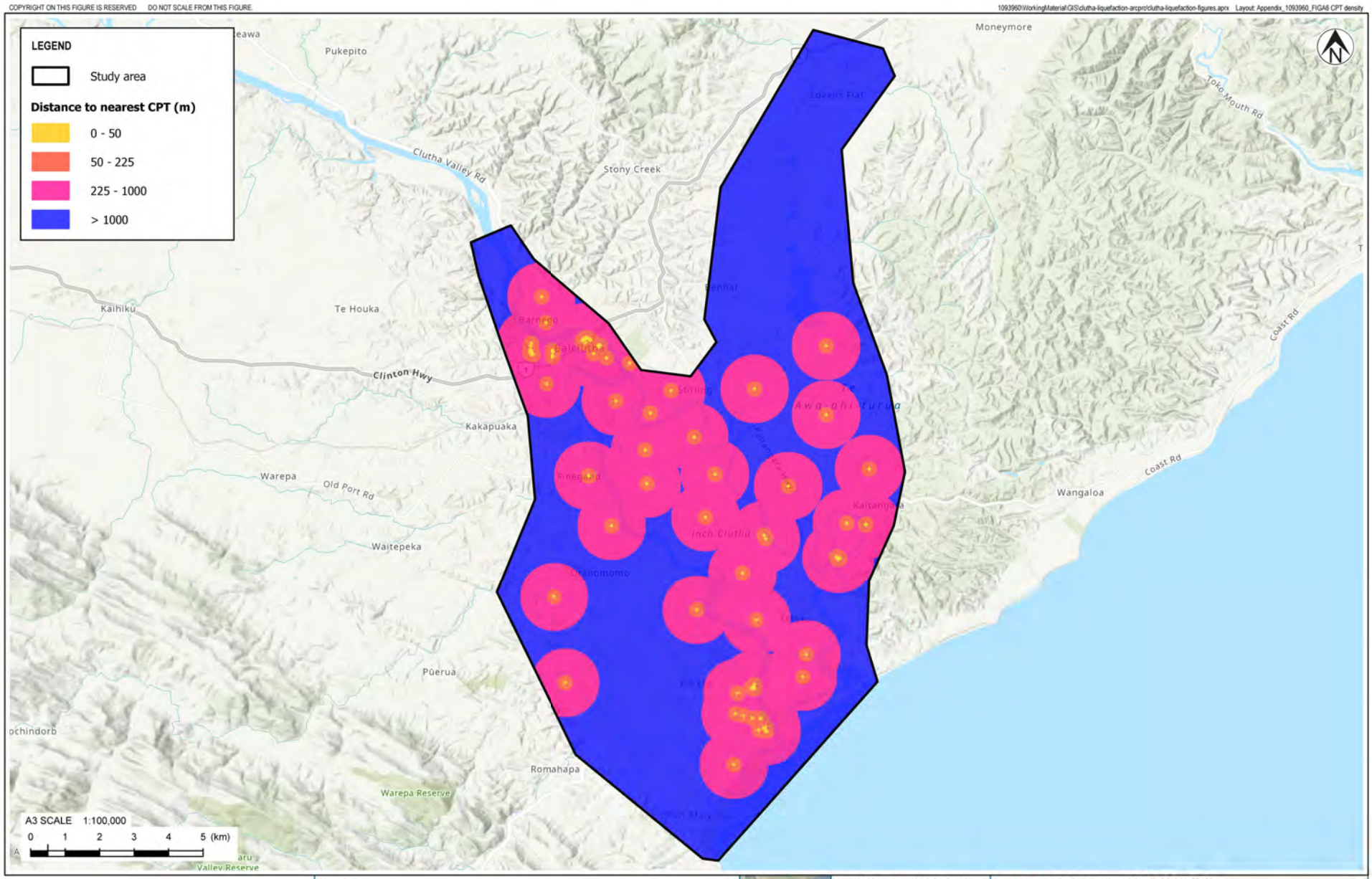
REV	DESCRIPTION	GIS	CHK	DATE
1.0	First version	MLO	ANDO	19/06/25

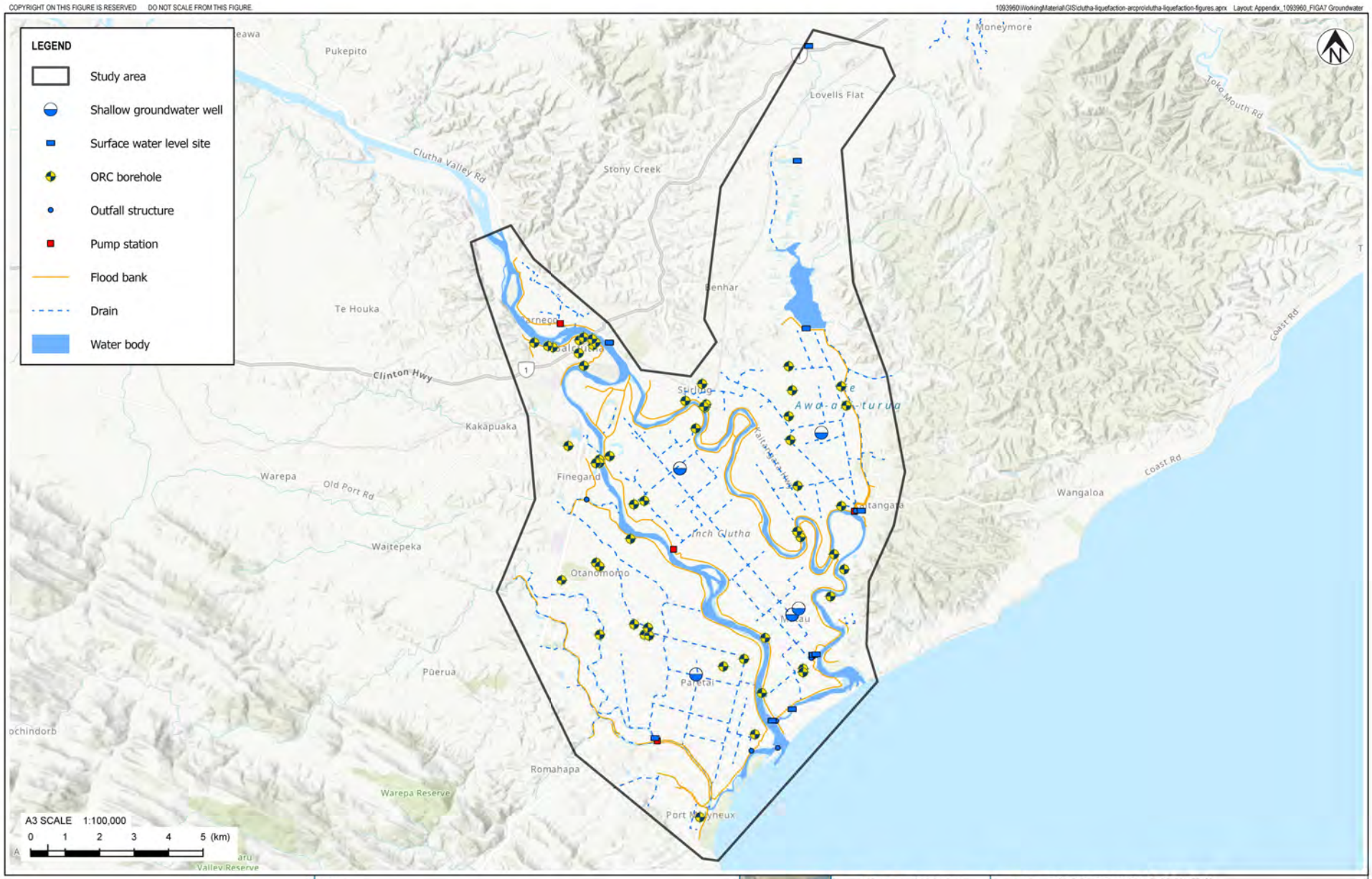
LOCATION PLAN

			APPROVED	DATE
DESIGNED	MLO	JUN.25		
DRAWN	MLO	JUN.25		
CHECKED	ANDO	JUN.25		

PROJECT No. 1093960.0000

CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE GEOTECHNICAL INVESTIGATIONS AVAILABLE ON NZGD WITHIN STUDY AREA
SCALE (A3) 1:100,000 FIG No. FIGURE A5 REV 0


COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.
1093960\WorkingMaterial\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGA6 CPT density
LEGEND
Study area
Distance to nearest CPT (m)
0 - 50
50 - 225
225 - 1000
> 1000
Moneymore
Pukepito
Toko Mouth Rd
Clutha Valley Rd
Stony Creek
Kaihiku
Te Houka
Clinton Hwy
Kakapuaka
Warepa
Old Port Rd
Waitepeka
Wangaloa
Coast Rd
Pūerua
Romahapa
Warepa Reserve
A3 SCALE 1:100,000
0 1 2 3 4 5 (km)
Tonkin+Taylor
Exceptional thinking together
www.tonkintaylor.co.nz
NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.
REV DESCRIPTION GIS CHK DATE
1.0 First version MLO ANDO 19/06/25
LOCATION PLAN
PROJECT No. 1093960.0000
DESIGNED MLO JUN.25
DRAWN MLO JUN.25
CHECKED ANDO JUN.25
APPROVED DATE
CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE CPT INVESTIGATION DENSITY
SCALE (A3) 1:100,000 FIG No. FIGURE A6 REV 0


COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.
1093960\Working\Material\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGA7 Groundwater
LEGEND
Study area
Shallow groundwater well
Surface water level site
ORC borehole
Outfall structure
Pump station
Flood bank
Drain
Water body
Pukepito
Moneymore
Lovells Flat
Toko Mouth Rd
Clutha Valley Rd
Stony Creek
Benhar
Te Houka
Clinton Hwy
Coast Rd
Kakapuaka
Warepa
Old Port Rd
Finegand
Wangaloa
Inch Clutha
Waitepeka
Otanomomo
Pūerua
Paretai
Romahapa
Warepa Reserve
Port Molyneux
A3 SCALE 1:100,000
0 1 2 3 4 5 (km)
Tonkin+Taylor
Exceptional thinking together
www.tonkintaylor.co.nz
NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.
REV DESCRIPTION GIS CHK DATE
1.0 First version MLO ANDO 19/06/25
LOCATION PLAN
PROJECT No. 1093960.0000
DESIGNED MLO JUN.25
DRAWN MLO JUN.25
CHECKED ANDO JUN.25
APPROVED DATE
CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE GROUNDWATER INFORMATION
SCALE (A3) 1:100,000 FIG No. FIGURE A7 REV 0.1

COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.

1093960\Working\Material\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGA8 Level of detail achieved

Tonkin+Taylor

Exceptional thinking together www.tonkintaylor.co.nz

NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.

REV	DESCRIPTION	GIS	CHK	DATE
1.0	First version	MLO	ANDO	19/06/25

LOCATION PLAN

PROJECT No.	1093960.0000		
DESIGNED	MLO	JUN.25	
DRAWN	MLO	JUN.25	
CHECKED	ANDO	JUN.25	
APPROVED		DATE	

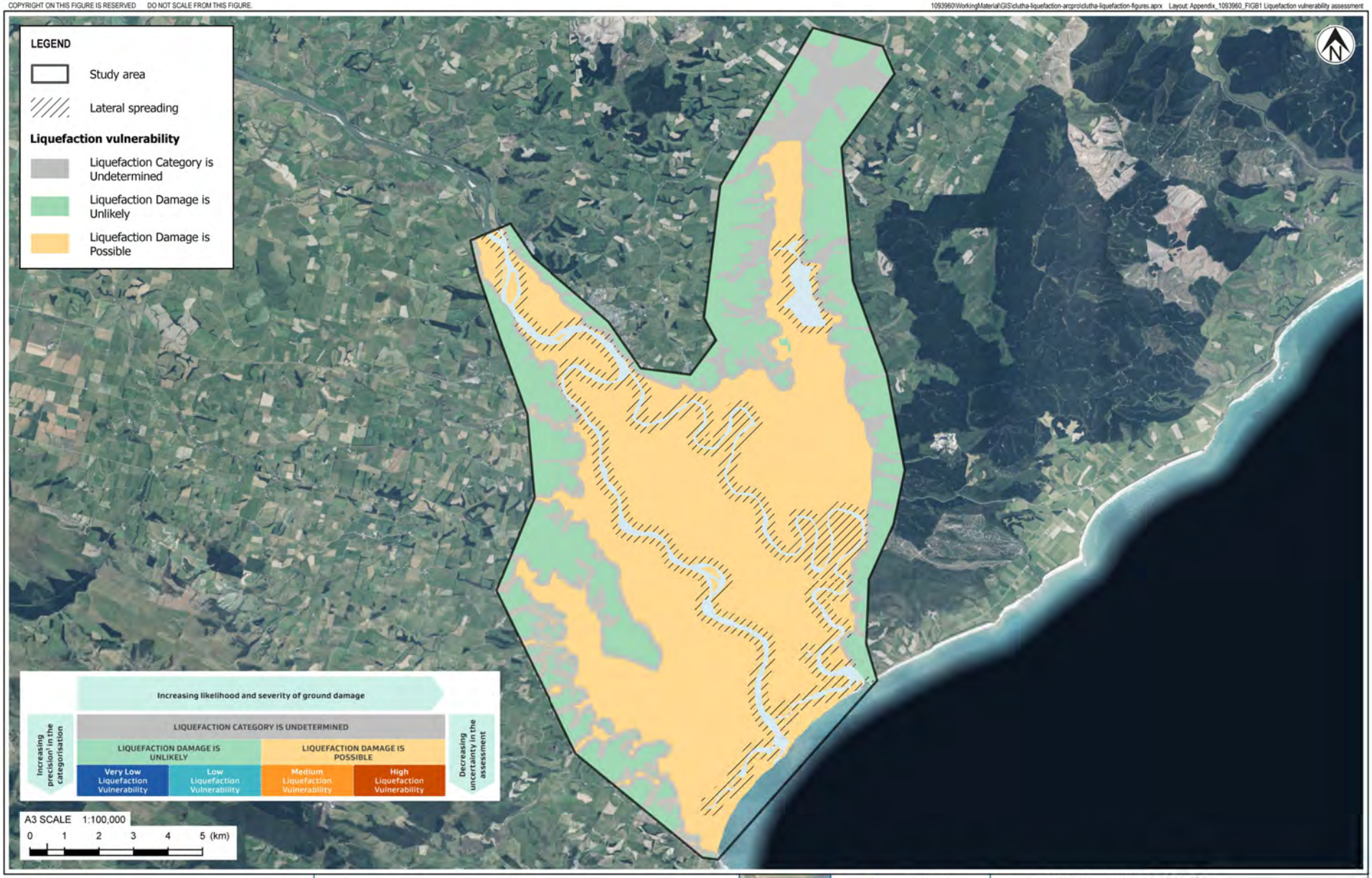
CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE ACHIEVED LEVEL OF DETAIL IN THE LIQUEFACTION ASSESSMENT
SCALE (A3) 1:100,000 FIG No. FIGURE A8 REV 1.0

Appendix B Risk analysis maps

- **Figure B1 – Liquefaction vulnerability categories for Study Area**

COPYRIGHT ON THIS FIGURE IS RESERVED DO NOT SCALE FROM THIS FIGURE.

1093960\Working\Material\GIS\clutha-liquefaction-arcpro\clutha-liquefaction-figures.aprx Layout: Appendix_1093960_FIGB1 Liquefaction vulnerability assessment



Tonkin+Taylor

Exceptional thinking together www.tonkintaylor.co.nz

NOTES:
This map is part of the report "Clutha Delta Liquefaction Vulnerability Study" prepared by T+T for ORC in 2025.
Refer to the report for further detail and applicability limitations.
Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.

REV	DESCRIPTION	GIS	CHK	DATE
1.0	First version	MLO	ANDO	19/06/25

LOCATION PLAN

			APPROVED	DATE
PROJECT No.	1093960.0000			
DESIGNED	MLO	JUN.25		
DRAWN	MLO	JUN.25		
CHECKED	ANDO	JUN.25		

CLIENT OTAGO REGIONAL COUNCIL
PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE LIQUEFACTION VULNERABILITY CATEGORIES
SCALE (A3) 1:100,000 FIG No. FIGURE B1 REV 1.0

www.tonkintaylor.co.nz

REPORT

Tonkin+Taylor

Clutha Delta Qualitative Risk Assessment (Seismic)

Prepared for
Otago Regional Council
Prepared by
Tonkin & Taylor Ltd
Date
August 2025
Job Number
1093960 v1.0

Together we create and sustain a better world
www.tonkintaylor.co.nz

Document control

Title: Clutha Delta Qualitative Risk Assessment (Seismic)					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
23/07/2025	0.1	Draft for Client and Peer Review	M Waugh & M Ogden	J Russell	J Russell
20/08/2025	1.0	Final	M Waugh & M Ogden	J Russell	J Russell

Distribution:

Otago Regional Council	1 PDF copy
Tonkin & Taylor Ltd (FILE)	1 PDF copy

Table of contents

1 Introduction 1

2 Methodology 3

2.1 RPS 3

2.1.1 Likelihood 3

2.1.2 Consequence 3

2.1.3 Risk 7

2.2 Seismic hazards 7

2.2.1 Seismic shaking 8

2.2.2 Liquefaction (co-seismic) 9

2.2.3 Lateral spreading (co-seismic) 10

2.2.4 Surface rupture 10

2.2.5 Hazard scenarios 10

2.3 Context & supporting information 11

3 Risk analysis 13

3.1 Consequence summary 13

3.2 Risk summary 17

3.3 Cascading risks 19

3.4 Discussion 21

4 Conclusions and next steps 22

5 References 23

6 Applicability 24

Appendix A Workshop Minutes

Appendix B Risk Register

Appendix C Asset Figures

1 Introduction

Otago Regional Council (ORC) engaged Tonkin & Taylor Ltd (T+T) to undertake a systematic Qualitative Risk Assessment (QRA) for seismic and co-seismic hazards within the Clutha Delta. It is understood that the purpose of this QRA study is to provide insight to guide future decision-making and to support emergency management planning. At this stage, there is no specific development plan for the QRA to inform.

This QRA follows on from the Clutha Delta Liquefaction Vulnerability Study (T+T report, June 2025) and utilises the liquefaction vulnerability and lateral spreading mapping established as part of this study. The findings from both the liquefaction vulnerability study and this QRA are anticipated to be of value to a range of stakeholders which include:

- Landowners and residents, to inform them of the potential risks posed by seismic and co-seismic hazards.
- The Clutha Delta natural hazards adaptation programme, particularly to inform assessments of seismic risks.
- The ORC Engineering team, as a high-level assessment of potential seismic and co-seismic impacts on ORC's scheme infrastructure, and the potential cascading impacts on the performance of the Lower Clutha Drainage and Flood Protection Scheme.
- The Clutha District Council (CDC), to build their awareness of the potential hazard and identify areas where this hazard may need to be considered more closely in building consent processes and infrastructure management.
- Emergency Management Otago, to build their understanding of potential event consequences for a major earthquake.

The Study Area for both the liquefaction vulnerability assessment and this QRA aligns with the boundary defined in Figure 1.1, which includes the townships of Balclutha and Kaitangata.

This report includes:

- An overview of the Proposed Regional Policy Statement (RPS) methodology for natural hazard risk assessment (Otago Regional Council, 2021) which was applied for the QRA (Section 2), including:
  - Definitions.
  - Assessment parameters.
  - Hazards.
  - Matters for consideration
- Risk analysis (Section 3), including:
  - Summary of the consequences.
  - Summary of the risk register and outputs from the assessment.
  - Discussion of cascading risks.
- Conclusions and next steps (Section 3.4).

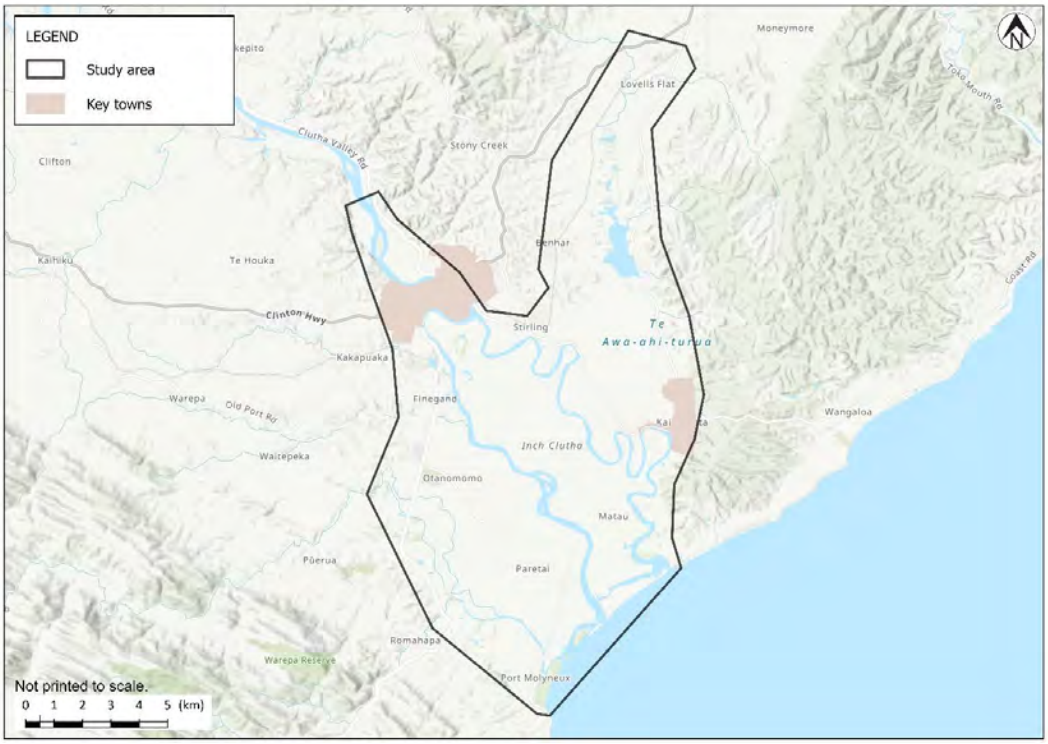


Figure 1.1: Map showing the extent of the Study Area and the townships of Balclutha and Kaitangata.

2 Methodology

The methodology is divided into three key sections:

- Proposed Regional Policy Statement (RPS) (Otago Regional Council, 2021) – natural hazard risk assessment framework.
- Seismic and co-seismic hazards – hazards for inclusion within the assessment.
- Context & supporting information – local context and other information used in the assessment.

2.1 RPS

The methodology and risk framework for this assessment is derived from the ORC RPS for natural hazard risk (Appendix 6). Risk is defined by combining hazard likelihood and consequence, in alignment with the ISO 31000:2018 approach to assessing risk (Figure 2.1).

Figure 2.1: Risk equation (Otago Regional Policy Statement, 2019).

2.1.1 Likelihood

Likelihood is defined as the probability of a natural hazard event occurring and is rated on a five-point scale (Table 2.1). As per the RPS methodology, three natural hazard scenarios representing a high likelihood, median likelihood, and maximum credible event need to be considered within the assessment. This limits the likelihood ratings to a three-point scale. In consultation with ORC, the likely, possible, and rare scenarios were selected for this assessment.

Table 2.1: Likelihood definitions

Likelihood	Indicative frequency
Almost certain	Up to once every 50 years (~2% AEP)
Likely	Once every 51 - 100 years (2 -1% AEP)
Possible	Once every 101 - 1,000 years (1 - 0.11% AEP)
Unlikely	Once every 1,001 - 2,500 years (0.1 - 0.04% AEP)
Rare	2,501 years plus (<0.04% AEP)

2.1.2 Consequence

Consequence in the context of this assessment refers to the impacts on human life (health and safety), property, infrastructure, and the environment from a given natural hazard. It is rated on a five-point scale and is broken into two main categories: built environment, and health and safety (Table 2.2). The built environment requires assessment of buildings and lifelines. Health and safety requires assessment of the number of fatalities and injuries. These are discussed in the following sections.

Table 2.2: Consequence definitions (reproduced from Table 7of the RPS) (Otago Regional Council, 2021)

Severity of Impact	Built				Health & Safety
	Social/Cultural	Buildings	Critical buildings	Lifelines	
Catastrophic (V)	≥25% of buildings of social/cultural significance within hazard impact area have functionality compromised	≥50% of buildings within hazard impact area have functionality compromised	≥25% of critical facilities within hazard impact area have functionality compromised	Out of service for > 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for > 6 months (affecting < 20% of the town/city population)	> 10 dead and/or > 1001 injured
Major (IV)	11-24% of buildings of social/cultural significance within hazard impact area have functionality compromised	21-49% of buildings within hazard impact area have functionality compromised	11-24% of critical facilities within hazard impact area have functionality compromised	Out of service for 1 week – 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for 6 weeks to 6 months (affecting < 20% of the town/city population)	1 – 10 dead and/or 101 – 1000 injured
Moderate (III)	6-10% of buildings of social/cultural significance within hazard impact area have functionality compromised	11-20% of buildings within hazard impact area have functionality compromised	6-10% of critical facilities within hazard impact area have functionality compromised	Out of service for 1 day to 1 week (affecting ≥20% of the town/city population) OR suburbs out of service for 1 week to 6 weeks (affecting < 20% of the town/city population)	11 – 100 injured
Minor (II)	1-5% of buildings of social/cultural significance within hazard impact area have functionality compromised	2-10% of buildings within hazard impact area have functionality compromised	1-5% of critical facilities within hazard impact area have functionality compromised	Out of service for 2 hours to 1 day (affecting ≥20% of the town/city population) OR suburbs out of service for 1 day to 1 week (affecting < 20% of the town/city population	10 injured
Insignificant (I)	No buildings of social/cultural significance within hazard impact area have functionality compromised	<1% of buildings within hazard impact area have functionality compromised	No damage within hazard impact area, fully functional	Out of service for up to 2 hours (affecting ≥20% of the town/city population) OR suburbs out of service for up to 1 day (affecting < 20% of the town/city population	No dead No injured

2.1.2.1 Buildings

To assign a consequence level for damage to buildings, the number of "functionally compromised" buildings need to be assessed. The ORC RPS does not define functionally compromised, therefore we have developed criteria drawing on published information.

The Bay of Plenty Regional Council RPS defines functionally compromised as: "…*the building cannot continue to be used for its intended use immediately after the event*." The actual criteria by which functionally compromised is assessed differs depending on the hazard type. For seismic hazards a functionally compromised building is synonymous with the definition of "loss of amenity" as defined by the MBIE guidance document "repairing and rebuilding houses affected by the Canterbury earthquakes" (MBIE, 2018). One of the key performance measures in the definition of loss of amenity is the concept of "readily repairable". The MBIE guidance document defines this as "…repairable without relocation of occupants for more than four weeks…" (refer to Section 8.2.3 and Table 8.1 of the MBIE (2018) guidance document).

Based on this, the following criteria have been developed for considering the proportion of buildings that are functionally compromised:

- The building cannot continue to be used for its intended use immediately after the event; and/or
- The building is not repairable without relocation of its occupants for more than four weeks.

In consultation with ORC, critical and social/cultural buildings were assessed together under the category of "critical buildings". This is because:

- There are relatively few social/cultural buildings in the Study Area.
- Those buildings often had a dual purpose as critical and social cultural buildings.
- The consequence criteria for critical and social/cultural buildings are identical.

2.1.2.2 Lifelines

To assign a consequence level for damage to lifelines infrastructure, the outage duration, and proportion of people affected needed to be considered. The level of service and proportion of community served for each lifeline utility was not provided/available for the assessment, therefore a qualitative approach was taken. The following factors were considered when applying a consequence rating to lifeline infrastructure:

- Exposure of the asset – where the assets were located in terms of mapped liquefaction vulnerability categories, proximity to rivers, and proximity to known mapped faults.
- Vulnerability of the asset – factors that influence how severe the damage may be e.g., location of critical equipment within substations, pipe fittings being a point of failure etc.
- Availability of resources for response/restoration – the population size, location, and access to the Study Area influenced the outage time.
- Network performance/connectivity – most lifeline utilities are network based, so the connectivity between key asset types was considered in terms of outage duration.

2.1.2.3 Health and safety

The key factors for assessing consequence to health and safety were number of injuries and fatalities. This was assessed qualitatively, with the following considerations:

- Population of the Study Area – population of the key townships were taken from StatsNZ, noting that this does increase in summer months due to tourism on the Pacific Coast Highway.
- Building construction (age, material, no. of storeys etc.) – building construction type, discussed during the scoping workshop, alongside the HAZUS building fragility functions were considered when applying the consequence rating (FEMA, 2020).
- Vulnerability of the population – key vulnerability factors as discussed during the scoping workshop were considered when applying the consequence rating.

2.1.2.4 Matters for consideration

The ORC RPS also recommends the following matters be considered during the consequence assessment:

> (1) the nature and scale of activities in the area,
>
> (2) individual and community vulnerability and *resilience*,
>
> (3) impacts on individual and community health and safety,
>
> (4) impacts on social, cultural and economic well-being,
>
> (5) impacts on *infrastructure* and property, including access and services,
>
> (6) available and viable *risk* reduction and hazard mitigation measures,
>
> (7) *lifeline utilities*, essential and emergency services, and their co-dependence,
>
> (8) implications for civil defence agencies and emergency services,
>
> (9) the changing *natural hazard* environment,
>
> (10) cumulative *effects* including *multiple* and *cascading hazards,* where present, and
>
> (11) factors that may exacerbate a *natural hazard* event including the *effects* of *climate change*.

These matters were discussed and documented during the scoping workshop with ORC and Civil Defence and Emergency Management (CDEM) staff (5 June 2025). A summary of that discussion is provided in Section 2.3 with further detail provided in the workshop minutes in Appendix A. They were then considered by T+T while undertaking the consequence assessment.

2.1.2.5 Consequence logic

Due to the inter-related nature of the co-seismic hazards, when assessing and rating consequences, the base case of seismic shaking was considered first. Liquefaction, lateral spreading, and fault rupture were then sequentially considered in that order, with each step evaluating whether the additional hazard materially altered the consequence for the asset as follows:

- If the additional hazard materially altered the consequence, the consequence level was increased.
- If the additional hazard did not materially alter the consequence, the consequence level remained the same.

2.1.3 Risk

Risk is defined by the combination of likelihood and consequence and is rated on a three-point scale: acceptable, tolerable, or significant (Table 2.3). Due to the use of three likelihood scenarios (likely, possible, and rare), only a sub-set of the risk framework is applied only to the rows outlined in blue in Table 2.3.

Table 2.3: Risk framework

	Consequence				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain					
Likely					
Possible					
Unlikely					
Rare					
Green = Acceptable Risk, **Yellow** = Tolerable Risk, **Red** = Significant Risk					

2.2 Seismic hazards

The Study Area is subject to a range of natural hazards which include seismic events and their associated ground failure mechanisms due to proximity to active faults.

The four seismic and co-seismic hazards that were assessed as part of this QRA are:

- Seismic shaking.
- Liquefaction (co-seismic).
- Lateral spreading (co-seismic).
- Fault rupture.

In consultation with ORC, other co-seismic hazards such as earthquake triggered landslides and tsunami were excluded from this assessment because the exposure in the Study Area was assessed as low relative to the other hazards listed above.

Cascading hazard effects (e.g., damage to the flood protection network and subsequent impacts on flooding) are important to consider and have been discussed in Section 3.3. However, in consultation with ORC, we did not include these within the risk register (i.e., they do not have an associated risk rating). This is because of the complexity of assessing the likelihood and associated risk of cascading hazards.

2.2.1 Seismic shaking

Seismic shaking occurs as a result of an earthquake and can vary in intensity due to ground conditions and proximity to the fault rupture. Magnitude is a measure of the amount of energy released at the earthquakes' source while peak ground acceleration (PGA) is a measure of the maximum acceleration of the ground during shaking (GNS Science, 2022). Three different shaking scenarios have been established for this assessment alongside the associated magnitude and typical PGA.

The Study Area is exposed to seismic hazard from several sources. While not located on a major plate boundary, it can be affected by large earthquakes from the Alpine Fault and local faults in the Otago region, such as the Akatore and Titri faults (Barrell, 2021) (Figure 2.2). These faults can generate significant ground shaking that could impact the Study Area.

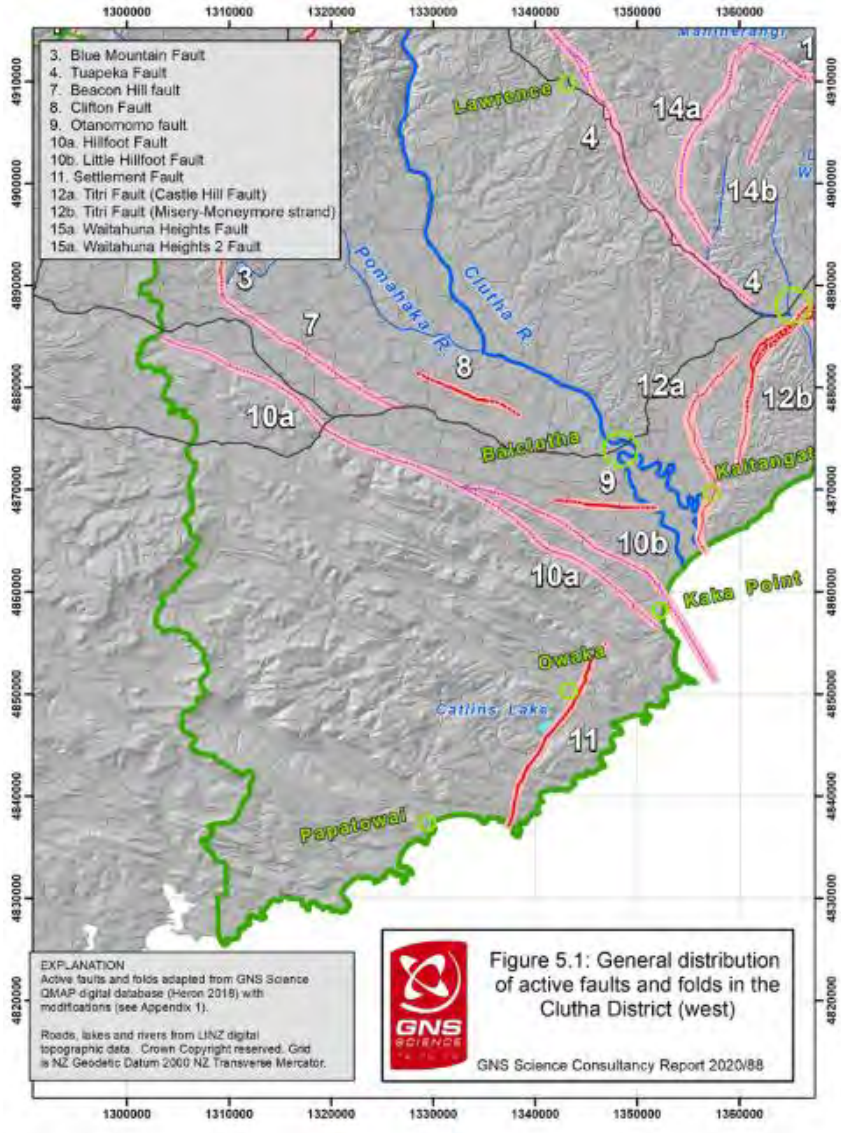


Figure 2.2: General distribution of active faults and folds in the western part of the Clutha District, Barrell 2021.

2.2.2 Liquefaction (co-seismic)

Liquefaction is a process where earthquake shaking increases the water pressure in certain types of ground conditions, resulting in temporary loss of soil strength.

The following three key elements are all required for liquefaction to occur:

- Loose non-cohesive or weakly cohesive soil (typically sands and silts, sometimes gravels, or fine-grained soils with low plasticity).
- Saturated or near-saturated soils (e.g., below the groundwater tables or in zones influenced by capillary rise).
- Sufficient ground shaking (a combination of the duration and intensity of shaking).

As outlined in the T+T report (June 2025), the elements listed above are present across significant parts of the Study Area identified as Liquefaction Damage is Possible in Figure 2.3. While there is uncertainty about where precisely liquefaction will occur in an earthquake event within the Study Area, it can be said with confidence, that in large earthquake events liquefaction will occur and that moderate-to-severe land damage is possible.

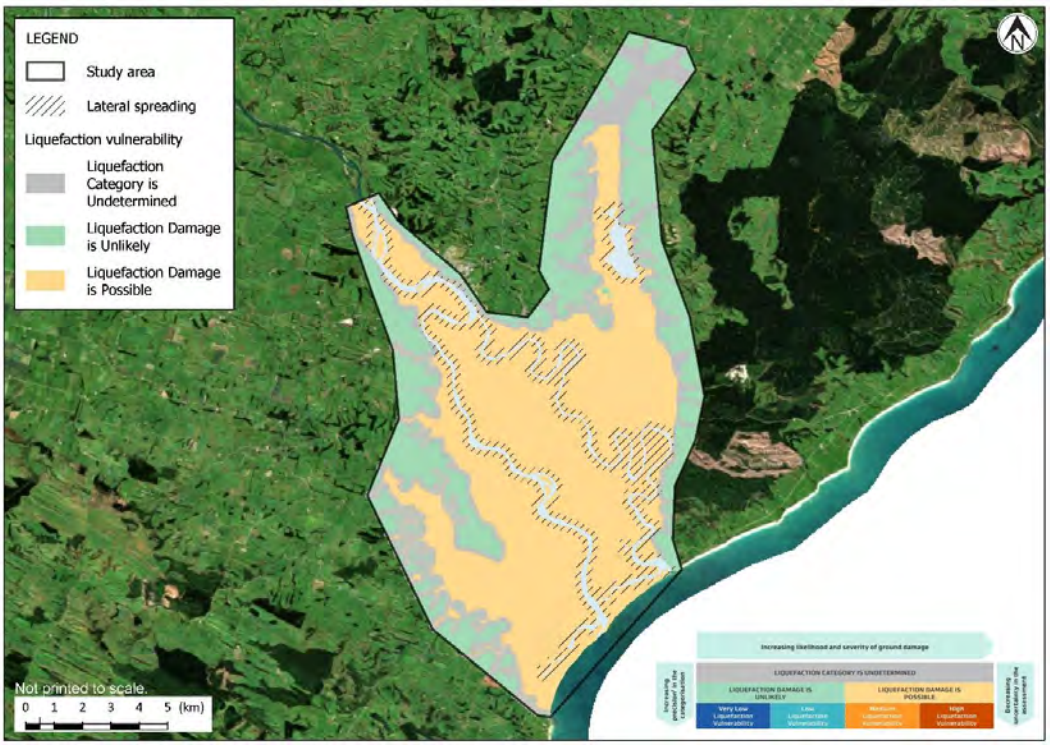


Figure 2.3: Liquefaction vulnerability classification (T+T, June 2025).

2.2.3 Lateral spreading (co-seismic)

Lateral spreading is the horizontal movement of ground towards a free-face or downslope (e.g., riverbank, channel, or road cutting), as a result of liquefaction of shallow underlying soils.

Figure 2.3 highlights areas which have the key elements required for lateral spreading to occur. Generally, the free faces associated with the larger river systems will likely result in lateral spreading which will increase in severity and extent as the seismic intensity increases. There are numerous drains across the Study Area which might also present a lateral spreading hazard but, given their smaller free-face height, the severity of damage is expected to be less extensive.

2.2.4 Surface rupture

Fault rupture refers to the displacement that occurs along a fault during an earthquake. Fault rupture may occur along a fault plane well below the ground surface or at the earth's surface (GNS Science, New Zealand's Faults, 2025). When it occurs at the earth's surface it is known as surface rupture and it is associated with visible cracks, scarps, or lateral offsets of the ground. Surface rupture was considered when assessing risks to infrastructure in this assessment.

Active faults are defined as faults that have ruptured in the past 125,000 years. If a fault has ruptured in the last 5,000 years, then it is considered a potential source of damaging earthquakes (Ministry for the Environment, 2003).

There are two active faults within the Study Area:

- Otanomomo fault.
- Titri fault (Castle Hill fault).

The Titri fault (Castle Hill fault) is located along the foot of the hills on the eastern edge of the Kaitangata township (Barrell, 2021). This fault is likely capable of generating a surface rupture; however, the likelihood of this happening is low (e.g., 10,000 to 20,000 recurrence interval). Due to the low likelihood of rupture, this has only been considered for the rare scenario.

2.2.5 Hazard scenarios

Three hazard scenarios were developed in this assessment, as per requirements under the ORC RPS:

- Likely
- Possible
- Rare

Each of the scenarios has different intensities of seismic and co-seismic hazards. These are described in detail below.

Likely – 1 in 100-year event
This scenario represents a magnitude 6.3 earthquake from a far-field source. The level of shaking is equivalent to that in an Alpine Fault 8.0 (AF8) scenario[1] for the Study Area. Light to moderate shaking is expected under this scenario, with a Modified Mercalli Intensity (MMI) of 5-6 and an average peak ground acceleration (PGA) of 0.09-0.13g. This level of shaking is generally felt both inside and outside. Most sleepers are awakened, and a few people may become alarmed. No surface rupture is generated locally, with liquefaction and lateral spreading effects limited to the most vulnerable soils or not triggered at all. No significant landsliding or tsunami generation occurs under this scenario within the Study Area.
Possible – 1 in 500-year event
This scenario represents a magnitude 6.4 earthquake, from a near-source (not directly inside the Study Area). Strong to severe shaking is expected under this scenario, with a MMI of 7-8 and an average PGA of 0.23-0.27g. This level of shaking is felt by all, and people may run outside. Walking steadily and standing can become difficult, with damage to fragile and unsecured objects. No surface rupture is generated locally; however, localised liquefaction and lateral spreading occurs (minor to moderate). No significant landsliding or tsunami generation occurs under this scenario within the Study Area.
Rare – > 1 in 2,501-year event
This scenario represents a magnitude 7.0 earthquake, due to rupture of the Titri Fault (Castle Hill Fault). Severe to extreme shaking is expected under this scenario, with a MMI of 8-9, and an average PGA of 0.39-0.43g. This level of shaking will produce general alarm, that may turn into panic. People will experience difficulty standing, and some buildings are damaged, with 'weak' buildings destroyed. Widespread ground deformation, liquefaction and lateral spreading occurs throughout the Study area. Surface rupture occurs along the Titri Fault (Castle Hill Fault) impacting directly on Kaitangata township and vertical and horizontal tectonic movement in the wider Study Area. No significant landsliding or tsunami generation occurs under this scenario within the Study Area.

2.3 Context & supporting information

Building and lifeline utility data was requested for the inclusion in this assessment. During the scoping workshop with ORC and Civil Defence and Emergency Management (CDEM) staff (5 June 2025), the following assets were confirmed for inclusion to assess the built environment:

- **Buildings**
  - All buildings within the Study Area were included within the assessment.
  - Critical and social/cultural buildings were identified spatially during the scoping workshop (5 June 2025).

[1] This scenario does not assess an Alpine Fault scenario, rather the same level of shaking that could occur based on the AF8 Scenario.

- **Lifelines**
  - Flood protection: pump stations, drains, floodbanks, and outfalls.
  - Transport: road, railway line, culverts, and bridges.
  - Three waters: pipes, treatment plant, pump station, flood gate, culvert, reservoir (water tanks), and intake locations.
  - Fuel: fuel sites.
  - Electricity: transmission towers, transmission lines, transmission, and distribution substations.
  - Telecommunications: fibre routes, critical cell sites, and cell phone towers.

Due to the importance of the flood protection scheme within the district, these assets were individually assessed within the risk assessment. The other lifeline utilities e.g., transport, three waters, electricity etc. were assessed at an amalgamated level, rather than at the individual asset level. For further detail on the spatial distribution of these assets, refer to Appendix C. During the scoping workshop (5 June 2025) with ORC and CDEM staff, the matters for consideration listed in Section 2.1.2.4 were discussed. The following is a summary of that discussion with further detail provided in the workshop minutes in Appendix A:

- **Population:** The population in the Study Area is approximately 5,000 – 6,000. Balclutha is the main town with a population of approximately 4,000. Kaitangata is a smaller residential community with a population of approximately 800. The remaining population is located on rural farms and lifestyle blocks with a low population density.
- **Economic activity:** The Clutha Delta is characterised by intensive agricultural activity and is anchored by the main town of Balclutha. The area is supported by key employers such as Silver Fern Farms (Finegand), Fonterra (Stirling dairy plant), and Danone (infant-formula plant at Clydevale). The drainage network plays a vital role in maintaining the viability of agriculture activities on the lower delta. Beyond agriculture, the region supports other significant activities including a large prison at Milburn (north of the Study Area) and steady tourism along the Pacific Coast Highway/ Catlins.
- **Buildings:** Most of the building stock are timber or masonry buildings. There are some mid-century, brick façade buildings (e.g., Library and Community Pool), however no buildings more than three storeys high. The two key community hubs of Balclutha and Kaitangata.
- **Lifelines:** Critical lifeline infrastructure such as State Highway (SH) 1, including the Clutha River bridge, and the two bridges to Inch Clutha, highlighted single points of failure. Failure at these sites could severely disrupt access to essential services, food supply to the rest of the South Island and isolate communities.
- **Health and safety:** While the general population is considered relatively resilient, three vulnerable populations were identified as elderly residents, migrant workers, and tourists. Health and safety risks are heightened by ageing buildings and limited evacuation routes. Economic and cultural impacts could arise from employment disruption and damage to key service sites.
- **Emergency response:** Emergency services face logistical challenges, including gaps in welfare-centre suitability and volunteer coverage. These challenges are exacerbated by the interconnected nature of lifelines (co-located assets and interdependencies) and cascading hazard scenarios.

This contextual information was considered when applying the consequence ratings within the risk assessment.

3 Risk analysis

A total of 120 risks were assessed as part of this assessment which are documented in detail in the associated risk register which is the main deliverable of this risk assessment and provided as a digital supplement in Appendix B. There are 120 risks because:

- The assessment considered nine subgroups of assets and Health and Safety (i.e., ten subgroups in total)
- For two of the scenarios (Likely and Possible) there are three hazards
- For one of the scenarios (Rare) there are four hazards

This section provides a summary of both the impacts (consequences) and risks associated with the seismic and co-seismic hazards assessed. It also provides discussion about the potential for cascading risks associated with this assessment.

3.1 Consequence summary

The distribution of consequence ratings across the different hazards and likelihood scenarios is presented in Figure 3.1. It highlights the higher consequences associated with the Rare scenarios, and the lower consequences associated with the Likely scenarios. It also demonstrates the compounding effects of the co-seismic hazards considered i.e., the consequences for surface rupture are highest and the consequences for seismic shaking are lowest.

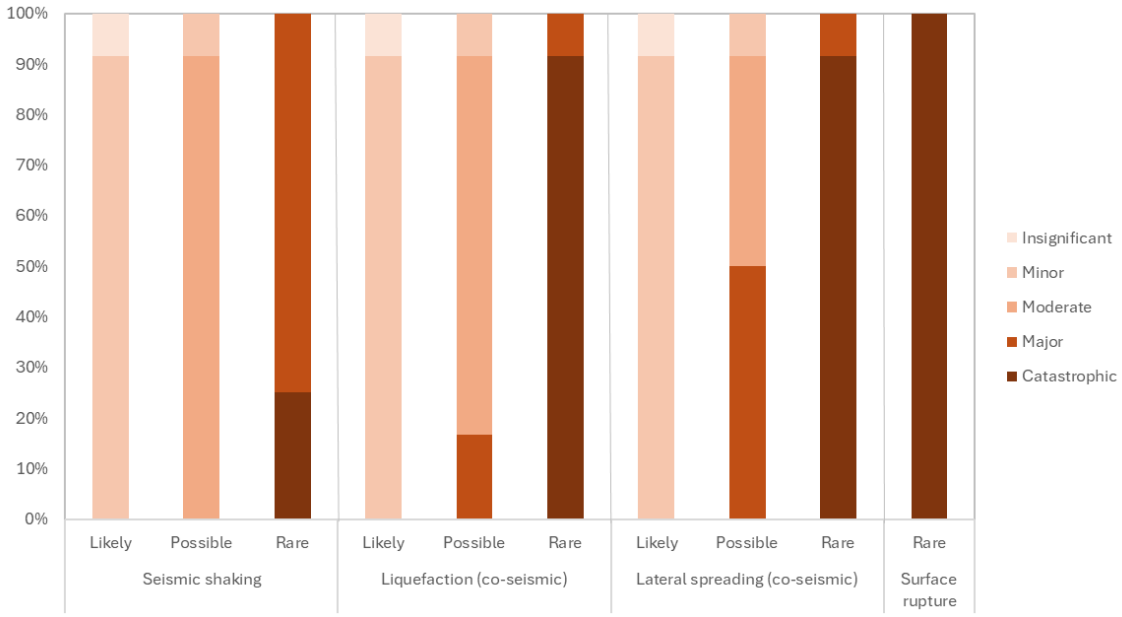


Figure 3.1: Distribution of consequence ratings across the different likelihood scenarios and hazards

Of the 120 risks assessed, 37 (31%) were rated as having a catastrophic consequence, 19 (16%) Major, 25 (21%) Moderate, 36 (30%) Minor, and 3 (2.5%) as Insignificant. Of the asset groups assessed, critical buildings and three waters had the highest number of catastrophic consequences (Figure 3.2). This reflects the conservative consequence thresholds for critical buildings, and the severity of the consequences if the three waters network were to be compromised. Flood protection and transport assets also have a high percentage of assets rated as catastrophic or major. This is largely due to the high exposure and vulnerability of these assets to liquefaction and lateral

spreading (Table 3.1). Health and safety had the highest number of insignificant consequences, which is a function of the relatively small population and nature of building stock in the Study Area.

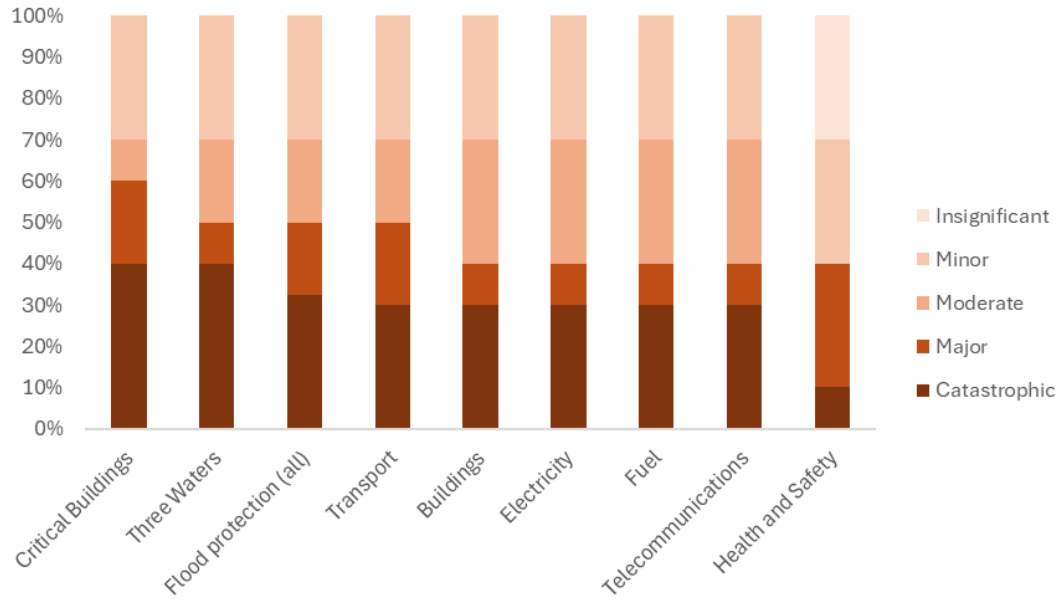


Figure 3.2: Consequence summary, grouped by asset grouping.

Particular factors that have influenced the consequence rating for each asset grouping are described in Table 3.1 below.

Table 3.1: Factors influencing the consequence rating

Asset group	Consequence discussion
Critical buildings	The lower thresholds associated with the percentage of buildings functionally compromised, results in a higher number of risks having higher consequence ratings.
Three waters	The exposure, and vulnerability to liquefaction and lateral spreading and the network performance of these assets, results in higher consequence ratings for this asset grouping.
Flood protection (all)	The exposure, and vulnerability to liquefaction and lateral spreading and the network performance of these assets, results in higher consequence ratings for this asset grouping.
Transport	The interdependent nature of these assets, alongside the percentage of population affected if disruptions were to occur, has resulted in higher number of major and catastrophic consequences.
Buildings	Given both the nature of the building stock within the Study Area, and the percentage thresholds, the consequence ratings are distributed relatively evenly across the scenarios.
Electricity	The consequence ratings are distributed relatively evenly across the scenarios, largely due to the prioritisation that is given to the electricity network post disaster (lowering the outage duration).
Fuel	The consequence ratings are distributed relatively evenly across the scenarios, given the reduced number of sites within the Study Area and the isolated nature of these assets.
Telecommunications	The consequence ratings are distributed relatively evenly across the scenarios, largely due to the prioritisation that is given to the electricity network post disaster (lowering the outage duration).
Health and Safety	The consequences ratings for health and safety are influenced by the small population within the Study Area, and the building stock i.e., no high-rise buildings. This limits the number of injuries and fatalities, and therefore higher consequence thresholds are not met.

Damage will also vary depending on the scenario and the asset type. A summary table of the likely damage and consequences for each hazard under each scenario is presented in Table 3.2.

Table 3.2: Summary of damage descriptions for each hazard and likelihood scenario

Hazard	Likely	Possible	Rare
Seismic shaking	• Hairline cracks in buildings and infrastructure • Minor displacements of fittings and joints in pipes, culverts, bridges and mechanical systems • Electrical and telecommunications equipment may require reset/ inspection • Temporary service outages (generally up to 1 day).	• Structural cracking and misalignment of components (pipes, cables, bridges, tanks) • Mechanical failure in pump stations and treatment plants • Temporary loss of sealing capacity e.g., flood gates and intake structures • Service disruption generally up to 1-week.	• Structural failure, and potential collapse of buildings, bridges and tanks • Rupture of pipes, and displacement of culverts • Widespread disruption to electricity, telecommunications and transport corridors • Service disruption likely to exceed 1-month in most cases.
Liquefaction	• Minor ground deformation, with limited structural impact • Slight settlement possible • Service disruption is limited to inspections and minor repairs.	• Localised liquefaction causing differential settlement and misalignment of assets e.g., pipes, culverts, drains, flood gates etc. • Ejected material may block culverts, drains, and outfalls, reducing flow capacity • Service disruption is likely up to 1-week.	• Widespread liquefaction causing severe ground deformation and structural failure • Rupture or uplift of buried infrastructure • Service disruption is likely to exceed 1-month.
Lateral spreading	• Limited horizontal movement near river margins • Minor displacement of foundations and buried infrastructure • Service disruption is limited to inspections and minor repairs.	• Localised lateral spreading may result in localised deformation • Misalignment and cracking of structures • Damage to embankments, bridges and pipe networks • Service disruption of up to 1-week.	• Extensive lateral spreading causing structural failure of bridges, and buildings • Severance of buried infrastructure, and potential collapse of containment systems • Service disruption is likely to exceed 1-month.
Surface rupture	-	-	• Surface rupture intersecting asset footprints can cause complete structural failure • Severance of buried infrastructure, transport corridors and flood protection assets • Total loss of function of schemes from ground deformation • Service disruption likely to exceed 1-month.

3.2 Risk summary

A total of 120 risks were assessed across a range of seismic and co-seismic hazards and likelihood scenarios. Of the 120 risks assessed, 70 (58%) were rated as Tolerable, 50 (42%) were rated as Acceptable, and no risks were rated as Significant – this is a function of the nature of the risk framework and the relatively low probability of high intensity seismic events in the area (i.e., high consequence events are typically rare).

Of the hazards assessed, liquefaction and lateral spreading had the most Tolerable risks (22 each), highlighting that these hazards pose the greatest potential risk for disruption across multiple asset types (Figure 3.3). All risks were rated as Tolerable for fault rupture, reflecting the rare but severe nature of this hazard. Seismic shaking had the highest number of acceptable risks, highlighting the high likelihood but generally lower consequence of this hazard independent of liquefaction and lateral spreading.

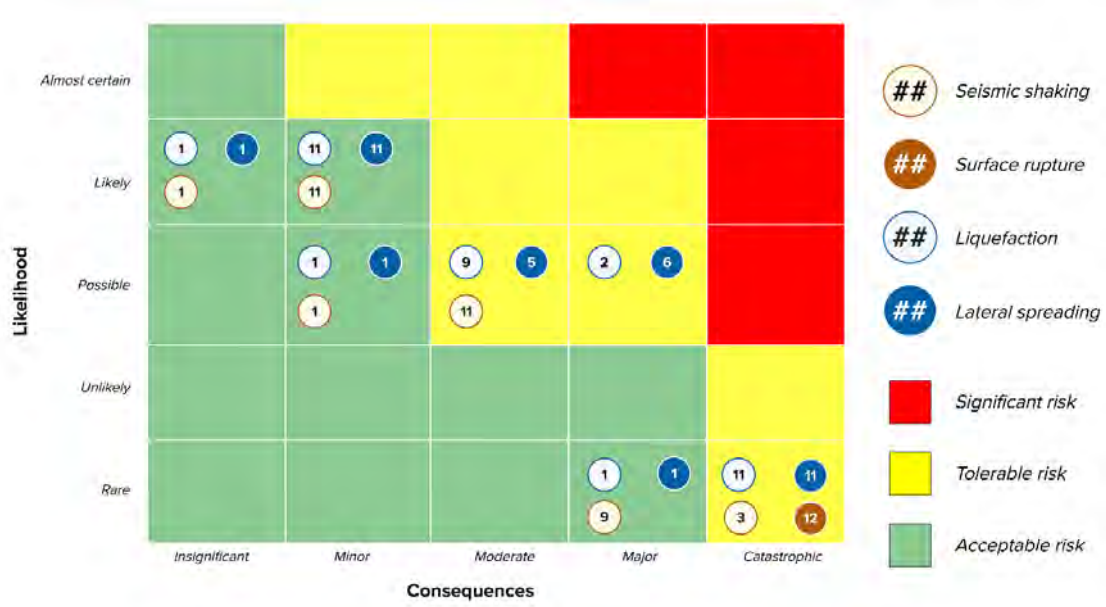


Figure 3.3: Risk summary matrix.

Of the assets assessed, critical buildings and floodbanks had more tolerable risks, highlighting the critical nature of these assets and the severity of the consequences if they were to be damaged or functionally compromised (Figure 3.4). Health and safety risks are generally rated as Acceptable, even under rare scenarios. This is a function of the relatively small population and nature of building stock in the Study Area (i.e., very few multi-storey buildings). However, the risk rating does increase to Tolerable when considering fault rupture, with the estimated number of fatalities driving this consequences rating. All other asset groups have 60% of risks rated Tolerable and 40% rated Acceptable.

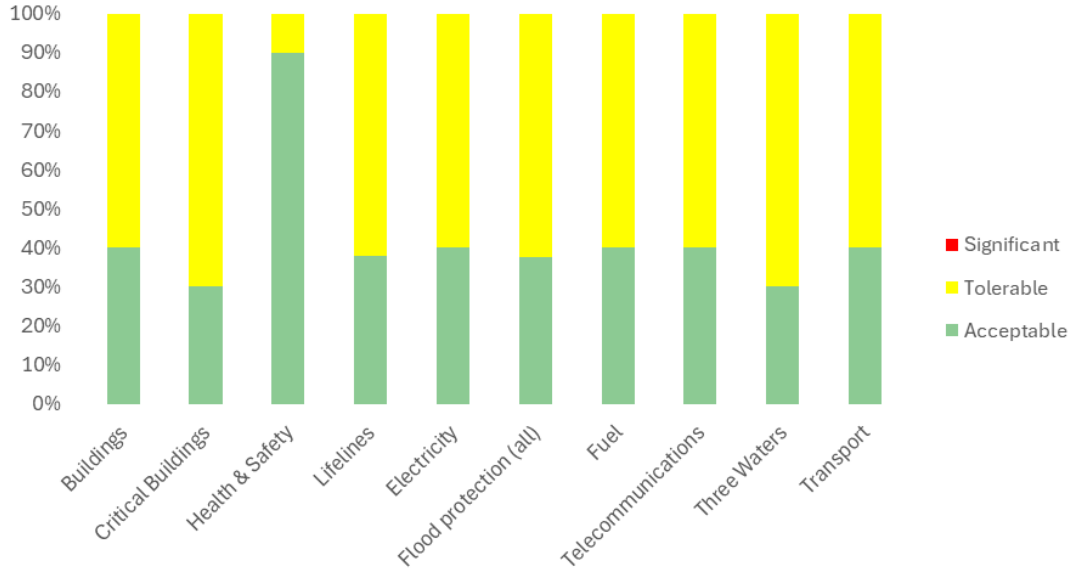


Figure 3.4: Risk summary, grouped by asset.

3.3 Cascading risks

Seismic and co-seismic events can result in widespread damage across critical infrastructure systems. Due to the interdependent nature of these systems, damage in one system can propagate through others, exacerbating the overall impact. Failure in some key infrastructure systems such as flood protection can also result in increased exposure to other hazards e.g., flooding. Figure 3.5 presents a summary of interconnections and potential cascading risks from seismic and co-seismic hazards.

Key observations from this cascade analysis include:

- The electricity network has many interdependent relationships, and failure of this network can result in disruption to:
  - Wastewater systems (treatment plant mechanisms).
  - Flood protection assets (mechanical components e.g., pump stations).
  - Telecommunications.
  - Fuel (payment mechanisms and petrol stations).
  - Transport (signal disruption).

  Failure in these systems can then result in impacts to public health and safety and can hinder emergency services, delaying response times.
- Damage and leakage of contaminants from wastewater and fuel systems can increase public health and safety and environmental risks. These impacts can be long lasting and can cascade into other networks e.g., the stormwater network may transport contaminated water into other receiving environments, and the water supply network can be compromised, resulting in potable water becoming unsafe for consumption.
- Fuel and electrical systems can increase the likelihood of fire. Damage to electrical infrastructure such as short circuits, arcing or equipment failure during or after a seismic event can ignite fires, particularly if flammable materials are present. Similarly, ruptured fuel lines and damaged storage tanks can release flammable liquids or gases, which may be ignited by electrical sparks or other ignition sources. The lifelines fuel site is located within close proximity to a residential area, so has potential to spread rapidly if ignited.
- Damage to both the flood protection and stormwater networks, can result in an increased flood risk post seismic event. Ejected material because of liquefaction, and ground deformation associated with lateral spreading and surface rupture may also exacerbate flood risk within the Study Area (as was seen following the Canterbury Earthquake Sequence).

  In a rare (>2,501 year ARI) scenario, impacts to the functioning of the flood protection and drainage scheme are expected to be widespread and extensive, with significant long-term repair and construction required. These impacts include:
  - Widespread deformation and cracking of floodbanks increasing the likelihood of failure
  - Drain blockage from sediment collapse and redirection of flowpaths
  - Structural damages to pump stations and outfall structures or rendered inoperable due to power supply disruption (as described above).

  As highlighted by the consequence descriptions in the risk register and summaries provided above, the potential damage to the flood protection and stormwater is extensive and would take a long time to repair and restore to previous levels of service. While this repair is underway, the exposure and associated risk of flooding in the study area would be significantly elevated. As the owner and operator of the flood protection network, this cascading risk is of particular relevance to ORC.

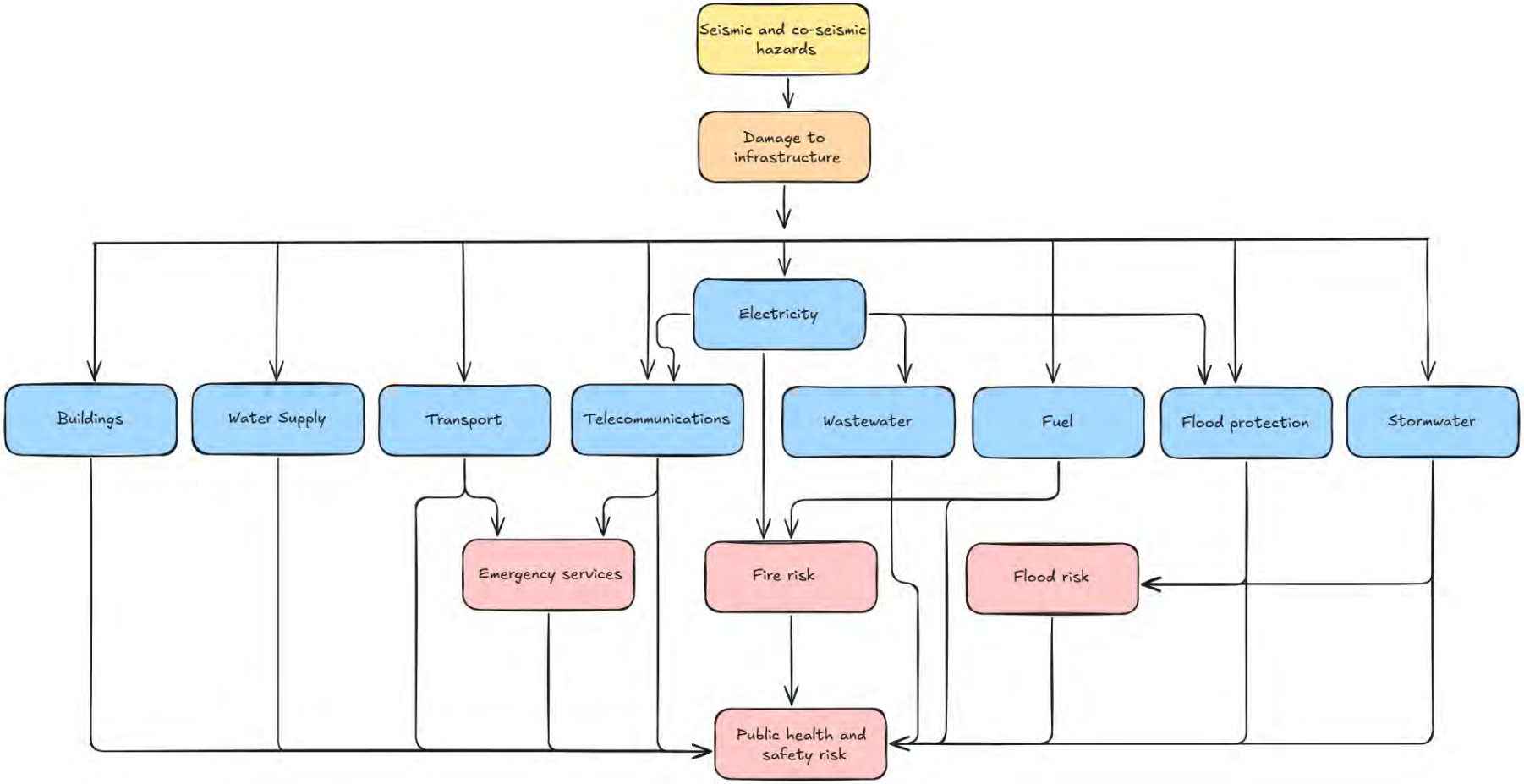


Figure 3.5: Cascading risks from seismic and co-seismic hazards.

3.4 Discussion

While no risks were identified as Significant in accordance with the RPS, a large proportion (53%) of the Tolerable risks were associated with Rare scenarios and Catastrophic consequences. These types of risks are commonly referred to as low probability, high consequence (LPHC) risks. LPHC risks create a governance challenge: how to manage risks that are infrequent yet catastrophic, especially under the conditions of deep uncertainty associated with seismic hazards.

Risk mitigation concepts that can be useful under these circumstances include:

- **Risk tolerance and the ALARP Principle**: The Natural Hazards Commission's Risk Tolerance Methodology (Toka Tū Ake EQC, 2023) offers a nationally aligned framework differentiating acceptable, tolerable and intolerable risk levels. For those risks deemed tolerable, the "as low as reasonably practicable" (ALARP) principle may guide proportional decision-making. The principle pursues risk reduction until further measures would be disproportionate to the expected benefit. Documenting where further mitigation is deemed proportionate, helps to support transparency and public confidence in decision-making.
- **Preparation for Emergency Response:** For LPHC risks, especially those with cascading hazards, preparedness for emergency response is critical. Stock piling of materials (e.g., suitable fill material, sheet piles and pumps), pre-arranged contracts, clear access plans, and prioritisation protocols could all be effective means to reduce recovery time and the consequences of such events. Consideration of alternative risk transfer mechanisms such as parametric insurance products to fund emergency response efforts could also be of use.
- **Dynamic Adaptive Policy Pathways (DAPP):** The DAPP framework was specifically developed to support planning under deep uncertainty and ORC has signalled its intent to use DAPP for adaptation planning in its Clutha Delta programme (van Woerden, Conroy, & Payan, 2023). This approach results in mapping of short-term no-regrets measures (e.g., enhancing redundancy and cross-training staff), medium to long term adaptation pathways, and associated decision triggers (e.g., updated hazard information and infrastructure performance degradation).

In summary, approaches to managing LPHC are not about elimination of risk, they target proportionate risk reduction (where practical), preparation for response, and remaining adaptable over time. Further consideration of these risk reduction methodologies, and other relevant examples, constitute useful next steps.

4 Conclusions and next steps

This QRA has identified and evaluated seismic and co-seismic hazards across the Clutha Delta, focusing on impacts to three main asset groups: buildings, lifelines infrastructure, and health and safety. The risk assessment highlighted that seismic shaking is the most likely hazard, with liquefaction, and lateral spreading triggered under a higher intensity of shaking, and surface rupture occurring under a rare scenario only.

Liquefaction, lateral spreading, and surface rupture pose more severe risks, particularly under rare event scenarios. This is due to the additional damage they cause in relation to seismic shaking. Critical buildings, three waters, and flood protection assets were identified as having the highest number of catastrophic and major consequences. With the same asset groupings having the highest number of risks identified at Tolerable.

While no risks were classified as Significant, a large proportion of those rated Tolerable are low probability, high consequence (LPHC) risks. These risks have the potential to cause catastrophic impacts to critical assets and generate cascading consequences across interconnected infrastructure systems.

Seismic and co-seismic events pose a significant cascading hazard risk due to the high interdependencies between infrastructure systems. Damage to lifelines such as electricity, wastewater, fuel, and transport can quickly propagate into wider service failures. For example, power outages can disable pump stations, disrupt telecommunications, and hinder emergency response, while damage to flood protection assets can heighten flood risk during recovery.

The flood protection and drainage networks are of particular relevance to ORC because it owns and operates them. Ensuring the resilience and preparedness of these assets is therefore a core responsibility for ORC.

Possible next steps for ORC based on this assessment:

- Share findings with key asset managers, and validate the assumptions made within this assessment.
- Complete a quantitative and/or site-specific risk assessment for key asset groups such as flood protection assets, critical buildings, and three waters. This can provide further granularity in the assessment and support prioritisation of risk mitigation efforts. The approach should remain adaptive, with regular updates and reviews as new hazard information becomes available.
- Complete a detailed assessment of cascading risks, focusing on how damage to flood protection assets from seismic hazards could increase the likelihood and severity of subsequent flooding (e.g., breach modelling).
- Consider different risk mitigation and management approaches that are suitable for LPHC risks. Examples introduced in this assessment include exploration of risk tolerance using the ALARP principle, and Dynamic Adaptive Policy Pathways (DAPP).
- Use the risk assessment as the basis of a review of emergency management plans, focusing on welfare centre locations, and evacuation routes in relation to the risks identified within this assessment.
- Share findings with asset owners e.g., New Zealand Transport Agency, so they can consider the need for develop of mitigation strategies for high-consequence assets, e.g., floodbanks, critical buildings, and single point of failure infrastructure (SH1 bridge).

5 References

van Woerden, T., Conroy, A., & Payan, J. (2023). *Clutha Delta Natural Hazards Adaptation. Report OPS2341 to the Otago Regional Council Safety and Resilience Committee.*

Barrell, D. (2021). *General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago.* GNS Science.

FEMA. (2020). *Hazus Earthquake Model Technical Manual - Hazus 4.2 SP3.*

GNS Science. (2022). *Understanding Ground Shaking.*

GNS Science. (2025). *New Zealand's Faults*. Retrieved from GNS Science: https://www.gns.cri.nz/our-science/natural-hazards-and-risks/earthquakes/new-zealands-faults/

International Standard. (2018). *ISO 31000:2018 Risk Management Guidelines.* ISO.

MBIE. (2018). *Repairing and rebuilding houses affected by the Canterbury earthquakes.* Ministry of Business, Innovation & Employment.

Ministry for the Environment. (2003). *Planning for Development of Land on or Close to Active Faults.* Ministry for the Environment.

Ministry of Business, Innovation and Employment & Ministry for the Environment. (2017). *Planning and engineering guidance for potentially liquefaction-prone land.* Wellington: Ministry of Business, Innovation and Employment & Ministry for the Environment.

Otago Regional Council. (2021). *Proposed Otago Regional Policy Statement June 2021: Integrating the management of Otago's natural and physical resources.*

Toka Tū Ake EQC. (2023). *Risk Tolerance Methodology.*

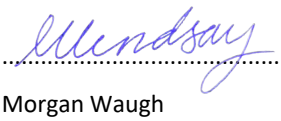
Tonkin & Taylor Ltd. (2025). *Clutha Delta Liquefaction Vulnerability Study.*

6 Applicability

This report has been prepared for the exclusive use of our client Otago Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

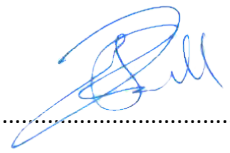
Report prepared by:



.....

Morgan Waugh
Climate Risk and Geospatial Consultant

Authorised for Tonkin & Taylor Ltd by:



.....

James Russell
Project Director

MOLI
t:\tauranga\projects\1093960\issueddocuments\2025-08-20 qra final report and risk register\orc_cluthadelta_qra_final-20-08-2025.docx

Appendix A Workshop Minutes

Minutes

Meeting:	Clutha Delta QRA | Context & Pre-screening Workshop		
Venue:	Online	**Date:**	5 June 2025
Job No:	1093960	**Time:**	1:30 pm
Present:	Tim van Woerden (ORC), Pete Weir (ORC), Jason Michie (Otago CDEM), Paula Cathie (Otago CDEM), James Russell (T+T), Morgan Waugh (T+T), Matt Ogden (T+T)		
Apologies:	None		

Agenda	
	Agenda Item
1	Introductions
2	Confirmation of study extent
3	Confirmation of hazards
4	Risk framework overview (including matters for consideration)
5	Built environment assets
6	Health and safety considerations
7	Agreeing outputs
8	Summary and close

Actions				
Action Item		**Responsible**	**Due Date**	**Status**
1	Compile workshop outcomes and circulate summary for confirmation.	Matt O	13/06/2025	In progress
2	Finalise critical-asset map and issue for validation.	Matt O	13/06/2025	In progress
3	Provide Lifeline Vulnerability Report.	Tim vW	N/A	Completed
4	ORC to screen for additional historic-cultural sites within boundary.	Jason M/ Paula C	13/06/2025	In progress

1 Workshop objectives

The aim of the workshop was to:

- Confirm the geographic extent of the Clutha Delta Qualitative Risk Assessment (QRA).
- Agree the list of seismic and co-seismic hazards to be considered.
- Validate the qualitative risk-assessment framework—particularly hazard-likelihood scenarios—against the Otago Regional Policy Statement (RPS).
- Develop the inventory for the built-environment, lifeline, and community assets (including identifying vulnerable populations).
- Outline deliverables (Excel-based risk register and report).

2 Key discussion points

The key topics that were discussed with their outcomes are summarised in Table 2.1.

Table 2.1: Key discussion points from workshop

Topic	Outcome from workshop
Assessment approach	The team endorsed a qualitative risk matrix (3-point likelihood × 5-point consequence). Annual-recurrence-interval (ARI) numbers (1 in 100, 1 in 500, 1 in 2,500) are mapped to the qualitative likelihood categories (“likely”, “possible”, “rare”). **Quantitative loss modelling is out of scope.**
Study extent	Analyse the whole Clutha Delta as one unit; spatial variation of the hazard will be considered.
Hazards in scope	Ground shaking, liquefaction (free-field & lateral spreading), fault rupture. ORC raised that work is being undertaken towards improving the fault mapping database. We will integrate the findings of this research should it become available ahead of delivery of the QRA. Commentary for landslide risk will be included but excluded from the risk assessment due to minimal exposure across the study area.
Asset categories & critical facilities	Assets discussed included – key lifelines (State Highway 1 and rail bridges, pump stations, drainage network, 33 kV sub-station, transmission lines, water intakes/outfalls), supermarkets as essential-goods supply, social-critical buildings (hospital, community hub, schools, Clutha District Council, welfare centres). Schools should be classified “critical” for their role in emergency-management.
Vulnerable populations	Prisoners (Milton/Milburn – discussed but outside of study area), transient agricultural workers, assisted-living and retirement facilities, Samoan communities on the coast, residents now living in the historic hospital premise, and tourists to the region.
Risk-register design	Deliverable will include excel workbook which includes: 1 Risk framework tab (definitions, qualitative scales, colour scheme) 2 Risk register tab (one row per asset class × hazard) 3 Filtered risks (inspection of risk register by various groupings) 4 Risk totals – summary (count of risks by hazard)

	A report will accompany the risk register outlining the implementation of the risk framework and commentary about hazards not included within the risk register, as stated above.

3 Matters for consideration

Matters for consideration are presented in the ORC RPS (advice note 2) which were discussed in the workshop as an important component of developing the context.

3.1 Nature and scale of activities in the area

- **Primary land uses** – Balclutha is a small service town at the centre of an intensively farmed flood-plain; dairying and cropping dominate the rural delta.
- **Key industries/employers** – Silver Fern Farms meat-works at Finegand, Fonterra's dairy plant at Stirling, and the Danone infant-formula plant at Clydevale are major regional employers.
- **Other activities** – A large prison at Milburn (just north of the study area), small-scale coal mining near Kaitangata and year-round tourism on the Pacific Coast Highway / Catlins coast.

3.2 Individual and community vulnerability and resilience

- **Inherent rural resilience noted** – Farm communities have equipment, skills and a "can-do" culture that speeds self-help recovery.
- **Vulnerable groups identified**:
  - Balclutha rest home (~60 beds) and an adjacent hospital wing.
  - Retirement housing complexes on Charlotte St.
  - Disability centre ("PACT House") on the flood plain.
  - Ethnically diverse migrant worker communities on the coast and dairy farms.
  - Former hospital site (Hospital Road) now used for transient accommodation (raised as potential concern).
  - Tourists to the region.

3.3 Impacts on individual and community health and safety

- **Bridge failure** could cut access to food, fuel and medical care for the wider Southland region.
- **Only two bridges to Inch Clutha** – failure would isolate farms and residents.
- **Earthquake-prone or older buildings** – mid-century brick-facade buildings, the library and community pool noted as potential higher risk. Note that we will not use the term "earthquake-prone" unless an official notice exists. Buildings should be described by age and construction type instead.
- **Aftershock sequences** could delay recovery and prolong unsafe conditions.

3.4 Impacts on social, cultural and economic well-being

- **Employment disruption** at meat-works, dairy factories and mine if utilities or bridges fail.
- **Tourism losses** along the Catlins scenic route if Southern Scenic Route or coastal campsites are cut off.
- **Cultural values & sites** – Māori coastal urupā (burial grounds) outside but near the study area noted as sensitive.

3.5 Impacts on infrastructure and property (incl. access & services)

- **Critical bridges** – State Highway 1 and rail bridges at Balclutha, Clydevale bridge, new Beaumont bridge; all carry heavy freight, utilities and fibre backhaul.
- **Drainage & stop-bank network** – essential for keeping the low-lying delta farmable; pump-stations not designed for major flood pumping.
- **Substation north of Balclutha** and co-located utilities depend on bridge corridors (raised verbally).

3.6 Available and viable risk-reduction / hazard-mitigation measures

- **Existing measures** – flood banks, day-to-day groundwater pump-stations and engineered drainage network.
- **Proposed analysis** – qualitative risk register, asset-grouping approach and updated fault-awareness mapping (another project which is in progress).
- **Design standards** – bridges (e.g. new Beaumont bridge) built to higher seismic ratings, providing redundancy.

3.7 Lifeline utilities, essential & emergency services, and their co-dependence

- All three waters, power and fibre share the two bridge corridors – single points of failure.
- Police station and St John ambulance hub lie inside the flood-plain and have already been relocated once because of rising groundwater.
- Six lifeline categories will be assessed (roads, rail, power, telecoms, three waters, flood protection) as separate asset rows in the risk register.

3.8 Implications for civil defence agencies and emergency services

- **Welfare-centre network** – Cross Rec Centre (in flood hazard), Milton Library, new Kaitangata church, Lawrence Centennial Park and Clinton community centre identified; suitability of some venues questioned.
- **Alternate ECC / HQ** – Rosebank Lodge and South Otago High School named as backup if Council HQ or police out of action.
- **Volunteer fire service coverage gaps** on holiday weekends noted; misinterpretation of sirens by migrant groups highlighted as a communication risk.

3.9 Changing natural hazard environment

- **Sea-level rise raising groundwater** can result in higher liquefaction potential.
- **Ground-subsidence feedback loop** – liquefaction-induced settlement thins the non-liquefying crust, increasing future vulnerability.
- **Altered rainfall patterns** could change pump demand and groundwater balance, adding uncertainty.

3.10 Cumulative effects incl. multiple and cascading hazards

- **Aftershocks** – repeated liquefaction events (Christchurch analogue) extend damage and delay recovery.
- **Cross-contamination risks** – simultaneous sewer damage and potable-water pipe failure identified as a cascade to public-health impacts.
- **Drainage & stop-bank network failure** – contributing to increased flooding risk.

3.11 Factors that may exacerbate a natural-hazard event (incl. climate change)

- **Climate-driven groundwater rise** (sea-level rise and rainfall) exacerbates liquefaction likelihood and severity.
- **Shallow groundwater** (≤4 m) means even small rises materially increase risk.

Appendix B Risk Register

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
1	Lifelines	Flood protection- Pump station	Seismic shaking	Likely	Minor	Damage to pump stations is likely to be minimal (cosmetic). However, power outages may result in loss of electric and back-up power leading to service disruption of up to 2 hours.	Acceptable
2	Lifelines	Flood protection- Pump station	Seismic shaking	Possible	Moderate	Damage to pump stations is likely to be moderate. Some structural damage may occur, with power outages causing service disruptions of up to 1-week.	Tolerable
3	Lifelines	Flood protection- Pump station	Seismic shaking	Rare	Major	Damage to pump stations is likely to be extensive. Structural damage can occur, with pumps being damaged beyond repair. Power outages may result in service disruption of up to 1 month.	Acceptable
4	Lifelines	Flood protection- Pump station	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, however minor ground deformation may occur. Pump station likely to have service disruption based on seismic shaking.	Acceptable
5	Lifelines	Flood protection- Pump station	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction is likely, causing minor to moderate damage to pump stations. This could result in settlement of ground surface (up to 100 mm in height) which could result in misalignment and loss of service up to 1-week.	Tolerable
6	Lifelines	Flood protection- Pump station	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, resulting in significant ground deformation (>100 mm). Pump stations may experience foundation failure and structural damage, with service disruption more than 1 month. All flood protection pump stations within the study area are located in zones mapped as "liquefaction is possible".	Tolerable
7	Lifelines	Flood protection- Pump station	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading is likely to be limited and concentrated near river margins if it is triggered. Pump station foundations may incur damage leading to misalignment of equipment. Service disruption of up to 1-day is likely.	Acceptable
8	Lifelines	Flood protection- Pump station	Lateral spreading (co-seismic)	Possible	Major	Localised lateral spreading may result in major damage to pump station structures and pipelines. Service disruption of up to 2 weeks is likely, with potential for cascading impacts on the drainage network. Three (60%) of the pump stations within the study area are located within mapped lateral spreading zones. Increased flood risk is likely due to service disruption.	Tolerable
9	Lifelines	Flood protection- Pump station	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, particularly in areas with shallow groundwater and soft soils. Pump stations may experience structural failure and complete loss of function. Service disruption exceeding 1 month is likely, with significant implications for flood management across the delta.	Tolerable
10	Lifelines	Flood protection- Pump station	Surface rupture	Rare	Catastrophic	Surface rupture intersecting pump station footprint may result in complete structural failure. Deformation associated with surface rupture could significantly impact how the scheme functions, with service disruption exceeding 1 month. The Rutherford and Kaitangata pump stations are located within close proximity to the Titri fault, therefore are more susceptible to surface rupture than the other pump stations within the scheme.	Tolerable
11	Lifelines	Flood protection- Floodbank	Seismic shaking	Likely	Minor	Minor cracking and potential slumping of floodbanks is likely. No breach expected, but inspection and minor repairs may be required (up to 1-day).	Acceptable
12	Lifelines	Flood protection- Floodbank	Seismic shaking	Possible	Moderate	Moderate deformation of floodbanks may occur, including cracking and settlement. Temporary reduction in flood protection capacity is expected (up to 1 week).	Tolerable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
13	Lifelines	Flood protection- Floodbank	Seismic shaking	Rare	Catastrophic	Extensive deformation and cracking likely, leading to potential breach of floodbanks. Loss of flood protection function may occur, requiring significant repair. Property and infrastructure located within Inch Clutha will likely have increased flood risk.	Tolerable
14	Lifelines	Flood protection- Floodbank	Liquefaction (co-seismic)	Likely	Minor	Minor ground settlement may occur beneath floodbanks. No significant impact on structural integrity is expected.	Acceptable
15	Lifelines	Flood protection- Floodbank	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in moderate settlement and cracking of floodbanks. Temporary reduction in effectiveness is likely. Loss of service of up to 1-week is likely. Ejecta within the river corridor may also reduce the capacity of the floodbanks and increase the flood risk of the surrounding area.	Tolerable
16	Lifelines	Flood protection- Floodbank	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, resulting in significant deformation or breach of floodbanks. This may compromise the integrity of the flood protection system, particularly in low-lying areas of the delta. Restoration could take several weeks-months, with full reconstruction required for some parts of the network.	Tolerable
17	Lifelines	Flood protection- Floodbank	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading is likely to be limited and concentrated near river margins if it is triggered. Floodbanks by nature are located within close proximity to river margins, therefore are more susceptible to lateral spreading. Floodbank is likely to have service disruption based on seismic shaking rather than lateral spreading in this scenario.	Acceptable
18	Lifelines	Flood protection- Floodbank	Lateral spreading (co-seismic)	Possible	Major	Localised lateral spreading may result in major damage and displacement of floodbanks, with potential for overtopping or breach. Emergency repairs are likely to be required, with a loss of service of up to 1-month. Increased flood risk post event is likely, particularly for Inch Clutha.	Tolerable
19	Lifelines	Flood protection- Floodbank	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing widespread displacement and failure of floodbanks. This may lead to uncontrolled flooding of rural land and isolation of communities, with long-term recovery required.	Tolerable
20	Lifelines	Flood protection- Floodbank	Surface rupture	Rare	Catastrophic	Surface rupture intersecting floodbanks may cause complete structural failure and uncontrolled water flow. Deformation associated with surface rupture could significantly impact how the scheme functions. Full reconstruction and potential realignment of damaged areas likely required (disruption exceeding 1 month). Floodbanks along the Clutha River/ Matau Branch are more susceptible to damage from surface rupture due to their proximity to the Titri Fault.	Tolerable
21	Lifelines	Flood protection- Drain	Seismic shaking	Likely	Minor	Seismic shaking may cause minor slumping of open drains and displacement of sediment within channels. Flow paths remain largely uninterrupted without blockages. Minor repairs/ reshaping and removal of material may be needed. Temporary reduction in drainage may occur in low-lying paddocks, particularly following a rainfall event.	Acceptable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
22	Lifelines	Flood protection- Drain	Seismic shaking	Possible	Moderate	Seismic shaking may result in slumping, bank cracking, and partial blockage from sediment collapse. Repairs/reshaping and removal of excess sediment is likely, with up to 1-week of disruption. Reduced flow capacity may result in increased surface ponding and drainage issues.	Tolerable
23	Lifelines	Flood protection- Drain	Seismic shaking	Rare	Major	Widespread bank collapse, blockage from sediment collapse and redirection of flowpaths is likely to occur under this level of shaking. Significant repair and reconstruction will be needed, with up to 1 month disruption. Prolonged disruption may result in waterlogging of farmland, and increased flood risk, where drains are the primary outlet.	Acceptable
24	Lifelines	Flood protection- Drain	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, however minor ground deformation may occur. Drain function will remain intact, and largely unaffected.	Acceptable
25	Lifelines	Flood protection- Drain	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in settlement of drain banks and infilling of channels with ejected material. Removal of excess sediment from drains will be needed, with service disruption of up to 1 week.	Tolerable
26	Lifelines	Flood protection- Drain	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, resulting in significant deformation and potential collapse of banks. Infilling of channels from ejected material will occur which can redirect and impact flowpaths. 141 km (98%) of drains are located within "Liquefaction is Possible" extents. Extensive repair and reconstruction is likely with outage of more than 1 month expected. Prolonged disruption may result in waterlogging of farmland, and increased flood risk, where drains are the primary outlet.	Tolerable
27	Lifelines	Flood protection- Drain	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading is likely to be limited and concentrated near river margins if it is triggered. Lateral ground movement may cause minor displacement of drain banks, however damage is likely to be limited to minor reshaping.	Acceptable
28	Lifelines	Flood protection- Drain	Lateral spreading (co-seismic)	Possible	Major	Localised lateral spreading may result in bank slumping, channel misalignment and partial blockage. Drains are more susceptible to lateral spreading due to inherently being free faces. Reduced flow capacity may result in increased surface ponding and drainage issues.	Tolerable
29	Lifelines	Flood protection- Drain	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing widespread displacement and slumping of drain banks, redirecting flows. 6 km (4%) of drains are located within mapped lateral spreading zones. Extensive repair and reconstruction is likely with outage of more than 1 month expected. Prolonged disruption may result in waterlogging of farmland, and increased flood risk, where drains are the primary outlet.	Tolerable
30	Lifelines	Flood protection- Drain	Surface rupture	Rare	Catastrophic	Surface rupture intersecting the drain network may result in the partial collapse or offset of channels, resulting in permanent redirection and blockage. Deformation associated with surface rupture could significantly impact how the scheme functions, with full re-establishment of the impacted drains likely, with outage of more than 1 month. While rare, rupture near Kaitangata from the Titri fault is possible, and could intersect drains within close proximity.	Tolerable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
31	Lifelines	Flood protection- Outfall	Seismic shaking	Likely	Minor	Seismic shaking may result in minor displacement or loosening of outfall components, including fittings and any gate structures. Cosmetic damage is likely, with functionality remaining intact. Outage time is limited to inspection and minor adjustments.	Acceptable
32	Lifelines	Flood protection- Outfall	Seismic shaking	Possible	Moderate	Seismic shaking may result in cracking, misalignment of fittings, and may damage mechanical components (if any). Some outfalls may be blocked and temporarily inoperable. Repair to damaged components needed, with disruption of up to 1 week likely.	Tolerable
33	Lifelines	Flood protection- Outfall	Seismic shaking	Rare	Major	Seismic shaking may result in structural damage to outfalls including cracking or slumping leading to the disruption of flows. This may increase flood risk and ponding upstream of the structure due to reduced capacity. Repair to damaged components needed, with disruption of up to 1 month likely.	Acceptable
34	Lifelines	Flood protection- Outfall	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, however minor ground deformation may occur. Outfall function will remain intact, and largely unaffected.	Acceptable
35	Lifelines	Flood protection- Outfall	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in settlement of outfall structures, misalignment of fittings and gates (if any). Outfalls may become blocked with ejected material, limiting the flow capacity. Clearance of sediment and realignment may be required, resulting in service disruption of up to 1 week.	Tolerable
36	Lifelines	Flood protection- Outfall	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, resulting in severe settlement and tilting of outfall structures. Gate mechanisms may be inoperable (if any) and outfalls may become blocked with ejected material, limiting flow capacity. All outfall structures are located within "Liquefaction is Likely" extents. Extensive repair and reconstruction is likely, with outage of more than 1 month expected. Prolonged disruption may result in ponding, and uncontrolled water levels disrupting adjacent farms.	Tolerable
37	Lifelines	Flood protection- Outfall	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading is likely to be limited and concentrated near river margins if it is triggered. Lateral ground movement may cause minor displacement of outfall structures, with damage limited to realignment and inspection.	Acceptable
38	Lifelines	Flood protection- Outfall	Lateral spreading (co-seismic)	Possible	Major	Localised lateral spreading may result in misalignment of gates, slumping of surrounding ground and potential partial or full loss of operability. This can lead to reduced control of water discharge and service disruption of up to 1 week.	Tolerable
39	Lifelines	Flood protection- Outfall	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing structural failure of outfalls and gate collapse (if any). All outfalls within the study area are located within mapped lateral spreading zones. Flow control may be lost, and full reconstruction may be necessary. Outage or more than 1 month likely. Prolonged disruption may result in ponding, and uncontrolled water levels disrupting adjacent farms.	Tolerable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
40	Lifelines	Flood protection- Outfall	Surface rupture	Rare	Catastrophic	Surface rupture intersecting outfall structures, may result in complete structural failure and may sever gate mechanisms (if any). Permanent redirection and blockage of flow is likely. Deformation associated with surface rupture could also significantly impact how the scheme functions. Service disruption is likely more than 1 month, with some reconstruction needed to impacted outfalls. The Kaitangata and Rutherford Locks are more susceptible to fault rupture due to their proximity to the Titri Fault.	Tolerable
41	Lifelines	Transport	Seismic shaking	Likely	Minor	Seismic shaking may result in minor cracking and surface deformation on roads and rail lines. Culverts may shift slightly, and bridges may experience minor joint movement or bearing displacement. Service disruption is likely to be limited to short-term lane or track closures for inspection and minor repairs (from 2 hours to 1 day). Minor disruption may occur on critical routes such as SH1 and the rail bridges at Balclutha.	Acceptable
42	Lifelines	Transport	Seismic shaking	Possible	Moderate	Moderate structural damage may occur to bridges and culverts, including cracking of abutments and misalignment of spans. Road and rail surfaces may experience differential settlement. Service disruption of up to 1-week is likely due to damage and closures (road and rail). Prioritisation will be given to critical roads such as SH1 to ensure connectivity to the lower Southland area. Some local roads may have disrupted access isolating communities and restricting access to key lifelines e.g., healthcare, food and fuel.	Tolerable
43	Lifelines	Transport	Seismic shaking	Rare	Major	Extensive structural damage is likely for bridges and culverts, including potential span failure or pier cracking. Road and rail corridors may be impassable due settlement/ deformation. Service disruption could range from 1-week to 1-month, with impacts to regional transport and supply chains (e.g., fast moving consumer goods). Damage/ failure of key structures such as the Clydevale or Balclutha bridges would isolate parts of the delta, and disconnect Southland from the rest of the country. These structures are co-located with other key utilities such as three waters, electricity and telecommunications. Cascading impacts are likely from the failure of these lifeline utilities.	Acceptable
44	Lifelines	Transport	Liquefaction (co-seismic)	Likely	Minor	Minor ground settlement may occur beneath roads/rail lines, with limited impact on structural components. Culverts and bridges remain functional. Service disruptions are likely to be brief, with a focus on inspections. No significant outage likely (up to 2 hours). Liquefaction is unlikely to be triggered in most areas under this scenario, however in low-lying areas with shallow ground water may have minor impacts.	Acceptable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
45	Lifelines	Transport	Liquefaction (co-seismic)	Possible	Major	Localised liquefaction may result in settlement and deformation of road and rail surfaces, misalignment of culverts, and damage to bridge approaches. Bridge abutments may be deformed, damaging bridge foundations and superstructure. 42 km (22%) of rail, 116 km (25%) of road , 22(100%) bridges and 8 (57%) culverts are located within "Liquefaction is Possible" zones. Service disruption could range from 1-week to 1 month, with road/rail closures for remediation. Prioritisation will be given to critical roads such as SH1 to ensure connectivity to the lower Southland area. Some local roads may have disrupted access isolating communities and restricting access to key lifelines e.g., healthcare, food and fuel.	Tolerable
46	Lifelines	Transport	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, resulting in severe settlement and loss of bearing capacity beneath roads, rail, and bridge abutments. Culverts may be uplifted or blocked. 42 km (22%) of rail, 116 km (25%) of road , 22(100%) bridges and 8 (57%) culverts are located within "Liquefaction is Possible" zones. Service disruption is likely to be greater than one month, with major detours in place and loss of critical structures. Damage/ failure of key structures such as the Clydevale or Balclutha bridges would isolate parts of the delta, and disconnect Southland from the rest of the country. These structures are co-located with other key utilities such as three waters, electricity and telecommunications. Cascading impacts are likely from the failure of these lifeline utilities.	Tolerable
47	Lifelines	Transport	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading is likely to be limited and concentrated near river margins if it is triggered. Minor displacement of road and rail surfaces may occur, with culverts experiencing slight joint movement and bridges showing minor abutment displacement. Service disruption is limited to short-term lane or track closures for inspection and minor repair (up to 1-day). These disruptions on critical routes such as SH1 could have minor impacts on the flow of goods and services.	Acceptable
48	Lifelines	Transport	Lateral spreading (co-seismic)	Possible	Moderate	Localised lateral spreading may result in slumping and cracking of road and rail embankments, misalignment of culverts and displacement of bridge abutments. 19 km (25%) of rail and 42 km (22%) of road, 7 (32%) bridges and 4 (29%) culverts are located within mapped lateral spreading zones. Service disruption of up to one-week is likely due to partial closures and repair works. Disruption to key routes such as SH1 and the rail corridor may restrict access to lifelines (e.g., healthcare, food and fuel), and isolate those communities particularly in Inch Clutha.	Tolerable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
49	Lifelines	Transport	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, particularly along riverbanks. Severe displacement may result in structural failure of bridges, collapse of culverts and impassable roads and rail corridors. 19 km (25%) of rail and 42 km (22%) of road, 7 (32%) bridges and 4 (29%) culverts are located within mapped lateral spreading zones. Service disruption will exceed one month, with major detour routes in place and long-term loss of critical structures. Damage/ failure of key structures such as the Clydevale or Balclutha bridges would isolate parts of the delta, and disconnect Southland from the rest of the country. These structures are co-located with other key utilities such as three waters, electricity and telecommunications. Cascading impacts are likely from the failure of these lifeline utilities.	Tolerable
50	Lifelines	Transport	Surface rupture	Rare	Catastrophic	Surface rupture intersecting transport corridors may result in complete structural failure of bridges, collapse or off-set of culverts, and severe offset of road and rail alignments. Deformation associated with surface rupture could significantly impact how the network functions. Service disruption will exceed one month, with full reconstruction or a new alignment required for damaged infrastructure. It is unlikely that SH1 will be directly impacted by surface rupture in this scenario, however key roads in and out of Kaitangata may be impacted, resulting in isolation of this community from critical lifelines (e.g., healthcare, food and fuel).	Tolerable
51	Lifelines	Three Waters	Seismic shaking	Likely	Minor	Seismic shaking may result in minor cracking (hairline) of buried pipes, displacement of fittings and cosmetic damage to reservoirs (water tanks) and pump stations. Flood gates and water intake structures may experience joint movement. Service disruption is likely to be limited to short-term outages (up to 1 day) for inspection and minor repairs. Electrical equipment at treatment plants and pump stations may be disrupted, resulting in short term service outages.	Acceptable
52	Lifelines	Three Waters	Seismic shaking	Possible	Moderate	Seismic shaking may result in cracking and misalignment of pipes and joints, alongside reservoirs (water tanks) that are concrete. Mechanical components at pump stations and treatment plants are likely to be damaged, with loss of sealing capacity at flood gates. Service disruption of up to 1 week is likely, with prioritisation likely focused on water supply and wastewater infrastructure.	Tolerable
53	Lifelines	Three Waters	Seismic shaking	Rare	Catastrophic	Seismic shaking may result in structural damage to treatment plants, collapse of reservoirs (water tanks) and failure of pump station components. Pipes may rupture, and culverts may be displaced or blocked. Service disruption of more than 1 month is likely with wider cascading impacts to other parts of the water supply, wastewater and stormwater system. Co-located assets i.e., bridges carrying pipes, may isolate parts of the network and delay recovery further. Prioritisation is likely to be focused on water supply and wastewater infrastructure.	Tolerable
54	Lifelines	Three Waters	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, however minor ground deformation may occur. Pipes and reservoirs (water tanks) may experience slight settlement, however functionality remains intact. Service disruption is limited to checks and minor repairs (up to 1-day).	Acceptable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
55	Lifelines	Three Waters	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in differential settlement, tilting of reservoirs (water tanks), and pump stations and misalignment of buried pipes. Ejected material may partially block culverts and intake structures leading to service disruption of up to 1 week, to allow for repair and clearance of material. 209 km (58%) of pipes, 5 (83%) treatment plants, 14 (74%) pump stations, 3 (100%) intake locations and 35 (90%) flood gates are all located within extents mapped as "Liquefaction is Possible".	Tolerable
56	Lifelines	Three Waters	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is expected, resulting in severe ground deformation, loss of bearing capacity and structural failure of reservoirs (water tanks), pump stations and intake structures. Pipes may rupture, and/ or uplift and ejected material is likely to block culverts and intake structures. 209 km (58%) of pipes, 5 (83%) treatment plants, 14 (74%) pump stations, 3 (100%) intake locations and 35 (90%) flood gates are all located within extents mapped as "Liquefaction is Possible". Service disruption is likely to exceed one month, with major reconstruction required. Failure of some of these key assets may result in loss of potable water, uncontrolled wastewater discharge, and increased flood risk.	Tolerable
57	Lifelines	Three Waters	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading is likely to be limited and concentrated near river margins if it is triggered. Minor displacement of buried pipes and fittings may occur, with pump stations and, treatment plants, intake locations and reservoirs (water tanks) experiencing slight misalignment. Service disruption is limited to inspection and minor repairs (up to 1-day).	Acceptable
58	Lifelines	Three Waters	Lateral spreading (co-seismic)	Possible	Major	Localised lateral spreading may shear pipe joints, displace reservoirs (water tanks), and misalign pump station foundations. Culverts and intake locations may be partially blocked or deformed, with flood gates becoming potentially inoperable. 62 km (17%) of pipes, 4 (67%) treatment plants, 11 (58%) pump stations, 3 (100%) intake locations, and 29 (74%) flood gates are located within mapped lateral spreading zones. Service disruption of up to 1-week is likely, with reduce service capacity in impacted areas.	Tolerable
59	Lifelines	Three Waters	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing rupture of pipes, collapse of reservoirs (water tanks) and structural failure of pump stations and intake locations. 62 km (17%) of pipes, 4 (67%) treatment plants, 11 (58%) pump stations, 3 (100%) intake locations, and 29 (74%) flood gates are located within mapped lateral spreading zones. Service disruption is likely to exceed 1 month, with widespread loss of service and cascading impacts to public health and flood management.	Tolerable
60	Lifelines	Three Waters	Surface rupture	Rare	Catastrophic	Surface rupture intersecting three waters infrastructure may result in partial or complete structural failure of reservoirs (water tanks), pump stations, treatment plants, and intake structures. Pipes may be severed or offset and culverts may collapse. Deformation associated with surface rupture could also significantly impact how the three waters network functions. Service disruption is likely to exceed 1 month, with isolated areas of service disruption. Three waters infrastructure located in and around Kaitangata is likely to be more susceptible to damage, due to its proximity to the Titri Fault.	Tolerable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
61	Lifelines	Fuel	Seismic shaking	Likely	Minor	Seismic shaking may result in minor displacement of above-ground tanks, loosening of pipe connections, and cosmetic damage to dispensing equipment. Service disruption is likely to be limited to short-term inspection and minor repairs (up to 1 day). Fuel sites located near transport corridors may experience minor disruption to supply logistics.	Acceptable
62	Lifelines	Fuel	Seismic shaking	Possible	Moderate	Seismic shaking may result in cracking of tank foundations, misalignment of underground piping and damage to mechanical fittings. Service disruption of up to 1 week is expected, with temporary closure of affected sites for inspection and repair. This may result in impacts to fuel availability within the study area for emergency services and agricultural operations.	Tolerable
63	Lifelines	Fuel	Seismic shaking	Rare	Major	Seismic shaking may result in structural damage to tanks, rupture of underground pipes, and structural failure of containment structures. Service disruptions of up to 1 month likely, with potential environmental and public health impacts from fuel leakage. Failure/ damage of this infrastructure may exacerbate impacts to the transport and emergency response efforts post event, particularly for isolated areas.	Acceptable
64	Lifelines	Fuel	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, though minor ground deformation may occur. Tanks and underground infrastructure remain functional, other than damage as a result of seismic shaking. Service disruption of up to 1-day is possible for inspections.	Acceptable
65	Lifelines	Fuel	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in settlement of tank foundations, misalignment of underground pipes, and damage to containment structures. Service disruption of up to 1 week is expected, with temporary closure of affected sites for inspection and repair. This may result in impacts to fuel availability within the study area for emergency services and agricultural operations.	Tolerable
66	Lifelines	Fuel	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, resulting in severe settlement and loss of bearing capacity beneath tanks and underground infrastructure. Rupture of pipes and failure of containment systems may occur. There are various petrol stations within the study area, alongside one fuel site (lifelines). 89% (8) petrol stations and the lifelines fuel site are located within "Liquefaction is Possible" extents. Service disruption is likely to exceed 1 month, with environmental remediation required. Fuel site failure may result in hazardous spills, increased fire risk, public health concerns and prolonged disruption to regional fuel supply.	Tolerable
67	Lifelines	Fuel	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading is likely to be limited and concentrated near river margins if it is triggered. It may cause minor displacement of tank foundations and underground piping. Service disruption is limited to inspection and minor repairs (up to 1-day).	Acceptable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
68	Lifelines	Fuel	Lateral spreading (co-seismic)	Possible	Moderate	Localised lateral spreading may shear underground pipes, misalign tanks, and damage containment systems. Service disruption of up to 1 week is likely, with partial loss of operability. This may result in impacts to fuel availability within the study area for emergency services and agricultural operations.	Tolerable
69	Lifelines	Fuel	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing rupture of underground pipes, collapse of containment systems and structural damage to tanks. 44% (4) petrol stations and the lifelines fuel site are located within mapped lateral spreading zones. Service disruption is likely to exceed 1 month, with environmental remediation required. Fuel site failure may result in hazardous spills, increased fire risk, public health concerns and prolonged disruption to regional fuel supply.	Tolerable
70	Lifelines	Fuel	Surface rupture	Rare	Catastrophic	Surface rupture intersecting fuel sites may result in complete structural failure of tanks, severing of underground pipes, and loss of containment. Service disruption is likely to exceed 1 month, with environmental and public health and safety risks requiring full remediation. The two petrol stations located near Kaitangata are more susceptible to damage due to their proximity to the Titri Fault. The lifelines fuel site is located in Balclutha so is less susceptible to damage from fault rupture.	Tolerable
71	Lifelines	Electricity	Seismic shaking	Likely	Minor	Seismic shaking may result in minor displacement of equipment, loosening of fittings, and cosmetic damage to substation components. Transmission towers may sway but remain structurally sound. Service disruption is limited to inspections and minor repairs (up to 1 day).	Acceptable
72	Lifelines	Electricity	Seismic shaking	Possible	Moderate	Seismic shaking may result in cracking of substation foundations, misalignment of switchgear and damage (cracking) to transmission tower footings. Transmission towers may sway, but remain structurally sound. Equipment within substations can become dislodged, or short-circuit resulting in disruption to services. Service disruption is up to 1 week, for inspection and repair. Temporary outages likely, with electricity disrupted immediately post event. Service disruption will have a cascading impacts on other lifeline utilities e.g., telecommunications, water and emergency services.	Tolerable
73	Lifelines	Electricity	Seismic shaking	Rare	Major	Seismic shaking may result in structural damage to substations, tilting of transmission towers and potential failure of high-voltage components. Shaking may also cause tall, or slim structures to oscillate causing damage to lines and co-located assets such as transformers. Equipment within substations can become dislodged, or short circuit, leading to power outages. Service disruption could range from 1-week to 1-month, with cascading impacts on other lifeline utilities e.g., telecommunications, water and emergency services.	Acceptable
74	Lifelines	Electricity	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, though minor ground deformation may occur around substation pads and tower footings. Equipment remains functional, with no structural damage expected. Service disruption is limited to inspections and minor repair (up to 1-day).	Acceptable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
75	Lifelines	Electricity	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in settlement of substation pads, minor tilting of transmission towers, and misalignment of buried cables. Electrical components and co-located assets such as transformers may be stressed, or dislodged. Service disruption of up to 1-week is expected with temporary outages likely. Re-routing is likely to be required. Service disruption will have cascading impacts on other lifeline utilities e.g., telecommunications, water and emergency services.	Tolerable
76	Lifelines	Electricity	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, resulting in severe settlement and loss of bearing capacity beneath substations and towers. Structural failure of footings and rupture of underground cables may occur. There is one transmission tower located within the study area and it is located within a "Liquefaction is Possible" extent. Service disruption is likely to exceed 1 month with some infrastructure needing complete reconstruction, while others needing repair. Service disruption will have cascading impacts on other lifeline utilities e.g., telecommunications, water and emergency services.	Tolerable
77	Lifelines	Electricity	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading may cause minor displacement of tower footings and substation foundations, particularly near river margins or free faces. Service disruption is limited to inspection and minor repairs (up to 1-day).	Acceptable
78	Lifelines	Electricity	Lateral spreading (co-seismic)	Possible	Moderate	Localised lateral spreading may shear buried cables, misalign components, and damage substation foundations and components. Co-located assets such as transformers can be stressed or short-circuited. Service disruption of up to 1-week is expected with temporary outages likely. Re-routing is likely to be required. Service disruption will have cascading impacts on other lifeline utilities e.g., telecommunications, water and emergency services.	Tolerable
79	Lifelines	Electricity	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, leading to shearing of cables, misalignment of components and damage to substation foundation and components. Tilting of transmission towers is possible, and stress of co-located assets is likely to occur. The one transmission tower within the study area is located within a mapped lateral spreading zone. Service disruption is likely to exceed 1 month, with widespread outages and cascading impacts on other lifeline utilities e.g., telecommunications, water and emergency services.	Tolerable
80	Lifelines	Electricity	Surface rupture	Rare	Catastrophic	Surface rupture intersecting electricity infrastructure may result in complete structural failure of towers, substations, severing both transmission and distribution lines. Service disruption would exceed 1 month, with widespread outages not only locally but within the region. There are no major electricity assets located within the Kaitangata township which is located within close proximity to the Titri Fault.	Tolerable
81	Lifelines	Telecommunications	Seismic shaking	Likely	Minor	Seismic shaking may result in minor displacement of cell tower components and minor deformation of fibre cable supports. Antennae may sway but remain structurally sound. Service disruption is limited to inspections and minor repairs (up to 1-day). Fibre routes co-located with bridges or road corridors may require inspection, but functionality is expected to stay intact.	Acceptable

Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
82	Lifelines	Telecommunications	Seismic shaking	Possible	Moderate	Seismic shaking may result in displacement of cell tower components, damage to antennae mounts and stress on fibre cables. Equipment cabinets may shift or short-circuit. Service disruption of up to 1-week is likely for inspections and minor repairs. Service disruption is also dependant on impacts / outages within the electricity network. Reduced signal strength and data capacity may result from this level of shaking. Disruption may affect emergency services communications and internet access, particularly in rural and coastal areas, with limited redundancy.	Tolerable
83	Lifelines	Telecommunications	Seismic shaking	Rare	Major	Seismic shaking may result in structural damage to cell towers, collapse of antennae, and severance of fibre cables. Equipment cabinets may be dislodged or damaged. Service disruption of up to 1 month is likely, with cascading impacts on emergency coordination, public communication and digital services. Failure of fibre backhaul may isolate communities digitally, particularly where co-located infrastructure is also damaged (e.g., SH1).	Acceptable
84	Lifelines	Telecommunications	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, though minor deformation may occur. Fibre cables and cell tower infrastructure is likely to remain functional. Service disruption is limited to inspections and any minor repairs (up to 1-day).	Acceptable
85	Lifelines	Telecommunications	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in settlement of cell tower and cell site foundations, misalignment of antennae and deformation of fibre cables. Service disruption is likely up to 1 week, with reduced signal strength, and data capacity. Service disruption is also dependant on impacts/ outages within the electricity network. Disruption may affect emergency services communications, and internet access, particularly in rural and coastal areas, with limited redundancy.	Tolerable
86	Lifelines	Telecommunications	Liquefaction (co-seismic)	Rare	Catastrophic	Widespread liquefaction is likely, causing severe settlement and potential structural failure of cell towers and cell sites. Fibre cables are likely to be severed/ ruptured, disconnecting communications locally. Service disruption is likely to exceed 1 month, with reconstruction of some infrastructure likely. Of the 4 cell sites/ towers within the study area, 3 are located within "Liquefaction is Possible" extents. 62 km (30%) of fibre cable is also located within "Liquefaction is Possible" extents.	Tolerable
87	Lifelines	Telecommunications	Lateral spreading (co-seismic)	Likely	Minor	Lateral spreading may cause minor displacement of cell tower footings, cell site foundations and fibre cables, particularly near river margins and free faces. Service disruption is limited to inspection and minor repairs (up to 1-day).	Acceptable
88	Lifelines	Telecommunications	Lateral spreading (co-seismic)	Possible	Moderate	Localised lateral spreading may result in the shearing of fibre cables, and damage of cabinet equipment. Service disruption of up to 1 week is expected, with reduced signal strength and data capacity likely. Service disruption is also dependent on impacts/outages within the electricity network. Disruption may affect emergency services communications, and internet access, particularly in rural and coastal areas, with limited redundancy.	Tolerable

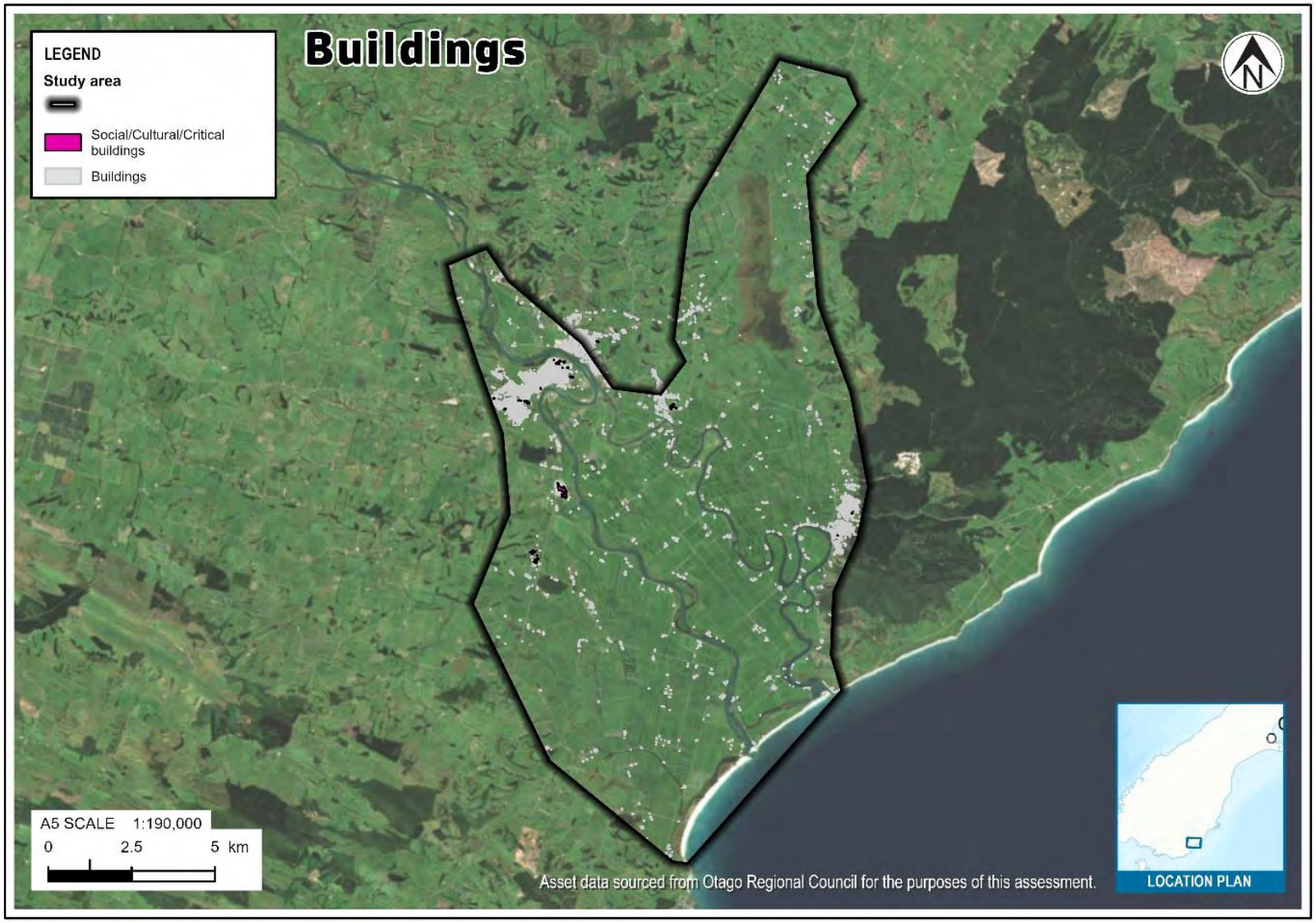
Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
89	Lifelines	Telecommunications	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing tilting of cell towers, structural damage to cell sites and severance of fibre cables. Equipment cabinets may be displaced or completely destroyed. Service disruption is likely to exceed 1 month, with full reconstruction needed for some damaged infrastructure. Failure of fibre backhaul may isolate communities digitally, particularly where co-located infrastructure is also damaged (e.g., SH1). One of the cell sites is located within mapped lateral spreading zones, alongside 22 km (11%) of fibre cable.	Tolerable
90	Lifelines	Telecommunications	Surface rupture	Rare	Catastrophic	Surface rupture intersecting telecommunications infrastructure may result in the collapse of cell towers, loss of structural integrity for cell sites and severing of fibre cables. Equipment cabinets may be displaced or destroyed. Service disruption is likely to exceed 1 month with full reconstruction required for damaged infrastructure. Failure of fibre backhaul may isolate communities digitally, particularly where co-located infrastructure is also damaged (e.g., SH1). One of the cell sites is located north of the Kaitangata township, so may be more susceptible to damage from fault rupture.	Tolerable
91	Buildings	Buildings	Seismic shaking	Likely	Minor	Seismic shaking may result in cosmetic to moderate damage of buildings. Small unstable fittings and objects may be displaced with some glassware and crockery broken. Some windows may also crack. Older unreinforced buildings are more susceptible to damage and some may be functionally compromised under this level of shaking.	Acceptable
92	Buildings	Buildings	Seismic shaking	Possible	Moderate	Seismic shaking may result in cracking and structural/non-structural damage. Unreinforced stone and brick walls can crack, with roof tiles being dislodged. Domestic chimneys may be damaged, alongside suspended ceilings. Unrestrained water cylinders may move or leak and windows are likely to crack.	Tolerable
93	Buildings	Buildings	Seismic shaking	Rare	Major	Seismic shaking may result in structural damage or collapse of unreinforced and poorly constructed buildings. Some monuments and elevated tanks and factory stacks are twisted or brought down. Some infill masonry panels damaged, with a few brick veneers damaged. Houses not secured to foundations may move.	Acceptable
94	Buildings	Buildings	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, however minor ground deformation may occur. Buildings may experience slight tilting or hairline foundation cracks. Inspections may be required (up to 1-day).	Acceptable
95	Buildings	Buildings	Liquefaction (co-seismic)	Possible	Moderate	Localised liquefaction may result in differential settlement of buildings, particularly those on susceptible soils. Foundations may tilt and crack, with minor structural damage occurring. Residents may need to temporarily evacuate for inspection and repairs.	Tolerable

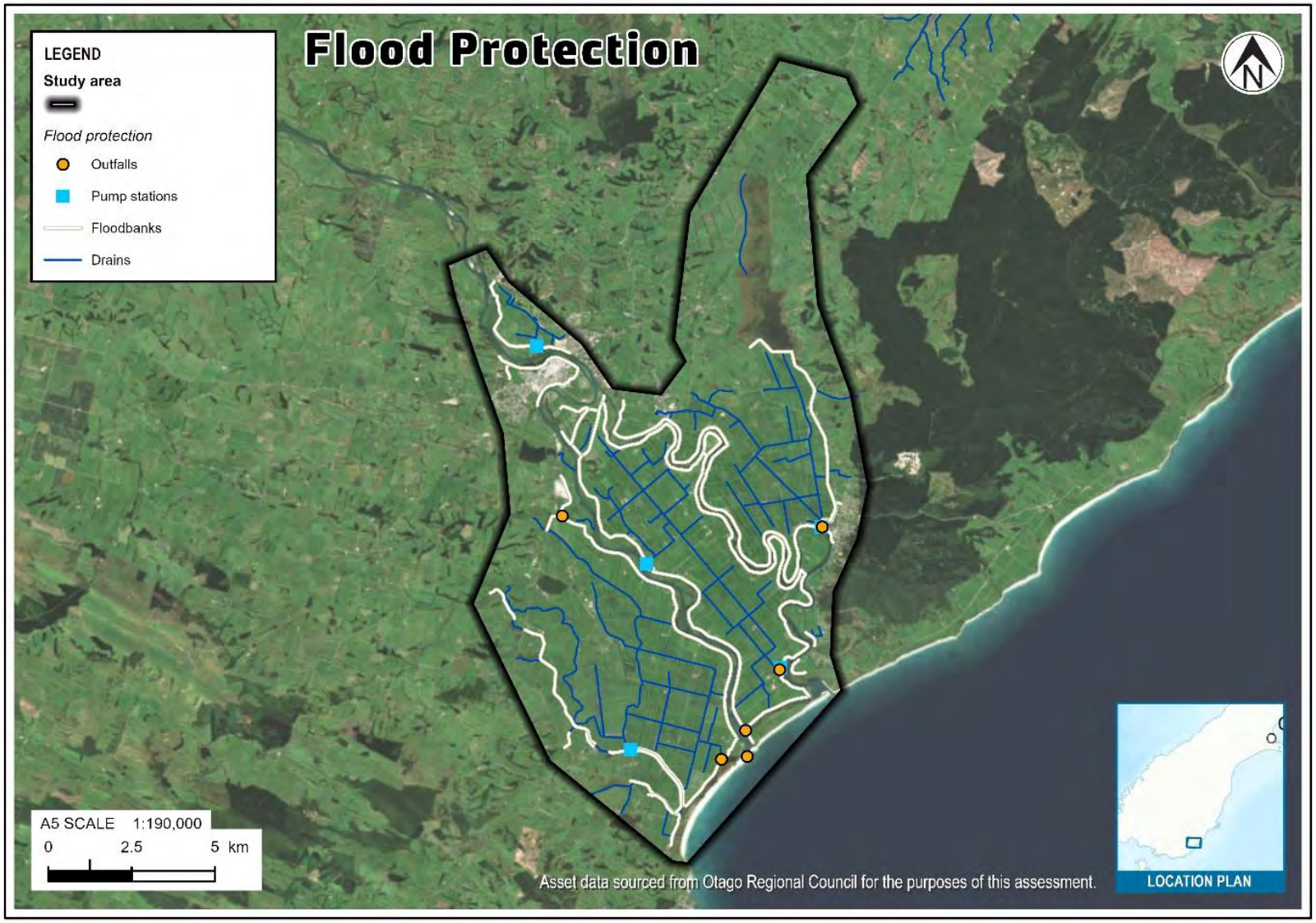
Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
96	Buildings	Buildings	Liquefaction (co-seismic)	Rare	Catastrophic	Liquefaction is expected to be widespread, particularly in areas with shallow groundwater and susceptible soils (33% (1,902) of buildings located within "Liquefaction is Possible" zones). Buildings may experience severe foundation damage, tilting and partial collapse. Functionality is likely to be compromised, with long term or permanent displacement likely for affected residents.	Tolerable
97	Buildings	Buildings	Lateral spreading (co-seismic)	Likely	Minor	Lateral ground movement may cause minor displacement of building foundations (hairline cracks) particularly those located near riverbanks/ free faces. Misalignment of doors/windows may occur as a result of displacement. Buildings will likely remain functional, and may need minor repairs.	Acceptable
98	Buildings	Buildings	Lateral spreading (co-seismic)	Possible	Moderate	Localised lateral spreading may result in foundation displacement and cracking, influencing the structural integrity of the building. Buildings may be temporarily uninhabitable while repairs are undertaken. Utility connections may also be displaced, causing disruption and health and safety concerns.	Tolerable
99	Buildings	Buildings	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing severe foundation displacement and structural damage. Buildings may undergo partial or full collapse resulting in long term and potentially permanent relocation for residents. 13% (765) of buildings are located within mapped lateral spreading zones.	Tolerable
100	Buildings	Buildings	Surface rupture	Rare	Catastrophic	Buildings located on or near the fault rupture zone may experience complete structural failure due to ground offset. Foundations may be split, or displaced leading to partial or full collapse. Total loss of building function is expected, with reconstruction required. Buildings located in Kaitangata are more susceptible to damage due to their proximity to the Titri Fault.	Tolerable
101	Buildings	Critical Buildings	Seismic shaking	Likely	Minor	Seismic shaking may result in cosmetic to moderate damage of buildings. Small unstable fittings and objects may be displaced with some glassware and crockery broken. Some windows may also crack. Older or unreinforced buildings are more susceptible to damage and may be functionally compromised under this level of shaking (e.g., Library and Community Pool).	Acceptable
102	Buildings	Critical Buildings	Seismic shaking	Possible	Moderate	Seismic shaking may result in cracking and structural/non-structural damage. Unreinforced stone and brick walls can crack, with roof tiles being dislodged. Domestic chimneys are likely to be damaged, alongside suspended ceilings. Unrestrained water cylinders may move or leak and windows are likely to crack.	Tolerable
103	Buildings	Critical Buildings	Seismic shaking	Rare	Catastrophic	Seismic shaking may result in structural damage or collapse of unreinforced and poorly constructed buildings. Some monuments and elevated tanks and factory stacks are twisted or brought down. Some infill masonry panels damaged, with a few brick veneers damaged. Houses not secured to foundations may move.	Tolerable
104	Buildings	Critical Buildings	Liquefaction (co-seismic)	Likely	Minor	Liquefaction is unlikely to be triggered under this scenario, however minor ground deformation may occur. Buildings may experience slight tilting or hairline foundation cracks. Inspections may be required, however functionality remains intact.	Acceptable

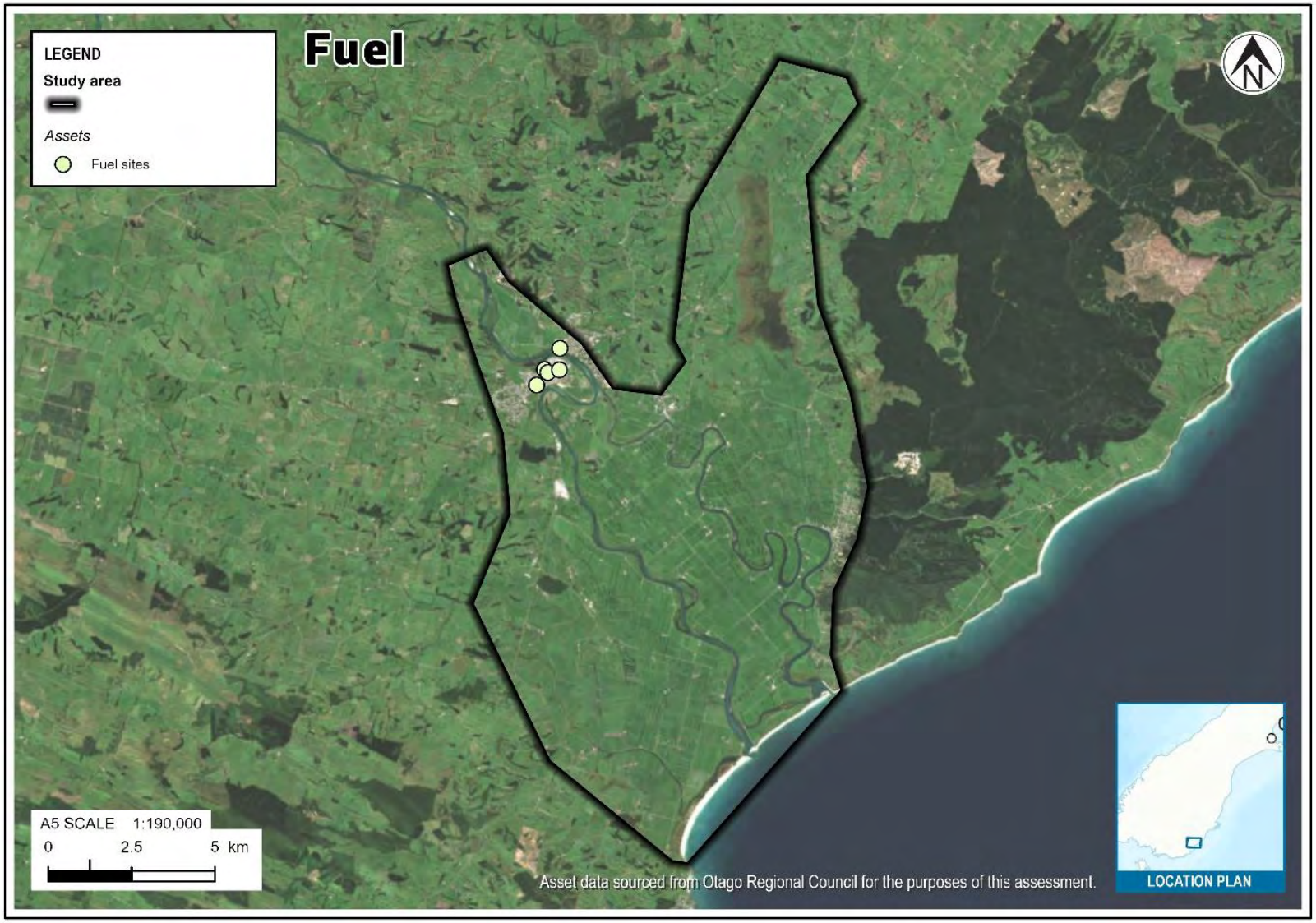
Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
105	Buildings	Critical Buildings	Liquefaction (co-seismic)	Possible	Major	Localised liquefaction may result in differential settlement of buildings, particularly those on susceptible soils. Foundations may tilt and crack, with minor structural damage occurring. Occupants may need to temporarily evacuate for inspection and repairs.	Tolerable
106	Buildings	Critical Buildings	Liquefaction (co-seismic)	Rare	Catastrophic	Liquefaction is expected to be widespread, particularly in areas with shallow groundwater and susceptible soils (17% (10) of critical buildings are located within "Liquefaction is Possible" zones). Buildings may experience severe foundation damage, tilting and partial collapse. Functionality is likely to be compromised, with long term or permanent displacement likely for affected residents.	Tolerable
107	Buildings	Critical Buildings	Lateral spreading (co-seismic)	Likely	Minor	Lateral ground movement may cause minor displacement of building foundations (hairline cracks) particularly those located near riverbanks/ free faces. Misalignment of doors/windows may occur as a result of displacement. Buildings will likely remain functional, and may need minor repairs.	Acceptable
108	Buildings	Critical Buildings	Lateral spreading (co-seismic)	Possible	Major	Localised lateral spreading may result in foundation displacement and cracking, influencing the structural integrity of the building. Buildings may be temporarily uninhabitable while repairs are undertaken. Utility connections may also be displaced, causing disruption and health and safety concerns.	Tolerable
109	Buildings	Critical Buildings	Lateral spreading (co-seismic)	Rare	Catastrophic	Extensive lateral spreading is expected, causing severe foundation displacement and structural damage. Buildings may undergo partial or full collapse resulting in long term and potentially permanent relocation for residents. 10% (6) of critical buildings are located within mapped lateral spreading zones.	Tolerable
110	Buildings	Critical Buildings	Surface rupture	Rare	Catastrophic	Buildings located on or near the fault rupture zone may experience complete structural failure due to ground offset. Foundations may be split, or displaced leading to partial or full collapse. Total loss of building function is expected, with reconstruction required. Buildings located in Kaitangata are more susceptible to damage due to their proximity to the Titri Fault.	Tolerable
111	Health & Safety	Health and Safety	Seismic shaking	Likely	Insignificant	Seismic shaking is expected to result in no injuries or fatalities. Most buildings will remain structurally sound, with only minor internal hazards e.g., falling objects.	Acceptable
112	Health & Safety	Health and Safety	Seismic shaking	Possible	Minor	Seismic shaking may result in minor injuries that are likely to require medical attention, particularly from falling debris or internal hazards in older buildings. No fatalities are expected. Estimating the number of fatalities and injured is dependant on many factors including building construction (age, construction and no. of storeys), time of day and the vulnerability of the population.	Acceptable
113	Health & Safety	Health and Safety	Seismic shaking	Rare	Major	Seismic shaking may result in multiple injuries (more than 100) and potentially up to 10 fatalities, particularly in unreinforced masonry buildings. Vulnerable populations within Balclutha, including the aged residents (Balclutha rest home, PACT House, and retirement housing on Charlotte Street), alongside migrant/ seasonal workers are likely at greater risk due to mobility limitations, building fragility and uncertainty around these types of events.	Acceptable
114	Health & Safety	Health and Safety	Liquefaction (co-seismic)	Likely	Insignificant	Liquefaction is unlikely to cause direct injury. Minor ground deformation may pose low risk to personal safety, no injuries or fatalities are likely.	Acceptable

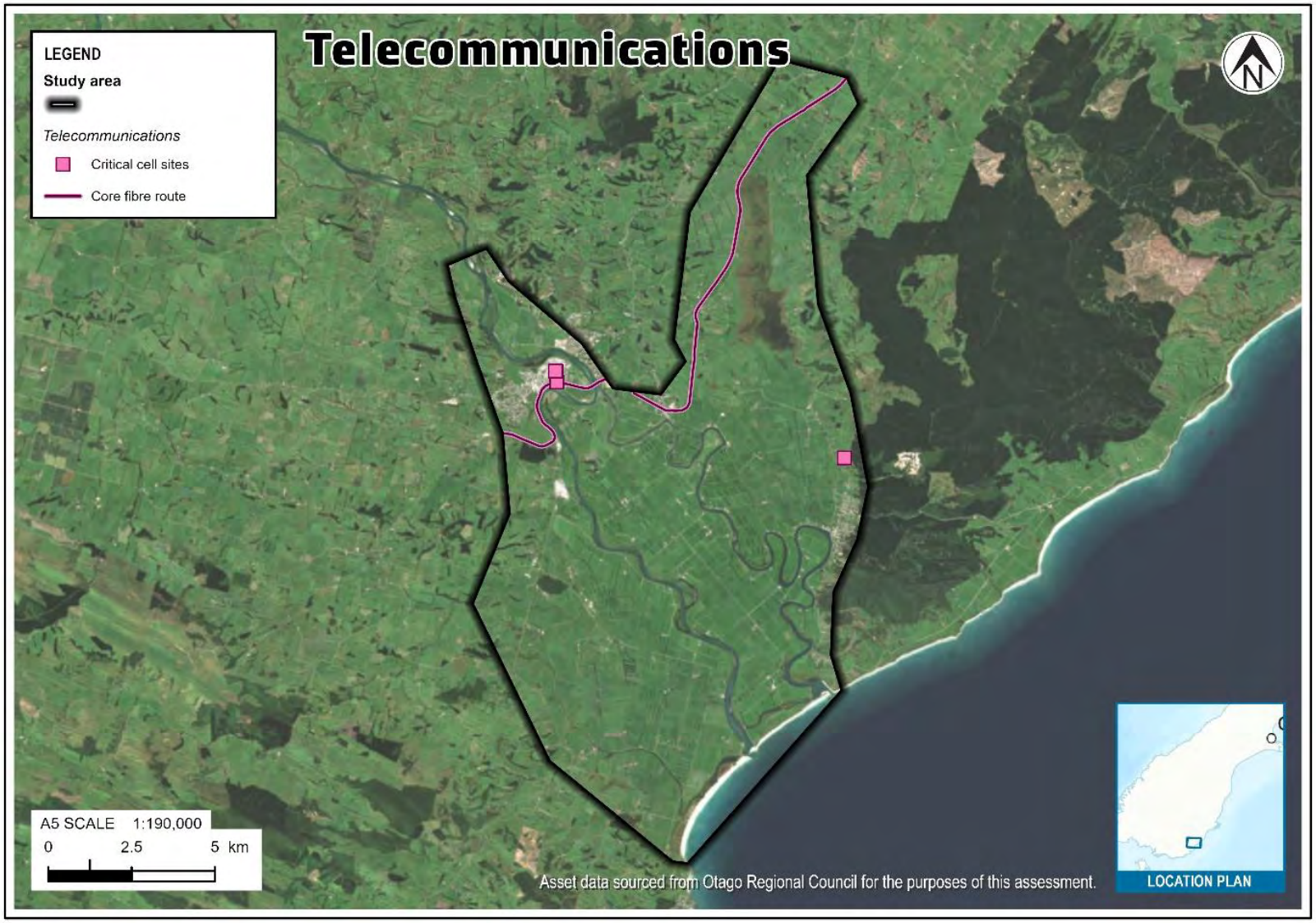
Risk ID	Asset Grouping	Asset Subgroup	Hazard	Likelihood	Consequence	Consequence description	Risk Score
115	Health & Safety	Health and Safety	Liquefaction (co-seismic)	Possible	Minor	Localised liquefaction may result in minor injuries due to ground instability or secondary hazards e.g., falling structures, tripping. Some injuries may require medical attention, particularly for vulnerable populations such as aged residents.	Acceptable
116	Health & Safety	Health and Safety	Liquefaction (co-seismic)	Rare	Major	Widespread liquefaction may lead to structural damage, with some partial collapse of buildings. This can result in injuries and potential fatalities. Vulnerable populations within Balclutha, including the aged residents (Balclutha rest home, PACT House, and retirement housing on Charlotte Street), alongside migrant/ seasonal workers are likely at greater risk due to mobility limitations, building fragility and uncertainty around these types of events.	Acceptable
117	Health & Safety	Health and Safety	Lateral spreading (co-seismic)	Likely	Insignificant	Lateral spreading is expected to be limited and not pose a significant risk to personal safety. No injuries or fatalities are expected.	Acceptable
118	Health & Safety	Health and Safety	Lateral spreading (co-seismic)	Possible	Minor	Localised lateral spreading may cause minor injuries as a result of ground displacement or structural movement. Some injuries may require medical attention, particularly for vulnerable populations such as aged residents.	Acceptable
119	Health & Safety	Health and Safety	Lateral spreading (co-seismic)	Rare	Major	Extensive lateral spreading may result in structural failure and potential collapse, particularly for buildings located near river margins. Both PACT House and Holmdede Home For The Aged are located within mapped lateral spreading zones so may be more susceptible to damage, and therefore health and safety risk for residents. Multiple injuries and potential fatalities are likely, particularly in unreinforced or poorly constructed buildings. Emergency response may be severely impacted as well, exacerbating health and safety risks.	Acceptable
120	Health & Safety	Health and Safety	Surface rupture	Rare	Catastrophic	Surface rupture may result in the collapse of buildings that it intersects. Multiple fatalities and injuries are likely, particularly in unreinforced or poorly constructed buildings. Emergency response may also be severely impacted.	Tolerable

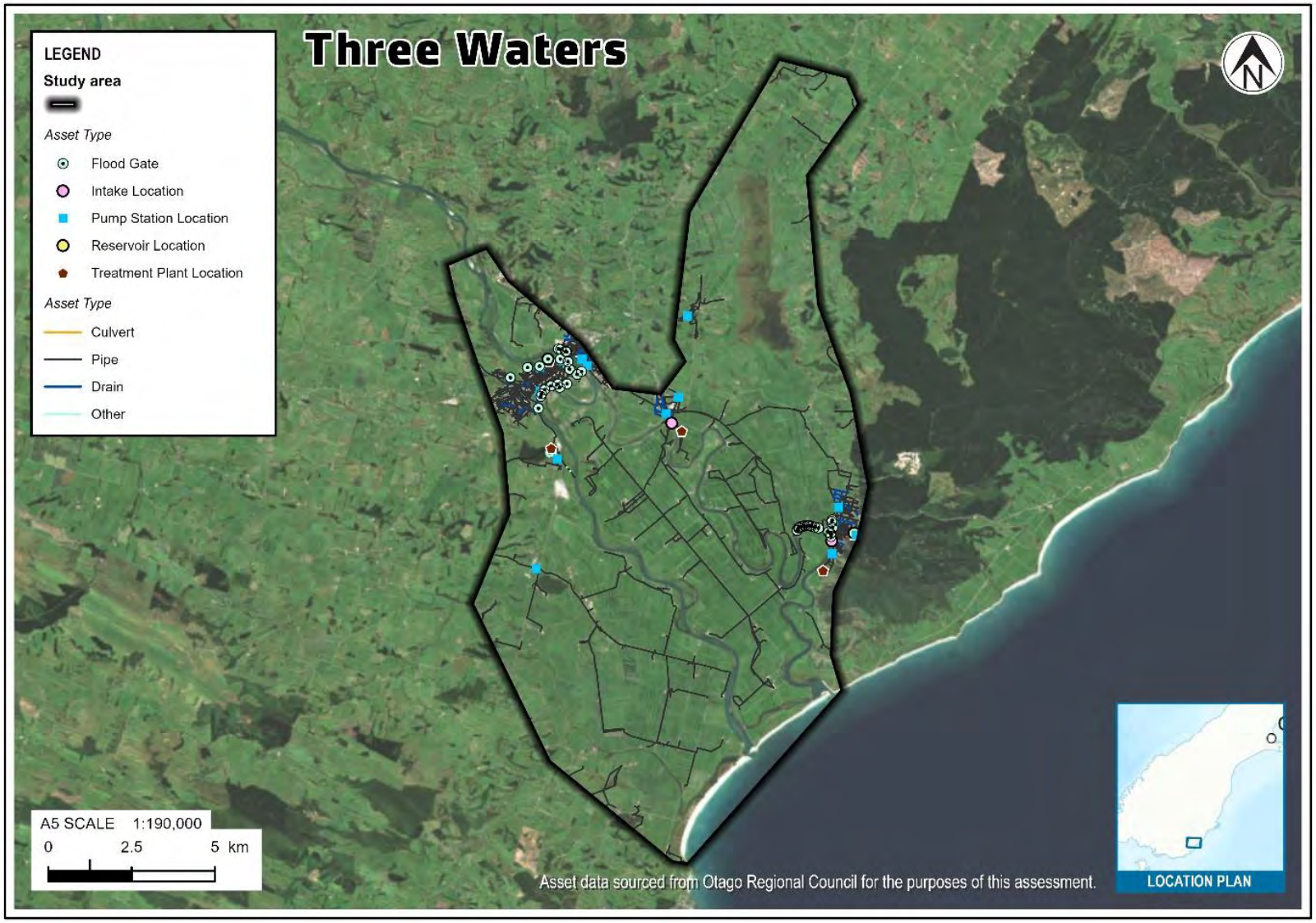
Appendix C Asset Figures

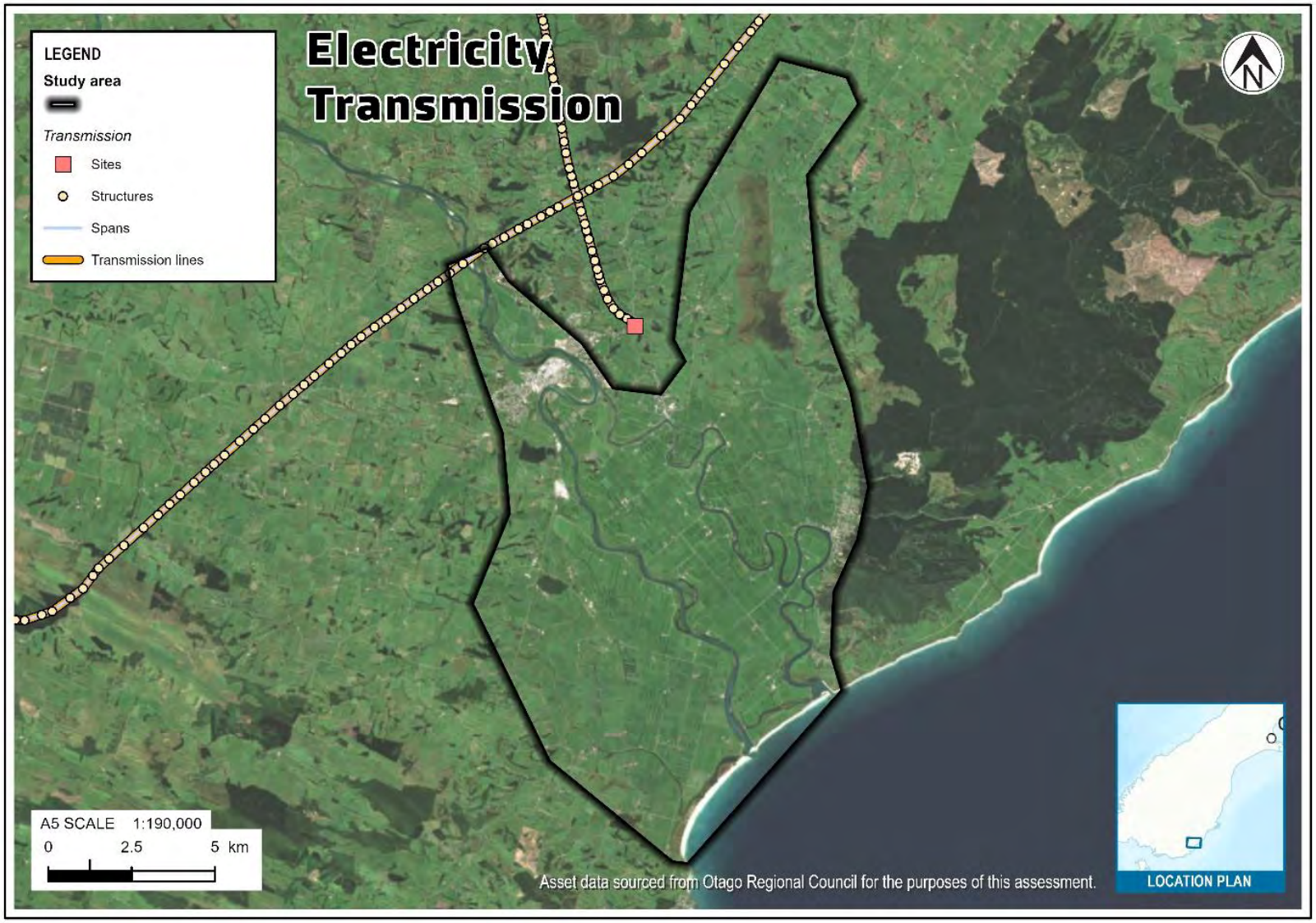

Buildings
LEGEND
Study area
Social/Cultural/Critical buildings
Buildings
N
A5 SCALE 1:190,000
0 2.5 5 km
Asset data sourced from Otago Regional Council for the purposes of this assessment.
LOCATION PLAN

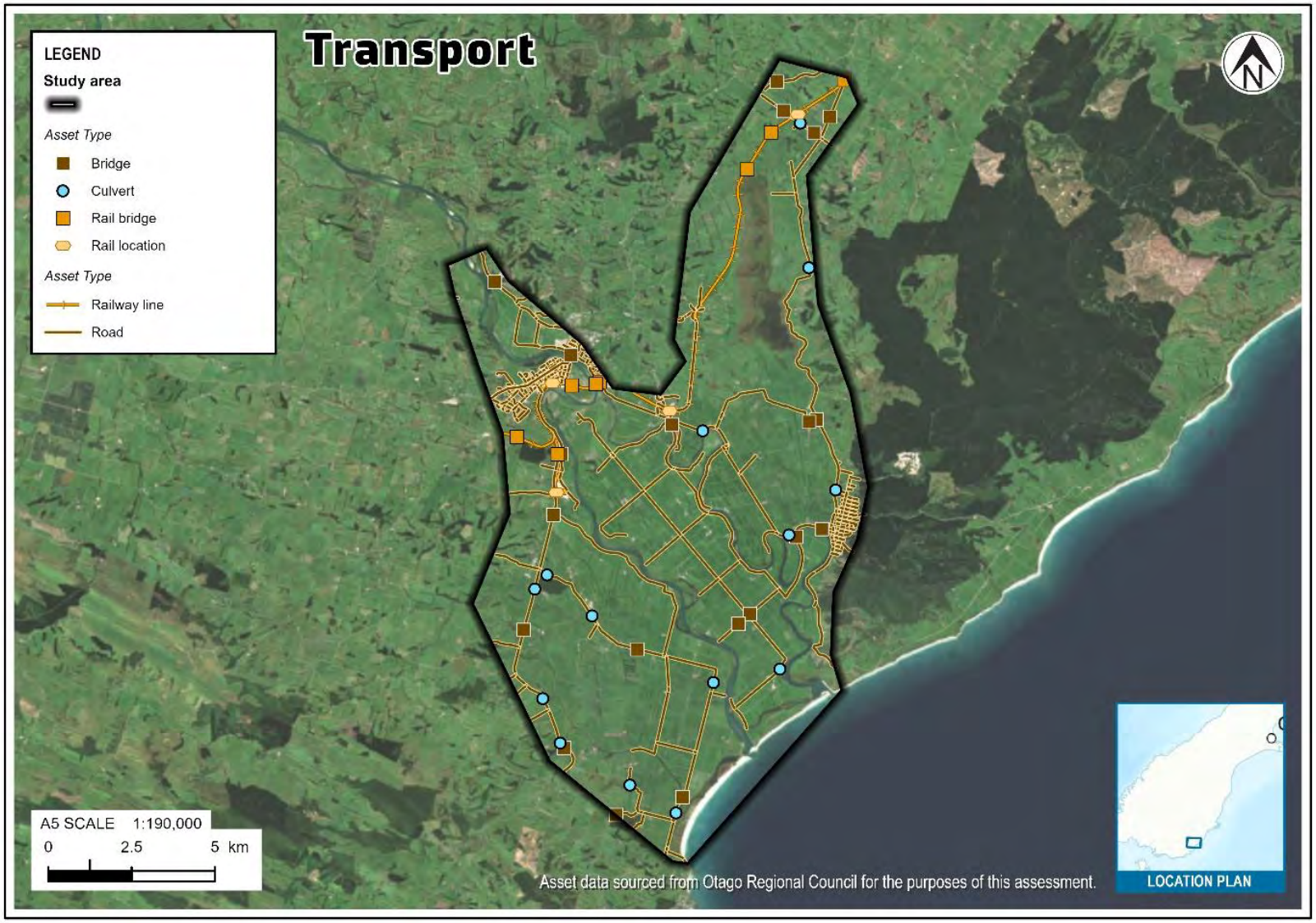

Flood Protection
LEGEND
Study area
Flood protection
Outfalls
Pump stations
Floodbanks
Drains
N
A5 SCALE 1:190,000
0 2.5 5 km
Asset data sourced from Otago Regional Council for the purposes of this assessment.
LOCATION PLAN


Fuel
LEGEND
Study area
Assets
Fuel sites
N
A5 SCALE 1:190,000
0 2.5 5 km
Asset data sourced from Otago Regional Council for the purposes of this assessment.
LOCATION PLAN


Telecommunications
LEGEND
Study area
Telecommunications
Critical cell sites
Core fibre route
N
A5 SCALE 1:190,000
0 2.5 5 km
Asset data sourced from Otago Regional Council for the purposes of this assessment.
LOCATION PLAN


Three Waters
LEGEND
Study area
Asset Type
Flood Gate
Intake Location
Pump Station Location
Reservoir Location
Treatment Plant Location
Asset Type
Culvert
Pipe
Drain
Other
N
A5 SCALE 1:190,000
0 2.5 5 km
Asset data sourced from Otago Regional Council for the purposes of this assessment.
LOCATION PLAN


Electricity Transmission
LEGEND
Study area
Transmission
Sites
Structures
Spans
Transmission lines
N
A5 SCALE 1:190,000
0 2.5 5 km
Asset data sourced from Otago Regional Council for the purposes of this assessment.
LOCATION PLAN


Transport
LEGEND
Study area
Asset Type
Bridge
Culvert
Rail bridge
Rail location
Asset Type
Railway line
Road
N
A5 SCALE 1:190,000
0 2.5 5 km
Asset data sourced from Otago Regional Council for the purposes of this assessment.
LOCATION PLAN

www.tonkintaylor.co.nz

NIWA
Taihoro Nukurangi

Clutha River morphology trends at Balclutha

Prepared for Otago Regional Council

March 2025

Climate, Freshwater & Ocean Science

Prepared by:
Arman Haddadchi, Graeme Smart

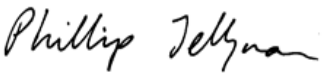
For any information regarding this report please contact:
Arman Haddadchi
Sediment Transport Scientist
Sediment Processes Group
+64 3 343 7896
arman.haddadchi@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8440

Phone +64 3 348 8987

NIWA CLIENT REPORT No: 2025057CH
Report date: March 2025
NIWA Project: ORC25501

Revision	Description	Date
Version 1.0	Final version sent to client	19 March 2025
Version 2.0	Updated version sent to client	12 May 2025

Quality Assurance Statement		
	Reviewed by:	Richard Measures
	Formatting checked by:	Rachel Wright
	Approved for release by:	Phillip Jellyman

Cover photo: Sentinel-2 satellite imagery of the Clutha River captured on 27th January 2025 showing the position of gravel bars.

© All rights reserved. This publication may not be reproduced or copied in any form without the permission of the copyright owner(s). Such permission is only to be given in accordance with the terms of the client's contract with NIWA. This copyright extends to all forms of copying and any storage of material in any kind of information retrieval system.

Whilst NIWA has used all reasonable endeavours to ensure that the information contained in this document is accurate, NIWA does not give any express or implied warranty as to the completeness of the information contained herein, or that it will be suitable for any purpose(s) other than those specifically contemplated during the project or agreed by NIWA and the client.

Contents

Executive summary **5**

1 Introduction **6**

1.1 Background 6

1.2 Scope of the work 6

2 Cross section data and adjustments **8**

2.1 Cross section data analysis 13

3 Satellite imagery **15**

4 Clutha River flow data and analysis **16**

5 Results **17**

5.1 Bed level changes 17

5.2 Changes across individual cross sections 25

5.3 Satellite imagery 27

5.4 Flow data analysis 28

6 Discussion **31**

6.1 Determine whether there is a significant trend in riverbed levels 31

6.2 Assess changes in gravel bars or islands 31

6.3 Identify factors driving changes observed 31

6.4 Evaluate whether observed riverbed level changes are sufficient to reduce flood capacity 32

7 Conclusions **33**

8 Acknowledgements **34**

9 References **35**

Appendix A Corrections made to historic cross section data **36**

Appendix B Cross section profiles for surveyed years **38**

Appendix C Maximum annual flow and mean annual flow vs. mean bed level for different survey years at each cross section **44**

Appendix D Satellite imageries of the Clutha River at Balclutha between 2016 and 2025 **56**

Tables

Table 2-1: Cross section data from the Clutha River near Balclutha township. 10
Table 2-2: End-point offsets and riverbed widths used for cross section data analysis including mean bed level calculations and area above mean bed level. 12

Table A-1: Adjustments applied to align historic cross section survey data. 36

Figures

Figure 2-1: The location of cross section surveys on the Clutha River at Balclutha together with the flow monitoring site. 9
Figure 2-2: Example of cross section data correction and interpolation between the measured points to find consistent start and end point for all surveyed years. 11
Figure 2-3: C1 cross sectional profile for all surveyed years. 13
Figure 2-4: Illustration of area above mean bed level for cross section C1 in 2024. 14
Figure 4-1: Annual maximum flow (a) and mean flow (b) for the Clutha River at Balclutha monitoring site. 16
Figure 5-1: Historical changes in the mean bed level (MBL) of the Clutha River near Balclutha township. 17
Figure 5-2: Changes in the mean bed Level over years at each cross section. 19
Figure 5-3: Mean bed level change relative to 1990 in the Clutha River near Balclutha, with surveys grouped by decade. 20
Figure 5-4: Evolution of mean bed levels with time and daily mean river flow at section C1 and section C6. 21
Figure 5-5: Historical changes in the minimum bed level of the Clutha near Balclutha. 22
Figure 5-6: Changes in the minimum bed Level over years at each cross section. 23
Figure 5-7: Historical changes in the height above bed level values of the Clutha River near Balclutha. 24
Figure 5-8: Changes in the average height above mean bed level over years at each cross section. 25
Figure 5-9: Satellite imagery of the Clutha River at Balclutha on two dates: January 10, 2016 (left) and January 27, 2025 (right). 27
Figure 5-10: Minimum bed level at times of flow gaugings near section C3. 28
Figure 5-11: Stage for flow compared with preservation of 1952 bed levels. 29
Figure 5-12: Stage for flow compared with preservation of 1978 bed levels. 29
Figure 5-13: Comparing stage for flow data from gauging measurements over the years. 30
Figure 6-1: Aerial photographs from 1946 (left) and in 1995 (right). Blue line indicates the mid-channel river training works upstream of cross section C6. 32

Figure B-1: Cross-sectional profiles of C2 to C7, M11, M12, K12, and K13 for all surveyed years. 43
Figure D-1: Satellite imagery of the Clutha River at Balclutha for seven years between 2016 and 2025. 62

Executive summary

To help maintain the integrity of flood protection and gravel resources, the Otago Regional Council undertakes periodic cross-section surveys of the Clutha River. This report analyses eleven of these sections alongside Balclutha and explores how the morphology of the river has changed over the surveyed period from 1865 to 2024. Bed level rise or fall, in a given reach, depends on the supply of alluvial sediment from upstream and any changes in reaches immediately downstream. Overall, the cross-section data suggest a long-term trend of lowering of the river bed from the 1950s to about 2002 with less trend evident since 2002. This could correspond to the river adjusting to a reduction in bed load coming from upstream following commissioning of the Roxburgh Dam in 1954. Other influences which can affect sediment supply from upstream are flood size and frequency, bank erosion and protection measures, upstream catchment changes and gravel and gold mining activities. Mean bed level analyses showed that ten of the eleven cross sections are stable or degrading. Section C4 (at the State Highway Bridge) shows a weak rising trend in mean bed level. Minimum bed levels are stable or falling at all cross sections except C6 (North end of Elizabeth Street) where the surveyed low point is rising with time. This change may result from historic, upstream river training works.

Channel flood capacity depends not only on a cross section but is influenced by hydraulic roughness and downstream flow conditions. These effects are captured by flood gauging measurements. Analysing the gaugings at Balclutha since 1952, shows channel capacity is increasing for floods up to around 1600 m^3/s. The extent of flood scour is unknown at Balclutha but, assuming this has not reduced due to coarsening of the sediment size, the historic cross section surveys do not indicate reduction of flood capacity of the Balclutha reach.

There are several factors which could affect the findings of this report, namely: (a) River beds can temporarily scour during a rising flood and refill as a flood falls so that the true cross section at a flood peak may not be captured by a subsequent cross-section survey. A few Balclutha cross section surveys have been made during floods, but an earlier Clutha model study noted that significant scour, below the surveyed bed level, was required to pass historic flood flows at the observed flood levels; (b) There are recent reports that gravel bars are now more evident at Balclutha. It is assumed this is because a stable bar will become more visible and appear to be higher if the river level falls alongside the bar. A field inspection may shed light on this possibility; and (c) The effect of river bed gravel mining on cross sections is captured by the surveys but its effect is not quantified.

Ongoing monitoring and, in particular, measurement of bed levels during future high flood flows, is strongly recommended. This would quantify the degree of bed scouring induced by floods and help refine future hydraulic modelling.

1 Introduction

1.1 Background

The Otago Regional Council (ORC) have commissioned NIWA to analyse and report on historical changes in riverbed levels in the Clutha River/Mata-Au near the Balclutha township, using data from cross section surveys, flow gaugings and imagery. The cross section surveys were undertaken by ORC and pre-cursor organisations. The results of the analyses will be used to help understand the complex dynamic fluvial processes and to guide river management strategies into the future.

Data from eleven cross section locations have been used for this analysis. Seven of these cross sections are within the Clutha River, four are located on the branches where the river splits in two just downstream of Balclutha. Cross section surveys for ten of the locations have been undertaken regularly since 1994 and, for the cross section located near the railway bridge, data extend as far back as 1878. Data earlier than 2008 are the same as given in Otago Regional Council report: Channel morphology and sedimentation in the Lower Clutha River (2008). All cross sections are viewed and discussed from a “looking downstream” point of view.

In 1954, closure of the Roxborough Hydro dam cut part of the supply of coarser alluvial sediment to downstream reaches. Prior to this about 328 kt/yr of bed sediment would have arrived at Balclutha but only 24.5 kt/yr of bed material now arrives (Hicks et al. 2000). Other influences which could affect sediment supply from upstream are flood size and frequency, bank erosion and protection measures, upstream catchment changes and gravel and gold mining activities. The usual geomorphic response to a large decrease in sediment supply is downcutting (degradation) of the river channel. The degradation typically decreases with distance downstream from the dam and the rate of degradation generally reduces with time (Grant et al. 2003).

While the analysis covers a long period, morphological change can occur between the dates of cross section measurements, particularly if there is gravel extraction or flooding. Information on changes given herein relates purely to the net change between the survey dates. Any effect of gravel mining on cross section levels is not quantified.

An earlier Clutha model study (Smart and Bind 2006) noted that significant scour, below the surveyed bed level, was required to pass historic flood flows at the observed flood levels. Thus, the true river cross section during a flood peak, may not be captured by a subsequent cross section survey.

Channel capacity depends not only on the cross-sectional flow area but is influenced by hydraulic roughness and downstream conditions. These effects are captured by flood gauging measurements.

The vertical datum used throughout this report is Dunedin vertical datum 1958 + 100 m (added to avoid negative levels).

1.2 Scope of the work

The objectives of the study are to:

- Determine whether there is a significant trend in riverbed levels at Balclutha in recent decades, beyond the expected range of typical bed level fluctuations or measurement uncertainties.

- Assess notable changes in the location, scale, or development of gravel bars or islands within this reach of the river.
- Identify the key factors driving any significant changes observed or, in the absence of such changes, to explore the reasons behind community perceptions of change in the river system.
- Evaluate whether the magnitude of any observed riverbed level changes is sufficient to reduce the flood capacity within this reach of the river.

To address these objectives, we have undertaken the following steps in our analysis:

- Collating all available ORC surveys and riverbed cross section data.
- Reviewing the raw survey data and refining it where discrepancies or mismatches with historical cross-section records were identified, ensuring consistency and accuracy.
- Overlaying and plotting the cross sections to provide a clear visual representation of changes over time.
- Analysing historical changes in riverbed levels by calculating the mean bed level and the minimum bed level for each cross section location.
- Evaluating changes in the extent of gravel bars by calculating the ratio of the area above the mean bed level to the cross section width, enabling an assessment of spatial trends in bar development.
- Using satellite imagery over time to analyse changes in the extent of gravel bars.
- Investigating the flow gauging record from the NIWA flow recorder site at Balclutha.

2 Cross section data and adjustments

Cross section surveys of the Clutha River, covering the Balclutha township area, are used to assess historical changes in bed level. These surveys are for cross section locations C1 to C7, K12, K13, M12 and M11. The location of these cross sections is shown in Figure 2-1. More information on the cross sections is provided in ORC (2008).

Although most cross sections were surveyed between 1994 and 2024, the specific years of surveys vary for the different cross section locations. Notably, for cross section C2, located at the present railway bridge, survey records extend further back, with the earliest data dating to 1878. Table 2-1 provides a summary of the number of surveys conducted at each cross section and the corresponding years of data collection. Cross section surveys conducted in 2023 were excluded from this study due to unexplained discrepancies when compared to both previous and subsequent surveys.

Figure 2-1: The location of cross section surveys on the Clutha River at Balclutha together with the flow monitoring site. The flow monitoring site is "Clutha at Balclutha".

Table 2-1: Cross section data from the Clutha River near Balclutha township. These data were used for the analysis historical bed level changes.

Cross section	Description	Number of surveys	Years*
K13	First downstream cross section of Koau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
K12	Second downstream cross section of Koau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
M12	First downstream cross section of Matau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
M11	Second downstream cross section of Matau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
C1	Most downstream cross section before Clutha River splits into Matau Branch and Koau Branch	11	1994, 1995, 1996, 1997, 2001, 2002, 2005, 2014, 2019, 2020, 2024
C2	Cross section near railway bridge	14	1878, 1893, 1939, 1994, 1995, 1996, 1997, 2001, 2002, 2005, 2014, 2019, 2020, 2024
C3	Cross section next to flow monitoring site	9	1994, 1995, 1996, 2002, 2005, 2014, 2019, 2020, 2024
C4	Cross section near Highway 1 bridge	8	1994, 1995, 1996, 1997, 2001, 2002, 2019, 2020, 2024
C5	Around 400m upstream of the Highway Bridge	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024
C6	North end of Elizabeth Street, Balclutha	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024
C7	Most upstream cross section analysed	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024

* 2023 survey data are considered unreliable and are not listed here.

When analysing the cross section database, several inconsistencies were identified across different surveys for various cross sections. For example, there was consistent horizontal displacement across some cross sections while the shape of their high banks remained identical (Figure 2-2). In our

comparison of bed level changes, corrections have been made to surveys having obvious offset errors. These corrections were identified by overlaying consecutive surveys and measuring the horizontal offsets. These offsets are listed in Appendix A (Table A-1).

To ensure comparability of cross-section analyses, consistent start and end points were selected for each cross-section. These points were selected to encompass measurements from all surveyed years, allowing for a reliable comparison of changes over time. For surveys conducted in years where selected end points lacked measured elevation data, elevations were estimated using linear interpolation between the closest measured points. In cases where the surveys did not fully cover the start and end points, extrapolation was used to estimate the missing elevations (Figure 2-2). Table 2-2 summarizes the end point offsets and riverbed width used in the analysis of cross section data.

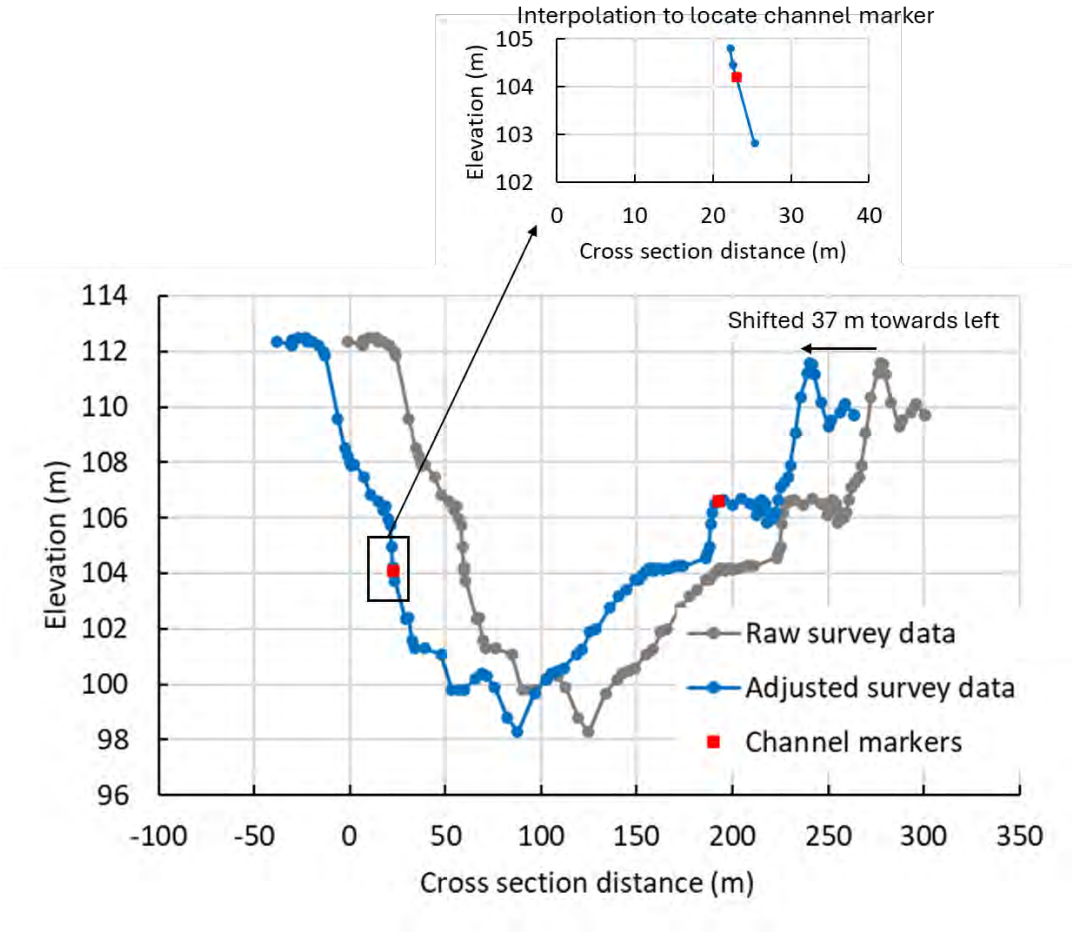


Figure 2-2: Example of cross section data correction and interpolation between the measured points to find consistent start and end point for all surveyed years. Data shown are for cross section C4 in 2020.

Table 2-2: End-point offsets and riverbed widths used for cross section data analysis including mean bed level calculations and area above mean bed level. Left and right bank offsets relate to the section survey data.

Cross section	Left (m)	Right (m)	Width (m)
K12	7.2	205.0	197.8
K13	3.7	125.8	122.1
M11	4.5	129.0	124.5
M12	5	85.7	80.7
C1	2.2	260.0	257.8
C2	26.0	255.0	229.0
C3	9.0	186.0	177.0
C4	23.0	193.0	170.0
C5	6.0	204.0	198.0
C6	4.0	249.0	245.0
C7	8.0	159.0	151.0

Figure 2-3 shows the final C1 cross section plot for all surveyed years in a form which can be used for further analysis and calculation of parameters. The remainder of the similarly processed cross section plots are shown in Appendix B. Grey vertical lines indicate the start and end point that is used for analysis of bed level change.

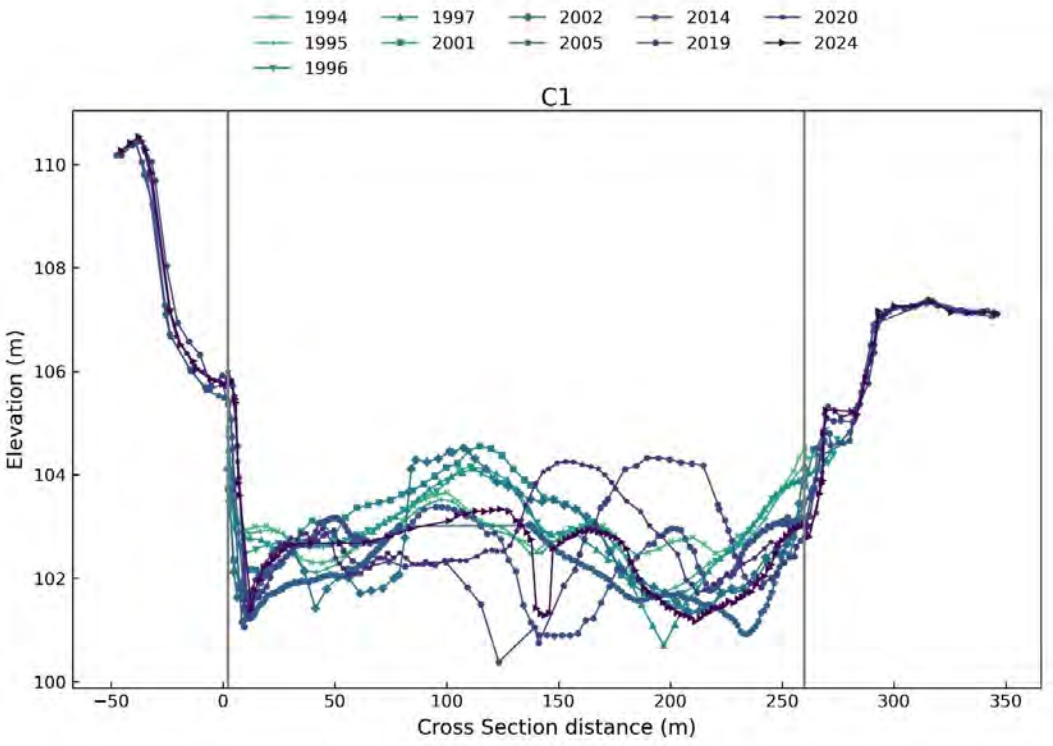


Figure 2-3: C1 cross sectional profile for all surveyed years. Grey vertical lines indicate the start and end points used for analysis of bed level change. The rest of the cross sections are plotted in Appendix B.

2.1 Cross section data analysis

To monitor changes in the riverbed and quantify any variations in the cross sections that have occurred over the years, a set of parameters is used:

- mean bed level.
- area above mean bed level divided by width.
- minimum bed level.
- stage for flow.

The mean bed level (MBL) was calculated between the same end points for each survey, summing the area above datum and dividing this area by the distance between the end points. Tracking changes in the MBL over time allows for the assessment of long-term river stability, helping to determine whether the riverbed is experiencing aggradation or degradation across different time intervals.

The minimum bed level (minBL) refers to the lowest point on the surveyed cross section. In some studies, minimum bed level is also referred to as the thalweg level. Comparing changes in the minimum bed level over time provides insights into sedimentation and erosion processes occurring in the deepest areas of the channel.

The cross section "area above mean bed level" was calculated by subtracting the cross section mean bed level from the elevation of each cross section point and determining the total area of the cross section lying above the mean bed level line.

Figure 2-4 shows the approach used to calculate this term for cross section C1 in 2024. The area above mean bed level was divided by the total width (as listed in Table 2-2) to give a consistent comparison between cross sections. The resulting average-height-above-mean-bed-level parameter helps quantify changes in morphological features across the river cross section. An increase in this parameter through time, means increased variation in bed levels across a cross section, which can indicate features such as sand or gravel bars or deeper channels forming.

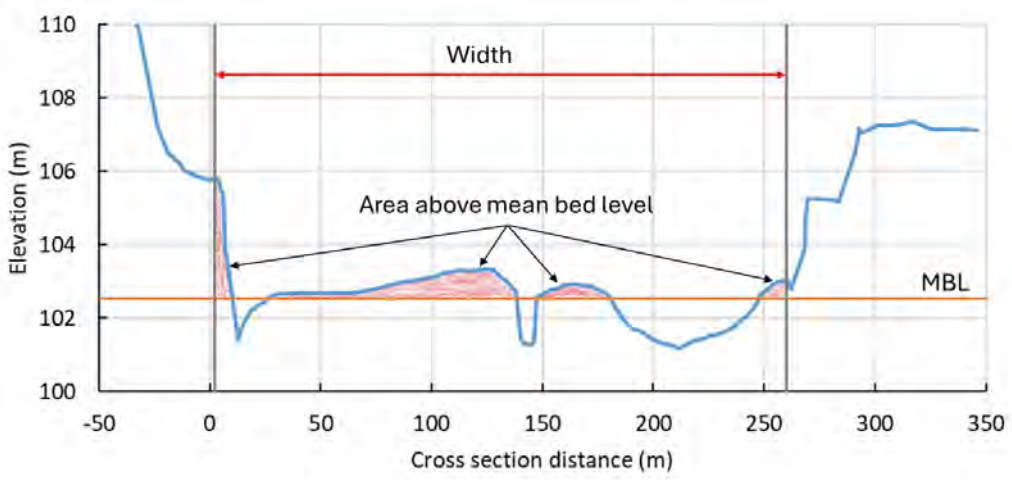


Figure 2-4: Illustration of area above mean bed level for cross section C1 in 2024.

The along-river distance of each cross section was measured accurately in GIS by digitising the centreline of the active channel as a smoothly curving line. These river distances were used to plot longitudinal river profiles. River distances were measured relative to cross-section C1 with positive distances representing upstream cross sections and negative distances downstream.

3 Satellite imagery

Sentinel-2 imagery was used to capture projected images and study river bars in the area of interest. As bars appear larger at lower flows and vice versa, comparison of bar sizes and positions at different times, should be made when there are similar flows in the river. Seven images from the period between 2016 and 2025 were selected on the basis of two criteria:

- Cloud cover of less than 10% to ensure a clear view of the river and gravel bars.
- Similar low-flow conditions, determined by selecting dates when there was satellite image acquisition and a low daily mean flow.

The selected imagery was downloaded from the Copernicus Data Space Ecosystem Browser (2025).

4 Clutha River flow data and analysis

Water level readings and gaugings to measure streamflow have been made at Clutha at Balclutha monitoring stations (NIWA site 75207) since 1952. The location of the site is shown on Figure 2-1. The maximum flow and mean flow for each year is shown on Figure 4-1. Orange circles indicate years where surveys from some or all cross sections were provided by ORC. There was a period with several very high flows between 1994 and 1999.

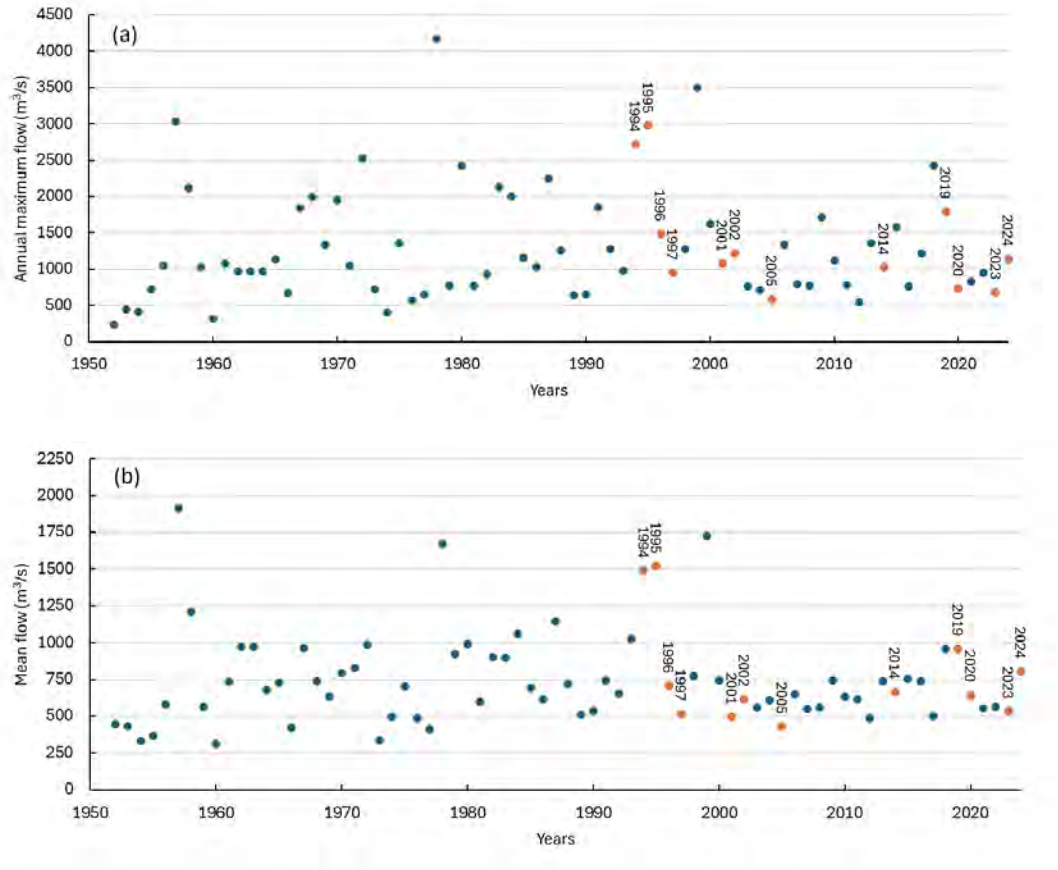


Figure 4-1: Annual maximum flow (a) and mean flow (b) for the Clutha River at Balclutha monitoring site.

A "stage for flow" analysis uses time-series data of flow gaugings made at the Balclutha water level recorder (NIWA site 75207). These data are collected to determine rating curves which relate the height of the water surface (the stage) to the corresponding river flow in cubic metres per second. While rating curves are made to allow calculation flow from a measured water level, they may be used in reverse to calculate how water level has changed, over the years. An increase in water level could be due to increased vegetation and other types of flow resisting roughness such as debris and bed-forms, or it could be due to morphological changes such as aggradation (rising) of the riverbed. In either case, if over time there is an increase in the stage for a given flow this is an indication that freeboard and flood capacity is decreasing.

5 Results

5.1 Bed level changes

5.1.1 Mean bed level

Characteristically, mean bed level falls in the downstream direction and is lower where an alluvial channel narrows. Here, mean bed levels (as defined in section 3) show a consistent pattern over the years, being high around sections C5–C6, falling by around a metre at section C4, then rising again moving downstream by around 1.5 m, to be highest where the river bifurcates into the Matau and Koau Branches (Figure 5-1). The changes in mean bed level upstream of the bifurcation show no clear trend on this graph with variations roughly within a 0.6m range over the last 30 years. From the bifurcation downstream, the range in bed level variation increases, reaching around 0.8 m in the Matau branch (at section M11). At the bifurcation, the bed levels dip, typically remaining lower into the Koau Branch in most years and rising downstream into the Matau Branch in all surveyed years. The mean bed level of the most downstream section on the Matau Branch (M11) is higher than more upstream sections.

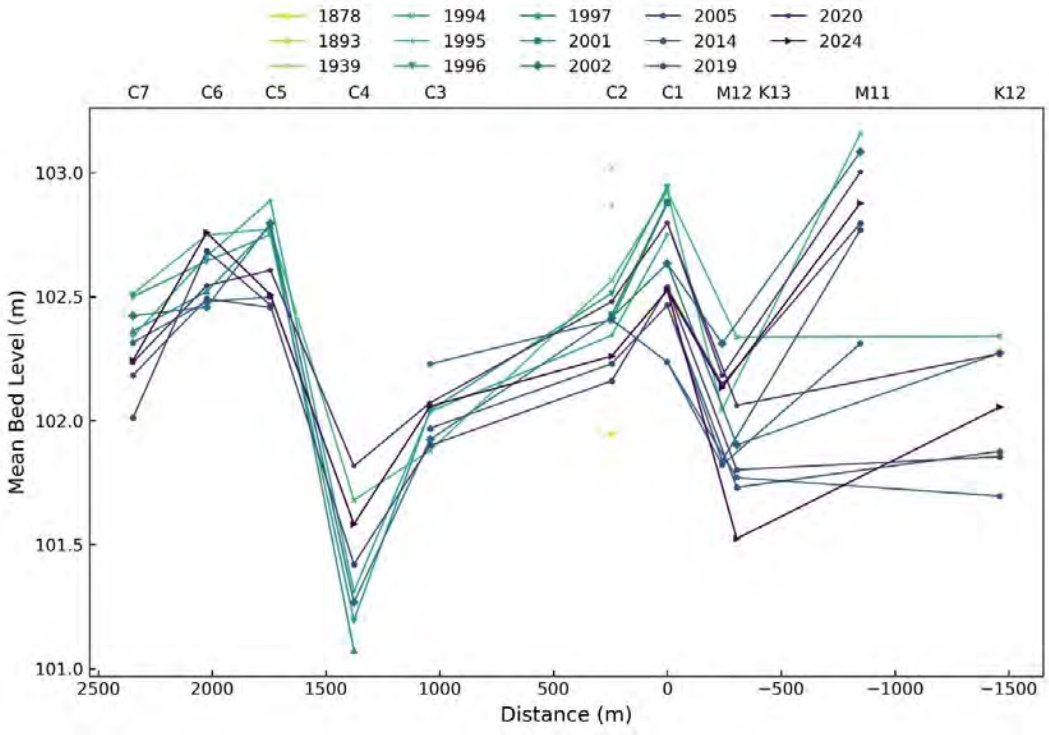


Figure 5-1: Historical changes in the mean bed level (MBL) of the Clutha River near Balclutha township. The x-axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross sections and negative distances downstream. Cross-section IDs are indicated at the top of the graph.

To better assess the temporal evolution of the bed level at each cross-section, mean bed level values were plotted against survey years (Figure 5-2). A linear regression line was fitted to each dataset to identify trends, and R-squared values were calculated to quantify how well the regression line explains variability in the data. All sections except C3, C4, C6, and M12 indicate a negative trend in mean bed level (i.e., lowering over the past 30 years). Sections C5 and C7, in particular, have higher R^2 values confirming significant riverbed degradation over time. At C5 and C7 the averaged mean bed level (the trendline value) has fallen by 0.35 m from the 1990s to the present day. Section K13 also shows degradation over time (R^2= 0.43) with 0.8 m decrease in averaged mean bed level.

At section C2, the first surveys (from 1878) show noticeable aggradation occurred before 1900. Conditions have since changed with land use and construction of the Roxburgh Dam and, if this early data is excluded, the section exhibits a clear negative trend in mean bed level over recent time, with an R^2 value of 0.85 (green line in Figure 5-2). A similar pattern is observed in cross-sections K12 and M11, where the exclusion of the 2005 survey—during which the middle bar was not surveyed—reveals mild riverbed degradation over time (green lines in Figure 5-2).

Sections M12, C3 and C6 do not display any significant trend in mean bed level and appear to have remained relatively stable over the analysed period. C4 shows a weak rising trend.

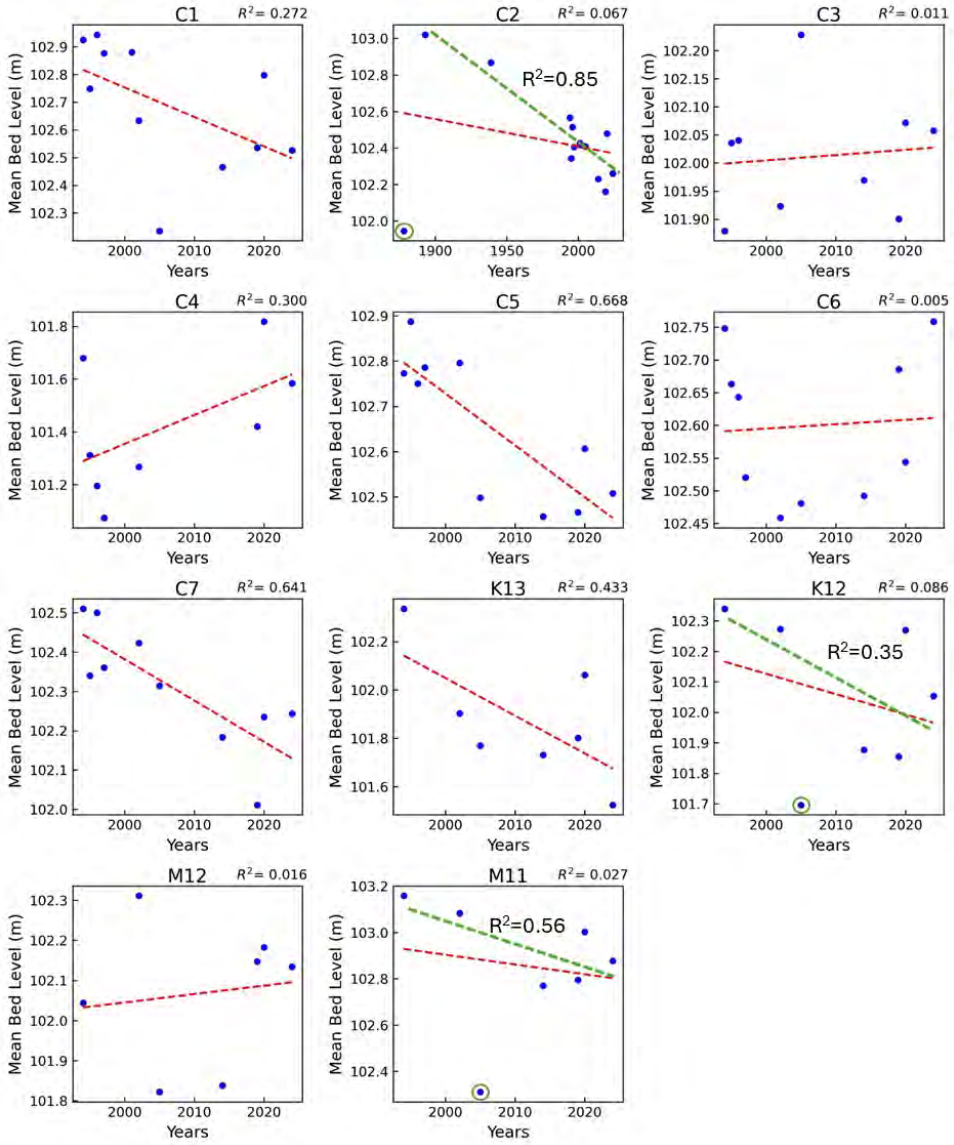


Figure 5-2: Changes in the mean bed Level over years at each cross section. The red lines indicate a linear regression trend for the years observed. The R-squared values for the regression lines, indicating the goodness of fit, are displayed in the top-right corner of each subplot. The green lines indicate linear regression trend after removing the outliers shown by green circles. For cross section C2, when the first survey in 1878 is ignored a strong trend of degradation in mean bed level is observed. For cross sections K12 and M11, the 2005 survey is ignored for the green line regression (part of the mid-river section was missing in the 2005 survey). Note that the axis scales differ on some plots.

Further analysis was conducted by averaging the mean bed level changes for each recent decade and comparing this with a 1990s baseline mean bed level (Figure 5-3). Following the period with very high flows from 1994 to 1999, bed levels generally fell below 1990 levels until the 2010s (blue and orange lines) then rose again in the 2020s (yellow line.) Except at C6, C4, C3 and M12, averaged levels are still below the 1990 levels. Section C4 has risen 0.4 m above the 1990 mean bed level.

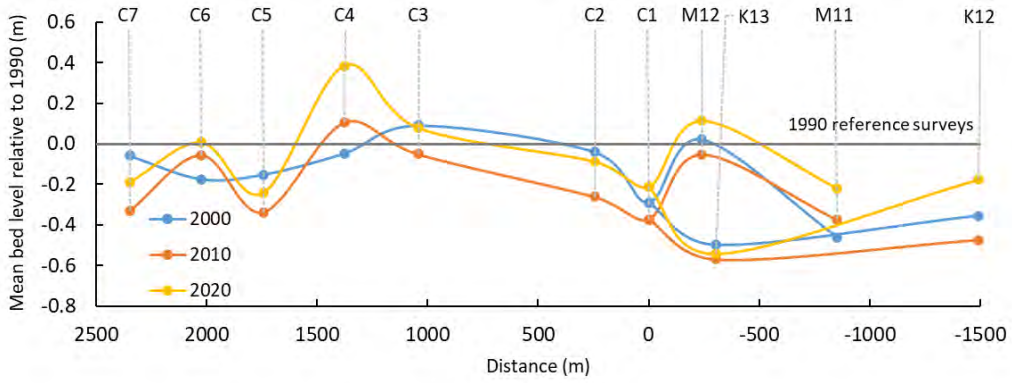
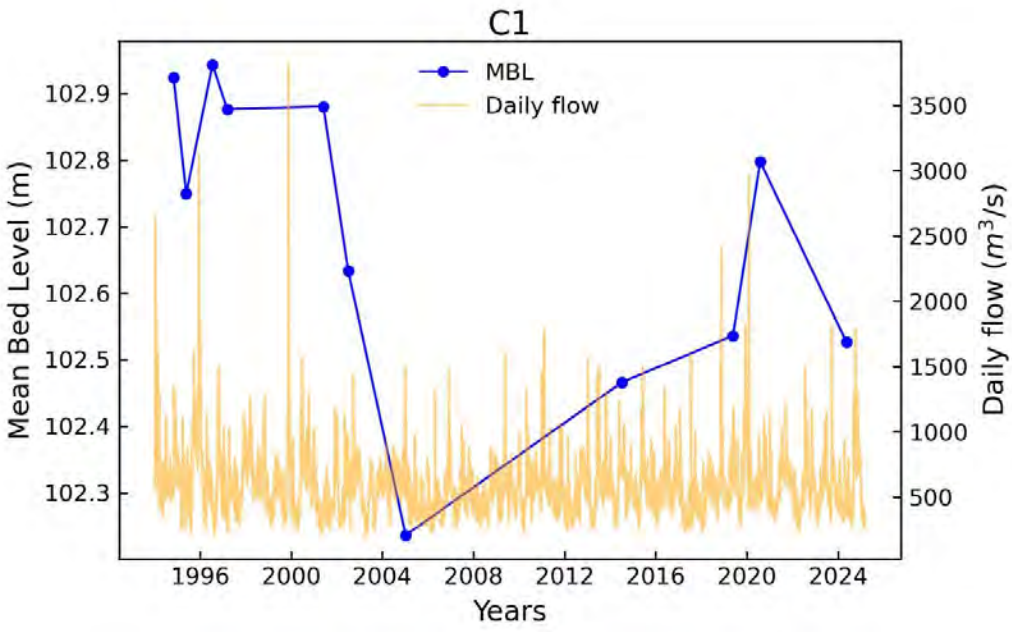


Figure 5-3: Mean bed level change relative to 1990 in the Clutha River near Balclutha, with surveys grouped by decade. The "1990" reference line represents combined surveys from 1990–1999, the "2000" line includes surveys from 2000–2009, the "2010" line covers surveys from 2010–2019, and the "2020" line represents surveys from 2020 onward. The x-axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross sections and negative distances downstream. Cross-section IDs are indicated at the top of the graph.

Changes in mean bed level over time were compared with mean annual flow and maximum annual flow. Examples are shown in Figure 5-4 for C1 and C6 with the remainder in Appendix C. There appears to be a tendency for the mean bed to rise when the flow rises but this not apparent at all cross sections and, at some sections, a reverse trend is evident, particularly after year 2020.



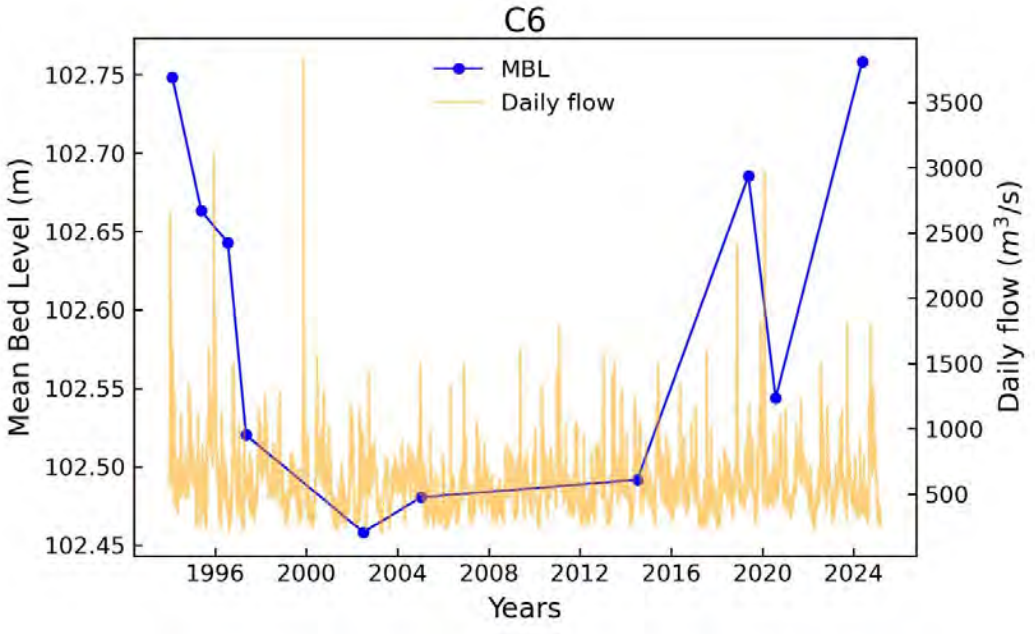


Figure 5-4: Evolution of mean bed levels with time and daily mean river flow at section C1 and section C6.

5.1.2 Minimum bed level

Changes in minimum bed levels are shown in Figure 5-5 with a separate line for each surveyed year. From cross section C6 to C4, the minimum bed level decreases in the downstream direction, reaching a low point around cross sections C3 and C4. Beyond this point, the bed level rises again in the downstream direction to cross-section C1. From C1, the minimum bed level falls moving down the Koau Branch (sections K13 and K12). For the studied cross sections, except for a high C1 level in 1994, the minimum bed level downstream in the Matau Branch is higher than at the upstream sections. The higher Matau Branch bed was also evident in the mean bed level analysis (Section 5.1.1).

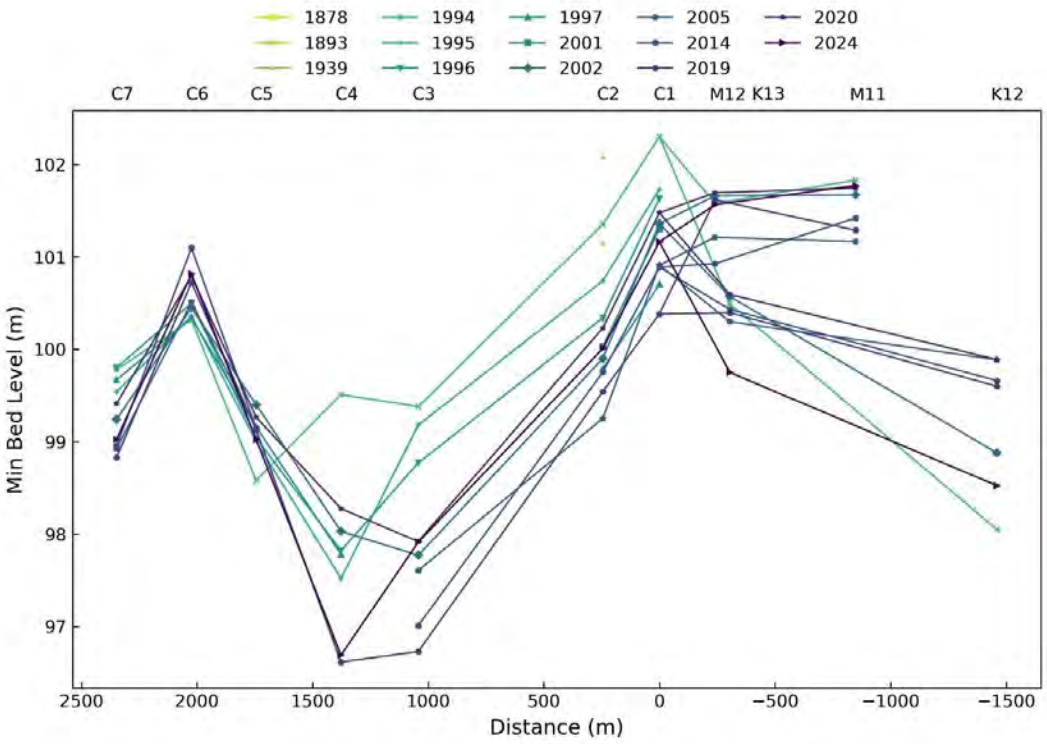


Figure 5-5: Historical changes in the minimum bed level of the Clutha near Balclutha. The x-axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross sections and negative distances downstream. Cross-section IDs are indicated at the top of the graph.

Trendline analysis for minimum bed levels is shown in Figure 5-6. While cross-section C6 exhibited no clear trend in **mean** bed level over time (Figure 5-2), the deepest point used to be on the true right side of the channel but is now in the centre (Appendix B). The **minimum** bed level shows a long-term rise in the deepest part of the river (Figure 5-6). These changes may be a result of historic, upstream river training works. Cross-section C3 similarly showed no discernible trend in mean bed level, but the minimum bed level indicated sustained erosion in the deepest portion of the channel, highlighting localized changes not captured by mean bed level analysis. Cross-section C7 displayed a consistent trend in minimum bed level that mirrored the overall changes observed in the mean bed level. The bed level changes at C7 are more uniform across the entire cross-section, affecting both the mean and minimum bed levels in a similar manner. Cross-section K13, on the Koau Branch, exhibited a similar pattern, with both the minimum and mean bed levels indicating recent deepening.

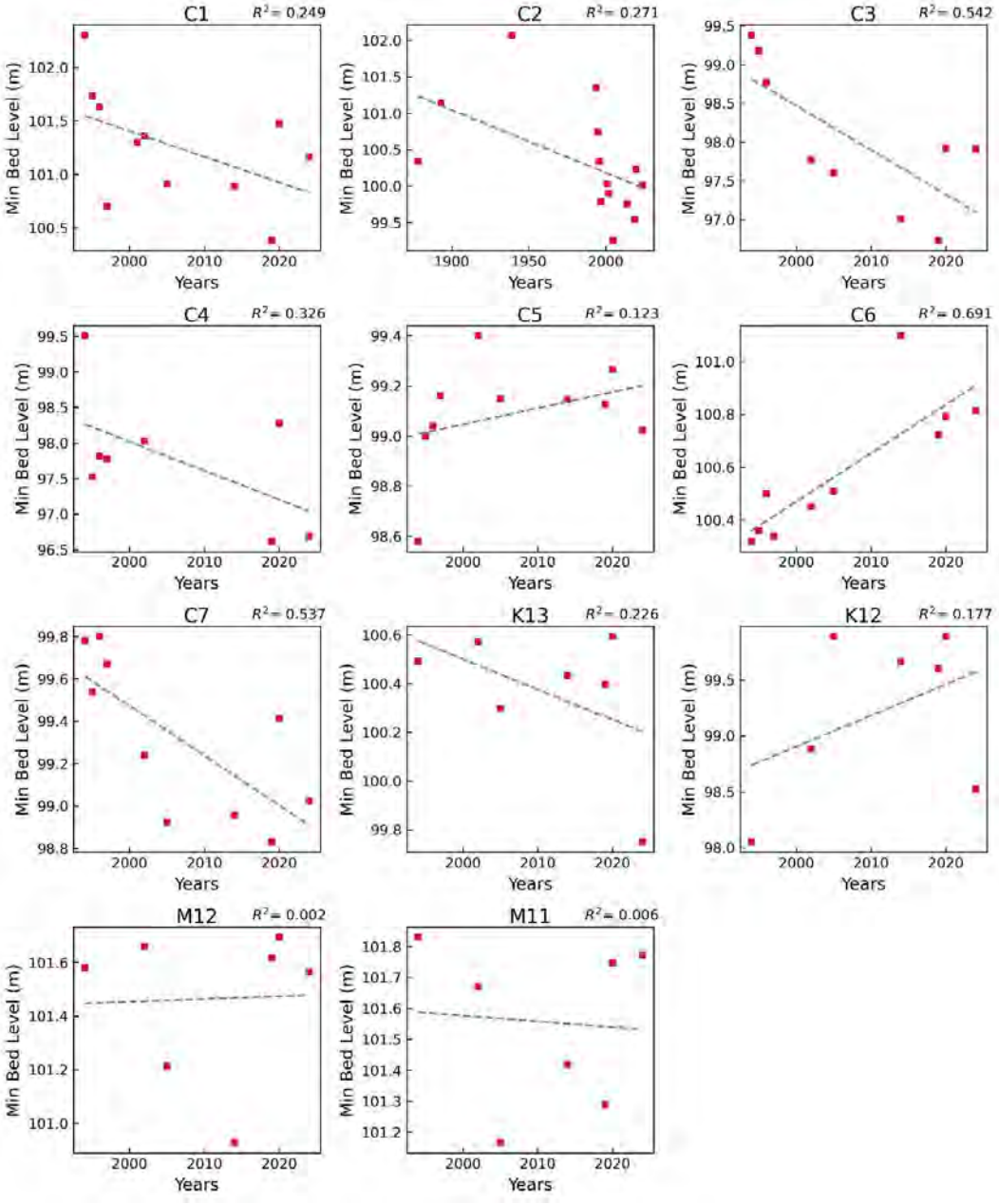


Figure 5-6: Changes in the minimum bed Level over years at each cross section. The dashed lines indicate the linear regression trend for the changes observed. The R-squared values for the regression lines are displayed in the top-right corner of each subplot. Note that the axis scales differ on some plots.

5.1.3 Average height above mean bed level

The area above mean bed level, divided by the total width, gives an average height of the part of the bed lying above mean bed level. This illustrates how much the bed level varies across a section. Changes in this parameter are plotted against downstream distance in Figure 5-7 for each surveyed

year. Overall, there is a slight trend of decreasing bed level variation across a cross section, moving in the downstream direction towards the bifurcation.

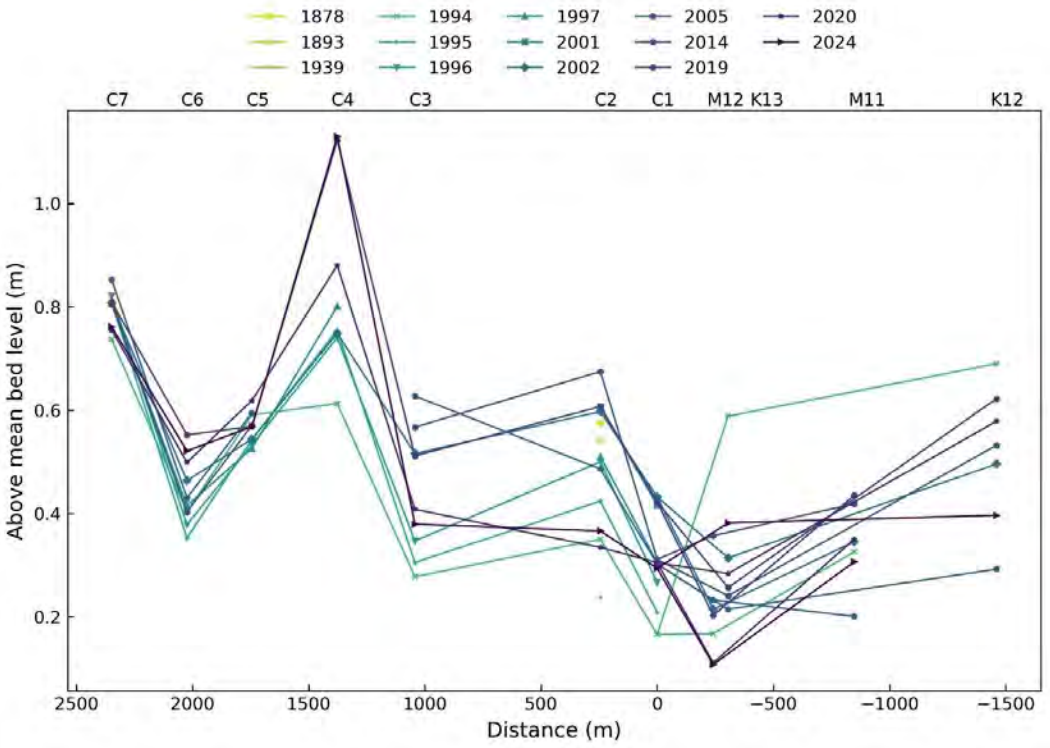


Figure 5-7: Historical changes in the height above bed level values of the Clutha River near Balclutha. The x-axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross sections and negative distances downstream. Cross-section IDs are indicated at the top of the graph.

The average height above mean bed level values show a clear increasing trend with time at cross sections C4 and C6, indicating an increase in the exposed (visible) area of the riverbed during low-flow conditions (Figure 5-8). Variation has increased significantly at section C4. This suggests the development or expansion of bars or deepening of low flow channels in these sections over time. In contrast, the height above mean bed level values at the other cross-sections did not exhibit any clear trends, implying minimal to no long-term changes in the bed forms.

There is no cross-section located on the large gravel bar between cross-sections C2 and C3 (located next to Kaitangata Highway and downstream of Ipswich Street. Therefore, it is not possible to quantify changes in the height of this significant bar.

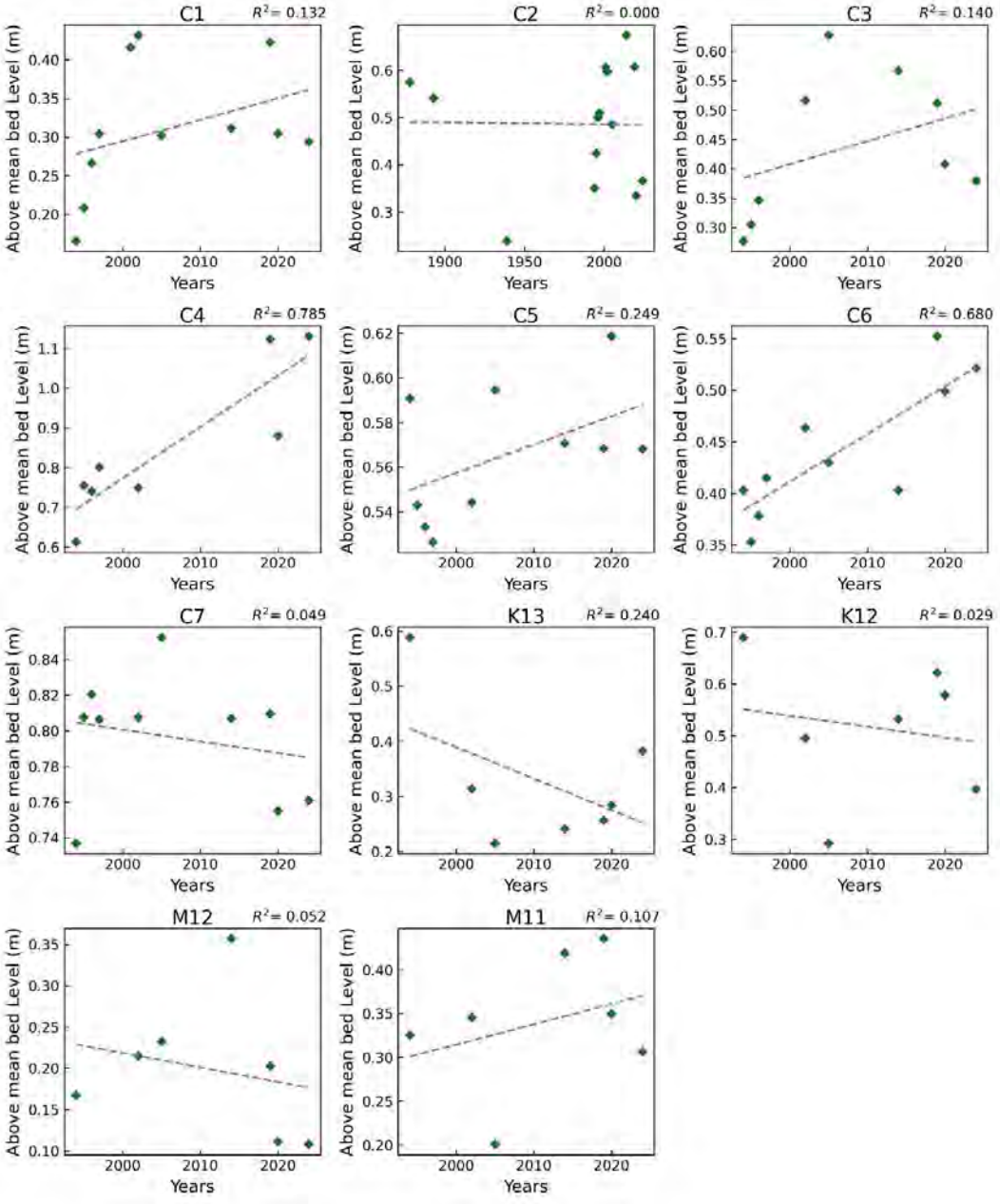


Figure 5-8: Changes in the average height above mean bed level over years at each cross section. The dashed lines indicate the linear regression trend for the changes observed. The R-squared values for the regression lines are displayed in the top-right corner of each subplot. Note that the axis scales differ on some plots.

5.2 Changes across individual cross sections

Considering the overlaid sections in Appendix B and parameter plots in Figures 5-2 to 5-6 we observe the following net changes moving from downstream to upstream:

- **Cross sections K12 and M11:** No clear trend of aggradation or degradation is evident over time based on the recorded survey data.
- **Cross section M12:** In the 1990s the section was relatively flat. The channel then deepened on the right side and raised on the left side of the centreline. By 2019, the channel had risen on the right side and by 2024 was again relatively flat. NIWA gauging comments indicate 10,000 cubic metres of gravel extraction occurred on the right bank and 8,500 cubic metres from the left bank of the downstream channel bifurcation over the period 17-Feb-2002 to 13-Mar-2002.
- **Cross section K13:** In the 1990s the section was high on the right bank of the main channel, but this bar was gone by 2002. The data then indicate low variation in bar height until 2020 when the channel deepens left of the main channel centreline and rises on the right bank of the main channel.
- **Cross section C1:** Over the last 10 years, a noticeable shift in the gravel bar located in the middle of the cross section is observed where the river splits into the two branches. The middle bar has migrated further to the right, resulting in increased bank erosion along the true left bank.
- **Cross section C2:** Being near the railway bridge, this cross section has the longest survey record, dating back to 1878. Between the first recorded survey in 1878 and the second in 1893, the riverbed experienced up to 2 m of aggradation across the cross section. By 1939, deposition of up to 1.5 m occurred towards the right bank, while scouring of up to 2 m was observed on the left bank. Between 1939 and the present day, slow degradation has dominated across the entire channel width.
- **Cross section C3:** Between 1994 and 2024, this cross section experienced periods of shifting in the middle bar and channel, along with phases of channel deepening (1994–2019) followed by significant aggradation (2019–2024). The middle bar rose approximately 2.3 m from 1994 to 2005, reaching its maximum recorded height. However, from 2005 to 2024, gradual erosion of the middle bar occurred, with about 1.1 m of bar height lost.
- **Cross section C4:** This section showed gradual scouring along the true left bank and deeper parts of the channel, while deposition was observed along the true right bank. Between 1994 and 2024 the deeper section of the channel experienced scouring of up to 3 m, whereas up to 2.1 m of sediment deposition occurred along the right bank.
- **Cross section C5:** A gradual degradation trend was observed from 1994 to 2024, accompanied by localized sediment accumulation along a small section of the true right bank between 185 to 220 m cross section distance.
- **Cross section C6:** Different patterns of change were observed across this cross section. Both the true left and right banks experienced deposition, whereas the mid-channel deepened. From 1994 the middle section of the cross section (between 100 m and 200 m) experienced a rise of up to 1.5 m by 2024. The true left bank (between 200 m and 250 m) rose up to 3 m, while the right bank (between 0 m and 80 m) experienced 1.1 m of rise. Overall, mean bed level degraded until 2002 then aggraded back to the 1994 level by 2024.

- **Cross section C7:** Scouring was observed at the true left bank between 1994 and 2024. The deeper section of the channel experienced erosion from 1994 to 2019, followed by deposition between 2019 and 2024.

5.3 Satellite imagery

Overhead imagery can reveal positions and sizes of channels and bars in a river. Examples are shown in Figure 5-9. Seven selected images, captured between 2016 and 2025, are presented in Appendix D. Interpretation of bar size and shape is not straightforward, as river flow was not the same when the images were captured.

A noticeable change occurred between 2016 and 2025 with the movement of the gravel bar on the right bank, just before the Clutha River splits into the Matau and Koau branches. In the 2016 imagery, this bar intersects the railway bridge and extends across both C1 and C2 cross sections. The bar shape evolves, and by 2025, has disappeared. From 2020 a new bar develops on the opposite bank, and by 2025 it has fully formed at the tip of Inch Clutha (Figure 5-9).

The location of the mid-river bar between cross sections C2 and C3 has remained relatively stable over the years.

The long, thin, right-bank bar extending from C4 to C5 is stable over the years and becomes progressively more vegetated until by 2025 it resembles a river berm.

Due to variations in river flow at the time of satellite captures, it is not possible to measure quantitative temporal changes in the size of the bars, on the basis of the imagery. Bar size is also discussed in Section 6-2.

Figure 5-9: Satellite imagery of the Clutha River at Balclutha on two dates: January 10, 2016 (left) and January 27, 2025 (right). Imagery from Sentinel-2 satellite data. Red lines indicate the cross section locations. The flow monitoring site is shown with a magenta dot.

5.4 Flow data analysis

A NIWA flow recorder has operated at Balclutha since 1952. The gauging cross-section was located near river cross-section C3 until 2007 when it was moved 180 to 250 m upstream of the previous cableway location.

5.4.1 Minimum bed level

Up until 2010, the maximum water depth was recorded at the time of a NIWA gauging. Subtracting max. water depth from the stage (water surface elevation) gives the minimum bed level at the time of the gauging. The minimum bed levels from gauging data are shown in orange on Figure 5-10 below. After 2007, NIWA changed to jet boat ADCP gauging 180 to 250 m upstream of the previous cableway and recording of maximum water depth was subsequently discontinued. The gauged upstream bed depths are shown in bright red on Figure 5-11. Also shown are the ORC cross section survey minimum bed levels at section C3 (from Figure 5-6). An abrupt rise in minimum bed level occurred during the 1957 November flood when the thalweg level was raised by the flood. From the 1970's to the present the minimum bed level at section C3 has been getting lower.

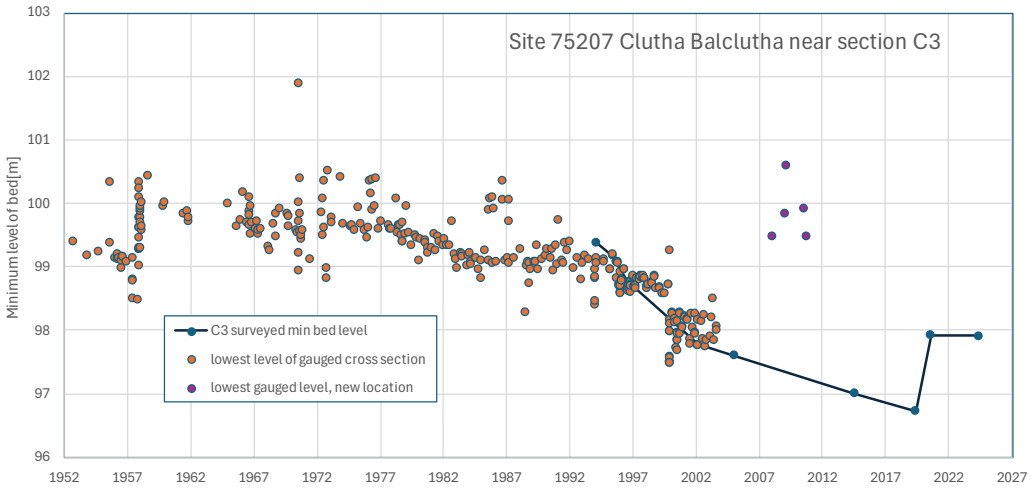


Figure 5-10: Minimum bed level at times of flow gaugings near section C3. Gauging data after 2007 (bright red dots) apply 180 to 250 m upstream of the previous cableway location.

5.4.2 Stage for flow results

Figure 5-11 shows the differences between measured water levels and what they would have been with no changes in the river bed since 1952 (i.e., no changes in the rating curves since 1952). Figure 5-12 shows differences in water levels compared to what they would have been with the December 1978 rating curve. While individual gaugings are made at different flows, and it is not meaningful to interpret every little change in these graphs, the graphs reveal any overall, long-term trends.

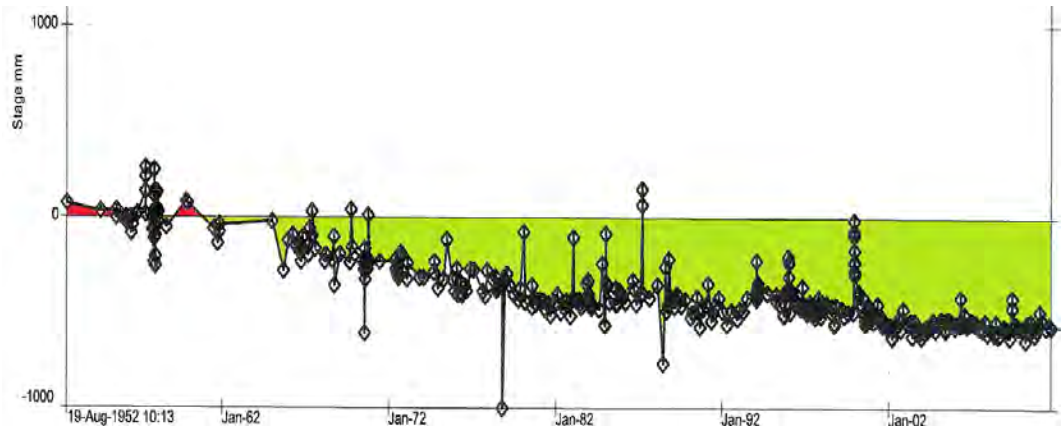


Figure 5-11: Stage for flow compared with preservation of 1952 bed levels.

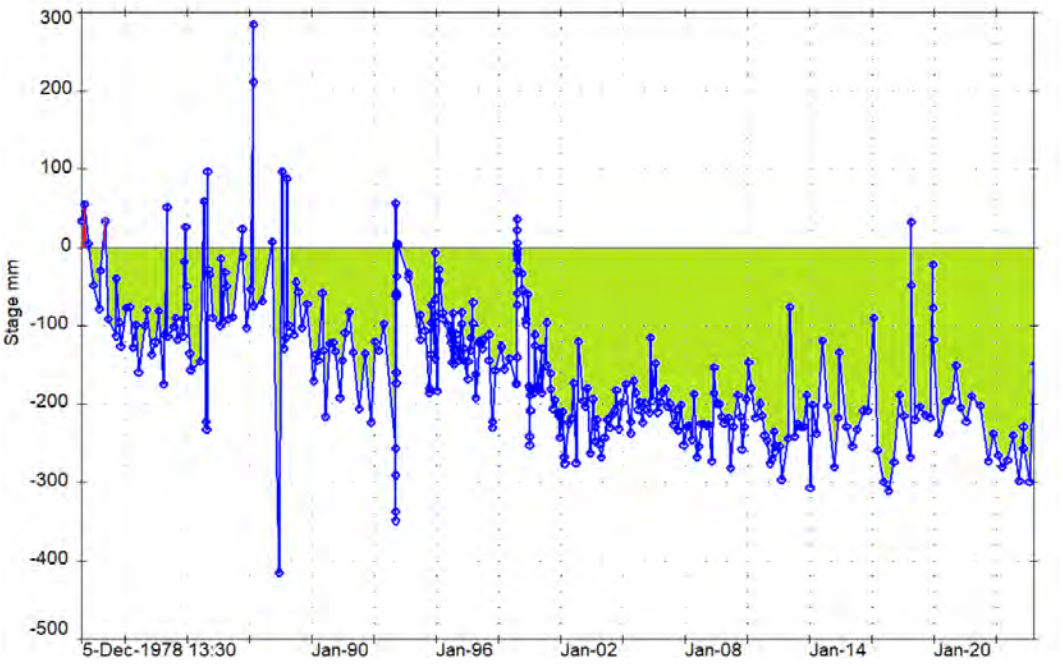


Figure 5-12: Stage for flow compared with preservation of 1978 bed levels.

According to these plots, water levels fell gradually from 1952 to be about half a metre lower by 1982. From 1983 to mid-2000 the levels oscillated with no net trend, then dropped approx. 0.2 m to reach another quasi-stable state for the most recent 20-year period.

Further information on water level trends at all measured flows can be found by comparing rating curves from gaugings made at different times. In Figure 5-13, flow gaugings are compared for three decades: 1952–1961, 1990–1999 and 2015–2024. Flows as low as 38.3 m^3/s occurred in the early record as Roxburgh Dam was filling in 1956. The lowest gauged flow was 50.3 m^3/s. In the middle decade there were several high floods (between 1994 and 1999). Figure 5-13 shows that in the 1990's flows up to 3000 m^3/s occurred at a lower stage than in the 1950's. In the most recent decade flows up to around 1500 m^3/s occurred at a lower stage than in the 1990's. This indicates channel

deepening or reducing flow resistance over the decades. For very high flood flows[1], the flood stage increased relative to the 1990's but, up to 3000 m^3/s, remains lower than in the 1950's. While moderate floods indicate deepening of the channel, the recent, slight increase in stage of very high floods indicates possible constriction, raising or roughening of floodplains downstream of the gauging station.

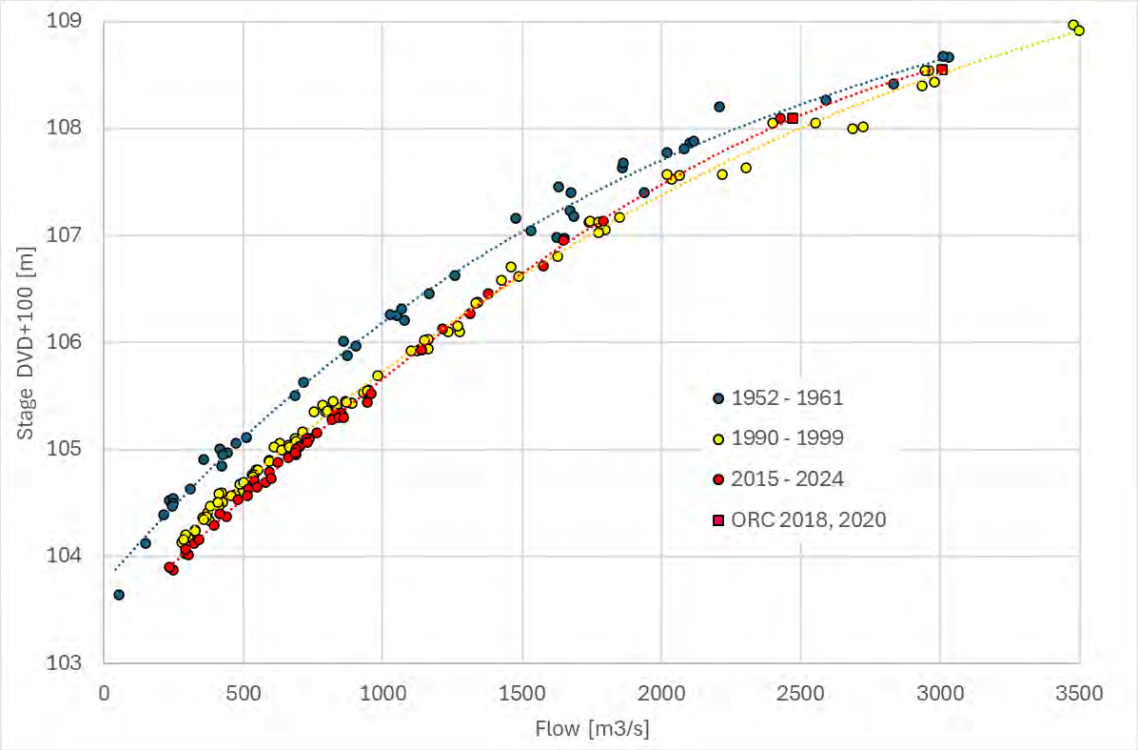


Figure 5-13: Comparing stage for flow data from gauging measurements over the years. Curves show three decades: 1952–1961, 1990–1999 and 2015–2024. Vertical axis is Dunedin Vertical Datum 1958 + 100 m.

[1] The two highest gaugings in 2015–2024 were made upstream of the NIWA rating site and adjusted by ORC to allow for the 2.5 km interdistance.

6 Discussion

6.1 Determine whether there is a significant trend in riverbed levels

Cross sections C1, C2, C5, C7, M11 and K12 show a clear degradational trend from the 1990's to the present. In particular, mean bed levels at C5 and C7 have fallen by around 0.35 m. Sections C3 and C6 do not display any significant trend in mean bed level and appear relatively stable over the analysed period. C4 shows a weak rising trend.

6.2 Assess changes in gravel bars or islands

The average height-above-mean-bed-level analysis indicates the vertical range in bed levels at measured cross sections. Changes in average height-above-mean-bed-level can indicate development or decay of channel bars. Over the surveyed years 1994 to 2024, there is a trend of increasing level variation at C4 and C6 but no noteworthy trend at other sections. Moving in the downstream direction, there is a slight general trend of decreasing bed level variation across the cross sections, which would suggest lower or flatter bars moving downstream past Balclutha.

Satellite imagery reveals a noticeable change between 2016 and 2025 with the movement of a gravel bar on the right bank, just before the Clutha River splits into the Matau and Koau branches. In the 2016 imagery, this bar intersects the railway bridge and extends across both C1 and C2 cross sections. The bar shape evolves, and by 2025, has disappeared. From 2020 a new bar develops on the opposite bank, and by 2025 it has fully formed at the tip of Inch Clutha. No net effect is evident in the C1 and C2 area above mean bed level plots. There is no cross-section located on a large gravel bar between cross-sections C2 and C3 (located next to Kaitangata Highway and downstream of Ipswich Street). Considering different flow rates at times of the satellite imagery, this bar appears stable over the 2016–2025 period.

6.3 Identify factors driving changes observed

In general, observed changes correspond to the expected long-term, morphological change following a severe reduction in sediment input (i.e., Roxburgh Dam construction). Bed levels and water levels have initially fallen and the rate of degradation appears to have tailed off with time. Recent reports that gravel bars are more evident at Balclutha may be due to the bar movement noted above and the fact that a stable bar can become more visible and appear to be higher if the river level falls alongside the bar. There has been a clear change in shape at section C6 (Appendix B). The deepest point (thalweg) used to be in the channel on the true right but is now in the centre. Historic aerial imagery below Figure 6-1) shows that between 1946 and 1995, mid-channel river training works narrowed and re-directed the channel upstream of C6. These works are likely to be the explanation for the thalweg movement at C6. There were also river training works to re-narrow the entrance to the Matau branch in the early 1970's [Retrolens.co.nz: air photos of 27/2/1968 and 28/2/1975].

Figure 6-1: Aerial photographs from 1946 (left) and in 1995 (right). Blue line indicates the mid-channel river training works upstream of cross section C6.

6.4 Evaluate whether observed riverbed level changes are sufficient to reduce flood capacity

Unless there is a strong overall trend, the interpretation of temporal changes in cross sections' effect on flood capacity is not straight-forward because a wide shallow section will not convey the same flow as a deep narrow section of equivalent area (or having the same mean bed level between bank benchmarks). Furthermore, flood levels at Balclutha can depend on conditions further downstream. While hydraulic modelling was beyond the scope of this study, the stage for flow analysis of gauging data provides reliable indications of changes in flood capacity at the NIWA gauging site near section C3. The gauging data from 1952 show water levels fell gradually from 1952 to be about half a metre lower by 1982. From 1983 to mid-2000 the levels oscillated with no net trend, then dropped approx. 0.2 m to reach another quasi-stable state for the most recent 20-year period. In the 1990's, flows up to 3000 m^3/s occurred at a lower stage than in the 1950's. In the most recent decade flows up to around 1600 m^3/s occurred at a lower stage than in the 1990's. This implies channel deepening (locally or downstream) or reducing flow resistance over the decades.

The relatively flat river gradient means changes in flood water levels at the NIWA gauging site will be reasonably representative of general changes in Clutha river levels alongside Balclutha and we can presume that flood capacity has not reduced. That said, the most recent flood gauging of 2425 m^3/s in October 2018 was at a slightly higher level than similar floods in the 1990s. Also, local changes in cross sections may re-direct currents against a bank with associated local superelevation and potential overtopping.

While a few of the Clutha cross section surveys were made during floods, an earlier model study (Smart and Bind 2006) noted that significant scour was required to pass historic floods at the flood levels observed at Balclutha. The required scouring was not evident in post-flood surveys. This indicates that temporarily scour may occur around the C3 location during a rising flood with the bed refilling as the flood falls. The extent of such flood scour is unknown but, assuming this has not reduced due to coarsening of the bed sediment size, historic behaviour does not indicate a reduction of flood capacity in the Balclutha reach.

7 Conclusions

The cross section data suggest a general long-term trend of lowering of the riverbed from the 1950s to about 2002 with less trend evident since 2002. This is consistent with the river adjusting to a reduction in bed load coming from upstream following commissioning of the Roxburgh hydro dam in 1954. Mean bed level analyses show that ten of the eleven cross sections are stable or degrading. Section C4 (at the State Highway Bridge) shows a weak rising trend in mean bed level. Minimum bed levels are stable or falling at all cross sections except C6 (North end of Elizabeth Street) where the surveyed low point is rising with time due to previous river training works. Cross sections C4 and C6 are the only sections which show any trend in growth or expansion of bars or deepening of low flow channels over time. Channel flood capacity depends not only on the cross section, but also hydraulic roughness and downstream slope. These effects are captured by flood gauging measurements. Analysing the gaugings at Balclutha, since 1952, shows channel capacity is increasing for floods up to around 1600 m^3/s.

Recent reports that gravel bars are now more evident at Balclutha may be due to the fact that a stable bar will become more visible and appear to be higher, if the river level falls alongside the bar. A field inspection may be able to shed light on this possibility.

Factors which could affect these conclusions are:

- Bed scour during a rising flood and deposition on a falling flood may mask the true cross section during a flood peak. The extent of such flood scour is unknown at Balclutha but, assuming this has not reduced due to coarsening of the sediment size (bed armouring), the studied cross section surveys do not indicate reduction in flood capacity of the Balclutha reach.
- The effect of any gravel mining on cross section evolution has not been quantified but any enduring effects have been captured by the cross section surveys.

Ongoing monitoring and, in particular, flow gauging during future high floods, is strongly recommended. This would help quantify the degree of bed scour induced by floods, which will improve future hydraulic modelling of the river.

8 Acknowledgements

Survey data and funding for these analyses were provided by the Otago Regional Council.

9 References

Copernicus Data Space Ecosystem. Copernicus Data Space Ecosystem Browser. European Commission. Retrieved February 21, 2025, from https://dataspace.copernicus.eu/

Grant, G. E., Fassnacht, H., McClure, E. M., Klingeman, P. C. (2003) Downstream effects of the Pelton-Round Butte hydroelectric project on bedload transport, channel morphology, and channel-bed texture, lower Deschutes River, Oregon. Water Science and Application, 7, 175-176.

Hicks, D.M., Walsh, J.M., Duncan, M.J. (2000) Clutha River Sediment Budget. NIWA Client Report CHC00/45.

Otago Regional Council (2008) Channel morphology and sedimentation in the Lower Clutha River. ISBN: 1-877265-59-4

Smart, G.M., Bind, J. (2006) Clutha Delta flood protection. NIWA Client Report: CHC2006-021. Project: ORC06504, February 2006.

Appendix A Corrections made to historic cross section data

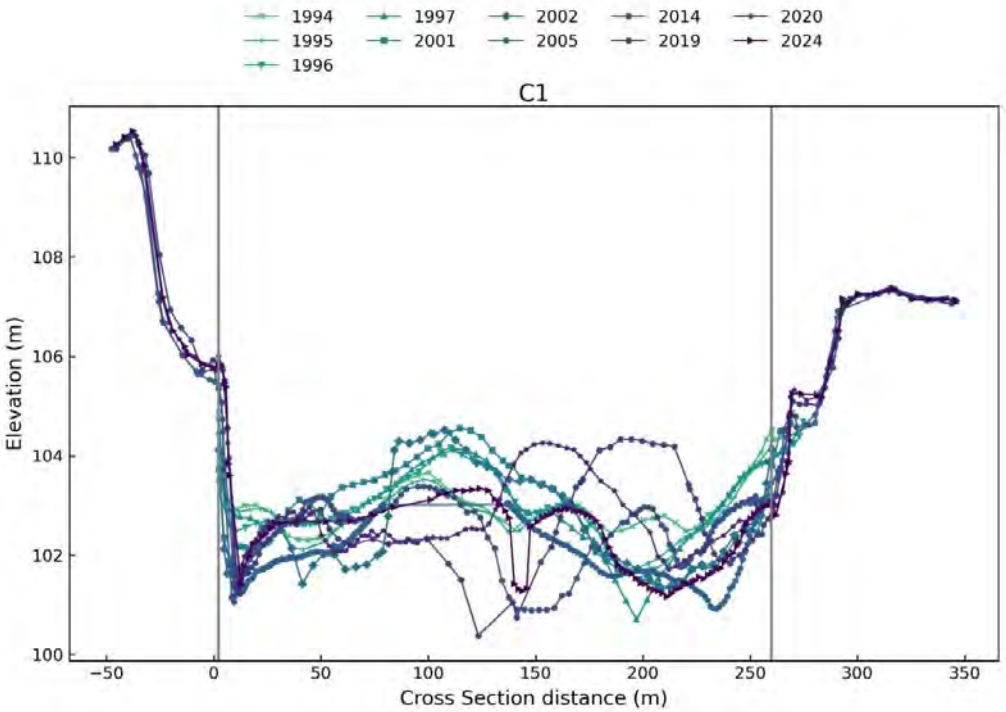
Table A-1: Adjustments applied to align historic cross section survey data.

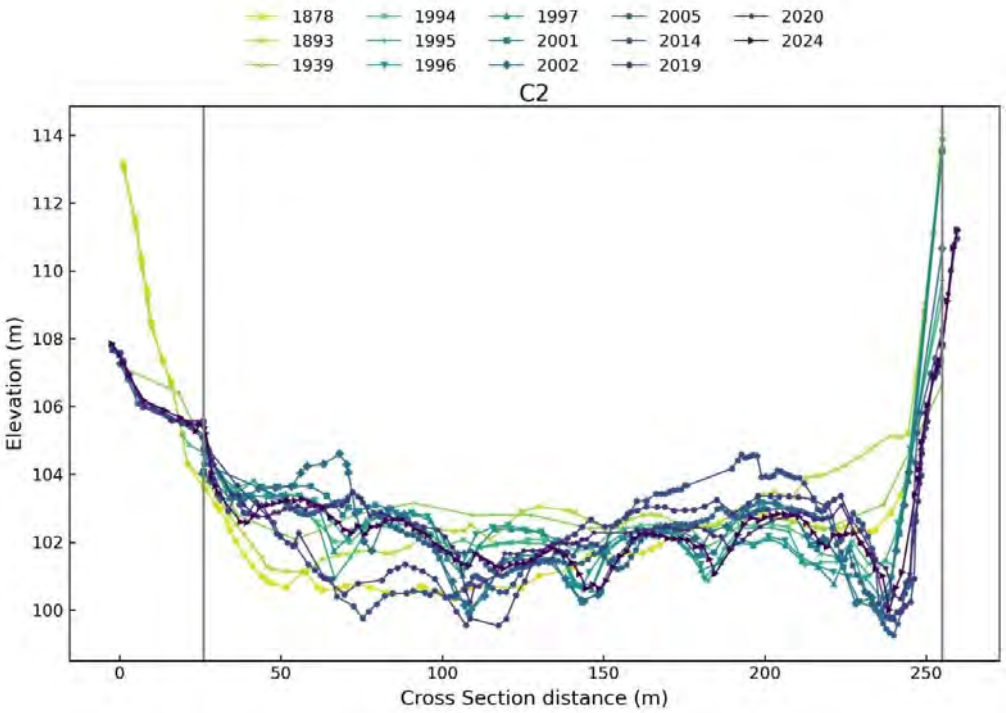
Cross section ID	Surveyed Year	Horizontal offset applied	Comments on surveys with incomplete or unreliable data
C1	1996	Shifted 10 m to right	
	1997	Shifted 9.1 m to right	
	2001	Shifted 12 m to right	
	2002	Shifted 12.2 m to right	
	2019	Shifted 37 m to left	
	2020	Shifted 37 m to left	
	2023	Shifted 37 m to left	Unreliable data - ignored in bed level change analysis
	2024	Shifted 37 m to left	
C2	2023		Unreliable data - ignored in bed level change analysis
C3	1994	Shifted 6.9 m to right	
	1995	Shifted 6.9 m to right	
	1996	Shifted 6.9 m to right	
	2002	Shifted 6.9 m to right	
	2023		Unreliable data - ignored in bed level change analysis
C4	2019	Shifted 37 m to left	
	2020	Shifted 37 m to left	
	2023	Shifted 37 m to left	Unreliable data - ignored in bed level change analysis
	2024	Shifted 37 m to left	
C5	2019	Shifted 26 m to left	
	2023		Unreliable data - ignored in bed level change analysis
K12	2005		Incomplete cross section data (up to 159 m distance) - ignored in bed level change analysis

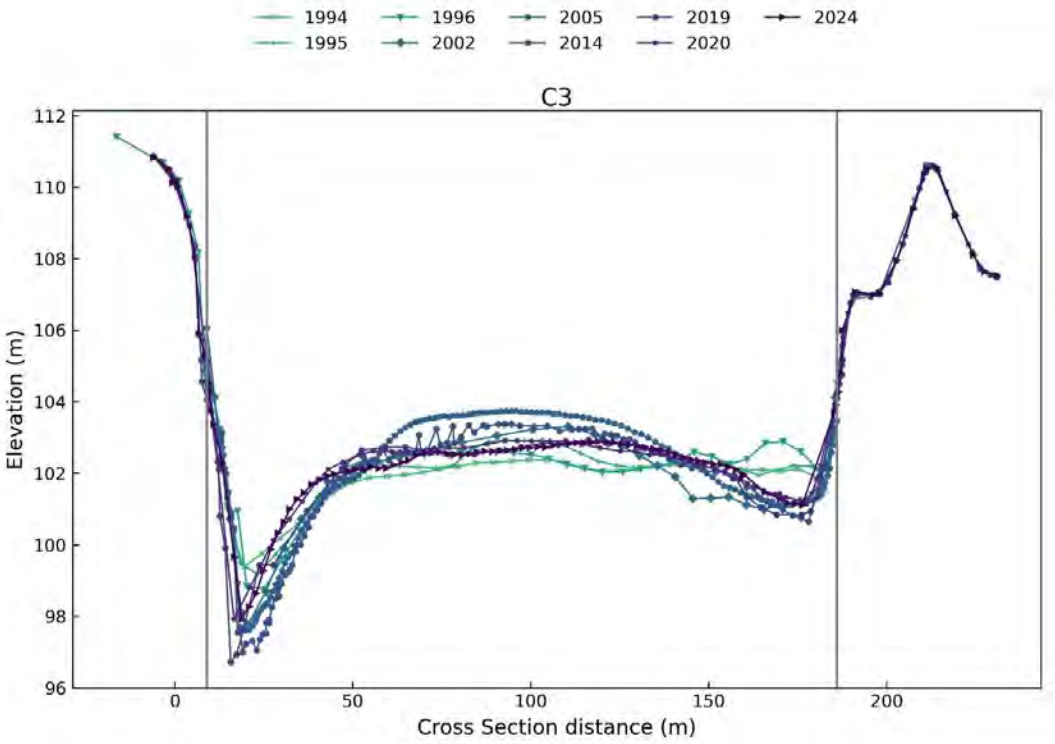
Cross section ID	Surveyed Year	Horizontal offset applied	Comments on surveys with incomplete or unreliable data
M11	2020	Shifted 26 m to left	
	2023	Shifted 26 m to left	Unreliable data - ignored in bed level change analysis
	2024	Shifted 26 m to left	
	2005		Incomplete cross section data (middle section between 25 to 64 m is missing) - ignored in bed level change analysis
	2023	Shifted 10 m to right	

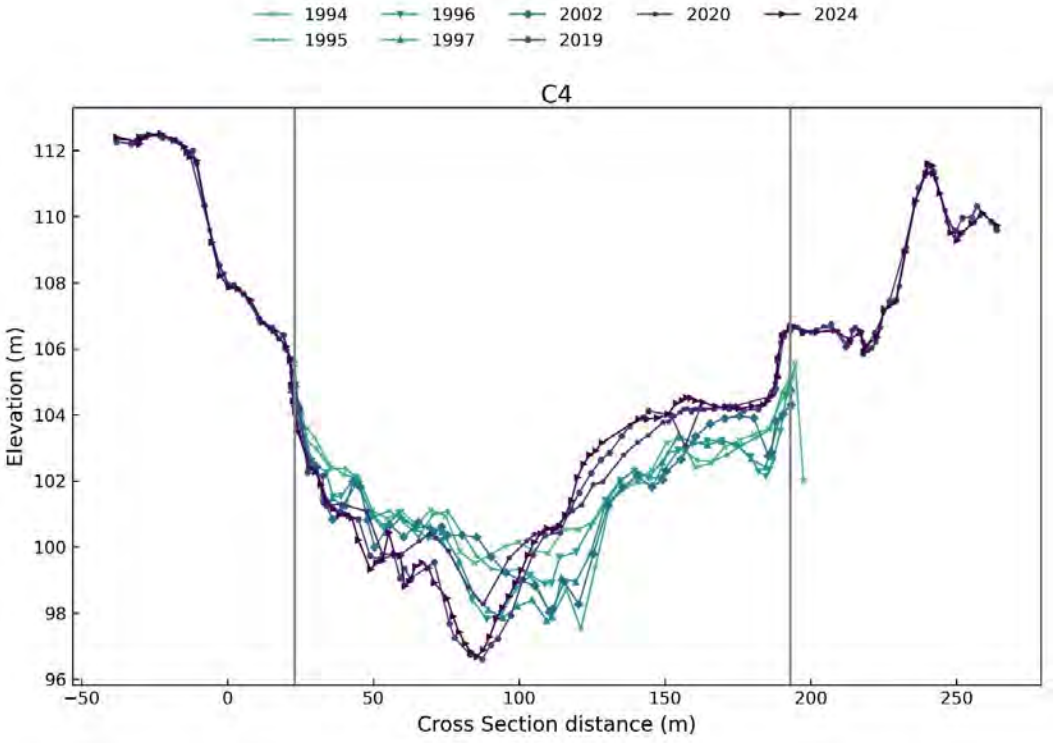
Appendix B Cross section profiles for surveyed years

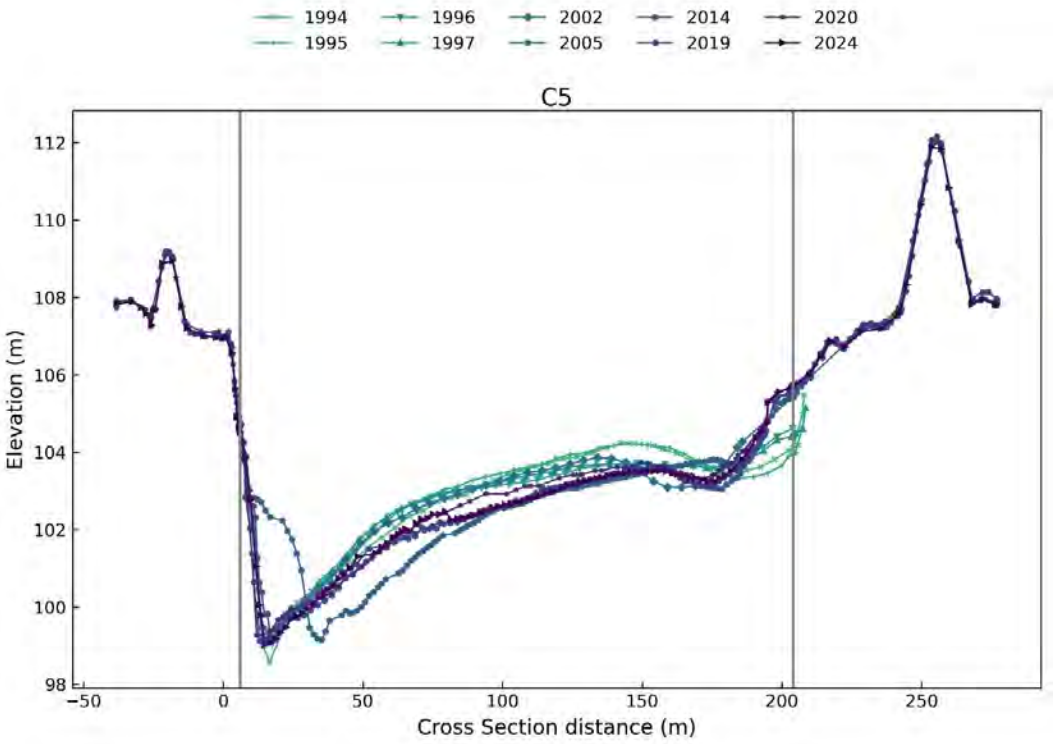
All cross sections are viewed looking downstream.

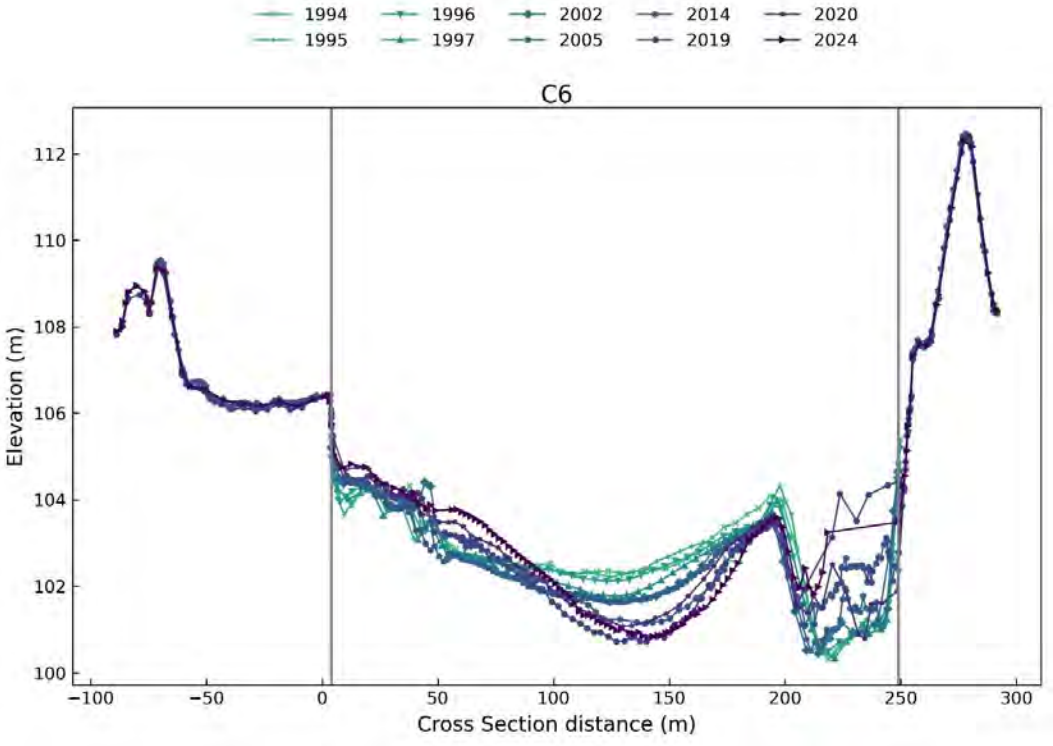


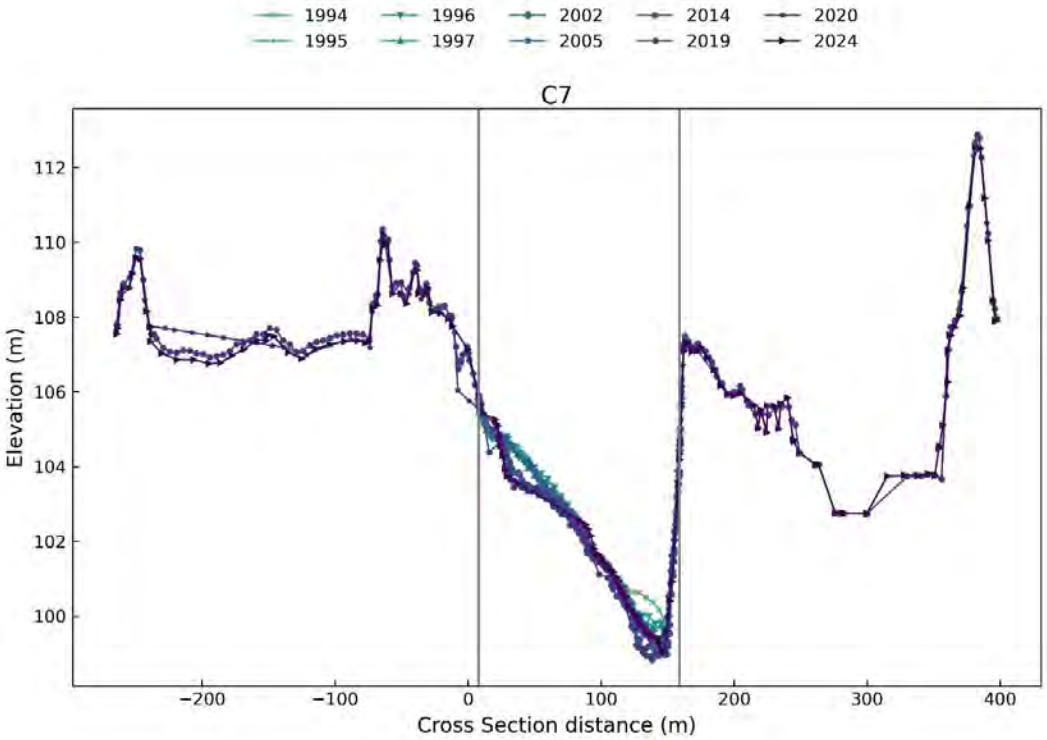


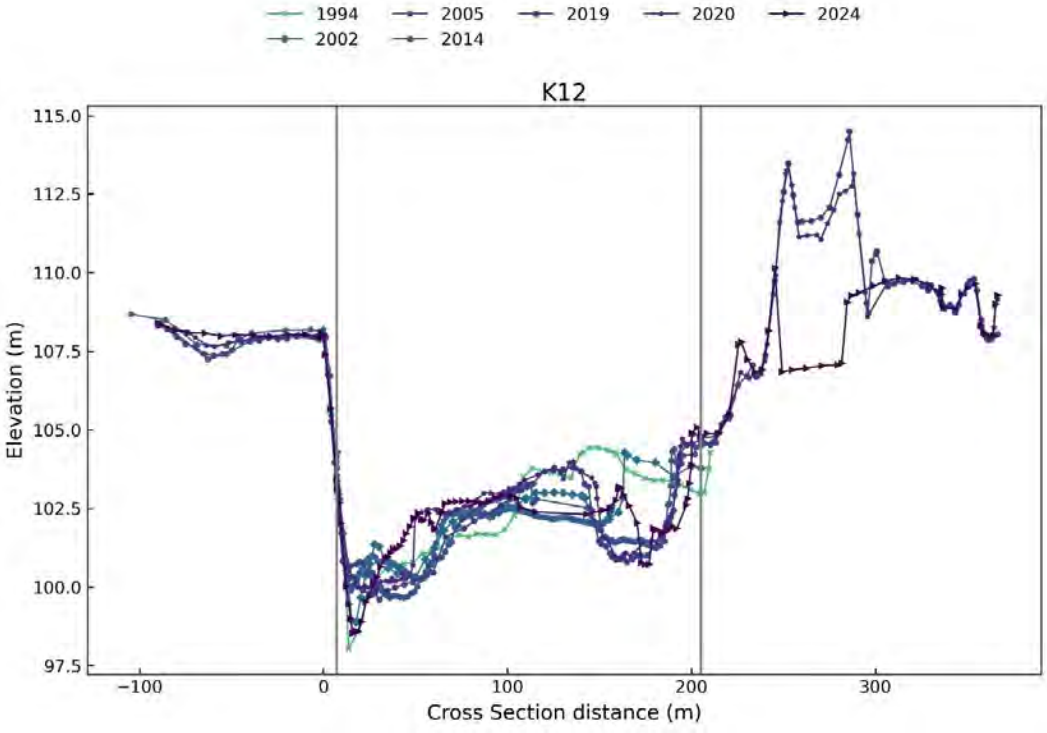

1994
1995
1996
2002
2005
2014
2019
2020
2024
C3
Elevation (m)
Cross Section distance (m)

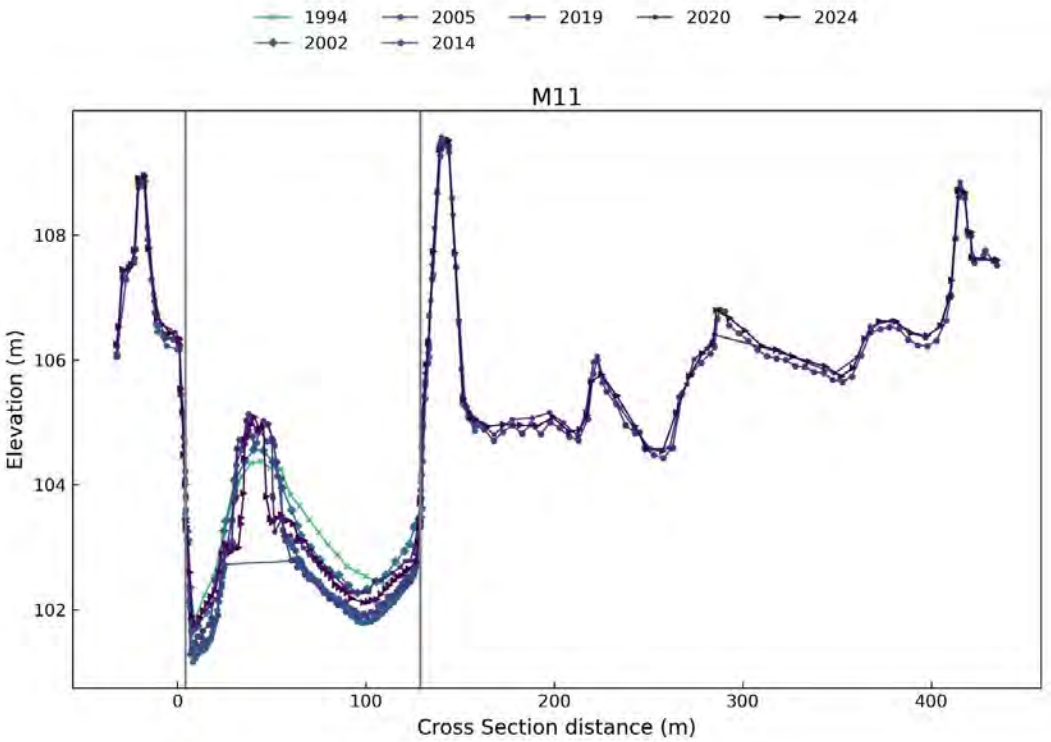

1994
1995
1996
1997
2002
2019
2020
2024
C4
Elevation (m)
Cross Section distance (m)

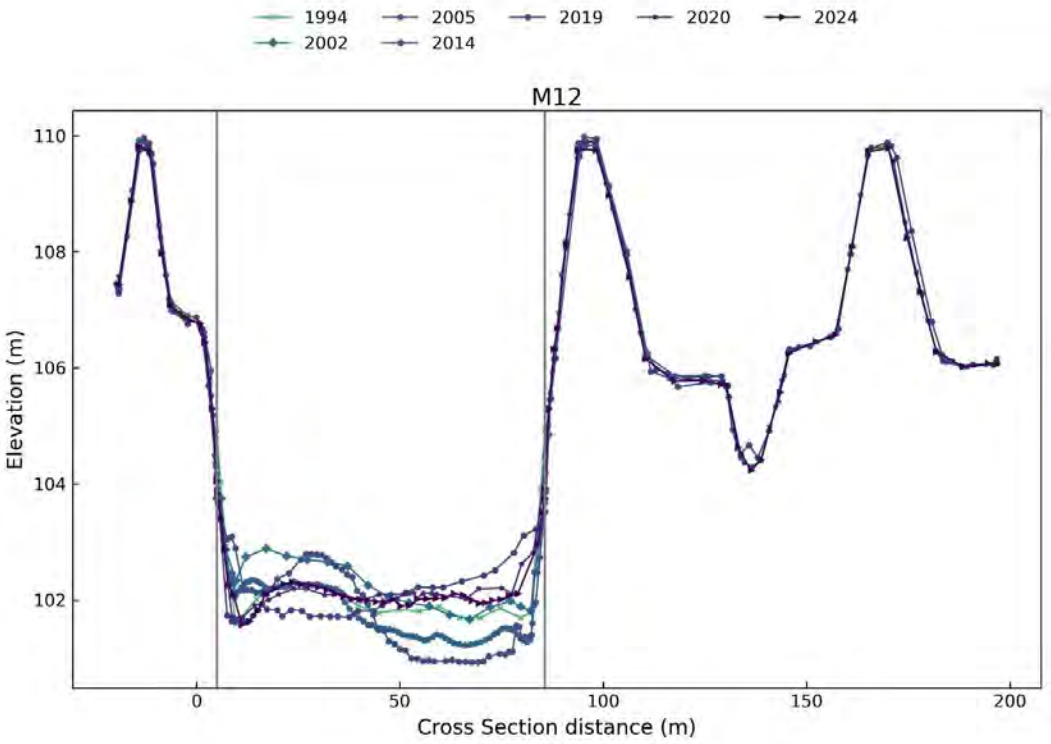

1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C5
Elevation (m)
Cross Section distance (m)


1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C6
Elevation (m)
Cross Section distance (m)


1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C7
Elevation (m)
Cross Section distance (m)


1994
2002
2005
2014
2019
2020
2024
K12
Elevation (m)
Cross Section distance (m)


1994
2002
2005
2014
2019
2020
2024
M11
Elevation (m)
Cross Section distance (m)


1994
2002
2005
2014
2019
2020
2024
M12
Elevation (m)
Cross Section distance (m)

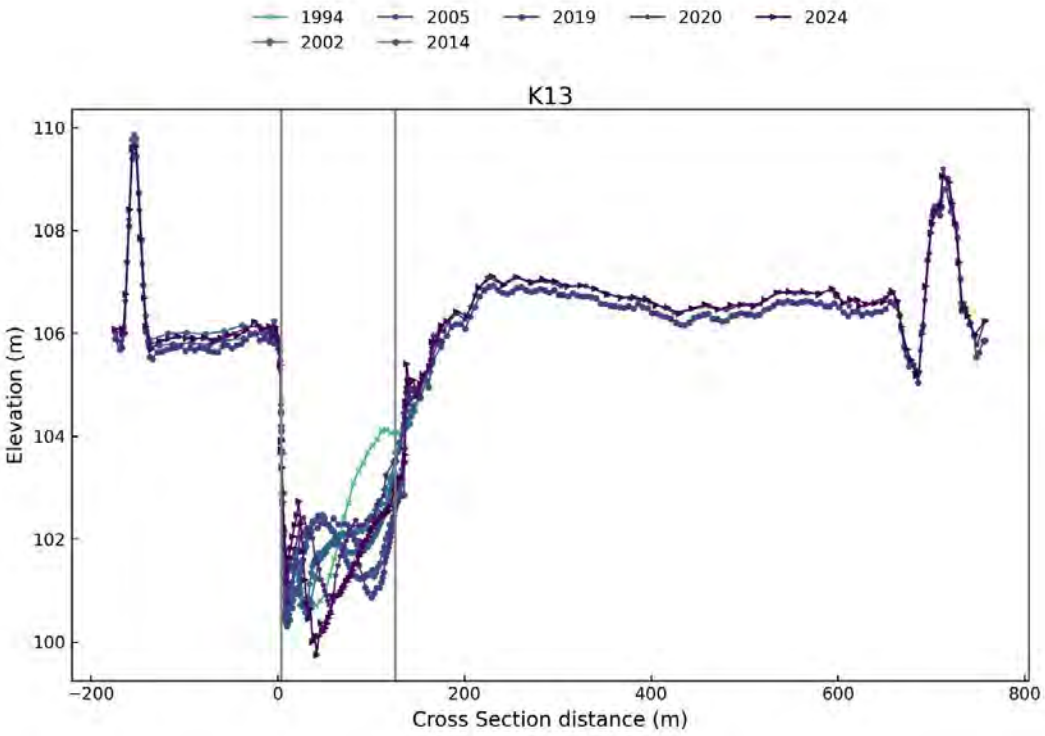
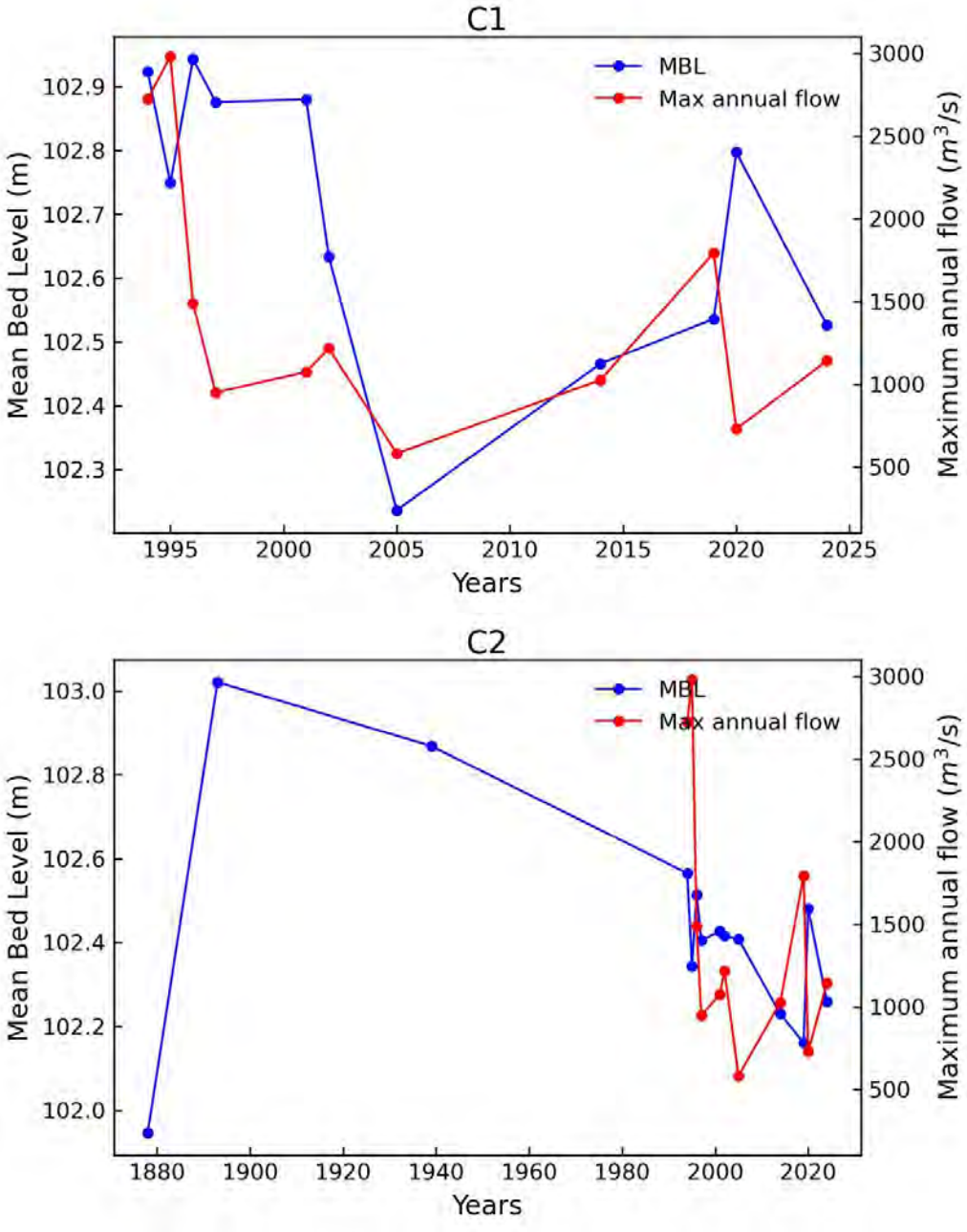
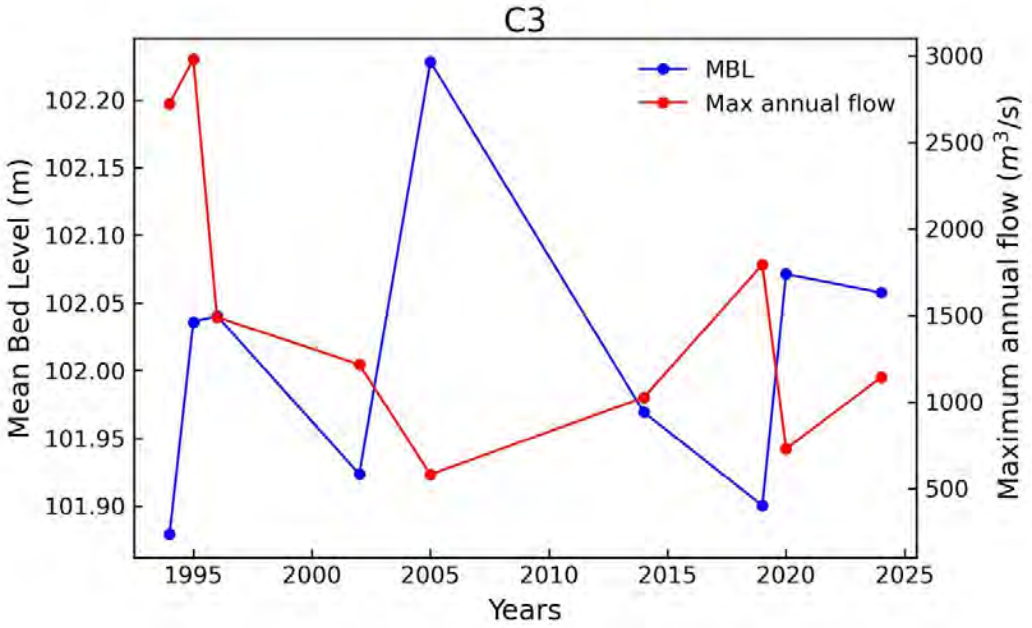


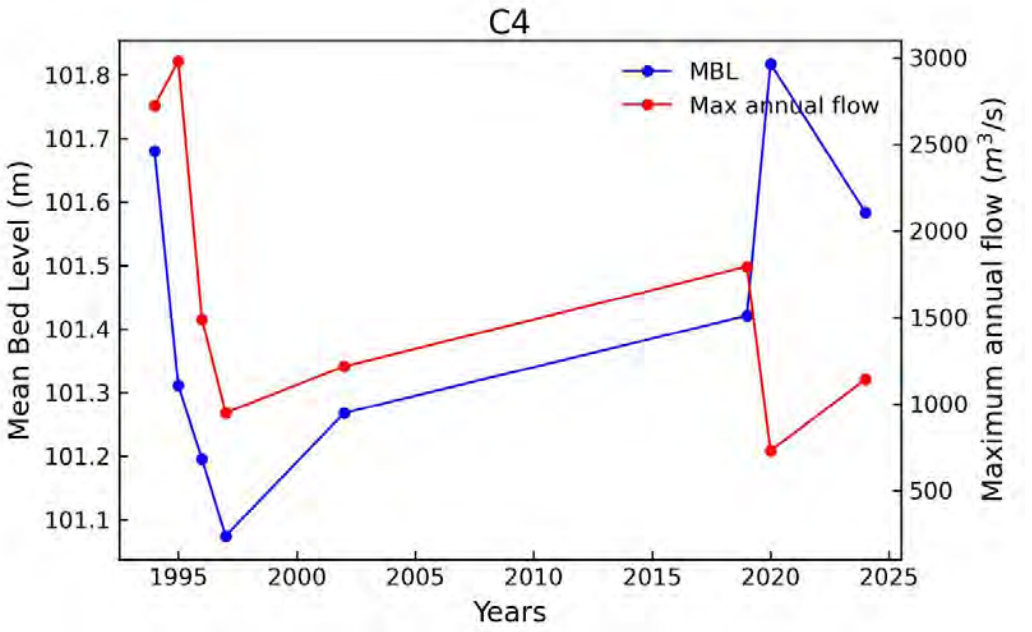
Figure B-1: Cross-sectional profiles of C2 to C7, M11, M12, K12, and K13 for all surveyed years.

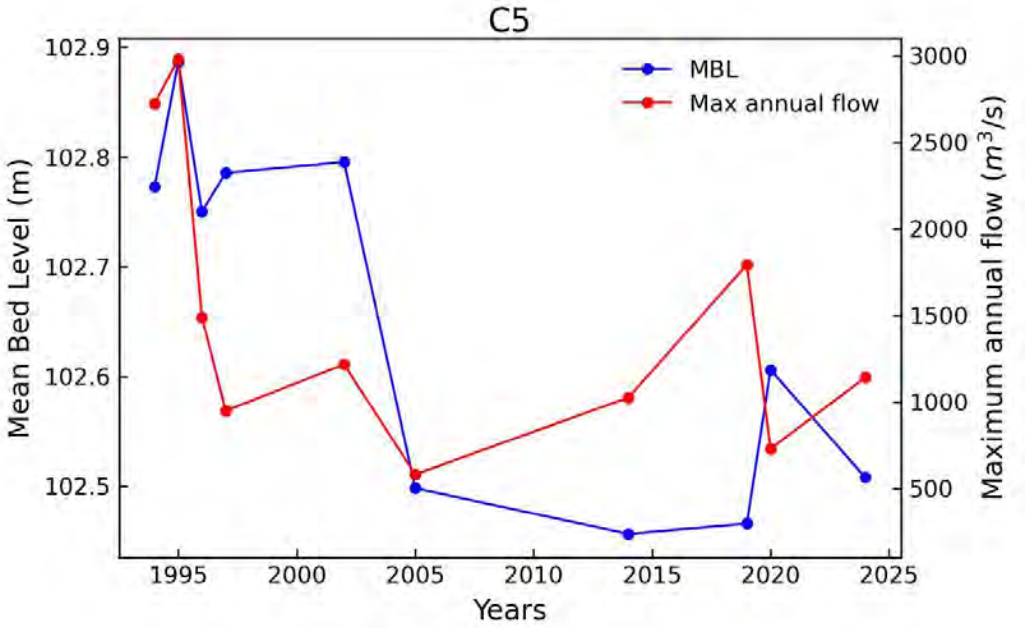
Appendix C Maximum annual flow and mean annual flow vs. mean bed level for different survey years at each cross section

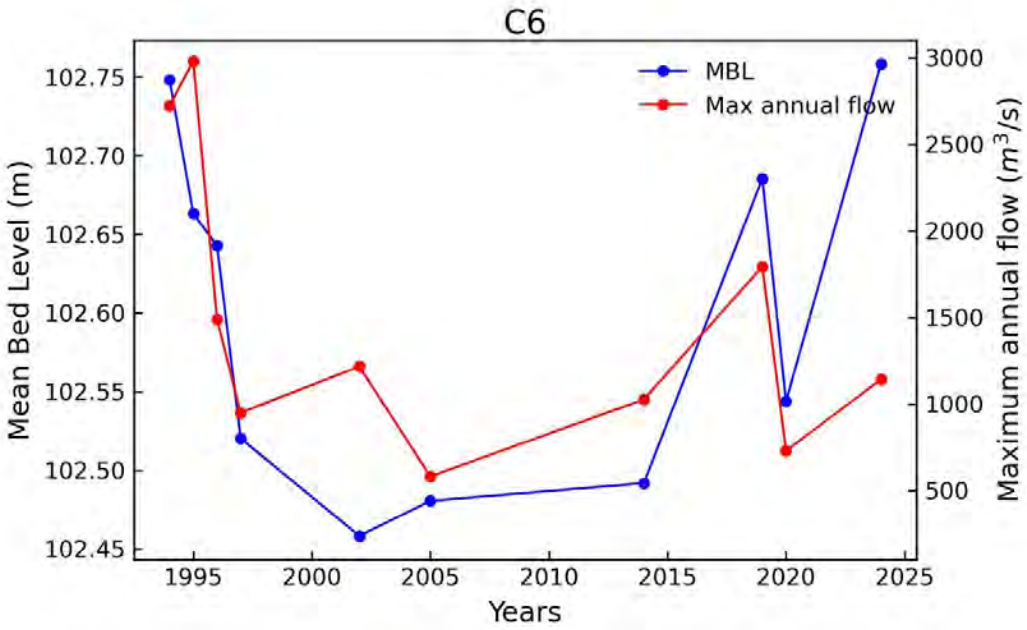
Note that axis scales differ on the plots.

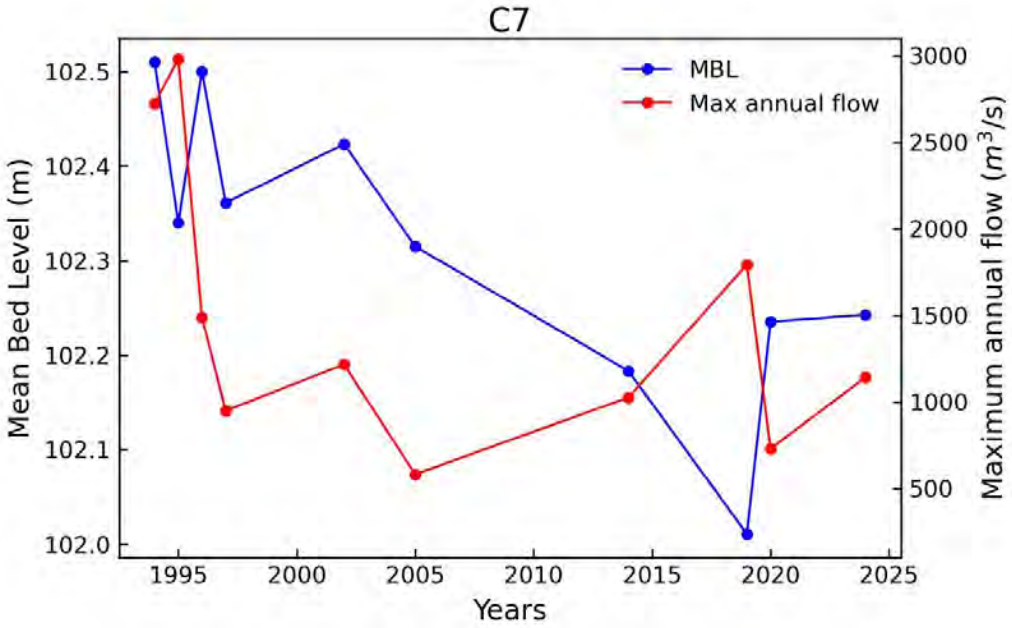


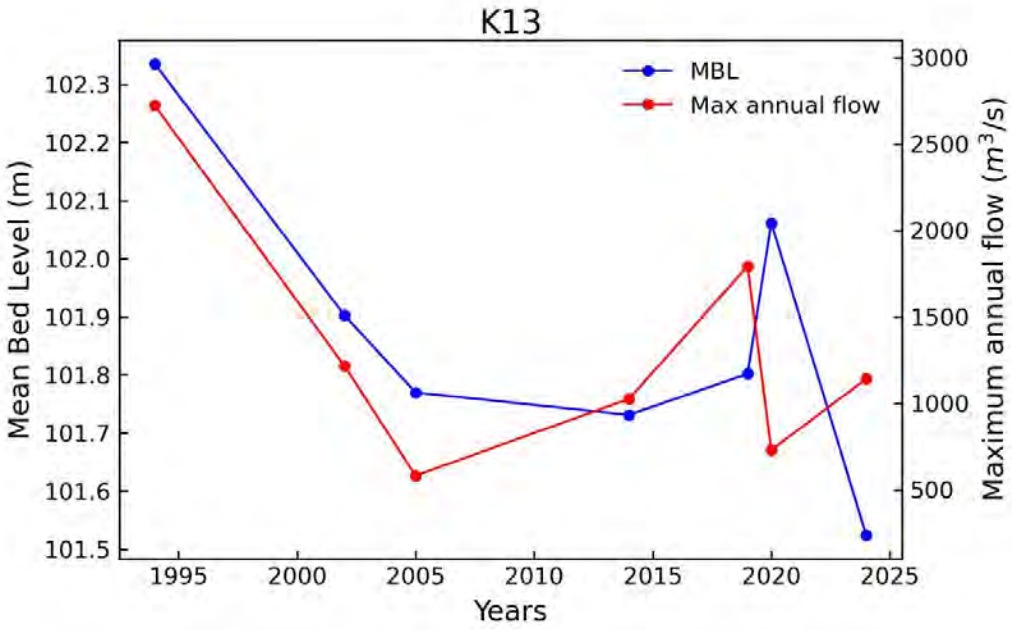

C3
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
102.20
102.15
102.10
102.05
102.00
101.95
101.90
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

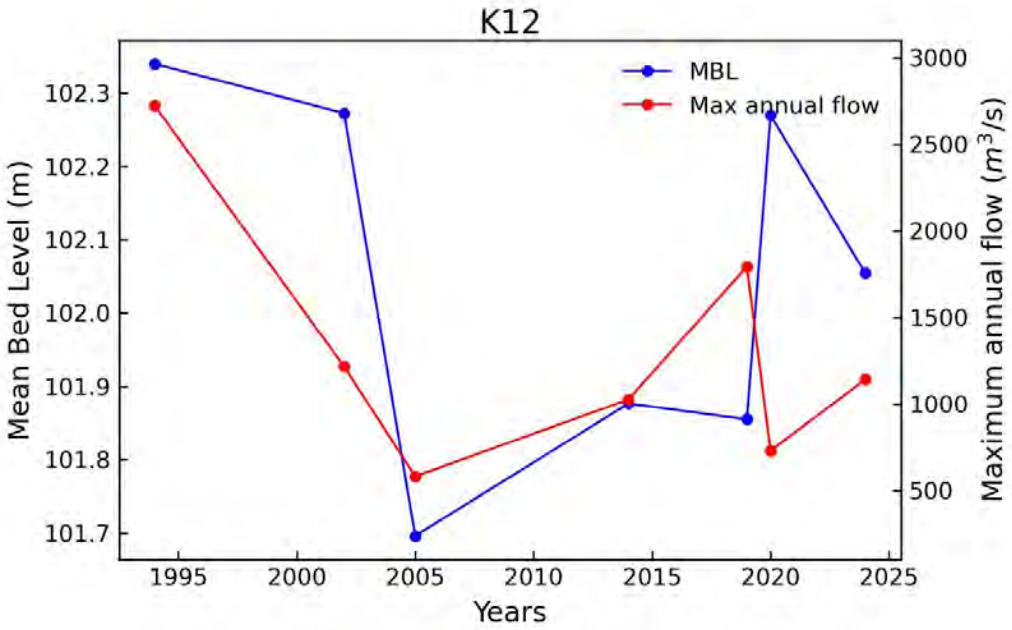

C4
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
101.8
101.7
101.6
101.5
101.4
101.3
101.2
101.1
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

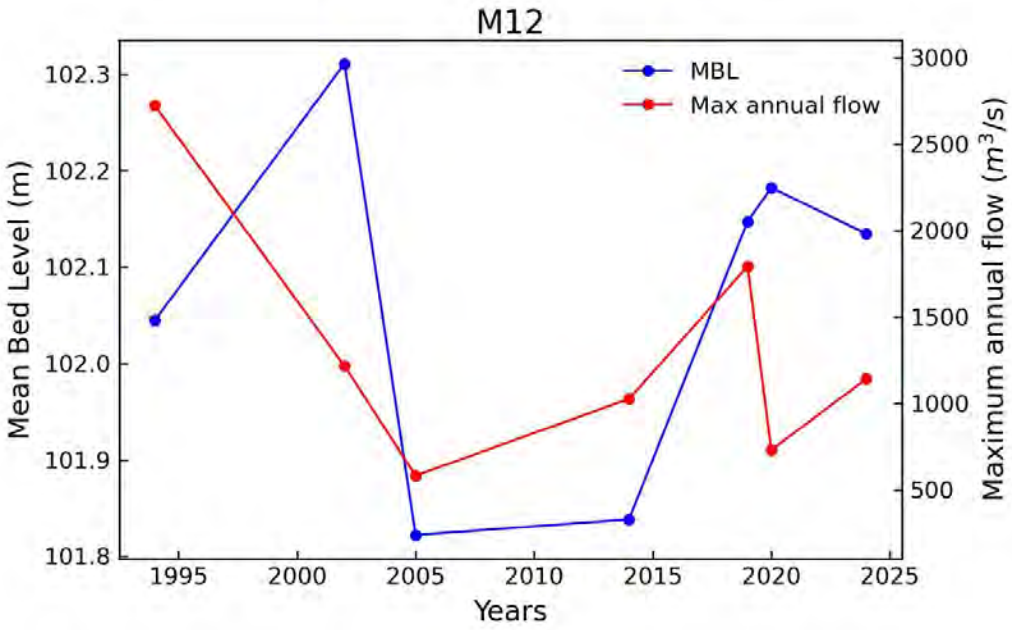

C5
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
102.9
102.8
102.7
102.6
102.5
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

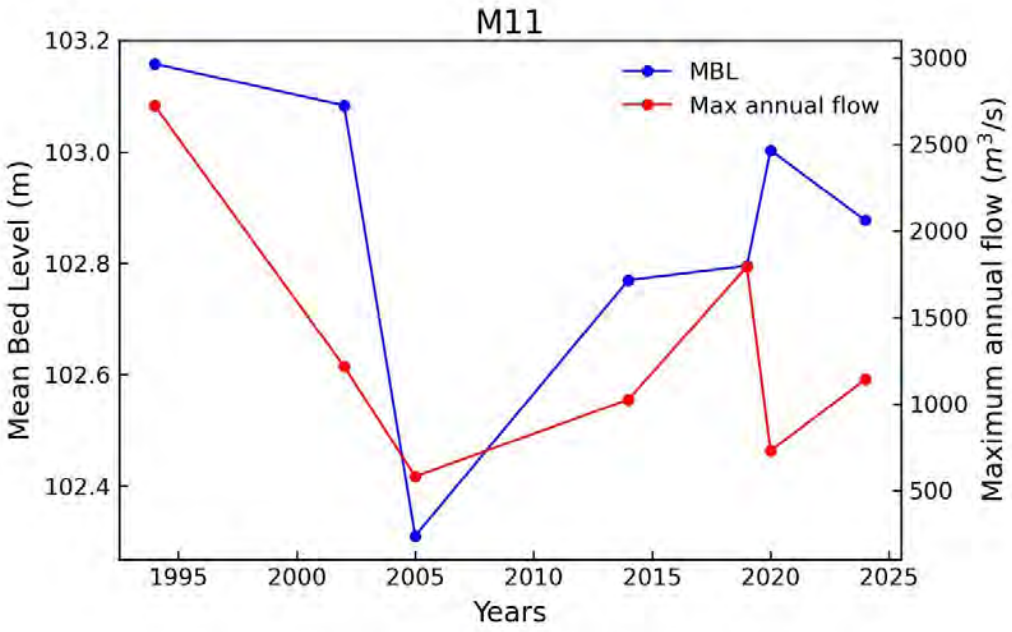

C6
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
102.75
102.70
102.65
102.60
102.55
102.50
102.45
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

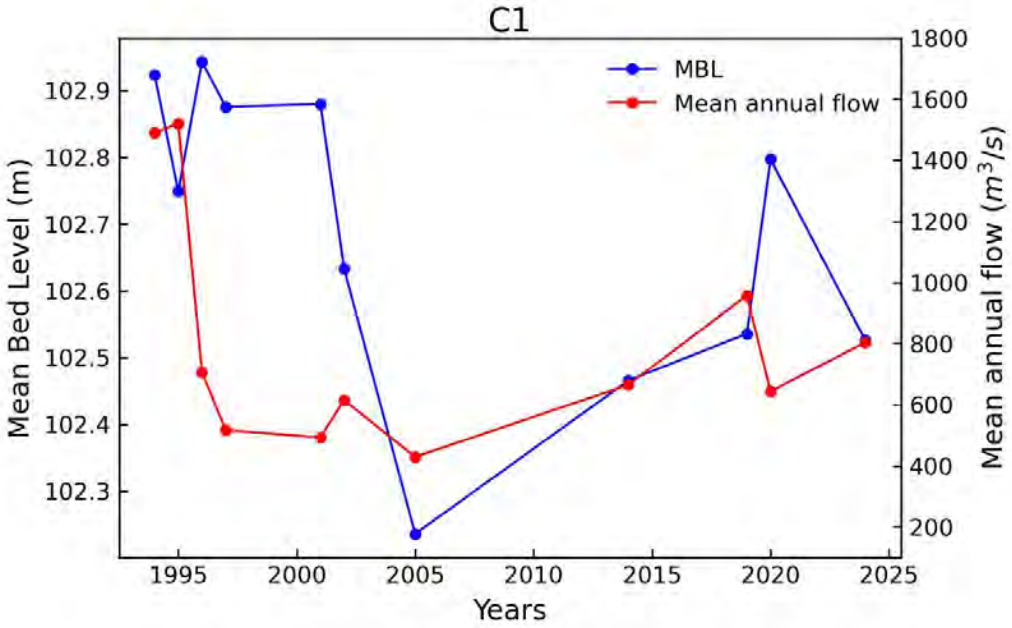

C7
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
102.5
102.4
102.3
102.2
102.1
102.0
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

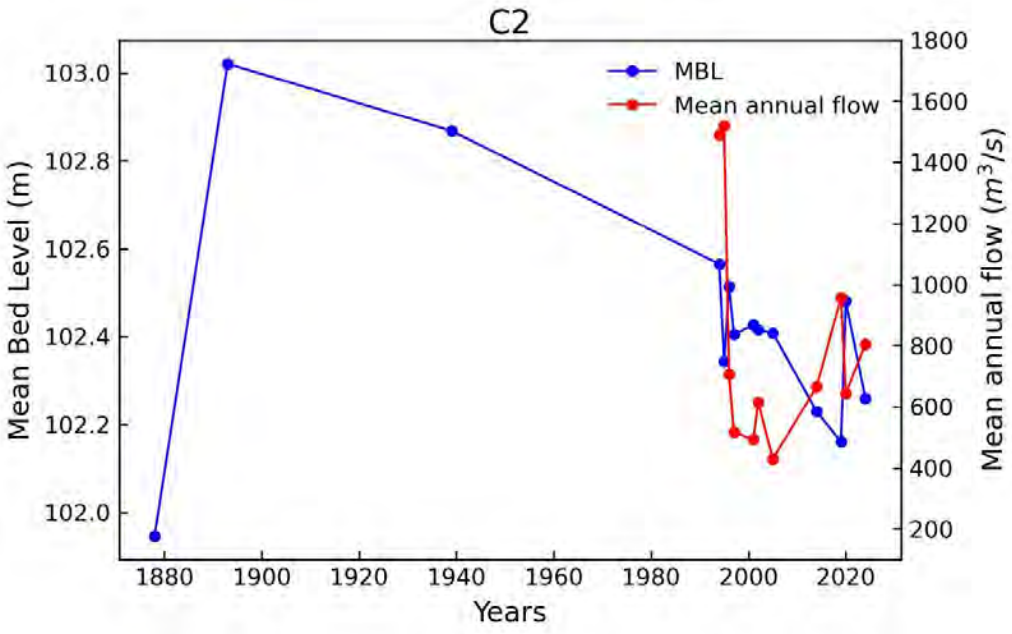

K13
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
102.3
102.2
102.1
102.0
101.9
101.8
101.7
101.6
101.5
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

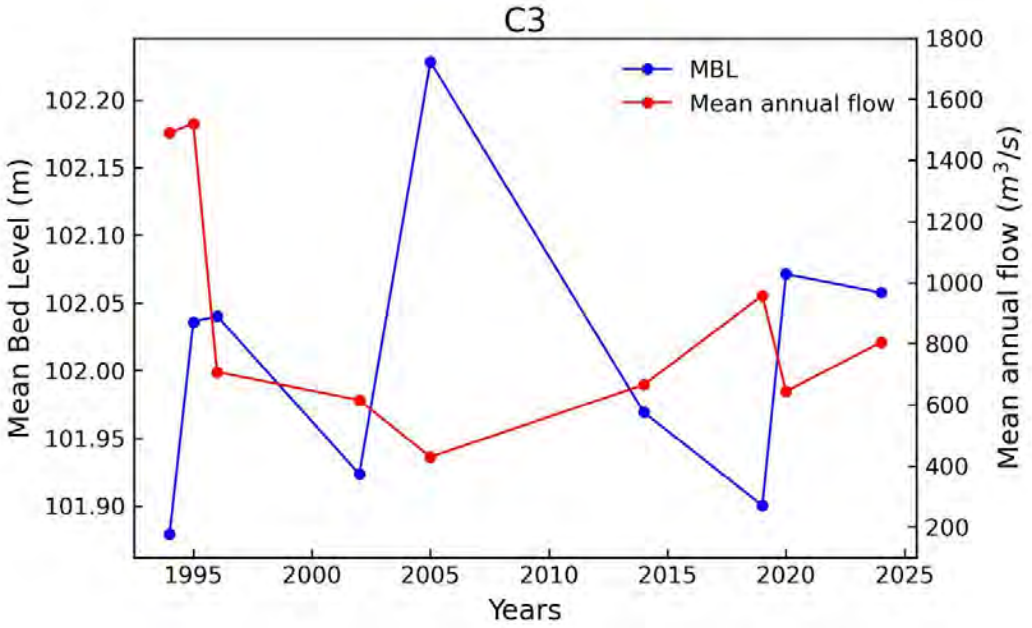

K12
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
102.3
102.2
102.1
102.0
101.9
101.8
101.7
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

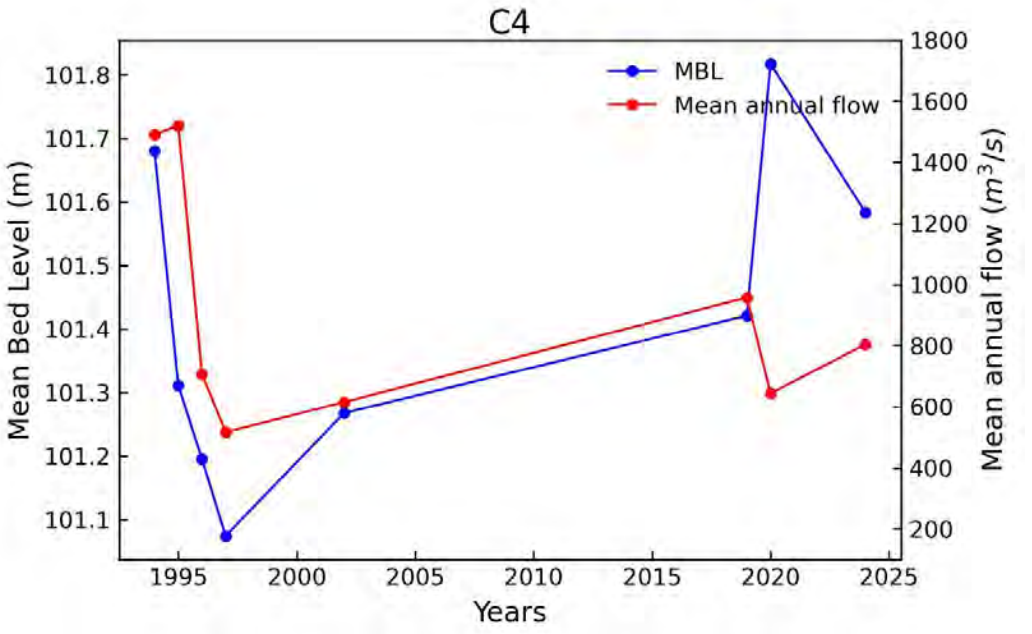

M12
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
102.3
102.2
102.1
102.0
101.9
101.8
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

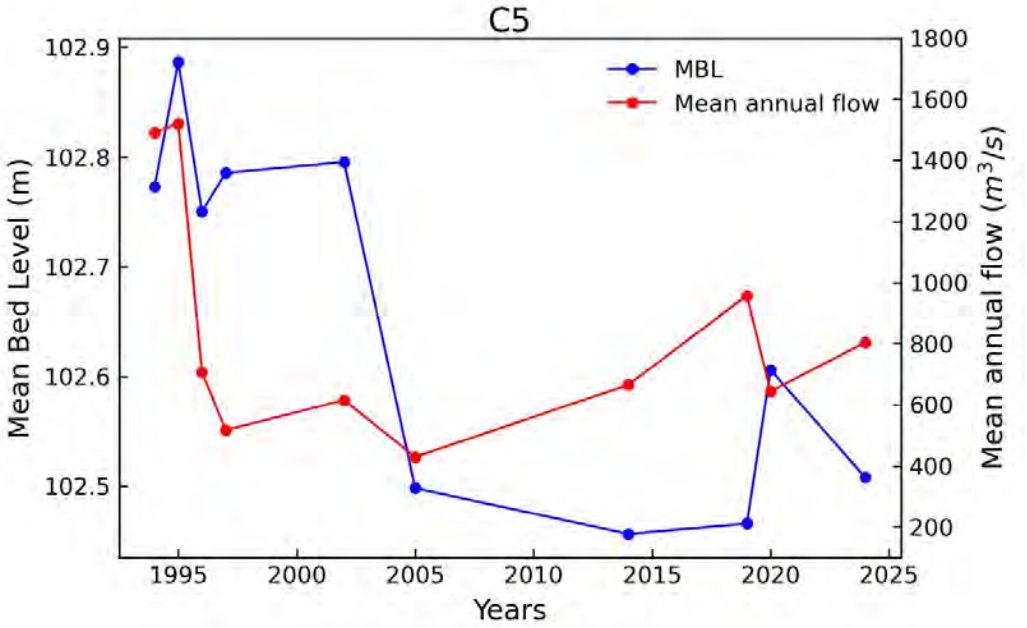

M11
MBL
Max annual flow
Mean Bed Level (m)
Maximum annual flow (m^3/s)
Years
103.2
103.0
102.8
102.6
102.4
3000
2500
2000
1500
1000
500
1995
2000
2005
2010
2015
2020
2025

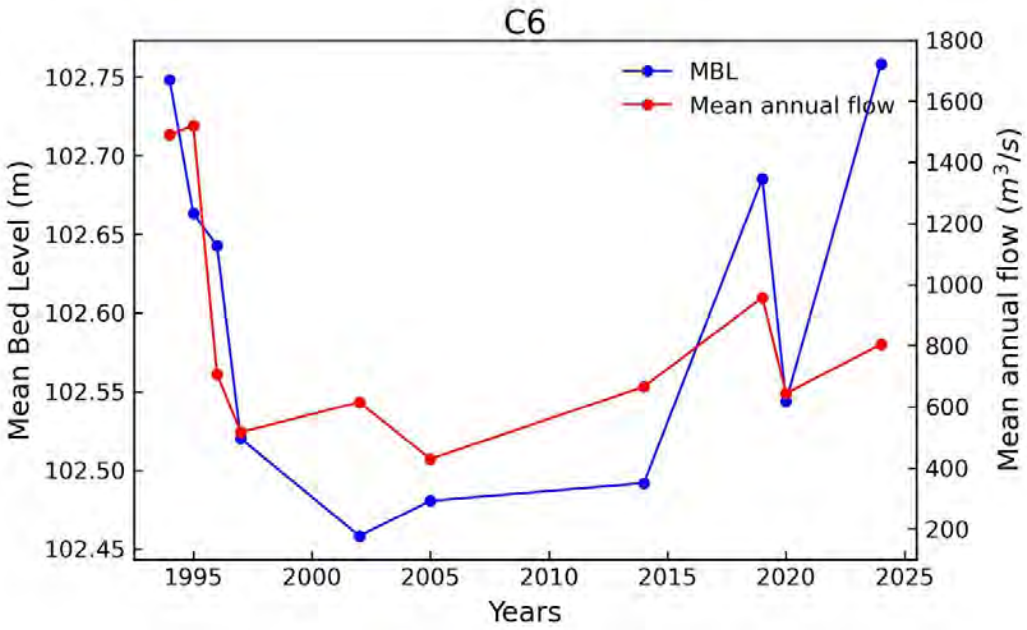

C1
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.9
102.8
102.7
102.6
102.5
102.4
102.3
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025

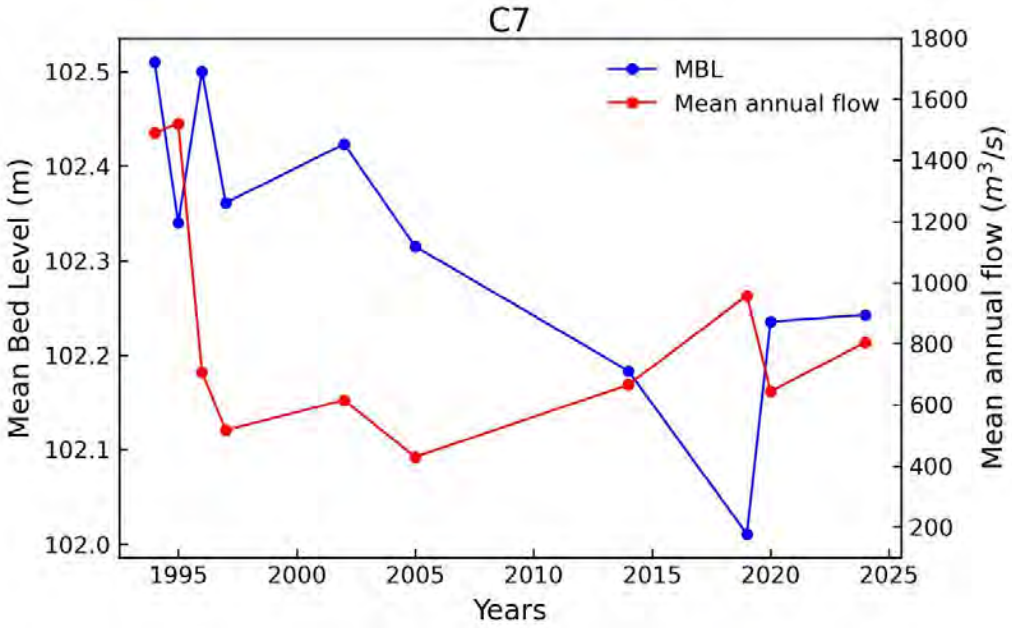

C2
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
103.0
102.8
102.6
102.4
102.2
102.0
1800
1600
1400
1200
1000
800
600
400
200
1880
1900
1920
1940
1960
1980
2000
2020

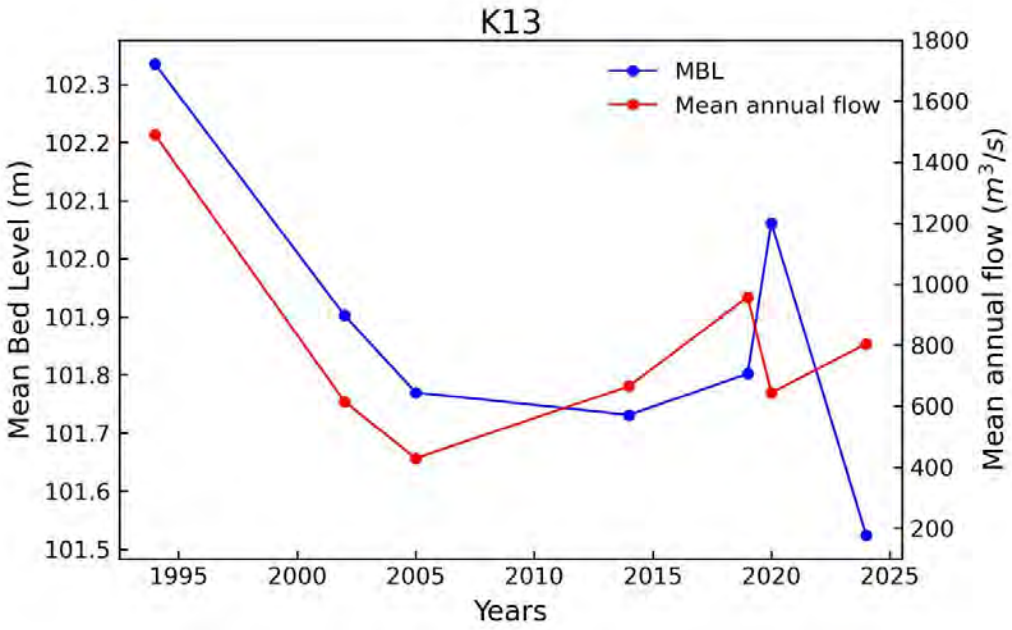

C3
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.20
102.15
102.10
102.05
102.00
101.95
101.90
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025

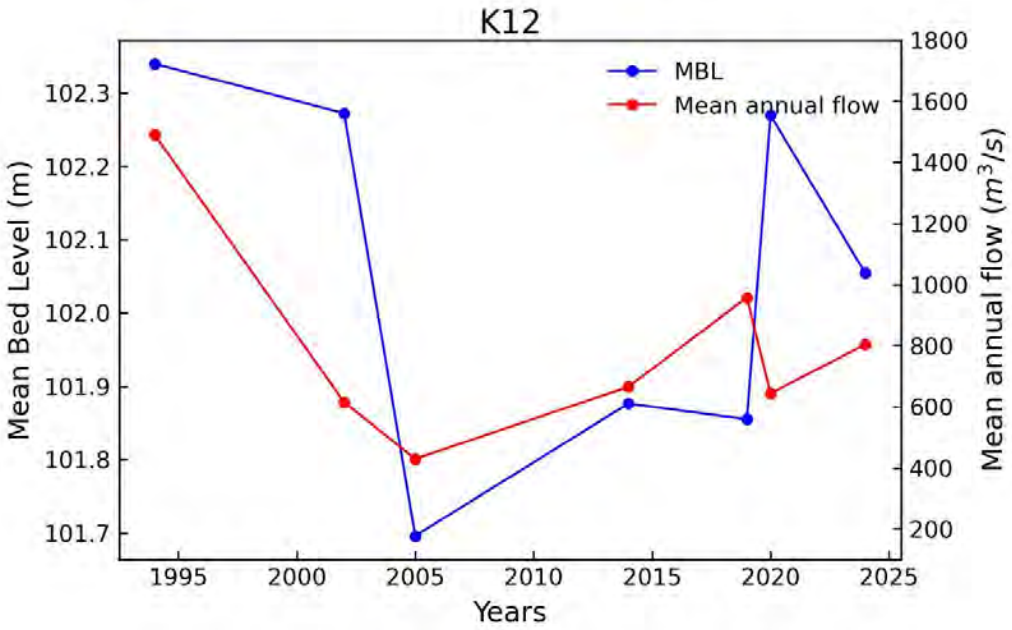

C4
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
101.8
101.7
101.6
101.5
101.4
101.3
101.2
101.1
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025

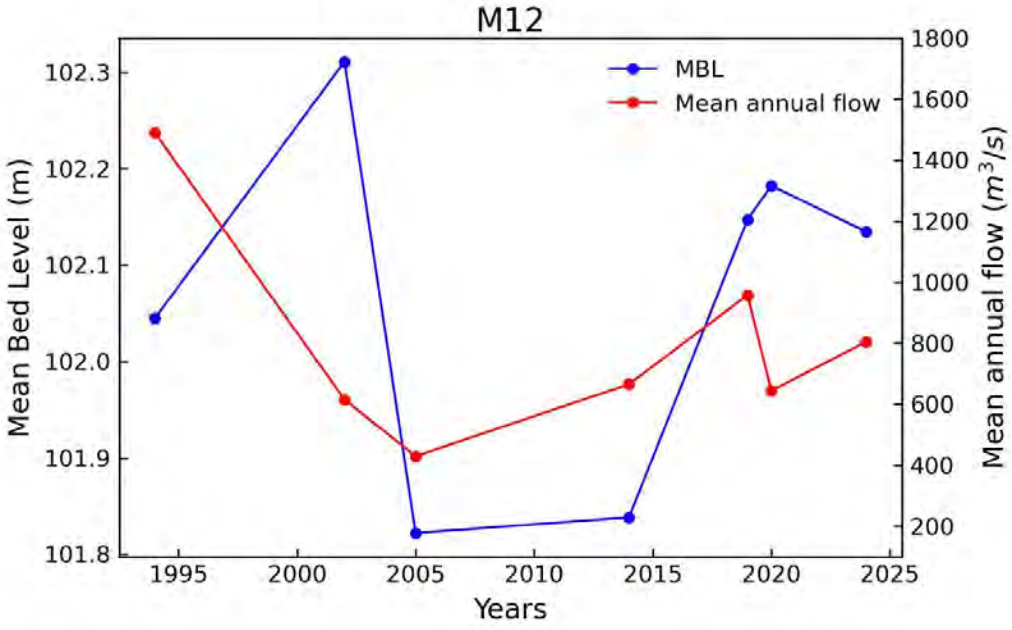

C5
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.9
102.8
102.7
102.6
102.5
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025

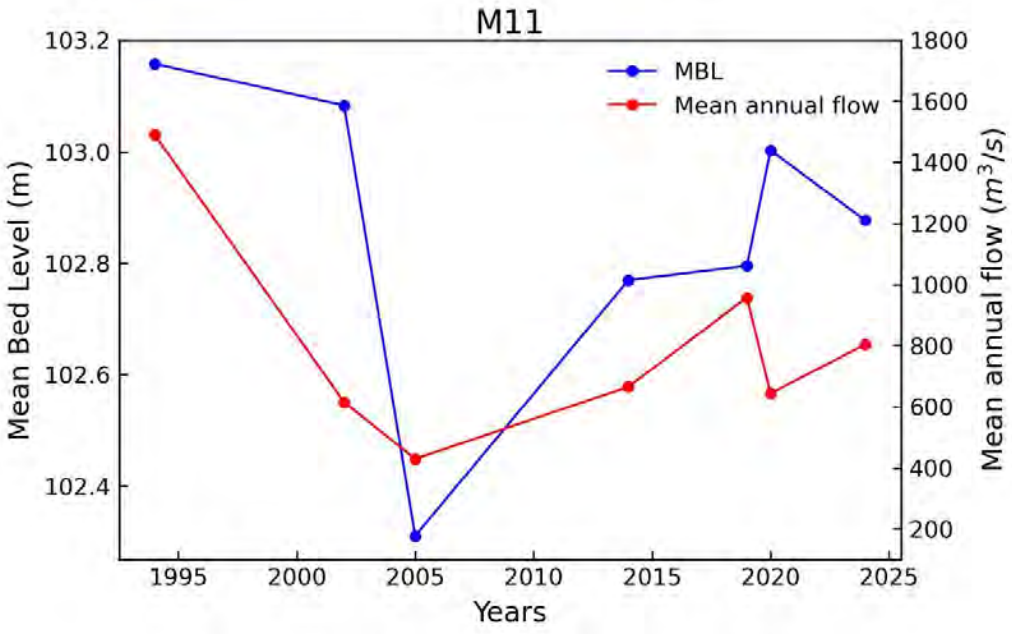

C6
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.75
102.70
102.65
102.60
102.55
102.50
102.45
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025


C7
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.5
102.4
102.3
102.2
102.1
102.0
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025


K13
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.3
102.2
102.1
102.0
101.9
101.8
101.7
101.6
101.5
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025


K12
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.3
102.2
102.1
102.0
101.9
101.8
101.7
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025


M12
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
102.3
102.2
102.1
102.0
101.9
101.8
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025


M11
MBL
Mean annual flow
Mean Bed Level (m)
Mean annual flow (m^3/s)
Years
103.2
103.0
102.8
102.6
102.4
1800
1600
1400
1200
1000
800
600
400
200
1995
2000
2005
2010
2015
2020
2025

Appendix D Satellite imageries of the Clutha River at Balclutha between 2016 and 2025

12-Jan-2018
Mean daily flow = 274 m3/s
N
0 0.2 0.4 0.8
Km

23-Apr-2020
Mean daily flow = 440 m3/s
N
0 0.2 0.4 0.8
Km

22-Mar-2022
Mean daily flow = 267 m3/s
N
0 0.2 0.4 0.8
Km

N
0 0.2 0.4 0.8
Km
27-Feb-2023
Mean daily flow = 371 m3/s

1-Mar-2024
Mean daily flow = 424 m3/s
N
0 0.2 0.4 0.8
Km

Figure D-1: Satellite imagery of the Clutha River at Balclutha for seven years between 2016 and 2025. The exact date of the satellite capture and mean daily flow values are inserted in bottom left of each image. Red lines indicate cross section locations.

NIWA
Taihoro Nukurangi

Plain language report on river bed changes at Balclutha

Prepared for Otago Regional Council

June 2025

Climate, Freshwater & Ocean Science

Prepared by:
Graeme Smart, Arman Haddadchi

For any information regarding this report please contact:

Graeme Smart
Principal Scientist
Natural Hazards and Hydrodynamics
+64 3 343 7851
Graeme.smart@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8440

Phone +64 3 348 8987

NIWA CLIENT REPORT No: 2025196CH
Report date: June 2025
NIWA Project: ORC25501

Revision	Description	Date
Version 1.0	Final version sent to client	30 June 2025

Quality Assurance Statement		
	Reviewed by:	Clare Wilkinson
	Formatting checked by:	Rachel Wright
	Approved for release by:	Helen Rouse

Cover photo: Imagery of the Clutha River showing movement of gravel bars from 2013 to 2024

© All rights reserved. This publication may not be reproduced or copied in any form without the permission of the copyright owner(s). Such permission is only to be given in accordance with the terms of the client's contract with NIWA. This copyright extends to all forms of copying and any storage of material in any kind of information retrieval system.

Whilst NIWA has used all reasonable endeavours to ensure that the information contained in this document is accurate, NIWA does not give any express or implied warranty as to the completeness of the information contained herein, or that it will be suitable for any purpose(s) other than those specifically contemplated during the project or agreed by NIWA and the client.

Contents

Non-technical summary 5

1 Introduction 7

1.1 Background 7

1.2 Scope of the work 8

2 Cross-section data and adjustments 9

2.1 Cross-section data analysis 12

3 Satellite imagery 14

4 Clutha River flow data and analysis 15

5 Results 16

5.1 Bed level changes 16

5.2 Changes across individual cross-sections 25

5.3 Satellite imagery 27

5.4 Flow data analysis 29

6 Discussion 33

6.1 Determine whether there is a significant trend in river bed levels 33

6.2 Assess changes in gravel bars or islands 33

6.3 Identify factors driving changes observed 33

6.4 Evaluate whether observed river bed level changes are sufficient to reduce flood capacity 34

7 Summary and Conclusions 35

7.1 Purpose 35

7.2 What was done 35

7.3 Important Findings 35

7.4 Cautions 35

7.5 Recommendations 35

8 Acknowledgements 37

9 References 38

Appendix A Cross-section profiles for surveyed years 39

Appendix B Satellite images of the Clutha River at Balclutha between 2016 and 2025 45

Tables

Table 2-1: Cross-section data from the Clutha River near Balclutha township. 11

Figures

Figure 2-1: The location of cross-section surveys on the Clutha River at Balclutha together with the flow monitoring site. 10
Figure 2-2: C1 cross-section profile for all surveyed years. 12
Figure 2-3: Illustration of area above average bed level for cross-section C1 in 2024. 13
Figure 4-1: Annual maximum flow (a) and annual average flow (b) for the Clutha River at Balclutha monitoring site. 15
Figure 5-1: Changes in the bed at Section C2 from 1878. 17
Figure 5-2: Changes in the bed at section C4. 18
Figure 5-3: Historical changes in the average bed level of the Clutha River near Balclutha township. 19
Figure 5-4: Changes in the average bed level over the years at each cross-section. 21
Figure 5-5: Average bed level change relative to 1990 in the Clutha River near Balclutha, with surveys grouped and averaged by decade. 21
Figure 5-6: Historical changes in the minimum bed level of the Clutha near Balclutha. 22
Figure 5-7: Changes in the minimum bed level over the years at each cross-section. 23
Figure 5-8: Historical changes in the height above bed level values of the Clutha River near Balclutha. 24
Figure 5-9: Changes in the average height above average bed level over the years at each cross-section. 25
Figure 5-10: Imagery of the Clutha River at Balclutha in March 2013 (top) and March 2024 (below). 28
Figure 5-11: Satellite imagery of the Clutha River at Balclutha on two dates: January 10, 2016 (left) and January 27, 2025 (right). 29
Figure 5-12: Minimum bed level at times of NIWA flow measurements near section C3. 30
Figure 5-13: Water level for a given flow compared with preservation of 1952 bed levels. 30
Figure 5-14: Water level for a given flow compared with preservation of 1978 bed levels. 31
Figure 5-15: Comparing water level for a given flow data from gauging measurements over the years. 32
Figure 6-1: Aerial photographs from 1946 (left) and in 1995 (right). 34

Figure A-1: Cross-sectional profiles of C2 to C7, M11, M12, K12, and K13 for all surveyed years. 44
Figure B-1: Satellite imagery of the Clutha River at Balclutha for seven years between 2016 and 2025. 51

Non-technical summary

The bed level of a river can rise or fall depending on changes in channel shape, changes in river flow and changes in the supply of sediment from upstream. River bed adjustment to such changes can take many decades. For the Clutha River at Balclutha, all of these factors have come into play over the river's history, and they have been studied in a technical report "Clutha River Morphology Trends at Balclutha" prepared for Otago Regional Council in March 2025. This plain-language report accompanies, complements and summarises findings of the more detailed technical analysis.

Otago Regional Council (ORC) collected detailed surveys of the bed level of the Clutha River since 1994, and pre-1990s surveys have been compiled from historical records back to 1878. The National Institute of Water and Atmospheric Research (NIWA) has also measured river depth and flow near the Balclutha railway bridge since 1952. More recent satellite imagery collected by Sentinel-2 shows the patterns of channels and bars in the river. This study investigates these data to reveal how the level of the Clutha river bed near Balclutha has changed with time. In particular, it considers eleven locations near Balclutha where bed levels have been measured, 482 river depth and flow measurements near the Balclutha railway bridge, and seven satellite images that show gravel bars in the river. Bed levels are typically measured at points along a line across the river to produce what is known as a cross-section.

An important question related to the Clutha bed level, is whether the river is more or less likely to flood into Balclutha now than it has been in the past. This is revealed by NIWA's measurements near the Balclutha railway bridge, which show how the water level for a given flow has changed from the past to the present.

The overall finding on river bed changes near Balclutha is that there was an increase in bed level in the late 1800s. Little is known about river bed levels in the early 1900's, then there was a long-term trend of lowering of the river bed from the 1950s to about 2002 with less of a trend evident since 2002. This behaviour corresponds to an increase in alluvial sediment produced by gold mining and sluicing in the late 1800s and then a severe reduction in sediment supply following commissioning of the Roxburgh hydro dam in 1954. Cross-section levels measured since 1994, show that the average bed level is stable or falling at ten of the eleven cross-sections near Balclutha. The section at the State Highway Bridge shows a small rising trend in the average bed level. Since 1994, minimum bed levels (in other words, the deepest points in the river) have been stable or falling at all cross-sections except at the North end of Elizabeth Street where the surveyed low point is rising with time. This change has resulted from historic, upstream river training works which have moved the deepest part of the channel away from the bank.

The NIWA flow measurements at Balclutha show the channel flood capacity (the ability of the river to pass a flood through the channel without overtopping) has been increasing since 1952 for floods up to around 1600 cubic metres per second. River beds may lower during flood events, but the extent of bed lowering during floods is unknown at Balclutha. Assuming this effect has not reduced over time, the historic cross-section surveys do not indicate a reduction of flood capacity of the Balclutha reach.

However, there are recent reports that gravel bars are now more evident in the river at Balclutha, which could provide a barrier to flow which could cause reduced flood capacity. This apparent paradox could be explained because stable bars can become more visible and appear to be higher when the river water level falls alongside a bar. A field inspection may help confirm this explanation.

Effects of river gravel mining on the river cross is measured by the cross-section surveys. However, as extraction times and volumes are not all known, it is difficult to attribute the influence of gravel extraction on observed cross-section changes.

Ongoing monitoring and, in particular, measurement of river bed levels during future high flood flows, is strongly recommended. This monitoring would help to answer questions about any changes in ability of the channel to handle high floods and about how much the bed scours during a rising flood before refilling on a falling flood, which will bury the actual cross-section during the flood.

1 Introduction

1.1 Background

Since 1954, the Roxburgh Hydro dam has captured Clutha (Mata-Au) sediment and prevented gravel from moving downstream. This effect reduces the amount of sediment reaching Balclutha each year by about 90%[1]. Other factors that affect sediment in the river include gravel extraction, gold sluicing, the size and frequency of floods, river erosion, bank protection works and other changes in the river catchments between Roxburgh and Balclutha.

Usually, when a dam cuts off sediment supply, a river starts to erode and cut deeper into its bed. This bed lowering tends to be more severe closer to the dam and decreases downstream. Over time, the rate of bed lowering generally slows down[2].

The Otago Regional Council (ORC) have commissioned NIWA to analyse and report on historical changes in river bed levels in the Clutha near Balcultha township, using data from bed level surveys, flow measurements and satellite imagery. The results of the analyses will be used to help understand any significant trends and to guide river management strategies into the future.

Bed levels are typically measured at points along a line across the river to produce what is known as a cross-section. All bed levels are presented with a common datum for which 100 m is the approximately mean sea level. Data from eleven cross-section locations have been used in this study. All cross-sections are viewed and discussed from a “looking downstream” point of view. Seven of the cross-sections are within the Clutha River and four are located on the two branches where the river splits, just downstream of Balclutha. Cross-section surveys for ten of the locations have been undertaken regularly since 1994 and, for the cross-section located near the railway bridge, data extend as far back as 1878.

While the analysis covers a long period, bed changes can occur between the dates of the cross-section measurements, particularly if there has been gravel extraction or flooding. Comprehensive gravel extraction data are not available, so the exact effects of gravel mining on the observed changes are not known. Moreover, areas of scour, or bed lowering, during a rising flood may refill on the falling flood and not be captured by a later cross-section survey. Consequently, the information on bed level changes reported here relates to the net change between the cross-section survey dates.

Local flood capacity of the river (the ability of the river to pass a flood through the channel without overtopping)depends on what happens downstream, the local cross-section and on localised flow influences from bars, river bends and bed material sizes. These effects are captured by making flow measurements during floods.

[1] Hicks DM, Walsh JM and Duncan MJ. (2000). Clutha River Sediment Budget. NIWA Client Report CHC00/45
[2] Grant, G. E., Fassnacht, H., McClure, E. M., & Klingeman, P. C. (2003). Downstream effects of the Pelton-Round Butte hydroelectric project on bedload transport, channel morphology, and channel-bed texture, lower Deschutes River, Oregon. Water Science and Application, 7, 175-176.

1.2 Scope of the work

The objectives of the study are to:

- Determine whether there is a significant trend in river bed levels at Balclutha in recent decades, beyond the expected range of typical bed level fluctuations or measurement uncertainties.
- Assess notable changes in the location, scale, or development of gravel bars or islands within this reach of the river.
- Identify the key factors driving any significant changes observed or, in the absence of such changes, to explore the reasons behind community perceptions of change in the river system.
- Evaluate whether the magnitude of any observed river bed level changes is sufficient to reduce the flood capacity within this reach of the river.

To address these objectives, we have undertaken the following steps:

- Collating all available ORC surveys and river bed cross-section data.
- Reviewing the raw survey data and refining it where discrepancies or mismatches with historical cross-section records were identified, ensuring consistency and accuracy.
- Overlaying and plotting the cross-sections to provide a clear visual representation of changes over time.
- Analysing historical changes in river bed levels by calculating the average bed level, the minimum bed level and changes in the higher parts (gravel bars) of each cross-section.
- Using satellite imagery over time to analyse changes in the extent of gravel bars.
- Investigating the record of flow measurements made at the NIWA flow recorder site at Balclutha.

2 Cross-section data and adjustments

Cross-section surveys of the Clutha River are made at fixed locations (Figure 2-1). Those covering the Balclutha township area are numbered C1 to C7, K12, K13, M12 and M11. More information on the cross-sections is provided in the report “Channel morphology and sedimentation in the Lower Clutha River” by Otago Regional Council (2008).

Although most of these cross-sections were surveyed between 1994 and 2024, different sections were surveyed at different times. Notably, cross-section C2, located at the present railway bridge, has survey records extending back to 1878. The years of cross-section surveys having reliable data are given in Table 2-1.

Figure 2-1: The location of cross-section surveys on the Clutha River at Balclutha together with the flow monitoring site. The flow monitoring site is near the North end of C3.

Table 2-1: Cross-section data from the Clutha River near Balclutha township. These data were used for the analysis of historical bed level changes.

Cross-section	Description	Number of surveys	Years*
K13	First downstream cross-section of Koau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
K12	Second downstream cross-section of Koau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
M12	First downstream cross-section of Matau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
M11	Second downstream cross-section of Matau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
C1	Most downstream cross-section before Clutha River splits into Matau Branch and Koau Branch	11	1994, 1995, 1996, 1997, 2001, 2002, 2005, 2014, 2019, 2020, 2024
C2	Cross-section near railway bridge	14	1878, 1893, 1939, 1994, 1995, 1996, 1997, 2001, 2002, 2005, 2014, 2019, 2020, 2024
C3	Cross-section next to flow monitoring site	9	1994, 1995, 1996, 2002, 2005, 2014, 2019, 2020, 2024
C4	Cross-section near Highway 1 bridge	8	1994, 1995, 1996, 1997, 2002, 2019, 2020, 2024
C5	Around 400m upstream of the Highway Bridge	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024
C6	North end of Elizabeth Street, Balclutha	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024
C7	Most upstream cross-section analysed	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024

* 2023 survey data are considered unreliable and are not listed here.

The cross-section data were aligned, and consistent start and end points were selected to compare measurements from different surveys. These results are shown in Appendix A with an example given

in Figure 2-2 below, for the C1 cross-section. The grey vertical lines indicate the start and end points that are used to give consistent comparisons of bed level changes between the different surveys.

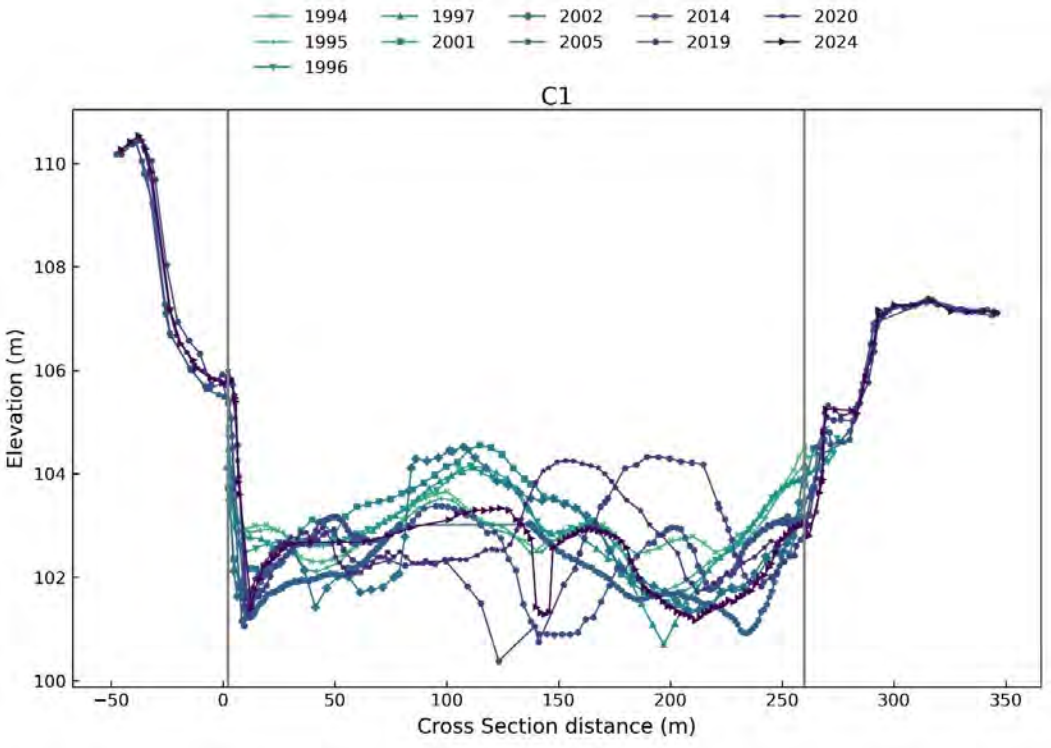


Figure 2-2: C1 cross-section profile for all surveyed years. Grey vertical lines indicate the start and end points used for analysis of bed level change. The sections are viewed looking downstream.

2.1 Cross-section data analysis

To monitor changes in the river bed, we have studied:

- The average level of the bed of the river between the start and end points.
- The area above average bed level divided by distance between the start and end points.
- The minimum bed level between the start and end points.
- The profile of the bed along the river.
- Changes in water level for different flows.

Assessing changes in the average level of the bed over time allows assessment of long-term river stability, showing whether the river bed is rising or falling between different cross-section survey dates.

The area above average bed level divided by distance between the start and end points of analysis indicates changes in high parts (gravel bars) of the channel.

Figure 2-3 shows an example of how these data can be used to identify gravel bars. The area above average bed level is shaded in red. This area is divided by the total width to give a consistent comparison between cross-sections. An increase over time means an increase in the range of bed level across a cross-section, which indicates the growth or enlarging of bars, or the formation of deeper channels.

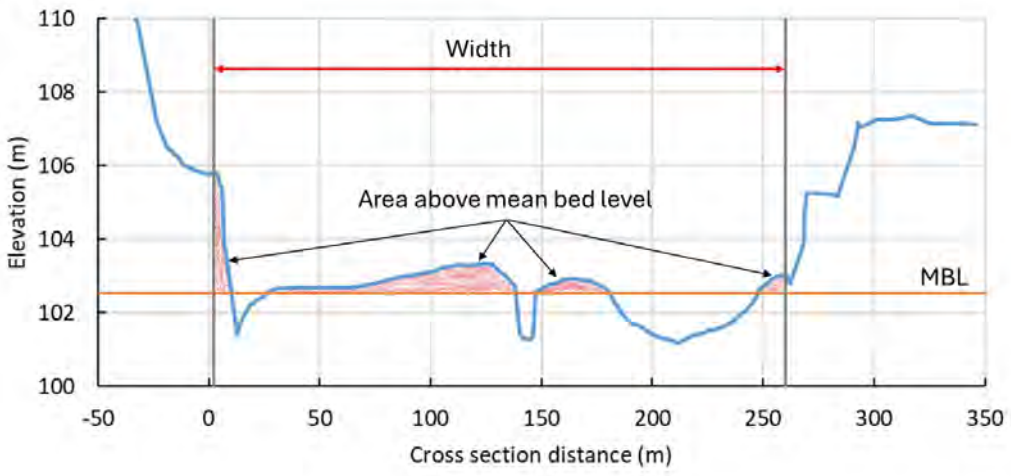


Figure 2-3: Illustration of area above average bed level for cross-section C1 in 2024.

The minimum bed level is the lowest point on the surveyed cross-section. Changes in the minimum bed level over time show any sediment build up or lowering in the deepest part of the channel.

The along-river distance between each cross-section is used to plot bed levels along the river. We report river distances relative to cross-section C1, with positive distances representing upstream cross-sections and negative distances representing downstream cross-sections.

3 Satellite imagery

Imagery from the Sentinel-2 satellite was used to study river bars in the area of interest. As river bars appear larger at lower flows and smaller at higher flows, comparison of river bar sizes and positions at different times should be made when there are similar flows in the river. Seven images from the period between 2016 and 2025 were selected based on two criteria:

- Cloud cover of less than 10% to ensure a clear view of the river and gravel bars, and
- Similar low-flow conditions, determined by selecting dates when there was satellite image acquisition and a low daily river flow apparent in the river flow record.

4 Clutha River flow data and analysis

Water level readings and streamflow measurements have been made at Clutha at Balclutha monitoring stations (NIWA site 75207; Figure 2-1) since 1952 (Figure 4-1). There was a period with several very high flows between 1994 and 1999.

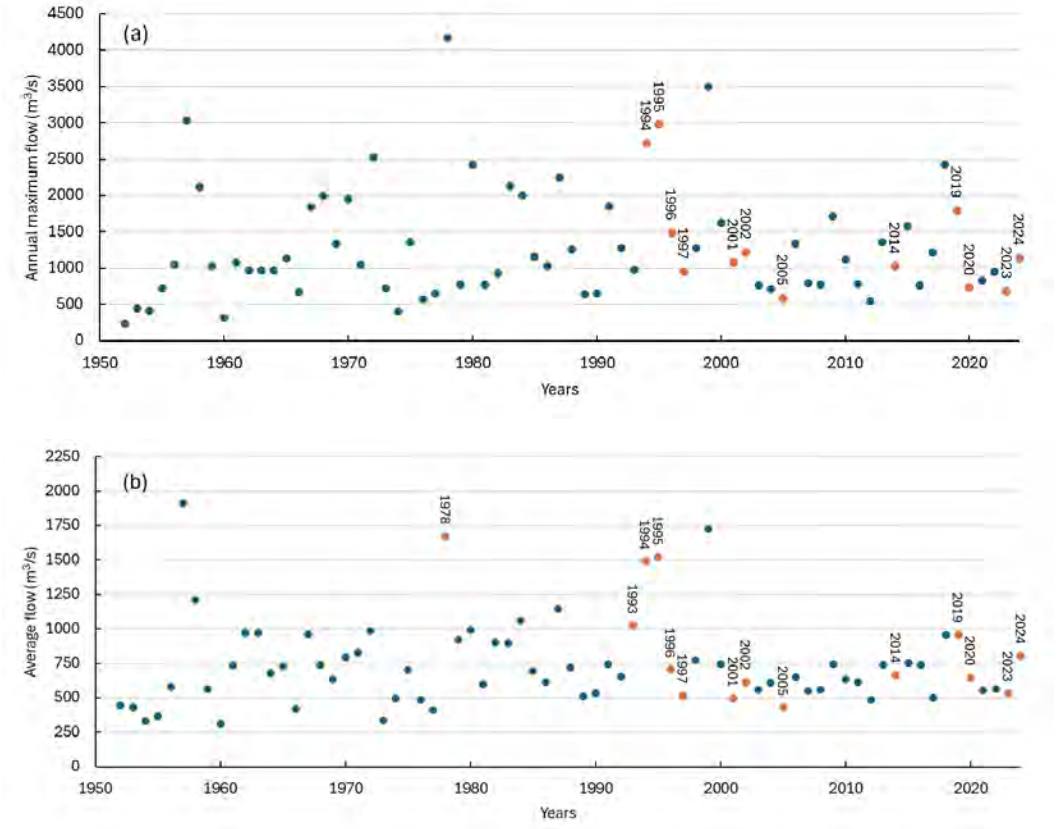


Figure 4-1: Annual maximum flow (a) and annual average flow (b) for the Clutha River at Balclutha monitoring site. Orange circles indicate years where surveys from some or all cross-sections were provided by ORC ease in bed level.

The Balclutha water level measurement data are collected to relate the water level to the corresponding river flow in cubic metres per second. While the data allow calculation of flow from a measured water level, they may also be used in reverse to calculate changes in water level over time, for a given flow. An increase in water level for a given flow could be due to increased vegetation and other types of flow-resisting roughness such as debris and gravel bars in the channel, or it could be due to general raising of the river bed. In either case, if over time there is an increase in the water level for a given high flow, this is an indication that the distance from the water surface to the top of the stopbanks (the freeboard), and consequently the flood capacity, is decreasing. Conversely, if over time there is a decrease in water levels for high flows, this would suggest an increase in flood capacity.

5 Results

5.1 Bed level changes

The changes in individual cross-sections can be compared by studying differences between successive surveys as shown for sections C2 and C4 in Figure 5-1 and Figure 5-2. Here, green areas indicate where the level of the bed has risen, and brown areas indicate where it has fallen.

5.1.1 Example cross-section changes

For section C2:

(a) from 1878 to 1994 the bed rose by around 2 metres on the left hand two-thirds of the channel and fell slightly on the right side.

(b) From the 1995 survey on, there is frequently a regular pattern of humps and hollows in the bed, probably caused by scour downstream of the railway bridge piers.

(d) By 2005 the bed troughs have filled, and a deep channel has developed on the right bank.

(e) By 2014 the bed has risen to the right of centre of the channel and fallen on the left side. The deep channel against the right bank persists.

(f) By 2020 the bed has become flatter across the channel and by 2024 there is evidence of new pier scour.

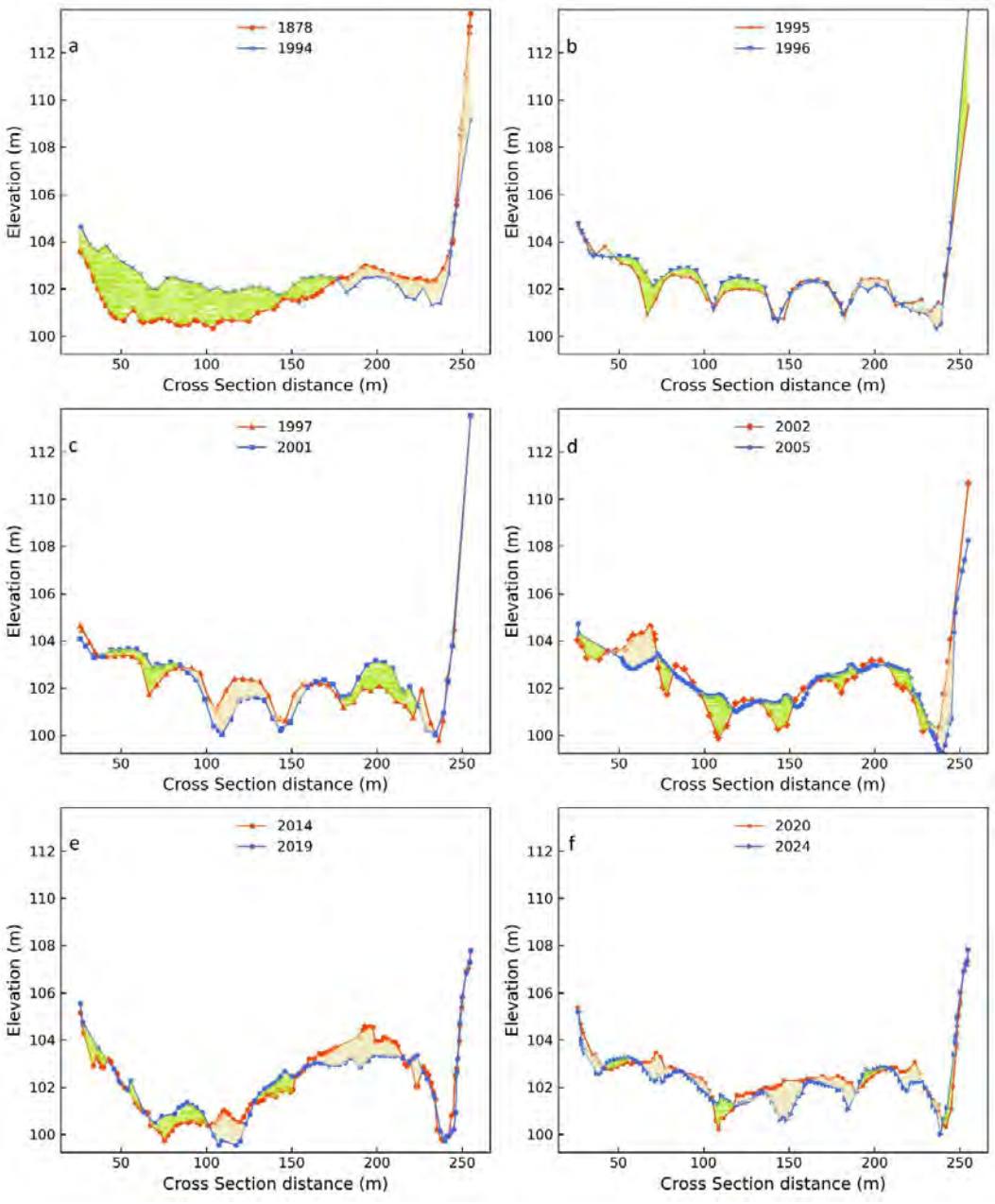


Figure 5-1: Changes in the bed at Section C2 from 1878. Brown areas indicate bed lowering, green areas indicate an increase in bed level.

For section C4 shown below:

(a) Between 1994 and 1995 there was lowering of more than 3 metres forming a channel in the centre of the bed.

(b) This lowering continued through 1996 – 1997.

(c) From 2002 to 2019 the channel deepened to the left of centre and filled from the centre to the right side.

(d) Between 2019 and 2020 the channel had refilled somewhat but again deepened to the left of centre and the bed rose to the right of centre by 2024.

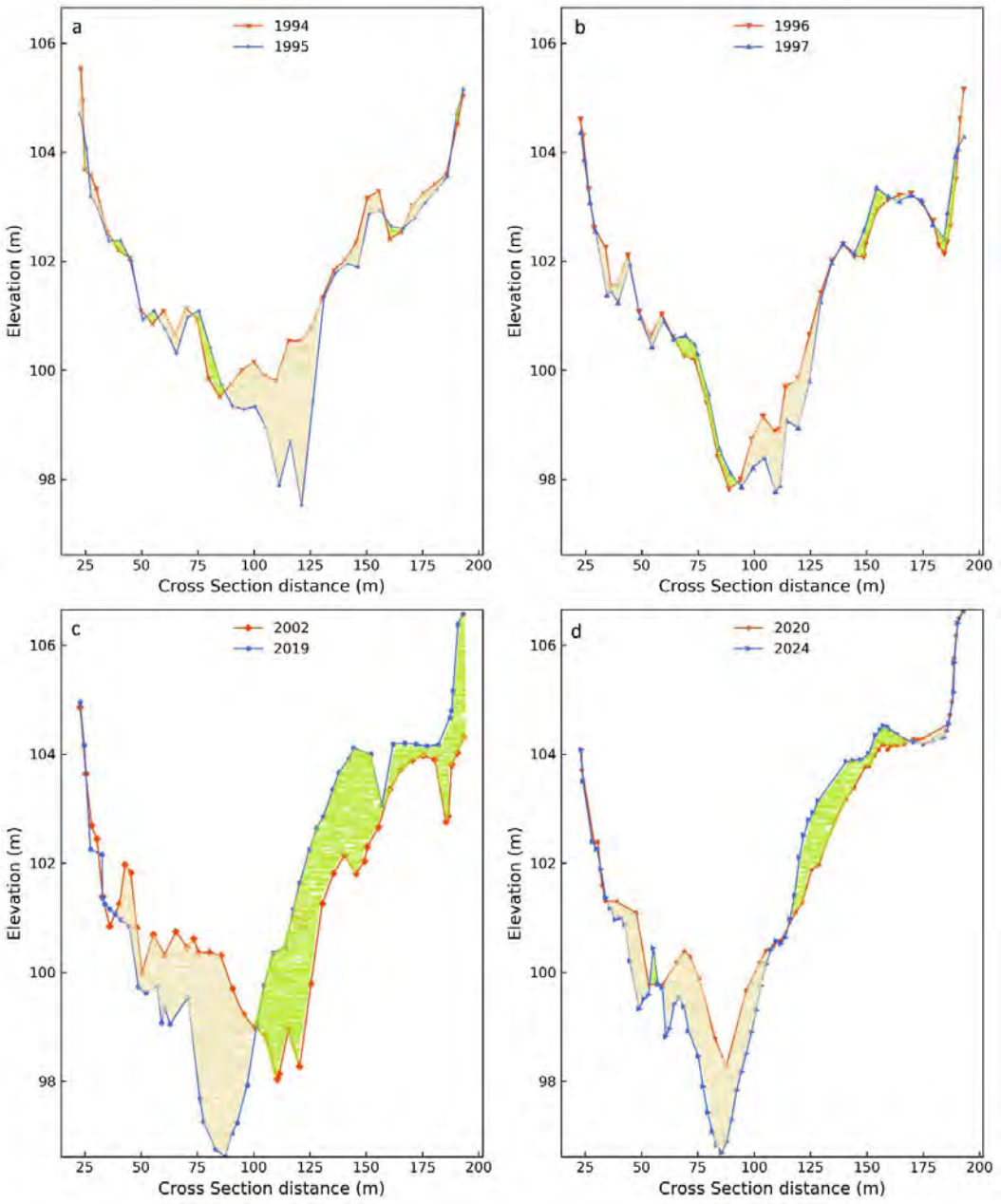


Figure 5-2: Changes in the bed at section C4. Brown areas indicate lowering of the bed, green indicates an increase in bed level.

5.1.2 Average bed level

For each cross-section survey, we can calculate the average level of the bed between the start and end points. Characteristically, average bed level falls in the downstream direction and is lower where a river channel narrows. The Balclutha average bed levels show a consistent pattern over the years, being high around sections C5–C6, falling by around a metre at section C4, then rising again moving downstream by around 1.5 m, to be highest where the river splits into the Matau and Koau Branches (Figure 5-3). The changes in average bed level upstream of the split show no clear trend on this graph with variations roughly within a 0.6 m range over the last 30 years. From the split downstream, the range in bed level variation increases, reaching around 0.8 m in the Matau branch (at section M11). At the split the bed levels dip, typically remaining lower into the Koau Branch in most years and rising downstream into the Matau Branch in all surveyed years. The average bed level of the most downstream section on the Matau Branch (M11) is higher than more upstream Balclutha sections.

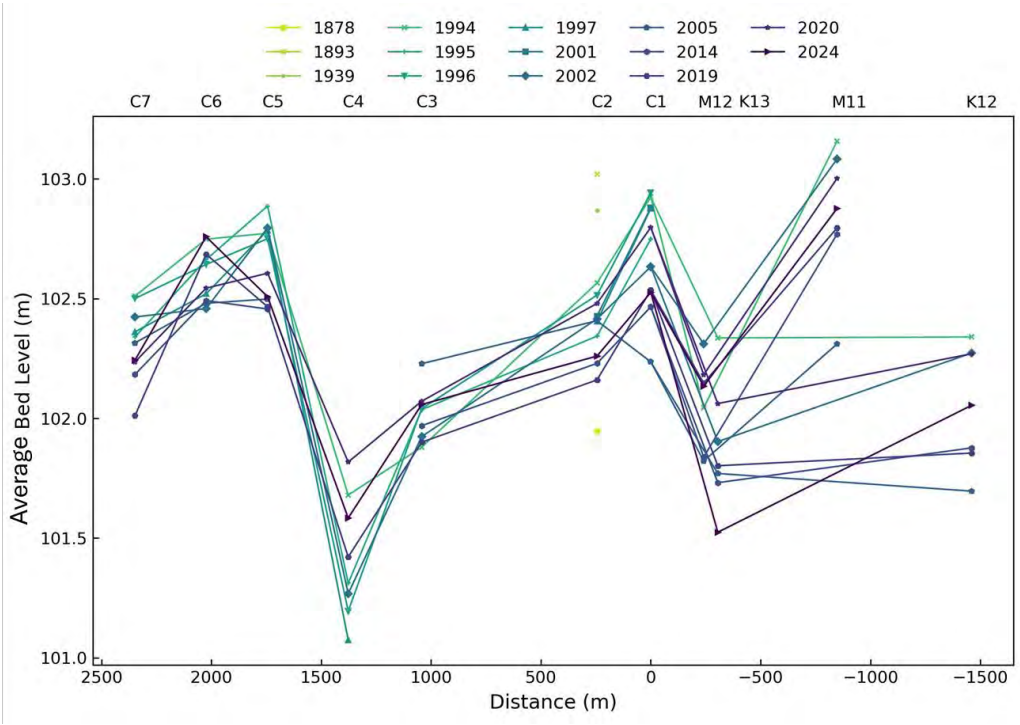


Figure 5-3: Historical changes in the average bed level of the Clutha River near Balclutha township. The horizontal axis shows river distances measured from cross-section C1, with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

To better assess changes in bed level at each cross-section, average bed level values were plotted against survey years (Figure 5-4). A straight line was fitted to the data points to identify any trends. The closeness of fit of data to the line is indicated by an R^2 number at top right of each graph. $R^2 = 1$ means a perfect trend whereas $R^2 = 0$ would mean no trend at all. All sections except C3, C4, C6, and M12 indicate a falling trend in average bed level over the past 30 years. Sections C5 and C7, in particular, have higher R^2 values confirming significant river bed lowering over time. At C5 and C7 the average bed level has fallen by 0.35 m from the 1990s to the present day. Section K13 shows lowering over time (R^2= 0.43) with 0.8 metre decrease in averaged bed level.

At section C2, the first surveys (from 1878) show noticeable bed raising occurred before 1900. Conditions have since changed with land use and construction of the Roxburgh Dam. To identify trends following these changes by excluding the pre-1900 data, the section exhibits a clear lowering trend in average bed level (green line in Figure 5-4). A similar pattern is observed in cross-sections K12 and M11 when outlying data points are excluded.

Sections M12, C3 and C6 do not display any significant trend in average bed level and appear to have remained relatively stable over the analysed period. C4 shows a weak rising trend.

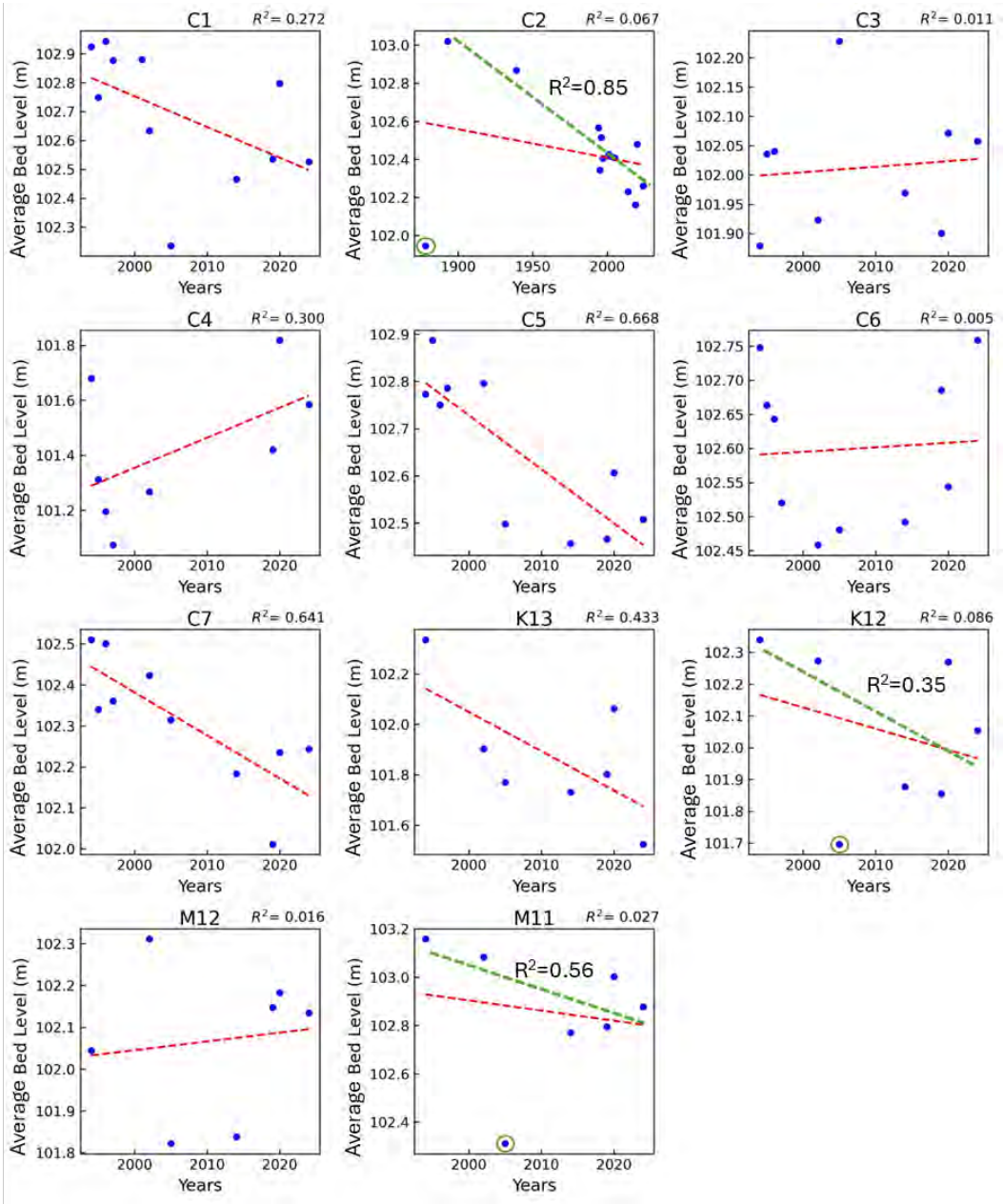


Figure 5-4: Changes in the average bed level over the years at each cross-section. The red lines indicate a straight-line trend for the cross-section survey years. The R^2 values in the top right corner of each sub plot indicate the goodness of fit for all data. The green lines and associated R^2 values indicate a straight-line trend after removing outliers. For cross-section C2, when the first survey in 1878 is ignored, a strong trend of lowering in average bed level is observed. For cross-sections K12 and M11, the 2005 survey is ignored for the green line (part of the mid-river section was missing in the 2005 survey). Note that the axis scales differ on some plots.

Further analysis was conducted by averaging the average bed level changes for each recent decade and comparing these values with a 1990s baseline average bed level (Figure 5-5). Following the period with very high flows from 1994 to 1999, bed levels generally fell below 1990 levels until the 2010s (blue and orange lines) then rose again in the 2020s (yellow line.). Except at C6, C4, C3 and M12, averaged levels are still below the 1990 levels. Section C4 has risen 0.4 m above the 1990 average bed level.

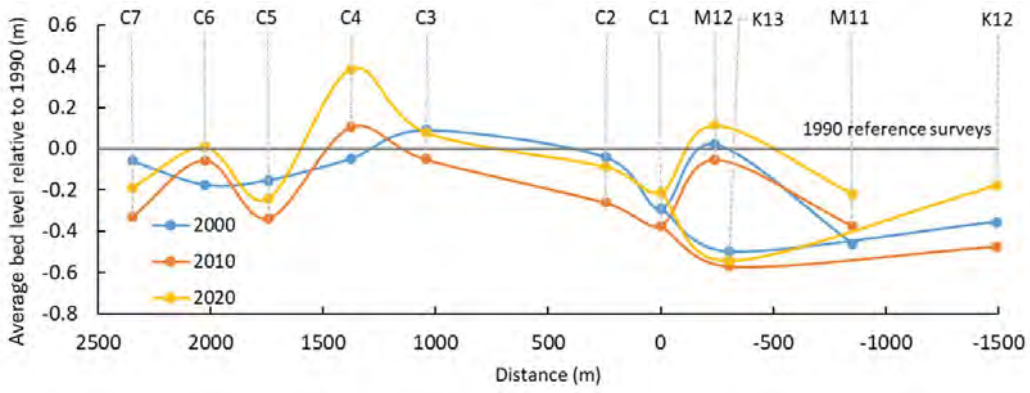


Figure 5-5: Average bed level change relative to 1990 in the Clutha River near Balclutha, with surveys grouped and averaged by decade. The "1990" reference line represents combined surveys from 1990–1999, the "2000" line includes surveys from 2000–2009, the "2010" line covers surveys from 2010–2019, and the "2020" line represents surveys from 2020 onward. The horizontal axis shows river distances measured from cross-section C1 with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

5.1.3 Minimum bed level

Changes in minimum bed levels are shown in Figure 5-6 with a separate line for each surveyed year. From cross-section C6 to C4, the minimum bed level decreases in the downstream direction, reaching a low point around cross-sections C3 and C4. Beyond this point, the minimum bed level rises again in the downstream direction to cross-section C1. From C1, the minimum bed level falls moving down the Koau Branch (sections K13 and K12). For the studied cross-sections, except for a high C1 level in 1994, the minimum bed level downstream in the Matau Branch is higher than at the upstream sections. The higher Matau Branch bed was also evident in the average bed level analysis (Section 5.1.1).

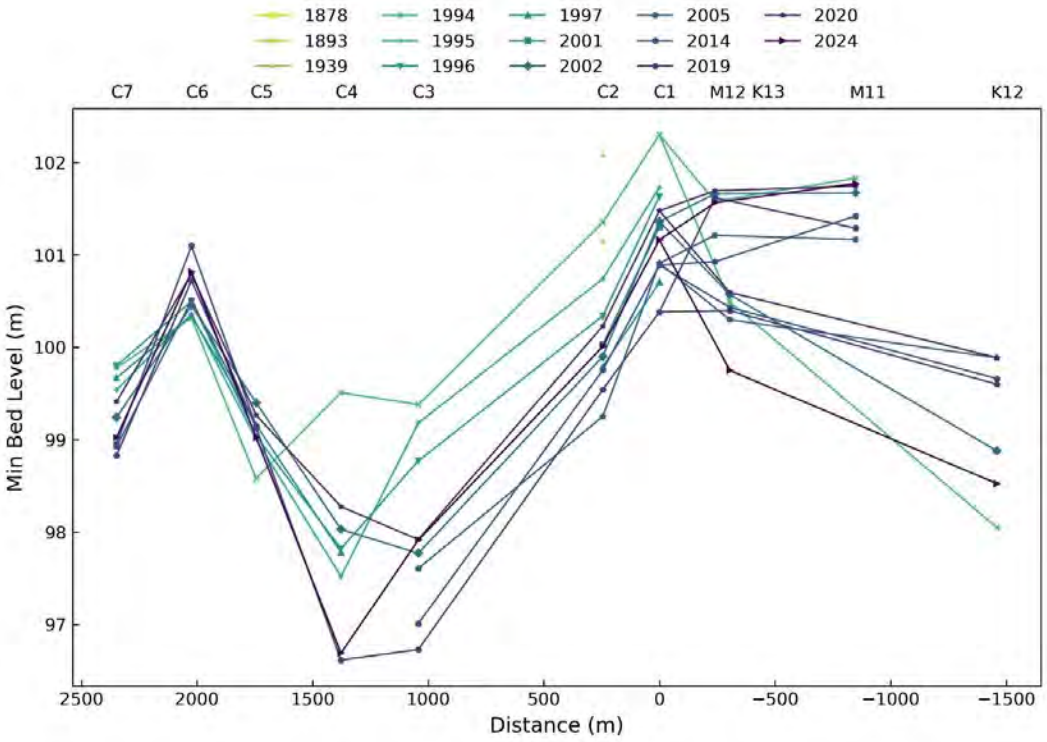


Figure 5-6: Historical changes in the minimum bed level of the Clutha near Balclutha. The horizontal axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

Straight-line trend analysis for minimum bed levels is shown in Figure 5-7. While cross-section C6 exhibited no clear trend in **average** bed level over time (Figure 5-4), the deepest point used to be on the right side of the channel but is now in the centre (shown in Appendix A). The **minimum** bed level shows a long-term rise in the deepest part of the river (Figure 5-7). These changes may be a result of historical, upstream river training works. Cross-section C3 similarly showed no discernible trend in average bed level, but the minimum bed level indicated sustained bed lowering in the deepest portion of the channel, highlighting localised changes not captured by average bed level analysis. Cross-section C7 displayed a consistent lowering trend in minimum bed level that mirrored the overall changes observed in the average bed level. The bed level changes at C7 are more uniform across the entire cross-section, affecting both the average and minimum bed levels in a similar manner. Cross-section K13, on the Koau Branch, exhibited a similar pattern, with both the minimum and average bed levels indicating recent deepening.

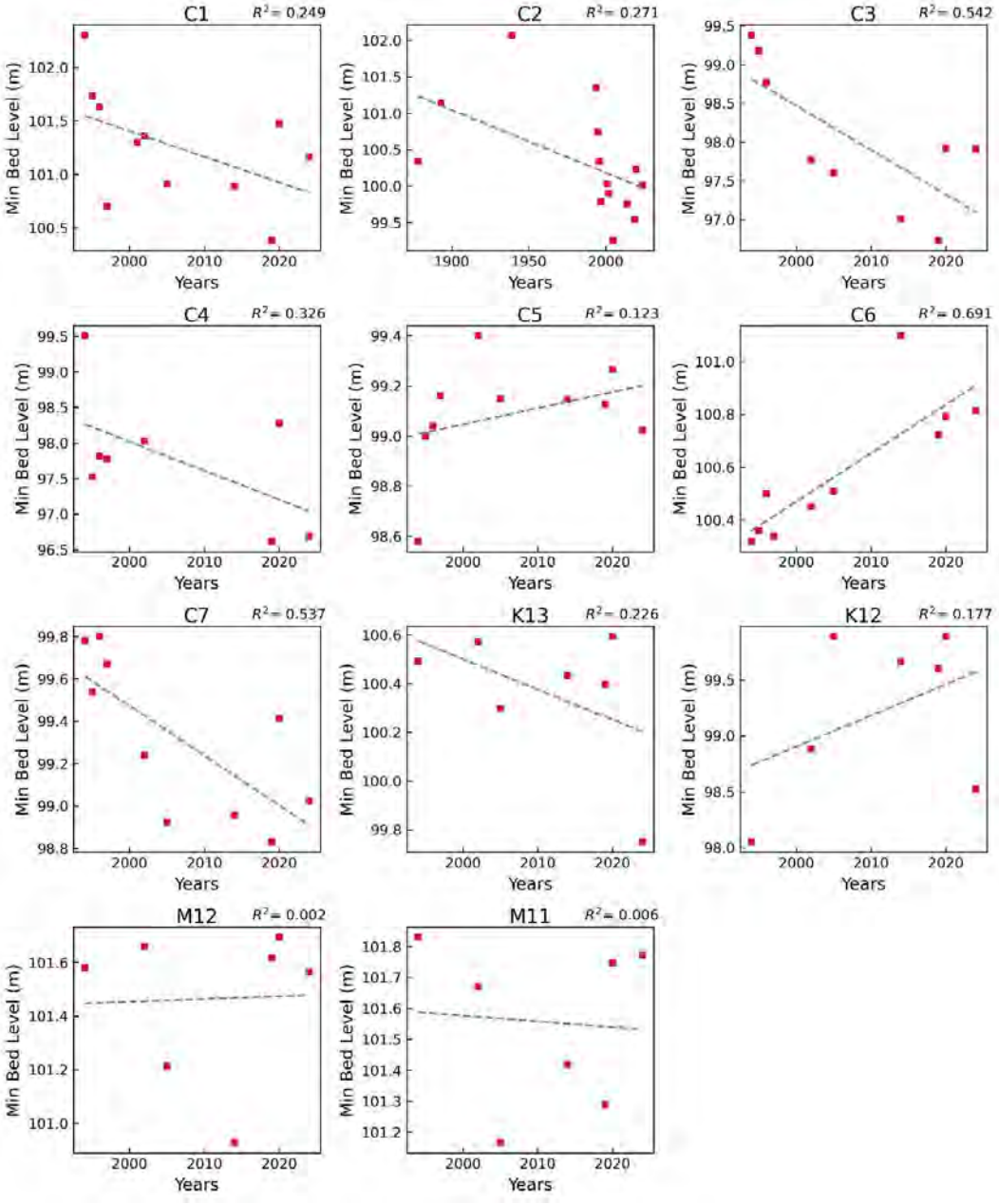


Figure 5-7: Changes in the minimum bed level over the years at each cross-section. The dashed lines indicate the straight-line trend for the changes observed. The R^2 values for the regression lines are displayed in the top-right corner of each subplot. Note that the axis scales differ on some plots.

5.1.4 Average height above average bed level

The area above average bed level, divided by the width of the cross-section, gives an average height of the part of the river bed lying above the average bed level. This value signifies how much the bed level varies across a section. This value is plotted against downstream distance in Figure 5-8 for each

surveyed year. Overall, there is a slight trend of decreasing bed level variation across a cross-section, moving in the downstream direction towards the split into the Koau and Matau branches.

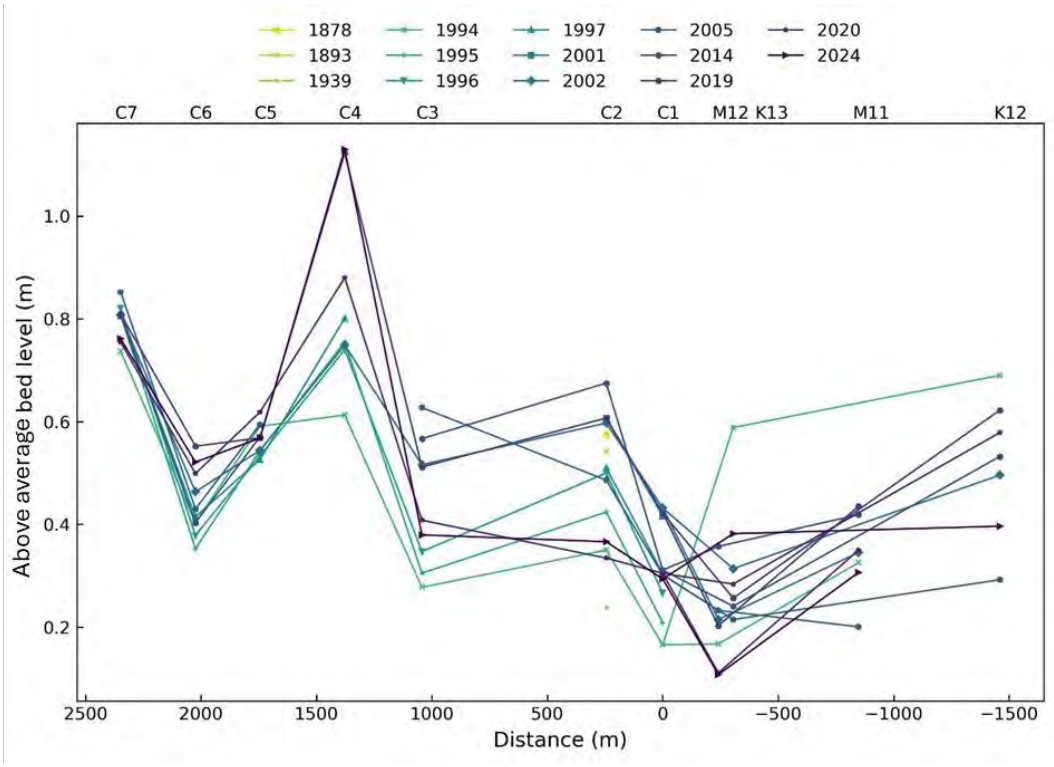


Figure 5-8: Historical changes in the height above bed level values of the Clutha River near Balclutha. The horizontal axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

Considering Figure 5-9, the average height above average bed level values show a clear increasing trend with time at cross-sections C4 and C6, indicating an increase in the exposed (visible) area of the river bed during low-flow conditions. Variation has increased significantly at section C4. This suggests the development or expansion of bars or deepening of low flow channels in these sections over time. In contrast, the height above average bed level values at the other cross-sections did not exhibit any clear trends, implying minimal to no long-term changes in the bed forms.

There is no cross-section located on a large gravel bar that exists between cross-sections C2 and C3 (located next to Kaitangata Highway and downstream of Ipswich Street). Therefore, it is not possible to quantify changes in the height of this significant bar from the cross-section data.

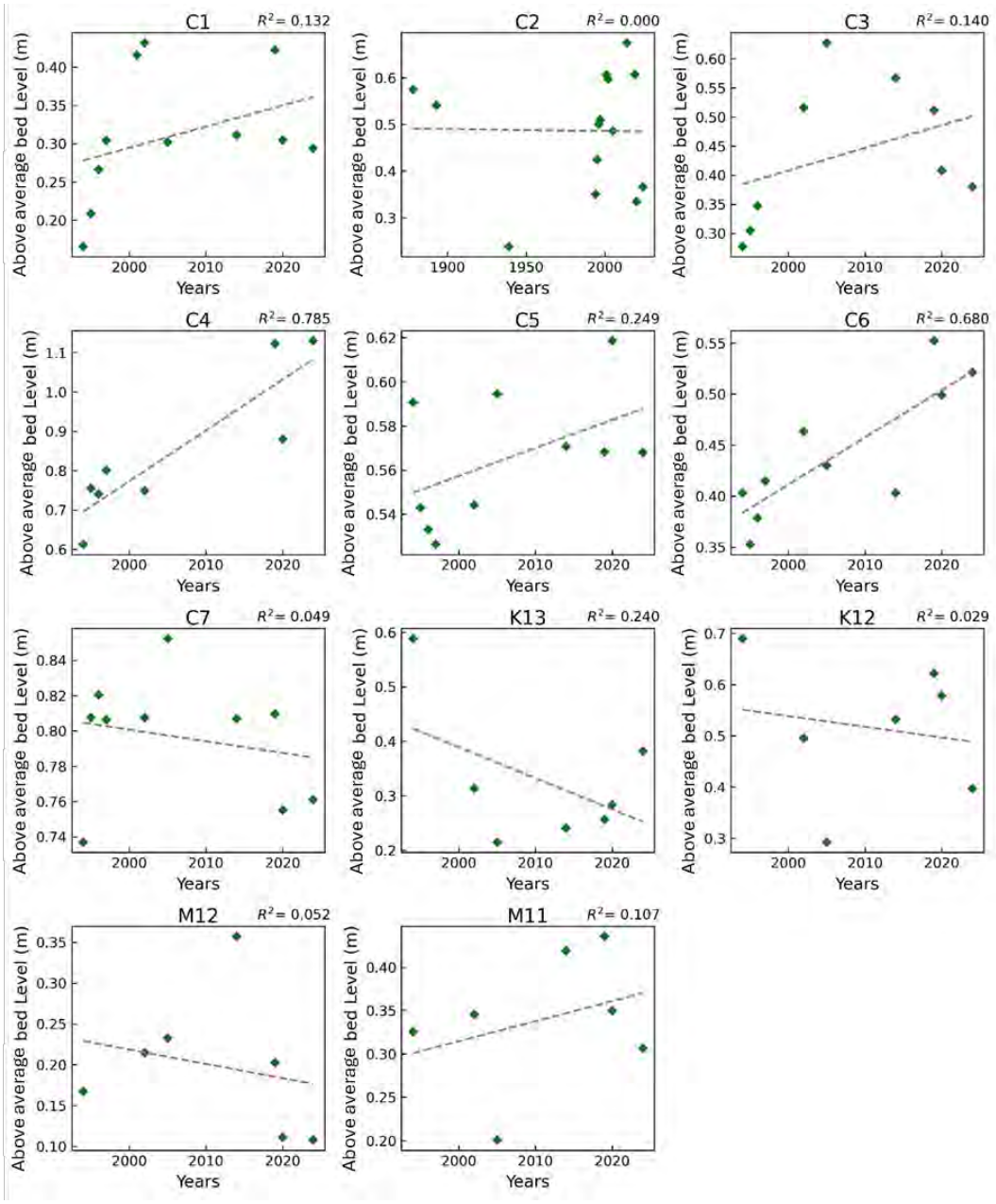


Figure 5-9: Changes in the average height above average bed level over the years at each cross-section. The dashed lines indicate the straight-line trend for the changes observed. The R^2 values for the regression lines are displayed in the top-right corner of each subplot. Note that the axis scales differ on some plots.

5.2 Changes across individual cross-sections

Looking at the overlaid sections in Appendix A and plots in Figures 5-2 to 5-6, we see the following net changes moving from downstream to upstream:

- **Cross-sections K12 and M11:** No clear trend of raising or lowering is evident over recent time based on the recorded survey data.
- **Cross-section M12:** In the 1990s the section was relatively flat. The channel then deepened on the right side and raised on the left side of the centreline. By 2019 the channel had risen on the right side and by 2024 was again relatively flat. NIWA gauging comments indicate 10,000 cubic metres of gravel extraction occurred on the right bank and 8,500 cubic metres from the left bank of the downstream channel split over the period 17-Feb-2002 to 13-Mar-2002.
- **Cross-section K13:** In the 1990s the section was high on the right bank of the main channel, but this bar was gone by 2002. The data then indicate low variation in bar height until 2020 when the channel deepens left of the main channel centreline and rises on the right bank of the main channel.
- **Cross-section C1:** Over the last 10 years, a noticeable shift in the gravel bar located in the middle of the cross-section is observed where the river splits into the two branches. The middle bar has migrated further to the right, resulting in increased flow and bank erosion along the left bank.
- **Cross-section C2:** Being near the railway bridge, this cross-section has the longest survey record, dating back to 1878. Between the first recorded survey in 1878 and the second in 1893, the river bed rose up to 2 metres across the cross-section. By 1939, raising of up to 1.5 m occurred towards the right bank, while lowering of up to 2 m was observed on the left bank. Between 1939 and the present day, slow lowering has dominated across the entire channel width.
- **Cross-section C3:** Between 1994 and 2024, this cross-section experienced periods of shifting in the middle bar and channel, along with phases of channel deepening (1994–2019) followed by significant raising (2019–2024). The middle bar rose approximately 2.3 m from 1994 to 2005, reaching its maximum recorded height. However, from 2005 to 2024 gradual lowering of the middle bar occurred, with about 1.1 m of bar height lost.
- **Cross-section C4:** This section showed gradual scouring along the left bank and deeper parts of the channel, while raising was observed along the right bank. Between 1994 and 2024 the deeper section of the channel experienced scouring of up to 3 m, whereas up to 2.1 m of sediment accumulation occurred along the right bank.
- **Cross-section C5:** A gradual lowering trend was observed from 1994 to 2024, accompanied by localised sediment accumulation along a small section of the right bank between 185 to 220 m cross-section distance.
- **Cross-section C6:** Different patterns of change were observed across this cross-section. Both the left and right banks experienced bed raising, whereas the mid-channel deepened. From 1994 the middle section of the cross-section (between 100 m and 200 m) rose up to 1.5 m by 2024. The right bank (between 200 m and 250 m) rose up to 3 m, while the left bank (between 0 m and 80 m) experienced 1.1 m of rise. Overall, average bed level fell until 2002 then rose back to the 1994 level by 2024.

- **Cross-section C7:** Bed lowering was observed at the left bank between 1994 and 2024. The deeper section of the channel experienced lowering from 1994 to 2019, followed by bed raising between 2019 and 2024.

5.3 Satellite imagery

Overhead images can reveal positions and sizes of channels and bars in a river. Examples are shown in Figure 5-10 and Figure 5-11. Seven selected images, captured between 2016 and 2025, are presented in Appendix B. Interpretation of bar size and shape is not straightforward, as river flow was not the same when the images were captured.

A noticeable change occurred between 2016 and 2025 with the movement of the gravel bar on the right bank, just before the Clutha River splits into the Matau and Koau branches. In the 2016 imagery, this bar intersects the railway bridge and extends across both C1 and C2 cross-sections. The bar shape evolves, and by 2025, has disappeared. From 2020 a new bar develops on the opposite bank, and by 2025 it has fully formed at the tip of Inch Clutha (Figure 5-11).

The location of the mid-river bar between cross-sections C2 and C3 has remained relatively stable over the years.

The long, thin, right-bank bar extending from C4 to C5 is stable over the years and becomes progressively more vegetated until by 2025 it resembles a river berm.

Figure 5-10: Imagery of the Clutha River at Balclutha in March 2013 (top) and March 2024 (below). The bars between the two bridges have moved downstream.

Figure 5-11: Satellite imagery of the Clutha River at Balclutha on two dates: January 10, 2016 (left) and January 27, 2025 (right). Imagery from Sentinel-2 satellite data. Red lines indicate the cross-section locations. The flow monitoring site is shown with a magenta dot.

5.4 Flow data analysis

A NIWA flow recorder has operated at Balclutha since 1952. The measurement cross-section was located near river cross-section C3 until 2007 when it was moved upstream of the previous location.

5.4.1 Minimum bed level

Up until 2010, the maximum water depth was recorded at the time of a NIWA measurement. Subtracting the maximum water depth from the water surface level gives the minimum bed level at the time of the measurement. The minimum bed levels from measurement data are shown in orange on Figure 5-12. After 2007, NIWA changed to jet boat measurements, made 180 to 250 metres upstream of the previous cableway. Recording of maximum water depth was subsequently discontinued. A few maximum bed depths made at the new location are shown in bright red on Figure 5-12 . Also shown are the ORC cross-section survey minimum bed levels at section C3 (from Figure 5-7). An abrupt rise in minimum bed level occurred during the 1957 November flood. From the 1970s to the present the minimum bed level at section C3 has been getting lower.

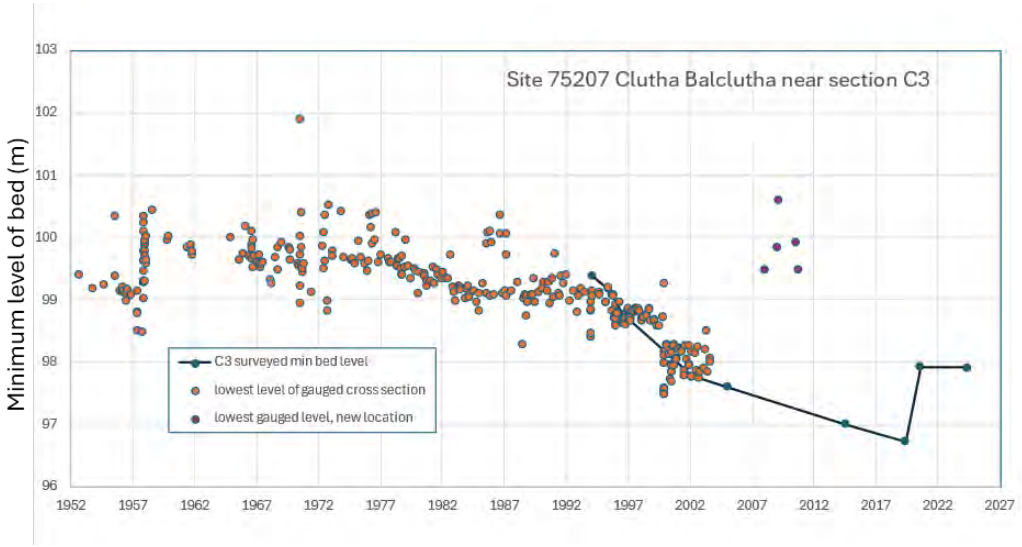


Figure 5-12: Minimum bed level at times of NIWA flow measurements near section C3. NIWA measurements after 2007 (bright red dots) apply 180 to 250 m upstream of the previous cableway location.

5.4.2 Water level for a given flow

Figure 5-13 shows the differences between measured water levels and what the water level would have been if there had been no changes in the river bed since 1952. Figure 5-14 shows differences in water levels compared to what they would have been with the December 1978 river bed. While individual measurements are made at different flows, and it is not meaningful to interpret every little change in these graphs, the graphs reveal the overall, long-term trends.

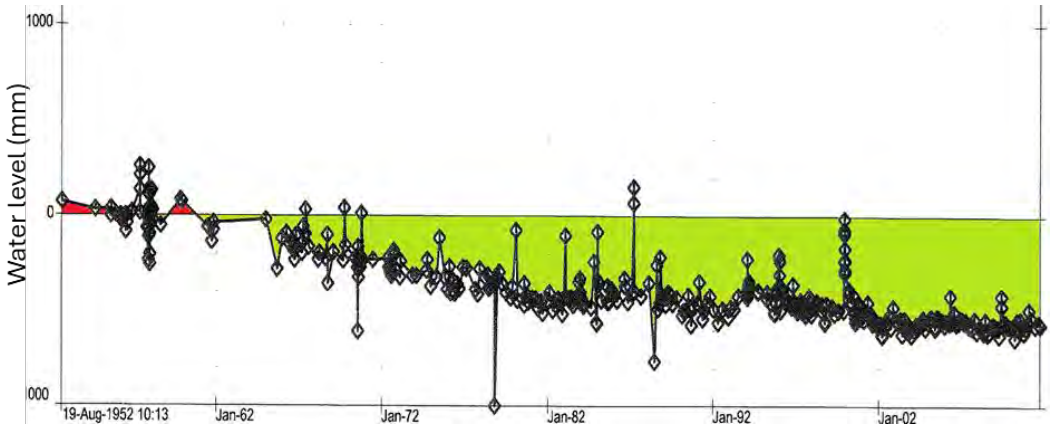


Figure 5-13: Water level for a given flow compared with preservation of 1952 bed levels. Red areas have a higher water level and green areas are lower than what they would have been in 1952.

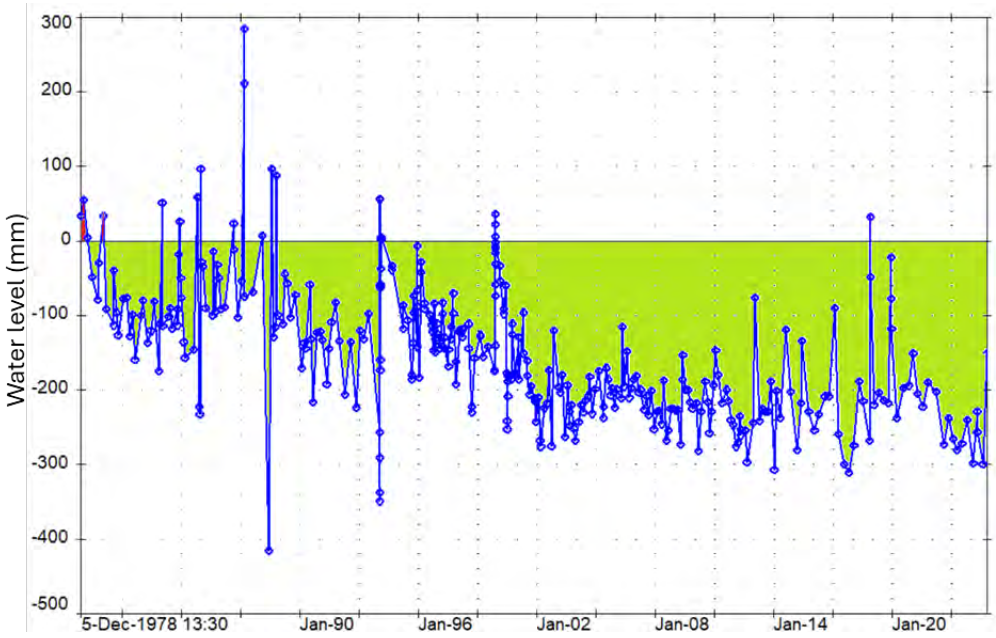


Figure 5-14: Water level for a given flow compared with preservation of 1978 bed levels. Red areas have a higher water level and green areas are lower than what they would have been in 1978.

According to these plots, water levels fell gradually from 1952 to be about half a metre lower by 1982. From 1983 to mid-2000 the levels oscillated with no net trend, then dropped approx. 0.2 m to reach another fairly stable state for the most recent 20-year period.

Further information on water level trends at all measured flows can be found by comparing water level -vs- flow curves from measurements made at different times. In Figure 5-15, flow measurements are compared for three decades: 1952–1961, 1990–1999 and 2015–2024. Flows as low as 38.3 cubic metres per second occurred in the early record as the Roxburgh Dam was filling in 1956. The lowest flow measured by NIWA was 50.3 cubic metres per second. In the middle decade there were several high floods (between 1994 and 1999). Figure 5-15 shows that, in the 1990s, flows up to 3000 cubic metres per second occurred at a lower water level than in the 1950s. In the most recent decade flows up to around 1500 cubic metres per second occurred at a lower water level than in the 1990s. This indicates channel deepening or reducing flow resistance since the 1950s. For very high flood flows[3] the trend line for flood level increased relative to the 1990's but, up to 3000 cubic metres per second, remains lower than in the 1950s.

[3] The two highest gaugings in 2015–2024 were made upstream of the NIWA rating site and adjusted by ORC to allow for the 2.5 km interdistance.

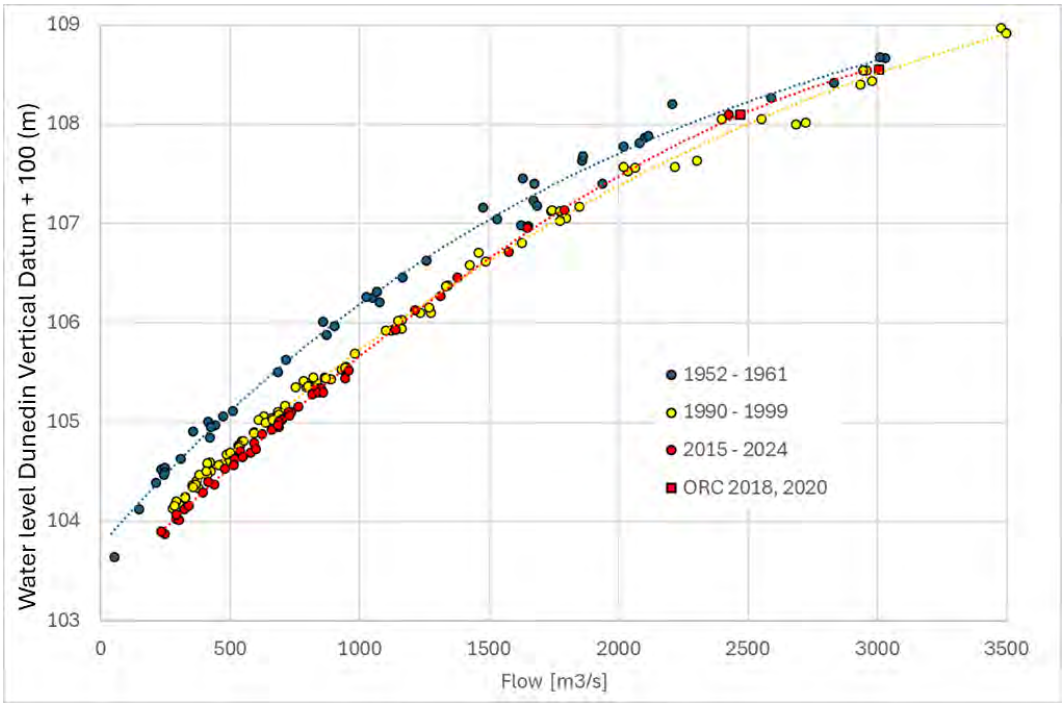


Figure 5-15: Comparing water level for a given flow data from gauging measurements over the years. Curves show three decades: 1952–1961, 1990–1999 and 2015–2024. Vertical axis is Dunedin Vertical Datum 1958 + 100 m.

6 Discussion

6.1 Determine whether there is a significant trend in river bed levels

Cross-sections C1, C2, C5, C7, M11 and K12 show a clear lowering trend from the 1990s to the present. In particular, average bed levels at C5 and C7 have fallen by around 0.35 m. Sections C3 and C6 do not display any significant trend in average bed level and appear relatively stable over the analysed period. C4 shows a weak rising trend.

6.2 Assess changes in gravel bars or islands

The average height-above-average-bed-level analysis indicates the vertical range in bed levels at measured cross-sections. Changes in average height-above-average-bed-level can indicate development or decay of channel bars. Over the surveyed years 1994 to 2024, there is a trend of increasing bed level variation at C4 and C6 but no noteworthy trend at other sections. Moving in the downstream direction, there is a slight general trend of decreasing bed level variation across the cross-sections, which would suggest lower or flatter bars moving downstream past Balclutha.

Satellite imagery reveals a noticeable change between 2016 and 2025 with the movement of a gravel bar on the right bank, just before the Clutha River splits into the Matau and Koau branches. In the 2016 imagery, this bar intersects the railway bridge and extends across both C1 and C2 cross-sections. The bar shape evolves, and by 2025, has disappeared. From 2020 a new bar develops on the opposite bank, and by 2025 it has fully formed at the tip of Inch Clutha. No net effect is evident in the C1 and C2 area above average bed level plots. There is no cross-section located on a large gravel bar between cross-sections C2 and C3 (located next to Kaitangata Highway and downstream of Ipswich Street). Considering different flow rates at times of the satellite imagery, this bar appears stable over the 2016 to 2025 period.

6.3 Identify factors driving changes observed

In general, observed changes correspond to the expected long-term, river response following a severe reduction in sediment input (i.e., Roxburgh Dam construction). Bed levels and water levels have initially fallen, and the rate of lowering appears to have tailed off with time. Recent reports that gravel bars are more evident at Balclutha may be due to the bar movement noted above and the fact that a stable bar can become more visible and appear to be higher if the river level falls alongside the bar. There has been a clear change in shape at section C6. The deepest point used to be in the channel on the right side but is now in the centre. Historic aerial imagery (Figure 6-1 below) shows that between 1946 and 1995, mid-channel river training works narrowed and re-directed the channel upstream of C6. These works are likely to be the explanation for the channel movement at C6. There were also river training works to re-narrow the entrance to the Matau branch in the early 1970s[4].

[4] Retrolens.co.nz: air photos of 27/2/1968 and 28/2/1975

Figure 6-1: Aerial photographs from 1946 (left) and in 1995 (right). Blue line indicates the mid-channel river training works upstream of cross-section C6.

6.4 Evaluate whether observed river bed level changes are sufficient to reduce flood capacity

The NIWA water level data show comparative water levels near C3 fell gradually from 1952 to be about half a metre lower by 1982. From 1983 to mid-2000 the levels varied with no net trend, then dropped approx. 0.2 m to reach another fairly stable state for the most recent 20-year period. In the 1990s, flows up to 3000 cubic metres per second occurred at a lower water level than in the 1950s. In the most recent decade flows up to around 1600 cubic metres per second occurred at a lower water level than in the 1990s.

Because the river is not steep, changes in flood levels at the NIWA gauging location are indicative of general changes in Clutha River levels alongside Balclutha, and we can presume that flood capacity at Balclutha has not reduced. While the levels of floods of a given size have not increased, the frequency of floods is expected to increase in the future due to climate change. Also, local changes in cross-sections can re-direct currents against a bank, possibly causing localised overtopping.

There is evidence that temporary bed lowering may occur during a rising flood with the bed refilling as the flood falls. Assuming this effect does not change, historic behaviour does not indicate a reduction of flood capacity in the Balclutha reach.

7 Summary and conclusions

7.1 Purpose

The Otago Regional Council commissioned NIWA to analyse and report on historical changes in Balclutha river bed levels to help understand any significant trends and to guide river management strategies into the future.

7.2 What was done

Data from river bed cross-section surveys, flow measurements and satellite imagery were studied. The data were overlayed and plotted to provide a clear visual representation of changes over time. Historical changes were quantified by calculating average bed levels, minimum bed levels and changes in the higher parts of each cross-section, representing gravel bars. Flow records were studied to determine whether the water level for a given flow has changed over time. Satellite imagery was studied to detect changes in the extent of gravel bars.

7.3 Important findings

The cross-section data suggest that there was an increase in the bed level at the railway bridge in the late 1800s. Little is known about bed levels in the early 1900s, and a general long-term trend of lowering of the river bed occurred from the 1950s to about 2002, with less trend evident since 2002. This behaviour is consistent with the river adjusting to a reduction in sediment load following the 1954 commissioning of the Roxburgh hydro dam which traps sediment from upstream.

Average bed level of ten of the eleven studied cross-sections is stable or lowering. Section C4 (at the State Highway Bridge) shows a weak rising trend in average bed level. Minimum bed levels are stable or falling at each cross-sections except C6 (North end of Elizabeth Street) where the surveyed low point is rising with time due to previous river training works. Cross-sections C4 and C6 show a trend of growth of the relative height of bars. This could be due to deepening of low flow channels beside the bars. Flow measurements at Balclutha, since 1952, show channel capacity is increasing for floods up to around 1600 cubic metres per second.

Reports that gravel bars are now more evident at Balclutha may be due to the fact that a stable bar will become more visible and appear to be higher if the river level falls alongside the bar.

7.4 Cautions

The following factors could affect these conclusions:

- Bed lowering during a rising flood and re-filling on a falling flood may mask the true cross-section during a flood peak. The amount of flood scour and its effect on channel flood capacity is unknown.
- The effect of any gravel mining on cross-section evolution has not been quantified.

7.5 Recommendations

- A field inspection may be able to shed light on the possibility that bars appear to be higher because the low flow channels beside the bars are deepening.

- Ongoing monitoring and, in particular, flow measurements during future high floods, is strongly recommended. This would help quantify the degree of bed scour induced by floods, which will improve understanding of the river behaviour.

8 Acknowledgements

Survey data and funding for these analyses were provided by the Otago Regional Council.

9 References

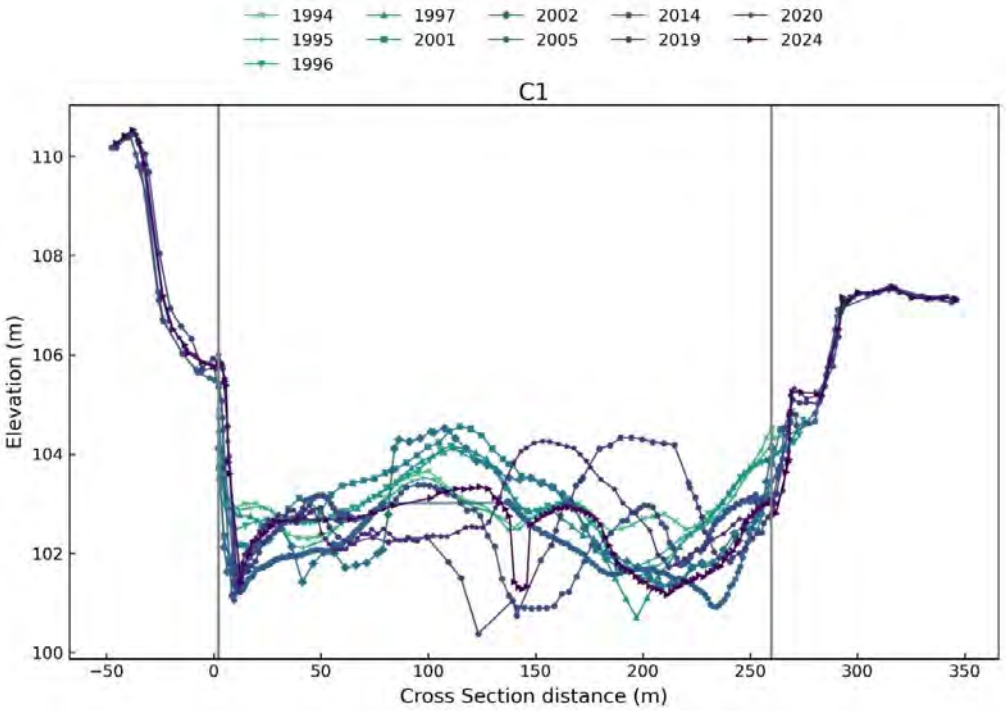
Grant, G. E., Fassnacht, H., McClure, E. M., & Klingeman, P. C. (2003) Downstream effects of the Pelton-Round Butte hydroelectric project on bedload transport, channel morphology, and channel-bed texture, lower Deschutes River, Oregon. Water Science and Application, 7, 175-176.

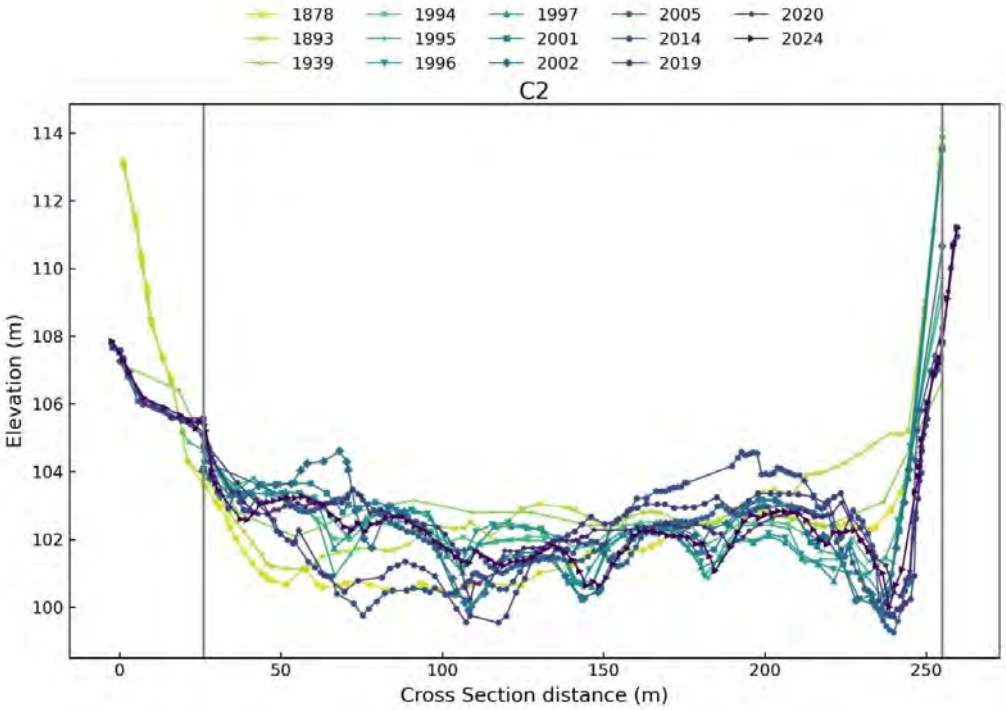
Hicks DM, Walsh JM and Duncan MJ. (2000) Clutha River Sediment Budget. NIWA Client Report CHC00/45.

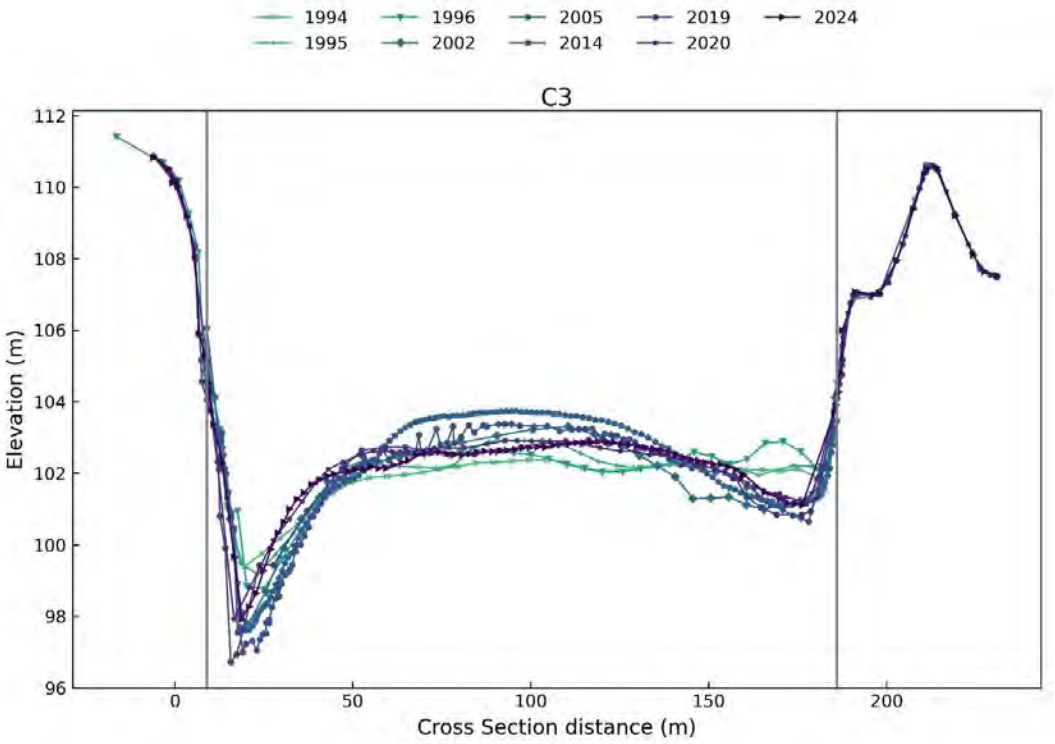
Otago Regional Council (2008) Channel morphology and sedimentation in the Lower Clutha River. ISBN: 1-877265-59-4

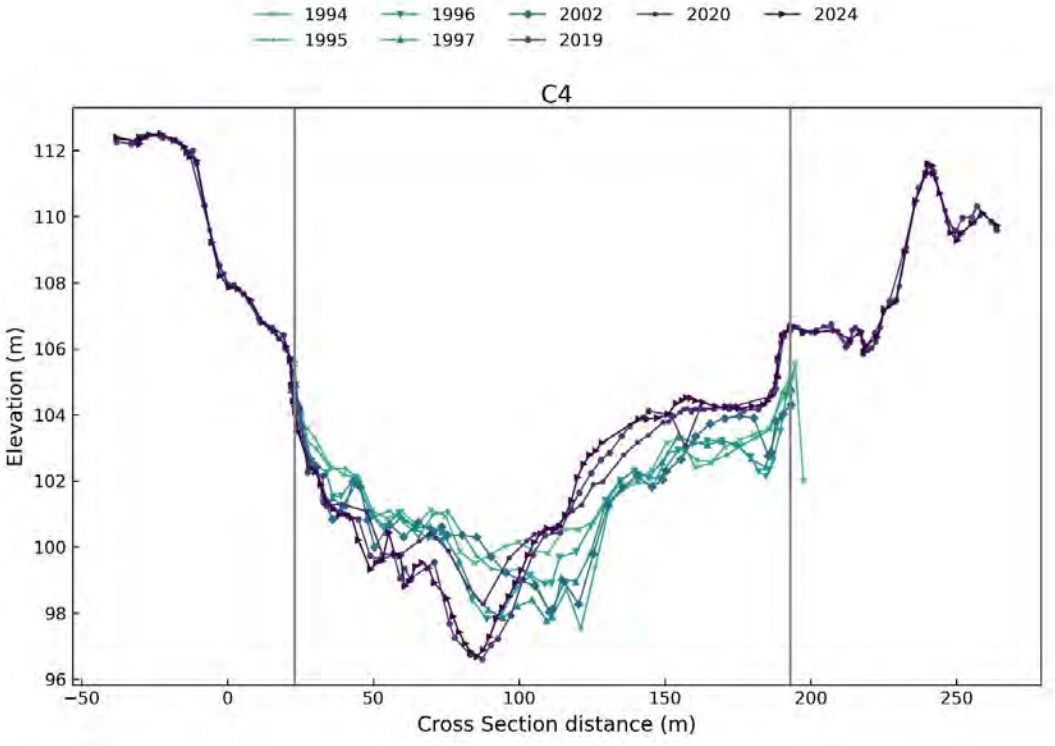
Appendix A Cross-section profiles for surveyed years

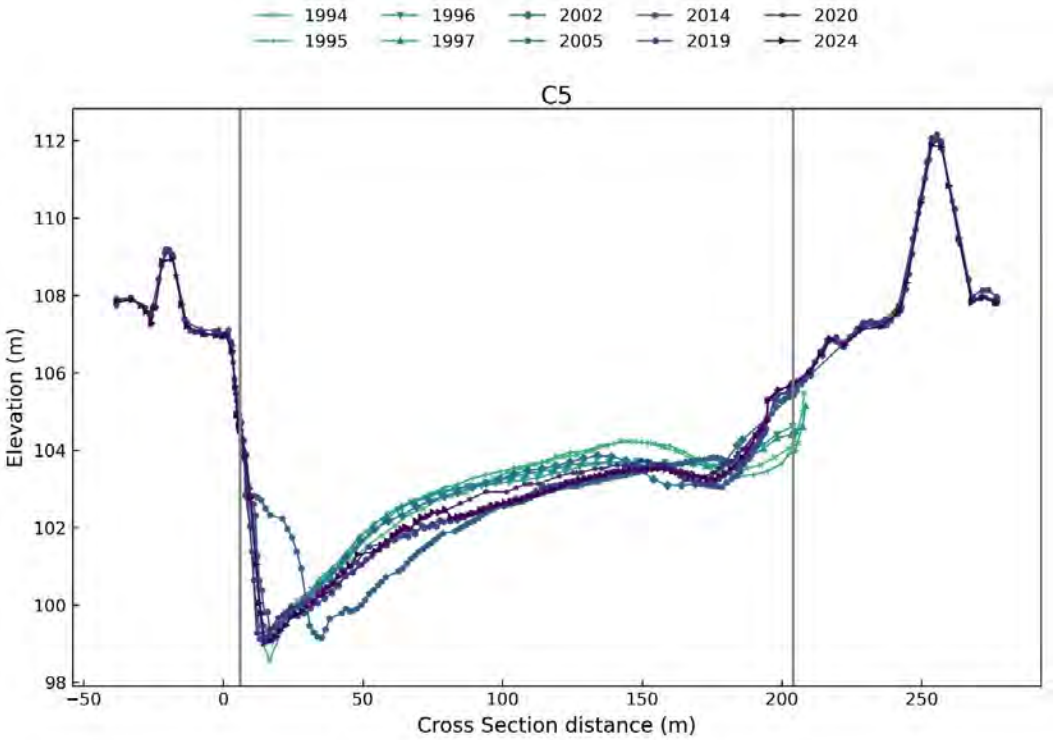
All cross-sections are viewed looking downstream.

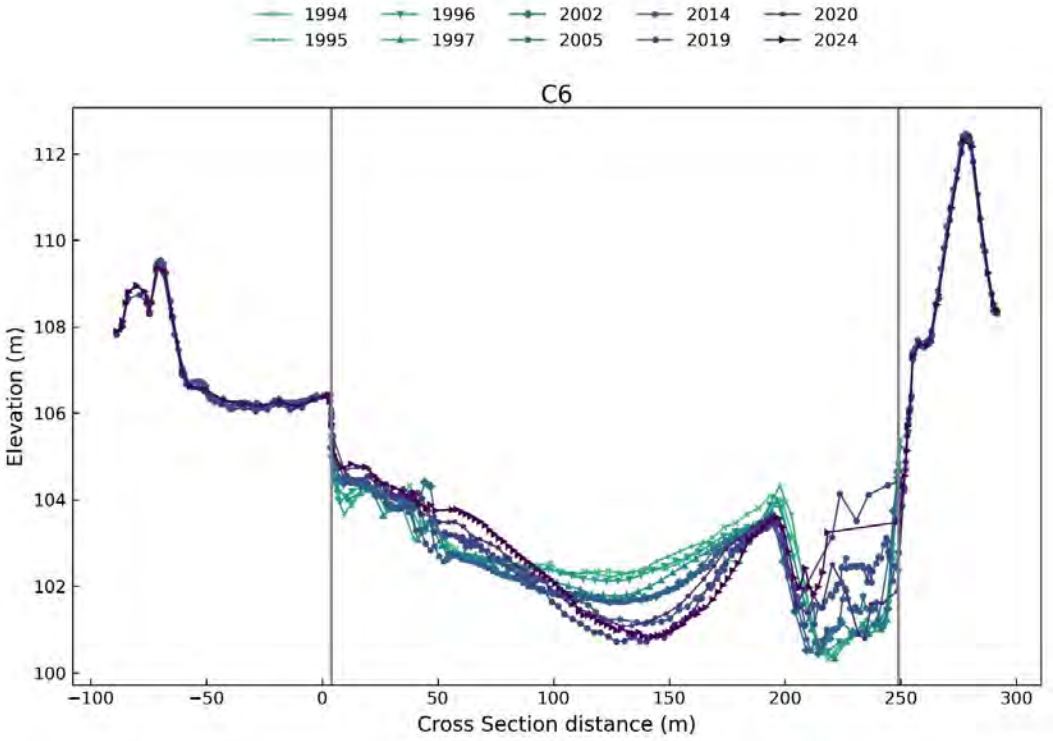


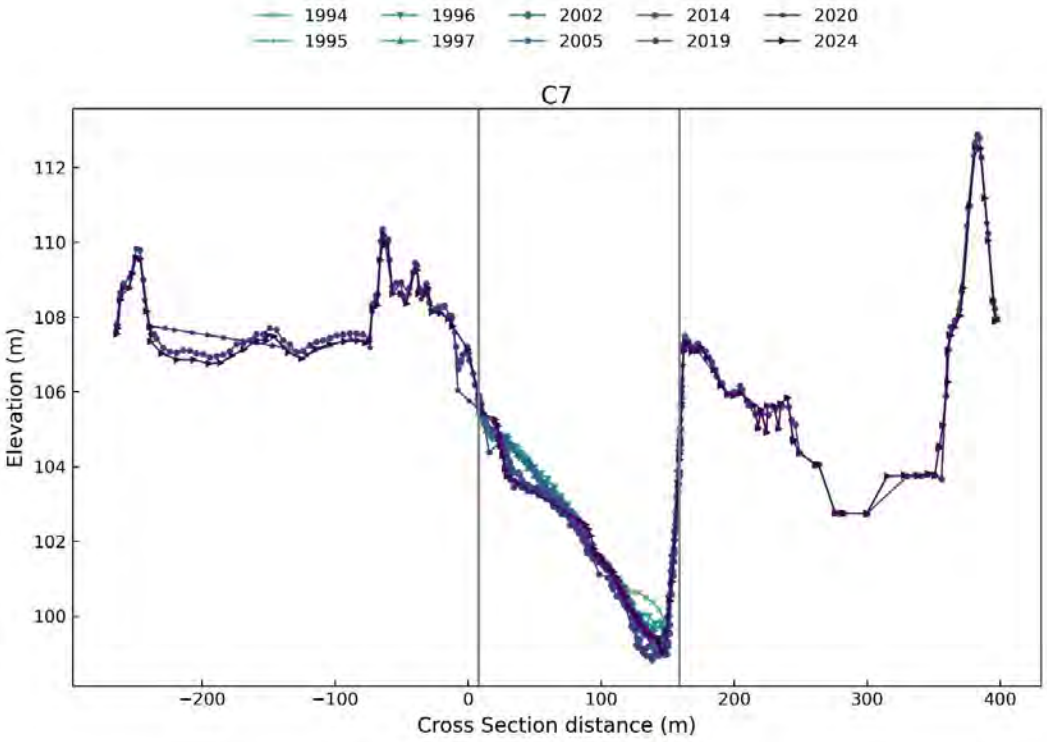


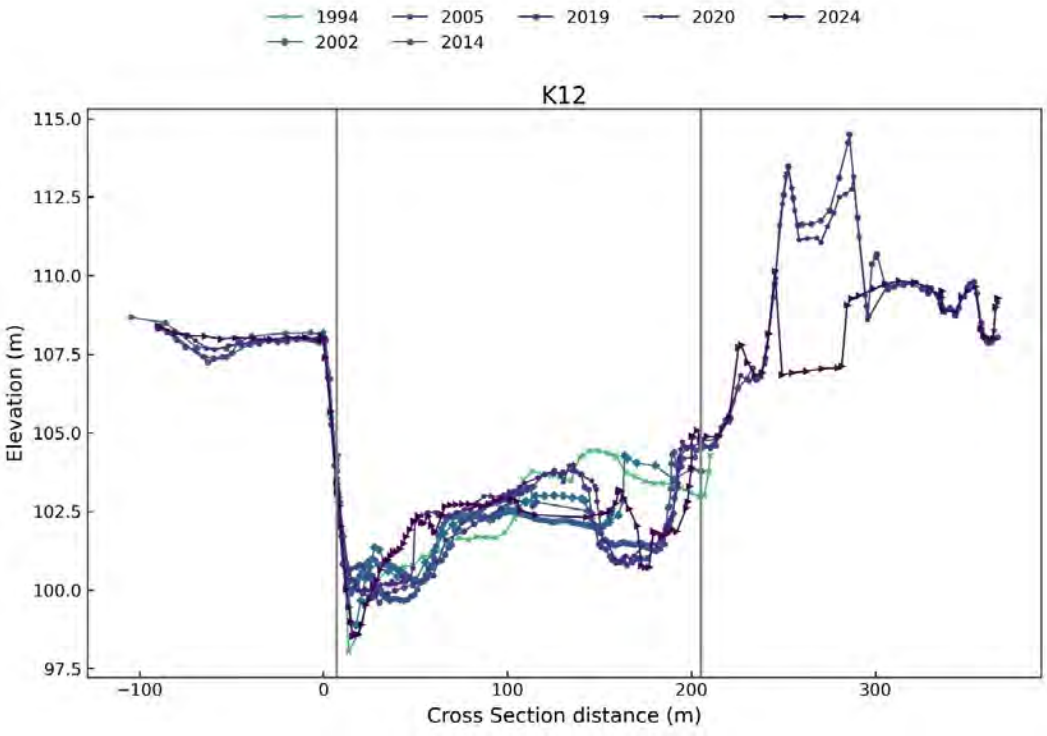

1994
1995
1996
2002
2005
2014
2019
2020
2024
C3
Elevation (m)
Cross Section distance (m)

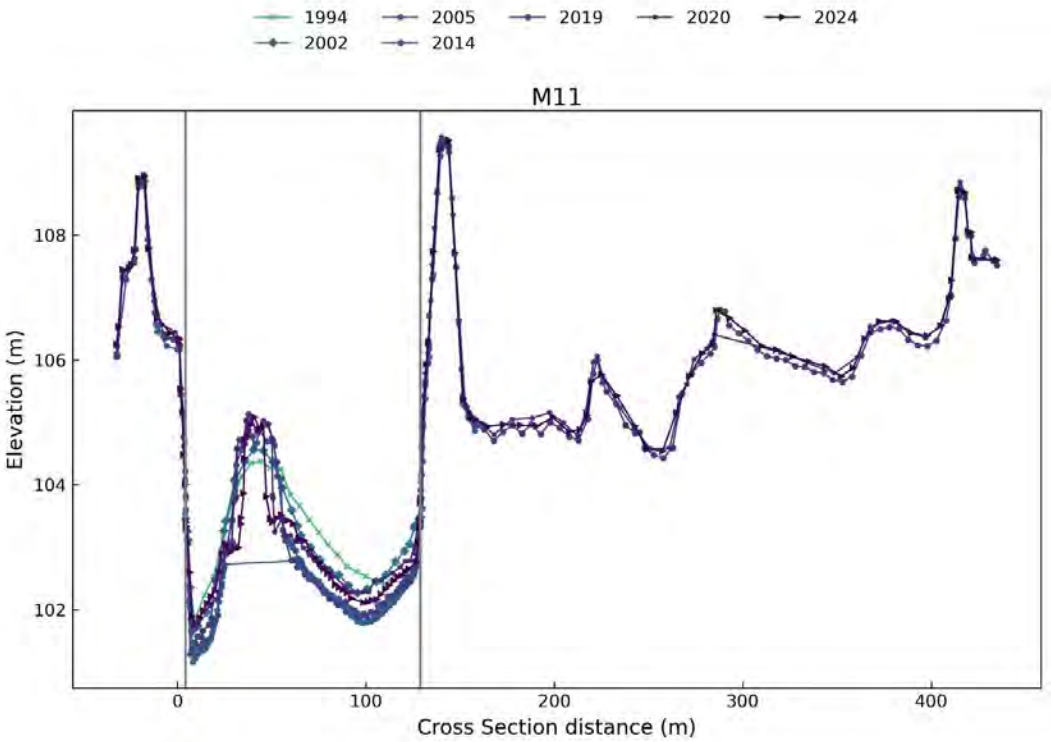

1994
1995
1996
1997
2002
2019
2020
2024
C4
Elevation (m)
Cross Section distance (m)

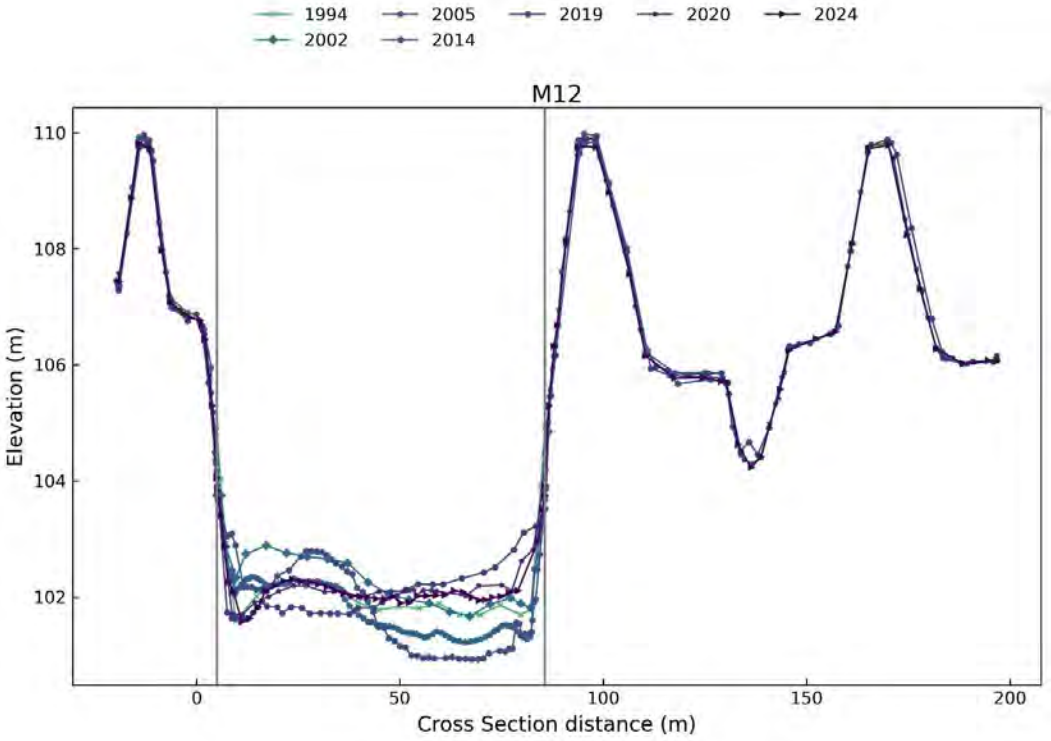

1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C5
Elevation (m)
Cross Section distance (m)


1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C6
Elevation (m)
Cross Section distance (m)


1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C7
Elevation (m)
Cross Section distance (m)


1994
2002
2005
2014
2019
2020
2024
K12
Elevation (m)
Cross Section distance (m)


1994
2002
2005
2014
2019
2020
2024
M11
Elevation (m)
Cross Section distance (m)


1994
2002
2005
2014
2019
2020
2024
M12
Elevation (m)
Cross Section distance (m)

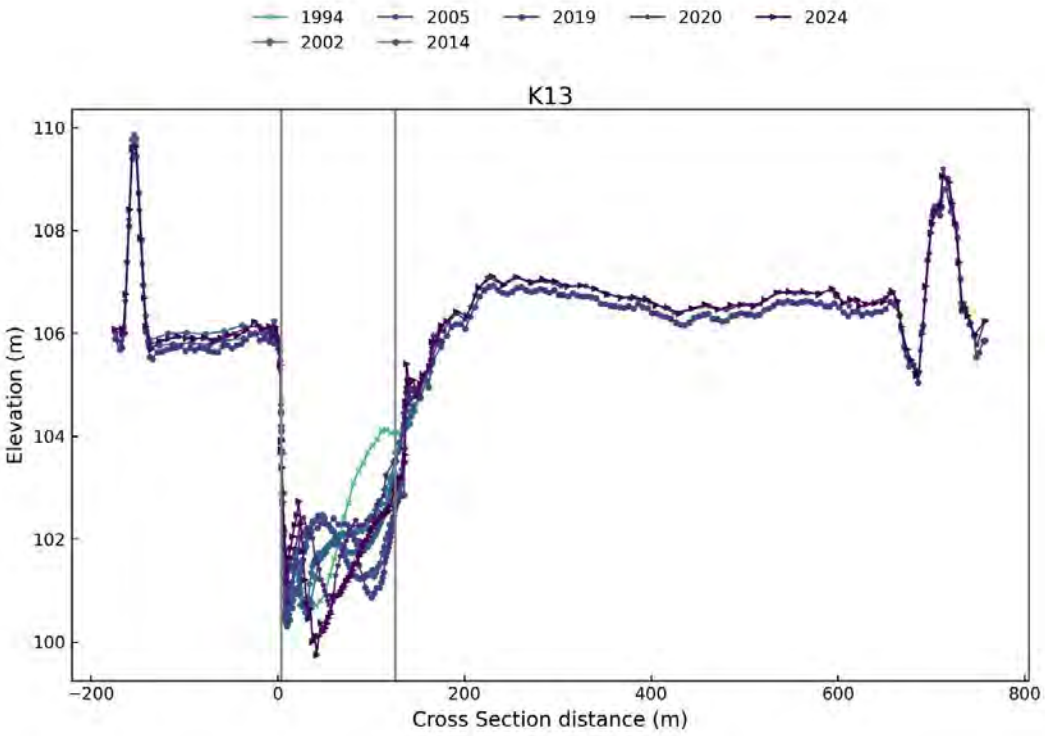


Figure A-1: Cross-sectional profiles of C2 to C7, M11, M12, K12, and K13 for all surveyed years.

Appendix B Satellite images of the Clutha River at Balclutha between 2016 and 2025

12-Jan-2018
Mean daily flow = 274 m3/s
N
0 0.2 0.4 0.8
Km

23-Apr-2020
Mean daily flow = 440 m3/s
N
0 0.2 0.4 0.8
Km

22-Mar-2022
Mean daily flow = 267 m3/s
N
0 0.2 0.4 0.8
Km

N
0 0.2 0.4 0.8
Km
27-Feb-2023
Mean daily flow = 371 m3/s

1-Mar-2024
Mean daily flow = 424 m3/s
N
0 0.2 0.4 0.8
Km

Figure B-1: Satellite imagery of the Clutha River at Balclutha for seven years between 2016 and 2025. The exact date of the satellite capture and average daily flow values are inserted in bottom left of each image. Red lines indicate cross-section locations.

Clutha Delta **Liquefaction Vulnerability Assessment**

ORC responsibilities

Previous studies have identified that the Clutha delta is likely to be vulnerable to liquefaction (GNS Science, 2019). To improve our understanding of the risks of liquefaction and other potential seismic hazards at the Clutha delta, ORC has engaged independent experts at Tonkin + Taylor Ltd (T+T) to undertake a liquefaction vulnerability assessment and seismic risk assessment.

What is liquefaction?

Liquefaction can occur when earthquake shaking causes loose, wet soil to temporarily behave like liquid.

The three key elements required for liquefaction to occur:

Soil condition + Ground water + Earthquake shaking

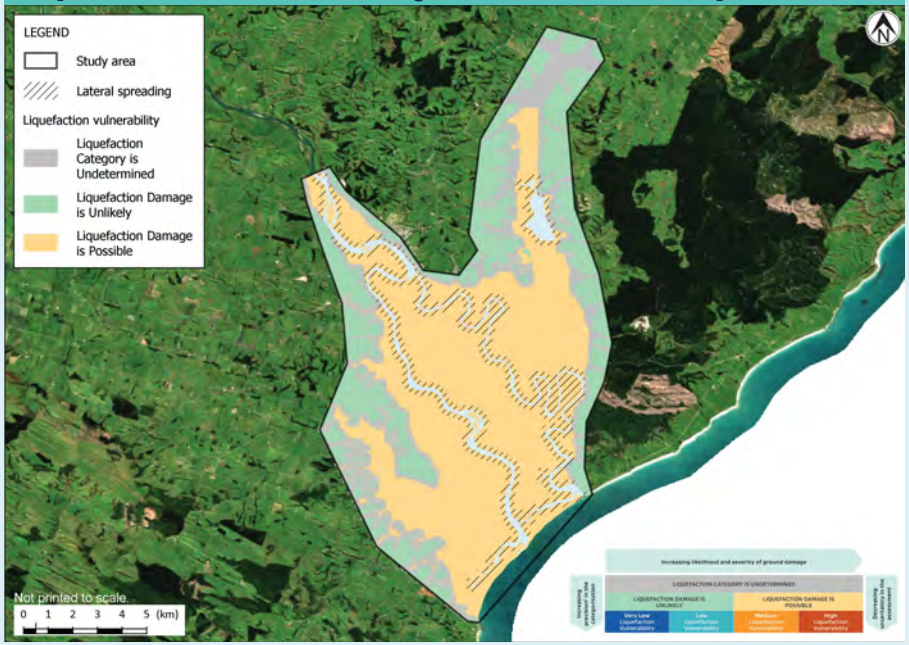
= Liquefaction

Potential impacts of liquefaction

- The ejection of sediment and water to the ground surface.
- Uneven deformation of the ground surface (subsidence).
- Slumping and sideways movement of the land (lateral spreading).
- Significant damage to land, the environment, buildings, infrastructure, and social and economic disruption.

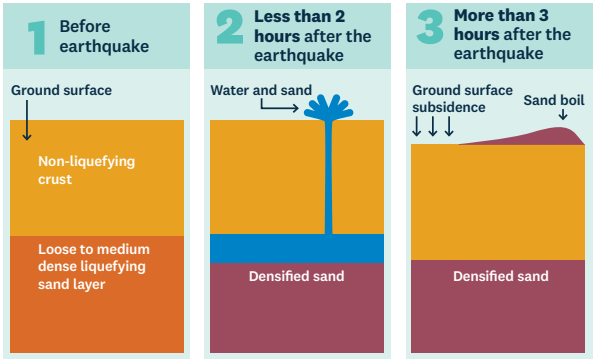
Examples of severe liquefaction (top) and lateral spreading impacts (bottom), Christchurch 2011.

Liquefaction vulnerability classification map (T+T 2025)



The process of liquefaction and impacts at ground level

Formation of liquefaction ejecta



The liquefaction hazard assessment

About

This new study is a more detailed investigation of that hazard — it uses data from over 100 underground tests (such as boreholes and geotechnical tests), which gives a much clearer picture of where liquefaction might happen and how significant the impacts could be.

This approach to liquefaction hazard assessment follows the New Zealand national guidance (MBIE/MfE guidance, 2017).

Assessment findings

- **Confirms susceptibility** of the delta area to liquefaction.
- **Refines previous liquefaction mapping** (GNS, 2019) through the extensive geotechnical tests included in the study — improving our understanding of the likelihood and consequences of a major earthquake.

Learn more at **orc.govt.nz/cluthaadaptation**

Otago Regional Council

Clutha Delta
Natural Hazards Adaptation Programme

Why do we need to adapt?

The Clutha delta — including Balclutha, Kaitangata, Stirling and surrounding rural areas — faces a range of natural hazards, including:

- **Flooding**
  The area has a history of river flooding, primarily from the Clutha River/Mata-Au, but also from smaller tributaries including the Pūerua and Waitepeka rivers.
- **Groundwater and drainage issues**
  As a low-lying floodplain area with elevations near sea level, groundwater levels are high and the area does not naturally drain easily. Keeping the land dry relies on extensive pumping and drainage infrastructure.
- **Earthquake hazards**
  A major earthquake could cause strong ground shaking and trigger liquefaction in the soft sediments of the delta. A number of active faults are located in the coastal parts of the Clutha district, including several in the Clutha delta area.
- **Coastal hazards**
  Sections of the coast are affected by high rates of erosion and exposed to inundation (flooding by the sea) from storm surge or tsunami.

Many of these hazards are expected to worsen with ongoing landscape changes and climate change.

What is ORC doing to manage hazards now?

The ORC is already undertaking a range of hazard management responses, monitoring, and forecasting related to natural hazards.

- Lower Clutha Flood Protection and Drainage Scheme mitigates flooding and drains 9,300 hectares from north of Balclutha to the sea. The Clutha River/Mata-Au, splitting into Koau and Matau branches, and other water sources contribute to the flow.
- Flood hazards forecasting and coastal hazards forecasting provide early awareness of river flow and sea conditions that may cause natural hazard issues.
- Environmental monitoring, including rainfall, river level and flow, riverbed profiles, coastal conditions, and groundwater levels.

What is the Clutha Delta Natural Hazards Adaptation Programme?

The Clutha Delta Natural Hazards Adaptation Programme intends to:

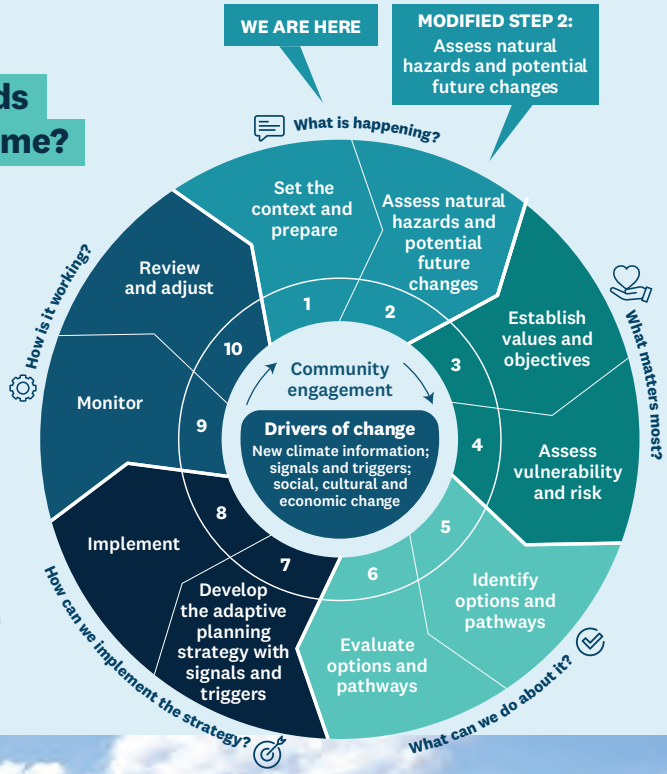
- understand natural hazard risks faced now and in the future
- work with partners and the community to understand local values, interests, and aspirations for the future
- collaborate with partners and the community to develop a strategy to manage and build resilience to long-term natural hazard risks.

The strategy will provide a common direction for our natural hazards management and adaptation planning and decisions at the Clutha delta. It will also support everyday decision making by individuals and the community.

We're using a method called Adaptation Pathways — a flexible, step-by-step approach that helps councils and communities make decisions even when the future is uncertain. It's already being used by ORC in South Dunedin and the Head of Lake Whakatipu.

This approach helps to:

- plan for different possible futures
- make decisions that can change as conditions change
- focus on long-term wellbeing, not just short-term fixes.



Adapted from the Ministry for the Environment's Coastal Hazards and Climate Change Guidance, 10-step Decision Cycle

Next steps

- Share findings from natural hazards investigations and provide opportunities for the community to share feedback and questions.
- Learn about the community's concerns, values, interests, and aspirations for the area.
- Explore approaches to manage risk and protect what matters most.

Flooding during the February 2020 flood event at Balclutha

Learn more at **orc.govt.nz/cluthaadaptation**

Otago Regional Council

Clutha River/Mata-Au bed levels at Balclutha

ORC responsibilities

ORC manages the Lower Clutha Flood Protection and Drainage Scheme, providing flood mitigation to the Balclutha township and the surrounding rural areas. ORC has responsibilities to assess potential natural hazards and monitor the region's river systems.

The location of cross-section surveys and the flow monitoring site on the Clutha River/Mata-Au at Balclutha

Bed level trends at Balclutha

To understand the capacity of the Lower Clutha Flood Protection and Drainage Scheme, and to be able to respond to community concerns, ORC contracted independent experts at NIWA to review changes to shape and elevation of the river channel at Balclutha over time, based on all available data.

These datasets include:

- monitoring of Clutha River/Mata-Au water levels and river flows (since 1952)
- regular surveys of Clutha riverbed levels (since 1994), plus several historical surveys at the railway bridge (since the late 1800s).

What did the study find?

- **Since the 1990s there has been a general lowering trend — average bed levels at 10 of the 11 cross-sections are stable or lowering.**
- Riverbed levels at cross-section C4 are about 0.4 m higher than 1990s levels.
- Riverbed levels have remained within about 0.5 m since the 1990s.
- Analysis of flow and water level data independently confirm these findings.
- Some gravel bars and islands have changed in size and position — but this is an expected natural behaviour of the river system.

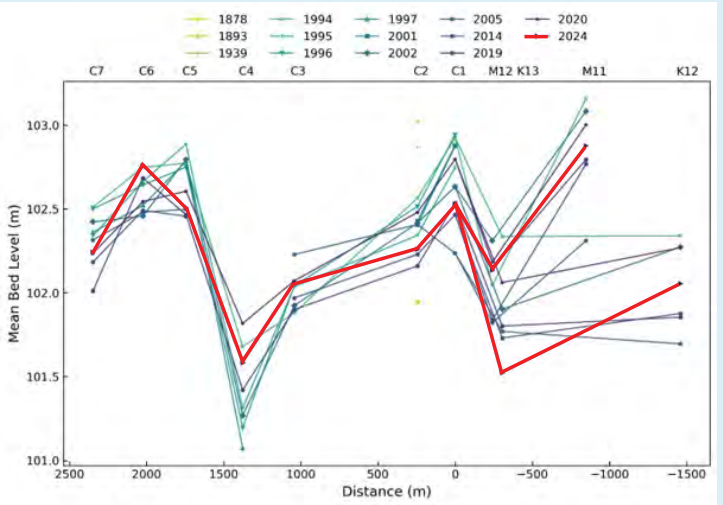
Assessment conclusions

There is no evidence for a widespread or substantial trend of rising levels or 'gravel buildup' at Balclutha.

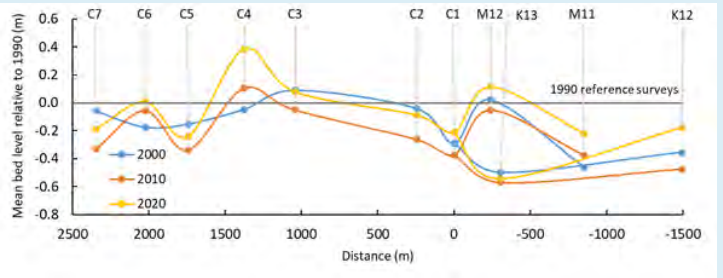
This analysis shows a general long-term trend of lowering of the riverbed since the 1950s.

Some channel changes have occurred (e.g. development or removal of gravel bars/islands), but these have not had a significant impact on bed levels.

You can access the report and more information at: orc.govt.nz/cluthatrends



Historical changes in mean bed level of the Clutha River/Mata-Au near Balclutha township



Mean bed level change relative to 1990 in the Clutha River near Balclutha, with surveys grouped by decade

Next steps

Continued monitoring

ORC will continue to monitor and assess changes to the riverbed levels and channel capacity — surveys every two years or after major flood events.

Gravel management

There is currently no urgent need for any active removal to improve channel capacity at Balclutha. If gravel builds up here or in other locations and could affect flood hazard, ORC will investigate the targeted removal of gravel.

Flood hazard assessment

ORC is assessing flood hazards in the Clutha delta and Balclutha, including how erosion and sedimentation could affect flood capacity. The study will finish by June 2026, with results shared publicly.

Learn more at **orc.govt.nz/cluthaadaptation**

Otago Regional Council

9.3. Communication and Disclosure of Natural Hazards Information

Prepared for:	Science and Resilience Committee
Report No.	HAZ2508
Activity:	Governance Report
Author:	Jean-Luc Payan, Manager Natural Hazards
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] To brief the Science and Resilience Committee on how natural hazard information is disclosed and communicated by ORC and on recent legislative changes.

EXECUTIVE SUMMARY

[2] Local authorities are holders of a significant body of data, information and knowledge on natural hazards. They fulfil an important and unique role recording knowledge of natural hazards on behalf of the community over the long-term.

[3] Although LIMs are prepared and issued by territorial authorities they rely in part on information created and provided by regional councils. ORC works closely with the region's territorial authorities to share information as it becomes available through the Otago Natural Hazards Database Portal.

[4] On 1 July 2025 an amendment to the LGOIMA came into force, aimed at ensuring that that natural hazard information in LIMs is clear, concise, and nationally consistent. The amendment introduced a provision to protect regional councils against liability for natural hazard information that is made available in LIMs in good faith.

[5] New Regulations outlining how natural hazard information should be included in LIMs and how it should be provided by regional councils to territorial authorities will come into force on 17 October 2025.

[6] ORC is currently working with the region's territorial authorities to ensure we meet the natural hazard obligations with respect to LIMs under the amendments to the LGOIMA and to prepare for the new Regulations.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*

BACKGROUND

[7] By virtue of the types and range of statutory functions[1] they perform, local authorities are holders of a significant body of data, information and knowledge on natural hazards. That includes data, information and knowledge acquired by their predecessor organisations and information created or received by the local authorities through their own work and activities. Local authorities fulfil an important and unique role recording knowledge of natural hazards on behalf of the community over the long-term.

[8] There are also other sources of natural hazard information from research organisations or central government that can complement the information held by local authorities.

[9] The data, information and knowledge are in various formats, such as reports, maps and plans but also photographs and videos.

[10] The expectation that local authorities are holders of public information on natural hazards and that they readily provide all that information and knowledge to the public upon request is regulated under several statutes.

[11] Under section 35A of the RMA (*Duty to gather information, monitor, and keep records*), regional councils and territorial authorities must gather information, and undertake or commission research, as is necessary to carry out effectively its functions. Regional councils and territorial authorities must keep records of natural hazards to the extent that the local authority considers appropriate for the effective discharge of its functions.

[12] The LGOIMA applies to all public information held by local authorities, including natural hazard information. The LGOIMA requires that the information shall be made available unless there is good reason for withholding it. In most situations, there is no reason for ORC to not make the natural hazard information available.

[13] Providing information on natural hazards so that communities and stakeholders can make informed decisions is a level of service part of ORC 2024-2034 Long-Term Plan[2] and associated annual plans.

[14] ORC uses mainly three methods to provide and communicate natural hazard data, information and knowledge:

a. Proactively releasing the information on the Otago Natural Hazards Database Portal[3], dedicated pages on the ORC website[4], and on the ORC Environmental data portal[5],

[1] For example, under the Resource Management Act, Local Government Act, Building Act, Soil Conservation and Rivers Control Act, Civil Defence Emergency Management Act

[2] https://www.orc.govt.nz/media/rttlfnpg/ltp-24-34-12-may-2025-rdc-long-term-plan.pdf

[3] https://www.orc.govt.nz/managing-natural-hazards/natural-hazards-adaptation/otago-natural-hazards-database/

[4] https://www.orc.govt.nz/managing-natural-hazards/

[5] https://envdata.orc.govt.nz/AQWebPortal

b. Organising or participating to community meetings and events to present and discuss natural hazard information,
c. Responding to direct natural hazard information requests.

Otago Natural Hazards Database Portal

[15] The Otago Natural Hazards Database Portal is a publicly available collection of ORC (and its predecessors) maps, reports and selected photographs that can help the public and interested organisations to understand natural hazards in the Otago region. It has been developed by ORC and is available to the public since 2012. The Database is searchable by type of hazard, general locality or by property address. Metadata ("data about data") gives the source and assumptions of the information so that the user can make an informed decision as to whether and how they should use that information for any particular purpose.

[16] The portal is regularly updated when new natural hazard information created by ORC becomes available. The portal helps ensure there are strong links and transparency between information creation, receipt and dissemination.

"Managing natural hazards" section of ORC website

[17] The "*Managing natural hazards*" section of ORC website provides a general description of the different natural hazards present in Otago and what ORC is doling to manage them (e.g. Otago Civil Defence Emergency Management Group activities and Engineering activities). It contains links to key natural hazards adaptation programmes such the South Dunedin Future or the Head of Lake Whakatipu Natural Hazards Adaptation programmes.

ORC Environmental data portal

[18] The ORC Environmental data portal provides the latest environmental data, such as water levels, rainfall and flow. The portal enables users to:
- Explore more than 350 monitored sites
- Easily find, view and interact with maps and tables
- See all available historical data
- Download data for offline use and assessments

[19] The live and historic data enable informed decisions to be made for example during a heavy rainfall event.

Community meetings and events

[20] ORC, through its Natural Hazards Team organise or participate in various community meetings or events to share information and knowledge about natural hazards. For example, the Team has recently organised a community meeting to discuss the flood hazard in Middlemarch[6] and supported a community drop-in session on flood hazard, flood protection and drainage in the Lower Clutha and Tokomairiro areas[7].

[6] https://www.orc.govt.nz/get-involved/events/2025/june/orc-natural-hazards-assessment-update-middlemarch/

[21] The team also supports the Otago Civil Defence Emergency Management Group readiness activities related to public education and emergency preparedness.

Direct natural hazard information requests

[22] ORC receives a number[8] of natural hazard information requests from the public, usually to inform a formal or informal property purchase due diligence process (from prospective buyers, real estate agents or solicitors) or to inform property insurance policies.

[23] Although ORC does not, in general, hold property specific natural hazards files or records, natural hazard information relevant to the area in the vicinity of a property is provided in response to direct information requests.

Land Information Memoranda

[24] In addition to the different methods ORC uses to communicate natural hazard data, information and knowledge, the LGOIMA has specific provisions related to sharing of natural hazard information through LIMs.

[25] LIMs are issued by territorial authorities upon request under Section 44A of the LGOIMA and are expressly required to include information relating to natural hazards, amongst other information such as the location of water and sewage pipes, rates details, consents and notices that have been issued by the territorial authority and relating to the property or neighbouring properties, likely future use such as new roads, and any other information the territorial authority regards as relevant.

[26] LIMs contribute to the management of natural hazards by providing information to property owners and potential purchasers to make informed decisions. LIMs do not warrant that land is good or safe and the regional council does not provide advice within LIMs. The natural hazard information provided by ORC is typically developed at a regional or catchment scale rather than individual properties. It provides important hazard context and helps show the wider hazard setting of individual parcels of land. A LIM is not a detailed assessment of an individual property but provides a snapshot at a particular time of known natural hazard information for a specific property and contribute to raise awareness about those hazards.

[27] Although LIMs are prepared and issued by territorial authorities they may rely in part on information created and provided by regional councils. ORC is working closely with the region's territorial authorities to share information as it becomes available directly and through the Otago Natural Hazards Database Portal.

---

[7] https://www.orc.govt.nz/your-council/latest-news/news/2025/july/south-otago-residents-encouraged-to-learn-more-about-the-local-flood-schemes/

[8] Between July 2023 and June 2024, the ORC Natural Hazards Team received and responded to 94 direct natural hazards related enquiries, 143 enquiries between July 2024 and June 2025 and 35 enquiries since July 2025.

DISCUSSION

[28] In 2023, an amendment to the LGOIMA was introduced to empower councils to better share information about natural hazards with the public. This was based on the conclusions by the Department of Internal Affairs (DIA) that LIMs did not currently deliver all key natural hazard information in a way that supports public decision-making.

[29] Three limitations were identified:

a. There are inconsistencies in the natural hazard information provided on LIMs and concerns LIMs may not contain all known information,
b. LIMs did not communicate natural hazard information in a way that the public could easily locate and understand, and,
c. Local authorities' concerns about legal liability could inhibit full disclosure of natural hazard information.

[30] The LGOIMA changes and Regulations are aimed to support decision-making by ensuring that LIMs provide natural hazard information that is clear, concise, nationally consistent in its presentation and easy to understand and to reduce regional council liability.

[31] The LIM related provisions in the LGOIMA came into force on 1 July 2025. The changes clarify what natural hazard information should be included in LIMs.

[32] The Local Government (Natural Hazard Information in Land Information Memoranda) Regulations 2025 come into force on 17 October 2025. They outline how natural hazard information to be included in LIMs should be provided by regional councils to territorial authorities.

[33] Figure 1 gives an overview of the requirements for regional councils. It shows the Act that came into effect on 1 July 2025, and the Regulation which come into effect on 17 October 2025.

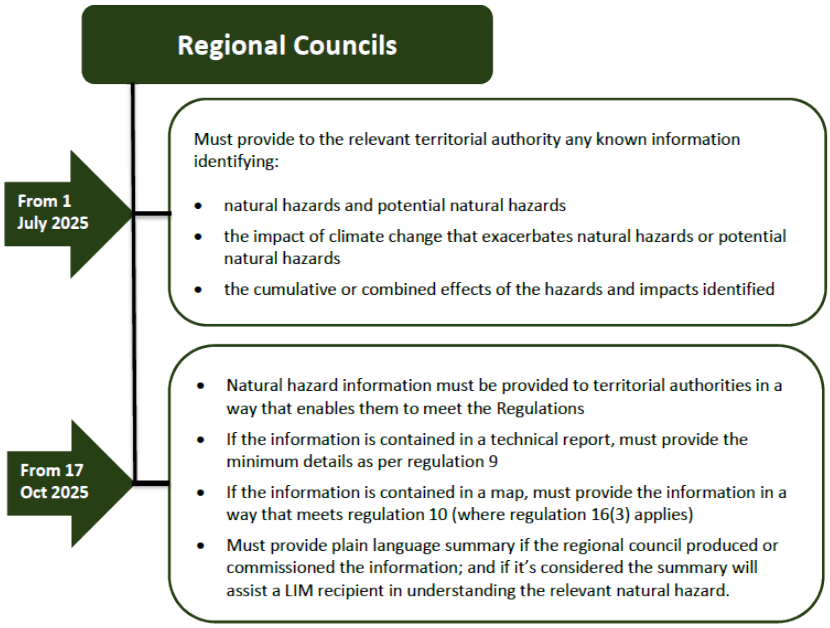


Figure 1. LGOIMA changes and regulations relevant to regional councils[9]

[34] New Section 44D of the LGOIMA protects councils against liability for natural hazard information that is made available in LIMs in good faith.

[35] The DIA has published guidance to support local authorities to implement the changes to the LGOIMA (Attachment 1). The guidance provides a summary of the requirements for regional councils and territorial authorities and provides responses to frequently asked questions. Additional guidance related to the regulations will also be available prior to October 2025.

[36] ORC is currently working with the region's territorial authorities to ensure we meet the natural hazard obligations with respect to LIMs under the new legislation and to prepare for the regulations that come into force on 17 October 2025.

[37] With this purpose, ORC organised a workshop with the territorial authorities in early July 2025 to progress this work. A copy of the presentation used to guide the discussion during the workshop is attached in Attachment 2.

[38] ORC will continue to collaborate with territorial authorities to ensure that natural hazard information is clear, concise and easy to understand and compliant with the law.

OPTIONS

[39] N/A.

[9] From *Guidance for Natural Hazard Information in LIMs*, Department of Internal Affairs | Te Tari Taiwhenua, July 2025

CONSIDERATIONS

Strategic Framework and Policy Considerations

[40] The provision of natural hazard information aligns with Council's Strategic Directions, where the 'Resilience' focus area has the aspiration that "*Otago builds resilience in a way that contributes to community and environmental wellbeing through planned and well-managed responses to shocks and stresses, including natural hazards*".

[41] It contributes to achieving the following goal of the Strategic Directions: "*Plans are in place to ensure that the region's most vulnerable communities (geographic and demographic) and ecosystems are resilient in the face of natural hazards*".

Financial Considerations

[42] Activities associated with the gathering, the monitoring, and the disclosure and communication of natural hazard data, information and knowledge is funded in the ORC Long-Term Plan 2024-2034.

Significance and Engagement

[43] Refer to Background and Discussion section of this report.

Legislative and Risk Considerations

[44] Refer to Background and Discussion section of this report.

Climate Change Considerations

[45] Information on climate change, in particular when it exacerbates natural hazards is provided by ORC using the methods described in the Background section of this report.

[46] The LGOIMA requires (section 44C (1) (a)) regional councils to include information that identifies the natural hazard (or potential natural hazard) and climate change impact (or potential impact) that exacerbates natural hazards that affects the land in a territorial authority district.

Communications Considerations

[47] ORC will continue its various activities supporting the communication of natural hazard to communities and interested organisations through organised meetings or during community events.

NEXT STEPS

[48] Continue working with territorial authorities to support the LIM process and on improving natural hazard information provision and to prepare for the LGOIMA regulations that come into force in October 2025.

[49] Continue to maintain and update the Otago Natural Hazards Database Portal with new information or new functionalities that improve the accessibility to information.

ATTACHMENTS

1. Guidance for Natural Hazard Information in LIMs - July 2025 [**9.3.1** - 17 pages]
2. LGOIMA amendments (LIM) - Workshop Presentation [**9.3.2** - 13 pages]

Internal Affairs
Te Tari Taiwhenua

Guidance for Natural Hazard Information in LIMs

July 2025

This work is licensed under the Creative Commons Attribution 4.0 licence. In essence, you are free to copy, distribute and adapt the work as long as you attribute the work to the Department of Internal Affairs (and abide by the other licence terms – see the plain English licence terms at creativecommons.org/licenses/by/4.0). Please note that the DIA logo may not be used in any way which infringes any provision of the Flags, Emblems, and Names Protection Act 1981 – attribution to the DIA should be in written form and not by reproduction of the DIA logo.

Legal disclaimer

Readers are advised to seek specific legal advice from a qualified professional person before undertaking any action in reliance on the contents of this document. The contents of this document must not be construed as legal advice. The Department of Internal Affairs (DIA) does not accept any responsibility or liability whatsoever whether in contract, tort, equity or otherwise for any action taken as a result of reading, or reliance placed on the Department of Internal Affairs because of having read, in part, or all, of the information in this document or for any error, inadequacy, deficiency, flaw in or omission from the document.

Internal Affairs
Te Tari Taiwhenua

Contents

Introduction 4
Summary of the requirements for regional councils and territorial authorities..... 4
Frequently Asked Questions 7
"Known" information 7
Types of information 10
Natural hazards 13
Ambiguous information 13
How this guidance was produced 14
Appendix 1: Summary of the Regulations 15

Internal Affairs
Te Tari Taiwhenua

Introduction

In 2025 two changes will impact natural hazard information disclosure in Land Information Memoranda (LIMs), and how regional councils provide natural hazard information to territorial authorities:

i. Changes to the *Local Government Official Information and Meetings Act 1987* (the Act) come into force on **1 July 2025** and clarify **what** natural hazard information should be included in a LIM/provided by regional councils to territorial authorities.

ii. The *Local Government (Natural Hazard Information in Land Information Memoranda) Regulations 2025* (the Regulations) come into force on **17 October 2025**. They outline **how** natural hazard information should be included in a LIM/provided by regional councils to territorial authorities.

"Natural hazard" has the same meaning here as in the Resource Management Act 1991:

> **natural hazard** means any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding) the action of which adversely affects or may adversely affect human life, property, or other aspects of the environment.

This guidance provides a summary of the requirements for regional councils and territorial authorities from the changes to the Act and the Regulations, and answers some frequently asked questions that have come up during engagement with councils.

It is provided for information only and cannot be relied on as evidence of complying with the requirements of sections 44A-D of the Act, or with the Regulations. This guidance does not cover information in a LIM/provided by a regional council to a territorial authority that does **not** relate to natural hazards.

Summary of the requirements for regional councils and territorial authorities

Figures 1 and 2 below give an overview of the requirements for regional councils and territorial authorities respectively. They show which come into effect when the Act changes on **1 July 2025**, and which come into effect with the Regulations on **17 October 2025**.

Internal Affairs
Te Tari Taiwhenua

Once the amendments have been incoporated into the Act they will be available at Local Government Official Information and Meetings Act 1987 – New Zealand Legislation.[1]

The Regulations are summarised in Appendix 2. The full Regulations can be read at Local Government (Natural Hazard Information in Land Information Memoranda) Regulations 2025 - New Zealand Legislation.

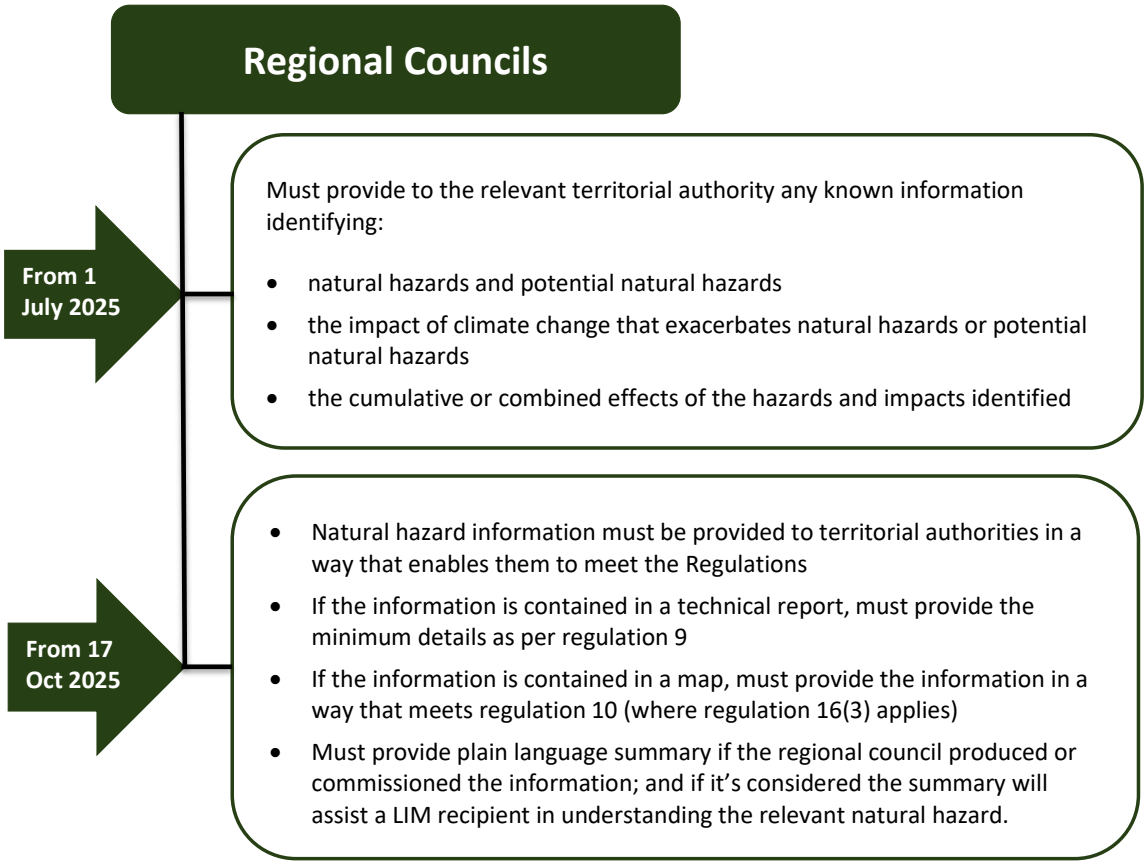


Figure 1: The Act changes and regulations relevant to regional councils

[1] In the meantime the full changes can be read in the Local Government Official Information and Meetings Amendment Act 2023 – New Zealand Legislation

Internal Affairs
Te Tari Taiwhenua

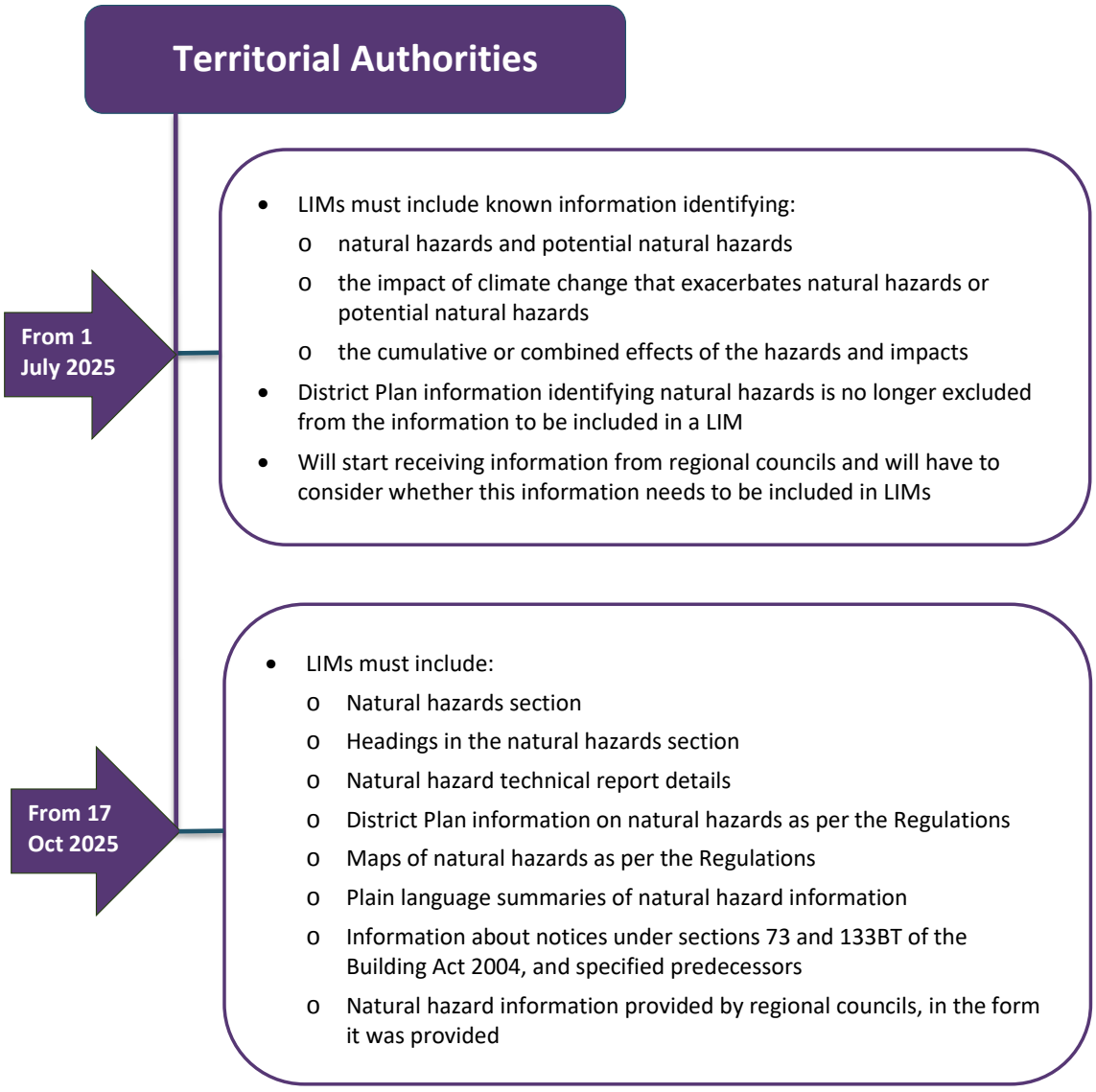


Figure 2: The Act changes and regulations that are relevant to territorial authorities

Internal Affairs
Te Tari Taiwhenua

Frequently Asked Questions

These FAQs are intended to provide guidance and are not legal advice.

"Known" information

1. What does "known" mean?

The word "known" has been used in section 44A(2)(a) of the Act since this section was added in 1992.

Original section 44A(2)(a)	**New section 44B(2)(a)**	**New section 44C(1)(a)**
(2) The matters which shall be included in [a LIM] are—	(2) A land information memorandum must include—	(1) A regional council must, as soon as is reasonably practicable in the circumstances, provide to a territorial authority within or partly within its region—
(a) information identifying each (if any) special feature or characteristic of the land concerned, including but not limited to potential erosion, avulsion, falling debris, subsidence, slippage, alluvion, or inundation, or likely presence of hazardous contaminants, being a feature or characteristic that— (i) ***is known to the territorial authority***	(a) information that identifies [the listed matters], to the extent that the information ***is known to the territorial authority***	(a) information that identifies [the listed matters], to the extent that the information ***is known to the regional council***

The courts have considered when information is "known".[2]

[2] See for example *Weir v Kāpiti Coast District Council* [2013] NZHC 3522

Internal Affairs
Te Tari Taiwhenua

Known means that the territorial authority or regional council knows about the information. It doesn't mean that they consider the information is accurate, nor that the information has been 'tabled' or 'adopted' by elected members.

2. What is "potential" and "reasonable possibility"?

LIMs must include *"information that identifies … each **potential** hazard, and each **potential** impact of climate change that exacerbates natural hazards … to the extent that the territorial authority is satisfied that there is a **reasonable possibility** that [it] will affect the land concerned"*.

Regional councils must provide *"information that identifies … each **potential** hazard, and each **potential** impact of climate change that exacerbates natural hazards … to the extent that the regional council is satisfied that there is a **reasonable possibility** that [it] will affect land in the territorial authority's district"*.

The meaning of "potential" is broad. The Courts have made it clear that there is a relatively low threshold for the identification of potential[3].

The requirement is to identify any potential hazard that the territorial authority or regional council considers has a "reasonable possibility" of affecting land. The High Court in *Weir* held that it is not feasible to attach a probability to possible future events, and that reasonable possibility is something that needs to be objectively determined.

3. Is there an obligation to provide new or updated information once the initial information has been provided?

There is a difference here in the requirements for regional councils and territorial authorities.

Regional councils

Must provide the listed information to territorial authorities "as soon as is reasonably practicable in the circumstances". New information that meets the requirements of the Act must be provided to the relevant territorial authority.

[3] *Marlborough District Council v Altimarloch Joint Venture Ltd* [2012 NZSC 11]

Internal Affairs
Te Tari Taiwhenua

Territorial authorities

The information included in a LIM is what is known at the time the LIM is issued. Territorial authorities do not have to re-issue LIMs if information changes or new information becomes known after the date of issue.

Some territorial authorities include a disclaimer which states that the LIM is valid as at the date of issue only.

4. How should a territorial authority or regional council deal with information that is known but perceived to be private or confidential?

Privacy is a narrow subject relating to identifying information about people. The state of land is not a privacy issue.

Information labelled as confidential may not in fact be confidential in terms of the Act. Some common examples where people think information is confidential, but it may meet the requirements for **providing to a territorial authority/including in a LIM** are:

- Reports that have been commissioned by an individual about their property and subsequently made known to a territorial authority or regional council, such as a Geotech report for a building or resource consent.
- Reports that have been commissioned for a council's internal purposes.

5. How do we treat draft technical reports (or draft information in general)?

When a report or another type of information is provided to the territorial authority or regional council, it generally becomes public information. While the information may not have been finalised, released or made publicly available, it may still be known and may be required to be **provided to a territorial authority/included in a LIM**. The Act changes support territorial authorities and regional councils to share draft information by limiting liability when sharing information in good faith.

Internal Affairs
Te Tari Taiwhenua

Types of information

6. What types of information need to be included/provided?

New sections **44B(2)(a)** and **44C(1)(a)** of the Act will require the **LIM to include information/regional council to provide information** that identifies the following, to the extent that the information is known to the territorial authority or regional council:

(i) each natural hazard, and each impact of climate change that exacerbates natural hazards, that affects the **land concerned/land in the territorial authority's district**,

(ii) each potential natural hazard, and each potential impact of climate change that exacerbates natural hazards, to the extent that the **territorial authority/regional council** is satisfied that there is a reasonable possibility that the hazard or impact may affect the **land concerned/land in the territorial authority's district** (whether now or in the future), and

(iii) the cumulative or combined effects of the hazards and impacts referred to in subparagraphs (i) and (ii) on the **land concerned/land in the territorial authority's district.**

This requires territorial authorities and regional councils to include information that *identifies* the natural hazard or climate change impact, rather than to include all information it holds about that.

Types of information may include (but are not limited to):

- Reports
- Maps
- Photos
- Notifications under section 73 of the Building Act 2004 (and listed predecessors)

7. In what ways might information be shared?

Territorial authorities and regional councils have discretion in how to share information, so long as the information they provide is sufficient to identify (to the extent that the information is known) the listed matters. The ways that this information might be provided to a **territorial authority/included in a LIM** include (but are not limited to):

- Where regional councils have a natural hazard portal, a link can be included/provided.
- Instead of providing a full copy of a technical report, state that a report exists and note how to access that report (along with the minimum requirements set out in the Regulations, from 17 October 2025).
- If a report has been turned into map data that is accessible online, a link to the map can be included/provided.

Internal Affairs
Te Tari Taiwhenua

- Photo of an area in a flood (or other natural hazard) – this might be the only information held about a particular hazard in a particular area.

Once it's been decided what information to **provide/include**, the Regulations cover how that information is to be **provided/included**. FAQs 8 and 9 talk about two of these – technical reports and plain language summaries.

8. What is a technical report? How are technical reports to be included/provided?

Land Information New Zealand describes a technical report as a document requested and funded to provide in-depth analysis, findings and recommendations on a particular subject. Such reports serve to inform decision-making in a structured format.

A technical report is generally written by a subject matter expert. It is a document that describes the process, progress or results of technical or scientific research, or the state of a technical or scientific research problem. Videos or other audio-visual media may be considered scientific or technical reports. Multimedia presentations such as PowerPoint may also be considered technical or scientific reports.

The Regulations set minimum requirements for information that must be included/provided about technical reports. These apply in two situations:

When a regional council is providing information contained in a technical report.

When a territorial authority refers the recipient of a LIM to information that is contained in a technical report, for the purposes of providing information about natural hazards under section 44B of the Act.

In these situations, the below details about the report must be provided to the territorial authority/included in the LIM. These requirements are the minimum, and additional details can be provided/included.

(a) the name of the person or entity that commissioned the report:

(b) the purpose of the report:

(c) the scope of the report (for example, whether the report relates to only 1 property, to 2 or more properties, or to a broader area or community):

(d) where or how to access the report (this can be a link to a publicly available internet site or online portal that provides access to the report):

(e) the title of the report:

(f) the date of the report:

(g) the name of the person or entity that prepared the report.

For example, if a LIM is going to refer to a site suitability report from a building consent or resource consent to identify a potential hazard, it would have to include the details listed above about that report (e.g. title, date, scope etc).

9. What is plain language? When is a plain language summary required?

Plain language helps to ensure readers can understand and act on information. It should match the reading skill of the intended reader, which in the case of LIMs is the general public. A plain language summary should be clear and concise, avoid jargon and using more words than necessary.

A plain language summary summarises the piece of information. It is not an analysis or an assessment of the information. When preparing a summary, any qualifications, assumptions or limitations on the information should be included.

If a third party provides a piece of information that meets the requirements of the Act has been provided by a third party, but it was not specifically commissioned by the territorial authority or regional council to do so, then the plain language summary requirement does not apply to that information.

Plain language summaries must be provided in the following situations:

Regional councils must provide plain language summaries to territorial authorities if the regional council:

(i) produced or commissioned the relevant piece of information; and

(ii) considers the summary will assist the recipient of the LIM to understand the relevant natural hazard.

There are two situations where plain language summaries are required in a LIM:

(i) The territorial authority produced or commissioned the information, considers a summary would assist the recipient of the LIM to understand a natural hazard identified in the LIM, and the information became known to the territorial authority on or after 17 October 2025; or

(ii) The territorial authority received the information from a regional council and the regional council has provided a plain language summary of that information. In this case, the territorial authority must include the summary in the LIM without change.

The plain language summary requirement is about pieces of information. Many territorial authorities provide notes, comments or notations in a LIM. While this summarises information that they know, it is not a summary of a piece of information.

Internal Affairs
Te Tari Taiwhenua

Natural hazards

10. Is there a list of natural hazards?

Natural hazard means any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding) the action of which adversely affects or may adversely affect human life, property, or other aspects of the environment. The impacts of climate change that exacerbate natural hazards, and the cumulative or combined effects of these hazards and impacts, are also included.

11. What does 'cumulative effects' mean?

Cumulative effects in this context are the overall impact of multiple hazard events, and how climate change might exacerbate these over time. If information identifying cumulative effects is known (for example, a technical report that models these), this will need to be considered for **providing to the relevant territorial authority/including in a LIM.**

The Act and Regulations do not require regional councils or territorial authorities to undertake any analysis to determine cumulative effects.

12. Does a risk assessment need to be undertaken?

The Act and Regulations do not require regional councils or territorial authorities to undertake risk assessments.

Ambiguous information

13. What if there is conflicting information about a hazard?

There are situations where conflicting information is known to a regional council or territorial authority. If the information meets the requirements in the Act it should be **provided to the territorial authority/included in the LIM**.

For example, there may be differences between sources of natural hazard information depending on their purpose and approach. Minimum key details, such as the purpose and age of the information, alongside plain language summaries, will help LIM readers understand the differences between the information and make their own judgment call on how much reliance to place on it.

A LIM is to put the reader on notice that a natural hazard/potential natural hazard, impact of climate change that exacerbates natural hazards/potential impact, and/or cumulative or combined effects of these hazards and impacts have been identified. It is not the territorial authority confirming the information for the reader or assessing which information is the 'right' information. The aim of the Act and the Regulations is that the LIM reader will have enough information to do their own due diligence.

Internal Affairs
Te Tari Taiwhenua

14. What if a piece of information is relevant to multiple sections of the LIM? How can this information fall under more than one heading without duplication?

The Regulations address this situation. If natural hazard information could be included under more than one heading, the territorial authority must include the information under the heading that it considers to be most appropriate. If a territorial authority includes natural hazard information in a LIM other than in the natural hazard section, then they must refer to the location of that information in the natural hazard section, under the relevant heading.

In practice, this may look like a cross-reference, where a territorial authority places the information under one heading, then under any other headings that the information is relevant to adds a note or a comment to direct the reader to the section that contains the information.

How this guidance was produced

This guidance was produced by the Department of Internal Affairs (DIA) with the contribution and assistance of local government representatives. This included working groups and reviewers with participants from territorial authorities and regional councils, as well as Taituarā.

The role of the working groups was to support the guidance by:

(i) ensuring a good understanding of the challenges and opportunities in the LIMs working environment

(ii) identifying priority areas for guidance

(iii) helping to identify and develop robust guidance.

The Department would like to thank Taituarā and the following councils for their contributions to this guidance:

Auckland Council, Christchurch City Council, Dunedin City Council, Hastings District Council, Hawkes Bay Regional Council, Horizons Regional Council, Kāpiti District Council, Napier City Council, Otago Regional Council, Tasman District Council, Tauranga City Council, Thames-Coromandel District Council, Waikato Regional Council and Wellington City Council.

Internal Affairs
Te Tari Taiwhenua

Appendix 1: Summary of the Regulations

The full regulations can be found here: Local Government (Natural Hazard Information in Land Information Memoranda) Regulations 2025.

Obligations on territorial authorities

Regulation 6: Limit on obligations on territorial authority

The territorial authority is not required to prepare a risk assessment, undertake any further analysis, or search for further information other than information that it is required to include under section 44B of the Act.

Regulation 7: Minimum requirements for LIMs

Each LIM must include a natural hazard section that includes the information required under section 44B of the Act, and each LIM must comply with the regulations. The natural hazard section may include other information about natural hazards that the territorial authority considers to be relevant.

Regulation 8: Content of natural hazard section

The natural hazard section of the LIM must include headings. Headings need to identify what information was sourced from the district plan and what information relates to the Building Act 2004. All other information must be under headings that reflect the identified hazard (e.g., flood, earthquake). Subheadings are allowed.

Where natural hazard information could be included under more than one heading, including in other sections of the LIM, the information does not need to be repeated but simply referred to.

Regulation 9: Minimum requirements in relation to technical report

If the territorial authority refers the LIM reader to a technical report, they need to include specific details about the report. This applies to all technical reports regardless of when the report was produced. Minimum requirements are:

(i) Name of person/entity that commissioned the report
(ii) Purpose of the report
(iii) Scope of the report (eg, what area does the report relate to?)
(iv) How to access the report (this can be a link to a publicly available internet site or online portal that provides access to the report)
(v) Title
(vi) Date
(vii) Author (person or entity)

Internal Affairs
Te Tari Taiwhenua

Regulation 10: LIM must include certain maps

If the information about natural hazards is included in a map that the territorial authority has produced or commissioned, or has received from the regional council, the territorial authority must include that map, either as a copy or as a hyperlink, if they consider it will assist the reader to understand the hazard identified.

Regulation 11: LIM must include plain language summary

The LIM must include a plain language summary of natural hazard information if that information has been produced or commissioned by the territorial authority, and they consider that it will assist the reader to understand a natural hazard identified in the LIM.

If the territorial authority receives natural hazard information from the regional council that includes a plain language summary, they must include the summary in the LIM.

Regulation 12: LIM must include information contained in a district plan

If the district plan contains natural hazard information relevant to the land concerned, the LIM must refer to this and direct the reader to the relevant part of the district plan. If the relevant information in the district plan includes a map, this must be included as a copy or a hyperlink.

Regulation 13: LIM must include information relating to notices under Building Act 2004

A LIM must specify whether any notifications of building consent have been provided for building on land subject to natural hazards (under section 73 of the Building Act 2004, section 434 of the Building Act 2004, section 36(2) of the Building Act 1991 or section 641A of the Local Government Act 1974).

A LIM must note whether a red or yellow placard/sticker (sign or notice under section 133BT of the Building Act 2004) has been placed on or near a building on the land concerned, and if so, whether any subsequent decision has been made under the Building Act 2004 to remove the sign or notice.

Regulation 14: Natural hazard information provided by regional council

When natural hazard information is provided by a regional council, the territorial authority must not alter the information provided, note in the LIM which information has come from the regional council and include a link to the regional council's online natural hazard portal (if they have one).

Internal Affairs
Te Tari Taiwhenua

Obligations on regional councils

Regulation 15: Limit on obligations on regional council

The regional council does not need to prepare a risk assessment, undertake any further analysis, or search for further information other than information that it is required to include under section 44C of the Act.

The regional council does not need to provide the territorial authority with information about natural hazards in response to each individual application for a LIM.

Regulation 16: How regional council must provide natural hazard information

The regional council must provide information in a way that enables the territorial authority to comply with the Act and the Regulations.

If the information is available on a publicly available internet site or portal, providing access to that site or portal is sufficient.

If the information is contained in a technical report, the regional council must provide the level of minimum information specified in Regulation 9.

If the information is contained in a map that the regional council has produced or commissioned, and the regional council considers that the map will assist the reader to understand the hazard identified, then the regional council must provide the information in a way that enables the territorial authority to comply with Regulation 10.

The regional council must provide a plain language summary of natural hazard information if that information has been produced or commissioned by the regional council, and they consider that it will assist a LIM reader to understand the natural hazard.

Otago Regional Council

LGOIMA amendments (LIM) - Workshop

Jean-Luc Payan – Manager Natural Hazards
Janet Ashcroft – Legal Counsel
7 July 2025

KARAKIA TIMATANGA

WHEN TO USE IT » To start the day • To open a meeting

Tuia ki runga	Unite above
Tuia ki raro	Unite below
Tuia ki waho	Unite without
Tuia ki roto	Unite within
Tuia ki te here tangata	Unite as one
Ka rongo te pō	Listen to the night
Ka rongo te ao	Listen to the world of light
Haumi e, hui e	We can now come together
Tāiki e!	as one!

Purpose and agenda

- **Present and discuss the new requirements to the issue of LIMs (natural hazards)**
- **Discuss current processes and potential adjustments**

1. **Background and summary of the requirements for regional councils and territorial authorities (TAs)**
2. **Current process for sharing natural hazard information with TAs**
3. **Proposed process changes and updates**
4. **Discussion:**
   - Collaborative approach
   - Gap identification
   - Good practice for Otago

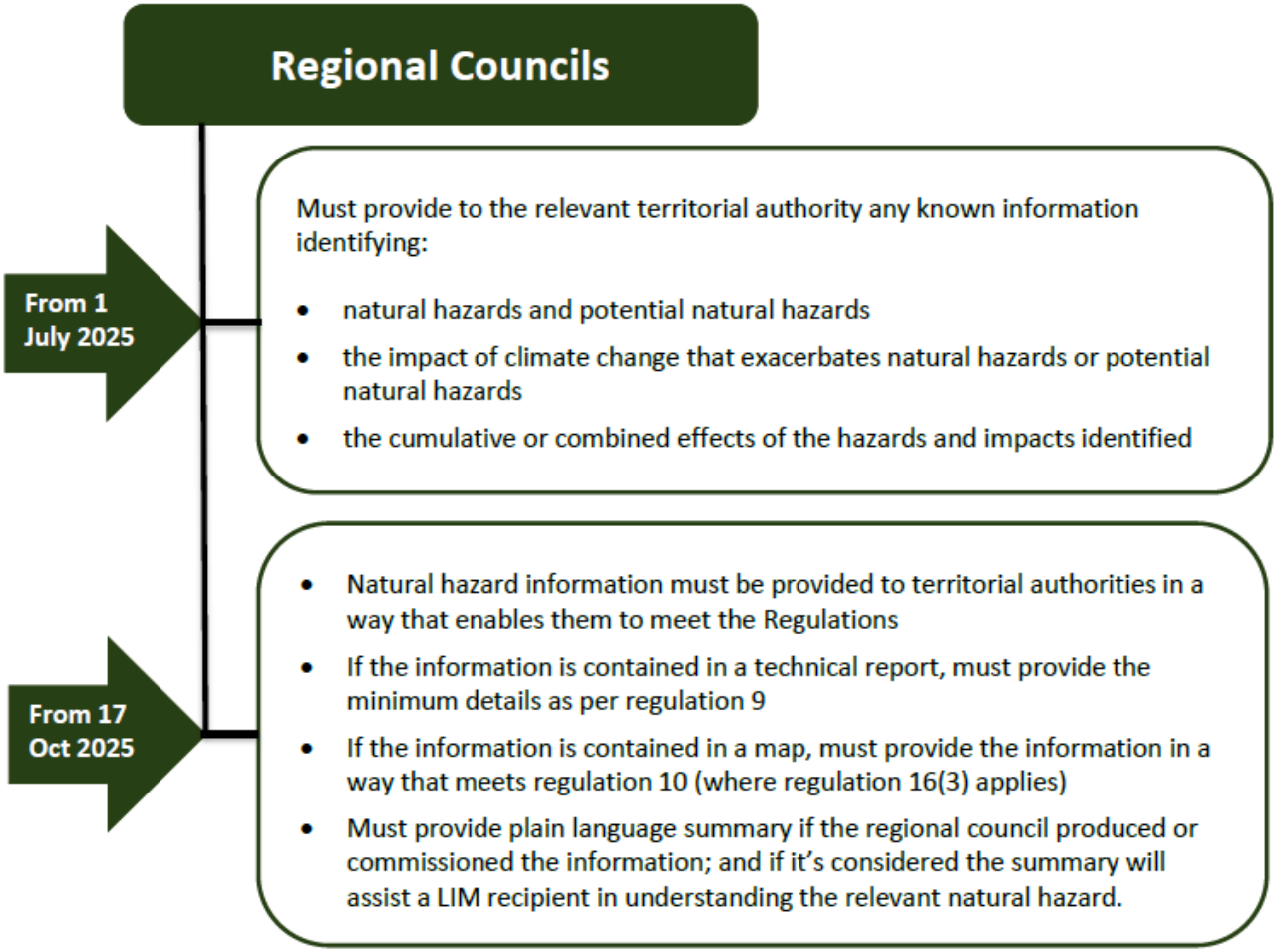
Background

- It can be difficult for councils to identify exactly what natural hazard information to provide to TAs and how.
- The recipient of a LIM may find it difficult to understand the information provided.
- Lack of a uniform approach to the inclusion of natural hazard information in LIMs has led to this legislative change.

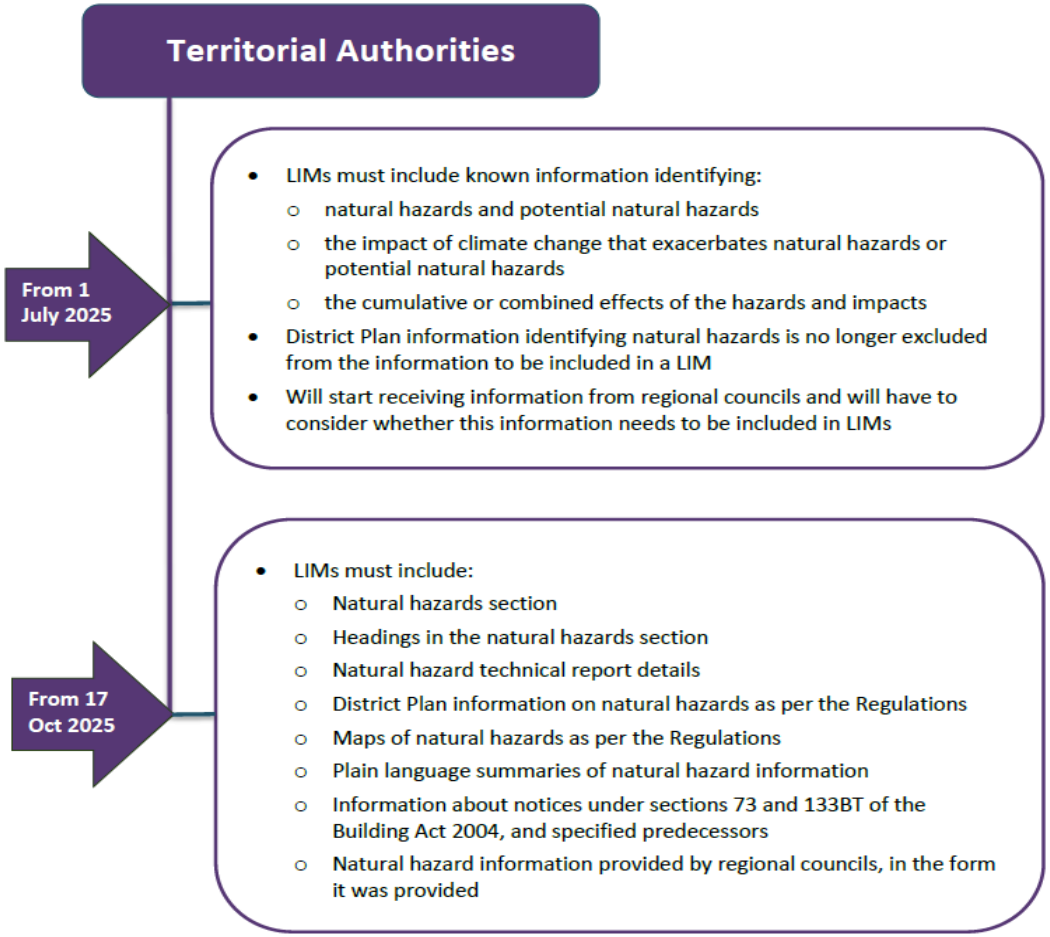
Background

- Changes to the Local Government Official Information and Meetings Act 1987 come into force on **1 July 2025** and clarify what natural hazard information should be included in a LIM/provided by regional councils to territorial authorities.
- The Local Government (Natural Hazard Information in Land Information Memoranda) Regulations 2025 (the Regulations) come into force on **17 October 2025**. They outline how natural hazard information should be included in a LIM/provided by regional councils to territorial authorities.

Act changes and Regulations – Regional Councils

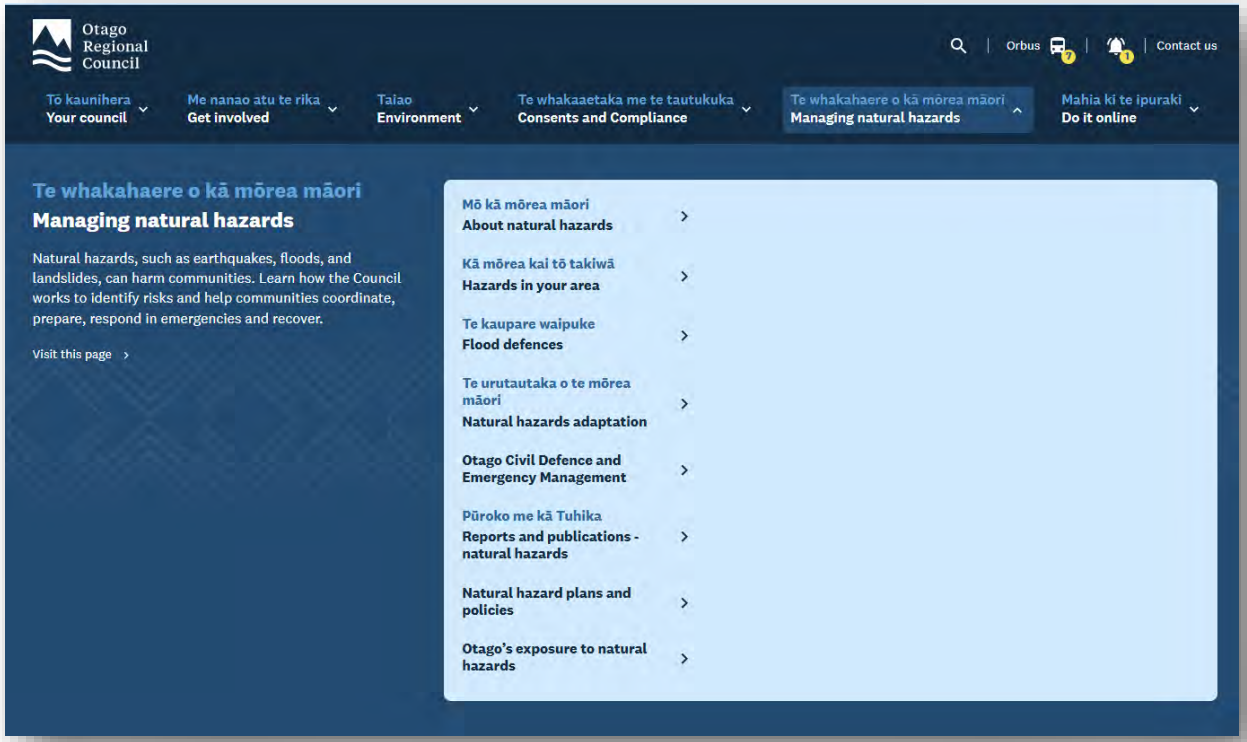


Act changes and Regulations – Territorial Authorities



Current process for sharing natural hazard information

ORC website - natural hazards section - https://www.orc.govt.nz/managing-naturalhazards/



Current process for sharing natural hazard information - ORC Natural Hazards Database

LoS: Provide information on natural hazards and risks, including the effects of climate change, so that communities and stakeholders can make informed decisions.

PERFORMANCE MEASURES	BASELINE RESULTS	2024/2025 TARGET	2025/2026 TARGET	2026/2027 TARGET	2027-34 TARGET
Natural hazards information is available via the web-based Otago Natural Hazards Database.	2022-2023: Achieved	Database is accessible and up-to-date 100% of the time.	Database is accessible and up-to-date 100% of the time.	Database is accessible and up-to-date 100% of the time.	Database is accessible and up-to-date 100% of the time.

9

Proposed process changes and updates

- Develop a memorandum of understanding on an agreed process with TAs
- Provide plain language summaries when required
- Provide a summary of ORC produced or commissioned natural hazard information in the last 20 years

Hazard event class	Hazard event type	Location name	Author	Date	Reference	Report link	Description of work completed	Level of detail	Limitations	Spatial datasets
Geological/ geomorphic	Landslide	Dunedin City District	GNS Science	2017	GNS (Barrell et al), 2017. Revised landslide database for the coastal sector of the Dunedin City district. GNS Science consultancy report; 2017/41.	https://www.orc.govt.nz/media/5753/barrell-2017-gns-report-cr_2017-041-revised-landslide-database-for-the-coastal-sector-of-the-dunedin-city-district.pdf				Compilation of mapping of existing landslide features
Geological/ geomorphic	Landslide	Otago Region	Institute for International Development (IID)	2006	Institute for International Development, 2006. Regional landslip risk and inventory project.	"Landslide reports" in ORC natural hazards portal				Compilation of mapping of existing landslide features
Geological/ geomorphic	Landslide	Add other local landslide reports here (e.g. Abbotsford, Moeraki, Shotover, Kawarau ...)								
Geological/ geomorphic	Alluvial fan/debris flow	Otago Region	Opus International Consultants & GNS Science	2009	Opus/GNS (Grindley et al), 2009. Otago Alluvial Fans Project, Report #1205 Version 2.	https://maps.orc.govt.nz/hazards/NHDBDocuments/Otago%20Alluvial%20Fans%20Project%20(Mar%202009).pdf	Regional (50k scale) alluvial fan assessment, mapping and classification of >2000 alluvial fan areas	Low		Mapping (1:50k scale) and classification of alluvial fan extents
Geological/ geomorphic	Alluvial fan/debris flow	Otago Region	GNS Science	2009	GNS (Barrell et al), 2009. Otago Alluvial Fans Project: Supplementary maps and information on fans in selected areas of Otago. GNS Science Consultancy Report 2009/052	https://maps.orc.govt.nz/hazards/ArchiveDocs/Otago%20Alluvial%20Fans%20Project%20Supplementary%20Investigation%20(April%202009).pdf	Landform mapping, description and assessment (10k scale) of 27 alluvial fan areas within the region.	Moderate		Landform mapping (1:10k scale) and classification of alluvial fan surfaces and catchments
Geological/ geomorphic	Alluvial fan/debris flow	Otago Region	GNS Science	2010	GNS (Watts J & Cox S), 2010: Assessment of debris flow potential on alluvial fans in Otago, New Zealand, using morphometry. GNS Science Consultancy Report 2010/144	"Alluvial fan reports" in ORC natural hazards portal		Low		None
Geological/ geomorphic	Alluvial fan/debris flow	Wakatipu, Queenstown, Wanaka, Makarora, Hawea, Kingston and Roxburgh	Otago Regional Council	2011	ORC (Woods R), 2011. Otago Alluvial Fans: High Hazard Fan Investigation	https://www.orc.govt.nz/media/2948/otago-alluvial-fans-high-hazard-fan-investigation.pdf	Description of catchment and alluvial fan characteristics and hazard assessment	Moderate		Mapping of 'alluvial fan hazard areas' and alluvial fan features

Discussion

- **Collaborative approach and agreed process**
  - Natural hazards categories
  - Type of information (reports, maps, photos…)
  - Timing and updates
  - Status of information (draft vs. final)
  - Use of the ORC Natural Hazards Database
  - “One stop-shop”: naturalhazards.enquiries@orc.govt.nz
  - Preferred approach to “crystalize” the process: MoU?

- **Any gaps?**
  - Data and information
  - Process
  - Contacts

Next steps

- ORC to draft and circulate MoU for TAs feedback
  Agreed and signed MoU by mid-September 2025
- ORC to provide summary of ORC produced or commissioned natural hazard information in the last 20 years
  By end of July 2025
- ORC to organise a follow-up meeting with TAs to confirm progress
  By mid-August 2025
- TAs to provide general email address to share information
  By end of July 2025
- TAs to provide 1- 2 examples of LIMs showing how natural hazards information is presented
  By end of July 2025

KARAKIA WHAKAMUTUNGA

WHEN TO USE IT » To end the day • To close a meeting

Kua mutu a mātou mahi	Our work is finished
Mō tēnei wā	For the moment
Manaakitia mai mātou katoa	Bless us all
O mātou hoa	Our colleagues
O mātou whānau	Our families
Āio ki te aorangi	Peace to the universe

Alternative karakia whakamutunga

Kia tau te rangimārie	Let peace reign
Ki runga i ngā iwi o te ao	On all peoples of the world

9.4. Otago Active Fault Mapping and Fault Awareness Areas

Prepared for:	Science and Resilience Committee
Report No.	HAZ2506
Activity:	Safety & Hazards: Natural Hazards
Author:	Tim van Woerden, Senior Natural Hazards Analyst Andrew Welsh, Spatial Analyst Jean-Luc Payan, Manager Natural Hazards
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] To update the Committee on review of the active fault mapping for Otago and development of a fault awareness area dataset.

EXECUTIVE SUMMARY

[2] The Resource Management Act 1991 (RMA) requires regional councils to control the use of land for the purpose of the avoidance or mitigation of natural hazards, and includes management of significant risks from natural hazards as a matter of national importance.[1]

[3] Surface fault rupture is a hazard causing damage to land and buildings situated in the vicinity of an active fault scarp. This ground deformation hazard cannot be mitigated by any known means other than through avoidance of the area.

[4] In 2022, the ORC Strategy and Planning Committee endorsed the use of a tiered approach to fault zone management in Otago – with Fault Avoidance Zones (FAZ) and Fault Awareness Areas (FAA). The Committee directed a report to be provided on a recommended option and implementation plan, for incorporating the tiered approach into planning frameworks across Otago.

[5] This paper presents work completed to review the active fault mapping for Otago and develop a Fault Awareness Area GIS (spatial) dataset.

[6] Initial engagement with the Otago territorial authorities (TA's) is in progress, and a paper to present a recommended option and implementation plan will be developed through a collaborative process with TA's, expected to be in early 2026.

[1] RMA, Section 6(h).

RECOMMENDATION

That the Committee:

1) ***Notes** this report.*
2) ***Notes** the report by GNS Science, Review and update of active geological fault and fold characterisation in the Otago Region, dated June 2025.*
3) ***Notes** the Fault Awareness Area (FAA) GIS dataset developed for Otago active faults.*

BACKGROUND

[7] Surface fault rupture is the permanent ripping and warping of the ground surface along a fault as the ground on one side moves sideways and/or up relative to ground on the other side during an earthquake on that fault. Surface fault ruptures can cause significant damage to buildings and infrastructure located within the immediate rupture area, which can be a few tens to a few hundreds of metres wide, and extending along the fault.[2]

[8] A recent review of Otago natural hazard exposure[3] estimated a total of about 20,000 people and 8,000 dwellings located in vicinity (within 250m) of mapped active faults in the region, with the larger exposures in population centres at Mosgiel, Alexandra and Wanaka.[4]

[9] A key step in proactive hazard risk management for fault rupture hazards is to identify locations of potential future fault rupture, and then avoid or manage development in those areas, to reduce the likelihood of buildings or infrastructure being damaged in future earthquakes on those faults. ORC has an ongoing work programme for active fault hazards, which is designed to take a risk-based approach to managing risk from fault rupture hazard in the region.

[10] Following completion of region-wide mapping of Otago's active faults over 2016-2021, a next step in furthering this hazard management approach is to collaborate with the Otago territorial authorities (TAs) on incorporating consideration of fault rupture hazards into their planning frameworks using Fault Awareness Areas (FAA) or Fault Avoidance Zones (FAZ).

[11] This approach was endorsed by the ORC Strategy and Planning Committee in April 2022,[5] which also directed ORC staff to report back on an implementation plan for incorporating a tiered approach for fault zone management into land-use planning frameworks.

[12] This paper presents the work completed since that date to progress towards development of an implementation approach.

---

[2] Jack H, Payan J, and Mackey B, 2020. Using earthquake fault information in the Waitaki District Plan review. Memorandum from Environment Canterbury and Otago Regional Council to the Waitaki District Council.
[3] van Woerden T and Welsh, 2025. Otago Region Natural Hazards Exposure Analysis.
[4] The natural hazards exposure report identified the largest exposure for an urban area to be for Dunedin City, associated with the Kaikorai Fault. However, this fault is no longer considered to be active, based on the review of geologic information by Barrell (2025).
[5] Payan J, Dawe A, and Hornblow S, 2022. Otago Active Faults: Planning Options. Report HAZ2201 to the Otago Regional Council Strategy and Planning Committee, 13 April 2022.

OTAGO ACTIVE FAULT MAPPING

[13] 'Active faults' are defined as faults that have moved within the last 125,000 years and could move again in future, causing an earthquake and possible surface fault rupture. Over 2016-2021, GNS Science[6] [7] [8] completed mapping of active faults and folds across the Otago region for ORC at a 1:250,000 scale.

[14] The active fault mapping is derived from regional-scale (~1:250,000) geological information. At this scale, the mapped fault traces are generalised with some details omitted to aid the clarity of presentation, for example smoothing of mapped lines, and complex fault zones may be simplified into single lines.[9] At the 1:250,000 mapping scale, faults are located no more accurately than ±100 m, at best, and ±250 m as a general rule.

[15] The spatial data for the mapped active faults dataset include the following attributes:

a. Surface form which quantifies how easily one could map a particular active fault or fold feature at site-specific scales (whether well expressed, moderately expressed, not expressed or unknown).

b. Certainty which signifies whether a mapped active fault/fold feature is known or suspected (whether definite, likely, possible, or potentially active).

c. Recurrence Interval. Because most active faults/folds lack paleoseismological data, GNS Science followed a method (pioneered in work mapping Canterbury region active faults for Environment Canterbury) for estimating the average recurrence interval for surface-rupture deformation events based on many assumptions but which is balanced by assigning large uncertainty terms. The recurrence interval affords linkage to risk-based planning guidelines for development on or close to active faults.[10]

ACTIVE FAULT MAPPING REVIEW

[16] In preparation for development of a proposed Fault Awareness Area dataset, GNS Science (now part of Earth Sciences New Zealand as of 1 July 2025) have reviewed and updated the Otago active fault mapping to take into account new information available since completion of the previous active fault/fold characterisation projects (2016-2021). This review is documented in the technical report included as Attachment 1.[11]

---

[6] Barrell DJA, 2016. General distribution and characteristics of active faults and folds in the Waimate District and Waitaki District, South Canterbury and North Otago. GNS Science Consultancy Report 2015/166, prepared for the Otago Regional Council and Canterbury Regional Council.

[7] Barrell DJA, 2019. General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago. GNS Science Consultancy Report 2018/207, prepared for the Otago Regional Council.

[8] Barrell DJA, 2021. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. GNS Science Consultancy report 2020/88, prepared for the Otago Regional Council.

[9] Morgenstern R, Litchfield NJ, Langridge RM, Heron DW, Townsend DB, Villamor P, Barrell DJA, Ries WF, Van Dissen RJ, Clark KJ, Coffey GL, Zoeller A, Howell A, and Easterbrook-Clarke LH, 2024. New Zealand Active Faults Database: the high-resolution dataset v2.0., New Zealand Journal of Geology and Geophysics. In press (https://www.tandfonline.com/doi/full/10.1080/00288306.2024.2427396).

[10] Kerr J, Nathan S, Van Dissen RJ, Webb P, Brunsdon D, King AB. 2003. Planning for development of land on or close to active faults: a guideline to assist resource management planners in New Zealand. GNS Science Consultancy Report 2002/124. Lower Hutt: GNS Science.

[11] Barrell DJA, 2025. Review and update of active geological fault and fold characterisation in the Otago region. GNS Science Consultancy Report 2025/48, prepared for Otago Regional Council.

[17] Changes and updates following this 2025 review include:

a. Refinement of fault location or length for a number of faults where higher-quality topographic information is now available (e.g. LiDAR or photogrammetric Digital Surface Model).
b. Removal of the Kaikorai Fault from the active fault's dataset, as geologic evidence no longer supports interpretation as an active fault.
c. Updating of fault information such as certainty or recurrence interval where new research has since been carried out.

FAULT AWARENESS AREAS

[18] A Fault Awareness Area (FAA) is a land-use planning tool, designed to highlight that an active fault is known (or suspected) to be present, but the existing regional-scale mapping is not accurate enough to be sure of its exact location.

[19] The intent of a Fault Awareness Area is that it is sufficiently large to encompass the full range of plausible locations of the active fault, to account for the inaccuracies involved in mapping at 1:250,000 scale, and to accommodate the possibility that future fault ruptures and associated ground deformation may not coincide exactly with mapped areas of previous fault rupture deformation.[12]

[20] The mapped FAAs show councils, developers, landowners or prospective buyers the general location of active or faults and it highlights locations where more detailed investigations could or should be undertaken for certain developments. In these areas, more detailed mapping and assessment could, if needed, be undertaken to define Fault Avoidance Zones (FAZ, refer to paragraph 33 for the definition of a FAZ).[13]

[21] In Otago, FAA have been previously developed for the Waitaki District in collaboration with Environment Canterbury (ECan)[14] [15], and policies relating to these Waitaki FAA are included in the proposed Waitaki District Plan.[16]

[22] In addition to those already existing for the Waitaki district, proposed FAAs have now been developed for active faults in the Dunedin City, Queenstown Lakes, Central Otago and Clutha districts.

DEVELOPING THE FAULT AWARENESS AREAS

[23] Fault awareness area buffers have been developed according to the approach which was developed for the Canterbury region.[17] Proposed FAA buffers were created in a GIS by ORC, and have then been reviewed by GNS Science.

---

[12] Barrell DJA, Jack H, Gadsby M. 2015. Guidelines for using regional-scale earthquake fault information in Canterbury. Lower Hutt: GNS Science. GNS Science Consultancy Report 2014/211; Environment Canterbury Report R14/76. Christchurch: Canterbury Regional Council.

[13] Kerr *et al.*, 2003. Planning for development of land on or close to active faults: a guideline to assist resource management planners in New Zealand; Morgenstern *et al.*, 2024. New Zealand Active Faults Database: the high-resolution dataset v2.0.

[14] Developed collaboratively because the Waitaki district lies partially within both Otago and Canterbury.

[15] Jack *et al.*, 2020. Using earthquake fault information in the Waitaki District Plan review.

[16] https://waitaki.isoplan.co.nz/review/rules/0/26/0/3618/0/70

[17] Barrell *et al.*, 2015. Guidelines for using regional-scale earthquake fault information in Canterbury.

[24] FAA buffers are defined at either 250 or 500m metres in total width. The buffer width is determined based on the fault's surface form and certainty, based on the criteria in paragraphs 25 and 26.

[25] A 250 metre width FAA (125 m buffer either side of the fault or monocline fold) if the structure is categorised as;
a. Certainty 'definite', with surface form 'well or moderately expressed', or
b. Certainty 'likely', with surface form 'well or moderately expressed'.

[26] A 500 metre width FAA (250 m buffer either side of the fault or monocline fold) for all other faults and monocline folds (if Certainty is 'possible' or 'potentially active', or if surface form is 'not expressed').

[27] The narrower FAA buffer for well-expressed and moderately expressed faults and monocline folds reflects the fact that these features can likely be mapped in site-specific assessments more precisely than the not expressed and possible faults and monocline folds.

[28] The FAA developed for the Otago region are shown in Figure 1. FAA are categorised based on the fault certainty, resulting in four legend categories:
a. Definite fault awareness area
b. Likely fault awareness area
c. Possible fault awareness area
d. Potential fault awareness area

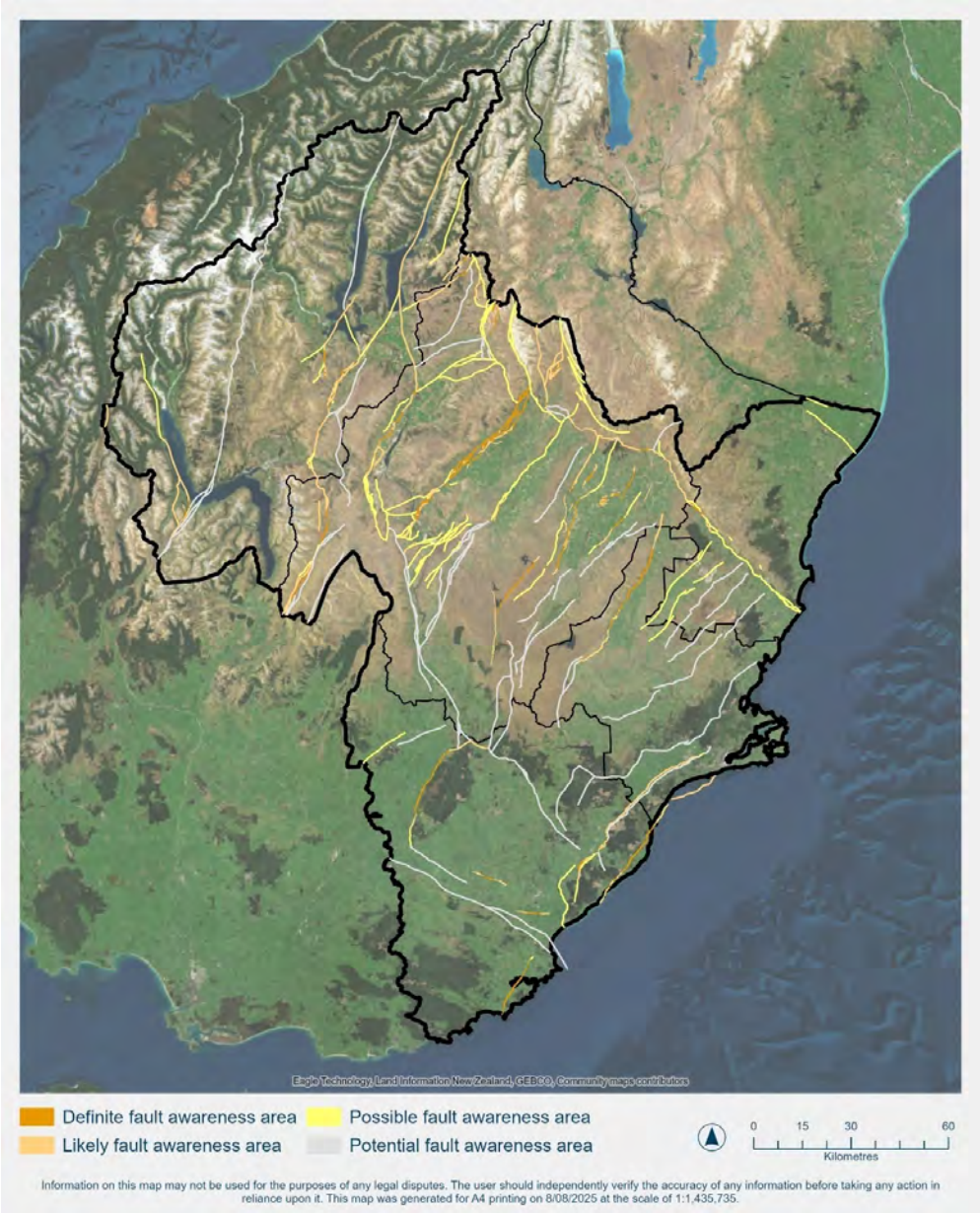


Figure 1: Fault awareness areas (FAA) for the Otago region, developed following the approach of Barrell *et al.* (2015) using the revised active fault mapping dataset of Barrell (2025). Territorial Authorities boundaries are are indicated in black lines.

DATA SHARING

[29] The revised (2025) active fault spatial dataset, the accompanying technical report, and the fault awareness area (FAA) polygons will be made publicly available in the ORC Natural Hazards Portal.[18]

[18] ORC Natural Hazards Portal

[30] Copies of the GIS datasets and report will also be provided directly to the Otago territorial authorities and any other relevant stakeholders.

ENGAGEMENT WITH TERRITORIAL AUTHORITIES

[31] A meeting was held with the Otago territorial authorities in early July 2025 to discuss potential approaches to implementation of FAA in land-use planning. It is expected that a series of further follow-up discussions will be required to understand/address TA questions and concerns, and to collaboratively work towards definition of an agreed approach.

[32] The timing and scope of any implementation by TA's is uncertain, as it is expected any review of District Plans will be delayed until the direction of resource management and local government reforms become clearer.

FAULT AVOIDANCE ZONE DEVELOPMENT

[33] A fault avoidance zone (FAZ) is an area created by establishing a buffer zone either side of a known fault trace or the identified likely fault rupture zone, recommended[19] to be a minimum of 20 metres either side of the fault rupture zone, as a precautionary approach to ensure a level of life safety.

[34] ORC should work to identify areas where an active fault ground deformation hazard indicates site-specific investigation and development of fault avoidance zoning would be beneficial.

[35] It is recommended to define criteria to systematically identify locations where development of FAZ is to be considered. For example, these could include:

a. Faults of shorter recurrence interval (e.g. recurrence interval of <10,000 years); and
b. Of greater confidence (Certainty 'definite' or 'likely'); and
c. Which intersect or lie close nearby to populated areas.

[36] Development of a fault avoidance zone would require completion of detailed investigations and fault mapping at a scale of 1:10,000 or better, and further engagement with territorial authorities to discuss potential inclusion within their planning frameworks.

[37] Candidate locations for possible FAZ development in Otago could include but are not limited to:

a. Akatore Fault (Recurrence Interval of ~1700 years) at Taieri Mouth settlement, and to the southwest along the fault where there has been increasing development of lifestyle properties in recent years.
b. Settlement Fault (recurrence interval of 5900 years) near Owaka, where the fault trace lies within ~350m of the township margins, but there are a number of residential properties within 100m of the fault. There may be a desire to expand residential developments or lifestyle properties westwards towards the fault location, so it would be prudent to account for the fault rupture hazard.

[19] Recommended by the national guideline for development of land on or close to active faults (Kerr *et al*. 2003).

c. NW Cardrona Fault (recurrence interval of 13,000 years) near Cardrona settlement and within the Wanaka urban area.

DISCUSSION

[38] The review and update of active geological fault and fold information for the region ensures this dataset reflects the current knowledge of active fault location and activity.

[39] The development of a Fault Awareness Area (FAA) GIS dataset is a first step towards consideration of fault zone hazards in land-use planning.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[40] The information presented and discussed in this report aligns with Council's Strategic Directions, where the 'Resilience' focus area has the aspiration that "*Otago builds resilience in a way that contributes to community and environmental wellbeing through planned and well-managed responses to shocks and stresses, including natural hazards*".

[41] The information contributes to achieving the following goal of the Strategic Directions: "*Plans are in place to ensure that the region's most vulnerable communities (geographic and demographic) and ecosystems are resilient in the face of natural hazards*".

Financial Considerations

[42] The further work described in this paper is provided for in the ORC 2024/34 Long Term Plan.

Significance and Engagement

[43] Refer paragraphs 31 and 32.

Legislative and Risk Considerations

[44] The work described in this paper helps ORC fulfil its responsibilities under sections 30 and 35 of the RMA.

[45] Providing the information presented in this paper helps the community and interested stakeholders and organisations understand and manage the seismic risks associated with fault rupture hazards.

Climate Change Considerations

[46] Not applicable.

Communications Considerations

[47] Refer paragraphs 28 and 29.

NEXT STEPS

[48] Engagement with TAs will continue, as we collaboratively work towards definition of an agreed approach for implementation of FAA in land-use planning.

[49] In early 2026 we intend to report back to the ORC Strategy and Planning Committee or to an equivalent Committee on a recommended approach and implementation plan for use of FAA in land-use planning.

ATTACHMENTS

1. Review and update of active geological fault and fold characterisation in the Otago region [**9.4.1** - 62 pages]

earthsciences.nz

Review and update of active geological fault and fold characterisation in the Otago region

DJA Barrell

GNS Science Consultancy Report 2025/48
August 2025

Earth Sciences
New Zealand

DISCLAIMER

This report has been prepared by the New Zealand Institute for Earth Science Limited (Earth Sciences New Zealand) exclusively for Otago Regional Council and for the specific purpose stated ('Purpose'). It is based on available information and professional judgment at the time of preparation, and is subject to any limitations or assumptions set out in the report. Unless otherwise agreed in writing by Earth Sciences New Zealand, Earth Sciences New Zealand provides no warranty as to the use of the report other than by Otago Regional Council for the Purpose and Earth Sciences New Zealand will not be liable for any loss, damage or expense (whether direct, indirect or consequential) arising from use of or reliance on this report or its contents by any person other than to Otago Regional Council for the Purpose.

Use of Data:

Date that Earth Sciences New Zealand can use associated data: August 2025

BIBLIOGRAPHIC REFERENCE

Barrell DJA. 2025. Review and update of active geological fault and fold characterisation in the Otago region. Lower Hutt (NZ): Earth Sciences New Zealand. 55 p. GNS Science Consultancy Report 2025/48. Prepared for Otago Regional Council.

Project Number COMN0384

CONTENTS

PURPOSE ..... **iv**

Executive Summary ..... **iv**

1.0 Introduction **1**

1.1 Background 1
1.2 Project and Report Outline 1
1.3 Methodology 2

2.0 Results **4**

3.0 Acknowledgements **16**

4.0 References **16**

TABLES

Table 2.1 Amendments to the mapping and/or activity classification of Otago region active faults and folds. 7

FIGURES

Figure 2.1 General distribution of active faults and folds (2025 update) in the Otago region (north). 9
Figure 2.2 General distribution of active faults and folds (2025 update) in the Otago region (centre north). 10
Figure 2.3 General distribution of active faults and folds (2025 update) in the Otago region (centre south). 11
Figure 2.4 General distribution of active faults and folds (2025 update) in the Otago region (southwest). 12
Figure 2.5 General distribution of active faults and folds (2025 update) in the Otago region (southeast). 13
Figure 2.6 General distribution of active faults and folds (2025 update) in the Otago region (northeast). 15

APPENDICES

APPENDIX 1 Commentary on Active Fault and Fold Characterisation Revisions **21**

A1.1 Introduction 21
A1.2 Central Otago and Queenstown Lakes Districts 21
A1.2.1 Cluden Fault Zone 21
A1.2.2 Dunstan Fault Zone 21
A1.2.3 Galloway Fault Zone (Conroys Fault) 22
A1.2.4 Gimmerburn Fault Zone 22
A1.2.5 Hunter Valley Fault 23
A1.2.6 Lake Onslow fault 23
A1.2.7 Launceston Fault 24
A1.2.8 Lindis Pass Fault Zone 24
A1.2.9 Livingstone Fault 24
A1.2.10 Long Valley Fault 25
A1.2.11 Moonlight Fault Zone 25

A1.2.12 Nevis Fault Zone 26
A1.2.13 NW Cardrona Fault 29
A1.2.14 Pisa Fault Zone 31
A1.2.15 Raggedy – Blackstone Fault 38
A1.2.16 Ranfurly Fault Zone 39
A1.2.17 Rocks Creek Fault Zone 39
A1.2.18 Stranraer Fault (Waihemo Fault Zone and Home Hills Fault Zone) 39
A1.2.19 Timaru Creek Fault 40
A1.2.20 Waihemo Fault Zone 41
A1.2.21 Waipiata Fault Zone 41
A1.2.22 West Wakatipu Fault 42
A1.3 Clutha, Dunedin City and Waitaki (in the Otago region) Districts 42
A1.3.1 Blue Mountain Fault 42
A1.3.2 Hyde Fault 43
A1.3.3 Kaikorai Fault 43
A1.3.4 Settlement Fault 44
A1.4 Appendix References 44
APPENDIX 2 Descriptive Metadata from the GIS Datasets 47
A2.1 Feature Class: Clutha_Dunedin_active_faults_April2025 47
A2.1.1 Summary 47
A2.1.2 Description 47
A2.1.3 Credits 48
A2.1.4 Use Limitations 48
A2.2 Feature Class: Clutha_Dunedin_active_folds_April2025 48
A2.2.1 Summary 48
A2.2.2 Description 48
A2.2.3 Credits 49
A2.2.4 Use Limitations 49
A2.3 Feature Class: CO_QL_active_faults_April2025 49
A2.3.1 Summary 49
A2.3.2 Description 49
A2.3.3 Credits 51
A2.3.4 Use Limitations 51
A2.4 Feature Class: CO_QL_active_folds_April2025 51
A2.4.1 Summary 51
A2.4.2 Description 51
A2.4.3 Credits 53
A2.4.4 Use Limitations 53
A2.5 Feature Class: Waitaki_Otago_faults_April2025 53
A2.5.1 Summary 53
A2.5.2 Description 53
A2.5.3 Credits 55
A2.5.4 Use Limitations 55

APPENDIX FIGURES

Figure A1.1 The photogrammetry DSM, and a sketch geomorphological map prepared during this review, at Drummond and Kingston creeks in the upper Nevis valley, with elevation profiles. 28
Figure A1.2 The photogrammetry DSM in the vicinity of Five Mile Creek, with interpreted geomorphological features annotated. 33
Figure A1.3 Map showing the photogrammetry DSM at Lochar Burn, with interpreted geomorphological features annotated. 35

PURPOSE

This report provides reviewed and updated information on the locations and assessed rates of activity of active geological faults and folds in the Otago region and is an addendum to previous reports issued between 2016 and 2021. The updated region-wide, GIS-format, data described in this report have been supplied separately to Otago Regional Council. This report and ancillary data are intended to assist Otago Regional Council in identifying and managing active fault and fold hazards, and in providing public information.

EXECUTIVE SUMMARY

This report documents a review and update of active geological fault and fold information for the entire Otago region. This report is an addendum to previous data compilation reports for Otago Regional Council issued in 2016 (Waitaki District), 2019 (Central Otago and Queenstown Lakes districts) and 2021 (Clutha and Dunedin districts). Recent research projects led by the University of Otago, and increasing coverage of Otago with high-precision digital topographic elevation datasets, have provided improved knowledge of the location and activity, and thereby earthquake-related risks, of several major active faults in Otago.

The previous reports give background information along with technical definitions and explanations, as well as description of the evidential basis for the mapping, interpretation and activity classification of each active fault or fold. This addendum report does not repeat the previous information, and focuses on giving updated descriptive explanations for the active faults and folds that have undergone amendments to their mapping, interpretation and/or activity characterisation as a result of this review.

The most notable knowledge improvements are for the Nevis Fault Zone and NW Cardrona Fault in northwest Otago, the Pisa Fault Zone near Cromwell, the Long Valley Fault near Poolburn Dam, the Raggedy – Blackstone Fault in the Ida Valley, the Lake Onslow Fault in the Teviot River catchment, the Stranraer Fault near Naseby, and the Settlement Fault near Owaka. New geological analyses have resulted in removal of one fault from the dataset, the Kaikorai Fault in Dunedin.

It is anticipated that Fault Awareness Areas, which indicate places where active faults or folds are a potential hazard to consider, will be produced using the updated mapping information documented in this report.

1.0 Introduction

1.1 Background

Between 2015 and 2021, GNS Science was engaged by Otago Regional Council (ORC) to compile maps of the extents of active faults and folds and assess their activity characteristics for the Otago region. The work expanded the inter-regional coverage of active fault and fold characterisation projects undertaken by GNS Science for Canterbury Regional Council (Environment Canterbury – ECan) between 2008 and 2016. The Otago work was documented in three reports, with associated Geographic Information System (GIS) datasets. The Waitaki District work was done under a joint contract with ORC and ECan (Barrell 2016), while the remainder of Otago was addressed in two successive projects, one encompassing the Central Otago and Queenstown Lakes districts (Barrell 2019), and the other for the Clutha and Dunedin City districts (Barrell 2021).

Since the previous active fault/fold characterisation projects were completed, improved topographic information resources have become available in many parts of Otago that allows for more precise mapping and characterisation of the faults and folds. The most notable information improvement comes from expanded coverage by aerial light detection and ranging (lidar) surveys and the associated generation of Digital Elevation Models (lidar DEMs), improved-resolution aerial (including satellite) imagery, and generation of extensive Digital Surface Models from aerial imagery (photogrammetry DSMs). Other new information on fault characteristics and activity has emerged from University of Otago research projects, and other reported observations.

The active fault and fold mapping is regarded as having regional-scale accuracy, highlighting the general locations and character of the faults and folds, but lacking sufficient precision for use in delineating and managing hazards at property-parcel scales. Regional-scale mapping is suitable for defining Fault Awareness Areas (FAAs). FAAs indicate places where active faults or folds are a potential hazard to consider. They are generated in the GIS by setting a perimeter of generous set width, typically either 125 m or 250 m, on each side of the mapped line representing the active fault or fold location. The FAA approach was originally developed by Barrell et al. (2015) for analogous active fault/fold datasets produced for the Canterbury region and has recently been adopted and formalised by Morgenstern et al. (2025) as part of standard approaches for New Zealand active fault hazard management and risk mitigation. Based on the previous 2016–2021 mapping, FAAs were generated by ORC, but these have not yet been formally issued. Ahead of reviewing and finalising FAAs for Otago, ORC engaged GNS Science (now part of the New Zealand Institute for Earth Science Limited – Earth Sciences New Zealand) to review, and as need be, update the existing active fault and fold mapping for the Otago region. It is anticipated the FAAs will be reviewed and updated using information documented in this report.

1.2 Project and Report Outline

The objective of the project is to provide reviewed and updated active fault and fold GIS datasets and associated activity characterisation information for the Otago region. The purpose and detail of the work is the same as for the precursor datasets described in the reports referenced in Section 1.1, as follows. The datasets highlight locations potentially subject to ground-surface fault-rupture hazard, and help define where further information may be desirable, for example for site-specific fault avoidance zonation if substantial building or infrastructural development is proposed. The datasets are not intended to be used directly for hazard zoning, but rather serve as a tool to assist councils in land-use planning, risk reduction activities, and hazard zoning prioritisation with respect to active faults.

The report documents the review and update of active fault and fold mapping in Otago. It is an Addendum to the three previous reports (Barrell 2016, 2019, 2021), and does not repeat background information or technical definitions and explanations in relation to active faulting and folding. It provides appended descriptions of amendments to the previous datasets.

1.3 Methodology

This review and update was primarily an office-based assessment, using available information, particularly including aerial imagery, DEMs and DSMs generated since the original assessments spanning 2016 to 2021, and open-access recent university research results targeting specific active faults. Limited reconnaissance field checking of mapped fault features was carried out in the Maniatoto Basin[1] of Central Otago, where there is no lidar coverage, although a photogrammetry DSM including the whole basin was available for examination.

The data sources and methodologies used in the previous reports are briefly summarised here, to provide context for the methodology used in the current project. The original source of the fault and fold information was the digital Geological Map of New Zealand 1:250,000-scale (QMAP; Rattenbury and Isaac 2012). Updated editions of QMAP have been made every few years. The work in the Waitaki, Central Otago and Queenstown Lakes districts used the first edition QMAP dataset (Heron 2014), whereas the work in the Clutha and Dunedin City districts used the second edition dataset (Heron 2018). The QMAP-sourced fault and fold linework was modified as needed for the 2008–2021 Canterbury and Otago active fault characterisation projects. In 2017, a slight shift in approach was made to the active fault mapping and characterisation. By 2017, there was increasing awareness that existing criteria for defining a fault as active[2] were not fully capturing the hazards posed by ground-rupturing faults. For example, analyses of New Zealand's major historical earthquakes found that only about half occurred on faults that would be classifiable as active (Nicol et al. 2016). This has led to consideration of Otago region faults that have accumulated substantial displacements (≥50 m) under the current tectonic regime, but have not moved sufficiently recently to be classed as active and instead referred to as potentially active (Villamor et al. 2018). Subsequently, potentially active faults were included in the ORC active fault and fold dataset for the Central Otago and Queenstown Lakes districts (Barrell 2019) and this approach was continued in the Clutha and Dunedin City districts (Barrell 2021). The latter dataset included several potentially active faults in the Waitaki District, because that category of fault was not within scope of the earlier mapping. The active faults and folds of the Otago region, as represented in the ORC dataset, have been included in generalised form in the New Zealand Community Fault Model (NZ CFM) dataset (Seebeck et al. 2022, 2024).

As for the previous projects, I did the mapping directly on-screen in the GIS, aided by various digital basemap information, including the Topo 50 topographic map, lidar DEMs, and photogrammetry DSMs[3]. Lidar provides the highest resolution topographic information, but its coverage across Otago remains incomplete. There is much more extensive coverage from photogrammetry DSMs. The DSMs provide good-quality elevation information, but they include all ground surface features, such as trees, buildings and fences. In that regard they differ from lidar DEMs, where those features have been processed out of the models. The lidar DEMs therefore provide a more detailed picture of the solid ground surface. The photogrammetry DSMs provide useful topographic information, but only offer a

[1] The area of Otago known as the Maniototo had its spelling corrected to Maniatoto, by Central Otago District Council in 2022.

[2] In New Zealand, a geological fault (or fold) is defined as active if it has experienced a ground-surface-deforming rupture within the past 125,000 years.

[3] The lidar DEMS (generated from lidar data), and photogrammetry DSMs (generated from processing of aerial imagery) used in this project all have 1-m cell size resolution. From both types of models, hillshade relief models (hillshades) are available, also at 1-m resolution. The mapping work used the hillshades for reconnaissance to detect active fault or fold landforms, and for diagram backgrounds. The DEMs/DSMs were used for topographic profiling and the generation of detailed topographic contours to aid interpretations of the character and size of active fault or fold landforms.

good approximation of the ground surface where vegetation is short (or absent). The Appendix 1 descriptions include information on whether the mapping review and revisions have used lidar DEMs or photogrammetry DSMs, or other information.

In localised areas, GIS processing was used to clip out areas of the elevation models (DEM or DSM), from which topographic contours (typically 5-m interval) were generated, to assist identification and mapping of active faults and folds – notably in the upper Nevis valley, the western margin of the Cromwell Basin, and in the Maniatoto Basin[4].

The technical approach and content mirrors that of the preceding reports, where the GIS datasets differentiate features according to:

1. Whether they are faults or folds.
2. The level of certainty with which they are recognized as active features (definite, likely, possible), or potentially active.
3. A classification of how well expressed they are on the ground surface (well-expressed, moderately expressed, not expressed, unknown).

Definitions of terms are given in Table 5.1 in each of the precursory reports (Barrell 2016, 2019, 2021). Descriptive information (metadata) attached to the digital GIS datasets is reproduced in Appendix 2.

[4] DEM/DSM clipping, and contour generation, place demands on computer memory and data storage space, and is most efficient when done for small areas.

2.0 Results

This report provides updated information on active fault and fold characteristics for the Otago region. Only those faults/folds that have undergone amendment are included in this report. Amended information for each fault/fold is compiled in summary form in Table 2.1, in similar format to the tables of the Barrell (2016, 2019, 2021) reports. Most of mapped fault/fold features did not need amendment, as there was no new information to hand. The update comprises the full region-wide GIS datasets, including any amendments, dated 2025. The 2025 dataset, addressed in the present report, is illustrated in a mosaic of overlapping maps in Figures 2.1 to 2.6. The convention from preceding reports of using lower case 'fault' or 'fault zone' for informal unpublished names is continued in this report.

Appendix 1 provides description of amendments that have been made to each fault/fold feature, including description of additions or removals of mapped features in the dataset. The active fault/fault entities that have been amended as a result of the 2025 review are included in Appendix 1 and listed below alphabetically. The feature number (Figures 2.1 to 2.6 and Table 2.1) relates to the numbers used in the precursory reports.

- Blue Mountain Fault (feature 3 of Barrell [2021]; Figure 2.4) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.
- Cluden fault zone (feature 19 of Barrell [2019]; Figure 2.2).
- Dunstan Fault Zone (feature 22 of Barrell [2019]; Figure 2.2).
- Galloway fault zone (Conroys Fault) (feature 29 of Barrell [2019]; Figure 2.3) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.
- Gimmerburn Fault Zone (feature 33 of Barrell [2019]; Figure 2.3).
- Home Hills fault zone (feature 26 of Barrell [2019]; Figure 2.3).
- Hunter Valley Fault (feature 14 of Barrell [2019]; Figure 2.1) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.
- Hyde Fault (respectively features 39 and 20 of Barrell [2019 and 2021]; Figure 2.3, Figure 2.5).
- Kaikorai fault (feature 18 of Barrell [2021]; Figure 2.5).
- Lake Onslow fault (feature 42 of Barrell [2019]; Figure 2.3).
- Launceston Fault (feature 35a of Barrell [2019]; Figure 2.3).
- Lindis Pass Fault Zone (feature 21 of Barrell [2019]) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.
- Livingstone Fault (feature 1 of Barrell [2019]; Figure 2.1).
- Long Valley Fault (feature 43 of Barrell [2019]; Figure 2.3).
- Moonlight Fault Zone – South section (feature 3 of Barrell [2019]; Figure 2.1) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.
- Nevis Fault Zone (feature 7 of Barrell [2019]; Figure 2.2).
- NW Cardrona Fault (feature 6 of Barrell [2019]; Figure 2.2).
- Pisa Fault Zone (feature 20 of Barrell [2019]; Figure 2.2).
- Raggedy – Blackstone Fault (feature 31 of Barrell [2019]; Figure 2.3).
- Ranfurly Fault Zone (feature 35 of Barrell [2019]; Figure 2.3).
- Rocks Creek Fault Zone (feature 24 of Barrell [2019]) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.
- Settlement Fault (feature 11 of Barrell [2021]; Figure 2.4).
- Stranraer Fault (feature 37a of Barrell [2019]; Figure 2.3).

- Timaru Creek Fault (feature 16 of Barrell [2019]; Figure 2.1) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.
- Waihemo Fault Zone (respectively features 26 and 37 of Barrell [2016 and 2019]; Figure 2.6).
- Waipiata Fault Zone (feature 38 of Barrell [2019]; Figure 2.3).
- West Wakatipu Fault (feature 2 of Barrell [2019]; Figure 2.1) – mapping position shifts only, no changes to classification or activity characteristics so not included in Table 2.1.

The following is a summary of some of the more notable information changes for specific faults.

The Hyde Fault (feature 20, Figure 2.5) now has much more known about its past activity thanks to University of Otago research. This information was incorporated in preliminary form in the Barrell (2021) report, but is now confirmed in published results (Appendix 1, Section A1.3.1). Varying previous estimates of slip rate, ranging from 0.25 mm/year (Stirling et al. 2012) to 0.71 mm/year (Litchfield et al. 2013, 2014), reflect the spareness of good data to quantify fault activity. A much stronger dataset based on geological investigation, trenching and dating[5] using OSL and CRN (Griffin et al. 2022a, 2022b) now indicates a slip rate of 0.24 mm/year and average recurrence interval of ~12,000 years.

University of Otago work has provided a chronology of past surface-rupture events on the Long Valley Fault, near Poolburn Dam (feature 43, Figure 2.3). Earlier slip rate estimates of 0.5 mm/year based on assumed ages for offset landforms indicated a recurrence interval of ~2800 years (Stirling et al. 2012; Litchfield et al. 2013, 2014). Barrell (2019) re-assessed the assumed landform ages and proposed a revised slip rate of 0.18 mm/year and recurrence interval of ~7900 years. New information from trenching and geological dating using OSL (Meyer 2021; Meyer et al. 2025) shows fault activity much less than previously thought, with slip rate in the range of 0.05 to 0.08 mm/year, and average recurrence interval of ~24,000 years (Appendix 1, Section A1.2.9).

The two most active faults of northwestern Otago, the Nevis Fault Zone and NW Cardrona Fault (respectively, features 7 and 6 in Figure 2.2) have also been targeted by University of Otago research projects, resulting in improved understandings of their levels of activity and earthquake recurrence. Trenching and geological dating using OSL for the Nevis Fault Zone (Williams et al. 2024), plus geomorphological interpretation aided by photogrammetry DSM (this report) collectively indicate a slip rate of 0.21 mm/year and average recurrence interval of ~12,000 years (Appendix 1, Sections A1.2.11). At the NW Cardrona Fault (Appendix 1, Section A1.2.12), trenching, geological dating using ^{14}C and OSL, and geomorphological interpretation (van den Berg et al. 2025; this report), indicates a slip rate of 0.31 mm/year, and a recurrence interval of ~13,000 years, notably longer than the ~5500 years previously estimated by Barrell (2019).

Much better quantification of Pisa Fault Zone activity has been achieved by geological dating using OSL and CRN by University of Otago (Vause 2025). This together with recent availability of detailed topographic information from lidar DEM and photogrammetry DSM has enabled more accurate mapping of the locations of its past ground deformation, and refined geomorphological interpretations (feature 20, Figure 2.2; Appendix 1, Section A1.2.13). The revised slip rate estimate of 0.19 mm/year is larger than previously inferred (Barrell 2019), and the updated recurrence interval of ~22,000 years, while a little shorter than previously estimated, still indicates that the Pisa Fault Zone is a low activity fault.

[5] Geological dating refers to various laboratory-based methods that provide numerical age estimates for specific types of geological materials. Radiocarbon (^{14}C) dating targets fossil organic material within sediments (e.g. wood, peat, charcoal). Optically Stimulated Luminescence (OSL) is applicable to non-organic sandy or silty sediments. Cosmogenic radionuclide (CRN) dating measures the length of time that a rock surface has been exposed to the sky, and is commonly applied to boulders protruding from glacial moraines, and river or stream terraces. ^{14}C is applicable back for ~50,000 years, OSL can provide ages back to between ~100,000 and ~200,000 years, while CRN can extend back many hundreds of thousands of years.

Improved DEM/DSM topographic information has enabled recognition of previously unknown evidence for geologically recent ground-surface deformation on the Ida Valley's Raggedy – Blackstone Fault (feature 31, Figure 2.3; Appendix 1, Section A1.2.14), the Maniatoto Basin's Stranraer Fault (feature 37a, Figure 2.3; Appendix 1, Section A1.2.17) and the Lake Onslow fault (feature 42, Figure 2.3; Appendix 1, Section A1.2.5). The new information elevates the Lake Onslow fault's activity classification from potentially active to likely active.

In coastal Otago, University of Otago research on the Settlement Fault has clarified its level of activity (feature 11, Figure 2.4; Appendix 1, Section A1.3.3). Information available to Barrell (2021) had enabled the calculation of only a short-term (<5000 years) slip rate that was relatively large at 0.79 mm/year. Trenching and geological dating using OSL documented by Williams et al. (2025) provide a longer term (~20,000 year) slip rate perspective. The revised estimates (Williams et al. 2025; this report) are slip rate of 0.27 mm/year and recurrence interval of 5900 years, compared to the previously estimated 1800 years (Barrell 2021). In the Dunedin area, re-assessment of geological map information has resulted in removal of the Kaikorai Fault from the dataset, due to lack of evidence for its existence as a potentially active fault. While evidence remains for a small fault (Barrell et al. in review), its short length makes it more likely associated with now-extinct volcanism between ~11 to ~16 million years ago (Scott et al. 2020) than the current active fault deformation in the Otago region (Villamor et al. 2018).

Table 2.1 Amendments to the mapping and/or activity classification of Otago region active faults and folds. Refer to text and appendix for further information. In the 'Name' column, a lower-case last term (e.g. fault) indicates an informal (i.e. not published) name while upper case (e.g. Fault) indicates a previously published name. Refer to the precursory ORC reports for earlier references for each feature. Calculated recurrence interval (RI) values are rounded to the nearest hundred years for values <10,000 years, the nearest thousand years for values <30,000 years, and to the nearest 5000 years for longer RIs.

Name (representative name for feature)	Observed Characteristics – Description of Feature(s)	Previous ORC Report, and any Subsequent References	Deformation Estimates					
			Basis of Estimates	Classification	Assigned Net Slip Rate (mm/year)	Calculated Recurrence Interval (RI) – Years	Comments	Indicated RI Class (following Kerr et al. 2003)
Cluden fault zone (feature 19 of Barrell [2019])	Fault zone in bedrock, with offset of peneplain; possible deformation of old sediments and landforms.	Barrell (2019); this report	Air photo interpretation; regional geologic mapping; geomorphologic interpretation	Possible active fault	0.19	22,000	The updated Pisa Fault Zone slip rate and RI applied to Cluden fault zone.	Class VI (>20,000 years)
Dunstan Fault Zone (feature 22 of Barrell [2019])	Fault zone(s) in bedrock, with deformed geologically young sediments and landforms.	Barrell (2019); Griffin et al. (2022b); this report	Air photo interpretation; field inspection and surveying; trenching and dating; lidar data; regional geologic mapping	Definite, likely and possible active fault and fold strands	0.51	8200	Minor changes to slip rate and RI.	Class IV (>5,000 to ≤10,000 years)
Gimmerburn Fault Zone (feature 33 of Barrell [2019])	Fault zones in bedrock with deformed geologically young sediments and landforms.	Barrell (2019); this report	Air photo interpretation; regional geologic mapping; photogrammetry DSM; geomorphologic interpretation	Definite, likely, possible and potentially active fault strands	0.39	6700	Northern limit of fault zone reduced. RI decreased slightly.	Class IV (>5,000 to ≤10,000 years)
Home Hills fault zone (feature 26 of Barrell [2019])	Fault zones in bedrock.	Barrell (2019); this report	Air photo interpretation; regional geologic mapping; lidar DEM	Potentially active fault	null	null	Eastern part now associated with Stranraer Fault. Remainder retained for possibility of secondary slip.	Class VI (>20,000 years)
Hyde Fault (feature 20 of Barrell [2021])	Fault in bedrock, offset of peneplain and deformed geologically young alluvial fan landforms.	Barrell (2021); Griffin et al. (2022a, 2022b); this report	Air photo interpretation; regional geologic mapping; lidar DEM, trenching and dating	Definite and likely active fault strands	0.24	12,000	Minor update of the slip rate and RI, no changes to fault mapping.	Class V (>10,000 to ≤20,000 years)
Kaikorai fault (feature 18 of Barrell [2021])	Inferred fault zone(s) in bedrock, with indicated offset of cover rock strata.	Barrell (2021); Glassey et al. 2021, in press); Barrell et al. (in review); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Discontinued as an active fault	null	null	Revised length no longer supports classification as a surface-rupturing active fault.	null
Lake Onslow fault (feature 42 of Barrell [2019])	Inferred fault zone(s) in bedrock, with offset of peneplain.	Barrell (2019); this report	Air photo interpretation; geomorphologic interpretation; photogrammetry DSM	Likely active fault	0.05	30,000	Suspected fault scarps identified on southern part of fault, reclassified to 'likely', minor positional improvements.	Class VI (>20,000 years)
Launceston Fault (feature 35a of Barrell [2019])	Inferred fault in bedrock with deformed geologically young landforms.	Barrell (2019); this report	Air photo interpretation; photogrammetry DSM; geomorphologic interpretation	Definite active fault	0.10	14,000	Minor improvements made to mapped fault positions. RI adjusted to match revisions to the Ranfurly Fault Zone.	Class V (>10,000 to ≤20,000 years)
Livingstone Fault (feature 1 of Barrell [2019])	Major fault in bedrock.	Barrell (2019); this report	Regional geologic mapping; air photo interpretation; lidar DEMs	Likely active fault	0.25	18,000	Slip rate of 1 mm/year (Barrell 2019) reduced to 0.5 mm/year by Seebeck et al. (2022, 2024), and to 0.25 mm/year in this report.	Class V (>10,000 to ≤20,000 years)
Long Valley Fault (feature 43 of Barrell [2019])	Fault in bedrock, with offset of peneplain and geologically young landforms.	Barrell (2019); Meyer (2021); Meyer et al. (2025); this report	Air photo interpretation; regional geologic mapping; field inspection; trenching and dating; geomorphologic interpretation; lidar DEM	Definite active fault	0.07	25,000	Recent investigation indicates much lower activity than previously inferred (Meyer 2021; Meyer et al. 2025).	Class VI (>20,000 years)
Nevis Fault Zone (feature 7 of Barrell [2019])	Fault zone(s) in bedrock, with deformed geologically young sediments and landforms.	Barrell (2019); Williams et al. (2024); this report	Air photo interpretation; regional geologic mapping; field inspection and trenching; geomorphologic interpretation; photogrammetry DSM	Definite and likely active fault strands	0.21	12,000	Some amendments to Williams et al. (2024) interpretations.	Class V (>10,000 to ≤20,000 years)

Name (representative name for feature)	Observed Characteristics – Description of Feature(s)	Previous ORC Report, and any Subsequent References	Deformation Estimates					
			Basis of Estimates	Classification	Assigned Net Slip Rate (mm/year)	Calculated Recurrence Interval (RI) – Years	Comments	Indicated RI Class (following Kerr et al. 2003)
NW Cardrona Fault (feature 6 of Barrell [2019])	Fault zone(s) in bedrock, with deformed geologically young sediments and landforms.	Barrell (2019); van den Berg (2025); this report	Air photo interpretation; regional geologic mapping; lidar data; field inspection and surveying; trenching and dating; geomorphologic interpretation; lidar DEM	Definite, likely and possible active fault and fold strands	0.32	13,000	Minor refinements to mapping, re-evaluated slip rate and RI.	Class V (>10,000 to ≤20,000 years)
Pisa Fault Zone (feature 20 of Barrell [2019])	Fault zone(s) with deformed geologically young sediments and landforms.	Barrell (2019); Vause (2025); this report	Air photo interpretation; regional geologic mapping; field investigations and trenching; geomorphologic interpretation; photogrammetry DSM	Definite, likely and possible active fault and monocline strands	0.19	22,000	Amendments to mapped positions of fault and fold strands, and activity classification.	Class VI (>20,000 years)
Raggedy – Blackstone Fault (feature 31 of Barrell [2019])	Fault in bedrock with offset of peneplain and suspected offset of geologically young landforms.	Barrell (2019); this report	Air photo interpretation; regional geologic mapping; lidar DEM; geomorphologic interpretation	Definite, likely and possible active fault and fold strands	0.14	22,000	Name amended from Blackstone to Raggedy – Blackstone Fault. Several definite and likely fault scarps added, some previously inferred strands removed.	Class VI (>20,000 years)
Ranfurly Fault Zone (feature 35 of Barrell [2019])	Deformed geologically young landforms.	Barrell (2019); this report	Air photo interpretation; geomorphologic interpretation; field inspection; photogrammetry DSM	Definite, likely and possible active fault strands	0.10	14,000	Amended mapped positions of fault strands; removal of some strands; fault length and RI reduced.	Class V (>10,000 to ≤20,000 years)
Settlement Fault (feature 11 of Barrell [2021])	Fault zone in bedrock, with indicated offset of peneplain and offset of geologically young landforms.	Barrell (2021); Williams et al. 2025; this report	Air photo interpretation, regional geologic mapping; geological dating, geomorphologic interpretation	Definite active fault	0.27	5900	Slip rate is the average value for the past 20,000 years.	Class IV (>5,000 to ≤10,000 years)
Stranraer Fault (feature 37a of Barrell [2019])	Fault zones in bedrock with offset of geologically young landforms.	Barrell (2019); this report	Air photo interpretation; regional geologic mapping; geomorphologic interpretation; photogrammetry DSM	Definite and likely active fault strands	0.07	30,000	Stranraer Fault separated from Waihemo FZ, and eastern end of Home Hills FZ added.	Class VI (>20,000 years)
Waihemo Fault Zone (feature 37 of Barrell [2019])	Fault zones in bedrock with suspected offset of geologically young landforms.	Barrell (2016, 2019); this report	Air photo interpretation; regional geologic mapping; geomorphologic interpretation; photogrammetry DEM	Likely active fault	0.12	40,000	Separation of Stranraer Fault from Waihemo FZ reduces fault length and therefore RI.	Class VI (>20,000 years)
Waipiata Fault Zone (feature 38 of Barrell [2019])	Fault zone in bedrock with suspected deformation of geologically young landforms.	Barrell (2019); this report	Air photo interpretation; regional geologic mapping; geomorphologic interpretation; photogrammetry DSM	Definite, likely and possible active fault and fold strands	0.10	24,000	Some revisions to mapping and interpretations.	Class VI (>20,000 years)

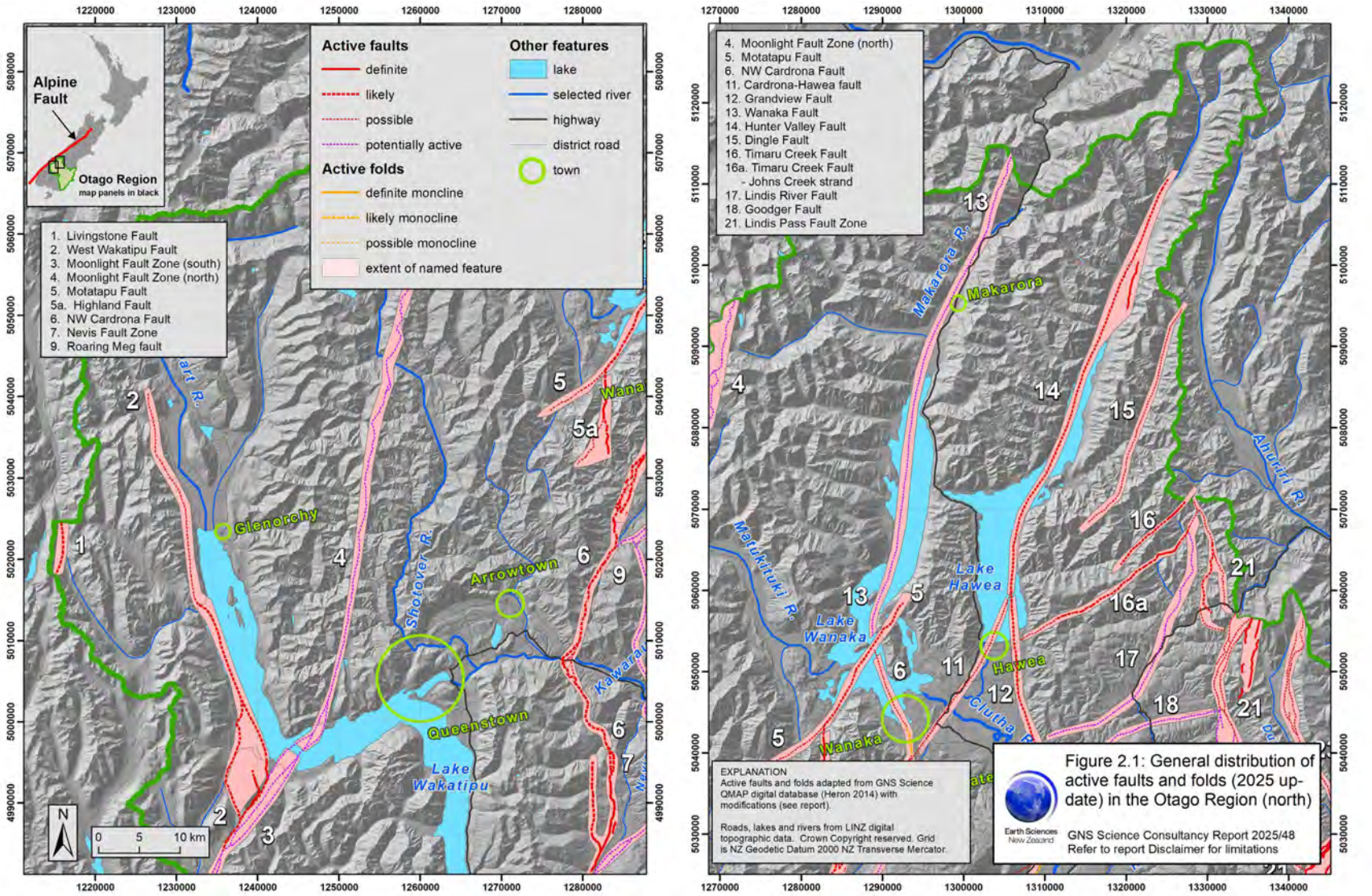


Figure 2.1 General distribution of active faults and folds (2025 update) in the Otago region (north). Overlapping sheet 1 of 6 (locations in inset). Pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault; they are purely illustrative and do not imply anything about the extent of fault-related ground deformation. Thick green line is the Otago region's perimeter. Numbering and labelling is common to the overall map, and the reader should refer to other overlapping sheets of the mosaic for any obscured text.

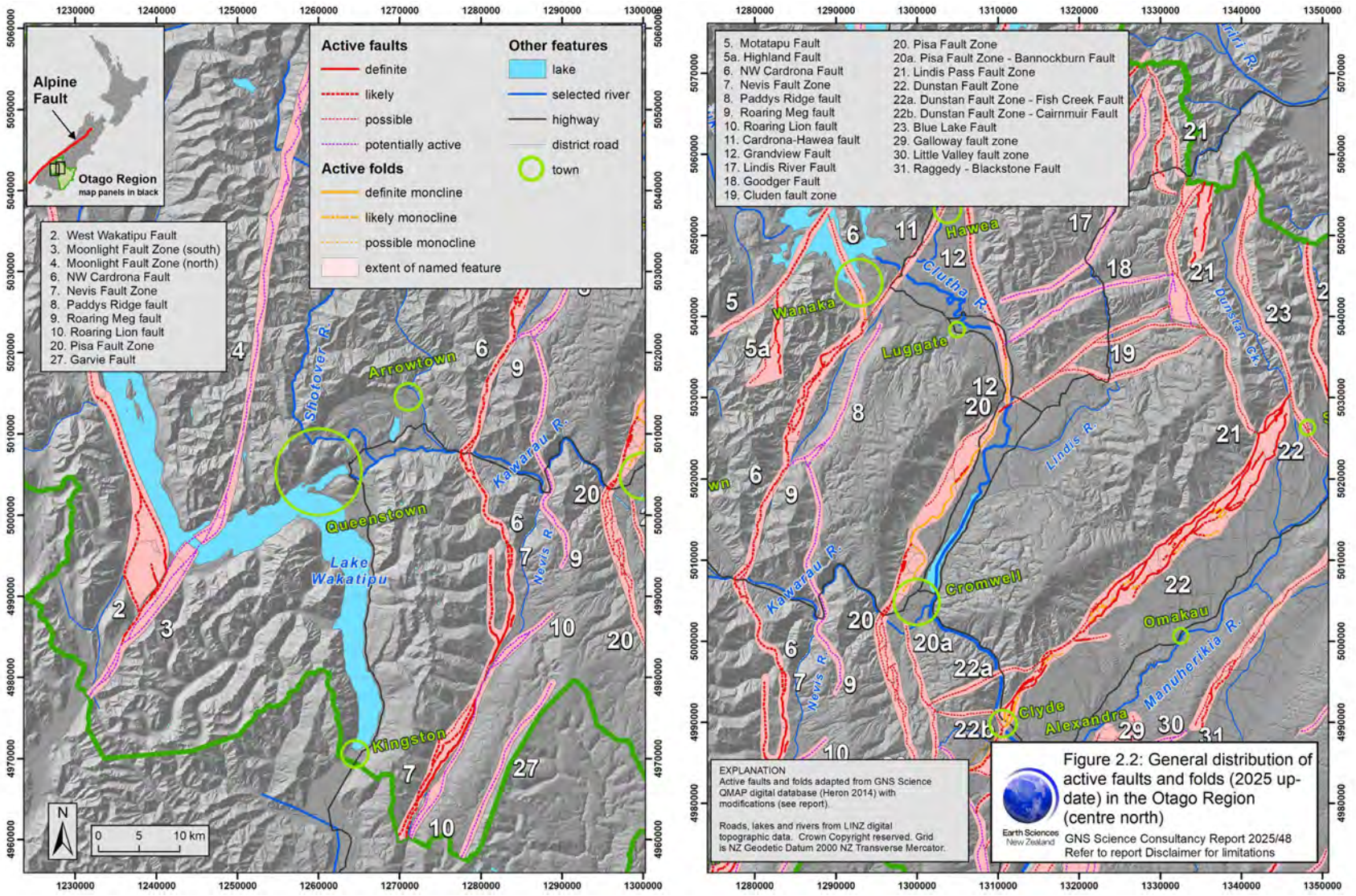


Figure 2.2 General distribution of active faults and folds (2025 update) in the Otago region (centre north). Overlapping sheet 2 of 6 (locations in inset). Pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault; they are purely illustrative and do not imply anything about the extent of fault-related ground deformation. Thick green line is the Otago region's perimeter. Numbering and labelling is common to the overall map, and the reader should refer to other overlapping sheets of the mosaic for any obscured text.

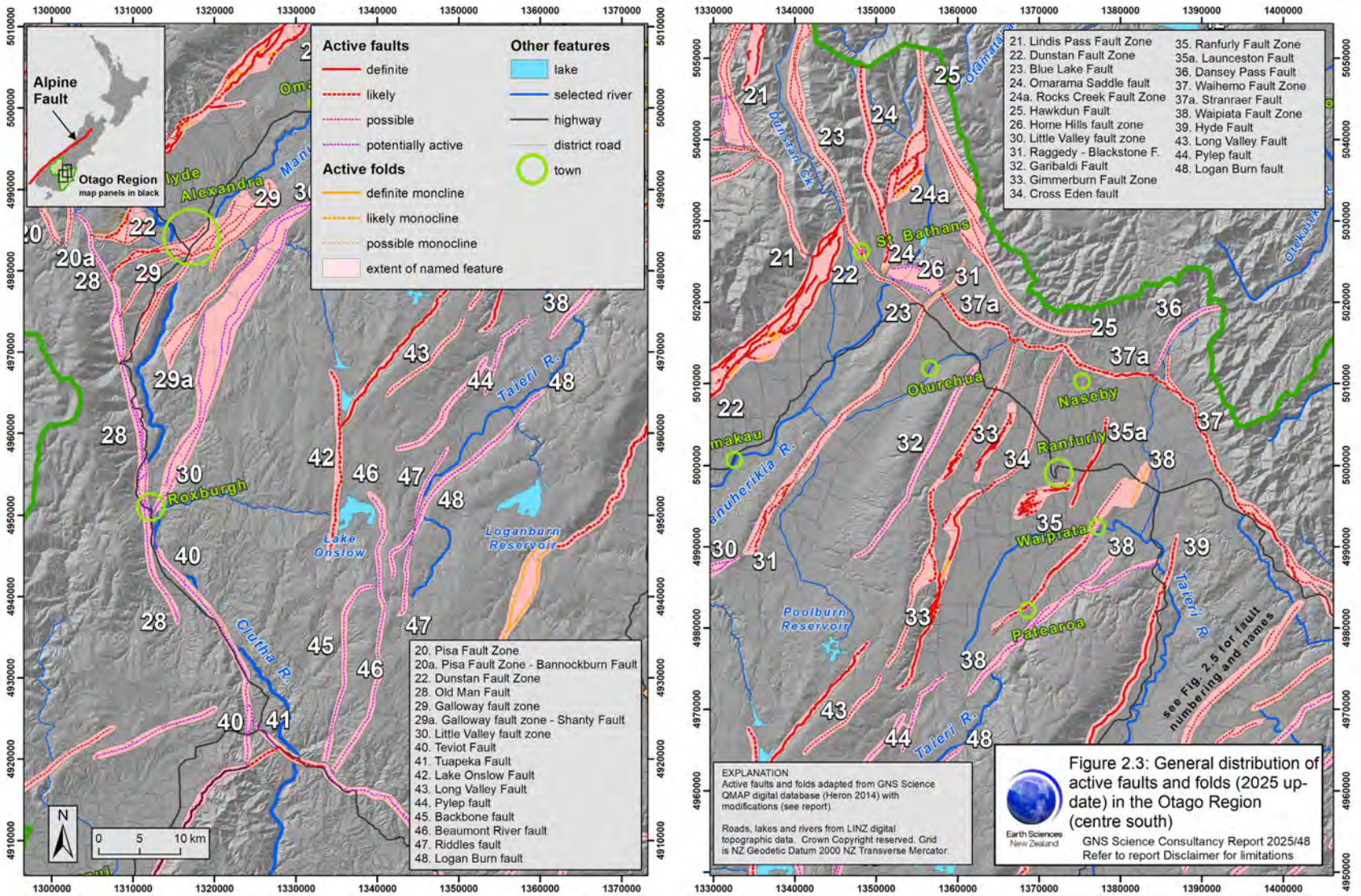


Figure 2.3 General distribution of active faults and folds (2025 update) in the Otago region (centre south). Overlapping sheet 3 of 6 (locations in inset). Pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault; they are purely illustrative and do not imply anything about the extent of fault-related ground deformation. Thick green line is the Otago region's perimeter. Numbering and labelling is common to the overall map, and the reader should refer to other overlapping sheets of the mosaic for any obscured text.

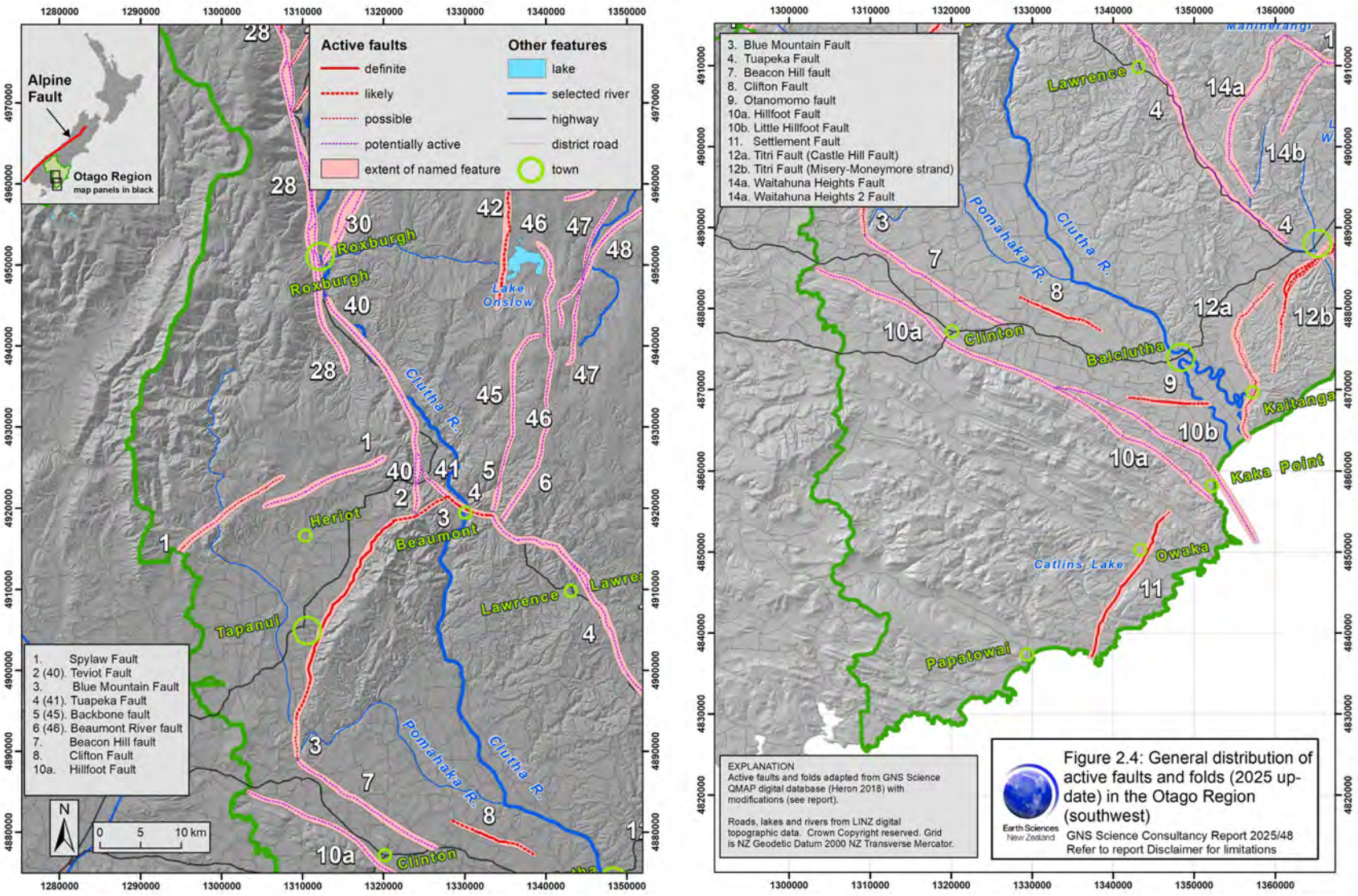


Figure 2.4 General distribution of active faults and folds (2025 update) in the Otago region (southwest). Overlapping sheet 4 of 6 (locations in inset). Pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault; they are purely illustrative and do not imply anything about the extent of fault-related ground deformation. Thick green line is the Otago region's perimeter. Numbering and labelling is common to the overall map, and the reader should refer to other overlapping sheets of the mosaic for any obscured text.

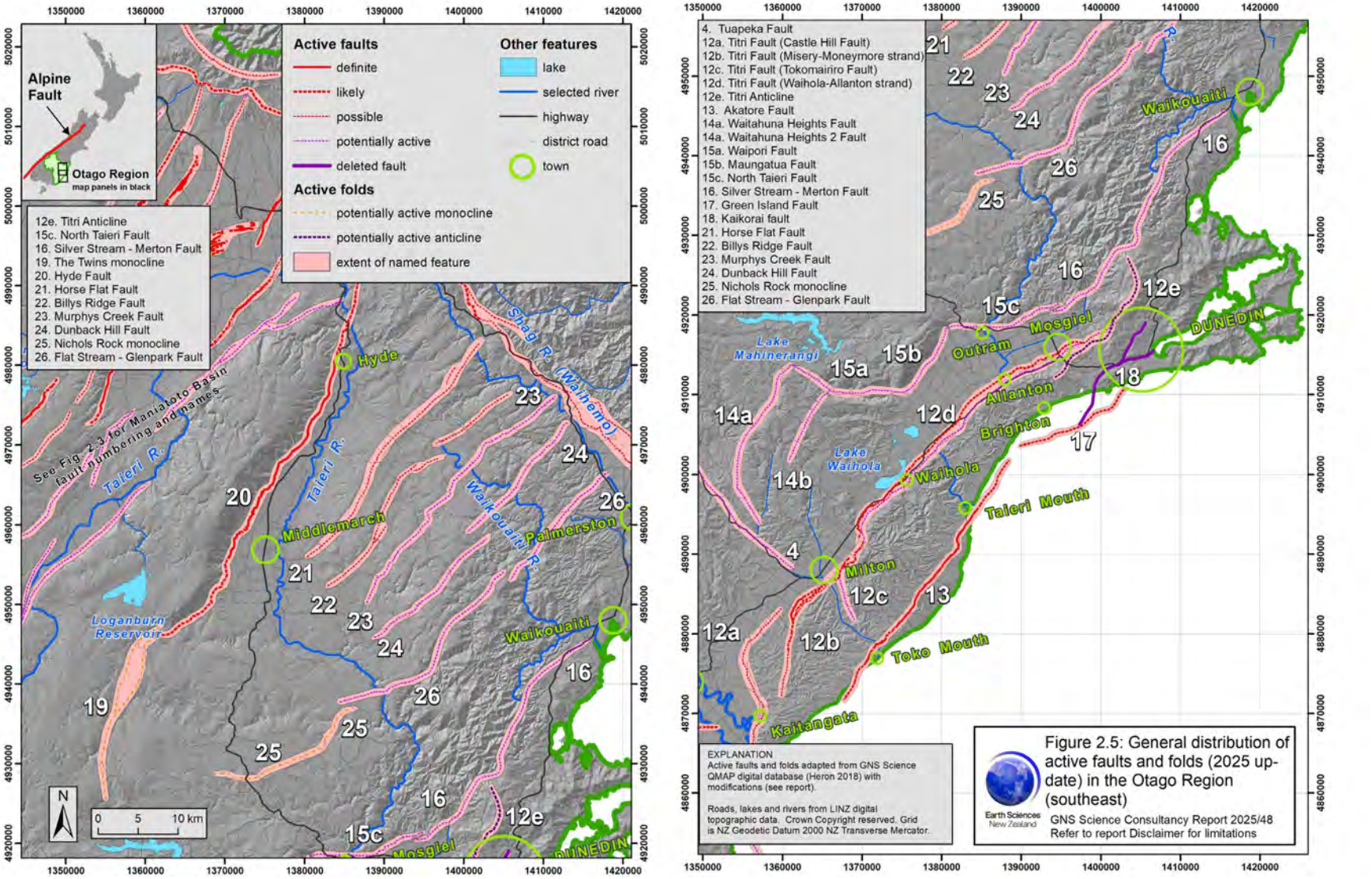


Figure 2.5 General distribution of active faults and folds (2025 update) in the Otago region (southeast). Overlapping sheet 5 of 6 (locations in inset). Pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault; they are purely illustrative and do not imply anything about the extent of fault-related ground deformation. Thick green line is the Otago region's perimeter. Numbering and labelling is common to the overall map, and the reader should refer to other overlapping sheets of the mosaic for any obscured text.

This page left intentionally blank.

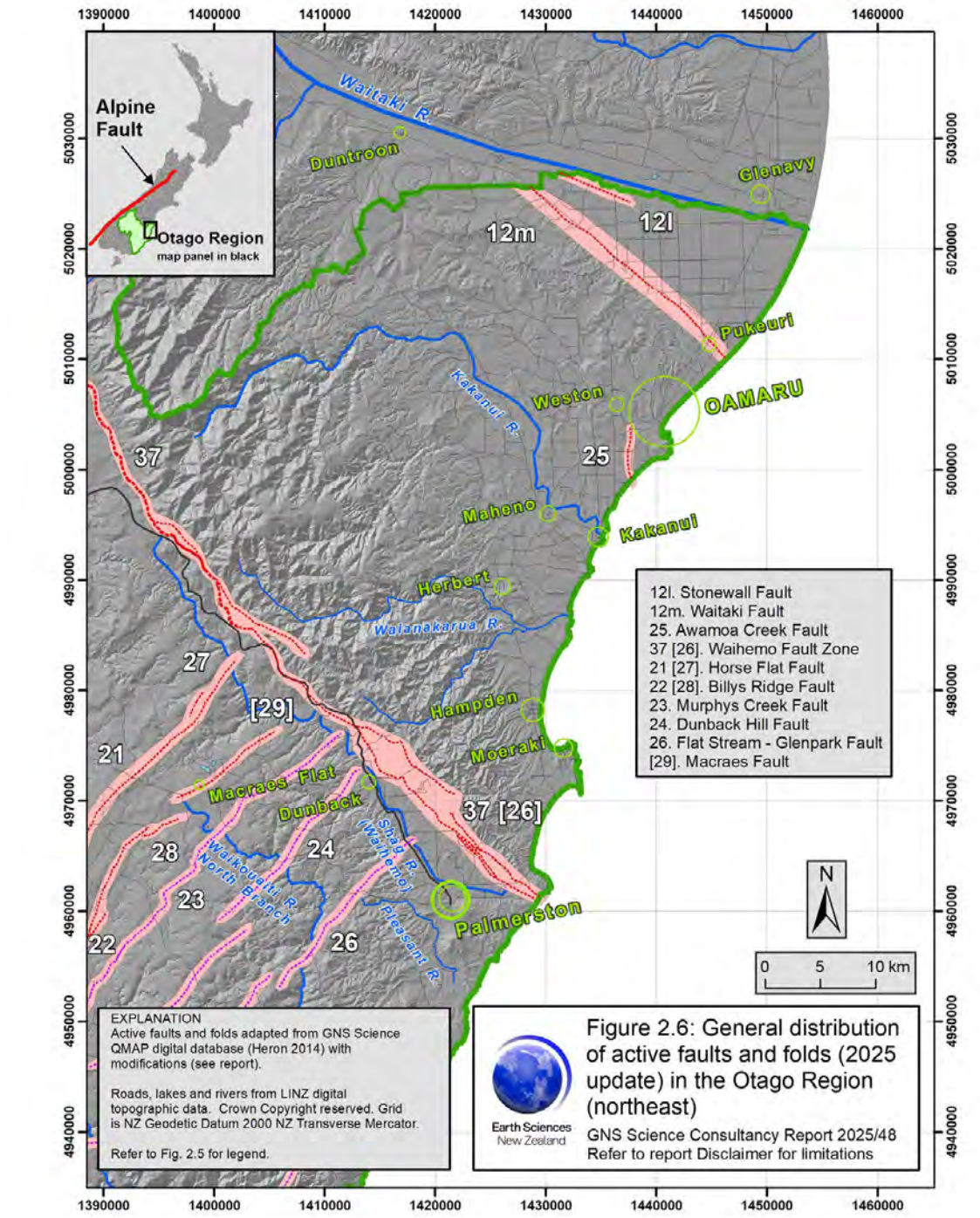


Figure 2.6 General distribution of active faults and folds (2025 update) in the Otago region (northeast). Overlapping sheet 6 of 6 (locations in inset). Pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault; they are purely illustrative and do not imply anything about the extent of fault-related ground deformation. Thick green line is the Otago region's perimeter. Numbering and labelling is common to the overall map, and the reader should refer to other overlapping sheets of the mosaic for any obscured text.

3.0 Acknowledgements

I am grateful to Jack Williams for discussions and review of several sections of the Appendix. Nicola Litchfield and Genevieve Coffey are thanked for many improvements resulting from their reviews of the overall report.

4.0 References

Barrell DJA. 2016. General distribution and characteristics of active faults and folds in the Waimate District and Waitaki District, South Canterbury and North Otago. Lower Hutt (NZ): GNS Science. 124 p. Consultancy Report 2015/166. Prepared for Canterbury Regional Council (Environment Canterbury) and Otago Regional Council.

Barrell DJA. 2019. General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago. Lower Hutt (NZ): GNS Science. 99 p. Consultancy Report 2018/207. Prepared for Otago Regional Council.

Barrell DJA. 2021. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. Lower Hutt (NZ): GNS Science. 71 p. Consultancy Report 2020/88. Prepared for Otago Regional Council.

Barrell DJA, Jack H, Gadsby M. 2015. Guidelines for using regional-scale earthquake fault information in Canterbury. Lower Hutt (NZ): GNS Science. 30 p. Consultancy Report 2014/211. Prepared for Canterbury Regional Council (Environment Canterbury).

Barrell DJA, Glassey PJ, Easterbrook-Clarke L, Smith Lyttle B. In review. Geology of the Dunedin urban area. Lower Hutt (NZ): GNS Science geological map.

Glassey PJ, Barrell DJA, Smith Lyttle B, Hornblow S, Mackey B. 2021. Geological model of South Dunedin. Lower Hutt (NZ): GNS Science. 70 p. (GNS Science report; 2021/03). https://doi.org/10.21420/B5E9-GE25

Glassey PJ, Barrell DJA, Easterbrook-Clarke L, Crundwell MP. In press. Geological model of South Dunedin, New Zealand: a framework for understanding Quaternary fluvial and marine processes. New Zealand Journal of Geology and Geophysics.

Griffin JD, Stirling MW, Barrell DJA, van den Berg EJ, Todd EK, Nicolls R, Wang N. 2022a. Paleoseismology of the Hyde Fault, Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. 65(4): 613–637. https://doi.org/10.1080/00288306.2021.1995007

Griffin JD, Stirling MW, Wilcken KM, Barrell DJA. 2022b. Late Quaternary slip rates for the Hyde and Dunstan faults, southern New Zealand: implications for strain migration in a slowly deforming continental plate margin. *Tectonics*. 41(9):e2022TC007250. https://doi.org/10.1029/2022TC007250

Heron DW, custodian. 2014. Geological map of New Zealand 1:250,000. Lower Hutt (NZ): GNS Science. 1 CD, scale 1:250,000. (Institute of Geological & Nuclear Sciences 1:250,000 geological map; 1).

Heron DW, custodian. 2018. Geological map of New Zealand 1:250,000. 2nd ed. Lower Hutt (NZ): GNS Science. 1 USB, scale 1:250,000. (Institute of Geological & Nuclear Sciences 1:250,000 geological map; 1).

Kerr J, Nathan S, Van Dissen R, Webb P, Brunsdon D, King A. 2003. Planning for development of land on or close to active faults: a guideline to assist resource management planners in New Zealand. Wellington (NZ): Ministry for the Environment. 67 p.

Litchfield NJ, Van Dissen R, Sutherland R, Barnes PM, Cox SC, Norris R, Beavan RJ, Langridge R, Villamor P, Berryman K, et al. 2013. A model of active faulting in New Zealand: fault zone parameter descriptions. Lower Hutt (NZ): GNS Science. 120 p. (GNS Science report; 2012/19).

Litchfield NJ, Van Dissen R, Sutherland R, Barnes PM, Cox SC, Norris R, Beavan RJ, Langridge R, Villamor P, Berryman K, et al. 2014. A model of active faulting in New Zealand. *New Zealand Journal of Geology and Geophysics*. 57(1):32–56. https://doi.org/10.1080/00288306.2013.854256

Meyer AFT. 2021. A paleoseismic investigation of the Long Valley Fault, Central Otago [BSc Hons thesis]. Dunedin (NZ): University of Otago.

Meyer AFT, Stirling MW, Griffin JD, Tarling MS, Stirling TW, Thomsen JM. 2025. Paleoseismology of the Long Valley Fault, Central Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. https://doi.org/10.1080/00288306.2025.2519711

Morgenstern R, Litchfield NJ, Langridge RM, Heron DW, Townsend DB, Villamor P, Barrell DJA, Ries RF, Van Dissen RJ, Clark KJ, et al. 2024. New Zealand Active Faults Database: the high-resolution dataset v2.0. *New Zealand Journal of Geology and Geophysics*. https://doi.org/10.1080/00288306.2024.2427396

Nicol A, Van Dissen RJ, Stirling MW, Gerstenberger MC. 2016. Completeness of the paleoseismic active-fault record in New Zealand. *Seismological Research Letters*. 87(6):1299–1310. http://doi.org/10.1785/0220160088

Rattenbury MS, Isaac MJ. 2012. The QMAP 1:250 000 Geological Map of New Zealand project. *New Zealand Journal of Geology and Geophysics*. 55(4):393–405. https://doi.org/10.1080/00288306.2012.725417

Scott JM, Pontesilli A, Brenna M, White JDL, Giacalone E, Palin JM, le Roux PJ. 2020. The Dunedin Volcanic Group and a revised model for Zealandia's alkaline intraplate volcanism. *New Zealand Journal of Geology and Geophysics*. 63(4):510–529. https://doi.org/10.1080/00288306.2019.1707695

Seebeck H, Van Dissen RJ, Litchfield NJ, Barnes PM, Nicol A, Langridge RM, Barrell DJA, Villamor P, Ellis SM, Rattenbury MS, et al. 2022. New Zealand Community Fault Model – version 1.0. Lower Hutt (NZ): GNS Science. 97 p. (GNS Science report; 2021/57). https://doi.org/10.21420/GA7S-BS61

Seebeck H, Van Dissen R, Litchfield N, Barnes PM, Nicol A, Langridge R, Barrell DJA, Villamor P, Ellis S, Rattenbury M, et al. 2024. The New Zealand Community Fault Model – version 1.0: an improved geological foundation for seismic hazard modelling. *New Zealand Journal of Geology and Geophysics*. 67(2):209–229. https://doi.org/10.1080/00288306.2023.2181362

Stirling M, McVerry G, Gerstenberger M, Litchfield N, Van Dissen R, Berryman K, Barnes P, Wallace L, Villamor P, Langridge R, et al. 2012. National Seismic Hazard Model for New Zealand: 2010 update. *Bulletin of the Seismological Society of America*. 102(4):1514–1542. https://doi.org/10.1785/0120110170

van den Berg EJ, Williams JN, Stirling MW, Barrell DJA, Griffin JD, Litchfield NJ, Wang N. 2025. Late Quaternary activity of the NW Cardrona Fault, Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. 68(1):151–171. https://doi.org/10.1080/00288306.2023.2297962

Vause A. 2025. Faulted terraces and earthquake behaviour of the Pisa Fault, Central Otago [MSc thesis]. Dunedin (NZ): University of Otago. https://hdl.handle.net/10523/45007

Villamor P, Barrell DJA, Gorman A, Davy BW, Hreinsdottir S, Hamling IJ, Stirling MW, Cox SC, Litchfield NJ, Holt A, et al. 2018. Unknown faults under cities. Lower Hutt (NZ): GNS Science. 71 p. (GNS Science miscellaneous series; 124). https://doi.org/10.21420/g2pw7x

Williams J, Stirling M, Langridge R, Niroula G, Vause A, Stewart J, Nicol A, Wang N. 2024. Along-strike extent of earthquakes on multi-segment reverse faults; insights from the Nevis-Cardrona Fault, Aotearoa New Zealand. *Seismica*. 3(2). https://doi.org/10.26443/seismica.v3i2.1310

Williams JN, Stirling MW, Barrell DJA, Niroula G, Wavelet E. 2025. Insights into temporal earthquake clustering from the Settlement Fault, southeastern Otago, Aotearoa New Zealand. *New Zealand Journal of Geology and Geophysics*. https://doi.org/10.1080/00288306.2025.2455076

This page left intentionally blank.

APPENDICES

This page left intentionally blank.

APPENDIX 1 Commentary on Active Fault and Fold Characterisation Revisions

A1.1 Introduction

The information in this appendix is largely of a technical nature and written for a technical audience. Its primary purpose is to set out the knowledge basis for the revisions to the interpretation of faults and folds in this report, compared to the previous reports that documented the original mapping. Readers of this Appendix may find it beneficial to refer to Google Earth, Google Maps and topographic maps such as may be accessed from www.topomap.co.nz.

Reference is made in this appendix to several nationwide datasets on active faults, comprising and abbreviated as follows: the 2010 update of the New Zealand National Seismic Hazard Model (2010 NSHM; Stirling et al. 2012); the New Zealand active fault model (NZAFM; Litchfield et al. 2013, 2014), the NZ active faults database (NZAFD; Langridge et al. 2016; Morgenstern et al. 2025) and the Community Fault Model component of the 2022 New Zealand National Seismic Hazard Model (NZ CFM; Seebeck et al. 2022, 2024).

To aid linkage to previous work, the discussion below collates faults that are in, or predominantly in, a particular territorial authority district, with Section A1.2 addressing the Central Otago and Queenstown Lakes districts (Barrell 2019) and Section A1.3 encompassing the Clutha and Dunedin City districts, plus the Otago part of the Waitaki District (Barrell 2016, 2021).

The convention from preceding reports of using lower case ‘fault’ or ‘fault zone’ for informal unpublished names is continued in this report. This is not reflected in the title-case style of the headings, but is made clear in the text.

A1.2 Central Otago and Queenstown Lakes Districts

A1.2.1 Cluden Fault Zone

This fault zone is a northeast-striking structure identified as feature 19 in the Barrell (2019) report. The interpretation of this fault zone given in the Barrell (2019) report was re-evaluated in relation to the new information on the Pisa Fault Zone in the current report. I consider that the new information increases the likelihood that these two fault zones have shared activity, as originally hypothesised by Beanland and Berryman (1989). The revised Pisa Fault Zone activity parameters are applied here to the Cluden fault zone.

A1.2.2 Dunstan Fault Zone

This N–NE-striking structure is identified as feature 22 in the Barrell (2019) report. There was full lidar coverage at the time of the fault mapping compilation documented by Barrell (2019), and no changes have been made to the mapping as part of this review.

Further dating and analytical work has been completed since the Barrell (2019) report, with dating using the cosmogenic radionuclide surface exposure dating (CRN) method (see footnote in report text) applied to fragile geological features to constrain past levels of strong earthquake shaking (Stirling et al. 2021), and applied to a faulted alluvial fan terrace sequence to estimate long-term fault deformation rates (Griffin et al. 2022b).

The Stirling et al. (2021) work focused primarily on earthquake shaking intensities and does not directly inform fault-related ground deformation. The Griffin et al. (2022b) work provides a long-term perspective on rupture behaviour of the Dunstan Fault Zone and found that, since ~320 ka[6], the average fault slip has been between 0.12 and 0.21 mm/year (median 0.16 mm/year). The Griffin et al. (2022b) work confirms previous interpretations that the Dunstan Fault Zone exhibits episodes of increased surface rupture activity, interspersed with episodes of less activity. Van Dissen et al. (2007[7]) found that the most recent activity on the fault comprised at least four and possibly as many as six surface-rupturing earthquakes that occurred between ~12 and ~24 ka. They also found that at least 5 m of vertical deformation occurred during that episode of activity, but with notable uncertainty regarding a maximum limit on the deformation. The uncertainty arose mainly from their investigation sites being on a relatively old alluvial fan landform (age of at least 40 ka), making it hard to determine whether all the indicated vertical deformation of the fan surface relates to that episode of activity. In contrast, Griffin et al. (2022b) were able to date a younger alluvial fan surface (26.2 ± 2.9 ka), and constrain the amount of vertical deformation due to surface rupture of the Dunstan Fault Zone since that time to no more than 9.5 m. I consider that although defined as a maximum amount, when weighed against all the other information available, that value is an adequate working approximation of the amount of deformation.

Characterising the activity of a fault that displays episodic rupture behaviour is challenging, especially when the data are insufficient to yield insights to whether there are typically patterns and lengths for episodes of activity and inactivity. As a result, average representative values have been applied. The information from the investigations documented in Van Dissen et al. (2007) produced a slip rate estimate of 0.6 mm/year, which was used in the Barrell (2019) report. The results from Griffin et al. (2022b) of 9.5 m vertical deformation since ~26.2 ka, when resolved onto a 45° dipping fault and assuming pure dip slip, gives a net slip rate of 0.51 mm/year. This slip rate, rounded to 0.5 mm/year, was used in the NZ CFM. For the revision described in this report, the 2010 NSHM fault characterisation methodology, with fault length of 60 km and 0.5 mm/year slip rate, a recurrence interval of ~8200 years is calculated. These values are adopted in this report.

A1.2.3 Galloway Fault Zone (Conroys Fault)

This northeast-striking component of the Galloway fault zone structure is identified as feature 29 in the Barrell (2019) report. An approximately 3 km long section of the Conroys Fault south of Chapmans Road has been repositioned by as much as about 100 m to better accord with topographic information from the lidar DEM and locations of rocky outcrops visible in aerial colour imagery. No changes are made to the fault activity characterisation.

A1.2.4 Gimmerburn Fault Zone

The north to northeast-striking Gimmerburn Fault Zone (feature 33 of Barrell 2019) is notable for having great complexity of surface faulting expression, comprising numerous relatively short fault scarps. The entire area of the fault zone now has photogrammetry DSM coverage. This has allowed some minor positional adjustments of fault scarps in the southern part of the fault zone, but elsewhere the previous mapping based on aerial photos is sufficiently accurate.

New information does not support the previously mapped northern extent of the fault zone near West Eweburn Dam, where Bishop's (1979) geological map depicts a northeast-striking fault, upthrown to the northwest. In recent years, I have examined geological relationships at West Eweburn Dam. The western half of the downstream foot of the dam has extensive exposure of schist bedrock, with layering (foliation) dipping approximately north at 40 to 50°. The schist is not particularly fractured though the outcrop includes a several-metre-wide fault zone near the western side of the dam that is

[6] 1 ka = 1000 years before present; 1 ky = a 1000-year interval

[7] Referred to in the Barrell (2019) report as 'GNS Science, unpublished data 2007'.

parallel to foliation in the schist, i.e. strikes east-west and dips approximately north at about 40 to 50°, thus striking near-perpendicular to the expected alignment of Bishop's (1979) fault. The schist is increasingly weathered towards the eastern side of the bedrock exposure. Beside the dam's eastern abutment is exposure of pale grey high plasticity clay, interpreted as a residual paleo-soil formed on top of the weathered schist and marking the Otago Peneplain at this location. The clay is overlain by bedded quartz fine gravel, sand and mud, interpreted as Stranraer Group fluvial sediment strata, with a gentle to moderate dip (~15 to ~20°) to the southeast. West of the dam, a low-relief hill formed on schist bedrock has a gentle to moderate slope to southeast and is interpreted as a slightly eroded remnant of the peneplain. The hillslope surface can be satisfactorily extrapolated across the dam to connect with the top of the weathered schist, meaning that no need exists for a fault dislocation of the peneplain as suggested by Bishop's (1979) map. It is conceivable that the foliation-parallel fault, which has been exposed for over a century since the dam was constructed (1898 – 1902; Hamilton 2009), contributed to Bishop's mapping of a fault at the dam. Along-strike of the foliation-parallel fault, the bedrock hill surface to the west has no indication of any elevational dislocation of the eroded peneplain surface. I therefore conclude that the foliation-parallel fault is unrelated to geologically – recent faulting, regard it as a deformation feature within the schist bedrock, and have removed the northern ~4 km of the strand of the Gimmerburn Fault Zone that formed part of the Barrell (2019) dataset near West Eweburn.

Barrell (2019) inferred a monoclinal fold to have elevated an alluvial fan terrace on the northwest side of Ewe Burn West Branch valley. The DSM reveals that this terrace is paired on the opposite side of the valley, and thus there is no topographic anomaly. Barrell (2019) noted the gentle slope of the topographic step on the western side of the valley in support of the fold interpretation, but I consider this can be adequately accounted for by accumulation of colluvial and aeolian sediments on the southeast face of this topographic step, in the lee of prevailing north-westerly winds. Finally, QMAP depicted two fault scarps on the Ewe Burn West Branch valley floor north of SH 85. The DSM indicates these are adequately explained as steps of fluvial origin, and they have been removed.

An editing error resulted in a component of information explaining the Gimmerburn Fault Zone slip rate estimation being inadvertently omitted from the Barrell (2019) report. The omission related to a field estimated fault scarp height of 5 m on an alluvial fan surface, inferred to be 18,000 years old. This results in a vertical slip rate of 0.28 mm/year. This converts to a net slip rate of 0.39 mm/year when resolved onto a fault plane of inferred 45° dip. That value, rounded to 0.4 mm/year, was used in the NZ CFM. The mapping changes described above reduce the fault length by 4 km to 38 km. Applying that length and the slip rate to the 2010 NSHM methodology produces a recurrence interval of 6700 years, slightly less than the previously assessed value of 7400 years given by Barrell (2019).

A1.2.5 Hunter Valley Fault

This N–NE-striking structure is identified as Feature 14 of the Barrell (2019) report. There is now coverage of the Hunter Valley area in a photogrammetry DSM. This has allowed the 'likely' 'well expressed' topographic step on the eastern side of the valley to be positioned more accurately. In the dataset described in this report, its position is shifted as much as about 100 m.

No other changes are made to the mapping or characterisation of the Hunter Valley Fault. The fault has been included in the NZ CFM, using the activity parameters from the Barrell (2019) report.

A1.2.6 Lake Onslow Fault

The north-striking Lake Onslow fault (feature 42 of Barrell 2019) now has coverage with lidar DEM and photogrammetry DSM. South of Lake Onslow, there is a series of topographic steps, up to several metres high, that are suspected to be fault scarps. As a result, the entire fault has its Certainty raised from 'potentially active' to 'likely active'. A section of the fault immediately south of Lake Onslow is classed as 'well expressed'. The remainder, except for a 'not expressed' section under Lake Onslow,

is classed as ‘moderately expressed’, because the overall topographic step representing the peneplain offset is prominent in the landscape.

No changes are made to fault activity parameters. The fault is included in the NZ CFM, using the activity parameters from Barrell (2019).

A1.2.7 Launceston Fault

The Launceston Fault (feature 35a of Barrell 2019) now has coverage by photogrammetry DSM, and minor improvements have been made to the positioning of the fault scarps. Recurrence interval is calculated for a combined Launceston Fault/Ranfurly Fault Zone length, and with reduced length, recurrence interval is revised to 14,000 years (see Ranfurly Fault Zone; Section A1.2.16). No other changes are made to fault activity parameters.

A1.2.8 Lindis Pass Fault Zone

This broad zone of overall north-striking faults is identified as feature 21 in the Barrell (2019) report. There is now full coverage of the area of the Lindis Pass Fault Zone with a photogrammetry DSM, and in the southern part of the area, with lidar DEM.

The Longslip Fault strand and the main strand of definite fault scarps in the Dunstan Creek catchment have been more accurately positioned, and divided in more detail into sections classified as either ‘moderately expressed’ or ‘not expressed’. A ~1.5 km long previously unrecognised fault scarp off the southern end of the main strand of the fault zone, in Tim Burn Left Branch, has been added to the dataset, classified as ‘definite’, ‘moderately expressed’. The DSM shows the scarp to be about 3 m high where it crosses a small alluvial fan.

No changes are made to the activity parameters provided in the Barrell (2019) report.

A1.2.9 Livingstone Fault

The approximately north-striking Livingstone Fault is a geologically major fault which originated during the Mesozoic Era, and separates distinctive types of basement rocks (Barrell 2019). Geological maps at 1:250,000 scale provide good confidence in the approximate location of the fault. It is identified as feature 1 in the Barrell (2019) report.

Partial coverage with a lidar DEM and full coverage from a photogrammetry DSM is now available for the ~6.5 km length of the Livingstone Fault that passes through the northwest corner of the Otago region. The topographic features that were previously suspected as likely related to fault offset, and classified as ‘moderately expressed’ are now confidently identified in the lidar DEM as glacial erosion lineaments (north of Lake McKellar) and ridge rents related to broad-scale slope instability (south of Lake McKellar).

Looking along-strike within the Southland Region, where lidar DEM coverage is good, there is nowhere that a fault-rupture topographic step is evident on the Livingstone Fault. However, parallelism of the Livingstone Fault and West Wakatipu Fault (most of which is classified as ‘likely’), and its relative proximity to the Alpine Fault, means that it is considered appropriate here to continue with a Certainty parameter for the Livingstone Fault in the Otago region as a ‘likely’ active fault. All sections of the fault in the Otago region are reclassified in this dataset as ‘likely’ and ‘not expressed’.

The fault was formerly represented in the 2010 NSHM as an active fault earthquake source called the ‘Hollyford Fault’. The NZ AFM identified the fault as an entity separate from the Hollyford Fault, and named it the ‘Livingstone Key Summit fault zone’, with a preferred slip rate of 1.0 mm/year. The entity, in slightly revised location, was incorporated within the NZ CFM as the ‘Livingstone Fault’, and assigned a best estimate (‘preferred’) slip rate of 0.5 mm/year (by the present author). This reduction in slip rate was based on the reported relatively minor size of inferred fault-related landforms The new information (lack of identified post-glacial fault scarps) indicates that consideration should be given to downgrading

the slip rate to an indicative 0.25 mm/year, which would be compatible with no post-glacial surface rupture. Reapplying the 2010 NSHM methodology, with full fault length of 65 km and slip rate of 0.25 mm/year, a recurrence interval of ~18,000 years is calculated. These values are adopted in this report.

A1.2.10 Long Valley Fault

This northeast-striking fault forms a prominent escarpment, upthrown to the southeast, in the upper catchment of Pool Burn, and is identified as feature 43 in the Barrell (2019) report. Since the time of that report, there is now complete coverage by lidar DEMs, and a University of Otago research project was undertaken in 2021 on the Long Valley Fault, which included trenching and dating of faulted and unfaulted sediments (Meyer 2021; Meyer et al. 2025).

The lidar DEM reveals that the northern part of the fault near Poolburn Dam was mapped between ~300 m and ~700 m too far southeast in the Barrell (2019) dataset, relative to newly identified well-expressed fault scarps crossing alluvial fan terraces and colluvial aprons. The lidar DEM was clear enough to allow minor revisions to the fault position, typically by a few tens of metres, along the entire length of the fault. The length of past fault ruptures is well constrained at ~23 km, with a termination to the southwest at the Lake Onslow fault, and a northern limit of the fault's late Cenozoic expression in peneplain terrain, with discrete fault scarps mappable for most of this length.

The 2021 trench across a fault scarp found schist thrust over Quaternary-age alluvial fan and colluvial sediments. Fault dip near the base of the trench was ~40°, with stratigraphic and structural evidence for three surface rupture events, with total net slip of approximately 5 m (5.0 ± 0.2 m). OSL dating of the sediments, and OxCal modelling of the age results, indicate that the three identified ruptures occurred at 74.5 ± 6.9 ka, 37.2 ± 18.1 ka and 10.5 ± 3.8 ka (Meyer et al. 2025). A minimum estimate of long-term slip rate of 0.06 mm/year is calculated from the smaller bound of total net slip (4.8 m) and the older bound of the earliest surface rupture earthquake (81.4 ka). Similarly, a maximum estimate of long-term slip rate of 0.08 mm/year is obtained from the larger bound of total net slip (5.2 m) and younger bound of the earliest surface rupture earthquake (67.7 ka). Using the dating and modelling results defining the three most recent surface ruptures of the Long Valley Fault, Meyer et al. (2025) obtained an average recurrence interval for surface rupture of 32.0 ± 12.3 ky. Within uncertainty, this is compatible with the recurrence interval obtained via the 2010 NSHM methodology, where preferred values for slip rate of 0.07 mm/year and fault length of 23 km result in a calculated recurrence interval of ~25,000 years. On that basis a representative recurrence interval of 25,000 years is adopted in this report.

The description of the nearby parallel fault given in the Long Valley Fault section of the Barrell (2019) report remains current.

A1.2.11 Moonlight Fault Zone

The Moonlight Fault Zone was divided into a South section and a North section, respectively features 3 and 4, in the Barrell (2019) report.

Examination of the full-coverage photogrammetry DSM supports the interpretation of Barrell (2019) of the likelihood of localised slip having been triggered on the Moonlight Fault Zone – South in proximity to the 'definite' strands of the West Wakatipu Fault. The DSM shows an approximately 5 m high scarp, moderately well expressed and up to the southeast, crossing glacially-smoothed hillslopes and alluvial fans for ~3.5 km southwest from the southwestern end of the westernmost 'definite' scarp of the West Wakatipu Fault. It is within the section of the Moonlight Fault Zone – South that was previously classified as 'likely', 'not expressed'. This ~3.5 km section is reclassified as 'likely', 'moderately' expressed.

Activity parameters for the Moonlight Fault Zone – South provided by Barrell (2019) have been taken up into the NZ CFM. No changes are made in this report to those parameters.

I make a note of clarification in relation to the Moonlight Fault Zone – North. A short (0.5 km long) active fault strand, trending north-northwest and down to the east, is depicted across an alluvial fan in the QMAP dataset (Turnbull 2000), and is included in the NZAFD. It was not included in the Barrell (2019) dataset, nor here, for reasons as follows. This fan occupies a low-relief basin within mountain terrain in the Murphys Creek South catchment about 12 km northwest of Arthurs Point. On the 1:50,000-scale topographic map, the basin is named Jones Flat, adjoining the low-relief Murphys Saddle. The illustrated fault strand is about 1.5 km east of the mapped position of the Moonlight Fault Zone – North This topographic step does not have continuity along trend, across other similar landforms, and the photogrammetry DSM reveals two nearby similar short topographic displacements of alluvial fan landforms, one trending east-west and down to the north, the other trending north and down to the west. I interpret all three to be formed by gravitational processes, involving deep-seated slope movement associated with a tensional basin. The mapped short active fault strand should be removed from both the QMAP and NZAFD datasets.

No changes are made to the mapping and parameterisation of the Moonlight Fault Zone – North documented by Barrell (2019).

A1.2.12 Nevis Fault Zone

The Nevis Fault Zone is identified as feature7 in the Barrell (2019) report. Photogrammetry DSM coverage has now become available for the entire fault. Aided by the DSM, adjustments to positional accuracy of fault scarps, along with more detailed distinction between different levels of the Surface Expression parameter, have been made along a ~2 km long section northeast of Schoolhouse Creek, and in an ~8 km section extending southwest from the Drummond Creek area.

The Nevis Fault Zone has recently been a focus of geological investigation and dating to quantify its degree of activity as part of a Natural Hazard Commission University Research Program at the University of Otago. Results are reported by Williams et al. (2024), as summarised below. Two fault investigation trenches were excavated across southeast-facing fault scarps of the Nevis Fault (a strand of the Nevis Fault Zone and equating to the 'Little Nevis Fault' of Beanland and Barrow-Hurlbert (1988)) crossing alluvial fans of two minor streams in the upper Nevis valley (locally named Stoney Creek and German Creek – i.e. not on LINZ topographic maps). The fault trenching replicated previous trenching in the Nevis valley reported by Beanland and Barrow-Hurlbert (1988), and its primary purpose was to obtain samples for geological dating by the OSL method, which had not been developed at the time of the earlier investigations. Measurement of fault offsets and OxCal modelling of dated faulted and unfaulted sediments from the trench exposures indicate bracketing ages for occurrence of the most recent surface rupture of the Nevis Fault between 7800 and 17,600 years ago, with an earlier (penultimate) rupture bracketed between 19,800 and 41,000 years ago. Single event displacements for fault rupture as estimated from the trench exposures are in the range of 0.7 to 1.7 m. For each trench site a localised surrounding area was image-surveyed using an Unmanned Aerial Vehicle (UAV), from which a high-resolution (pixel size 9–114 cm^2) DSM was generated. An image-survey for DSM generation was also undertaken across a set of faulted alluvial fan terraces at Drummond Creek, originally surveyed, trenched and described by Beanland and Barrow-Hurlbert (1988). Detailed examination and profiling of the localised high-resolution DSM confirms the Drummond Creek mapping and general interpretations of Beanland and Barrow-Hurlbert (1988), but Williams et al. (2024) were unable to replicate the previous interpretation that four surface rupture events are registered in the Drummond Creek terrace offsets. Instead, Williams et al. (2024) concluded that the Drummond Creek alluvial fan terrace faulting can be accounted for by two surface ruptures. I agree with that conclusion, as explained below.

Beanland and Barrow-Hurlbert (1988) robustly interpreted a terrace, preserved only on the upthrown side of the fault at Drummond Creek, as tectonic – meaning that it was cut by stream erosion following an uplift event on the fault. However, the existing papers (Beanland and Barrow-Hurlbert 1988; Williams et al. 2024) have not spelled out a salient conclusion that the height of the riser up to the adjacent main

surface of the fan is a close approximation of the single-event uplift or even stated the height of the riser. The DSM-generated elevation contours in Figure 11 of Williams et al. (2024) show the riser close to the fault is almost exactly 1.0 m high. Profiling by Beanland and Barrow-Hurlbert (1988) and Williams et al. (2024) interpret the height of the fault scarp produced during subsequent fault rupture that uplifted the tectonic terrace as 1.0 m, and 0.7 ± 0.1 m respectively. Beanland and Barrow-Hurlbert (1984, 1988) trenched the scarp at that location, from which they also obtained a 1.0 m scarp height estimate. Topographic profiling involves interpretation of projected ground surfaces either side of the fault and carries some degree of subjectivity. I drew numerous profiles across this scarp using the DSM and consider that about 1.0 m is a good approximation of fault scarp height. The two other profiles at Drummond Creek that produced scarp heights of less than 1 m (Beanland and Barrow-Hurlbert 1988; Williams et al. 2024) were along channel landforms. Close inspection of the DSM indicates that the scarps across these channel floors have been somewhat modified by erosional degradation caused by flow events down the channel, resulting from heavy rainstorms. In other words, the fault scarps across those channels have been affected post-rupture by localised fluvial action and I regard their heights as minima for the vertical component of the most recent fault surface rupture.

Based on the discussion above, I concur that the best interpretation of the upper Nevis geomorphology and the fault trenching on the Nevis Fault scarp across the youngest extensive fan surfaces is adequately accounted for by a two-rupture explanation, with a collective throw of about 2.0 m.

Another limitation of the previous surveying and profiling is that practicality dictated that it had to be very localised on the fault scarps (i.e. near-field) and could not encompass wider context. Using the photogrammetry DSM now available, I examined the wider context of the alluvial fan terraces and fault-related features, and drew a geomorphological sketch map, to assist in ensuring my DSM profiling was done on single contiguous alluvial fan landforms (Figure A1.1). The main finding concerns the Wrights Fault trace, a northwest-facing structure parallel with, and antithetic to, the Nevis Fault, lying about 1 km to the northwest (i.e. closer to the range-front). Beanland and Barrow-Hurlbert (1988) were cautious about interpreting the Wrights Fault's most recent deformation of the alluvial fan terraces, describing the fault expression as a 'subtle, 2 m high' feature. The lack of definitive evidence to confirm, or quantify, the deformation across the Wrights Fault resulted in it not being included in interpretations of Nevis Fault Zone activity (Beanland and Barrow-Hurlbert 1988; Williams et al. 2024). However, my DSM profiling of individual alluvial fan terraces (Figure A1.1) indicates that Wrights Fault has produced some deformation of the main alluvial fan surfaces that the Nevis Fault scarps displace, but the 1 to 2 m vertical component of Wrights Fault deformation is distributed across a zone typically 50 to 100 m wide. This highlights that it will be scarcely visible in the field and why it was not easily recognisable or quantifiable in previous work. The Wrights Fault, previously classified as 'definite' by Barrell (2019), is amended in this dataset to 'likely', to acknowledge that it may be more of monoclinal fold at the ground surface rather than a discrete fault.

For the youngest widespread alluvial fan surfaces of the upper Nevis, I adopt an indicative age of 20,000 years. This is compatible with regional correlations and dating by Williams et al. (2024). I think the timing of the penultimate rupture can be informed geomorphologically by the tectonic terrace at Drummond Creek. A ~2 m high scarp is common along this section of the fault, displacing the youngest widespread alluvial fan surfaces (T2 in Figure A1.1). The tectonic terrace suggests there was a fault rupture at about the time these fan surfaces were in the process of being abandoned by fluvial activity (at the end of the Last Glaciation). This advances the interpretation of Williams et al. (2024) whose estimates for the penultimate event's timing (19.8–41.0 ka) were constrained by OSL dates alone.

In the following re-evaluation of Nevis Fault Zone activity, I use round numbers to arrive at representative, indicative values, without worrying about uncertainties. Following the approach described by Griffin et al. (2022b), the vertical components of synthetic and antithetic fault displacements are combined, to obtain the vertical component of displacement on the underlying master fault. For this calculation, I adopt a representative dip for the master fault at depth of 45˚,

as used in the NZ CFM, and conservatively add a 1 m component for the Wrights Fault. Resolving 3.0 m of vertical movement onto that fault plane and assuming pure dip slip gives a dip slip value of 4.24 m. The calculated dip slip divided over the indicative 20,000-year time period since the youngest widespread alluvial fan surface was formed returns an average net slip rate of 0.21 mm/year.

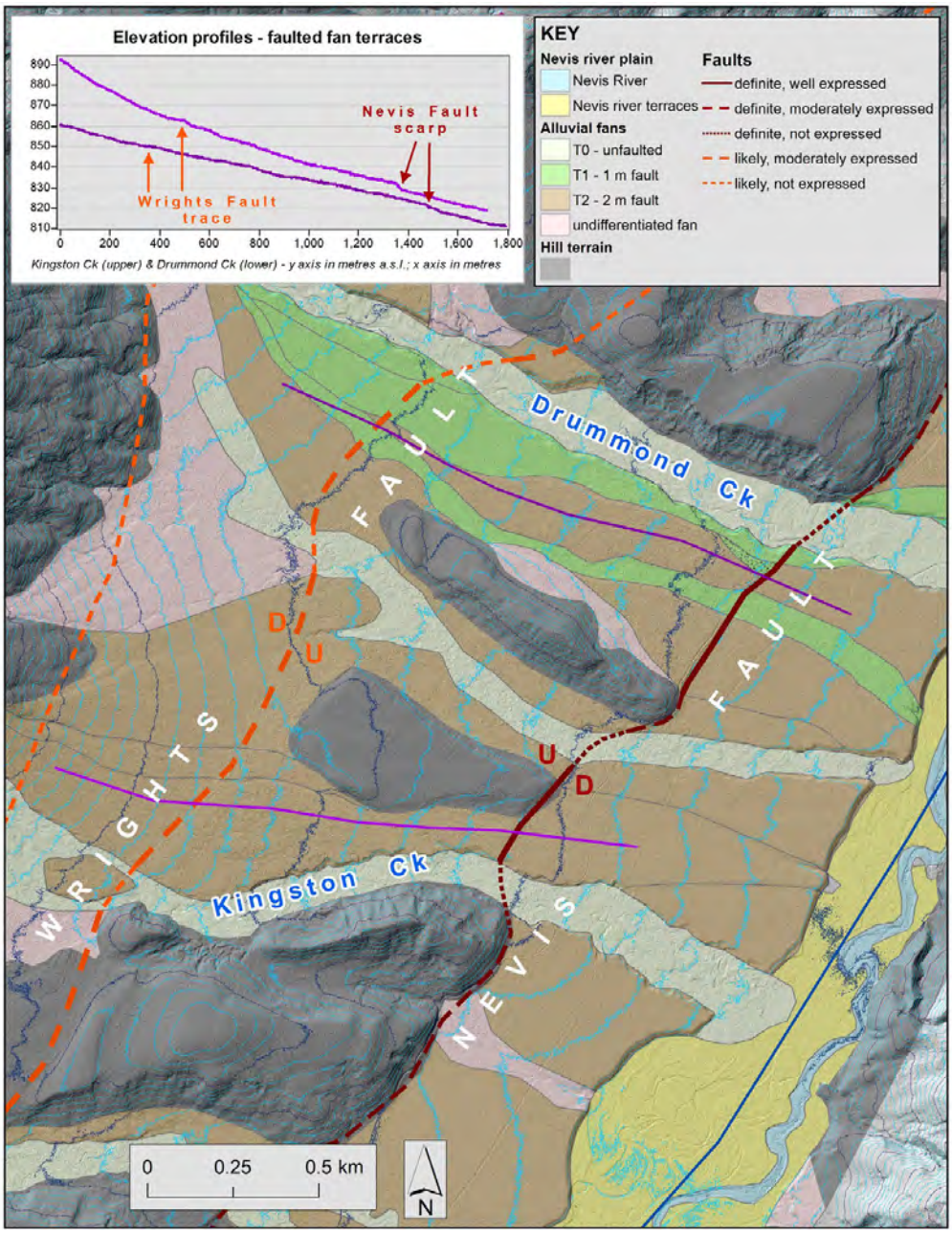


Figure A1.1 The photogrammetry DSM, and a sketch geomorphological map prepared during this review, at Drummond and Kingston creeks in the upper Nevis valley, with elevation profiles. 5-m interval topographic contours (light blue) were generated from the DSM, with navy blue highlighting 25-m intervals. Alluvial fan surfaces (T0, T1 and T2) differentiated by height of the Nevis Fault scarp across them; Drummond Creek tectonic terrace highlighted by stipple. The two profiles (purple lines), on T2 fan surfaces, show gradient perturbation southeast of the Wrights Fault, indicating surface deformation there post-dating formation of the T2 surface.

The NZ CFM compilation depicted a fault length of 49 km based on geological mapping interpretations, but this extends the fault several kilometres south of the topographic end of the hanging wall mountain range. I consider a 37 km fault length more in accord with topographic form on the fault's upthrown side. Applying that fault length and the 0.21 mm/year slip rate within the NSHM 2010 methodology results in an average recurrence interval of ~12,300 years and single-event displacement of 2.6 m. These values are compatible with the geological evidence described above.

A consequence of this re-evaluation is that it indicates a level of activity on the Nevis Fault broadly similar to that of the NW Cardrona Fault (see Section A1.2.13). The estimated surface rupture event timings and relatively small single-event displacements indicated by field evidence for both faults supports the long-standing conclusion that recent ruptures have not involved the two faults behaving as a single entity (Beanland and Barrow-Hurlbert 1988; Barrell 2019; Williams et al. 2024). As a last comment, the lack of prominent geologically young scarps on the Nevis Fault in the Lower Nevis basin suggests that surface deformation from the most recent fault ruptures have broken out in the range-front area, where extensive landslide terrain may obscure any surface fault rupture expression.

A1.2.13 NW Cardrona Fault

This major northeast-striking fault runs along the north-western side of the Cardrona valley and is identified as feature 6 in the Barrell (2019) report. This fault was the topic of a Master of Science research project at University of Otago (van den Berg 2020), which included geological investigations and dating at a trench exposure at Macdonalds Creek on a fault strand that is identified in the Barrell (2019) dataset as the 'NW Cardrona Fault – backfault'. The thesis work has recently been updated and published (van den Berg et al. 2025). In that paper, the fault strand is renamed the 'NW Cardrona Fault – Branch Burn strand' to give it better geographic context. That name is adopted in the revised dataset described in this report.

Other than two locations, no amendments have been made to the positional mapping of this fault, and the descriptive information in Barrell (2019) remains current. Those locations are the Spotts Creek valley, near the northern end of the Cardrona valley, where there is now photogrammetry DSM coverage, and the fault scarps have been positioned more accurately, involving positional shifts of as much as a few tens of metres. The other locality is in an area ~2 km south from the Kawarau River valley. There, short sections of the fault across two small stream valleys were previously interpreted, from aerial photos, to have broad scarps and were classified as 'moderately expressed' (Barrell 2019). Examination and profiling of a lidar DEM that is now available shows that there are no topographic steps crossing those terraces, and these fault sections are reclassified as 'not expressed'.

At Macdonalds Creek, van den Berg et al. (2025) adopted the suggestion of Barrell (2019) that the Branch Burn strand is developed over a locally blind section of the NW Cardrona master fault, and that the surface deformation is an expression of movement on the master fault. They used the trench investigation results and analyses, with incorporation of various uncertainties, to conclude that the most recent surface rupture of the Branch Burn strand of the fault occurred sometime between 2100 and 15,300 years ago, with an earlier rupture having occurred sometime between 12,700 and 28,300 years ago. Average single-event displacement for fault rupture is about 2.2 m. They also calculated a net slip rate of 0.13 ± 0.05 mm/year and recurrence interval of 11,800 ± 5100 yrs.

Information relating to the NW Cardrona Fault scarp at Gibbston in the Kawarau valley is re-evaluated in detail by van den Berg (2025), with the aid of the lidar DEM. They reinterpret the Beanland and Barrow-Hurlbert (1988) Gibbston trench exposure as registering two rather than three surface ruptures. The collective vertical component of movement is 5.6 m, as determined at the top of river gravel in the trench, and more than the scarp height of 4.7 m, due to differential erosion/deposition across the scarp (van den Berg et al. 2025). The vertical deformation resolved onto a fault plane dipping 45° (as observed near the base of the trench) equates to 8.0 m of dip-slip displacement and thus an average single-event dip-slip displacement of 4.0 m. A radiocarbon date from the trench is stratigraphically a maximum age

for the earlier (penultimate) rupture but is suggested to be a close approximation of the time of occurrence of that rupture. The calibrated age, obtained using the SHCal 20 calibration dataset, is 24,661 ± 2480 cal. yrs BP. Further modelling was undertaken by van den Berg et al. (2025) to define a representative time range of occurrence for the penultimate rupture, but as the interpretation comes from a single age determination, I prefer to use the as-determined calibrated age in the assessment here. Assuming pure reverse dip-slip movement of 8.0 m in relation to the older and younger bounds of the calibrated age (27,140 and 22,181 cal. yrs BP) gives an indicative slip rate of between 0.36 and 0.29 mm/year (median 0.32 mm/year).

It was proposed by van den Berg et al. (2025) that the activity characterisation for the Branch Burn strand obtained from the Macdonalds Creek investigation can be generally taken as representative for activity of the NW Cardrona Fault. My view, given the notably larger slip rate interpreted from the Gibbston trench, is to retain the suggestion of Barrell (2019) of treating the fault deformation on the Branch Burn strand as a minimum representation of movement on the NW Cardrona master fault.

I regard as robust the re-interpretation of data from the Gibbston and Macdonalds Creek trench localities indicating that two, rather than three, surface ruptures are represented in the geological records there. Also, the analyses of van den Berg et al. (2025) show sufficient similarity of times of occurrence of surface ruptures at Gibbston and Macdonalds Creek that they could be the same ruptures (though does not prove that they were). Those authors also note that there is no structural geological reason (e.g. changes in strike or hanging wall morphology) to indicate a segment boundary on the NW Cardrona Fault.

Overall, this highlights a need for re-evaluating the NW Cardrona Fault characterisation. Previous interpretations of the three-rupture scenario necessitated the occurrence of relatively small single-event displacements that were difficult to reconcile with the relatively long fault length of about 60 km. In consequence, the NW Cardrona Fault has previously been characterised as comprising two rupture segments, Cardrona North and Cardrona South (Stirling et al. 2012; Litchfield et al. 2013, 2014). The relatively short length of each segment was compatible with the relatively small single-event displacements. This approach was continued by Barrell (2019) and also brought forward (by the writer) to the NZ CFM as two ~30-km segments, NW Cardrona North and NW Cardrona South. To re-evaluate this interpretation, I applied the 2010 NSHM methodology, using the Gibbston dip-slip rate range (0.29 to 0.36 mm/year), to the two-segment scenario (each 30 km long) and a whole-fault scenario (60 km length). The two-segment scenario is analogous to that presented by Barrell (2019), noting that it was applied to a slightly higher slip rate of 0.38 mm/year. Applying the 0.32 ± 0.3 mm/year slip rate to the 30-km long segments returns an average recurrence interval of between 5200 and 7900 years (median 6500 years) and single-event displacement of 2.1 ± 0.2 m. In contrast the whole-fault scenario produces an average recurrence interval range of 10,400 and 15,800 years (median 13,200 years) and single-event displacement of 4.2 ± 0.4 m.

The whole-fault rupture scenario therefore accords better with the trench investigation evidence of only two surface ruptures in the past ~25,000 years (at least three ruptures would be expected with the two-segment scenario), and single-event displacement that is similar to that interpreted from the Gibbston trench information. There is also broad compatibility with the median recurrence interval of 11,800 years from the Macdonalds Creek trench data. The lesser single-event displacements and slip rate at Macdonalds Creek is inferred to reflect incomplete surface emergence of rupture displacement on the buried master fault.

Based on the above, the fault parameters presented by Barrell (2019) are amended in this report to an indicative slip rate of 0.32 mm/year, indicative recurrence interval of 13,200 years, and RI Class V (>10,000 to ≤20,000 years).

A1.2.14 Pisa Fault Zone

This northeast-striking fault zone is identified as feature 20 in the Barrell (2019) report (though incorrectly called feature 21 in the report's Appendix 2). There is now full coverage of the area of the fault zone in a photogrammetry DSM. This has enabled a more accurate assessment of fault-related deformation features. In addition, the fault was recently investigated, with dating of fault-deformed and undeformed alluvial fan terraces, in a University of Otago research project (Vause 2025).

A1.2.14.1 Reassessment of Landform Ages

The DSM has enabled much better interpretations of landform features, and the topography has been examined along the entire length of the fault zone. Surface deformation in the Pisa Fault Zone is expressed almost entirely as monoclinal folding, and the DSM information has allowed many improvements in the positioning and confidence of interpretation of the deformation.

A landscape aspect revealed in new detail by the DSM and relevant to the interpretation of faulting is the older glacial landforms of the upper Clutha valley. There are interpreted to have been three glacial episodes when ice from the Wanaka-Hawea catchments extended down the upper Clutha valley into the Cromwell Basin, with glacier terminal positions in the vicinity of Cromwell. These episodes are named, from older to younger, the Northburn Advance, Lowburn Advance and Lindis Advance (NZGS 1984; Beanland and Berryman 1989; McSaveney et al. 1992; Turnbull 2000). Deposits and landforms of the most recent episode, the Lindis Advance, are the best preserved, especially in high terraces near Lowburn, and in the Tarras to Bendigo area.

It is well documented that a glacial lake formed in the trough evacuated by the glacier at the end of the Lindis Advance (NZGS 1984; Beanland and Berryman 1989; McSaveney et al. 1992; Turnbull 2000), with silty lake sediments extensively preserved in and beneath the valley floor. McSaveney et al. (1992) report the dating of a calcite concretion collected from Lindis glacial lake silt overlying schist bedrock on the eastern side of the Clutha valley, just up-valley of the glacial terminus. The sample's map grid reference given by McSaveney et al. (1992) places it on the slope above State Highway 8, adjacent to 'Lions' lookout, ~9.2 km road distance northeast of Dead Mans Point bridge near Cromwell, at an elevation of ~265 m above sea level (asl) according to the DSM. The concretion was dated by the uranium-thorium (U/Th) method and yielded a median age of 413 ka, + infinity and -85 ka (McSaveney et al. 1992).

The interpretation of ages of the older upper Clutha glacial sequence is discussed by Barrell (2011, 2019). Turnbull (2000) correlated the deposits of the Lindis Advance with the Kawhaka Glaciation (MIS 12: 424 to 478 ka[8]), although Barrell (2011) noted that the concretion dating (and its uncertainty ranges) does not preclude correlation of Lindis Advance with the Nemona Glaciation (MIS 10: 337 to 374 ka). Barrell (2019) also noted the possibility that the interpreted older Lowburn Advance glacial deposits and landforms may be tectonically uplifted Lindis Advance features.

The Lindis Advance ice margin on the eastern side of the Cromwell Basin is marked by a semi-continuous series of terraces and benches cut on schist bedrock, with remnants of glacial till deposits (Turnbull 2000). Elevation profiles generated from the DSM are a useful adjunct to interpretation. Over a ~5 km distance south from the Bendigo area, the mapped ice margin decreases in altitude ~70 m, equating to a fall of ~14 m per km. This compares well with examples of other ice-age glaciers, such as the one that occupied the Lake Pukaki valley in the Waitaki River catchment, whose ice margin, at the final advance of the last glaciation, decreased in altitude ~60 m over a 5-km distance (Barrell and Read 2014). In contrast, outwash plains typically have notably gentler gradients than their source glaciers. For example, the last glaciation Albert Town and Hawea glacial outwash terraces

[8] MIS = Marine Isotope Stage geological time-scale. Ages given here are from Lisiecki and Raymo (2005).

preserved in the upper Clutha valley floor in the Tarras area both decrease in altitude by ~15 m over 5 km, representing a fall of 3 m per km and approximating the gradient of the Clutha River valley floor (i.e. excluding any sinuosity).

Another feature of the eastern side of the Cromwell Basin, slightly below the elevation of the mapped ice margin near the location of the U/Th dating site, is a line of semi-continuous remnants of terraces and benches cut on the bedrock schist, identified on the Turnbull (2000) map as a MIS 10 outwash terrace, extending up-valley for ~12.5 km to just north of Bendigo. However, the DSM shows that this terrace is horizontal, at an elevation of ~290 m asl. If its interpretation as a fluvial terrace were correct, it should have a fall of ~40 m over that distance. Its horizontal character means that the only viable interpretation is that it is a lake shoreline terrace, and its interpretation as a remnant of the Lindis glacial lake shoreline is straightforward. As far as I am aware, this is the first recognition of a shoreline from that ancient lake.

On the western side of the valley, at the northern end of the high terrace ~8 km north of Cromwell and near Pisa Moorings (a locality referred to here as Five Mile Creek), a remnant of the MIS 10 terrace (lower terrace) is mapped as the base of a ~20 to ~30 m high riser up to the main Lindis outwash terrace (higher terrace). Based on the evidence from the eastern side of the valley, I interpret the terrace riser and lower terrace as a shoreline cliff and shoreline terrace of the Lindis glacial lake. Significantly, the DSM shows, without ambiguity, that the terraces and terrace riser are warped over a monoclinal fold, with a vertical component of deformation of ~55 m (Figure A1.2). The monocline represents a locus of Pisa Fault Zone Quaternary tectonic deformation in this area. The monocline, defined primarily from bedrock geological relationships, is named Smallburn Monocline by Beanland and Berryman (1989), and illustrated in cross-section in that paper. Their interpretation is that the monocline has substantially deformed the Lowburn-age glacial deposits but has not deformed the Lindis outwash terrace. The new evidence from the DSM showing the substantial monoclinal deformation of the Lindis terrace (Figure A1.2) demonstrates that the previous interpretation is incorrect. It indicates a desirability of reviewing the geomorphological and tectonic interpretations in the high terrace and low hill terrain north of Cromwell.

The Vause (2025) research project included determining the length of time that boulders have been exposed at the ground surface using the cosmogenic nuclide surface exposure dating (CRN) method (see footnote in report text). That work was focused on the area farther up-valley around Lochar Burn, but included dating on the Lindis glacial outwash terrace, within 1.4 km south of the area shown in Figure A1.2. Vause (2025) referred to that terrace as ‘T4’, and the adjacent ‘Lowburn’ terrace on the crest of the monocline as ‘T5’. Vause (2025) inferred that slightly lower terraces on the upthrown side of the fault zone at Lochar Burn are also ‘T4’ and T5’, elevations of ~300 m and ~340 m respectively. However, as the upwarped shoreline terrace at Five Mile Creek stands at ~350 m (Figure A1.2), I think it highly unlikely that T4 and T5 between the two localities are age-correlative.

Vause (2025) collected samples from T4 and T5 terraces at each locality, but only those from the T4 landforms were analysed in time for inclusion in the thesis. My view is that the terrace sequence at each locality needs to be considered independently on its own merits, and therefore disagree with the Vause (2025) approach of combining of dates from T4 at both the Lochar Burn and Five Mile Creek localities to obtain an overall age for T4 (given as 125.3 ± 37.1 ka). There is a wide scatter of ages, and younger ages were selected in preference to older ages to arrive at the overall age.

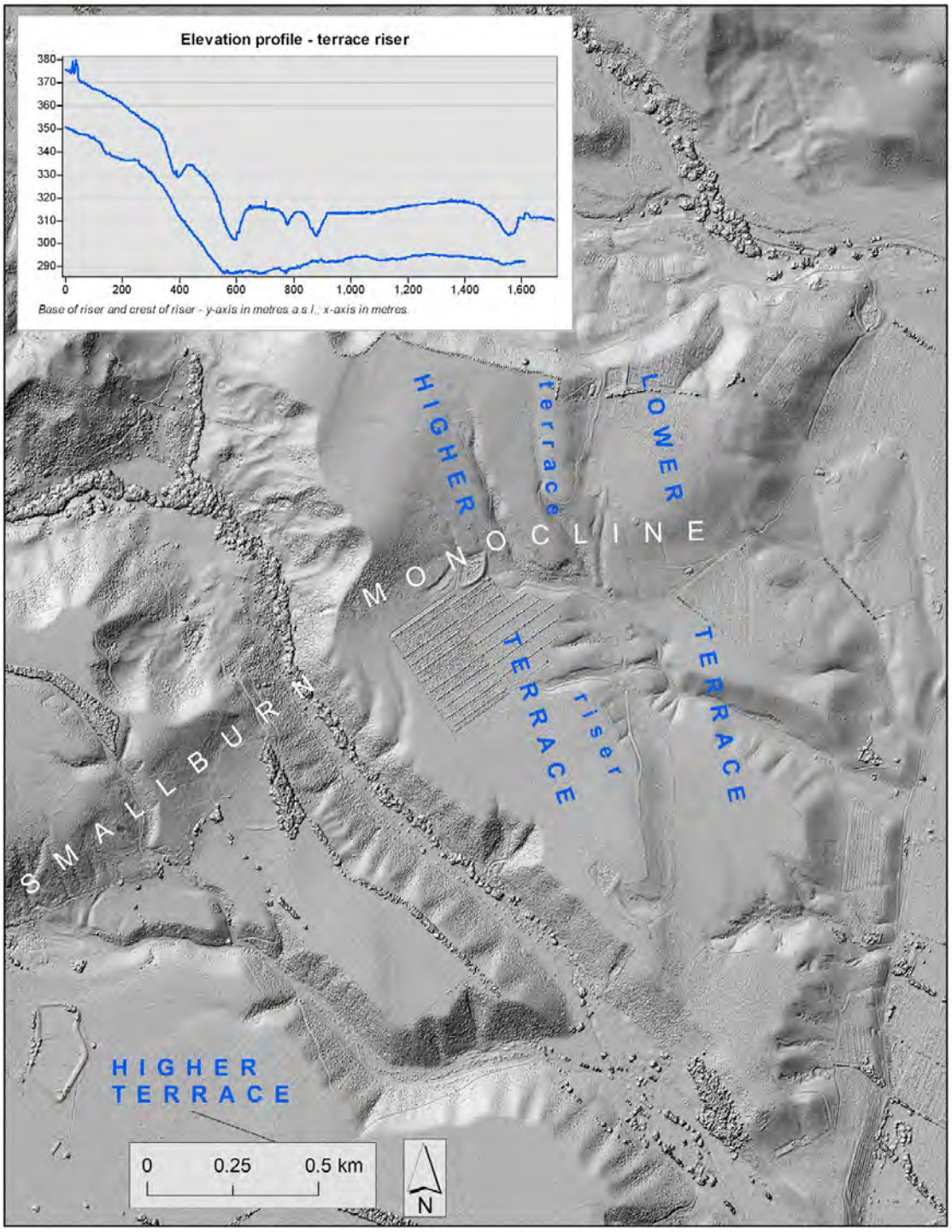


Figure A1.2 The photogrammetry DSM in the vicinity of Five Mile Creek, with interpreted geomorphological features annotated. Valley at centre is Five Mile Creek, immediately northwest of Pisa Moorings village, on Lake Dunstan's western shore. DSM-generated elevation profiles along the crest and base of the riser between the two terraces (terrace riser; profile lines omitted from the map for clarity) maintains its height across the monocline, illustrating it and the terraces have undergone ~55 m of monoclinal vertical deformation. The higher terrace is the Lindis glacial outwash plain, while the terrace riser and lower terrace are interpreted to be associated with the Lindis glacial lake shoreline.

Here, I consider only the five CRN dates obtained by Vause (2025) from the Lindis outwash terrace ('T4') at Five Mile Creek. Reported ages from youngest to oldest are 110.9 ± 3.7 ka, 121.9 ± 4.3 ka, 197.4 ± 7.0 ka, 320.2 ± 11.8 ka and 513.0 ± 19.0. Independent age information is available from the previously dated lake silt concretion. The concretion must be somewhat younger than the outwash surface that was abandoned due to glacier retreat that allowed the lake to form. The younger bound for the concretion date (328 ka) implies that the three younger CRN dates from the Lindis outwash terrace should be treated as minimum representations of the terrace's age of formation. Likely reasons for 'too-young' dates arise from various post-depositional processes, such as removal of original boulder surfaces by erosion, or post-depositional boulder exhumation by soil erosion. The second-oldest boulder date, in combination with the concretion date, would support a minimum estimate of ~330 ka for formation of the Lindis outwash surface at Five Mile Creek. This scenario would indicate that the oldest date arises from prior exposure of the boulder to cosmogenic radiation. On the other hand, the oldest date might be the only reliable indicator of the outwash surface's age of formation, with all other boulder dates affected by post-depositional processes. This possibility is not contradicted by the concretion date, with its maximum bound of infinity. Thus, the indicated age range for the outwash surface is between 330 and 532 ka (older bound of the oldest date), which can alternatively be expressed as 431 ± 101 ka. If the median age is taken as indicative, it places formation of the Lindis outwash surface (and thus culmination of the Lindis Advance) at Five Mile Creek late in the MIS 12 Kawhaka Glaciation, just before onset of the MIS 11 interglacial. This aligns with the Turnbull (2000) age interpretation.

At Lochar Burn, alluvial fan terraces on the true right (southwest) show differential amounts of deformation. Earlier investigations (NZGS 1984; Beanland and Berryman 1989) included survey levelling, trenching and drilling investigations and found that the deformation is a monoclinal fold (Lochar Monocline of the dataset reported here), with minor subsidiary faulting (Figure A1.3). Vause (2025) undertook detailed aerial photography via UAV to produce a high-resolution DSM, and cosmogenic dating of boulders on the alluvial fan terraces (the Lochar Burn true-right terraces are referred to in the thesis as the Tinwald Burn site). The older terrace ('T3') has 11.0 m of vertical deformation and an age of 62.0 ± 8.8 ka. The younger terrace ('T2') is reported as having 7.9 m of vertical deformation and an age of 45.6 ± 6.4 ka.

Through generation of topographic contours and multiple profile lines on the photogrammetry DSM, I confirm the 11 m throw on T3, but cannot replicate the reported 7.9 m throw on T2. Instead, I obtain 5 m throw on the T2 terrace surface and suspect the inaccuracy of the Vause (2025) value is an artefact of the modelling approach that was used in profile generation. The T2 and T3 surfaces have vertical separation of 5 m downstream of the monocline, and 11 m upstream of the monocline (Figure A1.3). This indicates that 6 m of throw affected the T3 surface prior to formation of the T2 surface. The difference in terrace height downstream of the monocline reflects fluvial processes. Lochar Burn was incised about 5 m lower than the T3 terrace on the downwarped side, at the time the T2 fan surface was formed. The similarity of amounts of fluvial incision to the vertical deformation before and after the T2 terrace was formed is simply coincidence.

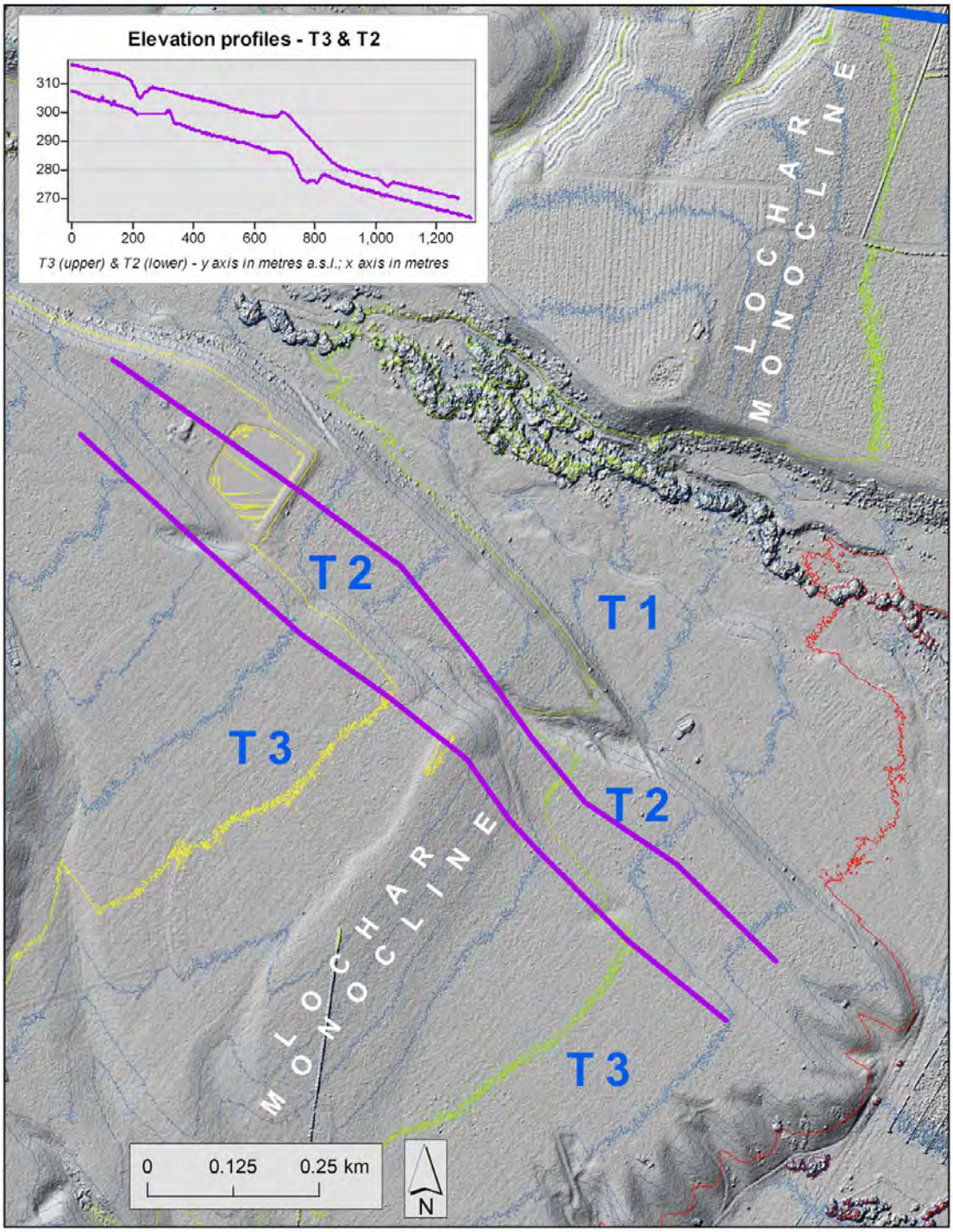


Figure A1.3 Map showing the photogrammetry DSM at Lochar Burn, with interpreted geomorphological features annotated. Topographic contours (light blue) generated from the DSM, with the 300 m, 275 m and 250 m contours respectively in yellow, green and red. The DSM incorporates surface features such as trees, buildings, dams and fences, which are included in the contouring. Crossing the line of the monoclinal fold are Lochar Burn alluvial fan terraces T1 (lowest, undeformed), T2 (intermediate, deformed) and T3 (more deformed). Purple lines denote locations of the elevation profiles that are inset at top left.

Adjacent to the confluence of Lochar Burn and the Clutha River, Vause (2025) reports OSL dates of sediments from Clutha River terraces. The main terrace surface, identified as 'T1a', and an inset lower terrace surface referred to as 'T1b', stand respectively ~28 and ~23 m higher than the Clutha River according to the DSM. Three OSL dates obtained from sediments associated with the T1a terrace range from ~22 ka to ~32 ka, with an average age of 27.2 ± 4.2 ka. The DSM coverage is sufficient for profiling of Clutha outwash terraces in the Cromwell Basin, back upstream to glacial moraines at the source of each outwash surface in the Wanaka/Hawea area. Correlation between T1a and the 'Mt Iron' moraine/outwash is suggested by Vause (2025), but my profiling upstream to the moraines supports its mapping by Turnbull (2000) as an Albert Town terrace. The DSM shows the T1b terrace to be a degradational terrace associated with the extensive Lochar Burn fan that overlies the Albert Town terrace. The degradation occurred where stream drainage cut through the edge of the Albert Town terrace to reach the level of the Mt Iron/Hawea outwash surface, or possibly a lower post-glacial degradation terrace, of the Clutha River.

Vause (2025) undertook CRN dating of two boulders on what is mapped as a Hawea outwash terrace near Maori Point, ~10 km up-valley from Lochar Burn and beside State Highway 8A. These boulders are part of a conspicuously bouldery deposit on, and within, the Hawea outwash gravel (McKellar 1960). The boulders are regarded as a lag deposit of bouldery landslide debris that has been reworked by fluvial action of the Clutha River (R. Thomson conversation with D. Barrell, late 1990s). The Hawea outwash terraces comprises an aggradation surface, flanked by a set of degradational terraces registering progressive fluvial incision of the Clutha River following the end of the last glaciation, locally dated at ~18 ka (McKellar 1960; Barrell 2011). DSM profiling highlights that the two boulders are on a degradational Hawea terrace, about 4 m lower than the main aggradation surface, and returned CRN dates of 15.8 ± 0.5 ka and 16.0 ± 0.5 ka. They provide a minimum age for formation of the Hawea aggradation surface, and a constraint on the timing of post-glacial fluvial degradation of the upper Clutha valley.

Remnants of the Luggate outwash terraces are too few and too discontinuous to allow an assessment of whether, and by how much, the Luggate outwash profile is deformed across the Pisa Fault Zone. In contrast, the Albert Town outwash surface is represented by numerous and relatively continuous terrace remnants, and profiling confirms previous assessments that the Albert Town outwash terrace profile is not discernibly (i.e. metre-scale) deformed where it crosses the projected location of the Pisa Fault Zone, and therefore was formed after the most recent Pisa Fault Zone deformation. Vause (2025) correlated the T2 terrace at Lochar Burn with the Albert Town outwash terrace of the Clutha valley. A key characteristic of the Albert Town outwash terrace is that it post-dates the most recent Pisa Fault deformation, and I think the T2 terrace at Lochar Burn would better be regarded as an un-named component within the alluvial fan terrace sequence.

As discussed above, the Vause (2025) OSL dates suggest a T1 age of ~27 ka, which I interpret as an Albert Town rather than Hawea outwash gravel deposit. A preferred correlation of the Albert Town moraine/outwash with MIS 4 (57 to 74 ka) by McSaveney et al. (1992) was adopted in the geological map dataset of Turnbull (2000), but was questioned by Barrell (2011) who considered that the Albert Town landform character and soil development indicate a younger age (e.g. MIS 2: 14 to 29 ka). Dating from elsewhere in the Southern Alps indicates that a prominent episode of glacier advance occurred between ~29 and ~25 ka, identified as Otira Glaciation Stadial E by Barrell et al. (2013). This episode is represented by well-dated moraines preserved in the Pukaki valley (Denton et al. 2021) and Tekapo valley (Strand et al. 2024), as a component of the Mt John Formation glaciogenic deposits of the upper Waitaki River catchment. The Albert Town moraines/outwash are tentatively interpreted as a prominent representation of that glacial episode in the upper Clutha catchment.

A1.2.14.2 Reassessment of Deformation Estimates

The updated age range and the newly recognised deformation of the Lindis outwash terrace and lake shore provide a long-term perspective on deformation rate for the Smallburn Monocline, and by implication, the Pisa Fault Zone. The 55 m of vertical deformation between 330 and 532 ka produces a vertical deformation rate of between 0.10 and 0.17 mm/year. Resolved onto an assumed 45° dipping fault plane with pure dip slip, this affords a net slip rate of 0.14 to 0.24 mm/year.

Turning to the deformation of the Lochar Burn alluvial fan terraces, as confirmed here with throws of 11 m on T3 and 5 m on T2, the amounts of net slip, if resolved onto an assumed 45° dipping fault plane with pure dip slip, are 15.6 m (T3) and 7.1 m (T2). Considering the older and younger bounds on the ages (T3 – 62.0 ± 8.8 ka; T2 – 45.6 ± 6.4 ka), net slip rate since T3 was formed has been in the range of 0.22 to 0.29 mm/year, and only 0.18 to 0.14 mm/year since T2 was formed.

The evidence indicates that no surface deformation has been registered on the Pisa Fault Zone, at least in the northeastern part of the Cromwell Basin, since formation of the Albert Town outwash deposits at 27.2 ± 4.2 ka (an age range of 23.0 to 31.4 ka). This constrains the timing of the 15.6 m of net slip associated with deformation registered on the T3 alluvial fan terrace, to between the younger age bound of the Albert Town outwash terrace (23.0 ka) and the older age bound of the T3 terrace (70.8 ka). Across that 47.8 ky time interval, the minimum average net slip rate was 0.33 mm/year. Similarly, the Albert Town older age bound and the T3 younger age bound constrain a maximum average net slip rate of 0.72 mm/year. This means that the slip rate associated with the most recent episode of repeated activity on the Pisa Fault Zone was notably greater than the long-term slip rate estimates. Together with the observation that no surface deformation has occurred since at least 23 ka, this supports previous interpretations that the Pisa Fault Zone exhibits episodic clustering of rupture activity.

The discovery of substantial (~55 m vertical) deformation of Lindis outwash and shoreline features at Five Mile Creek invites re-examination of fault interrelationships. A similar amount of deformation is documented in Lindis lake silt near Queensbury, and 50 m of vertical deformation of a buried geological unit at Lochar Burn was identified by geophysics and drilling, with these two localities illustrated by Beanland and Berryman (1989). Barrell (2019) suggested that the ~50 m height difference between mapped Lowburn and Lindis deposits across the Cluden fault zone north of Tarras may be tectonic. This means that combined rupture of the Pisa and Cluden fault zones, as interpreted by Beanland and Berryman (1989) should be considered a notable, and perhaps preferred, option for fault behaviour. This would give an overall fault length of 60 km, from near Cromwell to northeast of Tarras.

For the purposes of re-evaluating activity characteristics for the Pisa Fault Zone, I adopt the median value of the long-term slip rate (i.e. 0.19 mm/year) as a suitable representation that accommodates the effect of interspersed active and non-active episodes. Applying the 2010 NSHM methodology, with a best estimate fault length of 60 km, produces an average recurrence interval of 22,000 years, and net single-event displacement of 4.2 m. In relation to an assumed 45° fault dip, that single-event displacement comprises a 3.0 m vertical component. That in turn provides a basis for interpreting the ~11 m vertical deformation of the most recent episode of fault activity registered on the Lochar Burn alluvial fan terraces as the accrued result of four surface rupture deformation events. Finally, the average long-term recurrence interval is of similar order to the time elapsed since the most recent rupture and indicates little room for complacency regarding earthquake hazard for the Pisa Fault Zone.

A1.2.14.3 Fault Mapping Revisions

These descriptions proceed from southwest to northeast along the fault zone.

Northwest of Cromwell, the DSM has revealed a previously unrecognised array of small fault scarps in subdued hill terrain near the northwestern end of Burn Cottage Road, close to the range-front. Each scarp is no more than a few metres high and all except one are upthrown to the southeast, thus having

the appearance of antithetic faults. They are variously classified as ‘definite’ through to ‘possible’, depending on how continuous they are. Previously, the main strand of the Pisa Fault had been mapped through this area, an interpretation that is difficult to reconcile with the absence of an expected up-to-the-northwest step in this relatively high elevation terrain, and also not easily reconcilable with these indicated antithetic faults. A short southeast-facing fault scarp has been removed as its presence is not supported by the DSM information. A strand of the ‘master’ fault adjacent to the Smallburn Monocline was also removed, due to the now-increased significance of Quaternary activity on the monocline compared to what was previously thought.

The prominent tectonic deformation affecting the Lindis component of the upper Clutha high terrace sequence near Five Mile Creek is not evident along strike to the southwest, as mentioned above. However, to the south, high ground at the northwest margin of Lindis terrace remnants (the higher ground mapped as a Lowburn terrace) is considered a prospective continuation of the fault-related deformation registered across Lindis landforms at Five Mile Creek. Connecting these two areas has necessitated drawing a sharp southeasterly dogleg of the fold trace down the valley of Low Burn, and from there, returning to a southwesterly trend towards Ripponvale. This dogleg corresponds broadly to a southeasterly shift, of similar amount, in the position of the foot of the Pisa range-front, offering some reinforcement for the fold dogleg interpretation. A southeasterly-stepped fold structure is compatible with the array of apparently antithetic faults to its northwest near Burn Cottage Road.

The DSM has enabled the high-confidence placement of the monoclinal fold trace for the ~8 km from Park Burn to just northeast of Lochar Burn, with moderately to well-expressed sections across older landforms, and ‘not expressed’ connectors under stream valleys. Near Queensbury, the fold expression dies out, but there is good confidence that the active structure continues through this area, because deformed lake silts occur farther northeast near the Cluden/Grandview/Pisa fault convergence (Beanland and Berryman 1989; Barrell 2019). The concealed (‘not expressed’) fold trace is re-positioned to avoid remnants of Luggate-age outwash terraces that should show deformation but appear to be undeformed. Otherwise, much of this area comprises relatively young fans and terraces that are anticipated to be younger than the most recent deformation.

On the northwestern (upwarped) side of the Lochar Monocline, there is a ~1.5 km wide belt of somewhat higher terrain. An antithetic fault, upthrown to the southeast, is tentatively inferred along the northwestern margin of this belt, and is classified as ‘possible’, ‘not expressed’. North from Lochar Burn, there is a prominent up-to-the-southeast topographic scarp running across the ice-smoothed bedrock foot of the Pisa Range, which is classified as a ‘moderately expressed’ section of this inferred fault.

A1.2.15 Raggedy – Blackstone Fault

This fault lies along the southeastern side of the Raggedy Range to Blackstone Hill ridge. The Blackstone Hill section of this ridge is to some extent a fault block and to some extent an anticlinal fold (Markley and Norris 1999; Barrell 2019). This fault has previously been referred to as the Raggedy Fault or the Blackstone Fault, with Barrell (2019) preferring the latter due to precedence of first publication. It has now been identified in the NZ CFM as the ‘Raggedy – Blackstone Fault’, and that name is adopted in this revised fault dataset. There is now full coverage of the fault by lidar DEM, which has enabled improvements to fault mapping and interpretations.

The existence of two short strands of active fault depicted on QMAP near the junction of Pool Burn and Ida Burn, which appear to have been originally mapped based on topographic considerations, is not supported from by lidar information. Both can be adequately reconciled as the result of fluvial erosion, and they have been removed from the fault dataset. The eastern of these features related to a topographic step on an isolated high terrace in the middle of the Ida Valley, near the Pool Burn and Ida Burn confluence. Gradient profiling using the lidar DEM indicates former connection between this high terrace remnant and a high-level alluvial fan in the northern part of the Ida Burn catchment.

Most of this former fan has been eroded away in the Ida Valley. The topographic step on the high terrace previously regarded as fault-related can be satisfactorily interpreted as an Ida Burn fluvial degradation terrace.

The lidar DEM has enabled the mapping of likely and possible faults across alluvial fans a short distance out from the foot of the Raggedy Range, over about a 10-km distance from near Poolburn southwest to near Moa Creek. All these topographic steps are down to the southeast, with typical heights of 2 to 5 m, locally as much as ~10 m. In many cases the high sides comprise high-standing fan remnants, around the southeast sides of which younger fan sediment has accumulated. It is possible that the steps may have been formed by fluvial erosion of fans by Moa Creek or Pool Burn, flowing down the valley axis, with the base of the steps later buried by younger fan sedimentation. This is why most are mapped as 'likely', 'moderately expressed'. There is one location where one of these steps unambiguously displaces an alluvial fan surface, and is classed as 'definite'. This information supports the interpretation of other similar topographic steps as 'likely' fault scarps.

The position of the main fault strand has not been modified from its location in QMAP. It remains classified as 'possible', 'not expressed', except for a section near Poolburn that coincides with higher topography immediately to the northwest, which is classified as 'moderately expressed'. With removal of the QMAP active fault strands near the Pool Burn/Ida Burn confluence, a 'possible', 'not expressed' connector is drawn between similar strands at the bases of the Raggedy Range and Blackstone Hill.

The fault activity characteristics from Barrell (2019) have been incorporated into the NZ CFM. No changes have been made to those parameters for this report.

A1.2.16 Ranfurly Fault Zone

The Ranfurly Fault Zone (feature 35 of Barrell 2019) now has coverage by a photogrammetry DSM, enabling improved mapping of the fault scarps, and this was aided by brief field reconnaissance from roads. About half of the fault scarps have been removed, as the new information does not support their existence. 'Possible' extensions of the fault zone for 6 km to the southwest are also not supported, and these were also removed. Other information from Barrell (2019) remains valid. The Ranfurly Fault Zone is characterised in the NZ CFM using information from Barrell (2019). The fault length in the dataset described in this report is now reduced to 20 km. Using 2010 NSHM methodology with a preferred slip rate of 0.1 mm/year, the recurrence interval is reduced to ~14,000 years. These values are also applied to the Launceston Fault.

A1.2.17 Rocks Creek Fault Zone

This array of northeast-striking features is identified as feature 24 in the Barrell (2019) report. There is full coverage by lidar DEM which has enabled the more accurate repositioning of the fault and fold features associated with Vulcan Fault and Tunnel Hill Fault components of the Rock Creek Fault Zone. Some faults have been reidentified as monoclinal folds, and vice versa, and several new features added. No changes have been made to the fault activity characterisation, and the fault zone is included in the NZ CFM using the activity parameters from the Barrell (2019) report.

A1.2.18 Stranraer Fault (Waihemo Fault Zone and Home Hills Fault Zone)

Barrell (2019) associated the approximately west–east-striking Stranraer Fault as a component of the northwest-striking Waihemo Fault Zone, noting similarities of size and assumed age of the definite fault scarp on the Stranraer Fault at Little Kye Burn, and likely scarps farther east near the northwestern end of the Waihemo Fault Zone.

There is now lidar DEM coverage in the west and full photogrammetry DEM coverage of the northern part of the Maniatoto Basin. This information has enabled recognition of two short 'likely', 'well expressed' scarps coinciding with the Home Hills Fault Zone, which represents the westward along-strike equivalent of the Stranraer part of the Waihemo Fault Zone. The western 'likely' scarp crosses a fan terrace on the true left (east) side of the Hills Creek valley, is ~5 m high and is down to the south. I judge it borderline between 'likely' and 'definite'. The other scarp crosses a fan terrace on the true left (east) side of the Ida Burn valley, and is also ~5 m high and down to the south.

The DSM coverage now extending across the Little Kye Burn area has enabled refinements of the Barrell (2019) estimated heights of the Stranraer Fault definite scarp there. A photo of the terraces and scarp is presented in Figure 5.9 of the Barrell (2019) report. The DSM confirms that on the true right (west) bank of Little Kye Burn, the main valley-floor terrace ('low terrace') is ~20 m above the modern stream bed and is not faulted. A middle terrace, standing 14 m higher than the low terrace downstream of the fault, is crossed by a fault scarp, down to the south. Scarp height varies from ~6 m to ~10 m, the larger value associated with an 'island' of higher terrace on the eastern (valley-ward) side of the middle terrace. Its occurrence on only the upthrown side of the fault suggests a fault uplift event during formation of the then valley-floor (later to become a terrace). Overall, I regard the ~6 m scarp as best representing the offset since fluvial abandonment of the middle terrace level.

A somewhat higher terrace, preserved only upstream of the fault scarp, stands ~12 m higher than the middle terrace. If its preservation there is purely due to uplift north of the fault, it implies ~12 m of uplift prior to formation of the intermediate terrace. Alternatively, this higher terrace's absence downstream of the fault may be because it has been removed by fluvial erosion. Along-trend projection of the fault scarp into adjacent hill terrain coincides with a notable topographic step in the hill terrain (this terrain is called 'high terrace' in the Barrell [2019] Figure 5.9 illustration), with ground immediately north of the fault projection standing ~20 to ~40 m higher than ground to the south. The Stranraer Fault is recognised geologically by distinctive stratigraphic juxtapositions across a wide and complex fault zone (Bishop 1976, 1979; Forsyth 2001). This trend of higher versus lower hill terrain can be traced broadly westward through ground extensively disrupted by historic gold mining, while still coinciding with the fault zone.

The Stranraer Fault has been repositioned along that change in terrain height, and classified as 'likely', 'not expressed'. This allows it to plausibly be connected to the likely fault scarp at Ida Burn described above. I have then removed several short, geologically mapped, fault splinters in the fault zone, on the grounds that a satisfactory contiguous interpretation of the Stranraer active fault has now been achieved, aided by DSM information. The new depiction of the Stranraer Fault is ended at the Raggedy – Blackstone Fault, as no scarps are evident along-trend on the west side of that latter fault. In that area, the dataset retains remaining components of the Home Hills Fault Zone, on the same basis as described by Barrell (2019).

For quantifying fault activity, I reuse the assessment of Barrell (2019) of assigning the middle terrace of the Little Kye Burn valley a nominal age of 100,000 years. The fault scarp crossing the terrace indicates a vertical component of fault offset of 6 m (now confirmed by DSM). Assuming a fault plane dipping 60° and pure dip-slip motion, a net slip rate of 0.07 mm/year is indicated. The length of Stranraer Fault as mapped in the dataset described here is ~30 km. Applying that length within the 2010 NSHM methodology, a recurrence interval of ~30,000 years is calculated.

A1.2.19 Timaru Creek Fault

This northeast-striking feature is identified as feature 16 in the Barrell (2019) report. There is now coverage of the Lindis River headwaters in a photogrammetry DSM. This has enabled the more accurate repositioning of lines representing the fault scarps in the Lindis River valley, with positions shifted by as much as 100 m.

On the Johns Creek strand of the fault, the DSM reveals a previously unrecognised fault scarp across an alluvial fan about 1.5 km northeast of the previously identified fault scarp. The Certainty parameter in this area is raised from 'likely' to 'definite', and the scarp classified as well expressed.

No other changes are made to the mapping or characterisation of the Timaru Creek Fault. The fault has been included in the NZ CFM using the activity parameters from the Barrell (2019) report.

A1.2.20 Waihemo Fault Zone

This major northwest-striking fault lies along the southwestern foot of the Kakanui Mountains, and is identified as features 26 and 37 respectively in the Barrell (2016) and Barrell (2019) reports. The only amendment made here to what is in those previous reports is to recalculate the recurrence interval based on a reduced fault length, due to the separation of the Stranraer Fault as a stand-alone entity. The new length of the Waihemo Fault Zone to 68 km. Adopting a slip rate of 0.12 mm/year (Barrell 2019) and applying the 2010 NSHM methodology, results in a recurrence interval of ~40,000 years.

A1.2.21 Waipiata Fault Zone

With there now being complete coverage of the Waipiata Fault Zone (feature 38 of Barrell 2019) by photogrammetry DSM, several revisions have been made to its mapping. Topographic evidence for a fault scarp on the 'Waipiata Fault Zone – Waipiata strand' is discussed by Barrell (2019). The best evidence is in an area about 7 km southwest of Waipiata, where a distinct topographic step across alluvial fan terraces extends about 2 km southwest from the Pig Burn streambed. Barrell (2019) expressed caution that rather than being a fault scarp, it conceivably may be a fluvially-cut step, related to drainage from adjacent tributary fans to the southwest. However, the photogrammetry DSM, from which I generated 5-m interval topographic contours to aid examination of the landscape in this area, shows without ambiguity that the landform crossed by the topographic step comprises north-sloping alluvial fans, and the step displaces the fan surfaces. It is therefore reclassified as a definite, well expressed, fault scarp. Profiling of the DSM shows the fault scarp is between 3.5 and 4 m high, and that on an inset alluvial fan surface immediately southwest of the Pig Burn bridge, the fault scarp is the same height as it is on the alluvial fan further southwest.

The recognition of this feature as a definite fault scarp has provided a basis for generally increasing the confidence that the Waipiata strand is an active fault, described as follows. The fault is mapped across low hill terrain for ~3.5 km northeast of Pig Burn, and this section is reclassified as 'definite', 'moderately expressed'. A further ~1 km long section farther northeast is classed is likely, because it has a stream running along its foot, and its appearance may be fluvially influenced. Northeast from the Taieri River, where there is no discrete topographic expression of faulting, it remains classified as 'possible'.

Southwest from the 'definite' fault scarp on the Pig Burn alluvial fan, a topographic step across low hill terrain has been reclassified from 'possible' to 'likely', and from 'not expressed' to 'moderately expressed', except for some short 'not expressed' sections across gullies and across the Sow Burn valley floor at Patearoa. Southwest of the Sow Burn valley, a distinct topographic step between ~4 and ~10 m high at the northern margin of low hill terrain was previously mapped as a 'possible', 'moderately expressed' active fault, and is reclassified as 'likely'. A previously depicted extension a further ~2.5 km southwest beyond the end of the topographic is retained as 'possible', 'not expressed', but its position is shifted slightly southward to more closely follow the base of the low hill terrain.

In the Kye Burn valley, the Clunie strand of the Waipiata Fault Zone was interpreted by Barrell (2019) to comprise two monoclines. The photogrammetry DSM does not support the existence of short fault scarps inferred on the crest of the northwestern monocline, and these are removed from the dataset. The northwestern monocline comprises a broad topographic step that parallels, and is antithetic to, the main Waipiata Fault Zone. These considerations support its tectonic interpretation, but the

southeastern monocline, on a divergent trend, is re-interpreted as fluvial erosion feature and removed from the fold dataset. The interpretive measure supporting the original mapping of this now-removed fold was a subdued topographic form, but this is also attributable to sediment accumulation (e.g. windblown sand and silt) along the foot of the step. The northwestern monocline, while also subdued, has morphological aspects revealed in the DSM, such as terrace remnants near its crest that trend southwest down-valley but have surface gradients towards the southeast, possibly indicative that they have been tilted. Interpretation of this feature being a 'likely', 'moderately expressed' monocline is maintained.

A1.2.22 West Wakatipu Fault

With the aid of a photogrammetry DSM, minor refinements have been made to mapped positions of the two 'definite' fault scarps of the West Wakatipu Fault (feature 2 of Barrell 2019) east of Mt Nicholas. Profiling of the DSM confirms that the eastern of the two scarps is about ~1.5 m high across post-glacial lake beach ridges formed at the maximum post-glacial highstand of Lake Wakatipu. K.R. Berryman (email communications to the writer, September 2021) provided a description of the fault scarp across the beach ridges, recorded during fieldwork in 1978, summarised as follows. Scarp height across individual beach ridges ranges from 1.2 to 2 m, and there is a sinistral (left-lateral) sinistral displacement of individual ridges ranging from 1.6 to 2.4 m. The fault scarp was interpreted to have formed in a single-event displacement, associated with around 3 m of net slip with oblique sinistral/vertical sense. The DSM indicates that the fault scarp is not present on lake-margin landforms north of the highstand beach ridge complex. A section of the fault there classed as 'moderately expressed' is reclassified as 'not expressed'.

The DSM revealed a need for refining the mapping of the western of the 'definite' fault scarps. The northern end is reinterpreted as continuing north-northeast for ~1.2 km, along a vague topographic step, rather than curving to the northeast as previously interpreted. The southern end has been extended ~2 km southwest along the mapped line of the Moonlight Fault Zone – South. From there, the DSM shows a ~5 m high topographic step, down to the northwest, extending a further ~3.5 km southwest along the Moonlight Fault Zone – South. This is interpreted as a likely, moderately expressed, fault section (see Moonlight Fault Zone section).

The new information above, taking account of the reported oblique sinistral movement described above, when resolved onto a 60° dipping fault, returns the same net slip rate (0.19 mm/year) as given by Barrell (2019), and recurrence interval of ~20,000 years remains the same. Activity parameters for the West Wakatipu Fault from Barrell (2019) were incorporated into the NZ CFM, but a transposition error resulted in the slip rates being reduced by a factor of 10. Correction is desirable for the next version of the NZ CFM.

A1.3 Clutha, Dunedin City and Waitaki (in the Otago region) Districts

A1.3.1 Blue Mountain Fault

The northeast-striking Blue Mountain Fault (feature 3 of Barrell [2021]) now has complete coverage by photogrammetry DSM. The opportunity was taken to review and improve the detail of mapping of the subdued fault scarps along the foot of the Blue Mountains range-front. These scarps occur for about 28 km distance from Rankleburn Road northeast to the head of Heriot Burn. Most of this section of the fault has 'moderately expressed' scarps, and the DSM information allowed intervening sections of 'not expressed' fault to be considerably shortened. No amendments are made to the fault activity classification or the descriptive background provided by Barrell (2021).

A1.3.2 Hyde Fault

The northeast-striking Hyde Fault lies along the southeastern foot of the Rock and Pillar Range and is identified as feature 20 of the Barrell (2021) report. It was also discussed as feature 39 of the Barrell (2019) report. Trenching and dating of the fault was part of a PhD research project at University of Otago, with results published in two papers (Griffin 2022a, 2022b). Preliminary results from that work informed the interpretations presented for the Hyde Fault by Barrell (2021), but are updated here with the published results.

Trenching, dating and modelling provides evidence for the four most recent surface ruptures of the Hyde Fault, with times of occurrence approximating 47.1 ± 9.6 ka, 35.6 ± 10.9 ka, 23.5 ± 3.8 ka and 10.5 ± 2.6 ka (Griffin et al. 2022a). Translating the trench-observed vertical slip rate onto a fault plane dipping 45° gives a net slip rate since ~50 ka of between 0.15 and 0.3 mm/year, with a preferred estimate of ~0.22 mm/year. Using the trench-derived results, the mean elapsed time between surface ruptures (ignoring the elapsing time since the most recent rupture) has been 12.4 ky (Griffin et al. 2022a). Single-event displacements for the three most recent surface ruptures were in the range of 1.3 m to 2.6 m.

To get a longer time perspective on activity of the Hyde Fault, Griffin et al. (2022b) obtained cosmogenic surface exposure dating of boulders on faulted alluvial fan terraces. The results indicate a long-term slip rate on the Hyde Fault since ~115 ka in the range of 0.19 to 0.29 mm/year at 95% confidence, with a median value of 0.24 mm/year. The similarity of the inter-rupture durations, and the shorter-term and longer-term slip rates being indistinguishable, indicates that, unlike some other Central Otago faults, the Hyde Fault has been rupturing with general regularity rather than episodicity (Griffin et al. 2022b).

For completeness, the 2010 NSHM methodology was used to re-assess fault activity. Repeating the Barrell (2021) calculation of fault length 50 km and dip 45° with the slightly smaller slip rate of 0.24 mm/year (cf. 0.25 mm/year) gives recurrence interval of 14,500 years and returns a single-event displacement of 3.5 m, larger than observed. I re-ran the calculation, taking the ~40 km morphological length of the Rock and Pillar Range block uplifted on the northwest side of the Hyde Fault as fault length, and obtained a recurrence interval of 11,600 years and single-event displacement of ~2.8 m, closer to the trench-observed values.

For this report, the investigation-based recurrence interval value of 12,400 years (rounded to 12,000 years) is used. A lidar DEM was used to assist the 2021 mapping, and no mapping changes are made to the dataset described in this report.

A1.3.3 Kaikorai Fault

The existence of this northeast-striking fault was inferred from geological relationships (Villamor et al. 2018), and is identified as feature 18 in the Barrell (2021) report. Overall, the recognition of this feature as an active fault was based on various snippets of evidence, all subject to various caveats. Subsequent careful registration of geological unit boundaries in relation to detailed topographic characteristics based on lidar DEMs in the Kaikorai valley area as part of a geological map update (Barrell et al. 2025) has removed the geological basis for drawing the Kaikorai Fault as previously depicted. No fault is needed to account for the geological relationships in the lower part of Kaikorai valley. Evidence remains for a relatively short fault, for which the name Kaikorai is retained, but it is now interpreted as an inactive normal fault, associated with the tectonic regime operating around the time of Miocene-age volcanism in the Dunedin area. Identification of a fault under South Dunedin, previously suggested as a branch of the Kaikorai Fault (Barrell 2021; Glassey et al. 2021), is now correlated with the Opoho Fault, another short fault inferred to be an inactive normal fault, related more closely in time to Dunedin volcanism between ~11 and ~16 million years ago (Scott et al. 2020), rather than the current tectonic regime (Barrell et al. 2025; Glassey et al. 2025).

As the Kaikorai Fault is no longer supported as an active fault by the balance of evidence, it is removed from the dataset described here. Reconsideration will also be needed for depiction of active faults in the NZ CFM for the Dunedin area, including removal of the Kaikorai Fault as a component of the Green Island Fault offshore active geological structure.

A1.3.4 Settlement Fault

The northeast-striking Settlement Fault (feature 11 of Barrell 2021) has recently been a focus of geological investigation and dating to quantify its degree of activity, as part of a Natural Hazard Commission University Research Program at the University of Otago. Results reported by Williams et al. (2025) are summarised below. A trench was excavated near Owaka township, and dating carried out. Results indicate heightened fault activity over the past ~20,000 years. Consideration and modelling of the trenching and dating results and other existing information resulted in the derivation of a long-term slip rate of ~0.02 mm/year since 125 ka, and a shorter-term slip rate of ~0.27 mm/year since 20 ka.

No changes are made to the fault mapping. Williams et al. (2025) discuss possible evidence for a north-eastward continuation of Settlement Fault deformation as a blind fault/fold, but because any associated ground strains would be highly distributed (diffused), and the overall interpretation remains speculative, I have not brought that interpretation into the dataset.

Applying the 2010 NSHM methodology to an overall fault length of 23 km and the shorter-term slip rate of 0.27 mm/year (preferred here for conservatism), returns a recurrence interval of ~5900 years. This is adopted here as the preferred estimate, replacing the very short term (past ~3600 years) recurrence interval of 1800 years given by Barrell (2021).

A1.4 Appendix References

Barrell DJA. 2011. Quaternary glaciers of New Zealand. In: Ehlers J, Gibbard PL, Hughes PD, editors. *Quaternary glaciations, extent and chronology: a closer look*. Amsterdam (NL): Elsevier. p. 1047–1064. (Developments in Quaternary Science; 15). http://doi.org/10.1016/B978-0-444-53447-7.00075-1

Barrell DJA. 2016. General distribution and characteristics of active faults and folds in the Waimate District and Waitaki District, South Canterbury and North Otago. Lower Hutt (NZ): GNS Science. 124 p. Consultancy Report 2015/166. Prepared for Canterbury Regional Council (Environment Canterbury); Otago Regional Council.

Barrell DJA. 2019. General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago. Lower Hutt (NZ): GNS Science. 99 p. Consultancy Report 2018/207. Prepared for Otago Regional Council.

Barrell DJA. 2021. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. Lower Hutt (NZ): GNS Science. 71 p. Consultancy Report 2020/88. Prepared for Otago Regional Council.

Barrell DJA, Read SAL. 2014. The deglaciation of Lake Pukaki, South Island, New Zealand—a review. *New Zealand Journal of Geology and Geophysics*. 57(1):86–101. https://doi.org/10.1080/00288306.2013.847469

Barrell DJA, Almond PC, Vandergoes MJ, Lowe DJ, Newnham RM. 2013. A composite pollen–based stratotype for inter–regional evaluation of climatic events in New Zealand over the past 30,000 years (NZ–INTIMATE project). *Quaternary Science Reviews*. 74:4–20. https://doi.org/10.1016/j.quascirev.2013.04.002

Barrell DJA, Glassey PJ, Easterbrook-Clarke L, Smith Lyttle B. In review. Geology of the Dunedin urban area. Lower Hutt (NZ): GNS Science geological map.

Beanland S, Berryman KR. 1989. Style and episodicity of late Quaternary activity on the Pisa–Grandview Fault Zone, Central Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. 32(4):451–461. http://doi.org/10.1080/00288306.1989.10427553

Bishop DG. 1976. Mt Ida [map]. Wellington (NZ): Department of Scientific and Industrial Research. 1 sheet + 22 p., scale 1:63,360. (Geological map of New Zealand 1:63,360; sheet S126).

Bishop DG. 1979. Ranfurly [map]. Wellington (NZ): Department of Scientific and Industrial Research. 1 sheet + booklet, scale 1:63,360. (Geological map of New Zealand 1:63,360; sheet S135).

Denton GH, Putnam AE, Russell JL, Barrell DJA, Schaefer JM, Kaplan MR, Strand PD. 2021. The Zealandia Switch: ice age climate shifts viewed from Southern Hemisphere moraines. *Quaternary Science Reviews*. 257:106771. https://doi.org/10.1016/j.quascirev.2020.106771

Forsyth PJ. 2001. Geology of the Waitaki area [map]. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences Limited. 1 sheet + 64 p., scale 1:250,000. (Institute of Geological & Nuclear Sciences 1:250 000 geological map; 19).

Glassey PJ, Barrell DJA, Smith Lyttle B, Hornblow S, Mackey B. 2021. Geological model of South Dunedin. Lower Hutt (NZ): GNS Science. 70 p. (GNS Science report; 2021/03). https://doi.org/10.21420/B5E9-GE25

Glassey PJ, Barrell DJA, Easterbrook-Clarke L, Crundwell MP. In press. Geological model of South Dunedin, New Zealand: a framework for understanding Quaternary fluvial and marine processes. *New Zealand Journal of Geology and Geophysics*.

Griffin JD, Stirling MW, Barrell DJA, van den Berg EJ, Todd EK, Nicolls R, Wang N. 2022a. Paleoseismology of the Hyde Fault, Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. 65(4):613–637. https://doi.org/10.1080/00288306.2021.1995007

Griffin JD, Stirling MW, Wilcken KM, Barrell DJA. 2022b. Late Quaternary slip rates for the Hyde and Dunstan faults, southern New Zealand: implications for strain migration in a slowly deforming continental plate margin. *Tectonics*. 41(9):e2022TC007250. https://doi.org/10.1029/2022TC007250

Hamilton DJ. 2009. Early water races in Central Otago. In: *3rd Australasian Engineering Heritage Conference – engineering in the development of a region: history and heritage;* 2009 Nov 22–25; Dunedin, NZ. Wellington (NZ): Engineering New Zealand. 12 p.

Langridge RM, Ries WF, Litchfield NJ, Villamor P, Van Dissen RJ, Barrell DJA, Rattenbury MS, Heron DW, Haubrock S, Townsend DB, et al. 2016. The New Zealand Active Faults Database. *New Zealand Journal of Geology and Geophysics*. 59(1):86–96. http://doi.org/10.1080/00288306.2015.1112818

Lisiecki LE, Raymo ME. 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. *Paleoceanography and Paleoclimatology*. 20:PA1003. https://doi.org/10.1029/2004PA001071

Litchfield NJ, Van Dissen RJ, Sutherland R, Barnes PM, Cox SC, Norris RJ, Beavan RJ, Langridge RM, Villamor P, Berryman KR, et al. 2013. A model of active faulting in New Zealand: fault zone parameter descriptions. Lower Hutt (NZ): GNS Science. 120 p. (GNS Science report; 2012/19).

Litchfield NJ, Van Dissen RJ, Sutherland R, Barnes PM, Cox SC, Norris R, Beavan RJ, Langridge R, Villamor P, Berryman K, et al. 2014. A model of active faulting in New Zealand. *New Zealand Journal of Geology and Geophysics*. 57(1):32–56. https://doi.org/10.1080/00288306.2013.854256

Markley M, Norris RJ. 1999. Structure and neotectonics of the Blackstone Hill Antiform, Central Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. 42(2):205–218. https://doi.org/10.1080/00288306.1999.9514840

McKellar IC. 1960. Pleistocene deposits of the upper Clutha Valley, Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. 3(3):432-460. https://doi.org/10.1080/00288306.1960.10422087

McSaveney MJ, Thomson R, Turnbull IM. 1992. Timing of relief and landslides in Central Otago, New Zealand. In: Bell DH, editor. *Landslides: proceedings of the sixth international symposium*; 1992 Feb 10–14; Christchurch, New Zealand. Rotterdam (NL): A.A. Balkema. p. 1451–1456.

Meyer AFT. 2021. A paleoseismic investigation of the Long Valley Fault, Central Otago [BSc Hons thesis]. Dunedin (NZ): University of Otago.

Morgenstern R, Litchfield NJ, Langridge RM, Heron DW, Townsend DB, Villamor P, Barrell DJA, Ries RF, Van Dissen RJ, Clark KJ, et al. 2024. New Zealand Active Faults Database: the high-resolution dataset v2.0. *New Zealand Journal of Geology and Geophysics*. https://doi.org/10.1080/00288306.2024.2427396

[NZGS] New Zealand Geological Survey. 1984. Seismotectonic hazard evaluation for upper Clutha power development. Lower Hutt (NZ): New Zealand Geological Survey. Report EG 377.

Scott JM, Pontesilli A, Brenna M, White JDL, Giacalone E, Palin JM, le Roux PJ. 2020. The Dunedin Volcanic Group and a revised model for Zealandia's alkaline intraplate volcanism. *New Zealand Journal of Geology and Geophysics*. 63:510–529. https://doi.org/10.1080/00288306.2019.1707695

Seebeck H, Van Dissen RJ, Litchfield NJ, Barnes PM, Nicol A, Langridge RM, Barrell DJA, Villamor P, Ellis SM, Rattenbury MS, et al. 2022. New Zealand Community Fault Model – version 1.0. Lower Hutt (NZ): GNS Science. 97 p. (GNS Science report; 2021/57). https://doi.org/10.21420/GA7S-BS61

Seebeck H, Van Dissen R, Litchfield N, Barnes PM, Nicol A, Langridge R, Barrell DJA, Villamor P, Ellis S, Rattenbury M, et al. 2024. The New Zealand Community Fault Model – version 1.0: an improved geological foundation for seismic hazard modelling. *New Zealand Journal of Geology and Geophysics*. 67(2):209–229. https://doi.org/10.1080/00288306.2023.2181362

Stirling M, McVerry G, Gerstenberger M, Litchfield N, Van Dissen R, Berryman K, Barnes P, Wallace L, Villamor P, Langridge R, et al. 2012. National Seismic Hazard Model for New Zealand: 2010 update. *Bulletin of the Seismological Society of America*. 102(4):1514–1542. https://doi.org/10.1785/0120110170

Stirling MW, Abbott ER, Rood DH, McVerry GH, Abrahamson NA, Barrell DJA, Huso R, Litchfield NJ, Luna L, Rhoades DA, et al. 2021. First use of fragile geologic features to set the design motions for a major existing engineered structure. *Bulletin of the Seismological Society of America*. 111(5): 2673–2695. https://doi.org/10.1785/0120210026

Strand PD, Putnam AE, Schaefer JM, Denton GH, Barrell DJA. 2024. Tracking rapid ice recession in a major Southern Alps valley during the last glacial termination. *Quaternary Science Reviews*. 335: 108737. https://doi.org/10.1016/j.quascirev.2024.108737

Turnbull IM. 2000. Geology of the Wakatipu area [map]. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 sheet + 72 p., scale 1:250,000. (Institute of Geological & Nuclear Sciences 1:250,000 geological map; 18).

van den Berg E. 2020. Paleoseismology of the NW Cardrona Fault, Central Otago [MSc thesis]. Dunedin (NZ): University of Otago. 141 p. https://hdl.handle.net/10523/10474

van den Berg EJ, Williams JN, Stirling MW, Barrell DJA, Griffin JD, Litchfield NJ, Wang N. 2025. Late Quaternary activity of the NW Cardrona Fault, Otago, New Zealand. *New Zealand Journal of Geology and Geophysics*. 68(1):151–171. https://doi.org/10.1080/00288306.2023.2297962

Van Dissen R, Barrell D, Langridge R, Litchfield N, Villamor P, Tonkin P. 2007. Reassessment of seismic hazard at Clyde Dam, Central Otago: earthquake geology field investigations and determination of Dunstan Fault rupture characteristics. Lower Hutt (NZ): GNS Science. 2 vol. + appendices. Consultancy Report 2006/147. Prepared for Contact Energy Limited.

Vause A. 2025. Faulted terraces and earthquake behaviour of the Pisa Fault, Central Otago [MSc thesis]. Dunedin (NZ): University of Otago. https://hdl.handle.net/10523/45007

Williams J, Stirling M, Langridge R, Niroula G, Vause A, Stewart J, Nicol A, Wang N. 2024. Along-strike extent of earthquakes on multi-segment reverse faults; insights from the Nevis-Cardrona Fault, Aotearoa New Zealand. *Seismica*. 3(2). https://doi.org/10.26443/seismica.v3i2.1310

Williams JN, Stirling MW, Barrell DJA, Niroula G, Wavelet E. 2025. Insights into temporal earthquake clustering from the Settlement Fault, southeastern Otago, Aotearoa New Zealand. *New Zealand Journal of Geology and Geophysics*. https://doi.org/10.1080/00288306.2025.2455076

APPENDIX 2 Descriptive Metadata from the GIS Datasets

Note that the references given in this appendix have undergone some minor corrections and are in a different format to that given in the GIS metadata. What is provided in this appendix supersedes what is in the metadata.

A2.1 Feature Class: Clutha_Dunedin_active_faults_April2025

A2.1.1 Summary

This feature class comprises a regional-scale (approximately 1:250,000) depiction of the recognised active and potentially active faults of the Clutha and Dunedin City districts of the Otago region, New Zealand. It is based on a derivation and partial reinterpretation of the 'faults' component of the 1:250,000-scale geological map of New Zealand dataset (2nd edition). This feature class contains lines (arcs) representing the locations of active and potentially active faults at or near the ground surface. This feature class is a 2025 update of the original 2020 dataset.

A2.1.2 Description

The extracted QMAP 'NZL_GNS_250K_faults' dataset was modified by the addition of three new attribute fields, the repositioning of some faults or parts of faults, and the addition of new faults. The three new attribute fields are: ORC_name; Certainty and Surf_form. The 'ORC_name' field provides a local name for the mapped feature(s). The 'Certainty' attribute indicates the assessed level of the certainty with which each feature is recognized as an active fault (definite, likely or possible) or as a potentially active fault. The 'Surf_form' (Surface form) attribute provides an interpretation of the surface distinctiveness of each feature at the ground surface (well expressed, moderately expressed, not expressed, unknown).

A single active fault at depth is commonly expressed at the ground surface as a zone of splintering. An individual line of splinters (fault strand) may comprise fault offsets of the ground surface (fault scarps) or ground-surface folds (fold scarps), and typically a mixture of both. A fault zone may include several lines (traces) of semi-parallel strands and a fault zone can in some cases be several kilometres wide. Some strands have previously been named separately, and this name is retained in the GIS dataset, but the various strands that comprise an active fault are grouped under a common name (ORC_name). This is done to highlight that, collectively, the strands are regarded as part of a single active fault structure, whose movements at depth have produced an array of ground-surface fault and/or fold deformation.

The QMAP 'NZL_GNS_250K_faults' dataset contains many attribute fields that are not important for the dataset described here, and those fields have been deleted from this dataset, except for the 'DOWN_QUAD' field. The DOWN_QUAD indicates the relative direction of fault movement, by stating which side of the fault is downthrown (e.g. north, northeast, east, southeast, south, southwest, west, northwest).

Where an active fault has surface expression (i.e. is marked by a fault scarp), the line denoting its location is positioned along the middle to lower part of the fault scarp. This is of no practical significance where the scarp is relatively small (e.g. several metres high) but is more significant where the scarp is large (e.g. tens of metres high) and therefore has notable width in map view. Where a fault is assigned a Surf_form attribute of 'not expressed', its location is an inference, based on extrapolation or interpolation from adjacent sectors where the fault does have ground-surface expression. Unless indicated otherwise, all the fault data have been compiled at a regional scale (1:250,000) and the locations of active and potentially active faults in the 'Clutha_Dunedin_active_faults_April2025' feature

class should be regarded as having a general accuracy of ± 250 m, and at best, ± 100 m. The geographic coordinate system for the data is New Zealand Geodetic Datum 2000.

A2.1.3 Credits

Modified dataset compiled in 2020, and reviewed/updated in 2025, by DJA Barrell. Original data described and documented in:

Barrell DJA. 2021. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. Lower Hutt (NZ): GNS Science. 71 p. Consultancy Report 2020/88. Prepared for Otago Regional Council.

Revisions (if any) are described in:

Barrell DJA. 2025. Review and update of active geological fault and fold characterisation in the Otago region. Lower Hutt (NZ): Earth Sciences New Zealand. 55 p. Consultancy Report 2025/48. Prepared for Otago Regional Council.

Original source reference:

Heron DW. (custodian) 2018. Geological map of New Zealand 1:250,000 (2nd edition). Lower Hutt (NZ): GNS Science. 1 USB. GNS Science Geological Map 1.

A2.1.4 Use Limitations

This dataset is an accompaniment to a report prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Otago Regional Council. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of or reliance on any contents of that report or this dataset by any person other than Otago Regional Council and shall not be liable to any person other than Otago Regional Council, on any ground, for any loss, damage or expense arising from such use or reliance.

A2.2 Feature Class: Clutha_Dunedin_active_folds_April2025

A2.2.1 Summary

This feature class comprises a regional-scale (approximately 1:250,000) depiction of the recognised active and potentially active folds of the Clutha and Dunedin City districts of the Otago region, New Zealand. It is based on a derivation and partial reinterpretation of the 'folds' component of the 1:250,000-scale geological map of New Zealand dataset (2nd edition). This feature class contains lines (arcs) representing the locations of active and potentially active folds at or near the ground surface. This feature class is a 2025 update of the original 2020 dataset.

A2.2.2 Description

The extracted QMAP 'NZL_GNS_250K_folds' dataset was modified by the addition of three new attribute fields, the repositioning of some folds or parts of folds, and the addition of new folds. The three new attribute fields are: ORC_name; Certainty; Surf_form. The 'ORC_name' field provides a local name for the mapped feature(s). The 'Certainty' attribute indicates the assessed level of the certainty with which each feature is recognized as an active fold (definite, likely or possible) or as a potentially active fold. The 'Surf_form' (Surface form) attribute provides an interpretation of the surface distinctiveness of each feature at the ground surface (well expressed, moderately expressed, not expressed).

An active fold is generally regarded as having formed above an active fault at depth. The QMAP 'NZL_GNS_250K_folds' dataset contains many attribute fields that are not important for the dataset described here, and those fields have been deleted from this dataset. Only the ‘TYPE’ and ‘FACING’

fields are retained. The 'TYPE' field indicates the nature of the fold; in this dataset, the only fold type represented are 'monocline' and 'anticline'. The 'FACING' field indicates the relative direction of fold movement, by stating which side of the fold is downwarped (e.g. north, northeast, east, southeast, south, southwest, west, northwest).

The line denoting the location of a monocline is positioned along the middle of the fold feature, midway between its crest and its base. Where relevant, an assessment of the width of the fold is made in the descriptive text in Appendix 2 of the report that is a companion to this dataset (Barrell 2020). Unless indicated otherwise, all the fold data have been compiled at a regional scale (1:250,000) and the 'Clutha_Dunedin_active_folds_April2025' feature class should be regarded as having a general accuracy of ± 250 m, and at best, ± 100 m. The geographic coordinate system for the data is New Zealand Geodetic Datum 2000.

A2.2.3 Credits

Modified dataset compiled by DJA Barrell. Data described and documented in:

Barrell DJA. 2021. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. Lower Hutt (NZ): GNS Science. 71 p. Consultancy Report 2020/88. Prepared for Otago Regional Council.

Revisions (if any) are described in:

Barrell DJA. 2025. Review and update of active geological fault and fold characterisation in the Otago region. Lower Hutt (NZ): Earth Sciences New Zealand. 55 p. Consultancy Report 2025/48. Prepared for Otago Regional Council.

Original source reference:

Heron DW. (custodian) 2018. Geological map of New Zealand 1:250,000 (2nd edition). Lower Hutt (NZ): GNS Science. 1 USB. GNS Science Geological Map 1.

A2.2.4 Use Limitations

This dataset is an accompaniment to a report prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Otago Regional Council. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of or reliance on any contents of that report or this dataset by any person other than Otago Regional Council and shall not be liable to any person other than Otago Regional Council, on any ground, for any loss, damage or expense arising from such use or reliance.

A2.3 Feature Class: CO_QL_active_faults_April2025

A2.3.1 Summary

This feature class comprises a regional-scale (approximately 1:250,000) depiction of the recognised active and potentially active faults of the Central Otago District and Queenstown Lakes District of the Otago region, New Zealand. It is based on a derivation and partial reinterpretation of the 'faults' component of the 1:250,000-scale geological map of New Zealand dataset (1st edition). This feature class contains lines (arcs) representing the locations of active and potentially active faults at or near the ground surface. This feature class is an update of a dataset originally compiled in 2019.

A2.3.2 Description

This active fault feature class, prepared by GNS Science under contract to Otago Regional Council (ORC), is based on the GNS Science nationwide QMAP (Quarter-Million-scale geological mAP) digital

database. Fault data in the 'NZL_GNS_250K_faults' feature class in the 'NZL_GNS_250k_geology' geodatabase, for the area of the Central Otago and Queenstown Lakes districts, were extracted from the first-edition QMAP database (Heron 2014) in mid-2017. The published QMAP digital database is sourced from original geological map data from individually published geological maps Wakatipu (Turnbull 2000; western parts of both districts), Haast (Rattenbury et al. 2010; headwaters of the Wanaka and Hawea catchments), Murihiku (Turnbull and Allibone 2003; southernmost part of Central Otago) and Waitaki (Forsyth 2001; eastern part of Central Otago). See Credits for full citations.

The extracted QMAP 'NZL_GNS_250K_faults' dataset was modified by the addition of three new attribute fields, the repositioning of some faults or parts of faults, and the addition of new faults. The three new attribute fields are: ORC_name; Certainty; Surf_form. The 'ORC_name' field provides a local name for the mapped feature(s). The 'Certainty' attribute indicates the assessed level of the certainty with which each feature is recognized as an active fault (definite, likely or possible) or as a potentially active fault. The 'Surf_form' (Surface form) attribute provides an interpretation of the surface distinctiveness of each feature at the ground surface (well expressed, moderately expressed, not expressed, unknown).

A single active fault at depth is commonly expressed at the ground surface as a zone of splintering. An individual line of splinters (fault strand) may comprise fault offsets of the ground surface (fault scarps) or ground-surface folds (fold scarps), and typically a mixture of both. A fault zone may include several lines (traces) of semi-parallel strands and a fault zone can in some cases be several kilometres wide. Some strands have previously been named separately, and this name is retained in the GIS dataset, but the various strands that comprise an active fault are grouped under a common name (ORC_name). This is done to highlight that, collectively, the strands are regarded as part of a single active fault structure, whose movements at depth have produced an array of ground-surface fault and/or fold deformation.

The QMAP 'NZL_GNS_250K_faults' dataset contains many attribute fields that are not important for the dataset described here, and those fields have been deleted from this dataset. To make clear the linkage between the QMAP data and the original 'CO_QL_active_faults_Feb_2019' layer, five of the QMAP attribute fields are retained, comprising 'NAME', 'ZONE', 'DOWN_QUAD', 'QMAP_NAME' and 'QMAP_NUMB'. The NAME and ZONE fields respectively provide the fault name (if any) and any fault zone with which it is associated, mainly as applied in QMAP. The DOWN_QUAD indicates the relative direction of fault movement, by stating which side of the fault is downthrown (e.g. north, northeast, east, southeast, south, southwest, west, northwest). The last two fields refer to the original published QMAP sheet name, and the published sheet number. For fault features that are newly added (i.e. not on QMAP), these latter two fields carry a NULL entry.

Where an active fault has surface expression (i.e. is marked by a fault scarp), the line denoting its location is positioned along the middle to lower part of the fault scarp. This is of no practical significance where the scarp is relatively small (e.g. several metres high), but is more significant where the scarp is large (e.g. tens of metres high) and therefore has notable width in map view. Where a fault is assigned a Surf_form attribute of 'not expressed', its location is an inference, based on extrapolation or interpolation from adjacent sectors where the fault does have ground-surface expression. Unless indicated otherwise, all the fault data have been compiled at a regional scale (1:250,000) and the locations of active and potentially active faults in the 'CO_QL_active_faults_April2025' layer should be regarded as having a general accuracy of ± 250 m, and at best, ± 100 m. The geographic coordinate system for the data is New Zealand Geodetic Datum 2000.

A2.3.3 Credits

Modified dataset originally compiled in 2019, and reviewed/updated in 2025, by DJA Barrell. Data described and documented in:

Barrell DJA. 2019. General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago. Lower Hutt (NZ): GNS Science. 99 p. GNS Science Consultancy Report 2018/207.

Revisions (if any) to the original 2019 dataset are described in the following report:

Barrell DJA. 2025. Review and update of active geological fault and fold characterisation in the Otago region. Lower Hutt (NZ): Earth Sciences New Zealand. 55 p. Consultancy Report 2025/48. Prepared for Otago Regional Council.

Original source reference:

Heron DW. (custodian) 2014. Geological map of New Zealand 1:250,000 (1st edition). Lower Hutt (NZ): GNS Science. 1 CD. GNS Science Geological Map 1.

Individual QMAP sheet references:

Turnbull IM. 2000. Geology of the Wakatipu area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 72 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 18.

Forsyth PJ. 2001. Geology of the Waitaki area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 64 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 19.

Turnbull IM; Allibone AH. 2003. Geology of the Murihiku area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 74 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 20.

Rattenbury MS; Jongens R; Cox, S.C. 2010. Geology of the Haast area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 58 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 14.

A2.3.4 Use Limitations

This dataset is an accompaniment to a report prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Otago Regional Council. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of or reliance on any contents of that report or this dataset by any person other than Otago Regional Council and shall not be liable to any person other than Otago Regional Council, on any ground, for any loss, damage or expense arising from such use or reliance.

A2.4 Feature Class: CO_QL_active_folds_April2025

A2.4.1 Summary

This feature class comprises a regional-scale (approximately 1:250,000) depiction of the recognised active folds of the Central Otago District and Queenstown Lakes District of the Otago region, New Zealand. It is based on a derivation and partial reinterpretation of the 'folds' component of the 1:250,000-scale geological map of New Zealand dataset (1st edition). This feature class contains lines (arcs) representing the locations of active folds at or near the ground surface. This feature class is an update of a dataset originally compiled in 2019.

A2.4.2 Description

This active fold feature class, prepared by GNS Science under contract to Otago Regional Council (ORC), is based on the GNS Science nationwide QMAP (Quarter-Million-scale geological mAP) digital

database. Fold data in the 'NZL_GNS_250K_folds' feature class in the 'NZL_GNS_250k_geology' geodatabase, for the area of the Central Otago and Queenstown Lakes districts, were extracted from the first-edition QMAP database (Heron 2014) in mid-2017. The published QMAP digital database is sourced from original geological map data from individually published geological maps Wakatipu (Turnbull 2000; western parts of both districts), Haast (Rattenbury et al. 2010; headwaters of the Wanaka and Hawea catchments), Murihiku (Turnbull and Allibone 2003; southernmost part of Central Otago) and Waitaki (Forsyth 2001; eastern part of Central Otago). See Credits for full citations.

The extracted QMAP 'NZL_GNS_250K_folds' dataset was modified by the addition of three new attribute fields, the repositioning of some folds or parts of folds, and the addition of new folds. The three new attribute fields are: ORC_name; Certainty; Surf_form. The 'ORC_name' field provides a local name for the mapped feature(s). The 'Certainty' attribute indicates the assessed level of the certainty with which each feature is recognized as an active fold (definite, likely or possible) or as a potentially active fold. The 'Surf_form' (Surface form) attribute provides an interpretation of the surface distinctiveness of each feature at the ground surface (well expressed, moderately expressed, not expressed, unknown).

An active fold is generally regarded as having formed above an active fault at depth. A single active fault at depth is commonly expressed at the ground surface as a zone of splintering. An individual line of splinters (fault strand) may comprise fault offsets of the ground surface (fault scarps) or ground-surface folds (fold scarps), and typically a mixture of both. A fault zone may include several lines (traces) of semi-parallel strands and a fault zone can in some cases be several kilometres wide. Some fold strands have previously been named separately, and this name is retained in the GIS dataset, but the various strands that comprise fold components of an active fault are grouped under a common name (ORC_name). This is done to highlight that, collectively, the strands are regarded as part of a single active fault structure, whose movements at depth have produced an array of ground-surface fault and/or fold deformation.

The QMAP 'NZL_GNS_250K_folds' dataset contains many attribute fields that are not important for the dataset described here, and those fields have been deleted from this dataset. However, to make clear the linkage between the QMAP dataset and this active fold dataset, five of the QMAP attribute fields are retained, comprising ‘NAME’, ‘TYPE’, ‘FACING’, ‘QMAP_NAME’ and ‘QMAP_NUMB’. The 'NAME' field provides the fold name (if any). The 'TYPE' field indicates the nature of the fold; in this dataset, the only fold type represented is 'monocline'. The 'FACING' field indicates the relative direction of fold movement, by stating which side of the fold is downwarped (e.g. north, northeast, east, southeast, south, southwest, west, northwest). The last two fields refer to the original published QMAP sheet name, and the published sheet number. For fold features that are newly added (i.e. not on QMAP), these latter two fields carry a NULL entry.

The line denoting the location of a monocline is positioned along the middle of the fold feature, midway between its crest and its base. Where relevant, an assessment of the width of the fold is made in the descriptive text in Appendix 2 of the report that is a companion to this dataset (Barrell 2019). Where a fold is assigned a Surf_form attribute of 'not expressed', its location is an inference, based on extrapolation or interpolation from adjacent sectors where the fold does have ground-surface expression. Unless indicated otherwise, all the fold data have been compiled at a regional scale (1:250,000) and the 'CO_QL_active_folds_April2025' layer should be regarded as having a general accuracy of ± 250 m, and at best, ± 100 m. The geographic coordinate system for the data is New Zealand Geodetic Datum 2000.

A2.4.3 Credits

Modified dataset originally compiled in 2019, and reviewed/updated in 2025, by D.J.A. Barrell. Data described and documented in:

Barrell DJA. 2019. General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago. Lower Hutt (NZ): GNS Science. 99 p. GNS Science Consultancy Report 2018/207.

Revisions (if any) to the original 2019 dataset are documented in the following report:

Barrell DJA. 2025. Review and update of active geological fault and fold characterisation in the Otago region. Lower Hutt (NZ): Earth Sciences New Zealand. 55 p. Consultancy Report 2025/48. Prepared for Otago Regional Council.

Original source reference:

Heron DW. (custodian) 2014. Geological map of New Zealand 1:250,000 (1st edition). Lower Hutt (NZ): GNS Science. 1 CD. GNS Science Geological Map 1.

Individual QMAP sheet references:

Turnbull IM. 2000. Geology of the Wakatipu area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 72 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 18.

Forsyth PJ. 2001. Geology of the Waitaki area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 64 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 19.

Turnbull IM; Allibone AH. 2003. Geology of the Murihiku area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 74 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 20.

Rattenbury MS; Jongens R; Cox SC. 2010. Geology of the Haast area. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map + 58 p. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 14.

A2.4.4 Use Limitations

This dataset is an accompaniment to a report prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Otago Regional Council. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of or reliance on any contents of that report or this dataset by any person other than Otago Regional Council and shall not be liable to any person other than Otago Regional Council, on any ground, for any loss, damage or expense arising from such use or reliance.

A2.5 Feature Class: Waitaki_Otago_faults_April2025

A2.5.1 Summary

This feature class comprises a regional-scale (approximately 1:250,000) depiction of the recognised active and potentially active faults of that part of the Waitaki District lying within the Otago region, New Zealand. It is based on a derivation and partial reinterpretation of the 'faults' component of the 1:250,000-scale geological map of New Zealand dataset. This feature class contains lines (arcs) representing the locations of active and potentially active faults at or near the ground surface.

A2.5.2 Description

The original compilation of this dataset was done under joint contract with Canterbury Regional Council and Otago Regional Council and delivered as a GIS shapefile. In 2025, the original shapefile

was converted into a geodatabase feature class format by GNS Science under contract to Otago Regional Council (ORC).

This active fault feature class is based on the GNS Science nationwide QMAP (Quarter-Million-scale geological mAP) digital database. Fault data in the 'NZL_GNS_250K_faults' feature class in the 'NZL_GNS_250k_geology' geodatabase were extracted from the first-edition QMAP database (Heron 2014) in mid-2015, with extraction of potentially active faults in the southwest part of the Waitaki District from the second-edition QMAP database (Heron 2018) in 2019, The published QMAP digital database is sourced from original geological map data from the individually published geological map of the Waitaki area (Forsyth 2001). See Credits for full citations.

The extracted QMAP 'NZL_GNS_250K_faults' dataset was modified by the addition of three new attribute fields, the repositioning of some faults or parts of faults, and the addition of new faults. The three new attribute fields were: WMWK_name; Certainty; Surf_form. In 2025, the original shapefile was transferred into the same file structure used for the Central Otago – Queenstown Lakes active fault dataset. The original WMWK_name of the attribute field was amended to ORC_name. The 'ORC_name' field provides a local name for the mapped feature(s). The 'Certainty' attribute indicates the assessed level of the certainty with which each feature is recognized as an active fault (definite, likely or possible) or as a potentially active fault. The 'Surf_form' (Surface form) attribute provides an interpretation of the surface distinctiveness of each feature at the ground surface (well expressed, moderately expressed, not expressed, unknown).

A single active fault at depth is commonly expressed at the ground surface as a zone of splintering. An individual line of splinters (fault strand) may comprise fault offsets of the ground surface (fault scarps) or ground-surface folds (fold scarps), and typically a mixture of both. A fault zone may include several lines (traces) of semi-parallel strands and a fault zone can in some cases be several kilometres wide. Some strands have previously been named separately, and this name is retained in the GIS dataset, but the various strands that comprise an active fault are grouped under a common name (ORC_name). This is done to highlight that, collectively, the strands are regarded as part of a single active fault structure, whose movements at depth have produced an array of ground-surface fault and/or fold deformation.

The QMAP 'NZL_GNS_250K_faults' dataset contains many attribute fields that are not important for the dataset described here, and those fields have been deleted from this dataset. To make clear the linkage between the QMAP data and the 'Waitaki_Otago_faults_April2025' layer, five of the QMAP attribute fields are retained, comprising 'NAME', 'ZONE', 'DOWN_QUAD', 'QMAP_NAME' and 'QMAP_NUMB'. The NAME and ZONE fields respectively provide the fault name (if any) and any fault zone with which it is associated, mainly as applied in QMAP. The DOWN_QUAD indicates the relative direction of fault movement, by stating which side of the fault is downthrown (e.g. north, northeast, east, southeast, south, southwest, west, northwest). The last two fields refer to the original published QMAP sheet name, and the published sheet number. For fault features that are newly added (i.e. not on QMAP), these latter two fields carry a NULL entry.

Where an active fault has surface expression (i.e. is marked by a fault scarp), the line denoting its location is positioned along the middle to lower part of the fault scarp. This is of no practical significance where the scarp is relatively small (e.g. several metres high), but is more significant where the scarp is large (e.g. tens of metres high) and therefore has notable width in map view. Where a fault is assigned a Surf_form attribute of 'not expressed', its location is an inference, based on extrapolation or interpolation from adjacent sectors where the fault does have ground-surface expression. Unless indicated otherwise, all the fault data have been compiled at a regional scale (1:250,000) and the locations of active and potentially active faults in the 'Waitaki_Otago_faults_April2025' layer should be regarded as having a general accuracy of ± 250 m, and at best, ± 100 m. The geographic coordinate system for the data is New Zealand Geodetic Datum 2000.

A2.5.3 Credits

Modified dataset compiled by D.J.A. Barrell. Original data described and documented in:

Barrell DJA. 2016. General distribution and characteristics of active faults and folds in the Waimate District and Waitaki District, South Canterbury and North Otago. Lower Hutt (NZ): GNS Science. 124 p. Consultancy Report 2015/166. Prepared for Canterbury Regional Council (Environment Canterbury); Otago Regional Council.

Additional interpretive commentary on the Waihemo Fault Zone is provided in:

Barrell DJA. 2019. General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago. Lower Hutt (NZ): GNS Science. 99 p. GNS Science Consultancy Report 2018/207.

Identification and mapping of potentially active faults that are present in the Dunedin City district, but extend into the Waitaki District is provided by:

Barrell DJA. 2021. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. Lower Hutt (NZ): GNS Science. 71 p. Consultancy Report 2020/88. Prepared for Otago Regional Council.

There have been no amendments to the original fault mapping from the Barrell (2016) and (2020) reports as part of the 2025 review. The 2025 dataset is illustrated in maps in the following report:

Barrell DJA. 2025. Review and update of active geological fault and fold characterisation in the Otago Region. Lower Hutt (NZ): GNS Science. Consultancy Report 2025/48.

Original source references:

Heron DW, custodian. 2014. Geological map of New Zealand 1:250,000. Lower Hutt (NZ): GNS Science. 1 CD, scale 1:250,000. (Institute of Geological & Nuclear Sciences 1:250,000 geological map; 1).

Heron DW, custodian. 2018. Geological map of New Zealand 1:250,000. 2nd ed. Lower Hutt (NZ): GNS Science. 1 USB, scale 1:250,000. (Institute of Geological & Nuclear Sciences 1:250,000 geological map; 1).

Individual QMAP sheet reference:

Forsyth PJ. 2001. Geology of the Waitaki area [map]. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences Limited. 1 sheet + 64 p., scale 1:250,000. (Institute of Geological & Nuclear Sciences 1:250 000 geological map; 19).

A2.5.4 Use Limitations

This dataset is an accompaniment to a report prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Otago Regional Council. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of or reliance on any contents of that report or this dataset by any person other than Otago Regional Council and shall not be liable to any person other than Otago Regional Council, on any ground, for any loss, damage or expense arising from such use or reliance.

earthsciences.nz

9.5. Operations and Maintenance Annual Work Plan Update

Prepared for:	Science and Resilience Committee
Report No.	ENV2506
Activity:	Governance Report
Author:	Daniel King, Team Leader Operations and Maintenance Alana Reid, Operations and Maintenance Coordinator
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] To provide a summary of performance against the 2024/25 annual maintenance programme for the flood protection schemes in Lower Clutha, and Lower Taieri, as well as the drainage schemes in Tokomairiro, East Taieri, and West Taieri.

[2] To provide a summary of the proposed 2025/26 annual maintenance programme for the flood protection schemes in Lower Clutha, and Lower Taieri, as well as the drainage schemes in Tokomairiro, East Taieri, and West Taieri.

EXECUTIVE SUMMARY

[3] This report presents an overview of performance against the 2024/25 annual maintenance programme for the Otago Regional Council's flood protection and drainage schemes in Lower Clutha, Lower Taieri, Tokomairiro, East Taieri, and West Taieri. These schemes collectively service approximately 43,000 hectares and includes infrastructure such as 535 km of drainage channels, 218 km of flood banks, 14 pump stations, and 369 culverts, 42 bridges, and outfall structures.

[4] 100% of the planned scheme maintenance programme was completed in the 2024/25 financial year, involving 114 individual tasks. This result was made possible by full team capacity, favourable weather, and the absence of significant flood events.

[5] In addition to the planned maintenance activities, 75 reactive maintenance tasks were undertaken throughout the 24/25 financial year.

[6] The planned 2025/26 annual maintenance programme includes inspections, pump servicing, mechanical drain cleaning, vegetation and pest control. A total of 116 individual tasks are scheduled for completion by 30 June 2026.

RECOMMENDATION

That the Committee:

1) ***Receives** this report.*
2) ***Notes** the completion of the 2024/25 annual maintenance programme.*
3) ***Notes** the proposed 2025/26 annual maintenance programme.*

BACKGROUND

[7] The Otago Regional Council (ORC) owns and operates infrastructure servicing approximately 43,000 hectares across the schemes as indicated in Table 1.

Table 1. Asset portfolio summary for flood protection and drainage schemes Coastal Otago.

Scheme	Catchment Area (,000 ha)	Area Protected (,000 ha)	Flood banks (km)	Open Drains (km)	Pump Stations	Culverts	Bridges
Lower Clutha Flood Protection and Drainage Scheme	2,110	9.3	110	153	5	189	4
Lower Taieri Flood Protection Scheme	565	13	107	-	-	-	-
West Taieri Drainage Scheme	8	8.1	-	144	3	22	20
East Taieri Drainage Scheme	17	4.8	-	128	3	84	1
Tokomairiro Drainage Scheme	40	7.7	-	110	-	74	17
Total	**4,251**	**43**	**218**	**535**	**14**	**369**	**42**

[8] Operations and maintenance activities are delivered by the ORC Operations and Maintenance team, based at the Taieri and Balclutha depots.

[9] The 2024–2034 Long-Term Plan outlines the following levels of service:
"85% of planned scheme maintenance and channel works are to be completed within the 12-month period, meeting the key standards defined in relevant planning documents."

[10] Planned scheme maintenance activities include:

- Routine inspections of pumps, drains, outfall structures, flood banks, and other assets.
- 3 year, 6 year and 8 year pump servicing.

- Vegetation management and pest plant control (e.g., mowing, tree trimming, spraying).
- Mechanical drain cleaning.
- Pest control, particularly rabbit management.

[11] Reactive maintenance tasks are generated from customer feedback, weather events and scheduled inspections.

[12] Additional activities such as planning, inspections, monitoring, weed raking, asset protection and contractor coordination are required during flood events or periods of elevated river flow and drain levels.

DISCUSSION

Scheme Maintenance programmes

[13] For the 2024/25 year, 100% of the planned maintenance programme was achieved. The 2024/25 programme is outlined in Figures 1, 2 and 3.

- Figure 1 – Completed maintenance tasks broken down by scheme.
- Figure 2 – Quarters in which the tasks were completed.
- Figure 3 – Completed maintenance tasks broken down by work type.

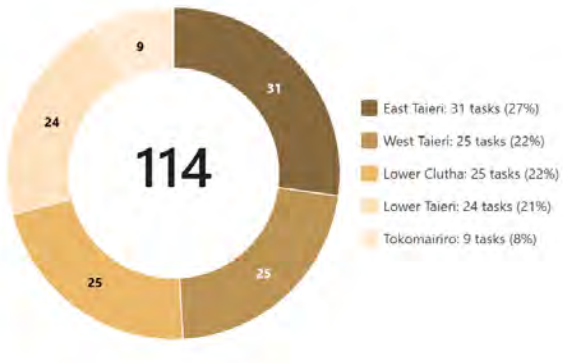


Figure 1 – Completed Maintenance Tasks by Scheme.

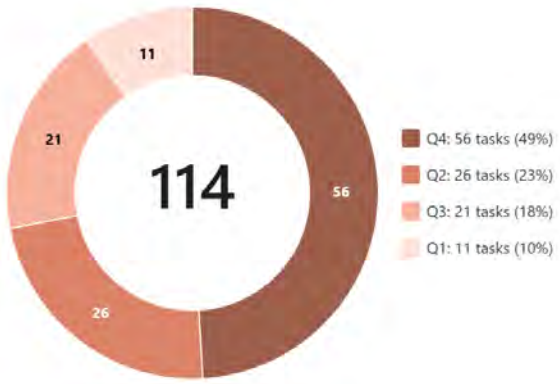


Figure 2 – Completed Maintenance Tasks completed by Quarter.

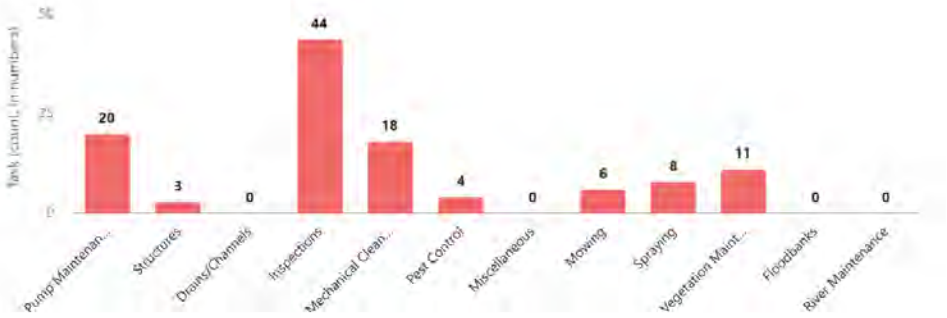


Figure 3 – Completed Maintenance Tasks by Work Type.

[14] The planned 2025/26 Annual Maintenance Programme includes inspections, pump servicing, mechanical drain cleaning, vegetation and pest control. A total of 116 individual tasks are scheduled for completion by 30 June 2026.

- Figure 4 – Planned maintenance tasks broken down by scheme.
- Figure 5 – Planned work to be completed by quarter.
- Figure 6 – Planned maintenance tasks broken down by work type.

Figure 4 – Planned Maintenance Tasks by Scheme.

Figure 5 – Planned Maintenance Tasks by Quarter.

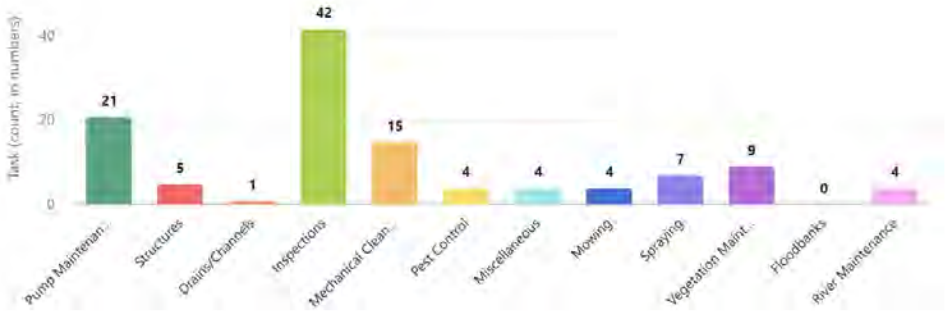


Figure 6 – Planned Maintenance Tasks by Work Type.

[15] The 2025/26 work programme is to be published on the ORC web site by 1 October 2025.

[16] Over the past several years, a significant programme of mechanical drain clearing across the drainage schemes has been completed. Approximately $300,000 of drain cleaning work in Lower Taieri and Tokomairiro is planned for 2025/26 and this is expected to address the majority of the remaining requirements to meet the expected drainage capacity. From 2026/27 onward, drain cleaning will transition to a reactive approach, based on assessed needs to maintain capacity.

[17] In 2025/26, the focus will shift to vegetation control, particularly the management of pasture grass within drain channels. A multi-year term maintenance contract is intended to be established for this work, which will also include pest plant management across all schemes.

[18] A multi-year term maintenance contract for mowing and animal pest control will be considered and planned for implementation in the 2026/27 year.

Reactive works

[19] During the 2024/25 period, 31 scheme-related customer enquiries were received via the ORC Customer Services team. All reported issues were investigated and responded to within 20 working days, in line with service level commitments.

[20] In addition, 75 reactive maintenance tasks were logged as they arose. These were also investigated and communicated back to the relevant contacts within the 20-day timeframe.

- Of the 75 reactive work tasks: 71 have been completed.
- Of the four outstanding tasks, 1 task is pending, awaiting permission from a third party and the other 3 have been incorporated into the 2025/26 planned maintenance programme.

Community Engagement

[21] A community drop-in session was held in Balclutha in on 5 August 2025 for the Lower Clutha and Tokomairiro Schemes and a session is planned for the 2 September 2025 for the Lower Taieri Flood Protection and Drainage Schemes. The session in Balclutha was well attended and valuable insight was gained from the community.

[22] The Lower Taieri Liaison Group was established via a public meeting in mid-December. The first formal meeting of the group occurred in May 2025.

[23] Engineering staff engage with landowners across the schemes on a daily basis. The first-hand knowledge of the landowners within schemes provides valuable perspective and information vital to the on-going performance of the schemes.

Process and Performance Improvement

[24] As part of ongoing work to improve efficiency, safety, and environmental outcomes, several innovations and enhancements are being investigated and introduced in the 2025/26 maintenance programme. These include:

- Drone technology for herbicide application in areas that are sensitive or difficult to access.
- Scope and install remote monitoring capability across our pump stations
- GIS Tools for mapping and reporting are being actively used in pest control operations and are under consideration for broader application in vegetation and pest plant management.
- Update and publishing a suite of Standard Operating Procedures to enhance our resilience to safety, and capability.
- Publishing ORC Engineering guidelines for staff and contractors for the application of agrichemicals within the schemes.
- Investigate environmentally friendly solutions for drain cleaning methods.
- Upskilling our staffs' understanding on contract and asset management.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[25] The works presented within this report contribute to ORC's Resilience goals within the Strategic Directions of:

- Plans are in place to ensure that the region's most vulnerable communities (geographic and demographic) and ecosystems are resilient in the face of natural hazards.

  and:
- Our infrastructure is designed and built to accommodate variability and uncertainty associated with changing weather patterns and sea level rise.

Financial Considerations

[26] The planned and reactive maintenance work were achieved within the allocated budgets in the Long-Term Plan 24/25. It is currently expected that the 25/26 planned maintenance programme will fall within allocated budgets.

Significance and Engagement

[27] Staff will communicate work programmes and associated timeframes with affected landholders, liaison groups and communities.

Legislative and Risk Considerations

[28] The nature and setting of the assets mean that they are vulnerable to damage during flood events, particularly within the flood protection scheme. This is a cost and reputational risk for ORC.

Climate Change Considerations

[29] Focus is on maintaining the existing schemes. Climate change considerations, particularly in the Lower Clutha Flood Protection and Drainage Scheme are being investigated by ORC as part of a separate programme of work.

Communications Considerations

[30] Communications including, publishing the maintenance programme on the ORC website, community meetings, liaison groups and direct discussion with affected landowners will continue for 2025/26.

NEXT STEPS

[31] Complete the 2025/26 planned maintenance programme by 30 June 2026.

[32] Provide an annual update to the committee on progress of the maintenance programme.

[33] Publish the 2025/26 work programme on the ORC web site by 1 October 2025.

[34] Continue to communicate with the community through the Liaison groups, drop-in sessions, discussions with landowners, and key stakeholder.

ATTACHMENTS

1. Scheme and Channel Maintenance 2024/25 [**9.5.1** - 2 pages]

Attachment: Scheme and Channel Maintenance 24/25

East Taieri - Drain A1A – Mechanical drain cleaning

Pre- clean

Post clean

Lower Clutha - Tree Maintenance – (Kaitangata Highway)

Pre-start

Completion

Flood bank mowing - East Taieri (Silverstream)

9.6. Freshwater Biodiversity Science Programme Update

Prepared for:	Science and Resilience Committee
Report No.	GOV2553
Activity:	Governance Report
Author:	Pete Ravenscroft, Biodiversity Team Leader Science Ciaran Campbell, Scientist Freshwater Ecology
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] This report provides an overview of the freshwater biodiversity science work programme.

EXECUTIVE SUMMARY

[2] This paper provides an overview of the freshwater biodiversity work programme. The work programme includes supporting minimum flow policy processes, catchment studies, state of environment fish monitoring, project-based fish monitoring, galaxiid recovery projects, fish passage, eDNA projects, threatened freshwater species projects, regional threat assessments, and freshwater invertebrate surveys.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*

BACKGROUND

[3] ORC's freshwater biodiversity science programme aims to map and monitor the ecology of Otago's freshwater rivers and streams. Although one of the traditional columns of the ORC science workload, the freshwater biodiversity programme has evolved in recent years. This has been in response to additional requirements from national direction, notably the National Policy Statement for Freshwater Management (NPS-FM 2020), whilst being responsive to the evolving landscape of freshwater priorities.

[4] Knowledge of freshwater biodiversity in Otago informs decisions for freshwater management, and the maintenance of indigenous biodiversity. These are core functions of Otago Regional Council, consistent with the strategic directions for Otago's environment.

[5] The freshwater biodiversity science work programme has traditionally focussed on providing science input into statutory processes, including minimum flow and allocation plan changes, the Proposed Otago Regional Policy Statement 2021, and the Draft Otago

Land and Water Regional Plan. An additional core component has been state of environment fish monitoring.

[6] The programme now incorporates additional project-based fish monitoring, galaxiid recovery projects, fish passage, support for eDNA projects, threatened freshwater species projects, regional threat assessments, and freshwater invertebrate surveys. These additions have been prompted by a combination of legislative direction, conservation priorities, community interest, and keeping up with the rapidly changing technological improvements.

DISCUSSION

[7] This section outlines the individual components of the freshwater biodiversity programme.

Ecohydrology (Minimum Flow Processes)

[8] The freshwater biodiversity programme contains an ecohydrology sub-programme which is one of the key drivers behind minimum flow processes. Ecohydrology can be defined as the field that studies the interactions between water and instream living organisms.

[9] Studies in this programme include designing catchment studies, undertaking instream habitat models, assessing flow scenarios for their ability to provide for instream values, and providing relevant flow recommendations aligned to proposed environmental objectives.

[10] Over recent years, the freshwater biodiversity programme has focused on minimum flow processes in the following catchments and tasks within:

- Manuherekia River – developed and implemented ecological and hydrological studies, reporting on study outcomes.
- Kakanui River – instream habitat assessment, modelling, and reporting.
- Waiwera River – revisited existing instream habitat models to check relevance and reliability.
- Waianakarua River – developed and implemented ecological and hydrological studies.
- Cardrona River – developed and implemented ecological and hydrological studies, reporting on study outcome.
- Arrow River – developed and implemented ecological and hydrological studies, reporting on study outcomes.
- Taieri River – developed a habitat model for the Tiroiti reach of the Taieri River.

[11] The proposed changes by Central Government to the NPS -FM (2020) are potentially likely to affect the final minimum flow number for individual catchments. The new directions will likely require to consideration the health needs of people, and communities to provide for their social, economic and cultural wellbeing equally with the health and wellbeing of the river.

[12] However, this shouldn't result in the need for any additional science or changes to existing ecological and hydrology reports. These reports are written in manner that considers the ecology and values in relation to flow. Social and economic values factor into the broader policy development process.

[13] One consideration is that habitat studies for some rivers were done several years ago, and may need to be updated prior to revision of minimum flow numbers. This is because the longer time elapsed since a study was undertaken, there is more likelihood for the need to revisit parts of the instream habitat modelling this is to ensure that the model being used is still representative of the river.

Localised Catchment Surveys and Studies

[14] The freshwater biodiversity programme includes targeted investigations at sub catchment scale, to improve understanding and facilitate informed decisions for management. Focal tasks and catchments include:

- Undertaking research on the distribution and habitat preferences of Manuherekia alpine galaxias (*Galaxias* aff. *paucispondylus* "Manuherikia") – a pencil galaxiid that is endemic to the Otago region and only found in braided river habitats and tributaries upstream of Falls Dam. Status: near completed.
- Developing a catchment study for the Taieri River, including ecological and hydrological studies. The scope includes interactions between ground and surface water (including for wetlands), physical habitat model relating flows to depth, wetted width, habitat availability, and the interaction of macrophytes on habitats on flows. Status: early development, expected delivery of five to ten years.
- Revisit all instream habitat models relevant to the pLWRP to ascertain whether they are still representative of the reach and therefore fit for purpose. Status: awaiting LWRP notification.
- Freshwater fish surveys of the Ida Burn and the Ewe Burn catchments are planned for the current year. These surveys will support the need for any future residual flows, that may be required to maintain instream values.

State of Environment Fish Monitoring

[15] The State of Environment (SoE) fish monitoring programme involves fishing at selected sites throughout the region. It is undertaken by the ORC Environmental Monitoring team in accordance with protocols developed by Joy et al. (2013)[1].

[16] Specific reporting requirements from the NPS-FM 2020 include the Fish Index of Biotic Integrity (Fish-IBI[2]), which is a compulsory attribute for reporting on the aquatic life component of ecosystem health.

[17] The Index of Biotic Integrity (Fish IBI) is a set of biological metrics used to assess the richness of fish species by comparing the species present at a site to the species that would be expected in the absence of human impacts.

[1] Joy, M., David, B., & Lake, M. (2013). New Zealand freshwater fish sampling protocols. *Massey University, Palmerston North, New Zealand*.

[2] Joy, M. K., & Death, R. G. (2004). Application of the index of biotic integrity methodology to New Zealand freshwater fish communities. *Environmental management*, *34*(3), 415-428.

[18] The Fish IBI is a multi-metric indicator that takes into account natural gradients in species richness (altitude and distance from sea). It is a composite index composed of six metrics of fish community composition:

1. total number of native species
2. number of native riffle-dwelling species
3. number of native benthic pool-dwelling species
4. number of native pelagic species
5. number of intolerant or sensitive native species
6. proportion of non-native species.

[19] A review has been initiated to analyse the comprehensive data that the monitoring yields above and beyond minimum NPS-FM reporting requirements (which is consolidated and included in Annual SoE water quality updates).

[20] The current SoE fish monitoring network consists of 26 sites across Otago monitored on an annual or biennial frequency, as outlined in the June update to Council. Rationale for the selection of sites is listed and varies from site to site from monitoring of minimum flow effects to water quality and urban runoff. Sites were not originally established to provide a statistically robust Fish SoE sampling network but are generally representative of the riverine environment of Otago.

[21] Of the 26 sites, some have been monitored since 2009, and others have been added to the network as recently as 2020. The fish state of environment monitoring programme will be included in an upcoming environmental monitoring network review. The review will rationalise and justify the focal sites and review the benefits or otherwise of adding and removing sites. The review process is scheduled to start towards the end of this current financial year, following analysis of existing data.

Galaxiid Recovery

[22] Otago is home to New Zealand's most threatened freshwater fish. Fourteen of the fifteen threatened fish species found in Otago are non-migratory galaxiids (Table 1). (The fifteenth threatened fish is the Lamprey, which is found throughout New Zealand).

[23] Otago non-migratory galaxias (Both Vulgaris species complex and the pencil galaxias) evolved as of result of landscape evolution and glaciation processes. The uprising of numerous mountain ranges splitting/capturing several river catchments have all gone to shape the diversity of both the *Galaxias vulgaris* species complex and Otago pencil galaxiids.

[24] These river capture events dating back hundreds of thousands to millions of years have provided the opportunity for species to diversify and become distinct species when they were isolated by river network change. This allopatric speciation (also known geographic speciation) in conjunction with the limited dispersal mechanism of non-migratory galaxiid (in comparison to diadromous species) has meant the majority of the non-migratory galaxiids species have relatively restricted geographical distributions. Many are confined to a single river catchment and in-turn this limits the potential number of populations.

[25] In addition, Central Otago has a dry climate which means that streams are more widely spaced than in most of New Zealand, which has further limited the dispersal of the galaxiids.

[26] Limited natural distribution and mobility, coupled with pressures, such as water demand, degrading of habitats, and the impacts from invasive species has resulted in Otago having the most threatened freshwater fish species in New Zealand.

Table 1: The number of extant freshwater fish species of New Zealand in threatened categories (Dunn et al. 2017), and endemic to or found in Otago. N.B. Non-migratory galaxiid species of Otago are shown in brackets.

Conservation status	New Zealand	Otago
Threatened: Nationally Critical	4	4 (4)
Threatened: Nationally Endangered	6	5 (5)
Threatened: Nationally Vulnerable	12	6 (5)

[27] Salmonids, such as Brown trout and to lesser extent rainbow trout and brook char have been shown to have significant negative impact on Otago's non-migratory galaxiid, and is the leading cause of the high threat status for non-migratory galaxiids. Salmonids are highly mobile and continue to expand their range, with salmonids continuing to move into non-migratory galaxiid habitats, generally resulting in localised extinction of the galaxiid.

[28] The objective of this Galaxiid recovery programme is to prevent localised extinction and provide habitat for threatened freshwater fish to recover. The primary intervention is to remove salmonids by electric fishing, as they are one of the greatest impediments to local persistence and recovery of Otago's threatened freshwater fish. This work is permitted in selected waterways by Otago Fish and Game through a salmonid removal licence.

[29] The programme is relatively modest and has largely been motivated by landowners and catchment groups who seek to see galaxiids survive and thrive in local waterways. Current galaxiid recovery projects focus on species that are threatened and endemic to the Otago region, and include:

- Thomson's Creek, for central Otago roundhead galaxias (*Galaxias anomalus*), in support of Manuherekia Catchment Group and the Manuherekia Exemplar catchment programme.
- Pigroot Creek and Siberia Creeks for Taieri flathead galaxias (*Galaxias depressiceps*) within the Shag River catchment, in support of the East Otago Catchment Group.
- Boundary Creek and Pisgah Creek for central Otago roundhead galaxias (*Galaxias anomalus*) in the Kye Burn catchment, in support of the Kye Burn Irrigation company.
- Three unnamed tributaries of the Nevis River, for the Nevis galaxias (*Galaxias* "Nevis").
- Kidds Creek, a Clutha River tributary on the Pisa Range for Clutha flathead galaxias (Galaxias "species D"). This project has been completed.

[30] The removal operation is undertaken by electric fishing and completed by undertaking multiple electric fishing passes. This has resulted in 13866 salmonids removed across all removal operations. Table two provides a breakdown of the number of salmonids removed from each water way and the number of years removal has been occurring.

Table 2: The number of salmonids removed from each location and the number of years removal has been operating.

Catchment Name	No. of years	No. of salmonids removed	Size range of salmonids (mm)
Boundary Creek	4	3,283	30 -300
Pigroot Creek	2	4,857	30 - 251
Nevis tribs	2	382	30 -197
Thomson's Creek	2	391	95 -300
Pisgah Creek	3	4,953	30 -232

[31] The removal projects in Boundary Creek and Pigroot creek span 12 km and 7km of channel length respectively. These catchments are favourable removal sites as salmonids are prevented re-occupying the targeted streams by natural waterfalls at the downstream end. Salmonid removal at this scale has never been attempted anywhere in New Zealand. Smaller scale electric fishing removal operations have been successfully completed elsewhere, such as Akatore Creek, Fraser spring (Twizel), Cabbage tree gully and Nessing spring (Hakataramea), Schoolhouse, and Kidds Creek (Pisa Range).

[32] Results to date show that eradiation at this scale is achievable. An example of this is Boundary Creek (Kye Burn catchment). This current year will be the fifth year of removal, but the fourth-full year, as the first year was only a single electric fishing pass was completed, which was part of a brown trout removal feasibility study.

[33] Table 3 shows the decline in brown trout numbers being removed over time, with a drastic reduction from over 2,000 fish in year two, to only 27 brown trout being captured last year (2024 – 2025). To confirm the low detection rates from electric fishing, an eDNA delimiting sampling survey was conducted at specific locations. The eDNA results detected brown trout at three locations; two sites were at extremely low detection rates (potentially a single fish) the third location had slightly higher presence of brown trout detected.

[34] It's envisaged that due to the low trout numbers, this will be the last year of dedicated brown trout removal in Boundary Creek. Going forward the operation will shift towards a surveillance programme, and if brown trout are detected then a targeted removal operation will be undertaken.

***Table 3: Table presenting the year, the number, and the size range of brown trout removed from Boundary Creek*:**

Year	Number of trout removed	Size range (mm)
1	476	30 - 300
2	2039	30 - 250
3	681	75 - 190
4	27	95 -210

[35] Very little data exists nationally that quantify the benefits of interventive management. Monitoring the response of galaxiids to salmonid removal projects in Boundary Creek, Pigroot Creek, and Siberia Creek is being conducted.

[36] To date galaxiid recovery in response to the salmonid removal has been significant. The increase in numbers and the recolonisation into new habitats that were once occupied by salmonids has been observed across all salmonid removal operations. An example of this is Pigroot Creek; Figure 1 presents the monitoring results of Pigroot Creek which compares Taieri flathead galaxias numbers in 2024 and 2025.

[37] Three hundred and fifty-eight galaxiid were captured during 2025 monitoring across all six monitoring locations (Figure 1). This is a significant increase compared to the 107 fish caught in the previous year. An increase in galaxiid numbers was seen within all the monitoring sites.

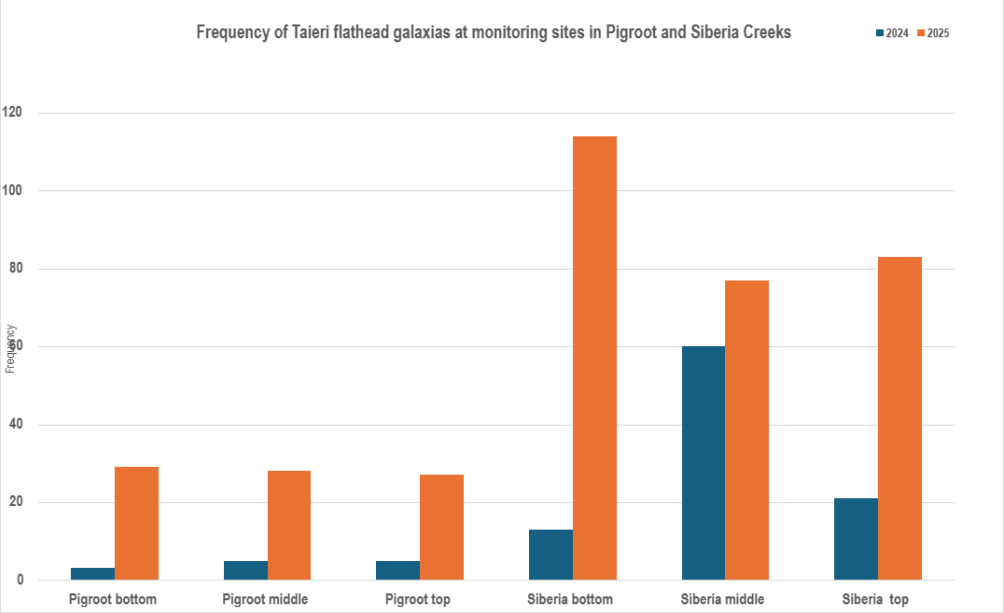


Figure 1: Frequency histogram of Taieri flathead galaxias numbers comparing between 2024 and 2025 in Pigroot and Siberia Creeks (2024 n= 107 ; 2025 n=358).

[38] The increase in galaxiid numbers between the monitoring years was particularly driven by increased numbers in the juvenile cohort, 0-year-old fish (Figure 2). Galaxiids of more than 60mm length are one + year old fish, therefore fish of length <60mm are young-of the-year. Young galaxiids are particularly vulnerable to trout predation.

[39] Two hundred and twenty-two juvenile fish (<60mm) were recorded in 2025 in comparison to thirteen during the 2024 monitoring period (Figure 2). This confirms that spawning and recruitment for this year was successful, with larvae surviving and becoming juvenile fish.

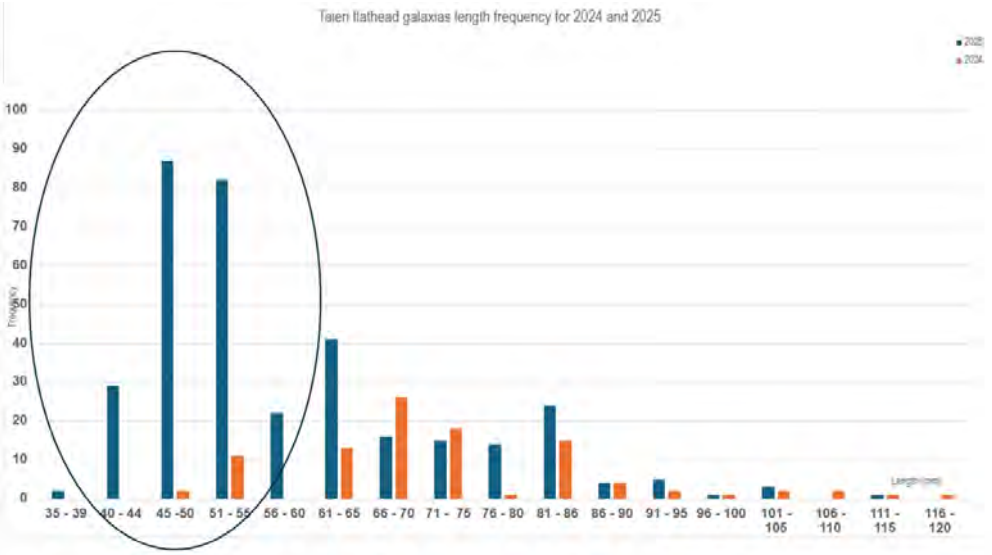


Figure 2: Fish length frequency histogram of Taieri flathead galaxias numbers comparing the 2024 and 2025 years in Pigroot and Siberia Creeks. The circled area of the graph highlights the increased number of juvenile fish recorded. (2024 n= 107 ; 2025 n=358).

[40] It is too early to confirm whether this increase in galaxiid numbers can be attributed directly to brown trout removal and a further year of monitoring is needed to support this. However, there is clear indication of a vast improvement in recruitment occurring between the two monitoring occasions based on the population numbers and size distribution.

Project-Based Fish Monitoring

[41] The freshwater biodiversity programme also includes monitoring of fish at sites that are not part of the SoE programme, including:

- Monitoring the nationally critical lowland longjaw galaxias (*Galaxias cobitinis*) in the Kakanui River catchment. A recent study of habitats and interactions between surface- and ground-waters in the Kauru River was formulated in response to fish monitoring, and reported to the Environmental Science and Policy Committee in February 2025.
- Returning to historic monitoring sites to re-capture tagged fish, including at Burnt Creek (Waipori catchment) and Schoolhouse Creek and Yellow Creek (Nevis catchment). These sites were initiated by DOC (2000 – 2015), where few of the estimated 5,000 tagged fish are still resident. This work provides information about the fish longevity and life cycle.
- There has been a new tagging monitoring site established in the Pomahaka catchment in collaboration with the Pomahaka Rivercare Group. To date 200 individual fish have been tagged. The Pomahaka galaxias (Figure 3) is a recently identified species, and this separation is based solely on genetics. Therefore, little in known on the lifecycle of this species, tagging data and ongoing monitoring will improve the ecological understanding of this species and establish whether any management requirements are required. This tagging programme is scheduled to continue for a further four years.

Figure 3: Photograph of the Pomahaka galaxias (Tag M97).

Fish Passage

[42] Fish passage broadly describes the ability of fish to travel along waterways. Impediments to fish passage, termed barriers, can include culverts, dams, waterfalls, or bridges. Barriers to fish passage can be viewed as a problem or a benefit depending on the setting and the behaviour of different fish species.

[43] Loss of fish passage is a resource management issue in Otago and of significance to iwi authorities[3]. For indigenous species, some instream structures prevent passage and make habitat inaccessible, while some structures provide protection from invasive species. For some exotic species, their passage is undesirable. For sports fishes, a balance needs to provide the achievement of environmental, social, and cultural outcomes.

[44] Fish passage requirements for regional councils are now prescriptive for new structures (National Environmental Standards for Freshwater 2020) and for existing structures (National Policy Statement for Freshwater Management 2020). Under the NPS-FM, ORC must include fish passage objectives in its regional plan as well develop a fish passage work and action plan (NPS-FM 2020 Clause 3.26 **Fish Passage**).

[45] A desktop assessment undertaken by NIWA identified ~13,000 in-stream structures in the Otago region (Figure 4), which is 10% of the total estimated ~130,000 structures identified nationwide. This desktop assessment utilised structure consent data held by local authorities, as well as running spatial intersects on rivers, roads, and rail. However, this comprehensive desktop exercise likely underestimates the total number of structures as many will exist under permitted activity conditions.

[46] Structures need to be assessed for their risk to fish passage, and for opportunities to maintain and improve fish passage in the region. To date, around 1000 structures have been assessed in the Otago region, with plans in place to speed up this laborious task by including in work programmes for summer temporary field staff, and by working with the Department of Conservation.

[3] https://www.orc.govt.nz/media/0byjddsh/clean-appeals-version-porps-21-july-2025.pdf

[47] Fish passage is not all about providing passage everywhere, as some structures protect threatened fish from invasive species. In certain locations in Otago, fish passage management will centre on preventing passage for some species. Council focus to date has included searching for and assessing waterfalls and other structures that protect threatened galaxiids.

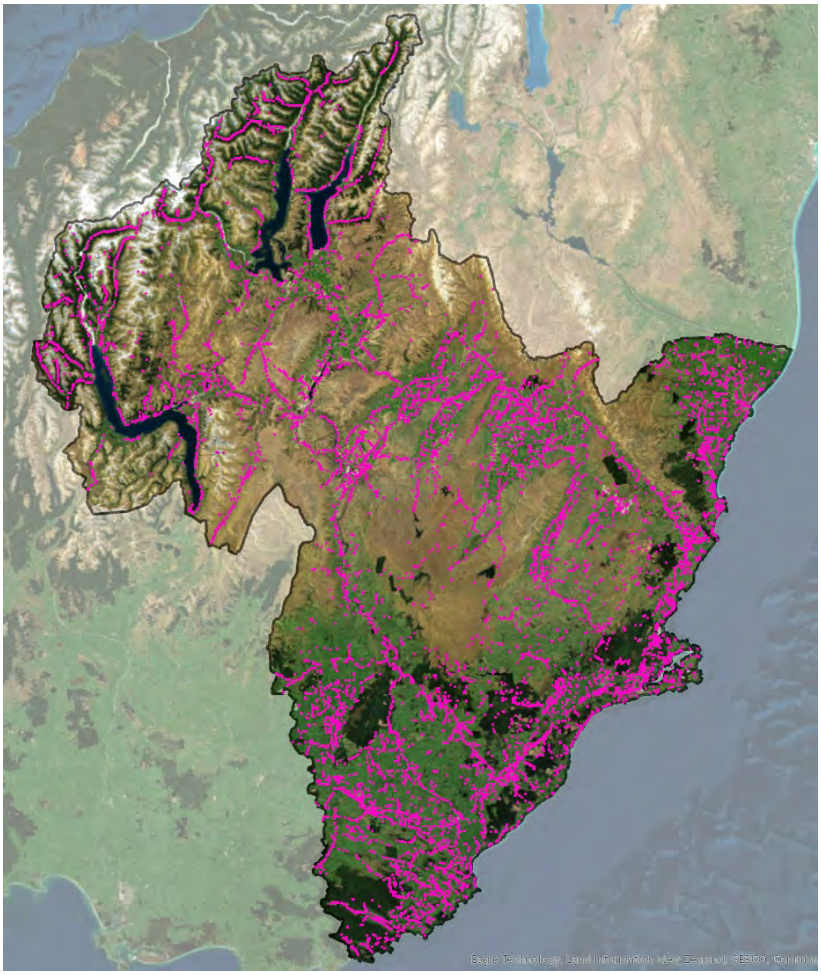


Figure 4: Structures (pink) in the Otago region which may pose an issue for fish passage, as recorded in the NIWA Fish Passage Assessment Tool[4].

[48] Progression for a fish passage science programme is not as advanced as other biodiversity programmes. This has largely been due to resource prioritization of the freshwater ecologists' input into the development of the draft Land and Water Regional Plan.

[49] Input into the draft Land and Water Regional Plan included important elements of the fish passage programme, including meeting NPS-FM requirements for identifying desired and undesirable fish species, and identifying rivers and receiving environments

[4] https://niwa.co.nz/freshwater/fish-passage/fish-passage-assessment-tool

where passage should be provided for desired species and prevented (where possible) for undesirable species.

[50] Additional fish passage requirements include the development of a fish passage action plan and a work programme to support the achievement of fish passage objectives. Important elements of the fish passage action plan are dependent on outcomes from planning and policy, as well as early engagement with tangata whenua and the community.

[51] Structure assessment to date has focused on those that protect threatened fish, and 35% of known sub-populations have been inspected, particularly within the Kye Burn, Cardrona River, Nevis River, Waipori River, Tuapeka River, Waitahuna, upper Taieri River, and Beaumont River catchments. Focus for the immediate future includes the Pomahaka River, Lake Mahinerangi, and upper Waipori River catchments.

[52] Addressing fish passage issues in the region will be a significant undertaking, and we now are beginning to gather information needed to address this. First steps involve consulting with mana whenua, Department of Conservation, Fish and Game, and the community in the development of a Fish Passage Action Plan consistent with national direction.

[53] At this stage the proposed changes to both the NPS-FM and NES have not indicated significant change to fish passage requirements.

[54] Remediation (remove, replace, repair) of structures that impede fish passage can be prioritised and/or opportunistic. Opportunistic and priority remedial actions have recently taken place in the Pleasant River in support of the Toitū te Hakapupu Pleasant River Catchment Restoration Project, utilising specific culvert design and concrete ramps (Figures 5 and 6).

Figure 5: Brookland Road culvert, Te Hakapupu Pleasant River (before). Due to the vertical drop and the high flow velocity Inanga (Galaxias maculatus) struggle to pass through the culvert.

Figure 6: After remedial works at Brooklands Road culvert, Pleasant River. Inanga (Galaxias maculatus) can now access habitats and complete their life cycle. The stones cemented into the concrete apron slow down the flow and provide areas for fish to rest out of the current. A thick rope running through the culverts provide a substrate for fish to climb along.

Environmental DNA

[55] Environmental DNA (eDNA) is genetic material that is shed by organisms as they move around their environment. By sampling the environment (e.g., water, soil, air) and isolating the genetic material, valuable data can be gained into the distribution of species through time and space, biosecurity threats monitored, fluctuations in ecosystem health quantified.

[56] Sampling the environment to identify organisms can be faster, safer, less time-consuming, and less invasive than other surveying or monitoring techniques. eDNA as a sampling and monitoring tool has recently rapidly grown in Aotearoa New Zealand and globally, reflecting its ease, cost-effectiveness, and the breadth and depth of information that is gained. Through this method, thousands of species of fish, macroinvertebrates, birds, mammals, reptiles, amphibians, plants, fungi, protists, bacteria, and other organisms can be identified, from half a litre of water or soil.

[57] ORC Science staff have expertise in eDNA, and ORC has been involved in several national, regional, and local initiatives to embed and improve eDNA as an emerging technique and technology. Although not a formal programme, eDNA is becoming a widely used tool within a range of ORC teams and more widely across the region. In addition to the sampling specifically undertaken by ORC (Table 4), the council contribute to thousands of publicly available results nationwide. Initiatives which council are involved in include:

- Sampling broadly throughout the region to build a baseline of eDNA data whilst improving understanding of the strengths and limitations of the technique and technology.

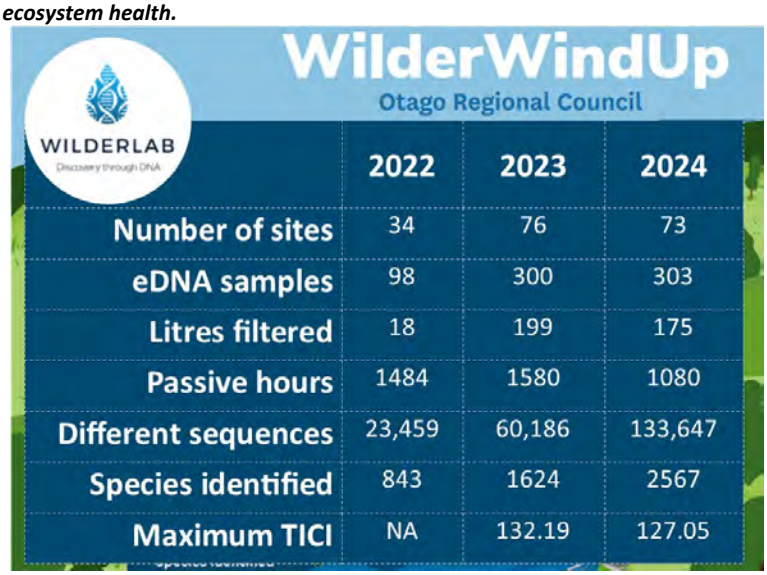
- Sampling specifically at State of Environment monitoring sites to build causal relationships between currently measured attributes and aspects of eDNA (e.g., Figure 7 – Kakanui River below).
- Sampling throughout catchments to investigate changes in eDNA species composition and health metrics with time and space.
- Sampling in support of landowners, community and catchment group restoration projects (e.g., WAI Wānaka, Orokonui Ecosanctuary, Manuherekia Catchment Group, Kauri Trees).
- Providing eDNA data in publicly accessible portals and encouraging others to follow FAIR data principles (Findable, Accessible, Interoperable, Reusable).
- Supporting biosecurity responses for the detection of unwanted or pest organisms (e.g., red-eared slider turtles, alligator weed).
- Developing biodiversity and biosecurity alert systems for the detection of focal species.
- Monitoring the success of management interventions (e.g., trout removal at galaxiid recovery projects as described above).
- Development of proof-of-concept tools for reading, analysing, and interpreting eDNA data, and supporting other national initiatives to develop these tools (e.g., eDNA dashboard, eDNA TICI dashboard, fish passage dashboard).
- Testing eDNA sampling method limitations using various replication levels (eight or sixteen replicates at the same site at the same time) to achieve comparative detection levels of fish as electric fishing following State of Environment monitoring protocols[5].
- Optimising eDNA sample replication, including by testing eight or sixteen replicates to achieve comparative species accumulation along detection curves, testing information gain against sampling cost[6].
- Testing the efficacy of two methods of filtering eDNA from water – active sampling by pushing water through the filter using a syringe, and passive sampling by deploying a filter in a lotic (flowing) environment for 24hrs (Figure 8 – syringes and filters below).
- Development of a riverine Taxon-Independent Community Index (TICI) to objectively assign indicator values to genetic material [7]. (A TICI score of: <80 = Very poor, 80 -90 = poor, 90 – 100 = Average, 100 – 110 = Good, 110 – 120 = Excellent and >120 = Pristine).

[5] David, B. O., Fake, D. R., Hicks, A. S., Wilkinson, S. P., Bunce, M., Smith, J. S., ... & Gleeson, D. M. (2021). Sucked in by eDNA–a promising tool for complementing riverine assessment of freshwater fish communities in Aotearoa New Zealand. *New Zealand Journal of Zoology*, *48*(3-4), 217-244.

[6] Smith, J., David, B., Hicks, A., Wilkinson, S., Ling, N., Fake, D., ... & Gault, A. (2024). Optimizing eDNA Replication for Standardized Application in Lotic Systems in Aotearoa, New Zealand. *Environmental DNA*, *6*(5), e70017.

[7] Wilkinson, S. P., Gault, A. A., Welsh, S. A., Smith, J. P., David, B. O., Hicks, A. S., ... & Bunce, M. (2024). TICI: a taxon-independent community index for eDNA-based ecological health assessment. *PeerJ*, *12*, e16963.

Table 4: A summary provided by Wilderlab showing the sampling effort by Otago Regional Council each year, 2022- 2024. Litres filtered is indicative of active syringe sampling, with the aim being to pass 1L of water through each filter. Passive hours are indicative of passive sampling effort, utilising filters deployed in stream for up to 24 hours. TICI scores, developed since 2022, are indicate of freshwater ecosystem health.



	2022	2023	2024
Number of sites	34	76	73
eDNA samples	98	300	303
Litres filtered	18	199	175
Passive hours	1484	1580	1080
Different sequences	23,459	60,186	133,647
Species identified	843	1624	2567
Maximum TICI	NA	132.19	127.05

Figure 7: Passive eDNA filters deployed for 24 hours at the SoE monitoring site (Kakanui River at McCone's).

Regional Threat Assessment for Freshwater Fishes in Otago

[58] The New Zealand Threat Classification System (NZTCS) is used to nationally assess species, with a complementary regional equivalent developed in the last decade. The regional threat classification system leverages off the national assessments in the NZTCS, providing information relevant with regional context at regional scale.

[59] ORC has completed regional threat assessments for Indigenous vascular plants, birds, reptiles, bats, velvet worms, mushroom fungi, and amphibians, which Dr Scott Jarvie has previously presented on Council. A website detailing the threat assessments is available here: Otago regional threat assessments.

[60] In 2024 an expert panel assessed 42 species of freshwater fish in the Otago region, nine of which are endemic to the Otago region. A report summarising the results of the assessment is in preparation and will be finalised in the current calendar year.

Freshwater Invertebrates

[61] Currently there is limited understanding of the presence and distribution of freshwater invertebrate fauna in the Otago region. Invertebrates are key parts of the freshwater

ecology food chain, and can be used as indicators of ecosystem health. It is necessary to improve understanding of the freshwater invertebrate fauna of Otago so any future management decisions will be knowledge based.

[62] In the past year ORC freshwater scientists completed a trial programme to trap and describe invertebrates as some stream sites in Otago (figure 8). ORC looked beyond the standard practices for monitoring water quality and invested in a method to collect species-level information. Species level information is important for both maintenance of biodiversity and to feed into development of future environmental indices. Our current understanding limits both our knowledge of what species are present and how they respond to environmental stressors.

[63] From the 20 samples, an estimated 11,800 insects representing 60 species from focal insect Orders (Ephemeroptera - Mayflies, Plecoptera - Stoneflies, Trichoptera - Caddisflies, Megaloptera - Dobsonflies) were recorded. Working with experts to capture, identify, and sequence Otago's freshwater insects will improve knowledge on Otago's diverse freshwater fauna, as well as improve the accuracy of eDNA results.

[64] A complementary desktop exercise has identified 270 (and counting) different freshwater invertebrate species recorded in existing databases in the Otago region. This result likely places Otago as the region with the greatest species diversity of freshwater invertebrates, as well as the region with the most comprehensive species list. Next steps will include expanding input data sources, seeking expert checking, and identifying candidate regional endemic freshwater invertebrates.

Figure 8: Adult freshwater invertebrates captured using light trapping, including mayflies, stoneflies, caddisflies, crane flies, true flies, moths, and dobsonflies. These have drowned and can now be preserved in ethanol for species identification and future genetic sampling.

OPTIONS

[65] This paper is for noting only.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[66] This programme informs the state of freshwater biodiversity and explores the management of freshwater through regulatory and non-regulatory functions, aligned to ORC's strategic directions, and ORC's current and draft biodiversity strategies.

Financial Considerations

[67] The freshwater biodiversity work programme is funded and planned under ORC's Long-Term Plan.

Significance and Engagement

[68] Not Applicable.

Legislative and Risk Considerations

[69] Many parts of the freshwater biodiversity programme (e.g., SoE Fish monitoring, Fish Passage) are requirements of the NPS-FM which is currently under review.

[70] The time elapsed since some previous ecohydrology studies (designed to inform minimum flow processes) means these may need to be redone prior to future plans.

Climate Change Considerations

[71] Establishing baseline data on the state and trend of freshwater biodiversity is useful for informing key considerations for environmental change, including through climate change.

Communications Considerations

[72] Not Applicable.

NEXT STEPS

[73] The projects will continue as outlined above.

ATTACHMENTS

Nil

9.7. Wetland Programme Update

Prepared for:	Science and Resilience Committee
Report No.	SCI2502
Activity:	Governance Report
Author:	Sami Khan, Senior Scientist – Freshwater Ecology Pete Ravenscroft, Team Leader Biodiversity
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] To update the Otago Regional Council's Science and Resilience Committee on the wetland mapping and monitoring programme.

EXECUTIVE SUMMARY

[2] National Policy Statement for Freshwater Management (2020) requires regional councils to identify and map all natural inland wetlands and develop and implement a monitoring plan to monitor the condition of natural wetlands. These are both aimed to generate sufficient information that will enable councils to assess whether policies, rules, and methods are ensuring "no loss of extent or values of wetlands".

[3] To meet the legislative requirement and equip the council with the required information, ORC launched a comprehensive wetland mapping and state of the environment type wetland monitoring programme in 2022. The wetland mapping programme consists of three phases: I) all regionally significant wetlands were remapped, II) detailed mapping of the Upper Taieri Scroll Plains Wetland Complex, and III) mapping all wetlands in the region >0.05 ha in area.

[4] Phase III, mapping wetlands in all over the region is the most demanding task, and to date 51% of the region has been completed. Over 35,000 wetlands have been mapped to date across 51% of Otago, the remainder of the region due to be completed by the end of 2025-2026. In Lower Clutha Rohe alone, over 19,000 wetlands have been identified and mapped.

[5] Concurrently, a fit for purpose Regional Wetland Monitoring programme was devised that helped select representative sites and monitor their condition. A pilot monitoring project was conducted documenting biodiversity values, hydrology and soil quality, and physico-chemical characteristics of wetlands in the Upper Taieri Scroll Plains and a some additional Regionally Significant Wetlands. On the FMU scale, wetland monitoring commenced in 2024 in the Catlins, and values in nearly half of the targeted wetlands have been documented. Information generated includes Wetland Condition and Pressure Indices which through time should be able to detect improving and deteriorating trends in wetlands at the FMU scale.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*

BACKGROUND

Otago Natural Wetlands Programme update

[6] Section 3.23 of the National Policy Statement for Freshwater Management (NPS-FM 2020; amended version as of October 2024) requires regional councils *to identify and map all natural inland wetlands* that are 0.05 hectares or greater in extent, or of a type that is naturally less than 0.05 hectares in extent (such as an ephemeral wetland) and known to contain threatened species. Further, the policy statement mandates councils to develop and implement a *monitoring plan* to monitor the condition of natural wetlands. Both the wetland inventories (extent and condition) are aimed to generate sufficient information that will enable councils to assess whether policies, rules, and methods are ensuring "no loss of extent or values of wetlands".

[7] This paper updates the Committee on the ORC's wetland mapping and monitoring programme established in response to these requirements.

[8] Its noted, that the NPS-FM and broader RMA is under review, and therefore some of these requirements may change. However, proposed changes shared to date indicate minimal changes are expected in relation to wetland mapping and monitoring requirements; changes are likely to focus on permitted activities in and around natural wetlands such as Resource Management Stock Exclusion regulations (RM-SE) and National Environmental Standards for Freshwater (NES-F) and timeframes for mapping wetlands. The ORC has submitted detailed feedback to the Ministry for the Environment on the proposed revised wetland regulations, and this was presented to the Councillors in July 2025[1].

NATURAL WETLANDS MAPPING

Introduction

[9] To recognise and protect Otago's wetland ecosystems 171 Regionally Significant Wetlands and Wetland Management Areas (RSWs) were identified, mapped and included in the Regional Plan – Water for Otago (RP: W: Schedule 9). These wetlands were incorporated into the RP: W (through Plan Change 2) in July 2011 and fully operative since October 2013.

[10] The NPS-FM (2020) requires regional councils to implement more stringent regulations for protection and management of all natural wetlands, not just regionally significant wetlands. The NPS-FM requirements for wetland mapping and protection varied from the criteria used for wetland provisions under the RP-W.

[1] Council Meeting - 23 July 2025; agenda point 9.1.3 Draft ORC Submission on Proposal for Freshwater National Direction (Package 3)

[11] Following the operative NPS-FM, a detailed and comprehensive regional wetland mapping programme was designed. The programme consisted of mapping wetlands in three phases.

- Phase I - RSWs review and remapping,
- Phase II - Upper Taieri Scroll Plains wetland mapping, and
- Phase III -Mapping wetlands >0.05ha (500 m^2) in area across the rest of Otago.

Regionally Significant Wetlands review and remapping

[12] Regionally Significant Wetlands (RSW) are systems that are identified in the current Regional Plan - Water for Otago (2004). These wetlands are significant as they are known to only exist in Otago, are representatives of naturally uncommon ecosystems, or are remnants of once common but now threatened ecosystems and contain one or more of 10 listed significant values in Chapter 10 of the plan. There are 171 RSW's in the current Regional Plan (Schedule 9).

[13] Following the updated guidance in the NPS-FM (2020), Otago's RSWs were remapped by ORC consultants using improved mapping techniques such as Sentinel-2 timeseries satellite imageries for delineating varying seasonal extent, Soil Maps and Landcover Database. Through this process, most of Otago's RSW's underwent boundary changes. The updated RSWs mapped a total area of 12,239 ha, a reduction of 927 ha from the RSW's in the Water Plan (RP-W Schedule 9: RSW maps). Contributing to the reduction, some originally mapped wetland complexes encompassed significant areas of terrestrial habitats. In addition, 2 RSWs were assessed as entirely terrestrial habitats and therefore removed from the revised list and maps (i.e., RSW # 35: Diamond Lake Wetland, and RSW # 42: Fernhill Marsh).

[14] As part of this review, the RSWs were classified into wetland types using Johnson and Gerbeaux Wetland Classification framework[2]. Swamps and marshes made up the greatest extent of the re-delineated RSW wetlands. Most wetlands were assessed as indigenous or mixed vegetation status.

[15] The extent of most RSWs were revised using desktop techniques (timeseries satellite and airborne imageries), however 16 were ground truthed using Wetland Delineation Protocols (WDTs[3]). The ground truthing resulted increasing in size in some wetlands as compared to the remote mapping, while other changing very little, and some decreasing, with an overall reduction in size of six hectares[4].

Upper Taieri Scroll Plains wetlands

[16] Upper Taieri Scroll Plains is one of the most remarkable and certainly the largest of such landscapes in New Zealand. 'Scroll Plain' is a pattern of river meanders in a plain generating a range of cutoff channels and wetland features. It is notable in his 2022 book, *Mountains. Volcanoes, Coasts and Caves: Origins of Aotearoa New Zealand's Natural Wonders*, that Bruce Hayward celebrates meander rivers by having chosen the Upper Taieri Scroll Plains for his cover illustration and defines these scroll plains as being *"among the most stunning examples anywhere in the world"*.

[2] Johnson and Gerbeaux (2004) – Wetland Types in New Zealand (link)
[3] New Zealand Wetland Delineation Protocols (link)
[4]For more detail please visit ORC website for reports (Reports and Publications – Wetland and Estuary)

[17] Among all the RSWs, reviewing the mapped extent of the Upper Taieri Scroll Plains (UTSPs) proved the most challenging, and attracted significant interest from landowners, stakeholders, the public, and central Government. This was largely due to the UTSP being comprised of an extensive number of smaller individual wetland features in an actively farmed area, where application of the Resource Management Stock Exclusion regulations was equally impractical from both a farming and wetland management perspective.

[18] Concurrently, a community-led and MfE funded project "Tiaki Maniototo" had resourcing for wetland fencing and needed defined wetland boundaries to enable fencing in the Scroll Plains.

[19] Due to the nature, mapping requirements, and the size and complexity of the UTSP, wetland mapping in the was conducted in a standalone project, separate from the regional wetland mapping described below. Mapping methodologies included using state of the art techniques (LiDAR data and machine learning methods for calculating wetness indices and depression analyses) combined with conventional manual digitisation. In the three basins of the scroll plains (i.e., Paerau/Styx basin, Māniatoto basin and Tunaheketaka/Taieri Lake basin) a total of 4,681.5 hectares of wetlands were identified, totalling 11,450 individual wetland polygons (see Figure 1 an example of the maps).

[20] Different methodologies were employed with the aim to map wetlands that most likely to meet the RMA definition of 'wetland'. Wetlands with altered vegetation were delineated using MfE's recommended Wetland Delineation Protocols (Vegetation, Hydric Soil and Hydrology Tools) to test whether they meet the 'natural inland wetland' definition criteria used in the NPS-FM (2020). A subset of 151 wetlands across the plains were tested (using Vegetation Test) and the results suggest that 60% of the surveyed wetlands do meet the criteria while 40% do not qualify or require further investigation (such as Wetland Delineation; Hydrology and Hydric Soil Tests).

[21] Due to the intrinsic complexity of the scroll plains system an alternative management approach was proposed for managing wetland and other values in the UTSPs. The proposed approach envisioned three broad management zones to be delineated, as opposed to managing thousands of individual wetland features. It is proposed each of the management zone will be defined in relation to its pertinent values such as the Taieri River and riparian areas, tributaries, natural wetlands, flood plains and scroll plains.

[22] Currently the mapping of individual UTSP wetland features has been completed, but the formal delineation of the area into management zones awaits pending RMA changes. In summary, the values being assessed for management zone 1 is an area that encompassing the Taieri river channel and its riparian zones including confluences of the tributaries, for zone 2, the extent that is being annually flooded including oxbows and marshes, and for zone 3, all the scroll plains landscape including paleo-channels, remote oxbows, ephemeral wetlands and remnants of inland saline systems (roughly an area that will be inundated by floods driven by extreme weather events such as torrential rains in early spring that causes snow melt and cloud bursts etc.).

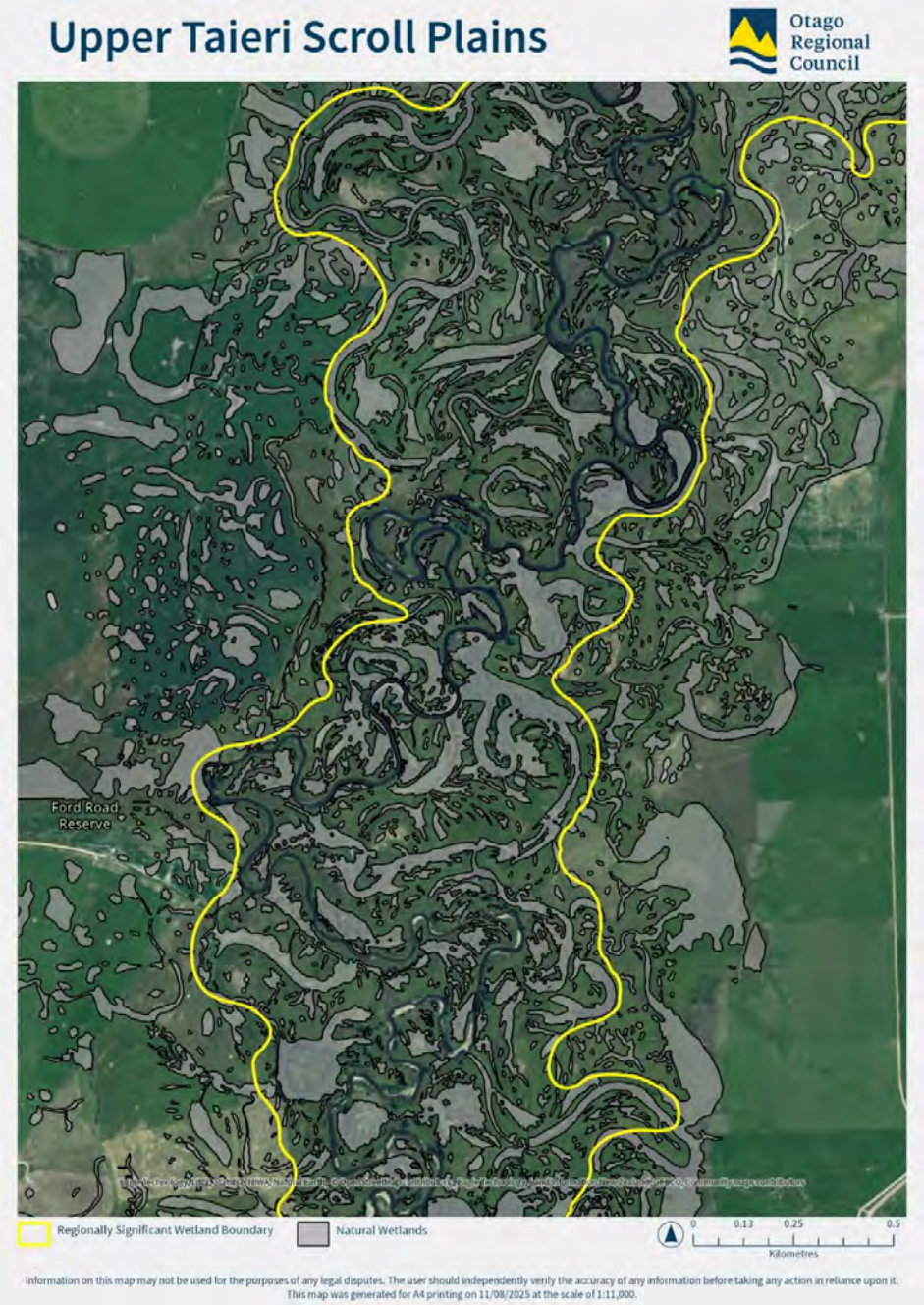


Figure 1: Example map of a portion of the Upper Taieri Scroll Plain. - Yellow line denotes original RSW boundary (as per Regional Plan – Water) while shaded polygons with black outline represent natural wetlands (as defined in the NPS-FM).

Regional Wetland Mapping Programme

[23] Phase III of the mapping programme is to map all natural wetlands in the region that are larger than 500 m^2 (0.05 Ha), or smaller if an ephemeral wetland and/or known to contain threatened species (NPS-FM section 3.23). This represents a significant body of

work as Otago contains large areas of dissected hill country and upland landforms, that will contain tens of thousands of smaller and ephemeral wetlands. The wetland mapping project was planned over four years, starting in 2023.

[24] Mapping in three FMUs (Dunedin and Coast, North Otago and Catlins) and two rohes (Upper Lakes and Lower Clutha rohe) has been completed in FYs 2022-2023, 2023-2024 and 2024-2025 (Table 1, Figures 2, 4 and 5; area figures are not yet available for Lower Clutha rohe). Partial mapping has been completed in Taieri FMU, Roxburgh rohe, Manuherekia rohe and Dunstan rohe, and are aimed to be completed in FY (2025-2026). Manuherekia catchment has been prioritised in collaboration with the Manuherikia Catchment Group.

Table 1: Wetland Mapping Programme Progress updates

FMU/Rohe	RSWs		Natural Wetlands		% completed	Progress
	Frequency	Area (Ha)	Frequency	Area (Ha)		
Upper Lakes	17	1,007	5,389	4,005	100	Completed (2023)
North Otago	13	356.8	5,686	1,926.3	100	Completed (2024)
Dunedin & Coast	22	938.65	2,431	1,668.22	100	Completed (2023-24)
Catlins	21	593.5	1,799	2,462.6	100	Completed (2023-24)
Lower Clutha	29	1,239	19,315	-	100	Completed (2024-25)
Taieri	35	3517	-	-	30	In progress (2026)
Dunstan	10	367	-	-	15	In progress (2026)
Roxburgh	12	894	-	-	15	In progress (2026)
Manuherekia	11	154	-	-	>60%	In progress (2026)

[25] All the wetland spatial data (maps, extent and values) are aimed to be compiled as an Interactive Regional Wetland Inventory (GIS infrastructure; see Figure 3 for example) containing the following attributes about each mapped wetland.

i. unique identifier (code) and location,
ii. GIS polygon (boundary),
iii. classification of wetland type as per Johnson and Gerbeaux Wetland Classification System (2004),
iv. wetland values (exotic, native, etc.), and
v. wetland condition (values and ecosystem health monitoring information).

[26] With respect to pending NPS-FM changes, it is proposed to continue the Regional Wetland mapping project as indications to date suggest little change to wetland mapping requirements, with the exception of a more relaxed mapping timeframe. Further, to date a significant progress has been made with ~70% of the region mapped, and delays or changes to methodology could impact data consistency and integrity.

[27] Beyond future regulatory requirements for wetland management, the data will have a wide range of regional utility including making informed decisions about land use diversification, sub-divisions, identifying areas for ecological restoration and preservation, potential carbon and biodiversity credits, and nature-based solutions. A regional wetland map will be instrumental in developing Catchment Action and Farm Plans.

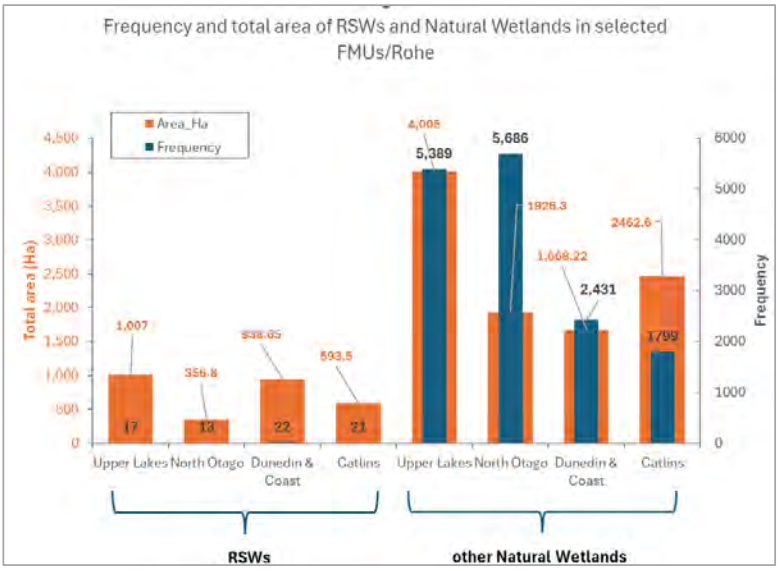


Figure 2: Frequency and area information of RSWs and other Natural Wetlands in selected mapped FMUs/Rohe

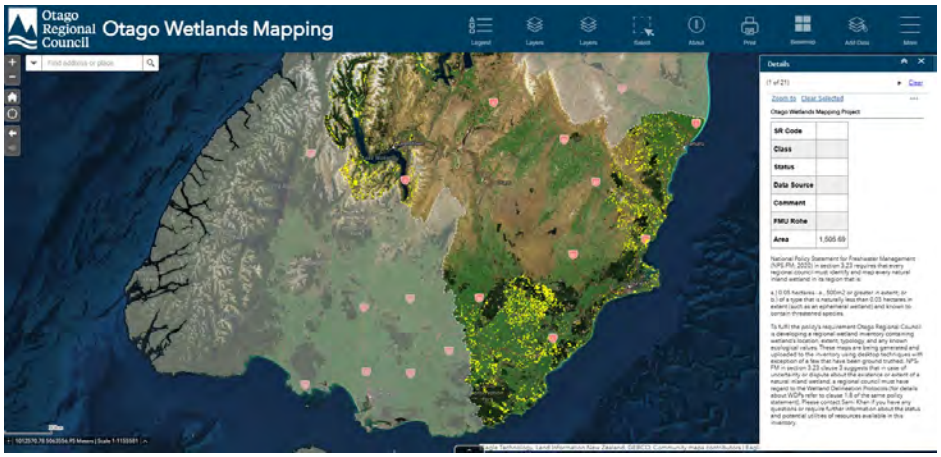


Figure 3: Example of the Interactive Regional Wetland Inventory (draft)

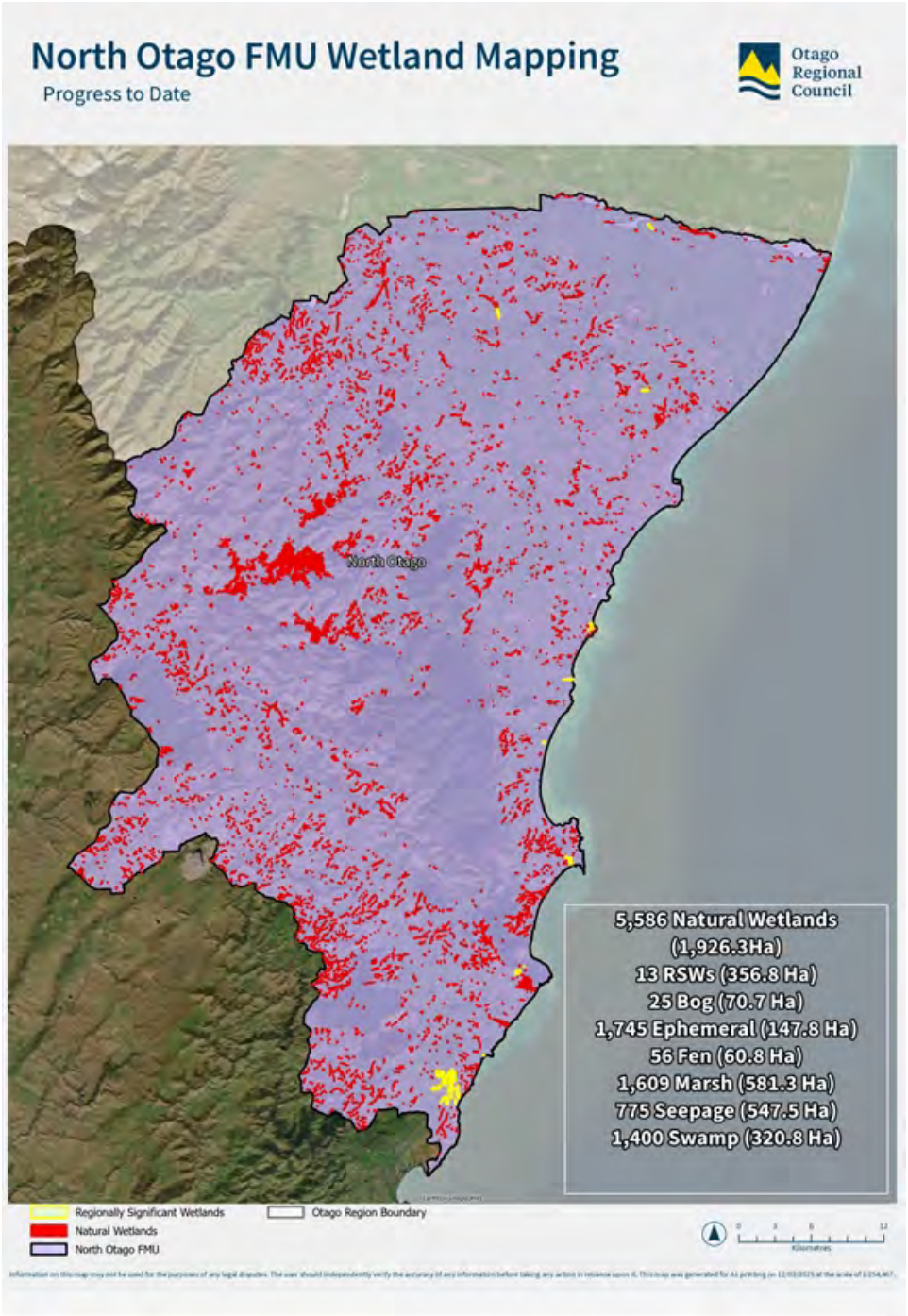


Figure 4: Location, typology and area information of RSWs and Natural Wetlands in North Otago (one of five completed FMUs/Rohe). Revised RSW wetlands are outlined in yellow and Natural Wetlands mapped as part of the Regional Wetland Mapping Programme in red.

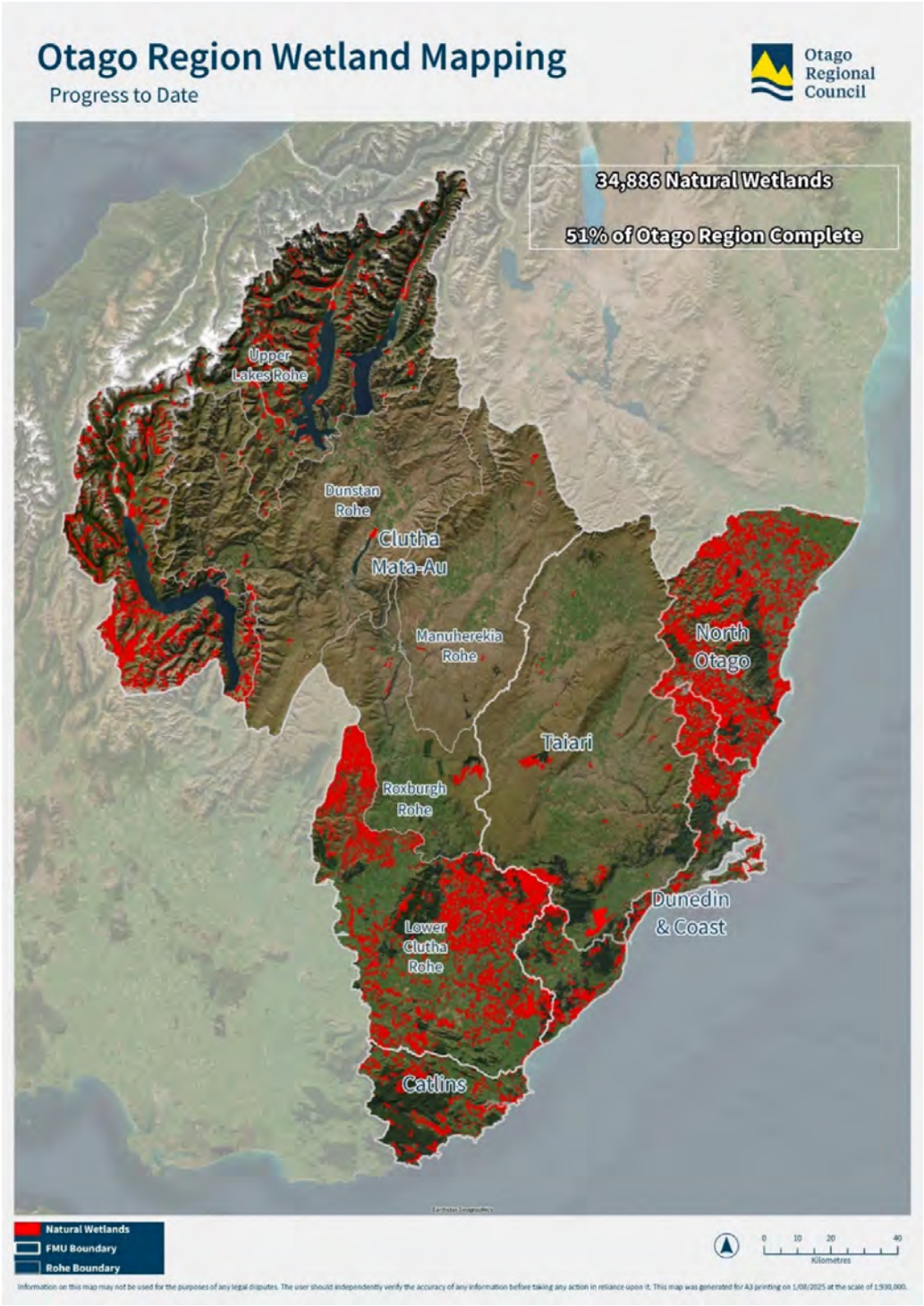


Figure 5: Mapped Wetlands in Otago region. Mapping completed in North Otago, Dunedin and Coast, Catlins, Lower Clutha, and Upper Lakes FMUs/rohe. Work in progress in Taieri, Dunstan, Roxburgh and Manuherekia.

NATURAL WETLAND MONITORING

Introduction

[28] NPS-FM (2020), specifically Policy 6. focuses on avoiding further loss of natural inland wetland extent, protecting their values, and promoting their restoration. To give effect to the policy it mandates all regional councils to identify and establish monitoring wetland sites within FMUs, including those that are representative of the area. However, the policy statement doesn't prescribe specific monitoring methods but requires that monitoring must be systematic and contain methods that allow for the detection of trends and the implementation of corrective actions when and where necessary.

[29] Following the NPS-FM direction, a detailed and comprehensive Regional Wetland Monitoring Programme was designed in collaboration with nationally recognised wetland experts. The programme consisted of two phases: 1) to monitor different wetland types in the region using available methodologies[5] and assess if the framework suits the regional context and able to generate data as prescribed in the NPS-FM, and 2) based on learning from the pilot projects then to develop and implement a fit for purpose Regional Wetland Monitoring Protocols.

Wetland Monitoring in Upper Taieri Scroll Plains (Pilot Project Stage 1)

[30] In 2022, ORC initiated a pilot project with Manaaki Whenua Landcare Research (MWLR) to better understand the ecology of Upper Taieri Scroll Palins (UTSPs) with aim to help inform an adequate management and monitoring plan. The work included assessing vegetation and soil condition in 151 plots across the Scroll Plains.

[31] Results revealed presence of 52 native plant species, seven of which are classified as threatened. Monitoring documented a heavily modified landscape where 30% of monitoring sites contained exclusively exotic species and 32% had 50% or more cover of exotic non-wetland species. The only woody species recorded were two species of willow (both invasive exotics). Nearly 2% of the sites contained solely native species, and all these plots had standing water present at time of monitoring (during a drought) and only 7% of the plots had greater than 50% cover of native species. Recent grazing was evident in all sampling locations of the wetlands despite some areas being classified as non-grazing zones (retired permanently), while current grazing was noted in more than half of the sites. The soil chemistry varied with scroll plain locations, and to some degree with grazing. Both soil pH and conductivity (EC) increased with distance down catchment. Soils in the Paerau/Styx basin tended to have higher percentages of nitrogen, potassium, and phosphorus than soils in the Māniatoto basin and Tunaheketaka/Taieri Lake (see report for more details[6]).

[32] It is intended these plots will be resampled after 10 years.

[5] Manaaki Whenua Landcare Research Handbook for Monitoring Wetland Condition (link)
[6] Upper Taieri Scroll Plains – Ecology report (2023)

Representative RSWs Monitoring (Pilot Project – Stage 2)

[33] In 2023-2024 the monitoring network was extended by adding four more Regionally Significant Wetlands: Tahakopa River Bogs, Lake Tuakitoto Wetlands, Upper Black Stream Marshes and Fortification Creek Wetland Management Area (a.k.a., Lake Onslow Scroll Plains). Forty-four plots were established across four wetland complexes, with an average of one plot per 20 ha. A total of 48 plant species were recorded in Tahakopa Marshes, eight of which were exotic and one threatened species. In Tuakitoto, 31 plant species were recorded and 18 of which were exotic. In Upper Black Stream Marshes, there were total of 38 plants species, 10 of which were exotic. In Fortification Creek Wetland Complex, a total of 84 plant species were recorded, eight of which were threatened and 19 exotic species. A total of 20 bird species were documented across the four wetland sites, two of which were threatened species. (Report is available on ORC website link). The methods employed for monitoring these sites were from the *Handbook for Monitoring Wetland Condition* developed by Bev Clarkson et al., (2004)[7].

Otago Regional Specific Wetland Monitoring Programme

[34] Regional mapping identified over 35,000 wetland sites (and counting), representing 15 (total 22 nationally) vegetation types of wetlands spread across nine Freshwater Management Units/Rohe. Given the sale and diversity of wetlands in Otago, there was a need for a tractable framework that would enable ORC to regularly monitor and report on extent, state and condition trends of a subset, representative of the diversity of wetland types found in the region at the level of the FMU. A regional framework[8] was developed (Figure 5) that helped select a subset of wetland for monitoring. The framework considered the relative number of regionally significant wetlands, distribution and frequency of threatened species, range of indigenous biodiversity, key threats to sustaining and enhancing wetlands and finally, the resources available to maintain the monitoring and reporting system.

[35] A total of 300 - 400 representative wetland sites across the region were shortlisted to be sampled using a restricted randomised approach on a ten-yearly rotation. Approximately half of these sites represent wetlands of regional significance (RSWs) and half are sites randomly selected using restricted randomisation basis to cover wetland types, within FMU/Rohe and elevation bands. Each year, 40 wetlands will be sampled across the spectrum of FMUs, wetland types, and habitat features, with an emphasis on lowland (60%) and montane (30%) sites reflecting threat levels.

[7] Handbook for Monitoring Wetland Condition
[8] ORC Framework for Prioritising Wetlands for Monitoring (under tab General Wetlands Reports)

Figure 6: ORC Wetland Monitoring Protocols

[36] A second framework[9] was developed suggesting methods for monitoring wetland condition in Otago (Figure 6). Firstly, an operational definition of wetland health and condition was developed, considering the major Otago Regional Council policies related to wetlands, and the available methods and approaches for assessing wetland condition. Monitoring methods include wetland condition and extent metrics that are clearly linked to facilitate a common understanding of monitoring rationale, and to focus attention on where improvements may be needed in the future. Otago region supports the most diverse and numerous wetland types of any region in New Zealand, and monitoring condition and extent therefore require a suite of methods at different scales to adequately report on progress towards maintaining and enhancing their health.

[37] A relevant and effective monitoring system focuses on the both the values identified for protection and the major threats to these in the area. Monitoring threats is relevant because it guides the formulations of policies and regulations. For biodiversity in general, monitoring can be challenging because of the numerous components, diverse values, multiple threats, and the natural dynamics. However, the NPS-FM 2020 sets out the values of interest regarding wetlands and provides a clear context for developing a wetland condition and extent monitoring framework.

[38] In our regional and council's context (may be relevant in general) enhanced wetland condition means increasing dominance of native species, including birds, plants, fish and invertebrates, and reduced threats from plant and animal pests, and encroaching landuse that reduces water quality and quantity in the wetland. Therefore, ORC's newly developed framework outlines a combination of inhouse and field measurements along with the appropriateness of the indicators for condition or

[9] ORC Framework for Monitoring Wetland Condition (under tab General Wetlands Reports)

pressure measures. The methods outlined in the framework are not based on explicit scoring system, as per Clarkson et al. (2013)[10] rather suggest a three-category score, to decrease observer variance and ambiguity.

Trialling Wetland Monitoring on FMU scale (Catlins)

[39] The newly developed monitoring methods were trialled on selected wetlands in Catlins FMU with the relevant information to assess their utility and develop a reporting format at the management unit level (see Attachment 1 for more details). The Wetland Condition Index and Wetland Pressure Index documents values at the wetland scale, which through time should be able to detect improving and deteriorating trends in wetlands at the FMU scale. As a pilot study the components for each of the indicators (i.e., Hydrological Integrity, Physico-chemical Integrity, Ecosystem connectivity and buffering, Browsing, predation and harvesting regimes, Human use, Dominance of native species and Extent) is being assessed by illustrating example dataset gathered in the 2024-2025 field season from 11 Regional Significant wetlands in the Catlins FMU. Vegetation and soils data was gathered from all 11, while acoustic recorders for bird monitoring were deployed in six of the wetlands. We also sourced data from aerial imagery and LCDB 5 as required. Final report is being prepared.

Figure 7: Blair Fen, Catlins FMU (Wetland Monitoring 2025). The tape marks a 10m x 10m square representative of the wetland.

[10] Clarkson BR, Champion PD, Rance BD, Johnson PN, Bodmin KA, Forester L, Gerbeaux P, Reeves PN 2013. New Zealand wetland indicator status ratings. Hamilton: Landcare Research.

Figure 8: Hungerford Point Salt Marsh, Catlins (Wetland Monitoring 2025)

OPTIONS

[40] This paper is for noting only.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[41] The wetland mapping and monitoring programme contributes to the strategic goal that ecosystems are healthy, our water is clean, and biodiversity loss is arrested across the region.

Financial Considerations

[42] The wetland mapping and monitoring programme is a funded Long-Term Plan workstream.

Significance and Engagement

[43] Science and policy staff have been in regular contact with the Upper Taieri landowners and community as the mapping has been undertaken and the proposed management plan has been developed.

Legislative and Risk Considerations

[44] The wetland mapping and monitoring programme was established in response to NPS-FM (2020) requirements, which are currently under review.

[45] The Upper Taieri Scroll Plain wetland had been given a ministerial exclusion from the stock exclusion regulations, while a management plan was developed.

Climate Change Considerations

[46] The wetland monitoring programme will provide a valuable dataset documenting the potential effects of climate change in the region.

[47] Wetland mapping will provide location of potential areas that are suitable for implementation of Nature Based Solutions particularly in the riverine floodplains and coastal areas domains for flood mitigation measures.

[48] Wetland mapping will be a useful resource for climate change mitigation and adaptation measures such as preservation of habitats and restoration of areas for carbon sequestration and storage.

Communications Considerations

[49] The wetland programme has a webpage with scientific and regulatory information available at: https://www.orc.govt.nz/environment/water-care/wetlands-and-estuaries/

[50] The regional wetland maps will be publicised when mapping is complete in 2026.

NEXT STEPS

[51] It is intended to complete the regional wetland mapping in FY 2025-2026. The wetland monitoring programme will continue following the framework detailed above.

ATTACHMENTS

1. Wetland Programme Update [**9.7.1** - 3 pages]

Attachment 1: Wetland Condition Index (WCI) and Wetland Pressure Index (WPI). Framework showing the indicator and the indicator components, "X" shows scale of measurement, relevance for either WCI or WPI, and whether data source along with possible methods.

Indicator	Components	Metrics	Measurement Scale			WCI	WPI	Data Source and methods
			Catchment	Wetland	Plot			
Hydrological Integrity	Impact of man-made structures on hydrological regime	Proportion of wetland influenced by drains, dams etc.		X		X		Use aerial imagery to determine if and where drains, dams are present
		Number, amount, and distance from wetland of water abstraction activities.	X				X	Use ORC records and consents database to map by catchment
	Change in water table depth	Depth to water table			X	X		Dig a small hole at each plot
	Dryland plant invasion	Number and cover of dryland plant taxa		X	X	X		Calculate from plot vegetation data and the wetland plant indicator status (includes native and exotic species).
Physico-chemical Integrity	Fire frequency	Time since last fire		X		X		Intersect map of wildfire locations (by year) with wetland polygons
		Number of wetland polygons burnt since last report by the wetland type.	X	X		X		Intersect map of wildfire locations (by year) with wetland polygons (for the first report, will use prior 10years)
	Soil chemistry	Carbon, nitrogen and phosphorus in soil, and field measures of soil water pH, conductivity, and temperature			X	X		Measure total C, total N, and total P in the lab on ~100g soil samples using methods in Blakemore et al. (1987). Use a pH and conductivity meter to measure soil water in the field.
	Soil organic matter	Organic content of soil				X		Field estimate of organic matter in soil, scored as: mineral, peaty, or peat (if peat, apply von Post index)
Ecosystem connectivity and buffering	Landuse intensity index	Proportion of catchment in indigenous vegetation, high intensity farming, extensive farming, and forestry.	X				X	Use LCDB to calculate proportion of different land uses by catchment

Indicator	Components	Metrics	Measurement Scale			WCI	WPI	Data Source and methods
			Catchment	Wetland	Plot			
		Proportion of wetland perimeter with indigenous vegetation		X			X	Buffer each wetland polygon by 50m (100m?, 200m?) and calculate proportion of buffer with indigenous vegetation
Browsing, predation and harvesting regimes	Damage by feral animals and livestock	Presence of feral animals and livestock in wetland		X	X	X		Report proportion of plots per wetland with animal sign (e.g. trampling/digging/droppings) and species seen within 25m of each plot
		Browse sign on vegetation.		X	X	X		Report proportion of plots per wetland with browse sign seen within 25m of each plot
	Introduced predator impacts on wildlife	Active, regular possum and mustelid predator control programme		X			X	Intersect map of predator control areas with wetland polygons. Also note evidence in and around the wetland of active control operations
		Rodent control programme		X			X	Intersect map of rodent control areas with wetland polygons. Also note evidence in and around the wetland of active control operations
Human use	Harvesting	Gamebird richness in the wetland and active seasonal hunting		X			X	Request data from Fish and Game
		Any other harvesting		X			X	Report any field notes of plant or animal harvest occurring
	Recreational use	Public access		X			X	Report if the wetland has public access
		Infrastructure (jetties, roads, tracks, trails etc)		X			X	Report if the wetland has built infrastructure in or nearby (within the buffer, distance TBD 50m?100m?, 200m?)
Dominance of native species	Native plants	Proportion of wetland with native vegetation cover		X	X	X		Using vegetation data from the plots, calculate the proportion of cover of native plant species (grouped by Wetland Plant Indicator Status)
		Number of native species present		X	X	X		Count of native species grouped by Wetland Plant Indicator Status
	Native birds	Number of native species present		X		X		Use Acoustic Recording Devices to do a modified 5min bird count, report the number of species by wetland. Or the Bird Atlas is another potential source.
		Number of wetland indicator bird species present (e.g. fern bird, bittern, crake)		X		X		Use Acoustic Recording Devices to do record presence of indicator bird species, report the species by wetland

Indicator	Components	Metrics	Measurement Scale			WCI	WPI	Data Source and methods
			Catchment	Wetland	Plot			
	Non-native plants	Number of naturalised plant taxa present		X	X	X		Using vegetation data from the plots, calculate the number of naturalised plant species present by wetland
		Number of wetland pest plants present.		X	X	X		Using vegetation data from the plots, calculate the number of pest plant species present by wetland
		Proportion of wetland covered by pest plants.		X	X	X		Use aerial imagery to map areas of pest plants in the wetland polygons, calculate proportion of wetland covered by each pest plant. Alternatively - mapping could be done in the field.
Threatened species	Status of threatened species in wetlands	Number of threatened species in wetland		X				Use plot data, DOC databases, and other databases to calculate number of regionally 'threatened' and at 'risk plant' species present in the wetland
		Number of wetlands supporting threatened species	X	X				Use plot data, DOC databases, and other databases to calculate number of wetlands with regionally 'threatened' and 'at risk' species present
Extent	Number and extent of wetlands	Number and area of wetlands according to FMU and wetland type	X					To be calculated from current wetland mapping

9.8. Artificial Lakes and Water Storage in Otago

Prepared for:	Science and Resilience Committee
Report No.	GOV2558
Activity:	Governance Report
Author:	Markus Dengg (Water Quality Scientist), Jason Augspurger (Principal Scientist), Amanda Riddle (Scientist - Hydrology)
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] This report is a stocktake of artificial water storage and was prepared to provide Council with insight into the status of water storage in the region.

EXECUTIVE SUMMARY

[2] The following report is a high-level investigation of artificial water storage in Otago. It gives an overview for the storage capacity per FMU, Rohe and catchment. The report considers surface water storage only, excluding aquifers. Included in the following are all artificial waterbodies that are currently known to the ORC. The report outlines estimated water storage capacity and provides an overview of water storage on an FMU and catchment level. This is important as rainfall patterns are likely to change under future climate scenarios, with dry regions becoming drier and storms becoming more intense.

[3] The total amount of water stored in artificial lakes in Otago is estimated at 1.86 billion m^3 ±746 million m^3. This does not include the three natural alpine Lakes, Lake Wakatipu (61.5 billion m^3), Lake Wanaka (33 billion m^3) and Lake Hawea (29.6 billion m^3) that have an estimated combined volume of 123 billion m^3.

[4] Of the 565 artificial lakes analysed in this report, 246 have a documented purpose. Usage falls in one of the following categories: Agricultural/Pastoral/Irrigation (156 Lakes), Detention (7 Lakes), Firefighting (6 Lakes), Hydro-Electrical (21 Lakes), Recreation/Amenity (7 Lakes), Snowmaking (6 lakes), Water Supply (18 Lakes), Other purpose (25 Lakes).

[5] Most of Otago's water stored in artificial waterbodies in Otago is in the Clutha FMU (1.3 billion m^3 or 73.1 %).

[6] The Manuherekia Catchment (154) has the highest number of artificial waterbodies, followed by the Taieri Catchment (151). The Shag catchment has the third highest number with 18.

[7] The Dustan Rohe is the single Rohe with the most water stored (1 billion m^3). This includes the total volume of water stored in Lake Dunstan, rather than the operational volume only. The operating range of lake Dunstan is 2% of its total volume.

[8] No artificial water storage (>1 ha) or dam registered in the ORC dam database has been identified in the Catlins FMU.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*

BACKGROUND

[9] Fresh water is one of the most important resources for environmental and human wellbeing and economical growth. Water storage in artificial lakes offers the potential to use water when and where it is needed most. The Otago Region has some of the driest and wettest areas of New Zealand, with an average annual rainfall ranging from below 400 mm in Central Otago to over 3000 mm in the Southern Alps. From and economical and agricultural perspective, this creates the opportunity to store water for human and agricultural use where it is scarce and offers the potential to use water for electricity generation where there is plenty.

[10] As rainfall patterns are changing, with dry regions becoming drier and storm events becoming more frequent and stronger, it is important to understand storage capacity within our region.

[11] This report is a high-level investigation of artificial water storage in Otago. It gives an overview for the storage capacity per FMU, Rohe and catchment.

[12] Given the importance of Otago's large alpine lakes in the region's water cycle, they are discussed in this report, albeit their total volumes are not reflected in any of the charts. The three large alpine lakes have a combined volume 100 times larger than total artificial water storage in Otago.

[13] The following report includes information from the Freshwater Environments New Zealand (FENZ) database[1] and the ORC dam database.

DISCUSSION

CALCULATING STORAGE VOLUME

[14] To create the dataset for this report, the FENZ (Freshwater Environments New Zealand) database was cross referenced with ORC internal compliance dam's database. This documented a total of 565 artificial waterbodies for the Otago region (Figure 1).

[1] FENZ refers to Freshwater Environments New Zealand, a spatial database provided by Land Information New Zealand.

[15] The FENZ database was last updated in 2023/2024 by Cawthron. It holds records for all lakes in New Zealand larger than 1 ha, and includes estimates of lake size, depth, the geomorphic class (how the lake was formed), and if it is constructed (artificial) or natural. For this report, only constructed lakes were selected, and this includes dams, constructed waterbodies and old mining pits that are now filled with water.

[16] The ORC dam database was last updated this year and holds information on all consented dams in Otago. It draws in information from RMA consents, building act permits, the old dam inventory (produced by MPI, 2000) and self-reported information from landowners. The dam database holds information, such as location, dam height or dam volume on a total 395 dams across Otago.

[17] For lakes where no depth or size information was available, the University of Waikato Lake modelling database was used to estimate these. For the 260 artificial waterbodies recorded in FENZ, but not in the ORC dam database, a maximum depth of 3m was assumed and the below formula was used to calculate volume; because this is the maximum depth a dam can have without a need for consent. For many dams, the uniform 3m depth may overestimate the volume of water stored as lakes typically become more shallow moving away from the dam.

[18] For dams where the volume was known from the consent, this volume was used in the analyses. For all other waterbodies, volume was calculated using the average depth and the area of the lake using the formula by Hutchinson (1961)[2]:

$$V = \left(\frac{depth}{2}\right) * area.$$

[19] Given the assumptions made for calculation of water volume, the presented values have an uncertainty of ~40% when calculated from maximum depth and area only.

[20] Dam storage was calculated as a “static” value based on volume when all dams are at full capacity. While an indication of the overall storage capacity of the region, this analysis does not consider “refilling”. Many dams may be drawn down and then refilled during a year and therefore store more than their physical volume in that year.

[2] Hutchinson, George Evelyn. "A treatise on limnology." *(No Title)* (1957).

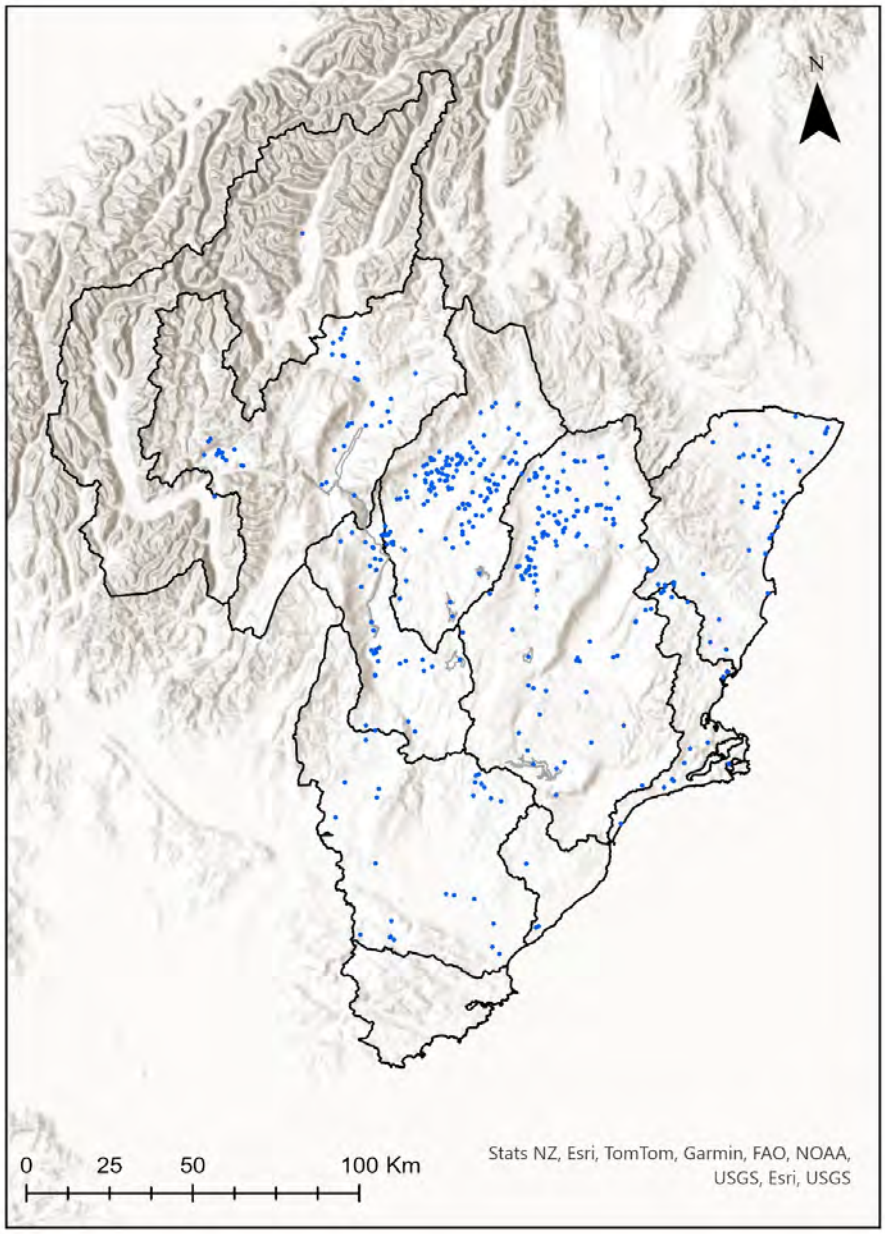


Figure 1: Location of artificial water bodies in Otago. Blue dots are indicative of the centre of each water body.

REGIONAL WATER STORAGE

[21] The total amount of water stored in artificial waterbodies in Otago is estimated at 1.86 (±0.746) billion cubic meters or 1.8 km^3 (cubic kilometers). This is excluding Lakes Wakatipu, Wanaka and Hawea but includes the full impounded volume of Lakes Roxburgh and Dunstan. Lake Wakatipu alone has a natural volume of over 60 km^3 and Lake Wanaka has a natural volume of over 33km^3.

[22] Lake Hawea is excluded, as the operational range (operational volume) of the lake, in combination with its size (natural volume) dwarfs any other artificial water storage in the region. The total volume of Lake Hawea, including operational range, is 29.6 km^3. The volume of the operational range alone is 2.6 km^3 (Figure 12).

[23] Most water ius stored in the Clutha Mata-Au FMU (73.1%, 1.4 billion m^3) (Figure 2) and within the FMU, most water is stored in the Dunstan Rohe (966 million m^3, including total volume of Lake Dunstan), followed by the Roxburgh Rohe (215 million m^3, including total volume of Lake Roxburgh) and the Manuherekia Rohe (180 million m^3). The Lower Clutha Rohe has a calculated water storage volume of 3 million m^3 in artificial waterbodies (Figure 3). The Upper Lakes Rohe has the least amount of water store in artificial waterbodies (0.41 million m^3). This excludes Lakes Wakatipu, Wānaka and Hāwea, with a combined estimated volume of 112 billion m^3.

[24] The Taieri FMU has a total 360 million m^3 water stored in artificial waterboides (19.4% of Otago storage), 140 million m^3 are stored in North Otago (7.3%) and 3.5 million m^3 are stored in the Dunedin and Coast FMU (0.2%,) (Figure 2). No artificial water storage larger than 1 ha, or in form of a consented dam, is recorded in the Catlins FMU.

[25] If the operating ranges of Lakes Dunstan and Roxburgh are used, rather than the total volume, the most water is still stored in the Clutha-Mata-Au FMU (63.7 %, 880 million m^3), followed by the Taieri FMU (26.2%) and the North Otago FMU (9.9%) (Figure 2B).

[26] Of the 565 waterbodies included in this analysis, 222 have a volume of 25,000 m^3 or lower (Figure 1C). This is potentially and artifact to the assumption made in calculating volumes, that all dams without a consent have a maximum depth of 3m and a maximum volume of 20,000 m^3. There are a total 25 water bodies that have a volume larger than 1 million m^3 (Figure 1C), these include Lake Dunstan, Lake Roxburgh and Lake Mahinerangi.

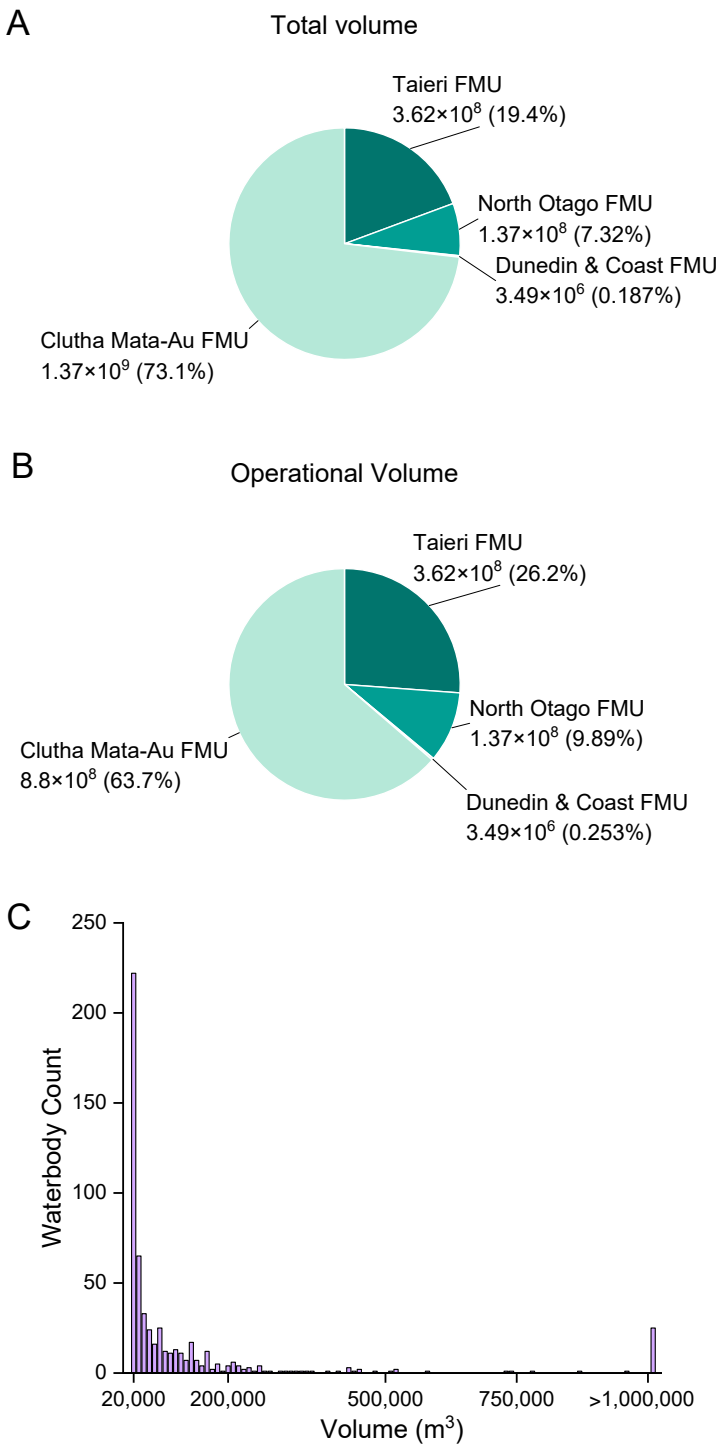


Figure 2: A: Total artificial water storage volume in m³ per FMU for 565 artificial lakes in Otago. B: Volume stored per FMU if operational rather than total volumes of Lakes Dunstan, Roxburgh and Mahinerangi are used. Lake Hawea not included in A or B. C: Distribution of waterbodies per volume. Note step change on x-Axis.

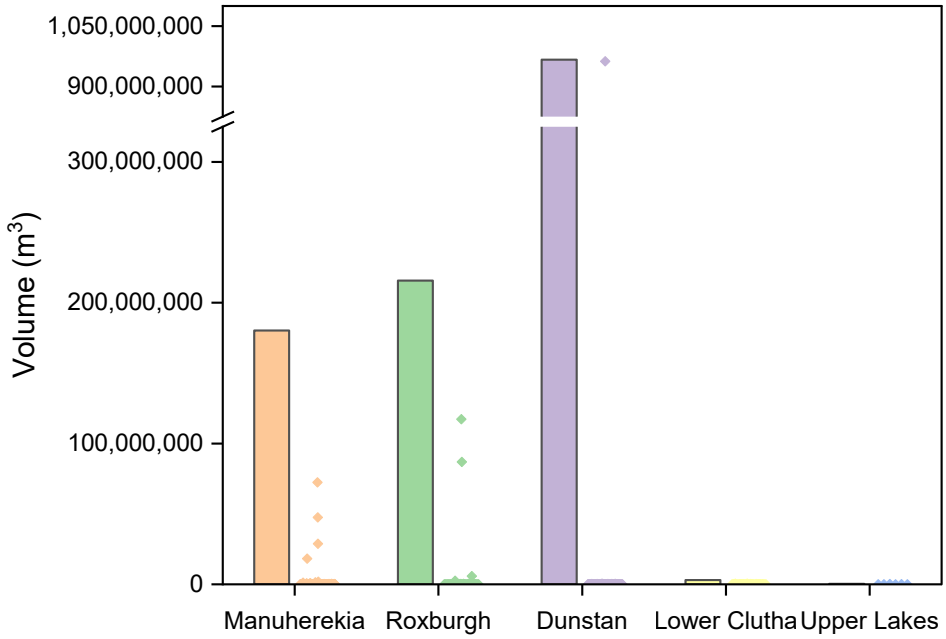


Figure 3: Volume of water stored in artificial lakes across the five Rohe in the Clutha FMU. Note axis break on y-axis. Bars show the total amount of water stored per Rohe. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment.

WATER STORAGE BY CATCHMENTS

[27] The artificial water storage per catchment within FMUs is presented below. Note that the Manuherekia Rohe and the Taieri FMU are each classified as a catchment. A further breakdown into sub catchments is currently not possible.

[28] The Taieri Catchment has a total artificial water storage of 361 million m^3 and the largest waterbody in the catchment is Lake Mahinerangi with a total storage volume of 272,587,358 m^3 (Figure 4).

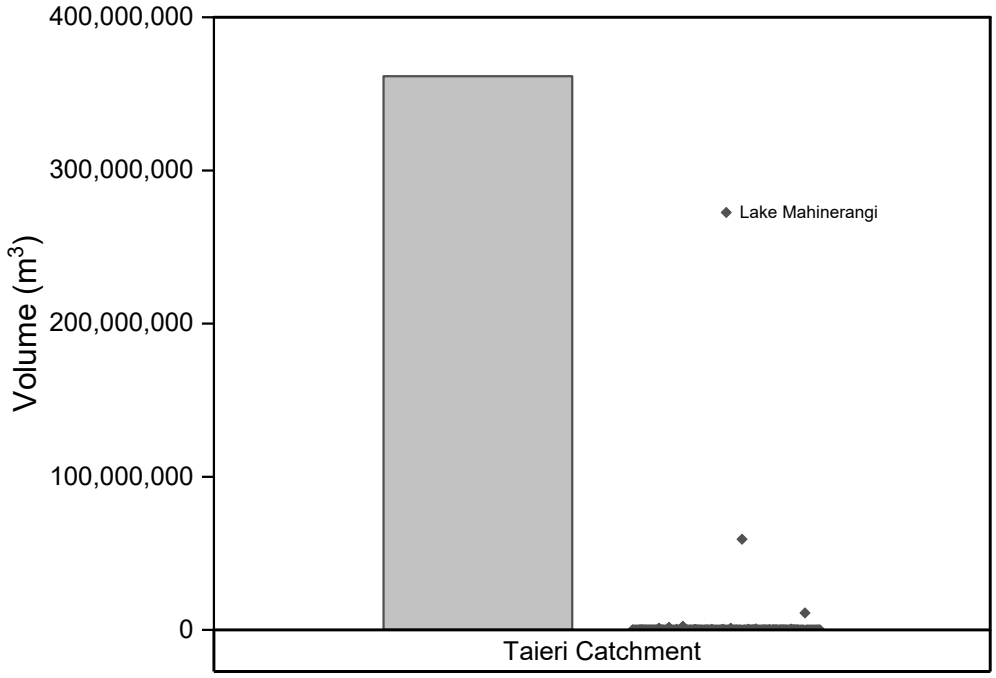


Figure 4: Volume of water stored in artificial lakes in the Taieri catchment. Bars show the total amount of water stored per catchment. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment.

[29] Of the total 136 million m^3 water stored in the North Otago FMU, most water (130 million m^3) is stored in the Shag Catchment, with a further 6 million m^3 stored across the other catchments (Figure 5). The three largest waterbodies in this FMU are all mine tailings dams.

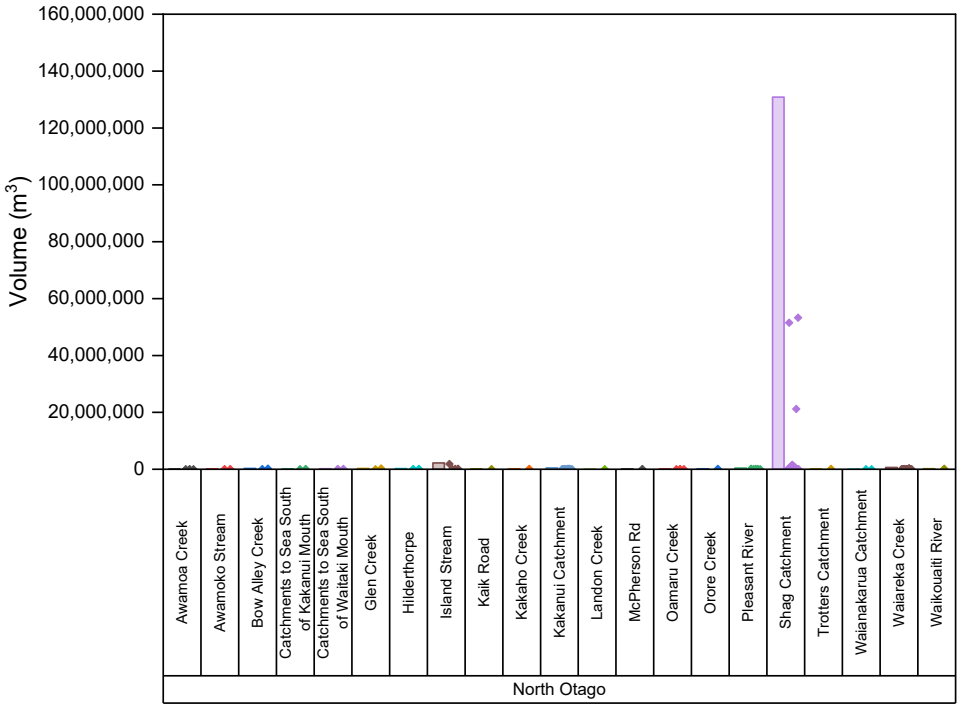


Figure 5: Volume of water stored in artificial lakes in the North Otago FMU. Bars show the total amount of water stored per catchment. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment. The FENZ database and ORC dam database did not hold information on individual names of waterbodies.

[30] In the Dunedin and Coast FMU, a total 3.5 million m^3 of water is stored in artificial waterbodies. The largest reservoirs are the Hawksbury Lagoon (958,927 m^3) in the Post Office Creek Catchment, followed by the Southern Reservoir in the Kaikorai Catchment (450,000 m^3) and Ross Creek (443,530 m^3) in the Water of Leith Catchment (Figure 6).

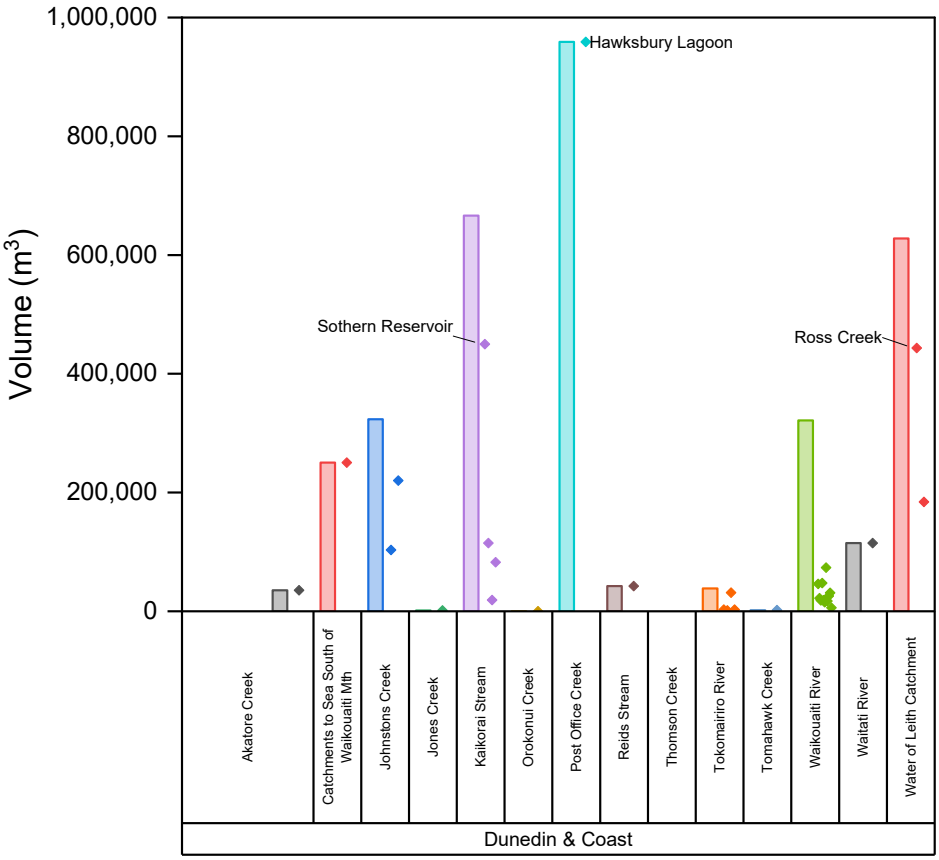


Figure 6: Water stored per catchment in the Dunedin and Coast FMU. Bars show the total amount of water stored per catchment. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment. Note that Hawksbury lagoon is dominantly fresh water, but can become slightly brackish during a King tide.

[31] Water storage in the Clutha Mata-Au FMU is discussed by individual Rohe.

[32] A total 180 million m^3 of water is stored in the Manuherekia Rohe in 154 artificial waterbodies (Figure 7). This makes the Manuherekia Rohe the catchment with the most artificial waterbodies within the Clutha Mata-Au FMU. Calculated volumes for the three largest waterbodies in the Manuherekia Catchment are 72.3 million m^3 for the Greenland Reservoir, 47.5 million m^3 for the Poolburn Reservoir, and 28.7 million m^3 for the Manorburn Reservoir (Figure 7). Falls Dam has a consented stored water volume of 11.5 million m^3.

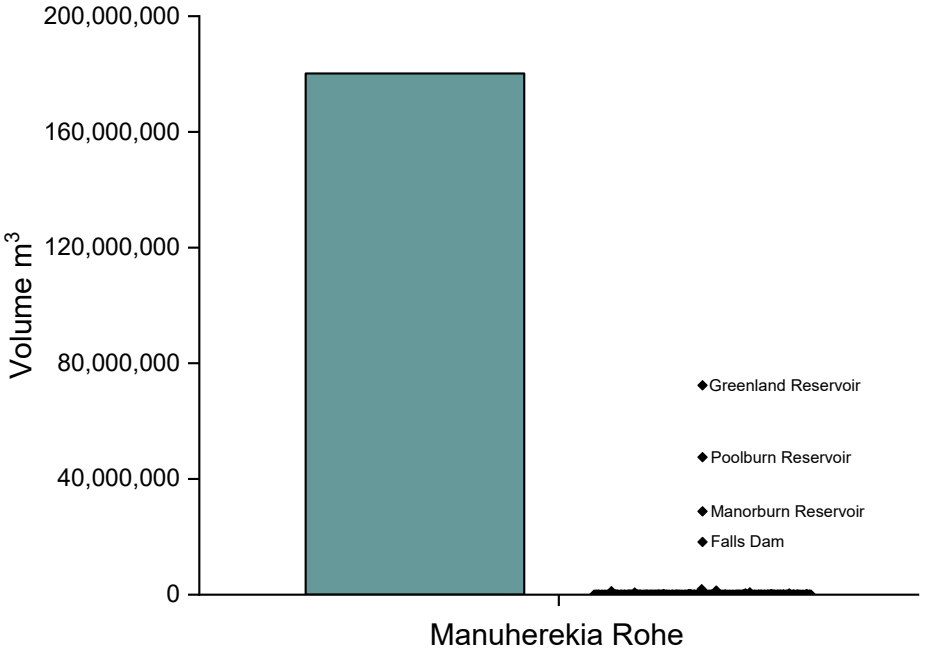


Figure 7: Water stored in the Manuherekia Rohe. Bars show the total amount of water stored and diamonds show the volume of water stored in individual artificial waterbodies.

[33] In the Roxburgh Rohe, a total 215 million m^3 water is stored in artificial waterbodies. The two catchments with the largest water storage are Lake Roxburgh Catchment and Teviot River and the two largest lakes are Lake Roxburgh and Lake Onslow with a total volume of 117 million m^3 and 86 million m^3 respectively (Figure 8).

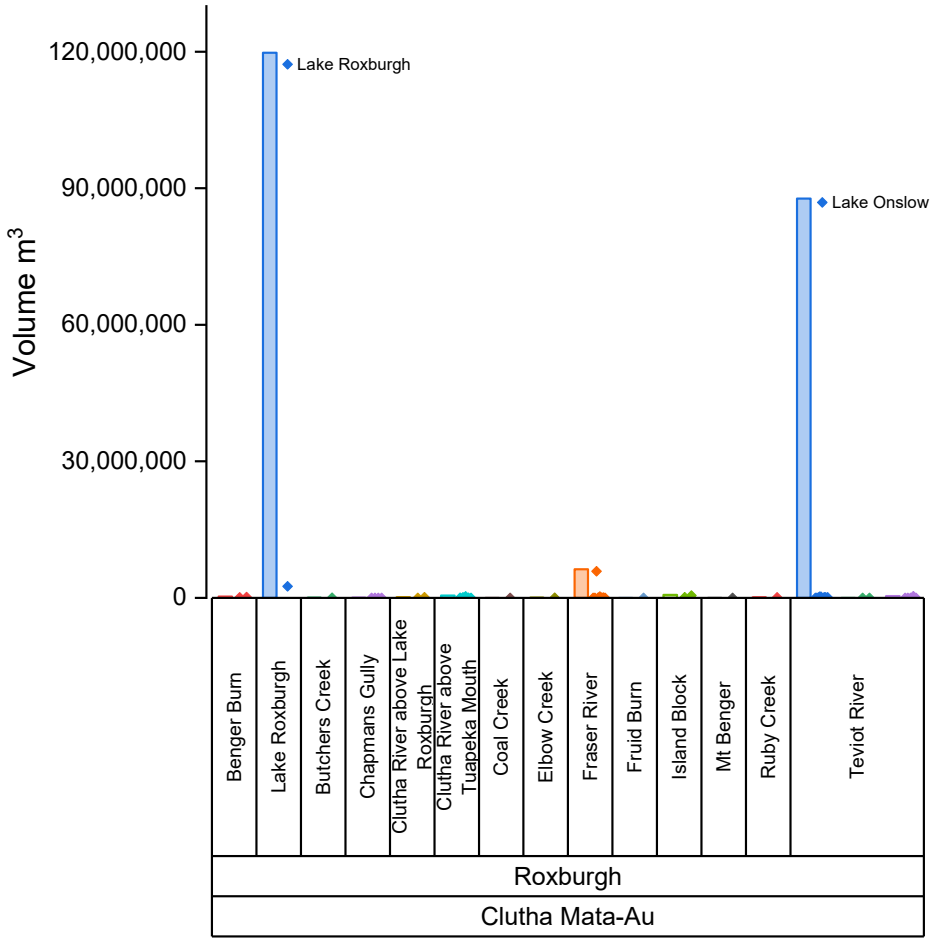


Figure 8: Water stored per catchment in the Roxburgh Rohe. Bars show the total amount of water stored per catchment. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment.

[34] In the Dunstan Rohe, most water is stored in Lake Dunstan (962 million m^3). This is about 50% of the total water stored in the Rohe. Catchments with a total water storage above 500,000 m^3 in the Rohe include the Lake Hayes Catchment and the Shotover Catchment (Figure 10).

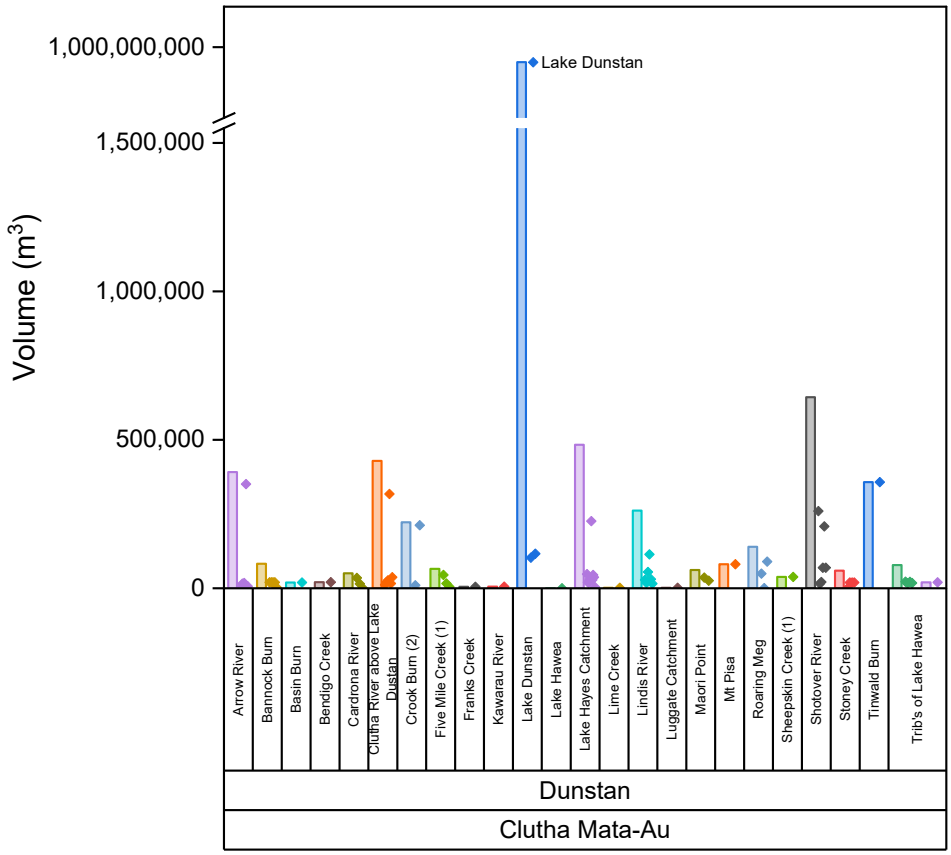


Figure 9: Water stored per catchment in the Dunstan Rohe. Bars show the total amount of water stored per catchment. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment. Note axis break on Y-axis.

[35] Most water in the Lower Clutha Rohe is stored in the Pomahaka, and Waiwera catchments with a storage volume of 842,087 m^3 and 530,660 m^3 respectively (Figure 10).

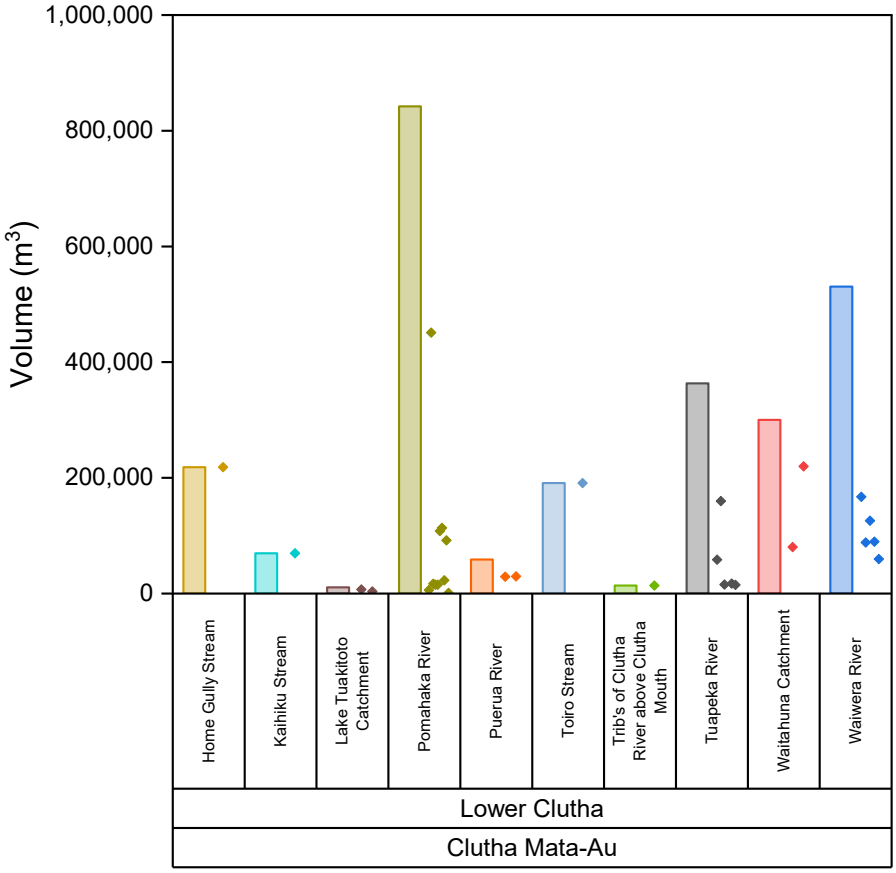


Figure 10: Water stored per catchment in the Lower Clutha Rohe. Bars show the total amount of water stored per catchment. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment.

[36] In the Upper Lakes Rohe, the highest amount of water stored in artificial lakes is in the Lake Wanaka catchment (Figure 11). The total amount of water stored in the artificial lakes in the Upper Lakes Rohe is 405,384 m^3, excluding the operational volume of Lake Hawea. If the operational volume of Lake Hawea is included, the total volume of water stored is 2.68 billion m^3 and if the total volume of all three large alpine lakes is considered, the Rohe has a water storage of 112 billion m^3.

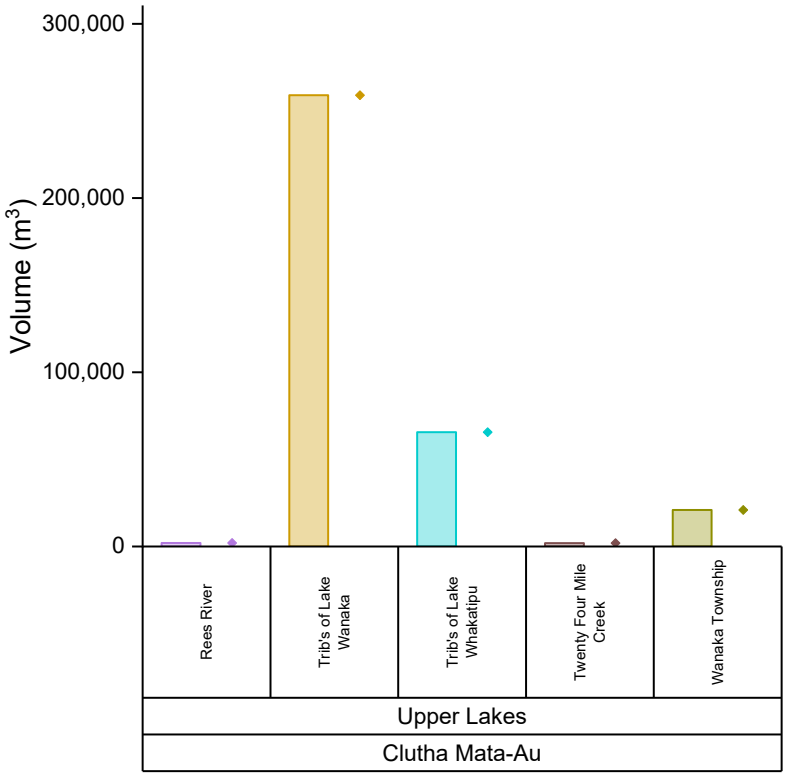


Figure 11: Water stored per catchment in the Upper Lakes Rohe. Bars show the total amount of water stored per catchment. Diamonds show the volume of water stored in individual artificial waterbodies for each catchment.

OPERATIONAL RANGE

[37] The 4 largest lakes by volume that have an operating level are Lake Hawea, Lake Dunstan, Lake Mahinerangi and Lake Roxburgh. The maximum operating volume for Lakes Hawea, Dunstan, Mahinerangi and Roxburgh is 10%, 2%, 34% and 9% of the total lake volume respectively (Figure 12).

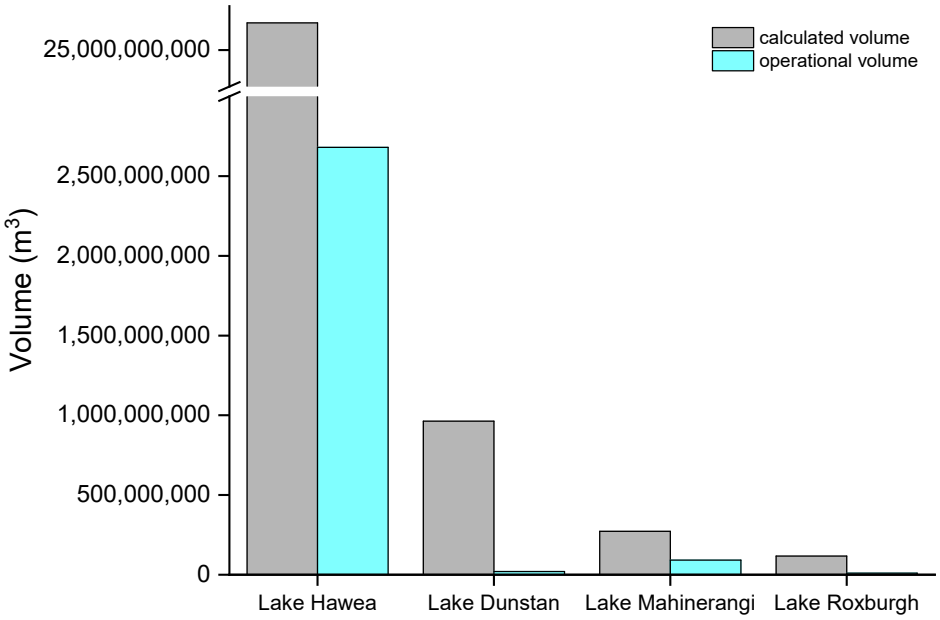


Figure 12: Total volume of lake (grey) in comparison to maximum operational volume (light blue) for the 4 largest lakes in Otago where level is controlled by human activity.

LIMITATIONS AND FUTURE WORK

[38] This report assumes a hypothetical scenario where every artificial water body in Otago is filled, there is no take and no recharge.

[39] For all lakes presented in this report, volume was calculated using maximum depth and area, assuming a waterbody has a perfectly trapezoidal shape. As this is not true for most natural waterbodies, and only true to some extent for constructed waterbodies, an estimated uncertainty of 40% applies to all volumes presented in this report. This uncertainty was estimated by calculating the average deviation of a natural lake compared to a perfect trapezoid[3].

[40] The status of a dam, i.e. online or offline, was not readily available from the dam's database or the FENZ database and is therefore not discussed in this report. While individual consents may hold further information about the online/offline dam that was built or proposed to be built, dam height and dam storage volumes have not been consistently included in consents in the past. The compliance and consents teams are currently working to improve information captured through those processes.

[41] The purpose or use is currently not known for more than half the artificial lakes in Otago. Further, the decade of construction is only known for 86 artificial lakes (15% of all lakes analysed in this report). This is not unexpected as this report contains a number of waterbodies that are below the minimum requirements for a consent. It might be

[3] Hutchinson, George Evelyn. "A treatise on limnology." *(No Title)* (1957).

beneficial to consider a process to capture key information (volume, height, area, purpose/use, status, year build) for dams that don't need a consent.

[42] Reservoirs with unknown volume, depth or area, but with an associated water meter were not analysed in this report as the information provided by water used does not allow to assess water storage volume. As the same reservoir can be filled multiple times over a year from a single take (Figure 13). This has two implications:

a. Dams can have variable impacts on water balance in a catchment as they might be filled multiple times within a year.

b. It is difficult to know what level of resilience the catchment may have to water restriction imposed by minimum flows or natural events without knowing dam volumes. This limits our ability to assess economic impacts of potential regulations, or climate/weather events. Currently, we have to apply an assumption when assessing economic impact. If we assume no storage, we likely overestimate the environmental impact.

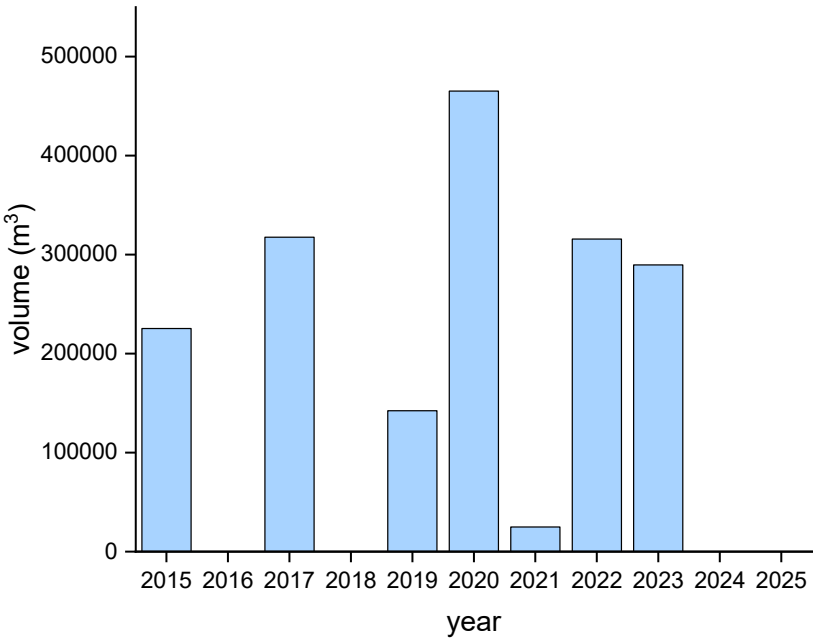


Figure 13: Example of a single take, linked to a single dam, showing annual variance in water takes for consecutive years.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[43] None, this is a stocktake of artificial water storage only.

Financial Considerations

[44] None, this is a stocktake of artificial water storage only.

Significance and Engagement Considerations

[45] None, this is a stocktake of artificial water storage only.

Legislative and Risk Considerations

[46] None, this is a stocktake of artificial water storage only.

Climate Change Considerations

[47] As rainfall patterns are changing, with dry regions becoming drier and storm events becoming more frequent and stronger, it is important to understand water storage capacity and water usage within our region.

ATTACHMENTS

Nil

9.9. An overview of the Envirolink scheme and ORC's involvement

Prepared for:	Science and Resilience Committee
Report No.	GOV2551
Activity:	Governance Report
Author:	Scott Jarvie (Senior Scientist Biodiversity), Ben Mackey (Manager Science)
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] This paper provides an overview of Envirolink, a regional council driven scheme with funds administered by the Ministry of Business, Innovation & Employment – Science and Innovation. The paper outlines how the scheme funds research organisations to transfer scientific knowledge to regional councils, and outlines the projects ORC has been successful in having funded.

EXECUTIVE SUMMARY

[2] Envirolink is a regional council driven scheme, with funds administered by the Ministry of Business, Innovation & Employment – Science and Innovation (MBIE). The Envirolink scheme funds research organisations to provide regional councils with advice and support for research on identified environmental topics and projects.

[3] Two funding mechanisms are available: Advice grants and Tool Development grants. While Envirolink was established in 2005, the ORC only became eligible to apply for Envirolink support through Advice grants in 2022.

[4] Advice grants provide expert consultation to apply existing knowledge held by scientists on regional environmental issues. Tools Development grants are for the development or adaption of new and/or existing resource management tools for use by more than one council.

[5] In total, ORC has been involved with 22 Advice grants and four Tools Development grants since 2022. These grants have enabled ORC to access expert advice from 11 different research agencies, including Universities and Crown Research Institutes.

[6] ORC's Envirolink grants span a diverse range of topics, including the: review and development of target values for soil quality indicators, revision and development of monitoring protocols for naturally uncommon ecosystems, synthesis and analysis of groundwater investigations, review of health benefits of air quality management strategies, and the quantification of intertidal vegetation cover in the coastal realm.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*

BACKGROUND

[7] Envirolink is a regional council driven scheme to transfer scientific environmental knowledge from research organisations to councils, with funds administered by the Ministry of Business, Innovation & Employment – Science and Innovation (MBIE).

[8] The Envirolink scheme commenced on 1 December 2005 in trial form and is now a well-established funding scheme. It was initially established to enable smaller regional Councils access to expert scientific advice.

[9] The Envirolink Scheme aims to:

- Improve science input to the environmental management activities of regional councils
- Increase the engagement of regional councils with the environmental research, science and technology sector
- Contribute to greater collective engagement between councils and the science system generally.

[10] The Envirolink scheme funds research organisations (Public Research Organisations – formerly Crown Research Institutes, universities and some not-for-profit research associations) to provide regional councils with advice and support.

[11] MBIE confirms the availability of funds for the Envirolink scheme each year.

[12] Funding has increased in the 2025 funding round to approximately $2 million (excluding GST) available each year to regional councils across New Zealand. There are two funding mechanisms:

- Advice grants
- Tool Development grants

[13] Both funding mechanisms typically focus on projects that are not considered Business-as-Usual. The scheme does not typically fund data acquisition, but focusses on expert consultation to identify information needs, the analysis of existing datasets, or the development or adaptation of new and/or existing resource management tools.

[14] Advice grants comprise:

- Small advice grants of up to $10,000 excluding GST. These grants aim to help identify information needs, receive advice on science techniques or meet training requirements.
- Medium advice grants of up to $40,000 excluding GST. These grants are for more detailed advice, or to help support the second phase of an initial small grant project.
- Large advice grants of up to $80,000 excluding GST. These grants are for consolidated advice involving more than one regional council.

[15] The following nine regional councils and unitary authorities were initially eligible to apply for Envirolink support through Advice grants:

- Northland Regional Council (NRC)
- Gisborne District Council (GDC)
- Hawke's Bay Regional Council (HBRC)
- Horizons Regional Council (HRC)
- Nelson City Council (NCC)
- Marlborough District Council (MDC)
- Tasman District Council (TDC)
- West Coast Regional Council (WCRC)
- Environment Southland (ES)

[16] Since mid-2022, an additional two regional councils became eligible to apply for Envirolink support through Advice grants:

- Otago Regional Council (ORC)
- Taranaki Regional Council (TRC)

[17] Advice grants fund each regional council up to $80,000 per year. Alternatively, funds can be drawn from a communal pool accessible to all eligible regional councils.

[18] Tool Development grants are generally larger, and provide funding to develop or adapt new and/or existing resource management tools for use by more than one council.

[19] Tool Development grants may target physical technologies or something more conceptual, such as a formalised or systematic approach to problem solving or analysis. The systems involve can include biological, physical, technological and/or social. Tool Development grants typically emphasise a stretch beyond the research — to translate, implement and apply new and existing knowledge.

[20] In general, $300,000 per year is available to support Tool Development grants across the regional sector. Individual projects are likely to be $100-200,000 each, with a duration of up to 2 years.

[21] All regional councils and unitary authorities are eligible to apply for the Tools development grants, including the five not mentioned previously:

- Auckland Council (AC)
- Bay of Plenty Regional Council (BOPRC)
- Environment Canterbury (ECan)
- Greater Wellington Regional Council (GWRC)
- Waikato Regional Council (WRC)

[22] Tool Development grants are initially assessed by the Envirolink governance committee. The final assessment and funding decisions are made by MBIE.

DISCUSSION

[23] Participation in the Envirolink programme allows ORC access to expert advice and analysis in areas which are beyond planned work or business as usual. It also fosters stronger ties between ORC scientists and leading New Zealand researchers, and encourages collaboration between regional councils working on similar problems or issues.

[24] Since 2022, ORC involvement in the Envirolink scheme has been with 22 Advice grants (Table 1) and four Tools Development grants (Table 2). Of these Advice grants, ORC has championed 17 and supported five others. A council is a champion of a grant where it has led the grant application, whereas supported is where a council is only named in the grant application.

[25] Most Advice grant were from ORC's annual allocation of approximately $80k/yr (15 grants) although seven were from the communal fund. Eighteen Advice grants were Medium grants, while three were Large grants and one was a Small grant.

[26] Transfer of knowledge from research organisations were for a diverse range of environmental topics and projects covering the broad range of science focused on in the regional sector. The range of advice obtained from the external experts has included:

- synthesis of existing data
- review of methods
- development of indicators or monitoring protocols
- guidance on national policy
- advice on databases to inform management
- compilation of information to inform management.

[27] ORC has been involved in advice grants from MBIE that total over $850,000.

[28] Advice grants have been picked up to by governmental agencies at times to inform research priorities that ORC scientists continue to contribute.

Table 1. Envirolink Advice Grants championed or supported by ORC

Description	Type	Funding round	Research Organisation	ORC allocation	ORC Role	Participating councils	Links to documents
Review of methods and data used to develop target values for soil quality indicators	Medium	2022	Manaaki Whenua – Landcare Research	Yes	Championed	ORC	Report
Coastal Turf monitoring programme	Medium	2022	Manaaki Whenua – Landcare Research	Yes	Championed	ORC	Report, Envirolink media
Otago Harbour: Review of existing ecological data	Medium	2022	Cawthron Institute	Yes	Championed	ORC	Report
The Anthropause baseline: identifying marine tourism derived ecosystem impacts	Medium	2022	Cawthron Institute	No	Supported	ES, ECan, ORC	Report
Synthesis of the groundwater investigations in the Waihemo/Shag River Valley	Medium	2022	GNS Science – Te Pū Ao	Yes	Championed	ORC	Report
Using Radon-222 and concurrent flow gauging to understand groundwater and surface water interaction in the Lower Kauru River, North Otago	Small	2023	GNS Science – Te Pū Ao	Yes	Championed	ORC	Report
The Anthropause baseline (Stage 2): identifying marine tourism derived ecosystem impacts during international travel restrictions	Large	2024	Cawthron Institute	No	Supported	ES, ECan, ORC	Pending
The impact of land use and land management on soil biological health	Medium	2024	University of Otago – Ōtākou Whakaihu Waka	Yes	Championed	ORC	Pending

Continued next page

Continued

Description	Type	Funding round	Research Organisation	ORC allocation	Role	Participating Councils	Links to documents
Determination and application of background soil concentrations in the Otago and Southland Regions	Large	2024	Manaaki Whenua – Landcare Research, e3Scientific, Hail Environmental	No	Championed	ORC, ES	Pending
A verified 'Type Locality' database of indigenous plant species	Medium	2024	Manaaki Whenua – Landcare Research	No	Championed	ORC, AC, BOPRC, ECan, ES, GDC, GWRC, HBRC, MDC, NCC, NRC, TRC, TDC, WRC, WCRC	Report
Land use change in Otago mid-country and high country from 1990 to today	Medium	2024	University of Canterbury – Te Whare Wānanga Waitaha	Yes	Championed	ORC	Report
Health benefits of air quality management strategies in Otago towns and improved characterisation of air quality in Alexandra	Medium	2024	University of Canterbury – Te Whare Wānanga Waitaha	Yes	Championed	ORC	Completed

Continued next page

Continued

Description	Type	Funding round	Research Organisation	ORC allocation	Role	Participating Councils	Links to documents
Biosecurity eDNA Dashboard – Turbocharging biosecurity threat reporting and decision-making based on eDNA data	Medium	2024	Manaaki Whenua – Landcare Research, University of Waikato – Te Whare Wānanga o Waikato	No	Supported	ORC, AC, BOPRC, ECan, ES, GDC, GWRC, HBRC, MDC, NCC, NRC, TRC, TDC, WRC, WCRC	Report
A case study on the use of state of environment for plan effectiveness evaluation: Data, review, and recommendations	Medium	2024	AgResearch – Āta Mātai, Mātai Whetū	No	Supported	ES, ECan, ORC	Pending
National guidance for threatened freshwater species in regional planning under the NPS-FM	Medium	2024	University of Canterbury – Te Whare Wānanga Waitaha	No	Supported	NCC, GWRC, ORC, DOC	Pending
Alternative field-based approaches to animal wintering	Medium	2024	AgResearch – Āta Mātai, Mātai Whetū	Yes	Championed	ORC	Pending
Advice on the use of models to support estuarine outcomes	Medium	2025	University of Waikato – Te Whare Wānanga o Waikato, University of Auckland - Waipapa Taumata Rau	No	Championed	ORC, HBRC	Pending

[29] Of the Tool Development grants, ORC have championed most of those that have been successful since 2022 (four out of five).

[30] These four successfully funded Tool Development projects have focussed on:

- Improving our understanding of naturally uncommon ecosystems, a terrestrial framework to classify terrestrial ecosystems
- Developing a handbook of standardised methods for monitoring of indigenous forest to inform management
- Quantifying intertidal coastal vegetation cover using remote sensing approaches
- Improving soil health by improving the efficacy of soil quality indicators.

[31] In total, the amount of Tool Development grants funded that ORC has championed is approximately $1,000,000.

[32] All results from Tool Development grants are still pending. Despite this, some Tool Developments grants have already been picked up to by governmental agencies at times to inform research priorities that ORC scientists continue to contribute. For example, the grant titled *Mapping and ground-truthing the extent of naturally uncommon ecosystems* was picked up by MfE as part of the work to develop a National Ecosystem Typology. This project investigates a unifying ecosystem typology that would bring together all the domains in Aotearoa New Zealand, with recommended next steps for development of a national typology.

Table 2. Envirolink Tool Development grants championed or supported by ORC

Description	Funding round	Organisation	Championed	Supported	Links to documents
Mapping and ground-truthing the extent of naturally uncommon ecosystems	2022	Manaaki Whenua – Landcare Research	ORC, GWRC	AC, BOPRC, ECan, ES, GDC, HBRC, MDC, NCC, NRC, TRC, TDC, WRC, WCRC	Pending
Improving soil health through improved efficacy of implementing soil quality indicators	2023	Manaaki Whenua – Landcare Research	ORC, WRC		Pending
Using remote sensing to quantify intertidal coastal vegetation cover	2023	National Institute of Water and Atmospheric Research (NIWA)	ECan, ORC, BOPRC		Pending
Handbook of standardised methods for monitoring outcomes of indigenous forest management	2023	Manaaki Whenua – Landcare Research	HBRC, ORC, HRC, AC	BOPRC, ECan, ES, GDC, GWRC, HRC, MDC, NCC, NRC, TRC, TDC, WRC, WCRC	Pending

OPTIONS

[33] This report is for noting only.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[34] N/A.

Financial Considerations

[35] Envirolink funds are administered by MBIE.

[36] The projects are completed in addition to ORC's planned and funded science programme.

Significance and Engagement

[37] N/A.

Legislative and Risk Considerations

[38] The fund is confirmed by MBIE annually, and future funding is not guaranteed.

Climate Change Considerations

[39] N/A.

Communications Considerations

[40] Envirolink reports are publicly available: https://www.envirolink.govt.nz/envirolink-reports/. A funding condition is that the outputs are circulated among interested parties, such as the regional sector or research groups.

[41] Envirolink projects can be featured as new stories on the Envirolink website, e.g., spatial prioritisation for biodiversity management, using GBIF for biodiversity and biosecurity management, developing a coastal turf monitoring programme

NEXT STEPS

[42] ORC staff will champion or support Advice grants and Tool Development grants while MBIE continues to fund the Envirolink scheme.

ATTACHMENTS

Nil

9.10. Nature Based Solutions

Prepared for:	Science and Resilience Committee
Report No.	GOV2597
Activity:	Governance Report
Author:	Nathan Anderson, Senior Flood Hazard Analyst Melanie White, Team Leader ICM
Endorsed by:	Joanna Gilroy, General Manager Environmental Delivery Tom Dyer, General Manager Science and Resilience
Date:	3 September 2025

PURPOSE

[1] This report provides a summary of the findings from the Ministry for the Environment (MfE) funded Nature-based Solutions (NbS) studies to complete "Modelling of Te Hakapupu Catchment to Investigate Flood Mitigation".

EXECUTIVE SUMMARY

Nature based Solutions Feasibility Study (Attachment 1)

[2] Te Hakapupu/Pleasant River Nature-based Solutions Feasibility Study, commissioned by Council and funded by the Ministry for the Environment, assessed the potential of Nature-based Solutions to manage flood hazards in East Otago. The study identified three feasible interventions—landcover management, river naturalisation, and wetland construction—that can reduce flood risks while enhancing biodiversity and water quality. These solutions all offer long-term resilience benefits, but their implementation requires funding, integrated planning, and strong governance practices to make them workable. The study recommends targeted actions to address financial barriers and promote the strategic use of Nature-based Solutions across Otago.

Nature based Solutions Engagement Study (Attachment 2)

[3] With funding from the Ministry for the Environment as part of a national initiative, Council commissioned an exploratory Engagement Study to better understand landowner perspectives on using NbS for flood mitigation and to begin to uncover barriers and opportunities around implementation on private property. Insights were gathered through interviews, surveys, and existing reports, building a regional picture of landowner awareness, readiness, and interest in implementing NbS such as wetland restoration, planting, and river naturalisation on private land. The Engagement Study paints a clear picture of the region's readiness to explore NbS for flood mitigation and uncovers exciting opportunities around partnerships and innovative, co-funded approaches.

Nature based Solutions Future Funding and Finance Pathways Study

[4] Following the recommendation to provide economic pathways to support the use of Nature-based Solutions, Council commissioned an additional study on Nature-based Solutions Funding and Finance Pathways. This report will be completed 31 August 2025.

Once delivered this report will be considered by staff to assess what Councils role could be in NbS. Any decisions required would be brought to Council to approve.

[5] This additional study builds upon the findings of Te Hakapupu/Pleasant River Nature-based Solutions Feasibility Study, and other recent analysis of Nature-based Solutions in New Zealand.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*

BACKGROUND

[6] The opportunity came about for this project, with MfE funding around how Nature based Solutions could buffer the effects of flooding. Using Te Hakapupu/Pleasant River as a test catchment developed out of the wealth of information held by Toitū Te Hakapupu project, about the catchment, and the engagement with partners Kāti Huirapa Rūnaka ki Puketeraki, along with East Otago Catchment Group and the wider community.

[7] Te Hakapupu/Pleasant River Nature-based Solutions Feasibility Study explores the potential of using Nature-based Solutions to manage flooding and associated hazards in the Te Hakapupu/Pleasant River catchment in East Otago. Nature-based Solutions are actions that seek to restore, protect, and use natural ecosystem features to address hazards in an area, in this case flooding. Nature-based Solutions, for example constructed wetlands and river naturalisation, can help to manage flooding hazards, while improving biodiversity and water quality.

[8] Like many Otago catchments, Te Hakapupu/Pleasant River catchment currently faces challenges such as flooding and erosion during extreme rainfall events. The Feasibility Study (Attachment 1), commissioned by ORC and funded by the Ministry for the Environment's Essential Freshwater Fund, aims to build evidence for the use of Nature-based Solutions in flood hazard management across Otago.

[9] The Engagement Study leaned on the connections built through the Toitū Te Hakapupu Project, and then reached more widely throughout Otago via catchment groups, industry, large scale landowners and word of mouth. The objective was to build a picture of what the awareness is of NbS and gauge the appetite for their more widespread use to buffer the effects of flooding and other environmental problems.

[10] Following the recommendation to provide economic pathways to support the use of Nature-based Solutions, Council has commissioned an additional study on Nature-based Solutions Funding and Finance Pathways. This additional study builds upon the findings of Te Hakapupu/Pleasant River Nature-based Solutions Feasibility Study, and other recent analysis of Nature-based Solutions in New Zealand.

What are Nature based Solutions?

[11] Nature-based solutions are strategies that protect, sustainably manage, or restore natural ecosystems to address challenges such as climate change, water quality and security, and biodiversity loss. They utilize natural processes—like those in forests, wetlands, and coastal systems—to deliver benefits including carbon sequestration, flood control, and improved air and water quality, while also supporting biodiversity and human well-being.

[12] Examples of Nature based Solutions include restoring/constructing wetlands in critical areas to absorb excess flood waters. Nature based Solutions can also be letting a river have more room to move, and planting margins, to a more natural form, adding turns and "roughness" and thereby helping slow the flow of excess water down during high rainfall. Another Nature based Solution is taking a look at the soil health in an ecosystem. Healthy soils can have increased water absorption, increased biodiversity, more resilience to drying out and provide better nutrients for growing our crops.

[13] Nature-based solutions are not a new concept—communities have long relied on natural systems to manage water, grow food, and protect against hazards. However, their intentional and systematic application to modern environmental and societal challenges is more recent. As climate impacts intensify, integrating these solutions into policy and planning is gaining momentum for their cost-effectiveness and co-benefits.

[14] In the past, a flooding issue would have usually been solved with hard structures built into a natural environment such as a stop bank on the banks of a river. There is a shift towards the use of "ecosystem services" found in nature, to develop solutions that mimic natural processes to add resilience to those structures and protect our communities and infrastructure. These types of solutions are Nature based Solutions.

DISCUSSION

Nature based Solutions Feasibility Study

Feasibility study approach

[15] As part of the feasibility study, several types of Nature-based Solutions were evaluated to establish their flood hazard management capabilities and their relevance to the catchment and its characteristics. A Rapid Flood Hazard Model was also developed to assist with understanding how the proposed solutions could affect the existing flood events in the catchment.

Three Nature-based Solutions were identified as being feasible within the catchment:

a. **Landcover management:** Restoring and expanding existing pockets of remnant native forest in vulnerable upper catchment areas. This approach addresses the "window of vulnerability" during forestry harvest cycles, which significantly increases sedimentation and flood risk
b. **River naturalisation:** Restoration of riparian vegetation, re-meandering channels, and reconnecting off-stream wetland areas along the catchments highly modified waterways. This approach slows flood flows, reduces sedimentation, and improves water quality.
c. **Wetland construction:** Restoring and constructing natural wetland features in flood prone catchment locations. This approach accommodates excess floodwaters, intercept and treats contaminants, and improves water quality.

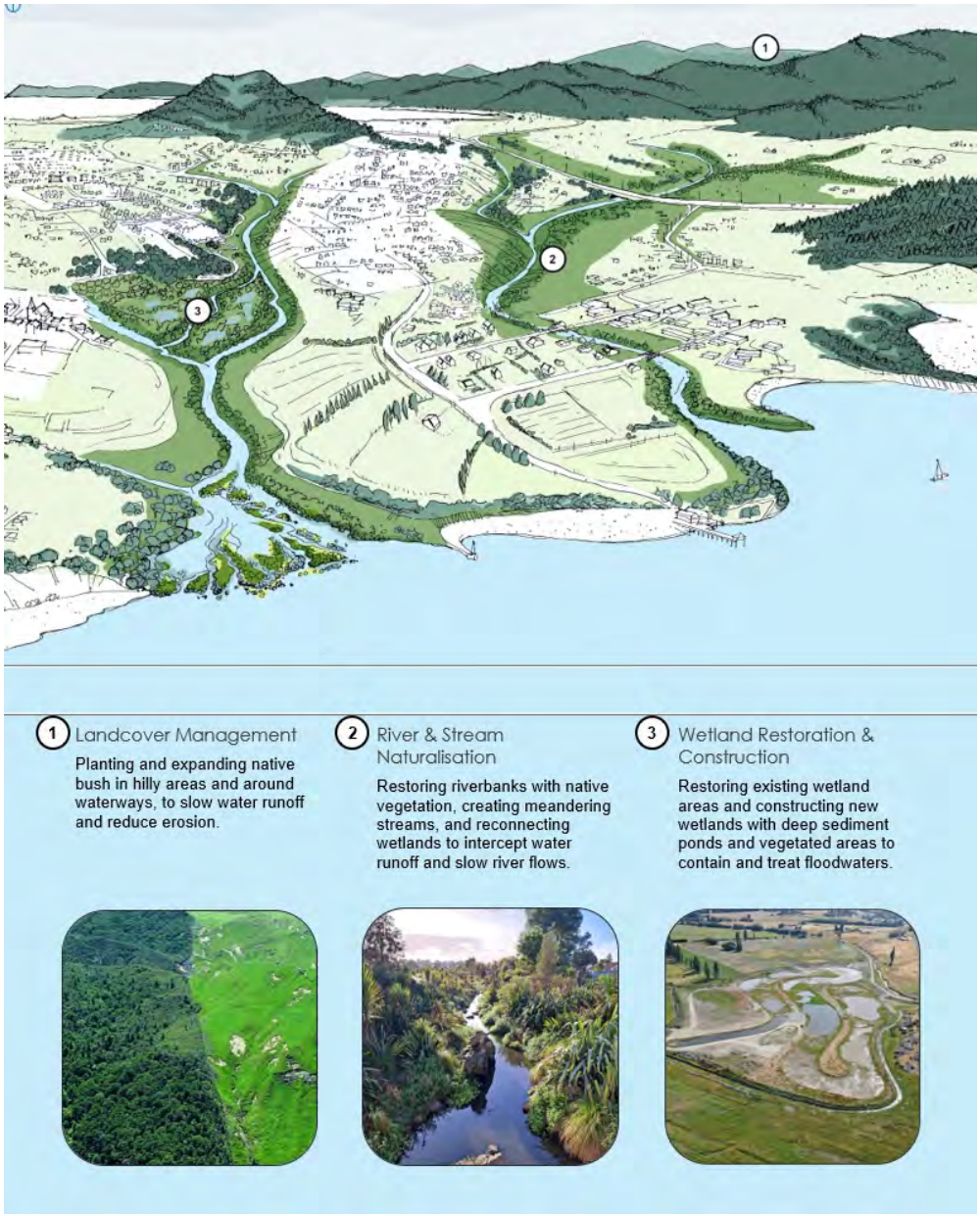


Figure 1: Graphic showing three NbS used in modelling Te Hakapupu for Feasibility Study

Key findings

[15] Five key findings were identified during the feasibility study of Nature-based Solutions in Te Hakapupu/Pleasant River catchment:

a. **Nature-based Solutions are feasible:** Nature-based Solutions can be effective methods for managing flooding and associated hazards.

b. **Landcover management in the upper catchment is important:** Landcover management solutions in vulnerable upper catchment areas will reduce flooding hazards in the long-term.
c. **Economic and Technical support is needed:** Innovative economic approaches are needed to address the current financial barriers that stop landholders using Nature-based Solutions.
d. **Scale is important:** To effectively manage flooding hazards, Nature-based Solutions work best when used over large areas.
e. **Integrated planning of solutions:** Nature-based Solutions can provide the greatest benefits when they are joined up across a catchment, working with each other and across land uses.

Feasibility Study Recommended Actions

[16] Five actions are recommended to support the practical use of Nature-based Solutions in Te Hakapupu/Pleasant River catchment and other similar catchments across Otago:

a. **Strengthen governance:** Form partnerships among governments, landholders, and communities to ensure the challenges and benefits of Nature-based Solutions are shared.
b. **Provide economic pathways:** Introduce grants, tax incentives, and payment schemes for land used for Nature-based Solutions to support landholders.
c. **Promote nature credit markets:** Enable landholders to gain revenue from land used for Nature-based Solutions by supporting access to biodiversity and carbon credits.
d. **Develop standards and policies:** Create regional Nature-based Solutions guidelines to build a common understanding of their use and streamline implementation.
e. **Integrate Nature-based Solutions into planning**: Embed Nature-based Solutions into catchment management plans so they can be strategically planned for at large scales.

Feasibility Study Next steps

[17] Following the recommendation to provide economic pathways to support the use of Nature-based Solutions, Council has commissioned an additional study into Nature-based Solutions Funding and Finance Pathways (Due 31 August 2025). This additional study builds upon the findings of Te Hakapupu/Pleasant River Nature-based Solutions Feasibility Study, and other recent analysis of Nature-based Solutions in New Zealand.

Nature based Solutions Engagement Study

[17] Around the world, Nature-based Solutions (NbS) have been credited with saving billions of dollars in flood damage costs - by working with nature instead of trying to control it. In many countries NbS, such as wetlands, planting and bioretention, are strategically implemented on both public and private land, with projects involving landowners, government and others benefiting the wider community.

Figure 2: Diagram highlighting some NbS options to buffer the effects flooding in Otago

[18] The study found broad interest in NbS from landowners, with many already involved in wetland and planting projects. Funding, regulatory certainty, trust-building and clarity around terminology were essential enablers, along with locally relevant data and practical case studies. Starting conversations around property access for maintenance, reporting and looking into what ORC's role could or should be, was also seen as important, with a focus group suggested.

[19] **Key strategic opportunities identified through the Engagement Study for ORC include:**

Partnerships

1. Mātauranga Māori integration into flood modelling, indicators, and engagement approaches.
2. Catchment-led models involving ORC, mana whenua, NGOs, technical experts and private funders.

3. Strategic collaboration with Crown landowners (e.g. other councils, NZTA, DOC, Pamu) and large landholders in upper catchments or high-risk areas.

Financial innovation

4. Environmental, Social and Governance (ESG) aligned partnerships, linking Nature-based Solutions to investor priorities around climate resilience and biodiversity.
5. Resilience bonds and green finance tools designed for infrastructure and catchment-scale interventions.
6. Pilots to build trust, reward early adopters, and test scalable co-investment pathways.
7. Eligibility mapping across multiple funding streams—climate, biodiversity, water quality—to enhance uptake.

Visual and non-technical communications and guidance

8. Case studies, animations, and explainer tools to improve comprehension and build trust (internally and externally)

[20] **Engagement Study Recommendations**

1. That Council **note** the key findings and strategic opportunities outlined in the Nature-based Solutions Engagement Study.
2. That Council continue to support embedding Nature-based Solutions into future planning and investment frameworks, including infrastructure projects and catchment strategies.
3. That Council support staff to work through the suggestions and recommendations in the report, including exploring funding partnerships and pilot initiatives, with a view to co-implementing NbS interventions with landowners and external agencies.
4. That visual guidance and stakeholder engagement tools be prioritised to enhance landowner trust and participation.

[21] **Nature based Solutions Future Funding and Finance Pathways Study**

The Nature-based Solutions Funding and Finance Pathways study will help ORC and its partners to:

1. Understand what investment tools have worked well globally to deliver Nature-based Solutions projects
2. Identify how suitable investment tools can be accessed and applied in Otago to support Nature-based Solutions projects
3. Define how ORC and its partners may best engage in funding and finance opportunities to effectively plan, coordinate, and deliver Nature-based Solutions projects in Otago.

The study considers the funding and finance options available to support landholder in Otago to deliver Nature-based Solutions projects. Options assessed in the study include both the current and emerging options across the public and private sector. These include:

1. **Government Investment Opportunities:** Central and local government bodies funding Nature-based Solutions through conservation and environmental management related investments.
2. **Nature-based Giving:** Not-for-Profit organisations, high net-worth individuals, and businesses funding Nature-based Solutions through investment in conservation projects and nature-related research and development. Funding options include philanthropic grants, donations, and commercial partnership funding.
3. **Nature-based Debt Finance:** Financial institutions, businesses, government bodies, and Non-Governmental Organisations financing Nature-based Solutions through providing sustainable lending facilities for nature-related projects. Finance options include the issuance of green bonds and sustainability-linked loans.
4. **Natural Assets and Infrastructure:** Government bodies, state-owned enterprises, and private infrastructure providers funding Nature-based Solutions alongside built infrastructure to address environmental challenges. Funding options include investments in natural assets, such as wetlands or forestry, as a standalone asset class
5. **Nature-based Credit Markets:** Government bodies, businesses, financial institutions, and Not-for-Profit organisations funding Nature-based Solutions through participating in nature-based credit markets. Funding options primarily include the sale of high integrity carbon credits and biodiversity credits.

These funding and finance options illustrate the variety of ways in which nature markets are developing and the various tools available to support landholders in Otago to deliver Nature-based Solutions projects.

[22] **Nature based Solutions Budget and spend**

Both the Feasibility and Engagement Studies together did not consume all the allocated budget that MfE provided. This enabled ORC to proceed with the Future Funding and Finance Pathways Study and utlilise the remaining funding.

Project Financial Summary - NBS Te Hakapupu

Total Project

Funding	
Grant Funding Received	260,000
	260,000
Expenses	
Accomodation/Travel	3,268
Motor Vehicle (ORC)	560
Professional Services and Consultants	218,274
Time/Salary (ORC)	35,757
	257,859
	$ 2,141

Figure 3: Budget/spend summary for ORC Nature based Solutions studies funded by Ministry for the Environment

CONSIDERATIONS

Strategic Framework and Policy Considerations

[23] **Develop design and practice standards for NbS implementation.**
Standards have already been developed for many parts of Aotearoa and globally and will only need minor adjustments to make them region-specific. These standards can be used as technical guides by both ORC and private landowners to implement NbS's.

[24] **Ensure NbS are discussed and presented throughout the Catchment Action Plan (CAP) process to consider to solve problems where appropriate**.
CAPs will set clear and reasonable objectives to address specific issues and identify appropriate NbS's that are suited to issue.

Financial Considerations

[25] There are no financial considerations as a result of this paper. Council staff will explore collaborative funding and technical assistance models and consider how ORC might be involved in funding NbS's across Otago.

Significance and Engagement

[26] Staff will look to develop a Communications and Engagement Strategy for NbS. This will assist the organisation (ORC) to align in NbS communications internally and provide guidance for staff about communicating about NbS external to the organisation.

Legislative and Risk Considerations

[27] Nil.

Climate Change Considerations

[28] Nature-based solutions help address climate change by absorbing carbon dioxide, reducing climate-related risks, and enhancing ecosystem resilience. Actions like reforestation, wetland restoration, and sustainable land management sequester carbon while also buffering communities from extreme weather events such as floods, heatwaves, and droughts. These solutions not only mitigate climate impacts but also support biodiversity and provide vital services for people and nature.

Communications Considerations

[29] Align communications across the organisation and ensure public communications are consistent and easy to understand. Develop a comprehensive communications and engagement plan for NbS. This should consider, what are NbS, the context of NbS globally, nationally and locally for ORC.

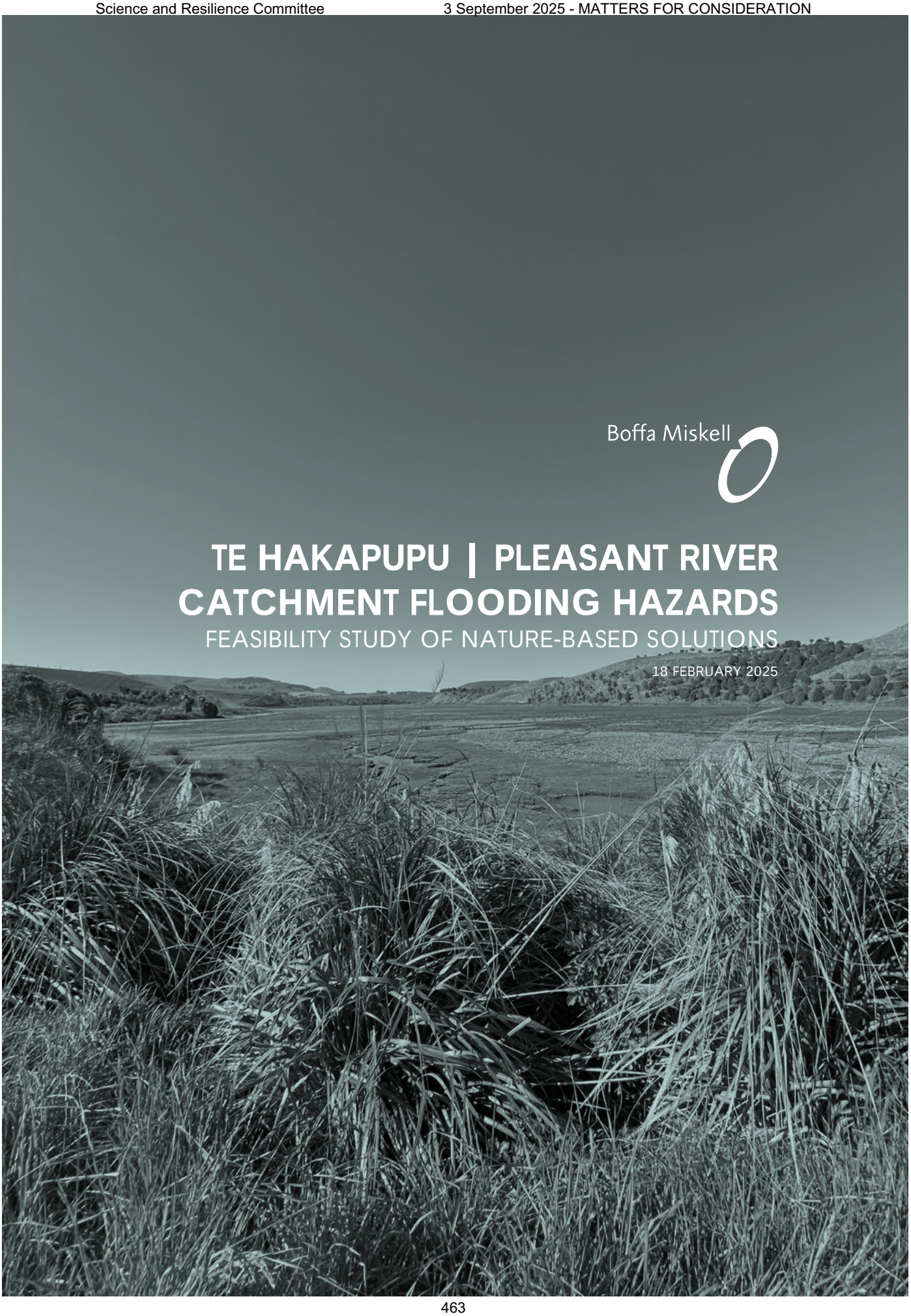
NEXT STEPS

[30] Where appropriate, staff will look to incorporate NbS into workplans to support Council alignment to its Strategies as a priority solution to environmental changes and issues due to climate change, land use and other human impacts.

[31] Staff will work on a communications and engagement strategy for NbS for internal and external communication about these techniques.

ATTACHMENTS

1. Te Hakapupu Nature-based Solutions Feasibility Study [**9.10.1** - 103 pages]
2. Appendix 1 Nb S Technical Specification [**9.10.2** - 14 pages]
3. Appendix 2 GH D- Te Hakapupu Model Build Report Final [**9.10.3** - 23 pages]
4. Appendix 3 Maps [**9.10.4** - 11 pages]
5. Appendix 4 Biodiversity [**9.10.5** - 4 pages]
6. Appendix 5 Landscape [**9.10.6** - 5 pages]
7. Appendix 6 Planning [**9.10.7** - 9 pages]
8. ORC Beca Natura-based Solutions Engagement Study [**9.10.8** - 27 pages]



Boffa Miskell

TE HAKAPUPU | PLEASANT RIVER CATCHMENT FLOODING HAZARDS

FEASIBILITY STUDY OF NATURE-BASED SOLUTIONS

18 FEBRUARY 2025

Boffa Miskell is proudly a
Toitū net carbonzero certified consultancy

DOCUMENT QUALITY ASSURANCE

BIBLIOGRAPHIC REFERENCE FOR CITATION:

Boffa Miskell, 2025. *Te Hakapupu | Pleasant River Catchment Flooding Hazards Feasibility Study of Nature-based Solutions*. Report by Boffa Miskell Limited for Otago Regional Council.

PREPARED BY:	Sam Parsons Climate Change Specialist Boffa Miskell Ltd	
CONTRIBUTORS:	Sue McManaway Principal | Landscape Planner Boffa Miskell Ltd	
	Dr Jaz Morris Associate Principal | Ecologist Boffa Miskell Ltd	
	Laurissa Jackson GIS Specialist Boffa Miskell Ltd	
	Deborah Rowe Senior Principal | Planner Boffa Miskell Ltd	
REVIEWED BY:	Rachael Eaton Senior Principal | Landscape Architect and Urban Designer Boffa Miskell Ltd	
STATUS: FINAL	Revision / version: 1.5	Issue date: 18 February 2025

CONTENTS

EXECUTIVE SUMMARY 4

1. INTRODUCTION 8

1.1 PURPOSE OF THE NATURE-BASED SOLUTIONS FEASIBILITY STUDY 8

1.2 FEASIBILITY STUDY METHODOLOGY 12

2. WHAT ARE NATURE-BASED SOLUTIONS? 16

2.1 DEFINING NATURE-BASED SOLUTIONS 16

2.2 TYPES OF NATURE-BASED SOLUTIONS 16

2.3 THE BENEFITS OF NATURE-BASED SOLUTIONS 19

2.4 CHALLENGES & BARRIERS 22

3. UNDERSTANDING TE HAKAPUPU/PLEASANT RIVER CATCHMENT 25

3.1 OVERVIEW OF CATCHMENT CHARACTERISTICS 25

3.2 IMPACTS OF CLIMATE CHANGE ON THE CATCHMENT 33

3.3 STATUTORY & POLICY CONTEXT 37

4. WHICH NBS ARE MOST SUITED IN THE CATCHMENT? 42

4.1 LANDCOVER MANAGEMENT 43

4.2 RIVER & STREAM NATURALISATION 47

4.3 WETLAND RESTORATION & CONSTRUCTION 49

4.4 OVERVIEW OF NBS FOR TE HAKAPUPU/PLEASANT RIVER CATCHMENT 51

5. HOW WILL THE PROPOSED NBS PERFORM? 54

5.1 LANDCOVER MANAGEMENT 55

5.2 RIVER NATURALISATION 65

5.3 WETLAND RESTORATION AND CONSTRUCTION 76

6. WHAT HAVE WE LEARNT? 90

6.1 FEASIBILITY OF NBS FOR FLOOD MANAGEMENT 90

6.2 FEASIBILITY STUDY KEY FINDINGS 91

6.3 RECOMMENDED ACTIONS 92

7. GLOSSARY 98

8. REFERENCES 100

EXECUTIVE SUMMARY

The use of Nature-based Solutions (NbS) within Te Hakapupu/Pleasant River catchment (the catchment) present significant opportunities to manage flooding and associated hazards. However currently, in New Zealand, the understanding and use of NbS as a tool to manage flood hazards remains in its infancy. To help build a strong evidence-base to inform the future use of NbS for flood hazard management across Otago, Otago Regional Council (ORC) has commissioned a feasibility study of NbS to manage flood hazards in Te Hakapupu/Pleasant River catchment.

The study will look at how NbS could help lessen the long-term effects of flooding in Otago, as well as bring other benefits to the region. The project is one of 21 nationally to be fully funded by the Ministry for the Environment's (MfE) Essential Freshwater Fund. In addition, the work builds on and supports Toitū Te Hakapupu: The Pleasant River Catchment Restoration Project, a partnership between Otago Regional Council and Kāti Huirapa Rūnaka ki Puketeraki to restore and enhance the mauri and health of the river system.

BUILDING AN UNDERSTANDING OF NATURE-BASED SOLUTIONS

Te Hakapupu/Pleasant River catchment in East Otago currently faces challenges from flooding and associated hazards, including streambank erosion and sedimentation, that occur during an extreme rainfall event. These challenges are commonly experienced in catchments across the Otago Region and wider New Zealand. As the effects of climate change continue to grow, the frequency and intensity of extreme rainfall events in the Otago Region are projected to increase, placing additional pressures on local communities and natural environment values.

NbS have the potential to effectively manage flood hazards in the catchment and other similar catchments in the Otago region. Taking actions to protect, conserve, restore, and sustainably use natural ecosystems can increase resilience to the effects of flood hazards, while simultaneously providing a wide range of social, economic, environmental, and cultural benefits.

As part of the feasibility study, several NbS interventions were evaluated to establish their flood hazard management capabilities, their alignment with global standards for NbS best practice, and their relevance to the catchment and its characteristics. A Rapid Flood Hazard Model was also developed to assist with understanding how the proposed NbS could affect the existing flood events in the catchment.

Three NbS interventions were identified as being feasible within Te Hakapupu/Pleasant River catchment.

1. **Landcover management:** Restoring and expanding existing pockets of remnant indigenous forest, working towards the gradual transition of large areas of landcover to permanent indigenous forest in vulnerable upper sub-catchment locations
2. **River and stream naturalisation:** Restoration of riparian vegetation, re-meandering channels, and reconnecting isolated or drained off-stream wetland areas along the catchments modified and unvegetated waterways
3. **Wetland restoration and construction:** Restoring and constructing surface flow wetland natural features, such as deep sedimentation ponds and shallow water vegetated areas in flood prone catchment locations

The possible application of these interventions across a typical river catchment is illustrated in Figure 1.

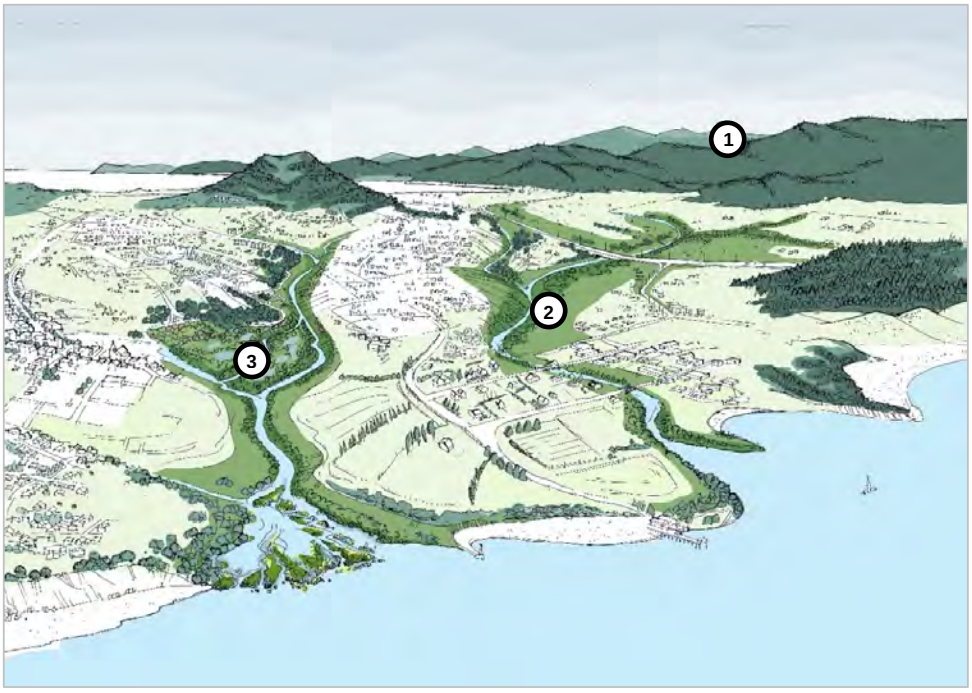


Figure 1: Possible application of the three nature-based solutions across an illustrative river catchment. 1: Landcover management; 2: River and stream naturalisation; and 3: Wetland restoration and construction. Source: Boffa Miskell Ltd.

The three NbS interventions were all assessed to provide significant benefits to flood hazard management within the catchment. They would also deliver a wide range of social, economic, environmental, and cultural benefits and support local catchment management goals currently being delivered by Toitū Te Hakapupu: The Pleasant River Catchment Restoration Project.

CHALLENGES FOR NATURE-BASED SOLUTIONS

While NbS interventions were evaluated to be technically feasible and beneficial for addressing flooding and associated hazards experienced within Te Hakapupu/Pleasant River catchment, at present, their practical application faces several barriers.

To sufficiently manage flood hazards in the catchment, NbS need to be considered at a catchment scale, across multiple land tenures. Specifically, in Te Hakapupu/Pleasant River catchment, it is recommended to progress landcover management in the upper catchment, before applying NbS in the lower catchment. This will safeguard against flood hazards currently experienced further downstream, during forestry harvest and replanting periods.

However, to do this, would require areas of land currently used for commercial forestry to be set aside for non-commercial native forest use.

Accordingly, in considering the large-scale land-use changes needed for NbS, the most significant challenges preventing their use would be the direct economic costs experienced by landowners from the loss of primary production lands (both forestry and agriculture).

To overcome these challenges and facilitate the wider use NbS in Te Hakapupu/Pleasant River catchment and other Otago catchments, it is recommended that a range of governance measures and economic incentives are in place that could encourage landowners to invest in NbS in the catchment.

FEASIBILITY STUDY KEY FINDINGS

Through the process of undertaking the feasibility study a number of key findings were established, that could guide the ongoing use of NbS as tools to manage flood hazards in Te Hakapupu/Pleasant River catchment and across the wider Otago region. It is recommended that these are tested further with ORC partners and stakeholders, including landowners, operators and investors, and the local community.

NbS are technically feasible

NbS are technically feasible as methods for the management of flooding and associated hazards in Te Hakapupu/Pleasant River catchment and across the wider Otago region. NbS will work to influence the natural processes across the catchment to effectively control and accommodate floodwater, and their use should be promoted as a method of flood mitigation.

Landcover management in upper catchment areas is the first step

Implementing land cover management NbS in the upper Te Hakapupu/Pleasant River catchment is critical to manage flooding and associated hazards, which are expected to increase in the lower catchment, during upper catchment forestry harvest periods.

NbS work most successfully when applied at scale

In a large catchment like Te Hakapupu/Pleasant River, to sufficiently manage flooding and associated hazards NbS should be applied at a suitably large scale[1]. NbS are most effective when implemented over larger areas or broader contexts, and while small-scale NbS projects can be useful, scaling them up maximises their ecological, economic, and social benefits.

Integrated NbS provide enhanced benefits

At scale, NbS need to work in an integrated manner to effectively manage flood hazards, working as a connected network and with surrounding land uses, across the catchment, from Ki Uta Ki Tai (mountains to the sea). When NbS are integrated across catchment areas their effectiveness and benefits are significantly enhanced.

Innovation is required to ensure NbS are economically viable

The current economic and funding framework presents one of the greatest challenges to NbS implementation, making them financially unviable for many landowners. To support large-scale adoption of NbS, especially across areas of productive forestry and farming land use like Te Hakapupu/Pleasant River catchment, innovative economic approaches are essential.

[1] E.g. The scale of a constructed wetland should be 1-5% of the contributing catchment area to effectively manage flooding and reduce contamination

RECOMMENDED ACTIONS TO SUPPORT THE USE OF NATURE-BASED SOLUTIONS

Successfully applying NbS will require strong governance and political backing, as well as economic support and financial assistance, for landowner, from both the private and public sectors. This could involve approaches like payments for environmental benefits, financial incentives for landowners, and cost sharing initiatives.

The following five actions are recommended to facilitate the practical implementation of NbS in Te Hakapupu/Pleasant River catchment and other similar catchments across the Otago region:

Action 1: Strengthen NbS governance and partnerships

Create innovative public and private partnerships, involving central and local governments, mana whenua, landowners, businesses, financial institutions, and community stakeholders to create a robust governance framework, that supports equitable application and funding of NbS for hazard management, and encourages time and financial investment by all parties.[2]

Action 2: Facilitate economic incentives for landowners

Develop and implement a model that provides economic incentives to landowners for transitioning existing land uses to NbS, (e.g. retiring productive farmland to become wetland). This could include mechanisms such as payments for ecosystem services, grants, tax incentives, and revenue from ecotourism.

Action 3: Promote Nature-based credit markets

Build greater understanding and application of the nature-based markets available for ecosystem services, and how they can be used to enable private investment in NbS as a tool to manage flood hazards (e.g. ability for private companies to finance NbS and associated carbon and biodiversity benefits to offset carbon emissions).

Action 4: Develop regional NbS policy, guidance, and standards

Develop NbS practice standards, guidance and supporting regional policies tailored for the Otago region to support landowners in adopting and implementing NbS on their properties. This includes ensuring consistency across the region by providing comprehensive guidance for NbS planning, addressing the required consenting pathways to streamline implementation

Action 5: Integrate NbS into catchment scale management and planning

Nature based solutions should be planned for and integrated within the Te Hakapupu Catchment Action Plan, and for other similar Otago region catchments through Integrated Catchment Management Planning (ICMP) processes to ensure they’re used correctly and cohesively with catchment land uses and community values.

[2] Financial institutions include banks, insurance companies, and other investment companies. These institutions are important to facilitating investment via tools such as green bonds and sustainability-linked loans

1. INTRODUCTION

1.1. PURPOSE OF THE NATURE-BASED SOLUTIONS FEASIBILITY STUDY

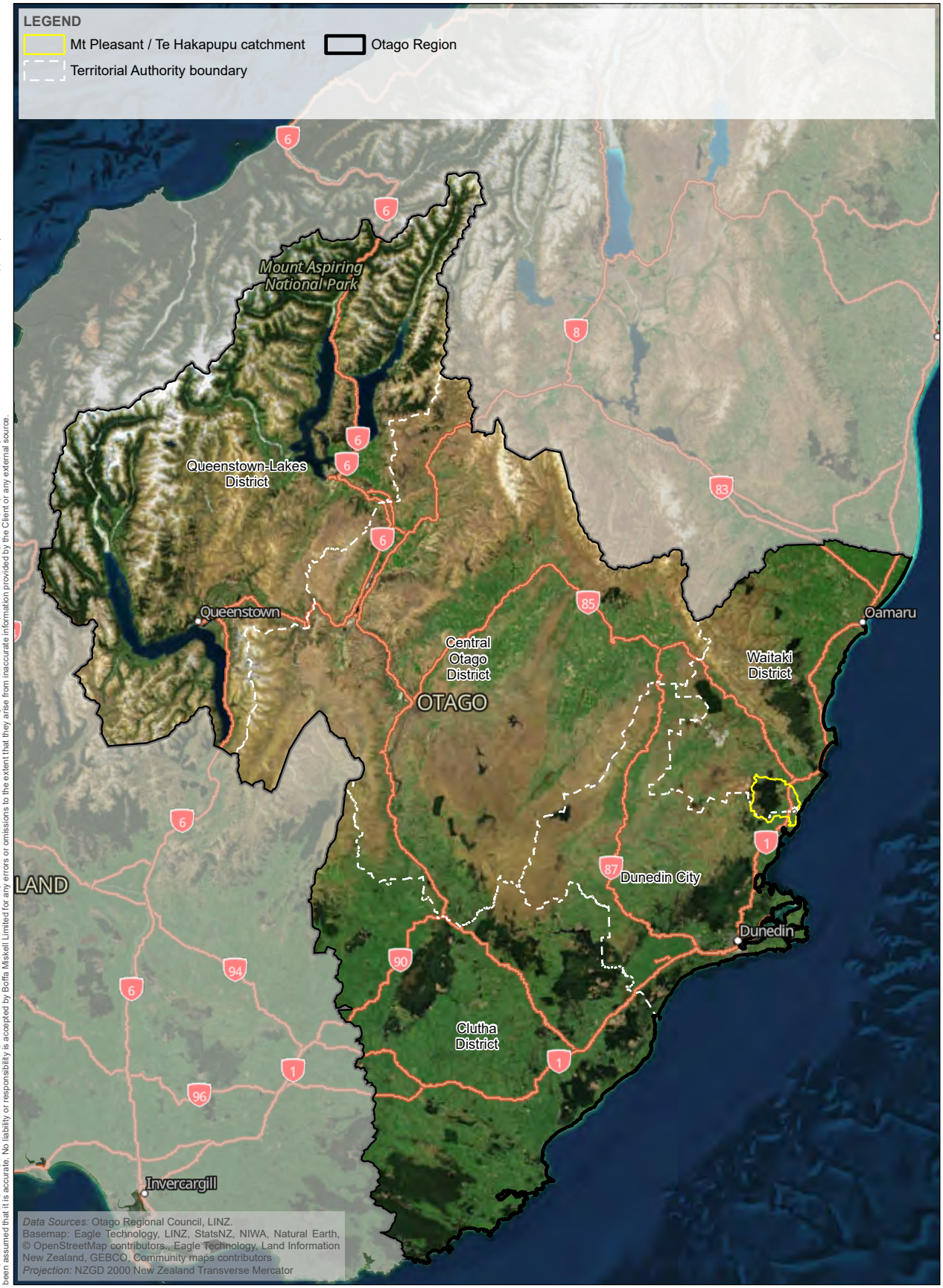
Boffa Miskell has been commissioned by Otago Regional Council (ORC) to undertake a feasibility study to investigate the use of nature-based solutions (NbS) in managing flooding and associated hazards in Te Hakapupu/Pleasant River catchment (the catchment).

The catchment is in Eastern coastal Otago (see Map 1) and covers about 12,800 hectares of rural land. It sits within the regional jurisdiction of ORC and spans the local authority boundaries of Dunedin City Council (DCC) and Waitaki District Council (WDC). The catchment includes Te Hakapupu / Pleasant River, Owhakaoho/Trotters Creek, Watkin Creek, and the Te Hakapupu / Pleasant River estuary wetland complex (see Map 2). The catchment is within the takiwā (territory) of Kāti Huirapa ki Puketeraki, who hold mana whenua status over East Otago and kaitiakitaka (guardianship) of the land.

The NbS feasibility study will inform ORC and its partners collective understanding of NbS and their benefits. It tests the viability of three NbS in managing flooding and associated hazards in the catchment and sets out several recommendations to take forward in the future. In addition, a key objective was to enable the transfer of the learnings from the study to other river catchments in the Otago region.

The NbS feasibility study will help ORC and its partners to:

- Establish an understanding of NbS based on global and national best practice, their benefits, and obstacles and barriers to implementation
- Understand how Te Hakapupu/Pleasant River catchment behaves in different extreme rainfall events, including during predicted peak flood periods
- Test how NbS best practice could contribute to flood hazard management in Te Hakapupu/Pleasant River catchment
- Provide recommendations for how ORC and relevant parties could work together to use NbS as a flood management tool in Te Hakapupu/Pleasant River catchment.
- Build upon the efforts and progress of the Toitū Te Hakapupu: Pleasant River restoration project, as a foundation to introduce and expand NbS within the catchment area.
- Establish regional NbS guidance, standards, and policy to enable the learnings from this study to be transferred to any catchment on Otago.



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 20 km
1:1,350,000 @ A4

TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

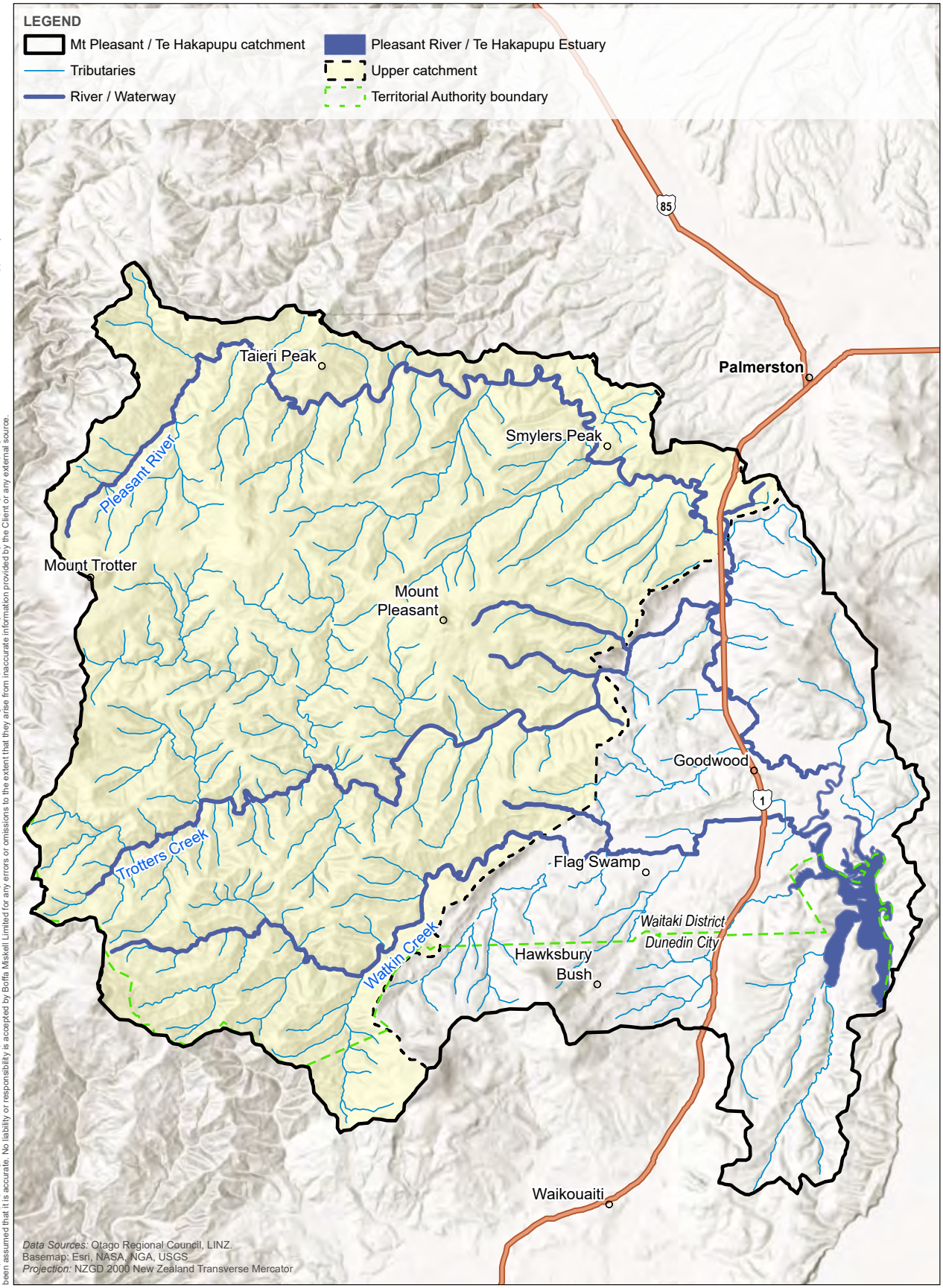
Catchment Location

Date: 04 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 1



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

Feasibility Study

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 2

1.1.1 Toitū Te Hakapupu: The Pleasant River Catchment Restoration Project

In 2021, the catchment received funding from the Ministry for the Environment 'Essential Freshwater Fund' to support the Toitū Te Hakapupu – Pleasant River Catchment Restoration Project.[3] The project is a four-year partnership between the Otago Regional Council (ORC) and Kāti Huirapa Rūnaka ki Puketeraki.

The $5.2 million project is focused on improving the health of the water in the catchment which includes Owhakaoho/Trotters Creek, Watkin Creek, and the estuary. It aims to restore and enhance the mauri and health of this important river system.

Since its establishment, the project has conducted environmental monitoring to understand the current pressures on the catchment and supported landowners to plant approximately 68,000 plants and erect 27 km of fencing for freshwater enhancement.

See Appendix 4 for Toitū Te Hakapupu – Pleasant River Catchment Restoration Project native planting and fencing statistics (as of December 2024).

[3] Toitū Te Hakapupu: The Pleasant River Catchment Restoration Project | Otago Regional Council

1.2 FEASIBILITY STUDY METHODOLOGY

The methodology for evaluating the feasibility of NbS in Te Hakapupu/Pleasant River Catchment has been grounded on international NbS best practice, supported by collaboration with ORC, mana whenua, and community stakeholders.

Building upon an established understanding of NbS global and national best practice, a strong understanding of the catchment was developed through hydrology modelling, geospatial analysis, and catchment specific literature review. At key stages throughout the delivery of the feasibility study, engagement with the Toitū Te Hakapupu Partnership Group and other community stakeholders was conducted to gather additional insights and test findings.

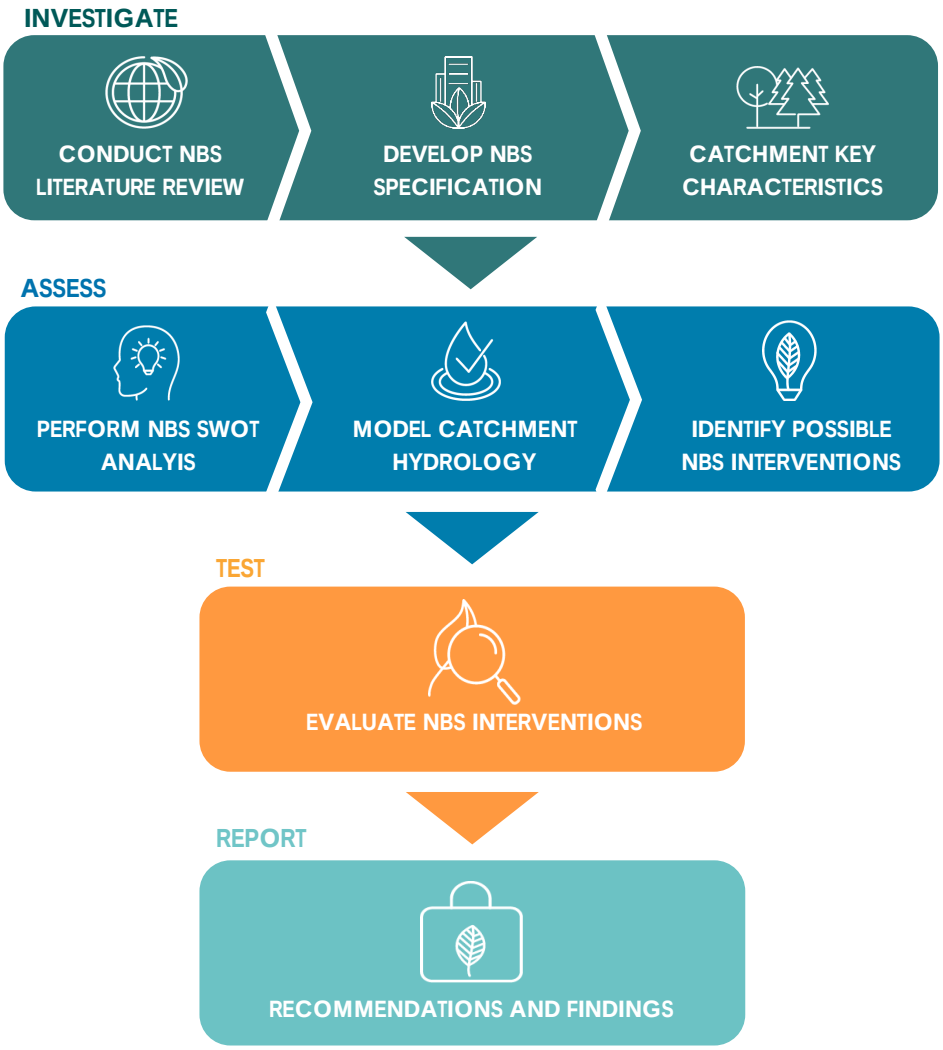


Figure 2: Overview of the Feasibility Study methodology

Investigation

To establish an understanding of NbS for flood management that could be applied in Te Hakapupu/Pleasant River catchment, a literature review was conducted. Based on leading international NbS literature sources, including the International Union for the Conservation of Nature (IUCN), the Nature-based Solutions Initiative, and the US Army Corps of Engineers, a variety of NbS approaches for flood hazard mitigation were identified for further investigation. Additionally, the literature review sought to uncover emerging NbS best practice standards and evaluation practices that should be considered throughout this feasibility study.

Applying the *IUCN 'Global Standard for Nature-based Solutions' (2020)* identified during the literature review, a 'Nature-based Solutions Technical Specification' was developed. This set the technical framework for the project, confirming the definition, functional criteria, and performance indicators to be used to design and evaluate NbS in the Otago region. The specification was developed to ensure NbS interventions proposed within Te Hakapupu/Pleasant River catchment reflect best practice guidelines and align with global NbS standards and agreements. See Appendix 1 for more information on the Technical Specification.

A spatial analysis was conducted for the catchment area to identify district plan landscape features and constraints, natural hazard zones, land uses, and remnant indigenous ecosystem coverage. Building upon this spatial information, a catchment specific literature review provided a strong understanding of the key catchment characteristics, environmental pressures, and values. This included gathering information concerning the water quality challenges in the catchment, mana whenua and community objectives for the catchment, and how the catchment would be affected by the projected impacts of climate change in the Otago region.

Assessment

Based on the various NbS approaches identified during the literature review, a SWOT (strengths, weaknesses, opportunities, and threats) analysis process was then conducted to assess and refine the use of NbS for flood hazard management in the catchment. This process sought to identify the key NbS that were deemed to most compatible within the environmental, social, and economic content of the Te Hakapupu/Pleasant River catchment. The SWOT analysis was conducted with input from technical experts, ORC project team members, Kati Huirapa Rūnaka ki Puketeraki, forestry operators, and the East Otago Catchment Group.

From the SWOT analysis, three NbS interventions were identified. These NbS were landcover management, river and stream naturalisation, and wetland restoration and construction.

Testing and evaluation

The three NbS interventions were tested in the catchment to understand their feasibility for flood hazard management. Using the functional criteria and relevant performance indicators from the NbS Technical Specification, and the Rapid Flood Hazard Modelling (RFHM) detailed below, an evaluation criterion was applied to each NbS intervention to test the opportunities, challenges, and possible benefits of NbS.

The evaluation of NbS interventions was conducted by technical planning, ecology, hydrologists, and landscape experts. To ensure interventions fit practically within existing landscape constraints and contribute to flood management, evaluations were further informed by the RFHM data and catchment geospatial information (GIS).

Evaluation considerations included the flood hazard management capability of NbS interventions, alongside the other possible benefits of NbS such as biodiversity, landscape character, economic value, and social benefits.

Findings and next steps

Outcomes of the evaluation processes and RFHM analysis have been collated in this feasibility study, with accompanying technical appendices and GIS resources provided. The conclusion of this feasibility study outlines the key findings and recommended actions needed for the successful implementation of NbS for flood management in Te Hakapupu/Pleasant River Catchment and other Otago catchments. These insights provide a foundation for informed decision-making and practical action across the region.

1.2.2 Rapid Flood Hazard Modelling

To inform the Te Hakapupu/Pleasant River catchment NbS feasibility study, Boffa Miskell commissioned hydrology modellers and technical experts to produce and analyse a Rapid Flood Hazard Model (RFHM) of the catchment.

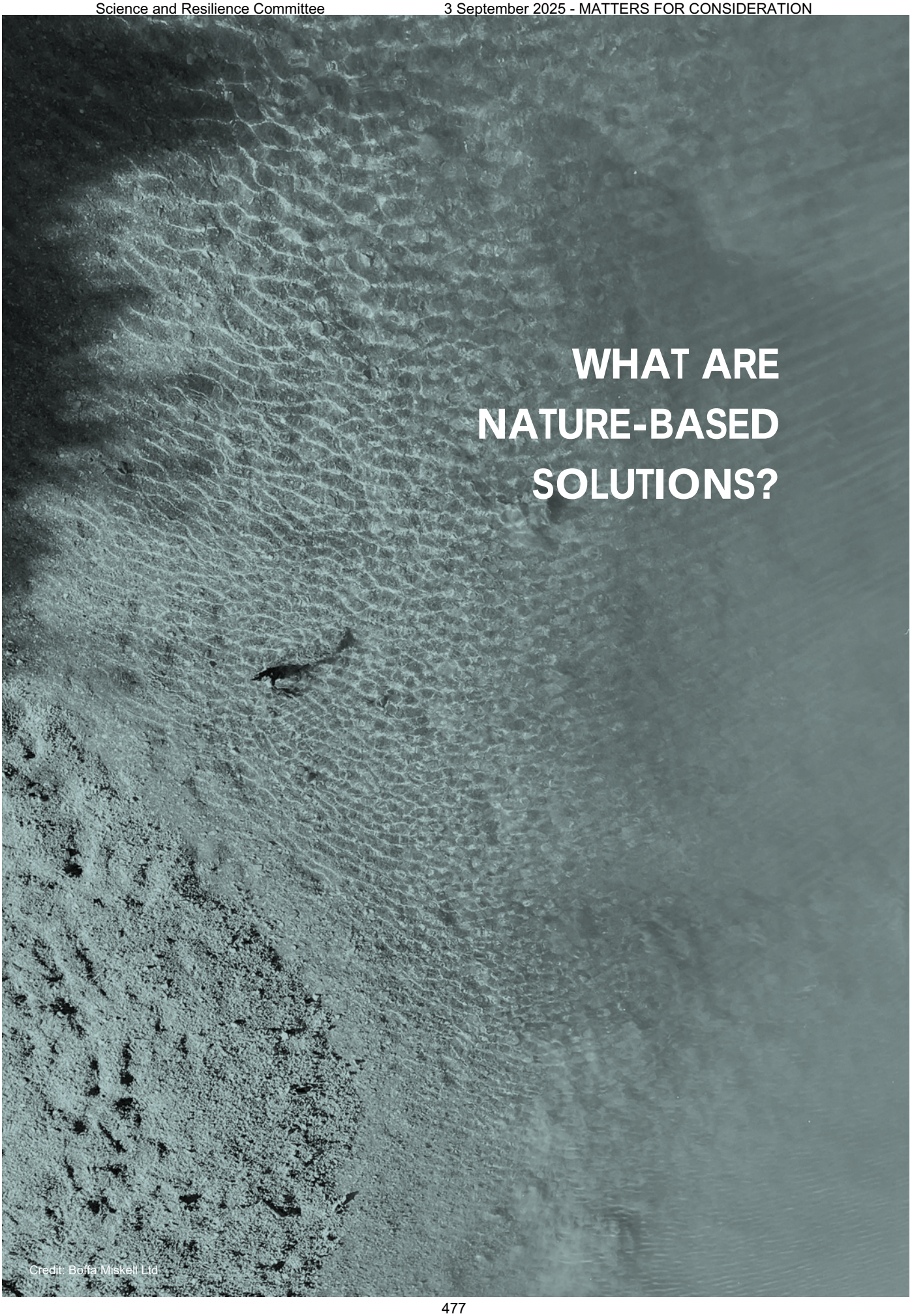
This modelling characterises how the current catchment will likely respond during an extreme rainfall event, in this case a one-in-100-year rainfall event (100-year annual return interval) with the added effect of climate change. The model simulates how rain, captured in the steeper inland areas of the upper catchment, flows through the main channels of Te Hakapupu / Pleasant River, Owhakaoho / Trotters Creek, and Watkin Creek into the flatter areas of the lower catchment.

The RFHM process aimed to establish and understand the expected characteristics of flood risks in the catchment during a one-in-10-year and one-in-100-year, 24-hour extreme rainfall event under future climate change scenario. RFHM outputs included predicted peak flood flow level, peak flood depth, and peak flood flow speed.

The RFHM helped to establish how the use of NbS would affect the predicted peak flood in the catchment, and their potential use in reducing flood magnitude and mitigating flood risks.

These findings, combined with coastal inundation modelling and the qualitative findings of this feasibility report, provides a suite of tools to evaluate how NbS and other flood management interventions may impact flood characteristics in the catchment. These tools will support the evolving understanding and application of NbS in the area and across the Otago region.

See Appendix 2 for more information about the RFHM process and outputs.


WHAT ARE
NATURE-BASED
SOLUTIONS?
Credit: Boffa Miskell Ltd

2. WHAT ARE NATURE-BASED SOLUTIONS?

2.1 DEFINING NATURE-BASED SOLUTIONS

Nature-based solutions seek to use natural processes to address environmental challenges, like flood hazards and risks, while providing biodiversity, human wellbeing, and community benefits

This NbS feasibility study uses the definition of NbS, formerly adopted by the United Nations Environment Assembly 2022 (UNEA). This definition builds upon the International Union for Conservation of Nature (IUCN) definition of NbS and other relevant NbS definitions formerly use to provide an internationally agreed approach for NbS.

'Nature-based solutions are actions to protect, conserve, restore, sustainably use, and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience, and biodiversity benefits' – (UNEA/EA.5/Res.5)

At present in New Zealand, a number of different definitions for NbS exist within various strategic planning frameworks, including council climate change and biodiversity strategies, the National Adaptation Plan, and Te Mana o te Taiao - Aotearoa New Zealand Biodiversity Strategy.[4] However, following the formal adoption on the UNEA NbS definition, work is currently underway by the Ministry for the Environment to communicate this collective definition across New Zealand NbS users.

To support the assessment of the feasibility of NbS for flood mitigation, currently being conducted by ORC and other regional or unitary councils, the Ministry of Business, Innovation, and Employment (MBIE) commissioned a literature review of NbS for flood management (NIWA. 2024). Applying the agreed UNEA definition of NbS, the literature review provided an up-to-date and in-depth analysis of the existing literature, case studies, and best practices related to the use of NbS for mitigating flood hazards. The literature review report provides a summary of the strengths, weaknesses, opportunities, and threats for NbS that can be used for flood hazard mitigation.

These themes are assessed in greater detail in this feasibility report for Te Hakapupu catchment.

2.2 TYPES OF NATURE BASED SOLUTIONS

As an umbrella concept, NbS include a number of related approaches that share a focus of protecting and enhancing the natural environment to address challenges, such as green infrastructure and water sensitive urban design (WSUD). Globally, NbS have been applied in response to a diversity of environmental challenges, including managing natural hazards and climate change adaptation, reducing greenhouse gas emissions (i.e. climate change mitigation), addressing biodiversity decline, or preventing land degradation.

[4] Note, definitions for Nature-based Solutions included in existing New Zealand planning frameworks predominantly reference NbS definitions from IUCN, the European Union, or WSUD guidance.

As illustrated in figure 4, NbS can be broadly classified under three core approaches of working with nature to address environmental challenges.

- **Protection, conservation, and restoration:** Protection and enhancement of natural environment features and ecosystems, such as river and flood plain naturalisation, coastal wetland, mangrove, and dune restoration, and control of browsing pest species.
- **Sustainable use:** The maintenance and sustainable use of natural environment values and ecosystems, such as native carbon forestry, community gardens, floodable recreation areas, regenerative agricultural practices.
- **Green infrastructure:** Development of issue-specific green infrastructure that creates natural environment features such as constructed wetlands, bioretention rain gardens and pervious paving in urban areas, and vegetated swales along flood prone waterways

Across a catchment, combining NbS with grey infrastructure can effectively maximize efficiency while minimizing economic trade-offs. Grey infrastructure can address critical planning challenges, such as enabling urban development within flood-prone areas by mitigating immediate risks from natural hazards. At the same time, NbS can complement these efforts by reducing the severity of hazards upstream and offering additional benefits, such as enhancing biodiversity and improving water quality, which grey infrastructure alone cannot achieve (TNC, 2023)

While a diversity of NbS approaches are available, careful consideration must be applied to ensure that NbS interventions are compatible with the natural landscape and existing land uses.

The type of NbS identified for testing in Te Hakapupu/Pleasant River Catchment were identified based on their ability to address the challenges associated with flood hazard, alongside their potential for enhancing the biodiversity values present in the catchment and ability to mitigate other environmental pressures, such as soil degradation and water quality decline.

Figure 3: Example of naturalisation of a waterway formerly contained in concrete channels as a method to manage the effects of extreme rainfall induced flooding. Source: Boffa Miskell Ltd.

Figure 4: Examples of the range of nature-based solutions that can be applied across a catchment. Image: Boffa Miskell Ltd.

2.3 THE BENEFITS OF NATURE-BASED SOLUTIONS

Healthy natural ecosystems act as the first line of defence against natural hazards, including flooding and associated hazards. When ecosystems are healthy, they buffer us from the impacts of natural hazards and increase our resilience to their effects (IUCN, 2020).

As shown in figure 5, NbS seek to protect, conserve, restore, and sustainably use natural ecosystems to address environmental challenges, such as flooding, while simultaneously contributing benefits for our environmental, social, economic, and cultural wellbeing. Through actions to establish or restore natural environment features, such as constructing wetland areas and replanting river riparian margins, NbS effectively manage flood hazards while enhancing the health of important ecosystems in a catchment.

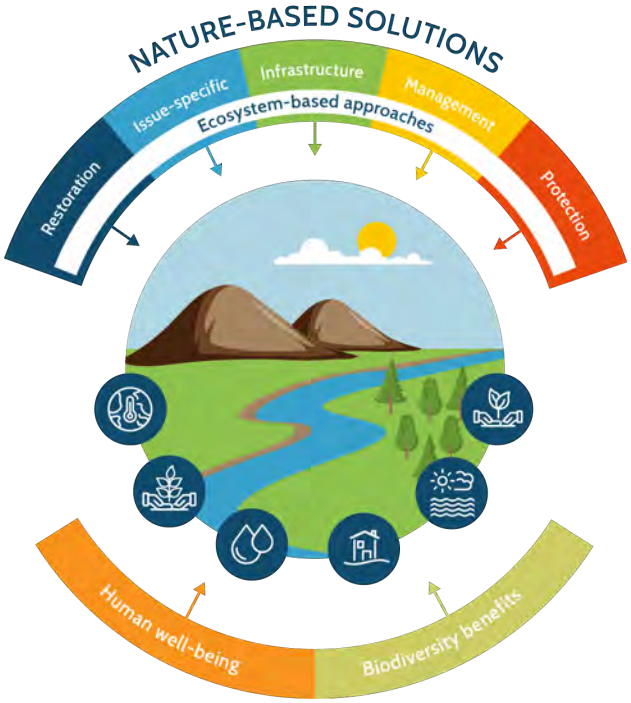


Figure 5: Diagram illustrating how Nature-based Solutions can result in benefits for human well-being and biodiversity. Source: IUCN, 2020

2.3.1 Flood hazard management

NbS are primarily designed as a response to an environmental challenge, such as flooding and associated hazards. NbS can act as practical additions or replacements for conventional 'grey' infrastructure to effectively mitigate and manage hazards across a landscape.[5] Whilst a historically tried and proven approach, in the face of climate change exacerbated flood hazards, 'grey' infrastructure approaches may face long-term challenges.

[5] **Grey infrastructure** refers to engineered structures such as dams, seawalls, or stormwater management pipes and drains.

Challenges include that grey infrastructure is often difficult and costly to adapt, maintenance costs increase as assets age, and they can negatively impact natural environment values through modifying the natural hydrology of a catchment (Climate Change Commission, 2024).

By contrast, NbS manage flood hazards by influencing the natural processes across a catchment to accommodate and redistribute water – changing how extreme rainfall is received by the environment and moves across the landscape.

These practices aim to restore and maintain the natural characteristics of a catchment's hydrology similar to those that existed pre-development.

2.3.2 Human wellbeing & social benefits

Table 1: Summary of human wellbeing and social benefits potentially gained from nature-based solutions. Adapted from More than Water – Assessing the Full Benefits of WSUD (Manaaki Whenua, 2019)

BENEFITS	SUMMARY
Provisioning / Mahika Kai	Traditional mahika kai sources in water bodies are abundant and carry a very low risk of human health effects from consumption.
Recreation	Water bodies are appealing for wide range of recreation, for instance having good water clarity, sandy bed sediments and limited levels of algal growth. Receiving water bodies are well suited to recreation, having a very low risk of human health effects from water contact due to excellent water quality.
Nature connection	Water bodies and green open spaces are celebrated as community assets and easily accessed, with stream and coastal margins in public ownership or easements, and well served by footpaths and accessways that allow views of the landscape and water in places.
Community resilience	Surface flooding is avoided or restricted to designated overland flow paths, flood storage basins and/or parks and reserves, allowing peak flows to spread out with low energy, limiting impact on private properties.
Supplementary water supply	Widespread harvesting and use of stormwater for potable and non-potable uses. Stormwater is detained in ponds/wetlands and is extracted for landscape irrigation during drought periods.

2.3.3 Biodiversity & environmental benefits

Table 2: Summary of biodiversity and environmental benefits potentially gained from nature-based solutions. Adapted from More than Water – Assessing the Full Benefits of WSUD (Manaaki Whenua, 2019)

BENEFITS	SUMMARY
More natural hydrological regime	Runoff volume, stream peak flows, time-to-peak, low flows, and flow variability are more similar to those in an undeveloped catchment than is the case with a conventional development approach
Better water quality	Concentrations of contaminants such as suspended sediments and nutrients in receiving water bodies (e.g. estuary wetland complex) are able to be processed and more similar to those in an undeveloped catchment than is the case with a conventional development approach
Better aquatic and riparian habitat quality	Stream channel geomorphology and bed substrate are more similar to those in an undeveloped catchment. Stream banks are stable and largely lined with diverse native riparian vegetation, providing shade and woody debris inputs to aquatic habitats
Better terrestrial habitat quality	The presence of significant areas of relatively undisturbed or rehabilitated natural vegetation provides high quality terrestrial habitat. Widespread green space is linked by vegetated corridors to maintain or restore a network of green corridors.
Drainage network and ecosystem connectivity	The natural drainage network is largely intact from its headwaters to the stream or river mouth, with few or no artificial barriers to fish passage and good habitat quality maintained throughout.
Natural Character	Characteristics of land, water bodies, and riparian margins are rehabilitated to largely the same as in undeveloped catchment, including the presence of significant undisturbed natural landforms, and improved channel form and sinuosity, water clarity, riparian and vegetation composition.
Carbon Sequestration and Mitigation	Widespread vegetation, especially trees and wetland plants, acts as significant sink of carbon, reducing overall land use emissions and contributing to climate change mitigation outcomes

2.3.4 Economic benefits

A healthy, biologically diverse environment offers substantial economic benefits. To maximize these, it is essential to evaluate the direct and indirect costs and benefits of NbS across their design, implementation, and maintenance phases.

Globally, NbS have the potential to reduce the intensity of climate hazards, such as flooding and coastal inundation, by 26%, with a potential cost saving from climate change impacts of USD 104 billion by 2030 and 393 billion by 2050 (WWF, 2022).

A recent report from WWF established that high-quality NbS can provide significant benefits to New Zealand's economic prosperity, with land-based environmental benefits, such as the provision of clean water and healthy soils, delivering benefits equivalent to 27% of New Zealand's GDP (WWF, 2024).

Furthermore, these natural environment values have been found to support employment, with approximately 1.2 billion jobs worldwide in sectors such as farming, fisheries, forestry, and tourism depending on the effective management and sustainability of healthy natural environments (WWF, 2020).

Implementing NbS to protect nature and achieve New Zealand's international biodiversity targets, under the Kunming-Montreal Global Biodiversity Framework, could save New Zealand an estimated $271.8 billion over the next 50-years (2025 – 2080). These savings stem from mitigating the impacts of nature decline and climate change while unlocking economic opportunities from a thriving natural environment (WWF 2024).

2.4 CHALLENGES & BARRIERS

Despite the significant opportunities NbS present, and as experienced by other NbS early adopters, their application within Otago and wider New Zealand faces a number of common challenges. Such challenges include economic viability of NbS, the ability for NbS to be applied at scale, a lack of national technical NbS guidance, standards and policies and misunderstanding about NbS, their purpose and value.

Economic viability of NbS

A key challenge that can impact the adoption and long-term viability of NbS are the economic challenges associated with private landowners changing land uses for NbS, from primary production land uses, such as farming and forestry, to natural ecosystems, such as wetlands. The economic viability of NbS, is impacted when landowners are unable to gain economic return from transitioning from productive land uses e.g farming and forestry to a natural ecosystem land use.

Ability to apply NbS at scale

If NbS are not made economically viable for landowners, their large-scale adoption and long-term use will likely remain limited. At present in New Zealand, limited funding, and financial incentives for NbS implementation and maintenance restricts their widespread use at scale required to address natural hazards, such as flooding and to bring other benefits.

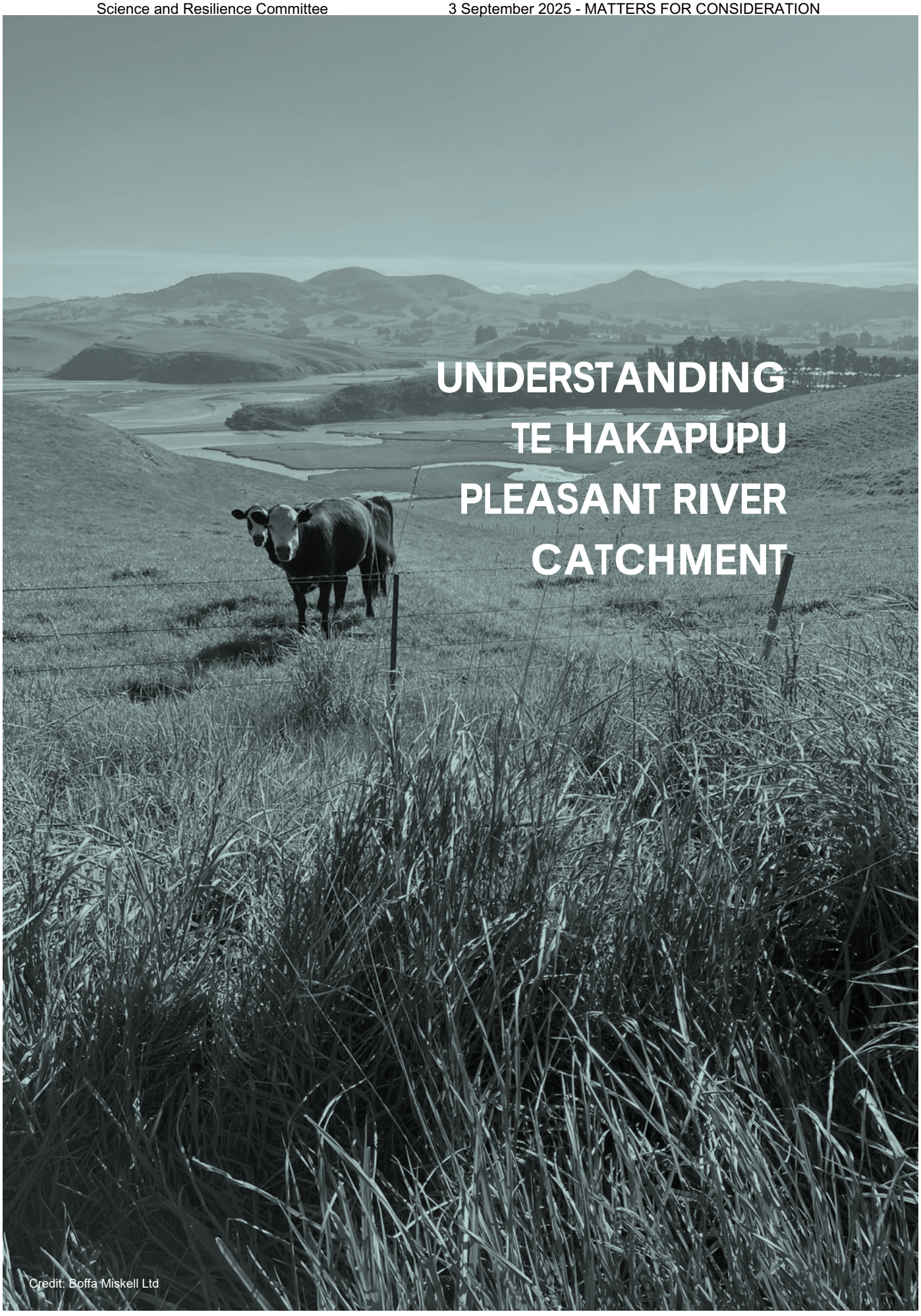
Where there is competition for use of land, including development pressures, the land available for NbS to function sufficiently can be constrained, further increasing the costs associated with the implementation of NbS. When presented with few economic incentives and competing land use pressures, achieving consensus between multiple landowners to implement NbS at large scales proves to be a challenge (NIWA, 2024).

Lack of a consistent technical NbS framework

Absence of comprehensive guidance and monitoring data leads to misuse or misinterpretation of NbS (UNEP, 2022). Without clear definitions and proper understanding, this may result in unintended adverse effects or failure to realise potential biodiversity benefits that could be gained.

While NbS can involve both natural and modified ecosystems, actions that degrade the overall integrity of natural ecosystems do not align with the NbS definition in the UNEA 5/5 Resolution or meet the criteria of IUCN's Global Standard for NbS, as they fail to provide environmental co-benefits (IUCN, 2024). For example, one of the common misconceptions is that actions designed exclusively for climate change mitigation, such as monoculture forest plantations are considered a nature-based solution.

As NbS continue to be adopted more frequently, there is a pressing need for greater clarity of what NbS entail, and what is required for them to be implemented successfully.


UNDERSTANDING
TE HAKAPUPU
PLEASANT RIVER
CATCHMENT
Credit: Boffa Miskell Ltd

3. UNDERSTANDING TE HAKAPUPU/PLEASANT RIVER CATCHMENT

3.1 OVERVIEW OF CATCHMENT CHARACTERISTICS

The Te Hakapupu/Pleasant River catchment lies on the east coast of north Otago, between Waikouaiti and Palmerston, north of Dunedin, covering about 12,800 hectares of rural land. The catchment is sparsely populated, with around 200 residents. It is a highly modified landscape characterised by rural settlements, farming, and forestry land uses.

3.1.1 Waterways and wetlands

The catchment contains a network of tributaries, that feed into three main rivers and waterways (Te Hakapupu/Pleasant River, Owhakaoho/Trotters Creek and Watkin Creek) all of which confluence at the coast at Te Hakapupu/Pleasant River Estuary Wetland Complex (See Map 3: Waterways and Wetlands).

The catchment varies in altitude from 616m above sea-level (Hikaroroa/Mt Watkin) to sea-level. The main tributary, Te Hakapupu/Pleasant River, has a reasonably well entrenched gradient of 1 in 110 above State Highway 1 (SH1). While below SH1, the channel opens out onto the estuary.

The wetland complex is predominantly an estuarine system of about 84 hectares in size. It is the largest wetland in the North Otago Freshwater Management Unit (FMU). Estuarine wetlands such as this are one of the Naturally Uncommon Ecosystems in New Zealand, meaning historically rare. It is also classified as ‘vulnerable’ due to historic and ongoing loss in extent and decline in its ecological integrity (Holdaway et al., 2012).

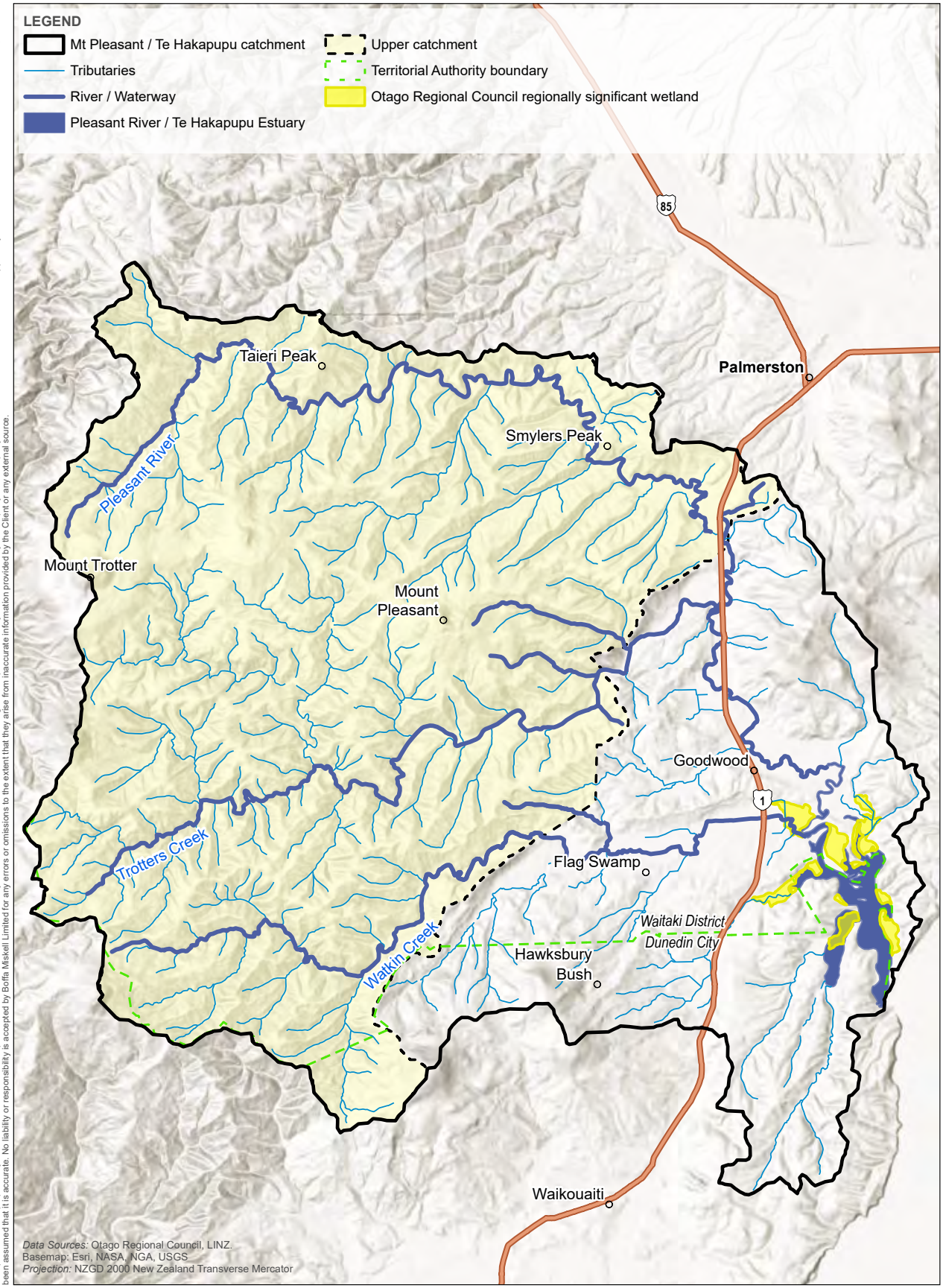
The wetland complex contains habitat for threatened and vulnerable freshwater and estuarine species, as well as providing recreational opportunities, and natural landscape character values. Additionally, mana whenua values are associated with the estuary wetland complex which supports mahika kai species, kaitiakitaka, mauri, and the practice and teaching of mātauraka Māori.

3.1.2 Landscape features

From the Te Hakapupu/Pleasant River estuary, the catchment rises to 616m elevation. The lower catchment is generally characterised as flat landscape with easy rolling hills, the upper catchment areas are dominated by more hilly terrain and steep slopes.

The upper catchment landscape contains six volcanic peaks, Mount Watkin (Hikaroroa), Mount McKenzie (Pakihiwitahi), Mount Trotter, Mount Royal (Te Ruatūpāku), Middle Mount, and Mount Pleasant. All peaks are identified as significant natural features in the Waitaki District Plan. Exotic forestry is a key feature of the upper catchment landscape.

See Appendix 5 for more information about the landscape context of Te Hakapupu/Pleasant River catchment.



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

Waterways and Wetlands

Date: 06 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 3

3.1.3 Ecosystems and habitats

At present, remnant indigenous ecosystems occur in small pockets across the catchment, with the estuary wetland complex containing valued indigenous plants, such as glasswort and sea primrose. In the upper catchment, small remnant areas of indigenous broadleaf forests, matagouri, coprosma, kōwhai scrub, and kānuka scrub are found. Collectively, these remnant indigenous forest and scrub areas cover approximately 1% of the catchment.

The estuary is identified as a Regionally Significant Wetland in the ORC Regional Plan, and as a Significant Natural Feature and an Area of Significant Nature Conservation Value under the Waitaki District Plan and as an area of significant biodiversity value in the Dunedin City Council 2nd Generation District Plan.

The estuary has a reduced size of approximately 2% of its historic extent due to drainage and reclamation (Leathwick *et al.,* 2010). State of the Environment monitoring of the estuary conducted by the ORC in 2022 has indicated that there are elevated nitrate and nutrient levels in the estuary. Additionally, sediment input, derived from natural and anthropogenic activities (farming and exotic forestry) in the catchment leads to enriched muddy sediments in the estuary (Forrest *et al,* 2022).

Built structures that impede salt marsh growth, such as causeways, flap gates and railway infrastructure, are common within the estuary wetland complex area. These structures have significantly altered estuary hydrology and disrupted the natural connectivity between the land and the sea, compromising the overall ecological health and ecosystem services of the estuary wetland complex (Ahikā Consulting Ltd, 2023).

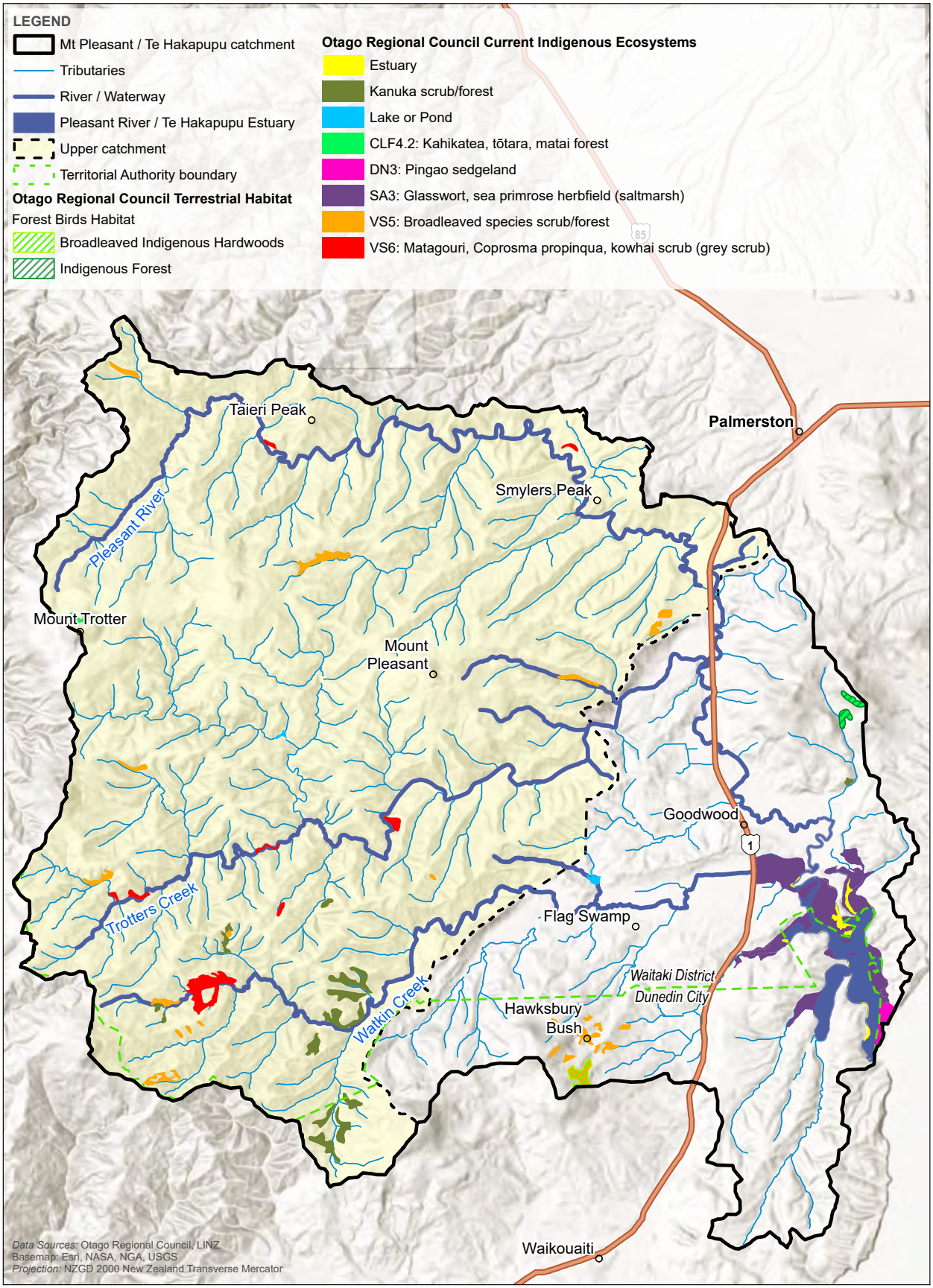
The catchment contains little formally protected conservation areas. These are mainly located at land surrounding the Pleasant River Sand Spit and the estuary mouth. Hawkesbury Bush represents the only moderately large QEII covenant in the catchment, covering 10 hectares of native forest remnants located near the southern extent of the catchment.

See Map 4 and Appendix 4 for more information about the biodiversity values identified within Te Hakapupu/Pleasant River catchment.

3.1.4 Land ownership and use

The land within the catchment is predominantly in private ownership, with nearly half being used for commercial exotic forestry. Plantation forestry land uses are located mainly in the steeper upper catchment area in the west of the catchment. Whilst a number of individual landowners undertake forestry activities as part of their farm businesses, four forestry companies (PF Olsen, Wenita, Ngāi Tahu Forestry, and Calder Stewart) oversee most of the forested area. The remaining land is used for farming, with small pockets of residential/lifestyle land near the coast. Pastoral farmland in the catchment is predominantly sheep and beef, with a smaller amount of dairy and deer farming. There are no arable farms within the catchment area.

Land use in Te Hakapupu/Pleasant River catchment is shown in Map 5



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

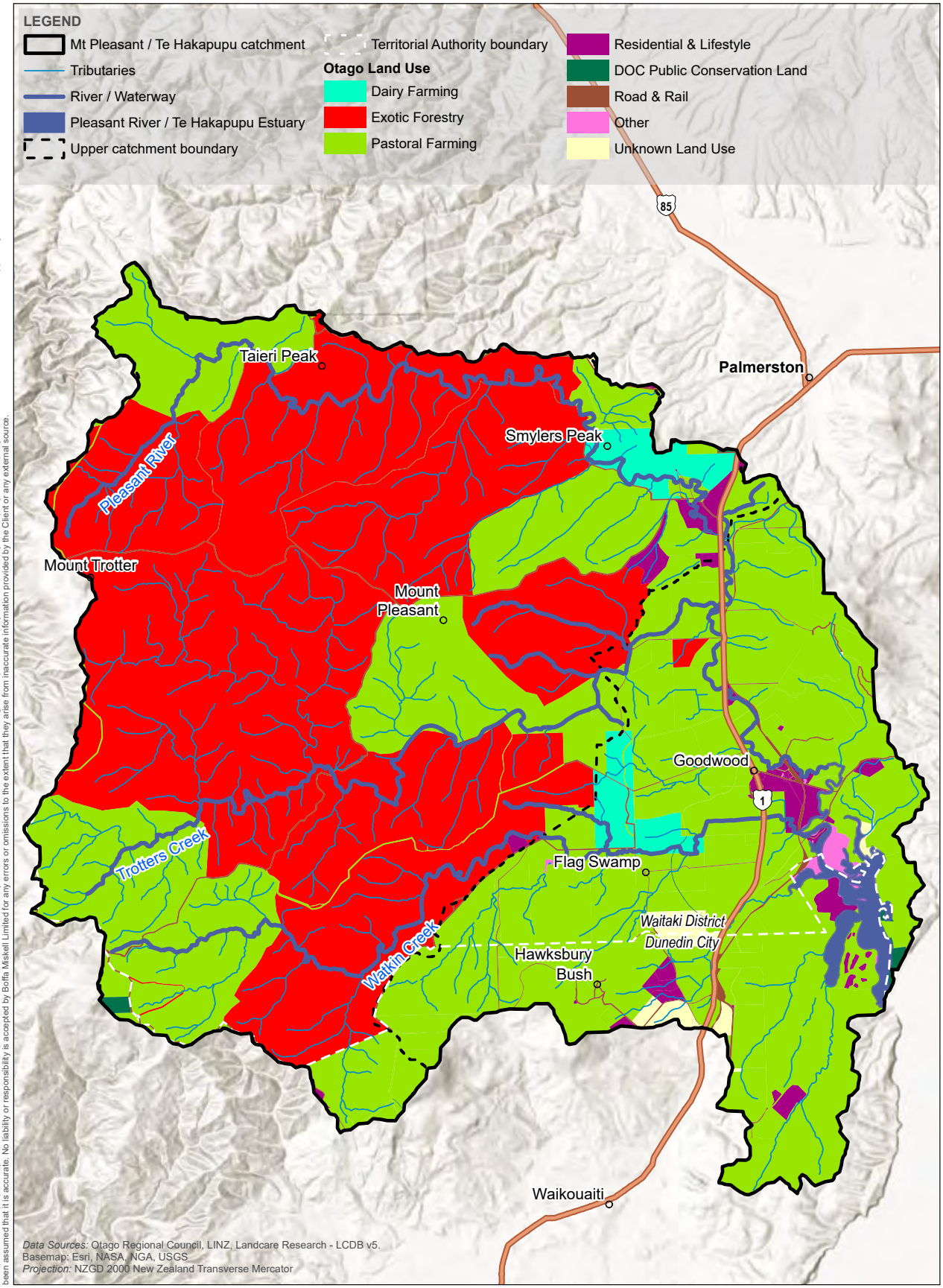
Ecosystems and Habitat

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 4



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

Land Use

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 5

3.1.5 Present day climate

The present day climate of Te Hakapupu/Pleasant River catchment is typical of coastal Otago, with annual mean temperatures ranging between 8-12°C. Summer mean temperatures range between 12-16°C and winter mean temperatures range between 6-8°C. Annual rainfall is comparatively low (compared to inland high elevation areas of the Otago Region), around 600-650mm, with the catchment sometimes becoming 'dry' by New Zealand standards during summer months, driven by higher evapotranspiration rates.

The East Otago area can also experience extreme high intensity rainfall events, typically occurring over a 12–72-hour period when a low-pressure zone is located to the east of the South Island. Historically, the average extreme rainfall depth received in the East Otago area is 166mm for a 100-year Annual Recurrence Interval (ARI) over a 24-hour period, and 95mm for a 10-year ARI over a 24-hour period, recorded at Palmerston (figure 6).[6]

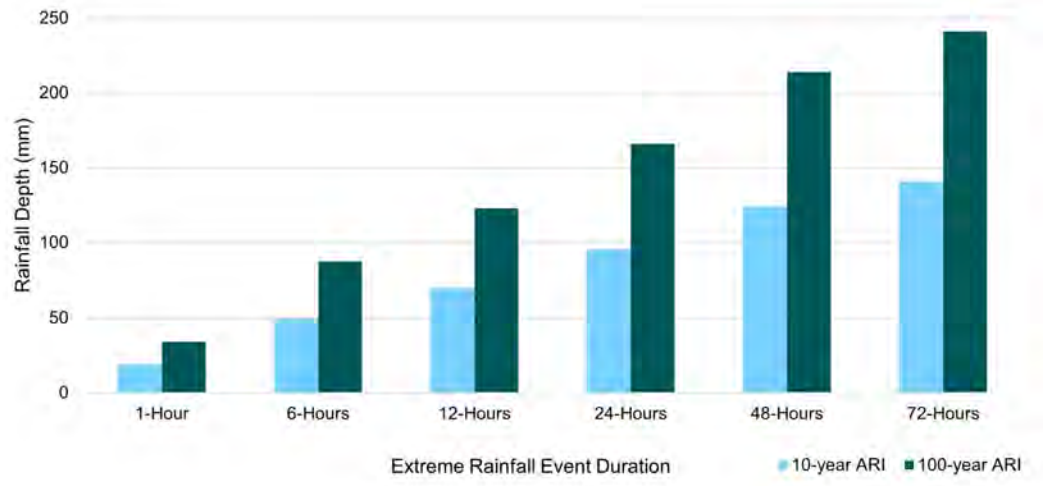


Figure 6: Historic 10-year ARI and 100-year ARI extreme rainfall event depths for 1-hour to 72-hour durations for the Palmerston area. Data sourced from Palmerston rain station, NIWA Cliflo

3.1.6 Flooding

In Te Hakapupu/Pleasant River catchment changes in land-use, land coverage, and catchment hydrology characteristics have increased the exposure to flooding and associated hazards within the catchment. This has included drainage of the large sections of the estuary wetland in the lower catchment and establishment, clearance of forest and scrub landcover for primary production lands in the mid and upper catchment, and later (in the 1990's) establishment of significant plantation forestry operations in the upper catchment.

[6] **Annual Recurrence Interval (ARI):** Extreme rainfall events are often considered in the context of their expected 'return period', known as an Average Recurrence Interval (ARI) (e.g. a 1-in-100-year rainfall event has an ARI 100). This does not mean that an ARI-100 rainfall event will happen regularly every 100-years or will only occur once in 100-years; it refers to the probability of the event occurring in any one year (i.e. 1%)

Significant recorded flood events in the catchment include:

- October 1947 – The Palmerston railyards were flooded to a depth of 0.9m and the main road was flooded in several locations.
- October 1968 – The floodwaters in the branch above Goodwood reached very high levels, flooding at least three houses and all of the Flag Swamp adjacent to Watkin Creek. The severity of flood inundation was attributed to debris build up on the rail bridge.
- July 2022 – A heavy rainfall event across coastal Otago areas, with some areas receiving between 110-150mm of rainfall, forcing the closure of SH1 between Dunedin and Palmerston, shown in figure 7.
- October 2024 – A heavy rainfall event across coastal Otago areas, with some areas receiving between 160-180mm of rainfall, causing numerous land slips along transport routes and forcing the closure of SH1.

While rainfall induced flooding are fundamentally driven by meteorological processes, it is the interaction between the receiving environment and the rainfall event that determines whether the process results in a flood.

Figure 7: Flooding at Big Kuri Creek, north of Hampden, experienced during the July 2022 East and North Otago extreme rainfall event. Source: NZTA

3.1.7 Water quality

Monitoring of water quality has been undertaken since 2021 as part of the Toitū te Hakapupu Pleasant River Catchment Restoration Project to establish baseline information for the catchment and provide a greater understanding of the source and state of water quality issues experienced.

With the geology of the catchment dominated by schist (38%), sandstone (28%), and siltstone (22%), a large proportion of the catchment is vulnerable to erosion. This leads to

the deposition of sediment into the Hakapupu waterways and estuary. These sediment inputs have been raised as a significant issue for water quality within the catchment, with the health of the estuary adversely impacted by sedimentation and nutrient runoff.

Streambank and subsoil erosion are the primary sources of sediment depositing in the waterways, accounting for more than 80% of sediment deposited at most sampled sites. At the catchment outlets, streambank erosion accounted for as much as 98% of deposited sediment (Swales *et al,* 2023).

Figure 8: Suspended sediments being transported within Te Hakapupu / Pleasant River. Source: Peak Geospatial

Following forestry harvesting in Owhakaoho/Trotters Creek sub-catchment, the Owhakaoho/Trotters Creek was observed, contributing a large portion of the long-term suspended sediment loads (~77%) being discharged from the Hakapupu catchment (Swales et al, 2023).

With a significant amount of land use within the Owhakaoho/Trotters Creek sub-catchment being drystock pasture, and exotic production forestry activities increasing in the upper reaches, the disturbance of vegetation cover during a forestry harvest and replanting will likely exacerbate soil erosion in this area (Ahikā Consulting Ltd, 2023). It is likely that other forested sub-catchments would contribute similar if they were harvested as well.

With exotic production forestry being the dominant land use within the catchment, the land use sources of recent sedimentation in waterways suggest that harvest areas have the capability to generate much higher sedimentation than pastoral areas.

Specific proportional yields of topsoil from harvest areas are likely approximately 69 times higher than from pastoral farming crops and activities (Swales *et al,* 2023).

While this NbS Feasibility Study is focused on evaluating solutions for the management of flood hazards, considerations of sediment management are required as part of NbS evaluation to mitigate the effects of sediment during flood events, including reduced optical water quality (i.e., visual clarity, light penetration) and smothering of river floor ecosystems.

3.2 IMPACTS OF CLIMATE CHANGE ON THE CATCHMENT

3.2.1 Temperature

Consistent with climate change projections for coastal Otago, mean annual temperatures are projected to continue to increase over the coming decades under all climate change scenarios, warming by 1.5 – 2.5°C by 2090. This increasing mean temperature will cause an additional increase the number of 'hot days' (>30°C) experienced in the catchment annually and reduce the number of 'frost days' (<0°C) (Macara et al, 2019).

3.2.2 Rainfall

Mean annual rainfall in the catchment is projected to increase under all climate change scenarios, with increases of up to 10-15% in mean annual rainfall expected by 2090 (under RCP 8.5).[7] The greatest mean rainfall increases likely experienced during winter (20-25%), with more moderate increases expected during summer (0-5%).

3.2.3 Sea level rise and coastal inundation

Relative sea-level rise is projected to occur in the coastal areas of the catchment in line with national sea-level rise rates, with minor vertical land movement (0.7± 2.2mm/year) at the estuary mouth, slightly moderating the relative effects experienced locally. 0.21m of relative sea-level rise is projected by 2050 and 0.74m by 2100 (under scenario SSP5-8.5 50th percentile). Consequently, the Te Hakapupu/Pleasant River estuary wetland complex is highly likely to be exposed to increasing salinity stress and from the effects of more frequent and intense coastal storm surges flooding further inland areas.

Areas at exposure to the future effects of coastal inundation during storm surge events include properties currently adjacent to the existing estuary as shown in flooding zones / hazard zones on Map 6.

3.2.4 Extreme rainfall events

A warmer atmosphere can hold more moisture, therefore extreme rainfall events are projected to increase in frequency and intensity with continued global warming. Following national trends, extreme rainfall events are projected to increase within the catchment in the coming decades.

Under best-case (RCP 2.6), mid-range (RCP 4.5), and hot-house (RCP 8.5) climate change scenarios, extreme rainfall events in the catchment are projected to increase in the coming decades, with the depth extreme rainfall expected to be more severe with higher levels of global warming. This change has the dual effect of increasing the physical depth of rainfall experienced during an extreme rainfall event and increasing the frequency of historic extreme rainfall events reoccurring.

[7] **Representative Concentration Pathways (RCPs):** Future climate change projections are considered under four emission scenarios, called Representative Concentration Pathways (RCPs) by the IPCC, based on future greenhouse gas concentrations, determined by economic, political and social developments during the 21st century. RCP8.5 is a 'business as usual' scenario with greenhouse gas emissions continuing at current rates

For example, under RCP 8.5 climate change scenario:

- A 100-year ARI 24-hour extreme rainfall event is projected to increase in depth from 166mm to 203mm by 2090 (i.e. increase in rainfall intensity) (Figure 6)
- The 166mm of rainfall historically expected during a 100-year ARI 24-hour event, is projected to be received during a 40-year ARI 24-hour event by 2090 (i.e. increase in the perceived frequency of historic events) (Figure 10)

The graph displayed in Figure 9 shows the projected increase in extreme rainfall depths under a hot-house (RCP 8.5) climate change scenario.

In the context of past extreme rainfall events experienced within the catchment, under a hot-house (RCP 8.5) climate change scenario, the annual reoccurrence interval of an extreme rainfall event, similar in magnitude to the flooding events of July 2022, would likely be approximately 10-years (i.e. 10% chance of occurring each year) by 2090 (NIWA HIRDS v4).

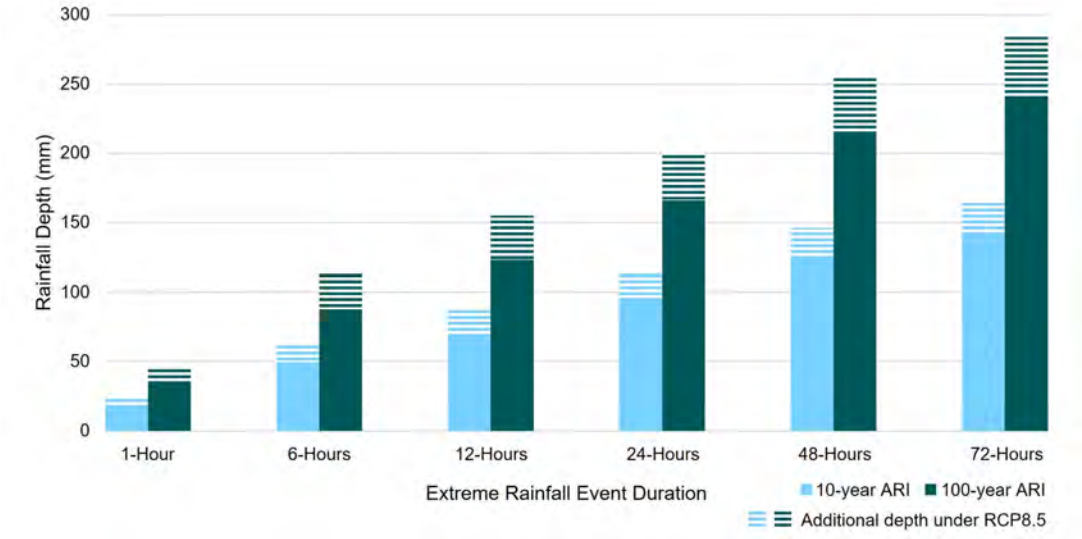
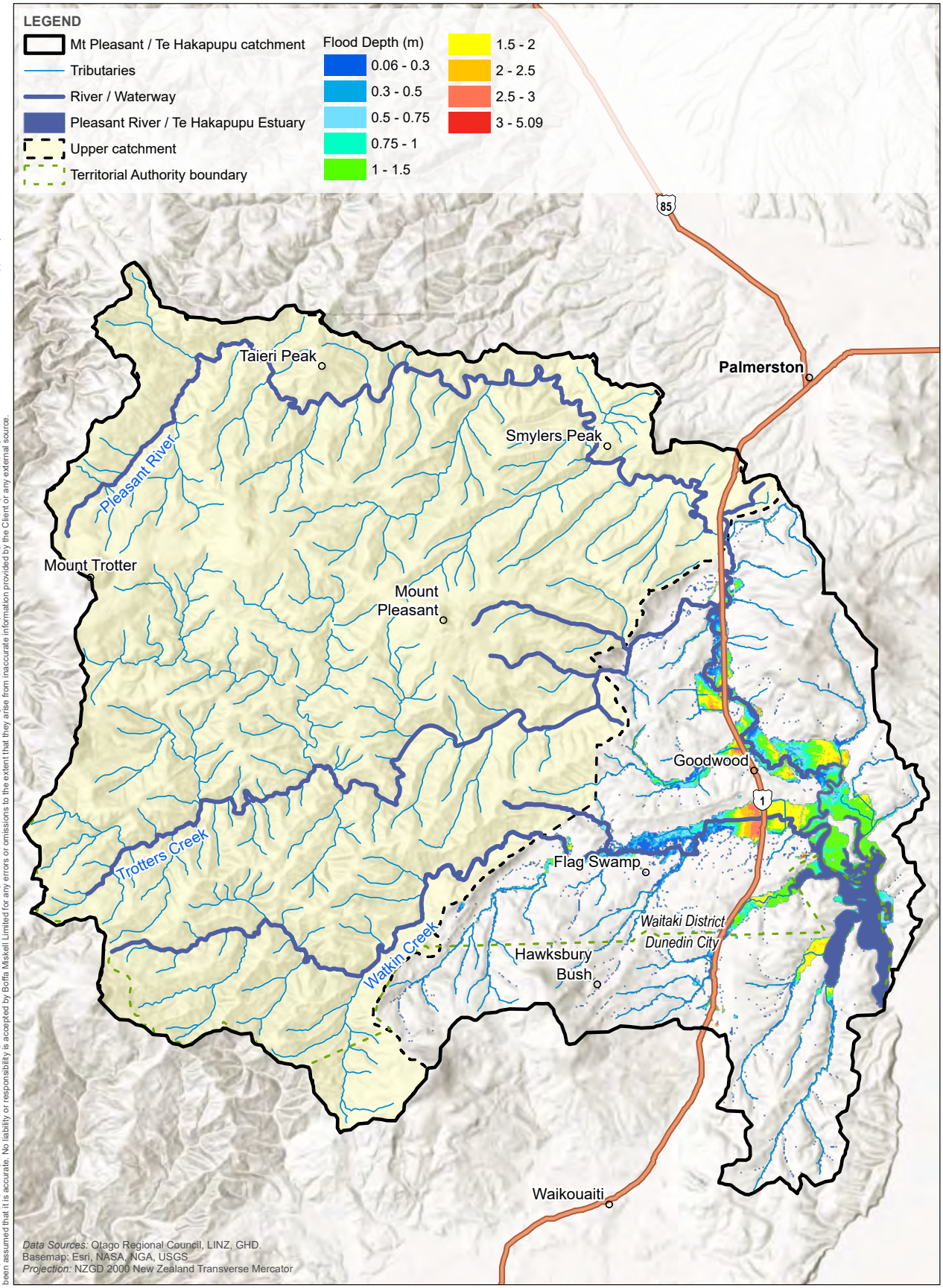


Figure 9: The projected additional rainfall depth (stripe bars) expected under climate change for historic 10-year ARI and 100-year ARI extreme rainfall event depths for 1-hour to 72-hour durations (solid bars). Data sourced from NIWA HIRDs database for climate change scenario RCP 8.5 at 2090

3.2.5 Extreme rainfall event induced flooding

Based on the Rapid Flood Hazard Modelling (RHFM) of the catchment, extreme rainfall event induced flooding is expected to exhibit similar behaviours to that observed during previous flood events.

The modelled flood characteristics that would occur in the catchment during a 100-year ARI 24-hour extreme rainfall event, under RCP 8.5, are shown in Map 6 (Flood Depth) and Map 7 (Flood Velocity). During extreme rainfall events, flood waters are modelled to flow down the upper and mid-catchment relatively swiftly, slowing as they approach the northern and western extent of the existing Te Hakapupu/Pleasant River estuary wetland complex. Surface flooding would commonly range from 0.5m to over 2.0m and is likely to occur in areas bordering the existing wetland, where lands have been historically drained and reclaimed for agricultural purposes.



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

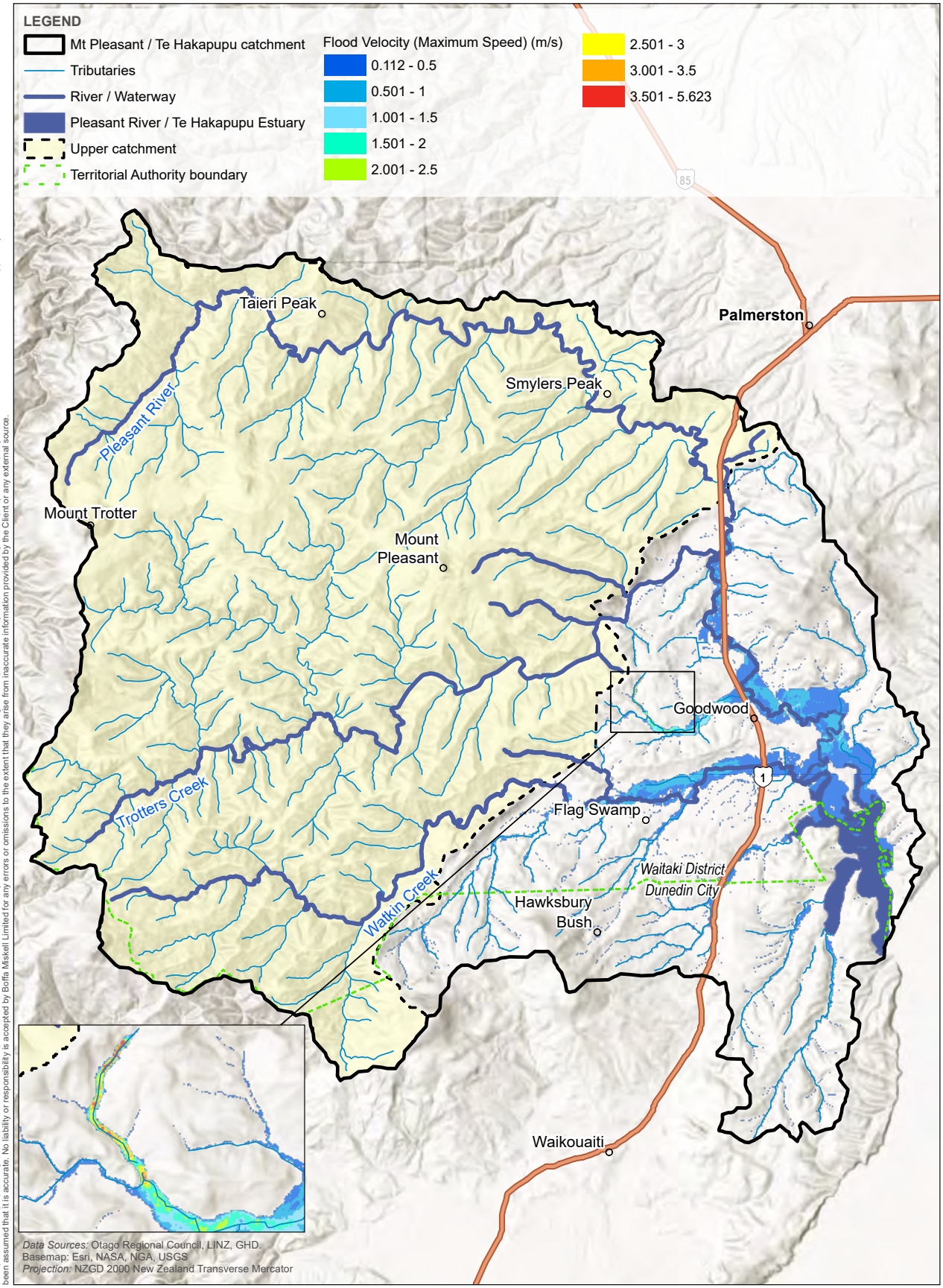
Flood Depth

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 6



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Data Sources: Otago Regional Council, LINZ, GHD.
Basemap: Esri, NASA, NGA, USGS
Projection: NZGD 2000 New Zealand Transverse Mercator

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

Flood Velocity

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 7

3.3 STATUTORY & POLICY CONTEXT

To further assist with understanding the potential application of NbS within the catchment and across the wider Otago Region, an initial high-level review of the regional and local statutory and policy context was undertaken. This helps to identify any consenting and/or regulatory opportunities and challenges that would need to be considered. For more information on the statutory and policy context applicable to the use of NbS in Te Hakapupu/Pleasant River Catchment, see Appendix 6 or visit the ORC website.

3.3.1 Regional plans

The Te Hakapupu/Pleasant River catchment is within the Otago region and therefore is subject to the provisions of the Otago Regional Policy Statement 2019 (RPS), Otago Regional Policy Statement 2021 (pORPS) and the Otago Regional Plan: Water 2004 (ORPW).

3.3.2 Otago Regional Policy Statement

The Otago Regional Policy Statement 2019 (ORPS) and its update, the proposed Otago Regional Policy Statement 2021 (pORPS), provide the strategic framework for managing natural and physical resources across the Otago region.

The ORPS sets out objectives and policies to address key environmental issues, including freshwater management, biodiversity, climate change, and sustainable development. The pORPS, currently under development, builds on the ORPS by refining and updating policies to align with new national directives, such as the National Policy Statement for Freshwater Management 2020 (NPS-FM). The policies reflect a strong commitment to Te Mana o Te Wai, and highlight the relationship of Kai Tahu with water, prioritising the importance of the health and well-being of water bodies to ecosystems and communities.

The ORPS and the pORPS enable the integration of Nature-based Solutions (NbS) into freshwater management by promoting approaches like wetland restoration, riparian planting, and natural flood management to address environmental challenges such as sedimentation, nutrient runoff, and biodiversity loss.

3.3.3 Otago Regional Water Plan

The Otago Regional Plan: Water 2004 (ORPW) is currently the primary regulatory regional document for managing activities affecting freshwater in Otago. A replacement draft Land and Water Regional Plan (LWRP) for the Otago region has been developed but as of January 2025 isn't operative.

Rules in the ORPW that are particularly relevant to the NbS include those that relate to:

- The take, use and management of water, and the management of discharges.
- Land use on lake or riverbeds, or within Regionally Significant Wetlands, specifically:
    - Alternation of the bed of a river or a Regionally Significant Wetland.
    - The introduction or planting of vegetation; and
    - The removal of vegetation
- Other land use activities including structures on the margins of lakes and rivers.

3.3.3 North Otago Freshwater Management Unit

The North Otago Freshwater Management Unit (FMU) is a defined area under the proposed ORPS (pORPS), and the draft Land and Water Regional Plan (LWRP). It serves as a framework for sustainable freshwater management, with objectives tailored to environmental, cultural, and community needs. Te Hakapupu/Pleasant River catchment is within the North Otago FMU.

Figure 10: North Otago Freshwater Management Unit (FMU) (Source Otago Regional Council)

The proposed vision for the North Otago FMU by 2050 is summarised below:

I. **Freshwater Management**:

- Freshwater resources are managed in alignment with Te Mana o te Wai, ensuring that the health and well-being of water bodies are prioritised.
- Acknowledges that the Waitaki River is influenced by catchment areas within the neighbouring Canterbury region.

II. **Ecosystem Health**:

- Healthy riparian margins, wetlands, estuaries, and lagoons are restored and maintained, supporting vibrant indigenous habitats, and enhancing downstream coastal ecosystems.

III. Sustainable and Resilient Practices:

- Encourages innovative and sustainable land and water management practices to support food production and improve resilience to the effects of climate change.

As currently drafted, the North Otago FMU provides an indication of the ORC's intended approach to freshwater management in Te Hakapupu/Pleasant River catchment and a practical framework for incorporating NbS into freshwater management practices by promoting initiatives such as wetland restoration, riparian planting, and the use of natural processes to improve water quality.

3.3.4 District Plans

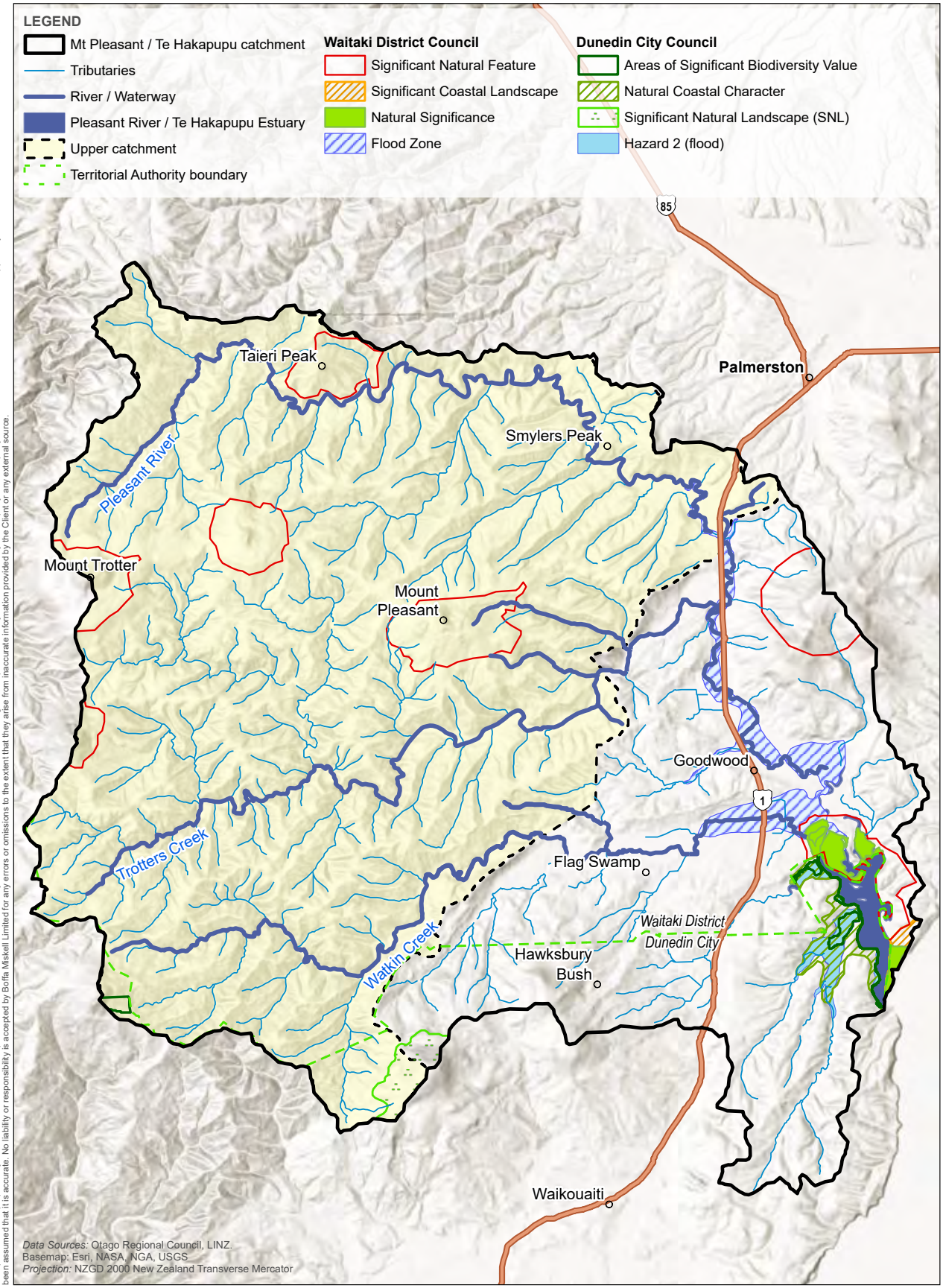
Te Hakapupu/Pleasant River catchment is mostly within the jurisdiction of the Waitaki District Council, apart from an area to the south of the estuary and part of Mt Watkin that fall in the jurisdiction of the Dunedin City Council.

The Waitaki District Plan and the Dunedin 2nd Generation District Plan are therefore the relevant district plans.

Within the Waitaki District, the catchment is largely within the rural zone, with some inland areas within the 'rural scenic' zone. Catchment areas within the Dunedin District Plan are also largely within the rural zone, except for a small rural residential area to the south of the Te Hakapupu/Pleasant River estuary. Both the Dunedin District Plan and the Waitaki District Plan identifies the estuary and surrounding wetland as areas of natural significance, with significant coastal and natural landscapes and features. The estuary and wetlands are also identified as flood hazard zones.

3.3.5 Kāi Tahu ki Otago Natural Resources Management Plan 2005

Policies in the Kāi Tahu ki Otago Natural Resources Management Plan 2005 (NRMP) express the cultural importance of water to Kāi Tahu and the importance of protecting and restoring the mauri of all water. The policies cover the protection and enhancement of existing wetlands as well as the reinstatement of wetlands that have been neglected.



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

Dunedin City and Waitaki District Plans

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 8

WHICH
NATURE-BASED
SOLUTIONS
ARE MOST SUITED
IN THE CATCHMENT?
Credit: Peak Geospatial

4. WHICH NATURE BASED SOLUTIONS ARE MOST SUITED IN THE CATCHMENT?

To assess how feasible the use of NbS are for the management of flooding and associated hazards in Te Hakapupu/Pleasant River catchment, three catchment specific NbS interventions were developed. With reference to the different types of NbS for flood management assessed in the recent NIWA literature review (NIWA, 2024), NbS interventions were considered for upper, middle, and lower catchment locations.

The three NbS considered most suited to the catchments environmental, social, and economic context are:

- Landcover management
- River and stream naturalisation
- Wetland enhancement and construction

These three NbS were developed based upon NbS best practice insights gathered through literature review and SWOT analysis discussions, hydrology modelling of the catchment during flood events, and the catchment's specific environmental characteristics.

Whilst targeted towards the management of how flood events are modelled to behave in the catchment, the NbS also seek to acknowledge the wider environmental challenges present in the catchment. These include the water quality challenges associated with streambank erosion and sedimentation, and the projected effects of sea-level rise and coastal storm surge inundation.

Additionally, the three NbS were developed with reference to the potential nature-based opportunities possible in the catchment. With reference to the Toitū Te Hakapupu Catchment Action Plan (CAP) (Ahikā, 2023), the NbS seek to contribute to the identified catchment restoration values. These include the enhancement of the natural functioning of the highly valued estuary wetland complex, with a focus on mahika kai and taonga species.

NbS interventions, such as bioretention systems, were not tested within the catchment. Whist contributing to flood management outcomes, these interventions were deemed impractical given the large scale and water quality pressures experienced in the catchment. Other related interventions, such as sedimentation ponds, were not considered in this feasibility study as they do not meet the definition of benefit requirements of NbS.

The below section describes the key characteristic of the three types of NbS that are considered in this feasibility study and outlines how they could conceptually be applied to the catchment environment. The outcomes of how the NbS were tested to performed in the catchment is detailed in section 5.

4.1 LANDCOVER MANAGEMENT

4.1.1 What is landcover management?

Landcover management is the practice of gradually transitioning areas of exposed clear-fell exotic plantation forestry to permanent indigenous forests work to manage flood hazards. This practice helps to moderate water yield and flows within a catchment, whilst avoiding the 'window of vulnerability' prompted by harvest cycles.

The "window of vulnerability" is a high-risk period that lasts for about eight years following the harvesting of a forest. During this time, the newly replanted trees have not yet grown enough to develop a full canopy or strong root systems capable of stabilising the soil and preventing sediment loss. Extreme rainfall events often increase the risk of sediment loss and flooding. Without tree cover and strong roots to hold the soil, more water flows downhill, carrying fine sediments and woody debris into lower areas.

Within Te Hakapupu/Pleasant River catchment, exotic plantation forestry is the most widespread single land use (~49%), predominantly situated in the steeper upper catchment. During an extreme rainfall event, sediment washing into waterways presents one of the greatest flood-related risks in the catchment. During flood events, sediment deposited in the riverbed, reduces the volumetric capacity of waterways. Sediment becoming dislodged from the riverbed and being washed down during floods is leading to sediment inundation of lower catchment freshwater and estuarine habitats.

These hazards associated with flooding are likely to be exacerbated during forestry harvest and replanting. Two major 'pulses' of forestry harvest are expected in the catchment over the coming decades (Map 10):

- The first harvest pulse occurring between present-day and 2028, covering approximately 33% of the catchment forestry estate.
- The second harvest pulse occurring from 2042 to 2049 covering approximately 40% of the catchment forestry estate.

Accordingly, the land exposed during the projected 'windows of vulnerability' is approximately 1,500 ha each year between 2024 – 2032, then larger again from 2042, to peak at over 2,500 ha per year (Ahikā, 2024).

4.1.2 How can landcover management work as a NbS?

Landcover management in Te Hakapupu/Pleasant River catchment will seek to restore and expand existing pockets of remnant indigenous forest, towards the gradual transition of large areas to permanent indigenous forest in vulnerable upper sub-catchment locations. Upper sub-catchment areas are shown in Map 9. With reference to the remnant indigenous forest ecosystems identified in Map 4, these areas will be prioritised for targeted pest control, maintenance, and planting to grow the extent of these areas and support natural regeneration.

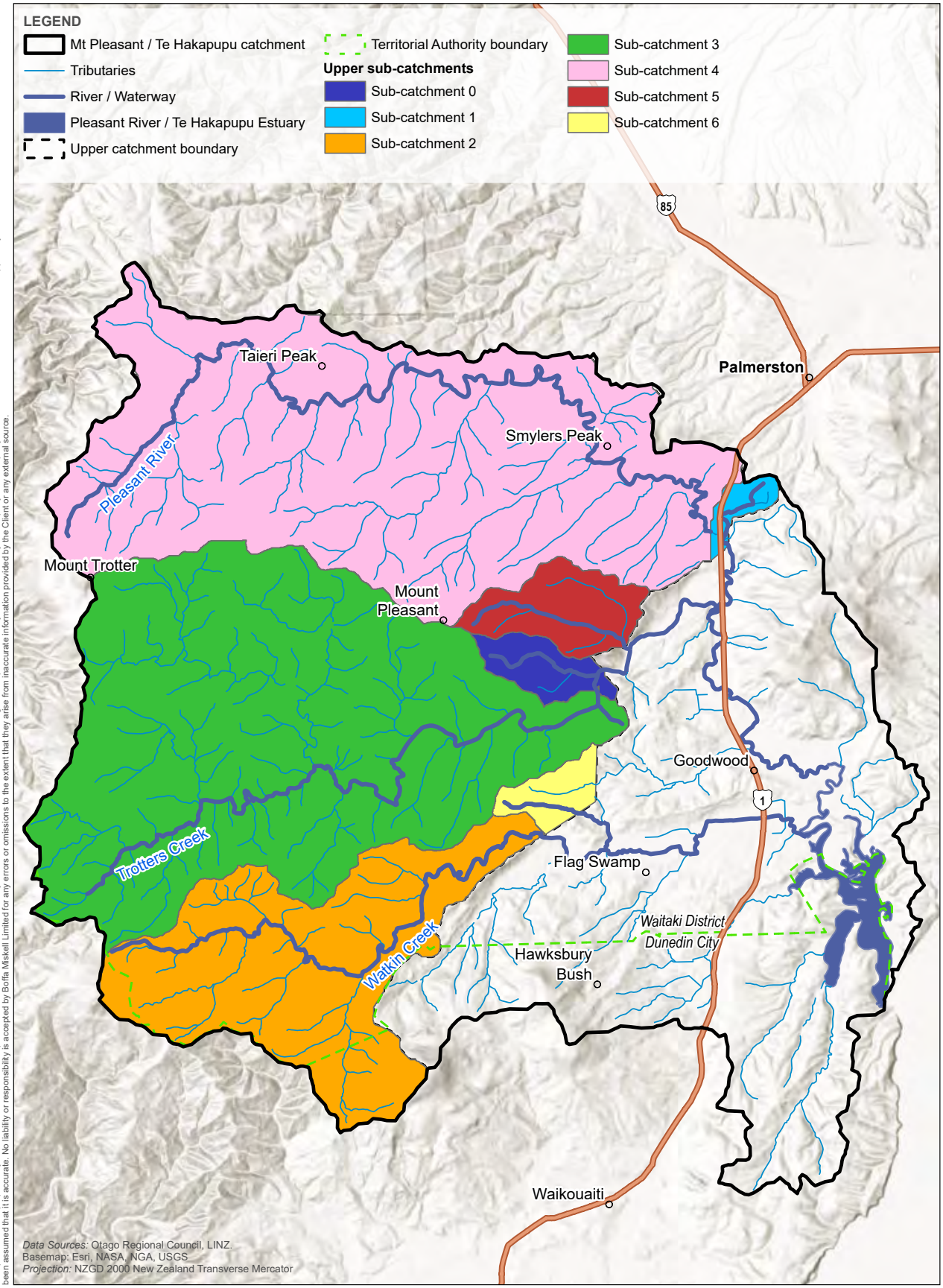
This approach will manage the impacts of flooding and associated hazards in the catchment through restoring and permanently retaining upper catchment forested land cover in vulnerable areas (e.g. on erosion prone slopes and in vicinity of waterways).

With the effects of climate change projected to increase the frequency and intensity of extreme rainfall events across Otago, this NbS would avoid exacerbating an already significant flood-related risk by eliminating the reoccurring ‘windows of vulnerability’ over future generations. By restoring indigenous forest across large areas and permanently retaining forested land coverage, the landcover management approach aims to safeguard the hydrology of the upper catchment to effectively buffer against the effects of extreme rainfall events

Plantation forestry within the Hakapupu Catchment is predominately contained within the upper catchment. Presently, there are 23 individual owners, of which four main forestry companies manage the vast majority of the planted area (Calder Stewart, Ngāi Tahu, PF Olsen, and Wenita). Aligning with existing harvest projections and replanting timeframes, this approach would require a long-term transition of upper catchment areas.[8]

Figure 11: Indigenous remnant forest area within pine forestry. Source: Pure Advantage

[8] While coupe harvest systems are being considered through the Te Hakapupu Forestry Action Plan as a practical solution to mitigate risks associated with harvest and replanting, this approach is not considered a NbS and is therefore excluded from this NbS feasibility study.



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

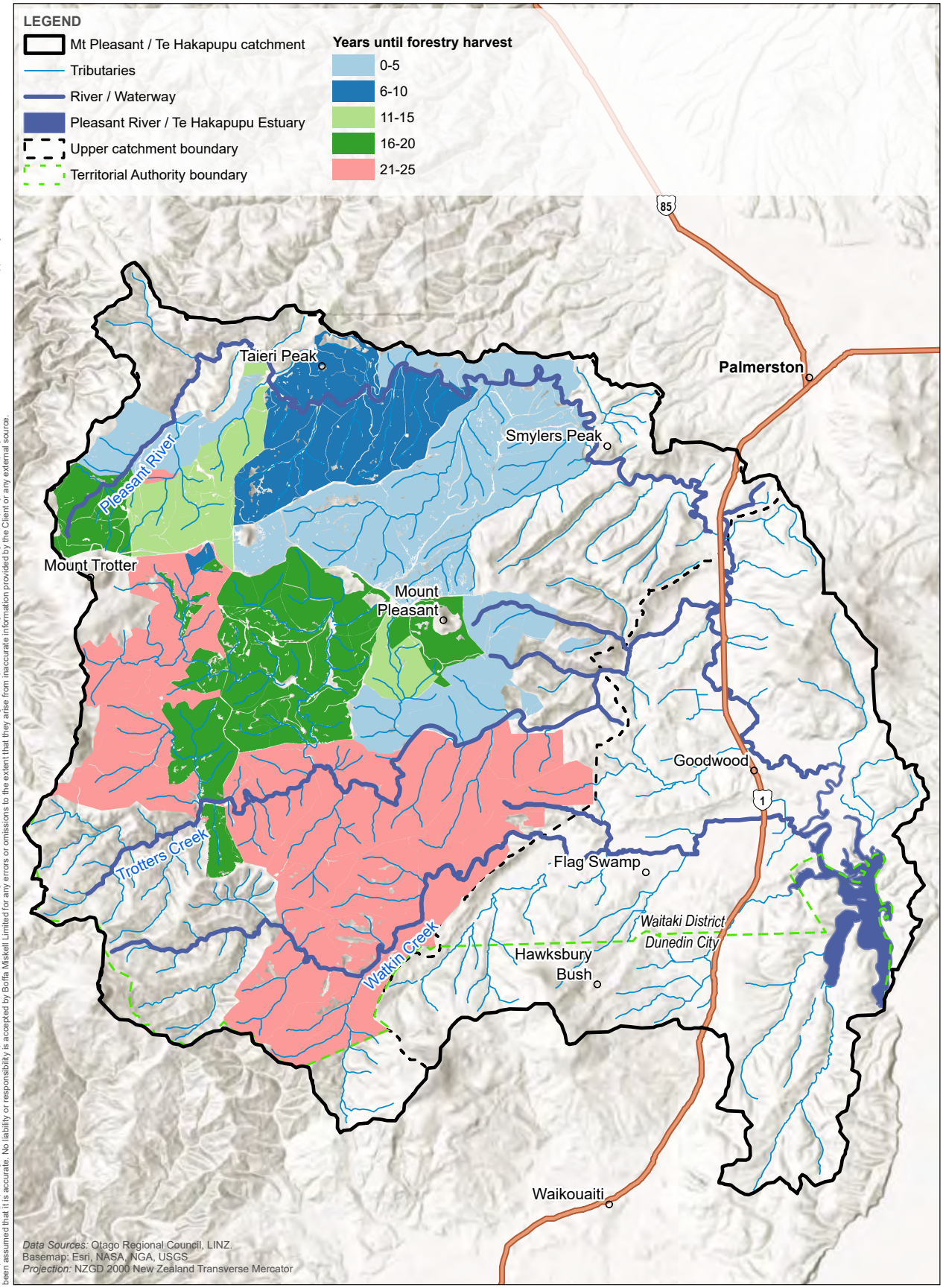
Catchment Map

Date: 06 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 9



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

Forestry Harvest Timing

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 10

4.2 RIVER & STREAM NATURALISATION

4.2.1 What is river and stream naturalisation?

River and stream naturalisation, includes:

- restoration of riparian vegetation (riparian buffers)
- 'making room for the river'
- reconnecting isolated or drained off-stream wetland areas
- works to mitigate flood hazards through intercepting contaminants entering the waterway during extreme rainfall events
- slowing peak flows
- stabilising banks to reduce erosion

Riparian buffers provide room for the natural dynamics of a waterway to function during extreme rainfall events. This includes accommodating the rise and fall of water levels, helping to slow down the velocity of peak flows, increasing water retention and infiltration, and reducing streambank erosion and thus the potential effects of associated downstream flood impacts (e.g., sediment inundation and water contamination).

Whilst channelisation of waterways is not as severe as other more hydraulicly modified catchments in the Otago Region, the main tributaries of the Te Hakapupu / Pleasant River, Watkin Creek, and parts of Owhakaoho / Trotters Creek in the mid-catchment currently have relatively bare, unvegetated riparian margins. As a result, these unvegetated, well entrenched channels facilitate fast peak flood flow velocities up to 5 m/s during an extreme rainfall event. With little riparian vegetation to protect stream banks, stream bank erosion accounts for as much as 98% of deposited sediment at the catchment outlets to the Hakapupu Pleasant River Estuary Wetland Complex (Swales *et al,* 2023).

Te Toitū Te Hakapupu partnership project has undertaken considerable restoration of riparian areas in the lower catchment in recent years, including 27km of fencing and almost 68,000 plantings. However, large sections of waterways throughout the Hakapupu catchment remain 'denaturalised' as farming land uses has constrained natural waterways and riparian corridors into more uniform, deeper channels to improve farm management.

Additionally, as waterways have become increasingly 'denaturalised', small adjoining tributaries and off-stream wetland areas that provide important spawning habitat for freshwater species, and help retain water during dry periods, have become piped or cut off from the main channel. Consequently, during extreme rainfall events, flood waters tend to flow at faster velocities through the main tributaries of Te Hakapupu / Pleasant River, Owhakaoho / Trotters Creek, and Watkin Creek. This causes surface flooding of low-lying areas in the lower catchment and allows for the rapid transport of sediment and other contaminants from the upper catchment into the vulnerable estuary wetland complex.

4.2.2 How can river and stream naturalisation work as a NbS?

Undertaking river and stream naturalisation, in the catchment, such as along Te Hakapupu/Pleasant River, Owhakaoho/Trotters Creek, and Watkin Creek, aims to reduce flooding hazards by restoring the natural hydrodynamics of the waterways. Naturalisation helps to slow down peak water flow speeds and increases the rivers' natural capacity to absorb and redirect water during heavy rainfall events.

A healthy vegetated riparian area helps protect the banks from erosion and act as a buffer between land and water, filtering sediments and contaminants from runoff. They also serve to shade waterways, regulating temperatures, minimising algae growth, and provide for in-stream habitat.

With increases in hot days (>30°C) projected to occur in the catchment with climate change, a healthy riparian area can play a critical role in mitigating the potential effects of direct warming and heat contamination in freshwater environments that may occur during an extreme rainfall event in future.

Figure 12: Naturalisation of a previously channelised waterway, including daylighting piped tributaries, restoring riparian buffer vegetation and re-meandering waterway. Source: Boffa Miskell Ltd.

4.3 WETLAND RESTORATION & CONSTRUCTION

4.3.1 What is wetland restoration and construction?

Wetland restoration and construction works to intercept, accommodate, and process excess floodwaters flowing down the catchment during an extreme rainfall event. Through restoring or constructing natural wetland features, such as deep sedimentation ponds or shallow water vegetated areas, wetlands can detain large volumes of water and remove contaminants including suspended sediments and nitrates.

To successfully accommodate flood flows and significantly reduce contaminant load in runoff, as a rule constructed wetlands need to be between 1% and 5% of their contributing catchment size (Tanner *et al,* 2021). Wetlands smaller than this scale will be frequently overwhelmed by flood flows and provide insufficient time to enable contaminant reduction. This 1% to 5% wetland size refers to the actual 'wetted' area under normal flow conditions, this does not include the additional areas required for marginal planting and landscape modification.

Te Hakapupu/Pleasant River estuary wetland complex is a critical receiving environment within the catchment. However, classified as a Naturally Uncommon Ecosystem and vulnerable due to its historic reduction in size and ecological decline, the estuary wetland complex faces numerous pressures including invasion from invasive weed species, grazing of remaining wetland areas, and alteration of natural flow characteristics (Holdaway *et al.,* 2012).

Te Hakapupu/Pleasant River Estuary Wetland Complex currently covers approx. 84 hectares (~0.6% of the catchment) following significant historical drainage. Consequently, the current extent of the wetland area limits its natural ability to accommodate flood water during extreme rainfall events, causing flooding of homes, productive agricultural lands, and associated infrastructure located on reclaimed land. Additionally, the reduced wetland extent limits the assimilative capacity of the wetland, driving the high sediment mud content with the estuary.

4.3.2 How can wetland restoration and construction work as a NbS?

Surface-flow constructed wetlands are used nationally and internationally to collect, treat, and store stormwater runoff. By providing storage volume space to accommodate flood flows and vegetative resistance to slow flood flows, constructed and restored wetland areas can buffer the impacts of flood flows entering into important habitats and ecosystems, and prevent damage and disruption to surrounding land uses and infrastructure.

Plausible locations for wetland restoration and construction have been considered at the northern and western extent of the existing wetland complex. Located on reclaimed areas, these low-lying locations occupy the most flood prone areas within the lower catchment and are modelled to receive between 1.5m – 3m flood depths outside of the existing channel during an extreme rainfall event. Flood water tends to move at slower velocities within these areas as shown in Map 8.

Various locations across the mid and upper catchment also lend themselves to construction or restoration of both on-stream and off-stream wetlands and sediment detention ponds (as identified in the Catchment Action Plan, 2024). Whilst these add value to flood hazard

mitigation across the catchment, restoration of the historically reclaimed estuary wetland complex is considered to provide the greatest biodiversity benefits and flood mitigation capacity.

Additionally, along with accommodating rainfall induced flood flows, the identified lower catchment wetland locations can act as a buffer for properties and assets potentially exposed to the future effects of coastal inundation from sea-level rise. Following late-century climate change projections (2090), these locations are projected to be exposed to inundation events from both extreme rainfall induced flooding and coastal storm surge.

By locating surface flow wetlands within these lower catchment areas, this NbS seeks to work with the existing landscape to effectively accommodate flood waters, mitigating the impacts of a flood event.

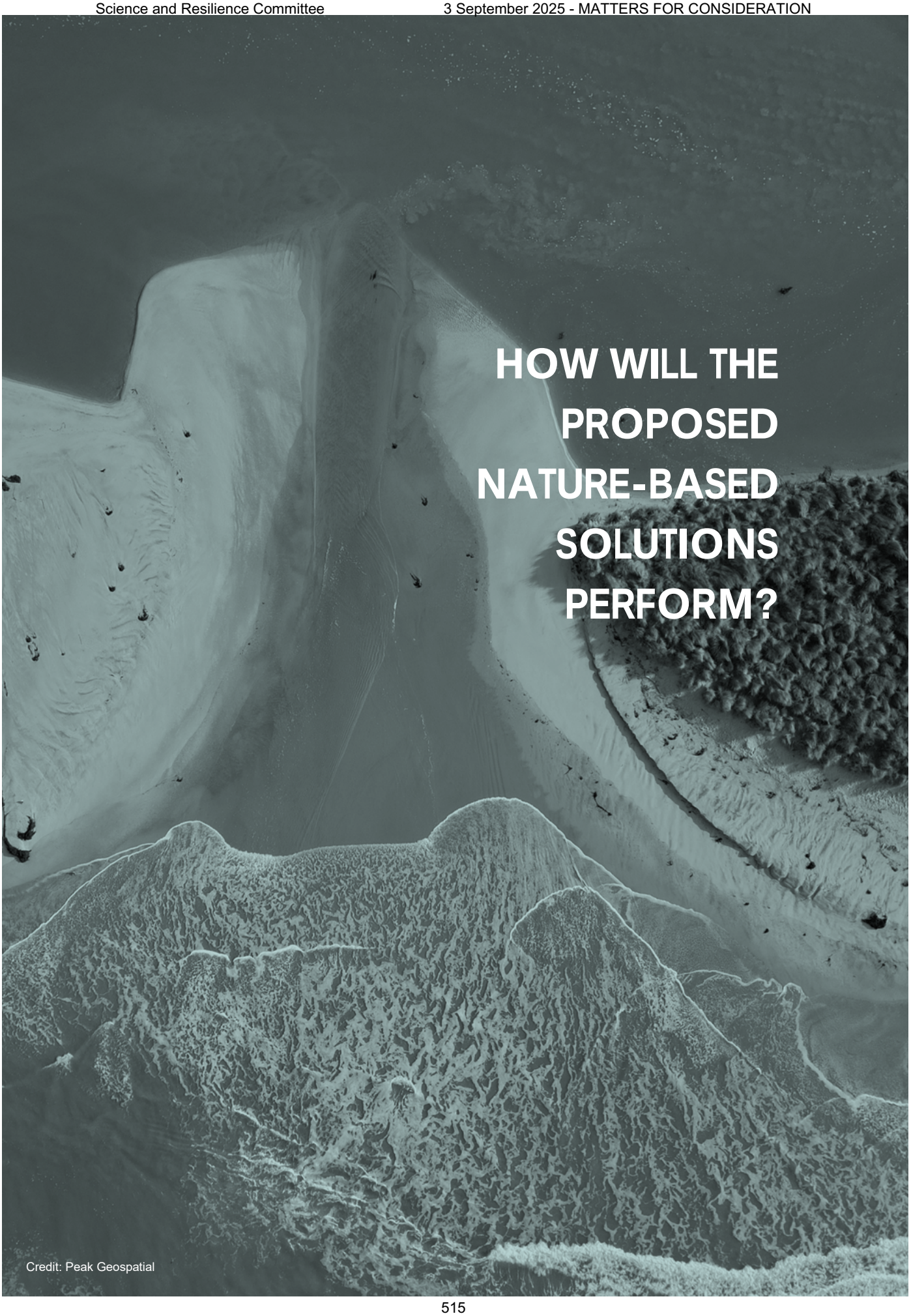
Figure 13: Construction of a wetland in Thomsons catchment, Otago. Source: Manuherekia Catchment Group

4.4 OVERVIEW OF NATURE-BASED SOLUTIONS FOR TE HAKAPUPU/PLEASANT RIVER CATCHMENT

Table 3: Overview of the three NbS interventions that are tested in Te Hakapupu/Pleasant River catchment

	1. LANDCOVER MANAGEMENT	2. RIVER AND STREAM NATURALISATION	3. WETLAND RESTORATION AND CONSTRUCTION
FLOOD HAZARD MANAGEMENT TYPE	The landcover management NbS approach seeks to manage flood hazards through: a. Protection of lower catchment areas from flood flows and flood-related impacts of sediment mobilisation and debris flows through permanently retaining water yield moderation and stabilising steeper surfaces. b. Avoidance of 'windows of vulnerability' prompted by ongoing plantation forestry harvest and replanting cycles.	The river and stream naturalisation NbS approach seeks to manage flood hazards through: a. Mitigation of surface flooding through the slowing of peak flood flows by increasing water retention and allowing for runoff infiltration. b. Accommodation of additional flood waters during extreme rainfall events through possible increases in volumetric capacity of the river channel. c. Protection of vulnerable ecological and mahika kai values within the Te Hakapupu/Pleasant River catchment through the interception of runoff contaminants and mitigation of streambank erosion.	The wetland restoration and construction NbS seeks to manage flood hazards through: a. Managed retreat of built infrastructure and primary production land used away from flood prone areas b. Accommodation of excess slow moving flood waters during extreme rainfall events in increased water retention areas c. Protection of vulnerable ecological and mahika kai values within the Te Hakapupu/Pleasant River estuary wetland complex through the interception and treatment of suspended sediments and other contaminants
SCALE	Expansion of remnant indigenous forest areas overtime, planned in alignment with projected forestry harvest events to cover large upper sub-catchment areas.	River and stream naturalisation length to span the unvegetated areas of all three waterways of the mid-catchment Te Hakapupu/Pleasant River corridor, the mid-catchment Owhakaoho / Trotters Creek corridor, the mid-catchment Watkin Creek corridor.	New wetland restoration and construction area cumulatively spanning approx. 140 ha. Resulting in total catchment wetland area exceeding 1.75% total catchment size.
KEY CHARACTERISTICS	For existing pockets of remnant indigenous forest areas within the plantation forest estate, restoration and enhancement work would support connecting existing remanent bush and create new areas that can act as seed sources for large scale transition to native forest and other catchment restoration activities, such as riparian buffer area planting. For large scale transition of areas of plantation forestry to permanent indigenous forest, restoration activities would align with existing harvest timeframes. Locally sourced indigenous species would be used for planting, with preference to hardy, fast growing species that meet Emission Trading Scheme requirements (i.e., 5 m canopy).	For restoration of riparian buffer areas, given the relatively flat to undulating topography of the mid-catchment areas, at minimum a 3 m fenced setback is considered for the identified waterways in alignment with National Environmental Standards for Freshwater. Additionally, livestock will be fenced for exclusion from the riparian area and structures identified as High Risk and Very High Risk to fish passage removed or remediated. Through river and stream naturalisation, detached and degraded oxbow sections of waterways / off-stream wetland areas will be reconnected to provide additional water retention capacity and important fish spawning habitat. Riparian buffer areas will be planted with native sedge and rush species in lower wet stream banks, surrounded by hardy riparian species such as Carex and harakeke species on embankments and tall tree species along the corridor proximity.	Given the challenges with Te Hakapupu catchment faces with water quality, particularly sedimentation transported from upper catchment plantation forestry areas during heavy rainfall events, wetland inflow locations will be constructed with deeper sedimentation ponds (1-1.5m deep and 20% of immediate wetland area) at inlet to intercept and store suspended sediments. While also providing increased water retention and detention capabilities during flood events, these sedimentation ponds will support the prevention of sediment deposition that could adversely impact the vegetated areas of the main wetland and could be transported into the lower estuarine environment. Wetland areas will be planted with native wetland sedge and bulrush species in shallow zones, surrounded by hardy riparian species on embankments and riparian margins.
POSSIBLE CATCHMENT APPLICATIONS	Restoration and expansion of existing pockets of remnant indigenous forest, towards the gradual conversion to wide-scale permanent indigenous forest to occur across vulnerable upper sub-catchment areas, covering Te Hakapupu / Pleasant River, Owhakaoho / Trotters Creek, and Watkin Creek sub-catchments	Te Hakapupu/Pleasant River and Watkin Creek naturalisation proposed to occur along the majority of its mid-catchment length. The Owhakaoho / Trotters Creek naturalisation proposed to occur in the upper-mid-catchment section, west of Wairunga.	Wetland restoration and construction is proposed at the western and northern extent of the present-day estuary wetland complex, located at the confluence of Watkin Creek and the wetland, and following Te Hakapupu/Pleasant River northwest.

1
2
3


HOW WILL THE PROPOSED NATURE-BASED SOLUTIONS PERFORM?
Credit: Peak Geospatial

5. HOW WILL THE PROPOSED NBS PERFORM?

Using the functional criteria and relevant performance indicators from the NbS Technical Specification, the following evaluation criterion was applied to each NbS intervention to test the opportunities, challenges, and possible benefits of its use for flood hazard management in Te Hakapupu/Pleasant River catchment.

Table 4: Evaluation criteria for Te Hakapupu NbS Feasibility Study in relation to IUCN Global Standards for Nature-based Solutions relevant functional criterion and performance indicators

	TECHNICAL CRITERION	PERFORMANCE INDICATORS	EVALUATION CRITERION
HAZARD	Nature-based Solutions effectively address societal challenges	The societal challenges addressed are clearly understood and documented	How does the NbS contribute to flood hazard management in the catchment?
LANDSCAPE	Design of Nature-based Solutions is informed by scale	The design of the NbS is integrated with other complementary interventions and seeks synergies across sectors	How does the NbS contribute to landscape amenity value, character, and recreation opportunities?
BIODIVERSITY	Nature-based Solutions result in a net-gain to biodiversity and ecosystem integrity	The NbS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss	What are the potential biodiversity benefits, challenges, and practicalities of the NbS in the catchment?
		Opportunities to enhance ecosystem integrity and connectivity are identified and incorporated into the NbS strategy	
ECONOMIC	Nature-based Solutions are economically viable	Cost-effectiveness is considered to support the choice of NbS	What are the high-level costs of the establishment and maintenance of the NbS in the catchment?
COMMUNITY & CULTURE	Nature-based Solutions equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits	The potential costs and benefits of associated trade-offs of the NbS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions	What are the potential impacts, benefits, and trade-offs the NbS may have in the catchment, alongside productive rural land uses and as part of Kāti Huirapa ki Puketeraki's takiwā?
CLIMATE	Nature-based Solutions are managed adaptively, based on evidence	A framework that enables adaptive management us applied throughout the intervention lifecycle	How does the NbS adapt to and/or help mitigate the effects of climate change in the catchment?
REGULATORY	NbS are sustainable and mainstreamed within an appropriate jurisdictional context	The NbS is informed by the facilitating policy and regulation frameworks to support its uptake and mainstreaming	Is the NbS consistent with consenting requirements and key legal or policy considerations? (e.g. land ownership, NPSFM, NESFW, NESPF, RPS, District Plan)

5.1 LANDCOVER MANAGEMENT

Landcover management will focus on the expansion of remnant indigenous forest pockets in upper sub-catchment areas, towards the gradual transition from clear fell plantation forestry to permanent indigenous forest in vulnerable locations. This NbS approach would seek to mitigate the effects of extreme rainfall induced flood through permanently restoring the natural hydrology in vulnerable upper sub-catchment areas.

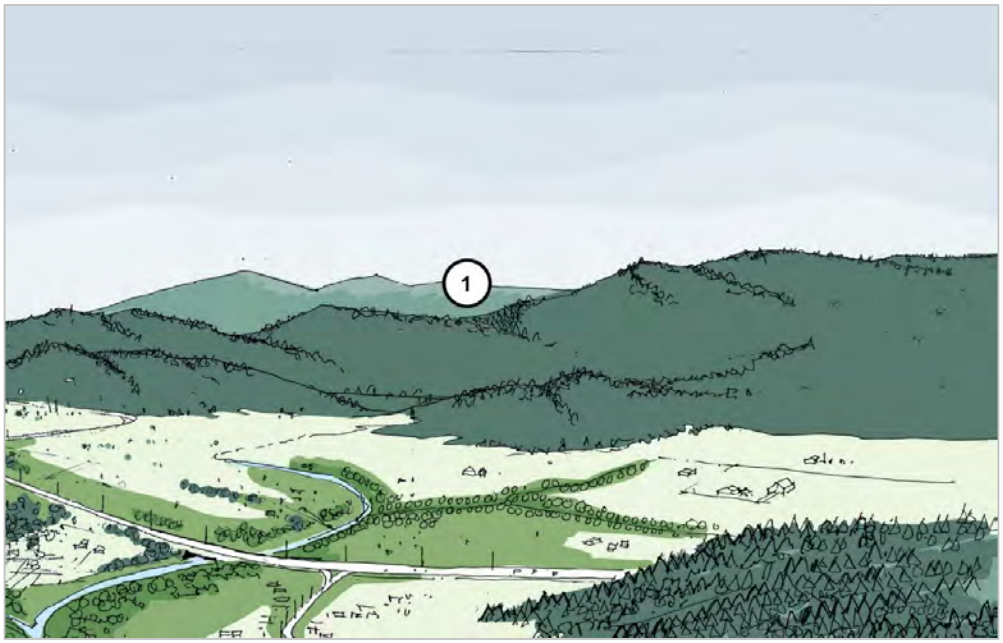


Figure 14: Possible application of landcover management in upper catchment areas in Otago catchments

5.1.1 How does landcover management contribute to flood hazard mitigation in the catchment?

In reference to the drivers of flooding and associated hazards within Te Hakapupu/Pleasant River catchment, this NbS would effectively increase environmental and infrastructure resilience in the catchment through the following means:

Protect: Protection of the relatively flat mid and lower catchment areas and land uses from exposure to the effects of flood flows and the flood-related impacts of sediment mobilisation and debris flows through permanently retaining water yield moderation and stabilisation of steeper surfaces.

Avoid: Avoidance of the windows of vulnerability, caused by ongoing plantation forestry harvest and replanting cycle in upper sub-catchment areas. These windows of vulnerability increase both the exposure and vulnerability of the relatively flat mid and lower catchment areas to increased flood flows and the flood-related impacts of sediment mobilisation and debris flows.

Overall, the Rapid Flood Hazard Model indicates that in a 100-year extreme rainfall event in a post-harvest scenario (i.e. during the period of plantation forestry harvest and replanting) there could be and increase in flow from upper catchment areas in the order of 25% or more, compared to the current plantation forestry coverage. This would likely exacerbate the impacts of flood events across the lower catchment.

If the current plantation forestry blocks in the upper catchment were transitioned back to a full native bush coverage, then a potential reduction in flow would be possible in the order of 6-7% during a 100-year extreme rainfall event, compared to the current plantation forestry coverage. Therefore, reducing the impacts of flooding across the lower catchment and avoiding increased flows during plantation forestry harvest and replanting periods.

5.1.2 How does landcover management contribute to landscape amenity value, character, and recreation opportunities?

The landcover management NbS intervention involves the restoration and expansion of existing pockets of remnant indigenous forest within the catchment, seeking a gradual, long-term transition of large areas in the upper sub-catchments from exotic plantation forestry to wide-scale permanent indigenous forest.

The restoration and enhancement work would support connecting existing remanent indigenous forested areas and create new areas that can act as important local seed sources.

Potential benefits

The long-term outcome of this NbS intervention would be a large-scale permanent indigenous forest across upper sub-catchment. Replacing the existing exotic plantation forestry with permanent indigenous forest will have a positive effect on the landscape, amenity and natural character values of the upper catchment areas and wider landscape.

By replacing the plantation forestry in vulnerable locations, the mobilisation of sediment and debris to waterways can be significantly mitigated, reducing flood-related risks in the catchment, effects on water quality and clarity, and effects on lower catchment freshwater and estuarine habitats. These changes would enhance and allow for the better protection of landscape and natural character values throughout the catchment, beyond the immediate location of the proposed change.

A gradual transition to permanent indigenous cover across upper sub-catchment would also have potential benefits for the perceptual and associative dimensions of landscape, and visual amenity, as well as the experiential aspects of natural character. The increase in native vegetation is likely to raise aesthetic values for example, in regard to levels of naturalness and visual coherence as it gradually leads to a more natural sequence of indigenous vegetation types in the area.

5.1.3 What are the potential biodiversity benefits, challenges, and practicalities of landcover management in the catchment?

Biodiversity benefits & challenges

Indigenous vegetation cover in the catchment is very limited (approximately 1%) and essentially all land cover is exotic in nature (pasture and plantation forestry). Gradual replacement of plantation forestry with permanent indigenous forests across large areas of the upper sub-catchments would massively increase local population sizes of indigenous flora and fauna species. Indigenous forest at large scales would, in time, be likely to be resilient and self-sustaining. Targeted plantings could be used to bolster desired threatened, at Risk or locally uncommon plant populations within the catchment.

Compared to tall exotic plantation forestry with high levels of rainfall interception and evapotranspiration, indigenous forest cover typically displays increased downstream water yield but reduced flow flashiness during rain events, an important ‘win-win’ in terms of buffering stream flows. They can therefore also act as ‘water storage’ during drier periods, mitigating currently occurring low flow periods in the catchment. Downstream runoff of sediment and ‘flashy’ stream flows in heavy rain events would be reduced in the long term if a large proportion of the catchment (particularly in steep and erodible areas) is permanently vegetated.

In regard to wider natural hazards in the catchment, extensive gorse or fast-growing successional indigenous forest types (e.g. kānuka scrub / forest) are flammable and vulnerable to fire. This also applies to existing pine plantations. Long term, mixed broadleaf native forests are generally resistant to fire.

Practicalities of implementation

The cost, nursery infrastructure, personnel, and planting maintenance requirements for large scale indigenous afforestation likely make an approach reliant on wholesale / widespread indigenous plantings infeasible. Therefore, any realistic approach would be reliant on facilitating native forests to regenerate themselves with minimal interference. This would likely still require targeted pest control (focused on the most concerning / habitat-altering plant and animal pests). Because of the limited existing seed source for indigenous forest species in the catchment, this approach would also be reliant on the rate and extent of natural spread from adjoining indigenous habitats, such as on Mt Watkins / Hikaroroa, and / or targeted indigenous plantings of ‘nodes’ to accelerate natural regeneration processes.

Noting the potential fire risk, an interim vegetation cover of gorse or other pioneer exotic species may establish in the short term, but in the long term (~30 years), with sufficient seed source, succession to native vegetation cover would be expected. Ongoing and effective suppression of browsing mammals will increase regeneration rates, as will interventions that increase populations of species such as kereru that are capable of transporting fruits of large-seeded tree species.

A more feasible approach than planting following forestry harvest may be to underplant indigenous species beneath an in-situ pine canopy. However, the major limitations of indigenous seed source and pests noted above would also apply. Additionally, harvest practices of the pine canopy would need to avoid damage and destruction of emerging indigenous species. If ‘nodes’ of plantings are used, this would likely still require many 10s-100s of thousands of plants, and as above, this would require several years lead-in time for a specialist nursery to propagate. While low stature plantings may mature within a short time

frame (<5 years), many forest tree / shrub species are slow-growing and will not mature for many decades (or centuries).

5.1.4 What are the high-level costs of the establishment and maintenance of landcover management in the catchment?

Establishment & Maintenance costs

Landcover management approaches of transitioning exotic plantation forestry into large scale permanent indigenous forest areas incur a number of costs associated with the establishment and upkeep of indigenous species. For large-scale indigenous afforestation being considered in this NbS intervention, afforestation estimates vary depending on access and existing environment, although broadly:

- The Climate Change Commission estimates that the establishment costs for large scale indigenous afforestation are estimated to be around $6,600 per hectare and can be as high as $24,000 to $50,000 per hectare (CCC, 2021).
- Motu Economic and Public Policy Research estimates that large scale indigenous afforestation establishment costs range from $24,000 to $66,000 per hectare (Pohatu *et al.* 2020)

These estimated costs do not consider the maintenance costs associated with indigenous plantings. The cost of fencing, planting, and continuous weed and pest management could range from $12,000 to $15,000 per hectare (Pohatu et al., 2019). By aligning with the wider Te Toitū Te Hakapupu restoration project for indigenous afforestation, this NbS may be able to recognise a couple of cost reduction opportunities for landowners, including plant purchasing and planting.

PLANT PURCHASING: Sourcing of suitable plant species for indigenous afforestation may be propagated from remnant pockets of indigenous forest through establishment of a community nursery. Additionally, with suitable plant species already present in remnant indigenous forest pockets in the upper catchment, controlling weed species and invasive browsing pests may be sufficient to enable those remanent pockets to expand across large area naturally over time. Although, it should be noted that natural regeneration in coastal Otago is slower compared to other more temperate North Island regions. Alternatively, crowd sourcing mechanisms such as ‘Trees that Count’ could be applied to provide funding for plant purchase or aligning with national government afforestation grants.

PLANTING: Planting efforts can be supported by using community groups, public planting days, or facilitating corporate volunteer planting days.

Land use change costs

Forestry and logging are an important industry within the Otago Region and Waitaki District economies, adding approximately $81 million of value to the regional economy and $13 million of value to the district economy (Yang *et al.* 2023). Although permanent indigenous forestry does not often match the same financial returns as plantation forestry, indigenous afforestation provides an opportunity for reducing sediment and nutrient losses, enhancing indigenous biodiversity, offsetting greenhouse gas emissions, and contribution to wider ecosystem services such as fibre, animal shelter, habitat for beneficial species and aesthetic.

Under present-day (2025) market settings, the transition of land use from exotic plantation forestry to permanent indigenous forestry would likely incur significant economic costs for landowners. With plantation forestry blocks in the upper catchment participants in the New Zealand Emissions Trading Scheme (NZ ETS), under current NZ ETS settings, transitioning exotic plantation forest cover to be replaced by smaller, slower growing indigenous species would reduce forest carbon stocks in the near to midterm, incurring significant carbon credit surrender liabilities for landowners. As indigenous forests and exotic forests recognised within the NZ ETS sequester and store carbon at different rates, when mature exotic forests are gradually replaced with new indigenous forest species, the overall carbon stock will progressively reduce.

Indigenous forests are expected to sequester high levels of carbon in the long-term than compared to exotic forest species. However, after 100-years, the amount of carbon stored in an indigenous forest would still likely be below the initial 40-year peak of an exotic forest. This deficit in carbon stocks between exotic and indigenous forest species creates a large financial liability for participants.

Without change in NZ ETS settings to encourage greater levels of indigenous afforestation, this NbS intervention would present a financial risk to forestry participants within the catchment and disincentives the long-term transition at a large scale (MPI, 2023).

5.1.5 What are the potential impacts, benefits, and trade-offs landcover management may have in the catchment, alongside productive rural land uses and as part of Kāti Huirapa ki Puketeraki's takiwā?

The NbS intervention of landcover management align with the identified values and strategies of the draft Toitū Te Hakapupu CAP (Ahikā, 2023). The relevant values and strategies are detailed below.

Value 1: Waterways

Value 1 of the draft Toitū Te Hakapupu CAP recognises that waterways in the catchment and the estuary wetland complex provide important habitat and eco-system services, however, these values have been degraded over time, particularly due to the effects of plantation forestry operations in the upper catchment. The NbS intervention of landcover management would contribute benefits towards the enhancement of Value 1, specifically aligning with the following CAP strategies:

- S1A. Levels of contaminants and sediment entering waterways & estuary wetland complex will be reduced, in accordance with target attribute states as set out in the LWRP
- S1F. Instream flows and hydrological functions are maintained or improved in the catchment, including restoring wetlands, re-naturalising waterways and managing invasive plant species, where this does not increase flood risk

With the gradual transition of upper sub-catchment landcover from clear-fell plantation forestry to permanent indigenous forest, this NbS would significantly reduce the window of vulnerability to increased sediment and debris inputs catchment waterways are exposed to during harvest and replanting periods.

The high-risk period during the 'window of vulnerability' exists for approximately 8-years from the time of harvest until the replanted crop establishes a full canopy and sufficient root structure. During this window, the loss of canopy cover and root structures in the steeper upper catchment areas would see an increase in overall water yield into the lower catchment during rainfall events, likely transporting fine sediments and other woody debris.

During extreme rainfall events, it is often the debris flows that cause the greatest damage to lower catchment waterways.

With the effects of sediment inflows into the main waterways already creating issues with water quality in the lower catchment and estuary wetland complex, restoring the upper catchment watershed to permanently avoid the increased risks posed by forest harvest would likely contribute the greatest benefits to achieving CAP water quality related strategies.

Value 2: Biodiversity

Value 2 of the draft Toitū Te Hakapupu CAP recognises that biodiversity within the catchment provides important habitat, ecosystem services, and landscape amenity. However, with the widescale modification of the indigenous environment over time towards a predominant mix of exotic pastoral and forest land cover, these values have been diminished. The NbS intervention of landcover management would contribute benefits towards the enhancement of Value 2, specifically aligning with the following CAP strategies:

- S2A. Existing remnants of indigenous vegetation and wetlands will be identified, protected, and enhanced
- S2B. Increase indigenous plantings in the catchment to support the creation of biodiversity corridors, including within the forestry estate

Within the existing plantation forestry areas across the upper catchment, a number of small remanent indigenous forest pockets provide isolated habitat for biodiversity. Through initially seeking to protect and enhance these remanent indigenous forests and support their expansion across larger areas of the upper catchment, connectivity can be enhanced.

Value 3: Cultural significance

Value 3 of the Toitū Te Hakapupu CAP recognises that the Hakapupu catchment is part of Kati Huirapa ki Puketeraki's takiwā and is culturally significant, however as mana whenua have lost access to large parts of the catchment and natural environment values have degraded, these values have become increasingly limited. The NbS intervention of landcover management would contribute benefits towards the enhancement of Value 3, specifically aligning with the CAP strategies:

- S3A. Water quality and habitat will be protected and enhanced with a focus on mahika kai and taonga species so that abundance is sufficient to support cultural practices.
- S3B. Access to key sites for cultural practices will be investigated, and where possible, re-established.
- S3C. Existing trails and access points will be enhanced.

For mana whenua, enhancing safe access to upper catchment areas where mahika kai values are supported helps sustain connections to wāhi tupuna and transfer of mātauraka Māori. Through the landcover management NbS intervention, mana whenua and community access to upper catchment areas could be safely enhanced without public interference in clear fell forestry operations. Access to key cultural sites could be supported through restoration activities, with opportunities to share mātauraka Māori for the sustainable use and protection of biodiversity values and taonga species.

5.1.6 How does landcover management adapt to and/or help mitigate the effects of climate change in the catchment?

Climate change adaptation

Beyond permanent indigenous forests being more resilient to the effects of extreme rainfall events and land instability, mature indigenous forest cover can support reducing catchment vulnerability to fire-related risks. The climate change effects on fire-related risks in New Zealand is an emerging research area. As such, the direct change a warmer and drier summer climate may have on fire risk within the catchment has not been specified within Otago Region Climate Change Projections (Macara *et al.* 2019). However, with more frequent extreme hot days and dry days (≤1mm) projected to occur across the Otago region, fire-risk profile of exotic forested areas may be subject to change.

Climate change mitigation

Undertaking a gradual transition from exotic plantation forestry to permanent indigenous forest presents both benefits and disbenefits for climate change mitigation – causing disbenefits in the near to mid-term, but benefits in the long-term. As detailed in the economic evaluation of this NbS, transitioning exotic forest species to permanent indigenous forest species creates change in the net-carbon stocks of a forested area, where the benefits will likely not be realised until future generations. Exotic forest species typically grow much faster than New Zealand indigenous species, sequestering and storing carbon within their biomass at a much higher rate per year. However, with slow continuous growth indigenous forests are expected to sequester comparatively high levels of carbon in the long-term.

In the scope of immediate climate change mitigation requirements, New Zealand, along with the rest of the world must rapidly reduce its net-carbon emissions in the coming years in effort to hold global warming well-below 2°C. The window of opportunity to achieve this target and avoid the more severe effects of climate change is closing fast within this decade (IPCC, 2021). Accordingly, reducing net-carbon stocks stored within Te Hakapupu forested would likely provide a disbenefit to net-emissions reduction efforts required to achieve near and mid-term emission budgets.

Alternatively, however, transitioning the catchments forested areas to permanent indigenous may contribute positively to national climate change mitigation efforts, as New Zealand must reach net-carbon zero and remain at net-carbon zero. Well-maintained permanent indigenous forests provide for longer term carbon sequestration beyond the end of this century and ensure greater permanence of carbon stocks. As climate change intensifies, the risks to exotic forestry plantations, such as flooding and fire, also increase. In contrast, permanent forest species with a well-established understory tend to be less vulnerable to these hazards.

5.1.7 Is landcover management consistent with consenting requirements and key legal or policy considerations?

Land ownership characteristics

The landcover management NbS would likely occur over the largest area of the three NbS, across large sections of the upper sub-catchments. There are 48 parcels of land in the forested upper catchment, and a total of 19 landowners, predominantly private entities.

There is a number of forestry companies who hold significant areas of land within this area, with Calder Stewarts, PF Olsen, Wenita, and Ngāi Tahu Forestry being the largest landowners.

Regulatory implications

At a very high-level, the NbS intervention of landcover management essentially seeks to facilitate the gradual conversion of exposed clear-fell plantation forestry areas to permanent indigenous forests. This NbS might involve the following activities (assuming that clearance of existing plantation forestry is undertaken in accordance with relevant rules and standards):

- Planting of indigenous vegetation, which may include within riparian areas
- Ancillary earthworks
- Fencing to exclude stock and browsing pests from restored areas

A summary of the potential consenting requirements associated with these activities under the relevant regulatory instruments is set out in Appendix 6. Note that it is assumed that the works will not occur in proximity to any inland natural wetlands as defined in the NPS-FM, but that a detailed site survey should be undertaken to verify this. If natural inland wetlands are affected, then there could be consent requirements under the NES-F.

Similarly, this NbS is not anticipated to trigger any consent requirements under the Otago Regional Plan: Water as it is unlikely to involve the types of activities managed under that plan (e.g. damming, diversion, discharge of water).

Policy considerations

General Policy Direction

It is expected that any improvement to water quality and freshwater habitat that arises as a result of the NbS would be broadly consistent with the general policy direction in the NPS-FM and the Otago Regional Plan: Water.

National Policy Statement – Indigenous Biodiversity

The NPS-IB has an overarching objective of maintaining indigenous biodiversity across Aotearoa New Zealand so that there is at least no net loss in indigenous biodiversity after the commencement date of the NPS-IB. Related policies seek to promote and provide for the restoration of indigenous biodiversity, [9] and to promote increased vegetation cover in both urban and non-urban environments.[10]

[9] NPS-IB Policy 13
[10] NPS-IB Policy 14

Dunedin District Plan

Objectives and policies in the Dunedin District Plan seek to maintain or enhance biodiversity values, including by encouraging conservation activity in all zones through the district. [11] Objective 16.2.3(f) seeks to maintain or enhance the rural character values and amenity of the rural zone, including by including extensive areas of indigenous vegetation and habitats for indigenous fauna. [12]

Waitaki District Plan

The Waitaki District Plan identifies ongoing modification and degradation of nature conservation values in the District as one of the key issues within the Rural parts of the District.[13] Related objectives seek to maintain biodiversity, nature conservation values and ecosystem functioning; as well as the quality of water, wetlands, lakes, rivers and their margins. [14]

Overall, landcover management would be generally consistent with the policy direction of the NPS-FM; NPS-IB; Otago Regional Plan: Water; the Waitaki District Plan; and the Dunedin District Plan.

Figure 15: Landcover post forestry harvest, Southland. Source: Videocopter.

[11] Dunedin District Plan Objective 10.2.1 and Policy 10.2.1.5
[12] Dunedin District Plan Objective 16.2.3(f)
[13] Waitaki District Plan Issue 8
[14] Waitaki District Plan Objectives 16.9.2(1) and (2)

5.1.8 Summary of landcover management as a nature-based solution

Opportunities

- This NbS intervention would permanently restore the natural hydrology of vulnerable areas in upper sub-catchment locations, avoiding the exacerbation of flood hazards during forestry harvest and replanting periods.
- Permanent indigenous afforestation typically increased downstream water yield but reduced flood flows, addressing flood hazards but not exacerbating water pressures during dry spells.
- The NbS is broadly consistent with national and local policy and planning direction.
- The NbS would significantly increase indigenous plant populations in the catchment, enhancing cultural and community amenity values.

Challenges

- Considerable economic costs are associated with the establishment and upkeep of indigenous forests at large scale and loss of plantation forestry revenue.
- Likely reduce the overall forest carbon stock for decades, incurring significant NZ ETS carbon credit surrender liabilities for landowners and impacting climate change mitigation targets.
- Would require action of up to 19 landowners to be implemented in vulnerable areas across upper sub-catchment locations.

5.2 RIVER NATURALISATION

The NbS intervention of river and stream naturalisation would target the predominantly unvegetated riparian areas of the main Te Hakapupu / Pleasant River, Watkin Creek, and Owhakaoho / Trotters Creek waterways. This NbS would seek to manage flooding and associated hazards along the middle and lower waterway corridors, primarily through slowing flood flow velocities and intercepting runoff.

Figure 16: Possible application of river naturalisation in a typical Otago river catchment

5.2.1 How does river naturalisation contribute to flood hazard mitigation in the catchment?

In reference to the drivers of flooding and associated hazards within the Hakapupu catchment, this NbS would effectively increase resilience to the experienced impacts of flood events through the following means:

Avoid: Mitigation of severe surface flooding of areas and land uses vulnerable to the effects of flood hazards adjacent to waterway corridors, by enhancing riparian areas to slow runoff entering waterway, increase bank permeability, and slowing in stream peak flood flow velocities flowing down the catchment.

Avoid: Avoidance of fast flowing flood waters and unrestricted surface runoff from surrounding productive lands entering waterways, causing high levels of streambank erosion and transporting contaminants, by enhancing riparian areas to stabilise streambanks and intercept runoff contaminants.

While there is evidence of channel modification in the catchment through diverting and straightening through some properties, the main channels are is largely still that of a braided river system – so there would only be localised opportunities to implement changes. Compounding this, the flood extent shown in Map 7 is significant. Naturalisation of these localised areas (through reinstating a more sinuous channel form and increasing storage) would be unlikely to be of a scale that would make a significant change in flood extent.

Restoration of riparian vegetation would likely achieve benefits in terms of erosion management and protection of channel banks, but also may result in increased channel roughness and reduced channel capacity.

5.2.2 How does river naturalisation contribute to landscape amenity value, character, and recreation opportunities?

This NbS intervention involves undertaking river and stream naturalisation along modified waterways at Te Hakapupu/Pleasant River, Owhakaoho / Trotters Creek, and Watkin Creek. This will be achieved through the exclusion of stock and development activities within riparian buffer areas and the restoration of riparian vegetation with native shrubs and tall native tree species along the waterway corridor.

By naturalising these waterways within the catchment there is an opportunity to restore the natural flow characteristics, slow peak flow velocities, and increase their capacity.

Existing character and values

The main tributaries of Te Hakapupu/Pleasant River, Watkin Creek, and parts of Owhakaoho/ Trotters Creek in the mid-catchment are currently modified through agricultural and infrastructure development. While some work has been done through the Toitū Te Hakapupu project to enhance riparian planting, overall, they have relatively bare, unvegetated riparian margins and entrenched channels with small adjoining tributaries and wet areas being piped or cut off.

Potential benefits

This NbS seeks to restore the mid-catchment sections of the three main river corridors to vegetated riparian margins which will enhance the landscape, amenity and natural character values of the river corridors and the wider catchment.

Creating vegetated riparian buffers will enhance physical landscape values, abiotic aspects, and biotic aspects of natural character which have been degraded. This will be achieved through protecting the riverbanks from further erosion, restoring natural flows, improving water quality and clarity by filtering sediments and contaminants, increasing biodiversity, and providing shade over the waterways. Shade from the plants will assist rivers' life-supporting capacity for aquatic ecosystems. Reducing the sediment and nutrients that get into the waterways will also assist with better protecting the range of landscape and natural character values of Te Hakapupu/Pleasant River Estuary Wetland Complex at the lowest part of the catchment. Restoring and naturalising these corridors will also enhance values relating to perceptual and associative dimensions of the wider catchment's landscape and visual amenity values, particularly as a result of planting the bare riverbanks.

5.2.3 What are the potential biodiversity benefits, adverse effects, and practicalities of river naturalisation in the catchment?

Biodiversity benefits & challenges

At present, the riparian vegetation cover along the main waterways in the catchment is largely limited (i.e. bare or grassed banks) and / or exotic in nature (e.g. plantation forestry and willow). River naturalisation including riparian plantings would create greater ranges and larger population sizes of indigenous flora and fauna species, and the re-creation of 'natural' indigenous sequences of riparian vegetation.

Targeted plantings could be used to bolster desired Threatened, At Risk, and locally uncommon plant populations within the catchment. In turn, by creating vegetated corridors, habitats suitable for use by terrestrial fauna (i.e. birds, lizards, and invertebrates), or riparian nesting habitat for waterfowl and wetland bird species, may develop in time. Increased riparian cover utilising indigenous plant species may improve in-stream habitat conditions by, for example, intercepting sediments and runoff, by providing riparian shade, and by reducing pulses of leaf litter from exotic riparian species (e.g. willows).

Works to re-align or 'make room for the river' will require robust erosion and sediment control measures in place. Salvage and translocation of freshwater fauna may be required if works include temporary channel dewatering and realignment. Works to re-align or 'make room for the river' will also need to ensure that hydrological conditions within the 'typical' or 'low flow' channel remain suitable for freshwater fauna. Excessively widened waterways risk reducing water velocity and depth, increasing water temperature and / or enabling macrophyte growth, sediment build up at the exclusion of suitable conditions for freshwater fauna.

Conversely, narrow waterway corridors of riparian plantings inherently suffer from 'edge effects' that reduce the long-term resilience and functioning of plant communities. In turn, this creates opportunities for ongoing weed invasion. This weed invasion risk may be mitigated by greatly increasing the width of planted areas.

Practicalities of implementation

Earthworks to 'create room for the river' and conduct any re-align waterways will trigger potentially complex consenting and permitting requirements. Ecological input into plantings and design (including constructed bank, streambed substrates, depths, and structures such as bridges if any), and effects assessment for consenting and permitting processes would be required.

Establishing riparian plantings of at least 3 m width along the unvegetated areas of Te Hakapupu / Pleasant River, Owhakaoho / Trotters Creek and Watkin Creek corridors equates to approximately 3 ha of plantings. Whilst this potentially means 30,000 plants are required, this NbS solution is considerably more straightforward and of smaller scale than the wetland construction and restoration or landcover management NbS approaches.

Plants for this NbS would require several years lead-in time for a specialist nursery to propagate. While low stature plantings may mature within a short time frame (<5 years), many riparian tree / shrub species are slow-growing and will not mature for many decades (or centuries).

5.2.4 What are the high-level costs of the establishment and maintenance of river naturalisation in the catchment?

Establishment and maintenance costs

Establishment and maintenance costs of river and stream naturalisation within the catchment are primarily associated with the costs of fencing and restoring riparian setback areas as detailed in Table 5.

Similar to wetland restoration and construction activities, aligning with the wider Toitū Te Hakapupu restoration project that includes stream naturalisation, this NbS may be able to recognise a couple of cost reduction opportunities for landowners, including:

PLANT PURCHASING: Sourcing of suitable plant species for riparian areas may be selectively sourced or propagated from neighbouring well-established riparian areas within the catchment. Additionally, suitable plant species may already present in the proposed locations in which case, simply removing grazing pressure and controlling weed species may be sufficient to enable those remanent riparian plants to expand along the waterway corridor.

Alternatively, crowd sourcing mechanisms such as 'Trees that Count' could be applied to provide funding for plant purchase.

PLANTING: Planting efforts can be supported by using community groups, public planting days, or facilitating corporate volunteer planting days

Table 5: Indicative costs per hectare of activities associated with river and stream naturalisation

	INDICATIVE COST	$/HA (EXCL. GST)	NOTES
SITE PREPARATION	$0.5 per plant	$2,222	Spot spraying cost per plant. Alternatives are to spray whole area or use mechanical clearance.
FENCING	$20 - $30 per l/m	$20,800 – $31,200	Retirement fencing with electric 4-wire assuming 20 m wide x 500 m long planting area, fencing both sides 1040 m)
PLANT PURCHASE	$1.80 - $5 per plant	$8000 - $22,220	Assuming a mix of shrubs and trees in revegetation/forestry grades
PLANTING	$2 - $3 per plant	$8,880 - $13,330	Including $0.2 cost for fertilizer tab per plant. $0.35 for bamboo stake to allow for location.
REPLACEMENT PLANTING	$1.80 - $5 per plant	$2,500 - $5,000	5% mortality assumed; includes plant purchase and planting
PROJECT MANAGEMENT	$1 per m^2 of riparian area	$10,000	Generally, works managed by landowner or, Landcare group, NGO or Council and don't typically see a PM cost.
MAINTENANCE	Lump sum	$2,000 - $4,000	Allow for three visits over 2 years of maintenance
TOTAL COST PER HA		$54,000 - $88,000 per hectare	

Land use change costs

River and stream naturalisation along the waterways of the Hakapupu catchment would require the exclusion of stock grazing and setback from waterway margins. Should exclusions be greater than current regulation to achieve greater flood mitigation and biodiversity benefits, this would reduce the productive area on farms and require alternative the provision of water supplies for livestock.

While national cost-benefit analysis (economic cost vs environmental benefits) of riparian restoration for a variety of low, medium, and high-cost restoration scenarios and buffer widths found benefits typically outweigh the costs by between 2:1 and 20:1, this does not consider the impacts that direct personal costs may have on individual landowners (Eppink *et al.* 2016).

As common with NbS benefit realisation, the benefits of implementing wide-scale riparian restoration activities may provide significant benefits for flood mitigation and water quality. However, these broader benefits may not provide direct financial benefits to individual landowners. In comparison, without national or regional funding to support riparian restoration, the direct costs of fencing and restoring riparian margins, developing alternative water sources, as well as the opportunity loss through loss of productive land area could be difficult and expensive for farmers (Daigneault *et al.* 2017; B+LNZ & Federated Farmers, 2020).

Land use change benefits

DairyNZ commissioned research in 2021 to investigate the cost-benefits of 'Productive Riparian Buffers'. The aim of this research sought to develop edge-of-field agricultural methods that improve water quality and ecological conditions, while also providing production benefits for farmers (Matthews & Matheson, 2021). Although a number of the productive buffers analysed do not meet NbS definition or criteria, options including planting tōtara along waterways to produce commercial by-products of foliage for oils and pole, and planting mānuka for foliage for essential oils may be viable in Otago. However, these financial benefits of these productive riparian buffer options are limited due to the high harvest labour requirements and limited market opportunities at present.

While vegetated riparian margins are not typically recognised within the NZ ETS, restoration and establishment of riparian margins at the appropriate scale could yield afforestation carbon credits.[15] Alternatively, riparian margins of smaller sizes (not complying with NZ ETS requirements) may be recognised at present through Voluntary Carbon Market (VCM) verification bodies should they meet requirements for additionality, transparency, and permanence.

While the amount of carbon sequestered is dependent on the biomass present within a riparian area (plant size and area) and its growth rate over time, the median sequestration values for riparian areas in New Zealand are estimated at 3.4 tonnes CO_2 per hectare per year.

[15] Current NZ ETS settings require post-1989 forests to be at least 1 ha in size, 30m wide, and consist of a 5m tall canopy.

5.2.5 What are the potential impacts, benefits, and trade-offs river naturalisation may have in the catchment, alongside productive rural land uses and as part of Kāti Huirapa ki Puketeraki's takiwā?

The NbS intervention of river and stream naturalisation align with the identified values and strategies of the draft Toitū Te Hakapupu CAPP (Ahikā, 2023). The relevant values and strategies are detailed below.

Value 1: Waterways

Value 1 of the draft Toitū Te Hakapupu CAP recognises that waterways in the catchment provide important habitat and eco-system services, however, these values have been degraded over time, particularly due to the modification and management practices around streambanks. The NbS intervention of river and stream naturalisation would contribute benefits towards the enhancement of Value 1, specifically aligning with the following draft CAP strategies:

- S1A. Levels of contaminants and sediment entering waterways and estuary wetland complex will be reduced, in accordance with target attributes states set out in the LWRP
- S1B. Riparian margins will be protected and enhanced, with stock and plantation forestry excluded
- S1C. Fish spawning areas will be protected and enhanced, and fish passage will be enhanced.
- S1F. Instream flows and hydrological functions are maintained or improved in the catchment, including restoring wetlands, re-naturalising waterways and managing invasive plant species, where this does not increase flood risk.

The naturalisation of the main waterways identified in the catchment would predominantly be achieved through the exclusion of livestock and enhancement or restoration of riparian margin vegetation. Conducted at an appropriate scale across the waterway corridors, this can support reducing the contaminants and sediment entering waterways and being transported into the estuary wetland complex. Suitably sized and maintained riparian areas support contamination removal from surface runoff from surrounding productive land uses through a combination of physical and biological processes.

By providing for enhanced riparian vegetation cover, shallow surface runoff flows experienced during extreme rainfall events can be slowed, allow particles (sediment, livestock waste, plant debris) to settle on bank areas, and slow the velocity of runoff.

Additionally, by increasing surface permeability, enhanced riparian areas can facilitate more surface runoff to infiltrate into the riparian soil, increasing the contact between soil and contaminants such as dissolved nitrogen and fine sediments (McKergow *et al.* 2022). The estimated performance of a well restored and vegetated riparian area for filtering sediment, nitrogen, and phosphorus from surface run off will vary dependant on topography and riparian setback width, however performance will generally increase with setback width.

Restoration and naturalisation of stream corridors in the catchment can also play an important role in reducing erosion and enhancing freshwater habitats, noting that stream

bank erosion accounts for as much as 98% of deposited sediment at catchment outlets into the estuary wetland complex. Through enhancing the root systems across a stream bank, riparian plants help to stabilise stream banks and buffer them from the effects of fast flows during extreme rainfall events, reducing sediment input from streambank erosion.

Value 2: Biodiversity

Value 2 of the draft Toitū Te Hakapupu CAP recognises that biodiversity within the catchment provides important habitat, ecosystem services, and landscape amenity. However, like the pressures experienced by waterways, these values have been degraded over time, particularly due to the modification and management practices around streambanks. The NbS intervention of river and stream naturalisation would contribute benefits towards the enhancement of Value 2, specifically aligning with the following draft CAP strategy:

- S2B. Increase indigenous plantings in the catchment to support the creation of biodiversity corridors, including within the forestry estate.

River and stream naturalisation of the presently unvegetated riparian areas of the main waterways within the catchment can support the enhancement of habitat and ecological functions of freshwater ecosystems. Key benefits that may enhance the biodiversity values found within catchment freshwater environments include:

- Reducing nutrients and sediments entering the waterway
- Providing or capturing organic material which can function as an important source of energy and serve as habitat for instream organisms
- Providing shading to moderate extreme temperatures in waterways.

Value 3: Cultural significance

Value 3 of the draft Toitū Te Hakapupu CAP recognises that the Hakapupu catchment is part of Kati Huirapa ki Puketeraki's takiwā and is culturally significant, however these values are diminishing as habitat available for mahika kai and taonga species is degraded. The NbS intervention of river and stream naturalisation would contribute benefits towards the enhancement of Value 3, specifically aligning with the CAP strategy:

- S3A. Water quality and habitat will be protected and enhanced with a focus on mahika kai and taonga species so that abundance is sufficient to support cultural practices.

River and stream naturalisation within Te Hakapupu catchment would provide beneficial outcomes for protecting and enhancing mahika kai abundance found within the catchment waterways by seeking to reduce the degrading pressures on these values from surrounding productive land uses. Riparian areas can be restored to contain a range of culturally important plant species, including those used for weaving or traditional medicines. Noting that important mahika kai species including Tuna, Banded kōkopu, and Īnaka are all ranked highly vulnerable to the effects of climate change, enhancing riparian areas to provide resilient habitat for these species will help protect these values for future generations (Egan *et al.* 2020).

5.2.6 How does river naturalisation adapt to and/or help mitigate the effects of climate change in the catchment?

Climate change adaptation

River and stream naturalisation of the currently unvegetated waterways of Te Hakapupu / Pleasant River, Watkin Creek, and parts of Owhakaoho / Trotters Creek, as identified in the NbS intervention, would provide beneficial outcomes to increasing the resilience of these freshwater environments to the effects of climate change.

As global warming drives the increase in mean annual temperatures across the Otago region in the coming decades, under a 'hot house' (RCP 8.5) climate change scenario, the catchment is projected to experience an increase of up to 1°C by 2040 and 2-2.5°C by 2090 (relative to a preset-day 1986-2005 average). Accordingly, as mean annual temperature increases, so too does the likelihood of extreme hot days (≥30°C). An additional 5 extreme hot days are projected annually for the catchment under a 'hot house' scenario by 2090.

Restoring riparian vegetation along the corridors of the main waterways across the catchment can reduce the effects of heat stress in freshwater environments, both through the shading of exposed areas during extreme hot days and by preventing heat contamination from runoff across hot surfaces entering waterways. Heat stress and surface water runoff across hot surfaces into surrounding waterbodies (e.g. a rainfall event after an extremely hot day) presents climate-related health risks to freshwater fish species. Sudden changes in water temperatures can alter the physical habitat conditions in freshwater environments and cause a range of physical and behaviour responses in freshwater species, through to death in severe circumstances.

Additionally, through re-establishing pre-existing off-stream wetland areas and small side tributaries, these can provide important water storage locations within the catchment. With longer and more frequent dry-spells projected for the Otago region, these areas enhanced through stream naturalisation can increase the resilience of freshwater resources during increasingly frequent low-flow events.

Climate change mitigation

While riparian vegetation that do not meet the size requirements of the NZ ETS are not currently recognised for their climate change mitigation benefits in New Zealand, these areas along with farm shelter belts and other vegetation types are intended to be considered in the coming years within on-farm net-emission monitoring.

Acknowledging the high sustainability of New Zealand's agricultural sector, comparative to international producers, the common agricultural land uses of the Hakapupu lower and mid catchment do emit considerable volumes of greenhouse gases. Consequently, fencing and restoring riparian areas along the main waterways of Te Hakapupu would provide a net-carbon reduction benefit to support climate change mitigation. As referenced in the economic evaluation, the median sequestration values for planted riparian areas are estimated at 3.4 tonnes CO_2 per hectare per year. Although these areas provide a comparatively low sequestration rate (compared to pinus radiata forest for example), when coupled with other emission reduction practices, riparian vegetation may provide an important contribution to achieving on-farm or regional net-carbon zero objectives.

5.2.7 Is river naturalisation consistent with consenting requirements and key legal or policy considerations?

Land ownership characteristics

Based on analysis which captured parcels of land within a 10m buffer of the reaches of the streams and rivers where it is proposed to undertake naturalisation activities, a total of 22 titles of land are affected, of which two are owned by the Crown. The remaining titles are privately owned.

Regulatory implications

Based on the current high-level understanding of the works associated with the NbS intervention of river and stream naturalisation in the Hakapupu catchment, it is anticipated that the works might entail:

- Removal of existing vegetation (which may or may not be pest plant species, but is assumed that no indigenous vegetation will be removed)
- Planting of vegetation within riparian areas
- Ancillary earthworks
- Fencing to exclude stock from riparian areas

A summary of the potential consenting requirements associated with these activities under the relevant regulatory instruments is set out in in Appendix 6. Note that it is assumed that the works will not occur in proximity to any inland natural wetlands as defined in the NPS-FM, but that a detailed site survey should be undertaken to verify this. If natural inland wetlands are affected, then there could be consent requirements under the NES-F. Similarly, this NbS is not anticipated to trigger any consent requirements under the Otago Regional Plan: Water as it is unlikely to involve the types of activities managed under that plan (e.g. damming, diversion, discharge of water).

Policy considerations

An overview of the policy direction relevant to the river and stream naturalisation NbS intervention is set out below.

National Policy Statement – Freshwater

The objective of the NPS-FM is to ensure that natural and physical resources are managed in a way that prioritises:

- First, the health and wellbeing of water bodies and freshwater ecosystems
- Second, the health needs of people
- Third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.

Related policies of relevance to this proposed NbS include that freshwater is managed as part of New Zealand's integrated response to climate change;[16] to ensure that the health and

[16] NPS-FM Policy 4

well-being of degraded water bodies and freshwater ecosystems is improved;[17] and that the loss of river extent and values is avoided to the extent practicable.[18]

National Policy Statement – Indigenous Biodiversity

The NPS-IB has an overarching objective of maintaining indigenous biodiversity across Aotearoa New Zealand so that there is at least no net loss in indigenous biodiversity after the commencement date of the NPS-IB. Related policies seek to promote and provide for the restoration of indigenous biodiversity, [19] and to promote increased vegetation cover in both urban and non-urban environments.[20]

Otago Regional Plan: Water

Objectives and policies in the Otago Regional Plan: Water seek to maintain or enhance the natural and human use values associated with Otago's lakes and rivers, as listed in Schedules 1A, 1B and 1C to the regional plan; [21] as well as the spiritual and cultural beliefs, values and uses of significance to Kai Tahu in Schedule 1D of the plan. [22] The provisions of public access long the margins of lakes and rivers is recognised; [23] as well as maintaining or enhancing the amenity values associated with these margins.[24]

Most of the related policies address water management issues, but Policy 5.4.13 seeks to encourage and support community initiatives that assist in the maintenance or enhancement of lakes and rivers and their margins. [25]

Dunedin District Plan

Objectives and policies in the Dunedin District Plan seek to maintain or enhance biodiversity values, including by encouraging conservation activity in all zones through the district. [26] Objective 16.2.3(f) seeks to maintain or enhance the rural character values and amenity of the rural zone, including by including extensive areas of indigenous vegetation and habitats for indigenous fauna. [27]

Waitaki District Plan

The Waitaki District Plan identifies ongoing modification and degradation of nature conservation values in the district as one of the key issues within the Rural parts of the district.[28] Related objectives seek to maintain biodiversity, nature conservation values and ecosystem functioning; as well as the quality of water, wetlands, lakes, rivers, and their margins. [29]

Overall, river and stream restoration would be generally consistent with the policy direction of the NPS-FM; Regional Plan: Water; the Waitaki District Plan; and the Dunedin District Plan

[17] NPS-FM Policy 5
[18] NPS-FM Policy 7
[19] NPS-IB Policy 13
[20] NPS-IB Policy 14
[21] Otago Regional Plan: Water, Objective 5.3.1
[22] Otago Regional Plan: Water, Objective 5.3.2
[23] Otago Regional Plan: Water, Objective 5.3.5
[24] Otago Regional Plan: Water, Objective 5.3.4
[25] Otago Regional Plan: Water, Policy 5.4.13
[26] Dunedin District Plan Objective 10.2.1 and Policy 10.2.1.5
[27] Dunedin District Plan Objective 16.2.3(f)
[28] Waitaki District Plan Issue 8
[29] Waitaki District Plan Objectives 16.9.2(1) and (2)

5.2.8 Summary of river naturalisation as a nature-based solution

Opportunities

- This NbS intervention would stabilise stream banks and intercept runoff to reduce in stream contaminants.
- Naturalisation of riparian areas would potentially create suitable habitat for indigenous freshwater species, allowing for larger population sizes species and could bolster mahika kai values.
- With larger riparian setback areas, river naturalisation can be developed into productive zones, offering landowners opportunities to diversify their income, such as through productive riparian farming or other sustainable land uses.
- River naturalisation would enhance the natural landscape character and aesthetic values of lower and mid catchment areas.

Challenges

- Most riparian vegetation is currently excluded from NZ ETS and on-farm systems as recognised carbon sink.
- Without cost-benefit sharing or realisation of nature-based market opportunities, such as productive riparian zones or carbon values, the retirement of productive farmlands would cause a loss of revenue.
- Many riparian tree / shrub species are slow-growing and will not mature for many decades.
- Would require action of up to 22 landowners to be implemented across all currently unvegetated waterways in the lower and mid catchment.
- Has less potential to actively mitigate flooding related risks than the other two NbS presented in this report.

5.3 WETLAND RESTORATION AND CONSTRUCTION

The NbS intervention of wetland restoration and construction in Te Hakapupu/Pleasant River catchment, including at the northern and western extent of the existing wetland estuary, would seek to mitigate the effects of extreme rainfall induced flood hazards primarily through the provision of suitable areas substantial enough to accommodate and retain flood water.

Figure 17: Possible application of wetland restoration and construction in a typical catchment

5.3.1 How does wetland construction and restoration contribute to flood mitigation in the catchment?

In reference to the drivers of flooding and associated hazards within the catchment, this NbS would effectively adapt to reduce the experienced impacts of flood events through the following means:

Managed Retreat: Managed retreat of built infrastructure and primary production land uses vulnerable to the effects of flood hazards in the lower reaches of the catchment, predominantly located on historically drained and reclaimed wetland areas where flood waters are naturally predisposed to flow and pool. Retreat of these values to less flood prone locations would effectively reduce the hazard exposure and the subsequent hazard risk profile for infrastructure, people, and livelihoods.

Accommodate: Restoration and construction of wetland area located in historically drained and reclaimed wetland areas where flood waters are naturally predisposed to flow and pool would provide the landscape function of accommodating flood flows through retention and detention.

Accommodation of flood flows would reduce the vulnerability of surrounding people, infrastructure, and livelihoods to the effects of surface flooding, providing greater capacity to buffer the effects of extreme rainfall events as they increase under climate change scenarios.

Additionally, with properly constructed and maintained sediment ponds at inlet locations, this NbS can also serve to accommodate sediment and contaminants coming down the catchment, reducing the exposure of the lower estuary wetland complex to the flood-related effects of sediment inundation.

While wetland restoration and construction is considered as an approach to manage flood extent, the scale and depth of flooding in the 100-year ARI event in Te Hakapupu/Pleasant River Catchment suggest that the results will depend on where this storage is provided (and what scale of flood reduction would be targeted).

A large volume of storage would be necessary to achieve a material reduction, given that there are flood depths of more than 1.5m across most of the floodplain. In addition, flows are entering the main floodplain from a number of different reaches means that multiple basins could be necessary across the catchment.

5.3.2 How does wetland construction and restoration contribute to landscape amenity value, character, and recreation opportunities?

The wetland restoration and construction NbS intervention would seek to restore the existing Te Hakapupu/Pleasant River estuary wetland complex and create additional wetlands. The existing estuary wetland complex covers approximately 84 ha which would be expanded to approximately 140 ha in this NbS intervention. As part of this NbS intervention, wetland areas and margins will also be planted with native riparian species.

Existing character and values

The existing Te Hakapupu/Pleasant River estuary wetland complex is identified as a Regionally Significant Wetland and a Significant Natural Feature and an Area of Significant Nature Conservation Value under the Waitaki District Plan.

The 2015 Natural Character and Outstanding Natural Features and Landscapes Assessment for Otago's coastal environment (the 2015 Natural Character and Landscape Assessment) [30] identifies the estuary as a place of significance to local Maori including a highly significant archaeological site on the spit. However, while this wetland complex contains attributes that contribute to natural character, its inland extent is largely characterised by increased modification in the form of drainage and reclamation for improved pasture and is under pressure from invasive weed species, grazing, and alteration of natural flow characteristics. Some riparian planting is being undertaken through the Toitū Te Hakapupu project.

The 2015 Natural Character and Landscape Assessment finds that the estuary has high – medium landscape and natural character values. The higher ratings are particularly at its eastern (mouth) end with low – moderate values in its upper (inland) reaches).

[30] Coastal Environment of Otago: Natural Character and Outstanding Natural Features and Landscapes Assessment, Dunedin City Section Report, 28 April 2015, prepared by Mike Moore et al

Potential benefits

This NbS suggests to restore and expand Te Hakapupu/Pleasant River estuary wetland complex. This will buffer the impacts of flood flows entering the estuary wetland complex, better protect and increase the level of indigenous planting and habitat and assist with intercepting and treatment of suspended sediments and other contaminants. Restoring and expanding the existing estuary wetland complex will enhance the legibility and expressiveness of this natural landscape feature, the level of naturalness, which is currently modified, aesthetic values, and both the abiotic and biotic aspects of natural character, which have been degraded.

Under the implementation of this NbS intervention, the important wetland habitats and ecosystems found in the estuary wetland complex will be better protected from floods and sedimentation, with improvements in water clarity and reduction in channel modification together with restoration of the riparian margin, all increasing levels of natural character. Biodiversity benefits as a result of the planting of indigenous, riparian species will also enhance physical landscape values of the wetland complex as well as contributing to its natural character values.

The significance of Te Hakapupu/Pleasant River estuary to Kati Huirapa ki Puketeraki is identified in the 2015 Natural Character and Landscape Assessment as relating, among other things, to its importance as habitat for birds and Mahika kai values. This NbS intervention provides an opportunity to enhance these ecological and mahika kai values for tangata whenua which would result in a positive outcome for the feature's associative landscape values. With the wetland restoration and construction, particularly the riparian planting proposed, amenity values associated with this estuary, wetland complex and its margins will also be enhanced.

Figure 18: Slope Hill wetland area planting. Source: Whakatipu Reforestation Trust

5.3.3 What are the potential biodiversity benefits, adverse effects, and practicalities of wetland construction and restoration in the catchment?

Biodiversity benefits & challenges

While the catchment already contains a relatively large area of estuarine wetland, areas of freshwater wetland habitat are currently far more limited in extent. The freshwater wetlands are typically small and potentially vulnerable, as they are largely surrounded by more intensive human activities and land uses.

A very large (c.140 ha) constructed and restored freshwater wetland would provide habitat for greater ranges and / or larger population sizes of indigenous flora and fauna. Targeted works could bolster desired Threatened, At Risk, and locally uncommon plant populations or support particular fauna species of ecological, cultural, or conservation importance within the catchment.

Where they sit low in the catchment, freshwater and brackish wetlands often provide important ‘overflow’ habitat. These ‘overflow’ habitat areas can be used seasonally or temporarily by coastal and estuarine species during high tide or climate conditions that reduce feeding habitats in the coastal environment, therefore benefitting coastal species as well. Additionally, increased wetland extent provides flow buffering for downstream waterways during flood and drought conditions, and open water areas provide refugia for aquatic species.

Constructed wetlands are often highly invadable by aggressive pest species, including plants (e.g., willows, alders), and tolerant fish species (e.g., rudd, perch). Whilst upfront design can reduce risk, ongoing and potentially costly pest control may be required if the desired outcome is to support indigenous species. Where constructed wetlands receive large sediment inputs from the upper catchment, this may ‘choke the system’ and prompt periodic maintenance and dredging. This risks additional cost, substantial mobilisation of sediment into downstream waterways, and loss of flora and fauna habitats that have established in the interim. This can be minimised by construction of forebays or implementation of additional measures to reduce sediment runoff in the first instance.

Practicalities of implementation

Wetland construction at the scale proposed in this NbS intervention is technically feasible in terms of design and construction but would be a large undertaking. Although, suitable land of existing low ecological value (productive farmland) is available on which a wetland could be constructed. Ecological input into plantings, wetland design (in terms of desired water levels and range, special features, and fish habitat and passage), and effects assessment for consenting and permitting processes (in relation to bulk earthworks and general works in / around waterways) would be required.

Furthermore, to achieve beneficial outcomes for biodiversity values within Te Hakapupu/Pleasant River catchment, wetland creation adjacent to waterbodies will likely require robust construction erosion and sediment control measures to be in place. Such measures will help minimise temporary impacts on in-stream habitat quality caused by construction activities.

Newly constructed wetland habitat (e.g. bare soils and shallow standing water) is highly invadable by weeds (as noted above). Therefore, very large-scale indigenous plantings to

rapidly establish a desirable vegetation cover will be needed. The scale of plantings required would need several years lead-in time for a specialist nursery to propagate.

5.3.4 What are the high-level costs of the establishment and maintenance of wetland construction and restoration in the catchment?

Establishment & maintenance costs

Establishment and maintenance of wetland restoration and construction can vary significantly depending on the site characteristics and associated pressures, as detailed in Table 6.

Table 6: Indicative cost per hectare (2020) to establish and maintain a new wetland area if all works were to be undertaken by contractors at commercial rates. Summarised from Tanner *et al,* 2022. Note, these estimates exclude consent-related costs.

	INDICATIVE COST	$/HA (EXCL. GST)	NOTES
SITE SURVEY AND WETLAND DESIGN	Lump sum	$3,000 - $7,000	Survey of wetland site and design, including positioning of inlet and outlet structures, treatment basins and estimate of excavation works
EARTHWORKS	$6.25 per m^2 of wetland surface are for initial site clearance. $15 per m^3 for site excavation	$110,000 - $130,000	Includes excavation and re-laying of topsoil to form wetland base for planting, and construction of a suitable weir and outlet structure at downstream end. Excludes provision for fish passage structures
FENCING	$5 - $10 per l/m	$1,000 - $5,000	Assumes optimised wetland shape to minimise fence length
PLANT PURCHASE	$1.80 - $5 per plant	$25,000 - $60,000	2.04 plants per square metre (0.7 m spacings) within the wetland area to be flooded; all plants purchased from commercial nurseries
PLANTING	$2 - $3 per plant	$28,000 - $43,000	Assumes planting is done by commercial planter
REPLACEMENT PLANTING	$1.80 - $5 per plant	$2,500 - $5,000	5% mortality assumed; includes plant purchase and planting
PROJECT MANAGEMENT	$1 per m^2 of wetland	$10,000	Earthworks and planting supervision
MAINTENANCE	Lump sum	$2,000 - $4,000	Per annum. Assumes bi-yearly clean-out of sedimentation pond
TOTAL COST PER HA		$175,000 - $260,000 per hectare	

The locations identified for wetland restoration and construction as a NbS to flood hazard mitigation, in alignment with the wider Te Toitū Te Hakapupu restoration project, lend themselves to a number of cost reduction opportunities, including:

EARTHWORKS: Locating the wetlands within the historical Te Hakapupu/Pleasant River wetland area with natural drainage channels will likely require less earthworks to create the wetland area.

PLANT PURCHASING: Sourcing of suitable plant species for wetland and riparian areas may be selectively sourced or propagated from neighbouring wetland and riparian areas. Additionally, suitable plant species may already be present in the proposed locations given their tendency for naturally accommodating flood flows, in which case, simply removing grazing pressure and controlling weed species may be sufficient to enable those remanent plants to expand across the wetland area naturally. Alternatively, crowd sourcing mechanisms such as 'Trees that Count' could be applied to provide funding for plant purchase.[31]

PLANTING: Planting efforts can be supported by using community groups, public planting days, or facilitating corporate volunteer planting days.

Following the construction and restoration of wetland areas, a well-established wetland should incur only minor maintenance costs. Maintenance costs, particularly in a catchment such as Te Hakapupu / Pleasant River, will include the maintenance of the sedimentation ponds that function to intercept and process suspended sediments before entering the wider estuary wetland complex.

Sediment accumulation within wetland ponds should be regularly monitored, particularly during upper catchment harvest periods and heavy rainfall events. Removal of accumulated sediments should be conducted when the sediment ponds are half full of accumulated sediments. This will ensure the wetland may continue to optimally function and does not resuspend stored sediments during extreme rainfall flood events.

Land use change costs

Wetland construction and restoration of an area large enough to successfully accommodate flood flows within Te Hakapupu catchment would require the retirement of existing productive agricultural landholdings in the lower catchment.

Landholdings identified in the NbS intervention for wetland construction and restoration generally occupy Land Use Class 2 for Land Use Capability in the New Zealand Land Resource Inventory tool, primarily used for beef farming. Sheep, beef, and grain farming are of particular importance within the Otago Region and Waitaki District, adding approximately $530 million of value to the regional economy and $70 million of value to the district economy (Yang *et al.* 2023). On average, farm sale prices for the Otago Region between March and May 2024 were approximately $17,370.00 per hectare.[32]

Land use change benefits

Whilst requiring land use change of existing productive agricultural landholdings, reducing income revenue for the landowner, wetland restoration and construction does offer financial opportunity through nature-based market mechanisms – namely, blue carbon credits and biodiversity credits. These nature-based markets are a type of 'green financing', used to encourage and facilitate private investment and provide income incentives to deliver NbS.

- **Blue carbon credits** refer to the carbon sequestered and/or stored in coastal and marine ecosystems, which can be used to offset carbon emissions.

[31] www.treesthatcount.co.nz
[32] Published by Statista Research Department, Jul 15, 2024

- **Biodiversity credits** refer to measurable biodiversity co-benefits provided by a project or activity, which can be used as an offset to support 'nature-positive' claims.

Although a relatively nascent market a not currently recognised under the New Zealand Emissions Trading Scheme (NZ ETS), recognition and financial return for high quality blue carbon and biodiversity credits through the Voluntary Carbon Market (VCM) is quickly gaining momentum internationally. Accordingly, interest in these nature-based markets is building within New Zealand, with collaborative effort across government, iwi, non-government organisations, researchers, and landowners to share information and create market opportunities (Jacobs, 2024).

Initial analysis of New Zealand blue carbon opportunity estimates New Zealand's current national blue carbon stock at approximately 2.66-3.76 megatonnes of carbon, with a likely carbon sequestration rate of 50,000-260,000 tonnes of CO_2 per annum (Ross *et al,* 2023). As reference, an NZU carbon credit (representing one tonne of carbon removed and stored) trades at $61.80 at time of writing. Recent research into blue carbon market activity indicates that there is the potential demand for New Zealand sourced blue carbon credits from both domestic and international buyers, with demand anticipated to increase in line with global trends (Claes *et al,* 2022). While complex land tenure and carbon rights present a key challenge for recognising blue carbon credits in New Zealand, as this NbS intervention considered the restoration of wetland areas on existing land tenure as opposed to public land and waters. Accordingly, many of the tenure-related challenges may not be experienced.

Additionally, when undertaking NbS development rather than solely pursuing carbon sequestration outcomes, the generation of carbon credits can also deliver biodiversity co-benefits. These biodiversity benefits may be applied to support carbon credits from NbS to yield a premium price (well above the average NZU trading price) or be recognised as standalone biodiversity credits. The potential price premium added by biodiversity credits reflect the positive narrative that can be used in corporate sustainability reporting and product marketing. The Ministry for the Environment recently consulted on the opportunity to facilitate growth of biodiversity credit systems in New Zealand, receiving overall strong support (Mfe, 2024).

Figure 19: Thomsons wetland planting, Otago. Source: Manuherekia Catchment Group

5.3.5 What are the potential impacts, benefits, and trade-offs wetland construction and restoration may have in the catchment, alongside productive rural land uses and as part of Kāti Huirapa ki Puketeraki's takiwā?

The NbS intervention of wetland restoration and construction align with the identified values and strategies of the Toitū Te Hakapupu Catchment Action Plan (CAP) (Ahikā, 2023). The relevant values and strategies are detailed below.

Value 1: Waterways

Value 1 of the draft Toitū Te Hakapupu CAP recognises that 'Waterways in the catchment and the estuary wetland complex provide important habitat and eco-system services'. However, these important habitats and ecosystem services are under pressure from the effects of erosion and sedimentation, particularly from pastoral farming and plantation forestry operations within the catchment reducing water quality and causing degradation to the estuary wetland complex.

The NbS intervention of wetland restoration and construction would contribute benefits towards the enhancement of Value 1, specifically aligning with the following draft CAP strategies:

- S1A. Levels of contaminants and sediment entering waterways and estuary wetland complex will be reduced, in accordance with target attributes states set out in the Land and Water Regional Plan (LWRP)
- S1E. Natural functioning of the estuary wetland complex will be enhanced, where there is landowner agreement

The restoration and construction of wetland areas identified in the catchment can support reducing the contaminants and sediment entering the estuary wetland complex. An appropriately maintained wetland occupying 1-5% of the catchment area, with sediment ponds developed at the inlet of wetland areas, on average should remove 50-90% respectively of the long-term sediment inputs through a range of physical, chemical, and biological processes (Tanner *et al,* 2021).

Suspended sediments being transported through the catchment from upper catchment operations and stream bank erosion are primarily removed in a constructed wetland by settling and deposition. Larger sand and soil particles will deposit in the inlet sediment pond, while the finer silt and clay sediments will be dispersed through the wetland where they may be removed through biological and chemical processes.

Additionally, dissolved nitrates present in agricultural runoff from pastoral farming activities can be removed by a restored and constructed wetland through biological processes, such as microbial de-nitrification and plant uptake. For cool climate zones, such as the Otago Region, the median nitrogen removal rates for a well-maintained wetland occupying 1-5% of catchment area range from approximately 20% to 40% respectively (Tanner *et al.* 2021).

The NbS intervention of wetland restoration and construction would also support enhancement of the estuary wetland area by increasing the spatial extent of the wetland area within its historic natural extent. At 84 ha, the estuary wetland complex has significantly reduced in size from its likely historic extend, to approximately 2% of its historic size. By considering the extension of the estuary wetland complex at its northern and western

present-day extend, a wetland restoration and construction NbS would seek to enhance the natural functioning of the complex. Growth of the wetlands within these locations would serve to increase the wetlands natural function of removing and processing suspended sediments and contaminant being transported downstream from developed productive lands.

Value 2: Biodiversity

Value 2 of the Toitū Te Hakapupu CMP recognises that 'Biodiversity within the catchment provides important habitat, ecosystem services, and landscape amenity'. However, these important habitats, ecosystem services, and landscape amenity are under pressure from land clearance, modification, and pest and weed species in the catchment. The NbS intervention of wetland restoration and construction would contribute benefits towards the enhancement of Value 2, specifically aligning with the draft CAP strategy:

- S2A. Existing remnants of indigenous vegetation and wetlands will be identified, protected, and enhanced

In alignment with S2A, the NbS intervention of wetland restoration and construction would contribute to the increase of indigenous vegetation and wetland area in the catchment. Through either the dedicated sourcing and planting of indigenous plant species or fencing and maintenance to facilitate the natural expansion of remnant indigenous wetland plant species, wetland restoration and construction delivered at scale within Te Hakapupu would significantly increase indigenous vegetation and wetland area. By connecting restored and constructed wetland areas to the existing Estuary Wetland Complex, protection and enhancement of indigenous vegetation and wetland area would likely increase the habitat availability for important biodiversity values.

Value 3: Cultural significance

Value 3 of the Toitū Te Hakapupu CMP recognises that 'the catchment is part of Kati Huirapa ki Puketeraki's takiwā and is culturally significant', however, mana whenua have lost access to large parts of the catchment, and cultural values are degraded. The NbS intervention of wetland restoration and construction would contribute benefits towards the enhancement of Value 3, specifically aligning with the following draft CAP strategy:

- S3A. Water quality and habitat will be protected and enhanced with a focus on mahika kai and taonga species so that abundance is sufficient to support cultural practices

The NbS intervention of wetland restoration and construction seeks to enhance the mahika kai values of Te Hakapupu/Pleasant River Estuary Wetland Complex. Historically, the estuary wetland complex has been rich source of mahika kai for Puketeraki whānau, with freshwater migratory species such as Kōkopu, Īnaka, and Tuna being found in the catchment's freshwater environments and Pātiki, Kahawai, and Aua being found in the marine estuary. Wetland restoration and construction in connection to the existing estuary wetland complex would seek to enhance the habitat availability and quality for mahika kai species present. Additionally, by increasing the extent of the estuary wetland complex further inland, the NbS would help increase the resilience of mahika kai to the effects of sea-level rise, coastal inundation, and increased salinity stress, noting that Tuna, Banded kōkopu, and Īnaka are all ranked highly vulnerable to the effects of climate change (Egan *et al.* 2020).

5.3.6 How does wetland construction and restoration adapt to and/or help mitigate the effects of climate change in the catchment?

Climate change adaptation

Wetland restoration and construction in the lower catchment areas identified in this NbS intervention, would help increase the resilience of the catchment to the future effects of climate change. As illustrated in Map 6, the lower catchment is exposed flood hazards associated with coastal inundation.

With minor vertical land movement (0.7± 2.2mm/year) at the estuary mouth, relative sea-level rise is projected to occur in line with national sea rise rates, with 0.21m of relative sea-level rise projected by 2050 and 0.74m by 2100 (under scenario SSP5-8.5 50th percentile). As a result, the catchment's estuary wetland complex is likely to be exposed to increasing salinity stress and coastal inundation from the effects of more frequent and intense coastal storm surges, causing flooding of inland areas.

By locating wetland construction and restoration NbS within areas exposed to future coastal inundation during storm surge events, this NbS serves to increase climate resilience through two key approaches:

- Reducing the exposure of existing productive agricultural landholdings to more frequent and severe coastal inundation events through the managed retreat of farming activities and infrastructure away from these areas.
- Providing additional habitat for wetland biodiversity values unable to cope with increasing salinity stress from rising sea levels to accommodate migration further inland, less exposed locations.

Wetland restoration and construction within these locations, effectively increasing the inland extent of the estuary wetland complex, will help buffer the effects of relative sea level rise and avoid the 'coastal squeeze' of critical biodiversity values within the catchment. Furthermore, this NbS would likely increase the connectivity between coastal, estuary, and wetland ecosystems, allowing greater potential for the gradual retreat and reorganisation of habitats to suit the changing environment over time.

Climate change mitigation

As a NbS, changing land use from agricultural to wetland would provide a net-carbon benefit. Acknowledging the high sustainability of New Zealand's agricultural sector, comparative to international producers, on average, sheep and beef farming in New Zealand emits 3.6 tonnes of greenhouse gases per hectare per year (between 0.16-7.1 tonnes/ha/year) (MfE, 2024). As discussed in the Land Use Change Cost and Benefits section, restoration and construction of wetlands as a NbS presents climate change mitigation opportunities, through the sequestration and storage of carbon dioxide (CO_2).

While significant gross reductions in gross greenhouse gas emissions is required to mitigate the effects of climate change, growth of permeant CO_2 removals is required to avoid the most severe effects of climate change. Wetlands are considered efficient carbon stores, with the ability to store significant volumes of carbon in plant biomass and sediments.

Although the specific carbon removal capability of wetlands still requires further research and site-specific analysis to quantify, an initial analysis of national blue carbon stocks (across

wetland, mangroves, salt marches, and sea grass) estimates current national carbon at approximately 2.66-3.76 megatonnes of carbon, with a likely carbon sequestration rate of 50,000-260,000 tonnes of CO_2 per annum (Ross *et al,* 2023).

5.3.7 Is wetland construction and restoration consistent with consenting requirements and key legal or policy considerations?

Land ownership characteristics

Of the approximate size identified within the wetland restoration and construction area; there are 24 titles of land which are owned by 17 landowners. Two of those owners are public entities – the Otago Regional Council and Waitaki District Council. The remaining landowners are private owners.

Regulatory implications of NbS

Based on the current high-level understanding of the works associated with NbS intervention of wetland restoration and construction within the Hakapupu catchment, it is anticipated that the works might entail:

- Restoration and enhancement of the existing wetland
- Construction of new wetland areas
- Associated earthworks
- Planting of vegetation (potential within existing wetlands and riparian areas)
- Removal of existing vegetation (which may or may not be pest plant species, but is assumed that no indigenous vegetation will be removed)
- Potential take, damming, or diversion of water
- Discharge of water

A summary of the potential consenting requirements associated with these activities under the relevant regulatory instruments is set out in Appendix 6.

Policy considerations for NbS

An overview of the policy direction relevant to the NbS intervention of wetland restoration and construction is set out below:

National Policy Statement – Freshwater

The objective of the NPS-FM is to ensure that natural and physical resources are managed in a way that prioritises:

- First, the health and wellbeing of water bodies and freshwater ecosystems
- Second, the health needs of people
- Third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.

Related policies of relevance to this proposed NbS include that freshwater is managed as part of an integrated response to climate change;[33] and that there is no further loss of natural inland wetlands, their values are protected, and their restoration is promoted. [34]

National Policy Statement – Indigenous Biodiversity

The NPS-IB has an overarching objective of maintaining indigenous biodiversity across Aotearoa New Zealand so that there is at least no net loss in indigenous biodiversity after the commencement date of the NPS-IB. Related policies seek to promote and provide for the restoration of indigenous biodiversity, [35] and to promote increased vegetation cover in both urban and non-urban environments.[36]

Otago Regional Plan: Water

Objectives and policies in the Otago Regional Plan: Water seek to recognise, sustain, maintain and enhance wetlands within the region. [37] This includes by identifying Regionally Significant Wetlands in accordance with specific criteria;[38] and promoting the conservation, creation and reinstatement of wetland areas. [39] Maintaining the passage of fish, and improving the passage of fish, is also recognised as an objective which could be relevant in relation to this NbS depending on the ultimate design of the proposal. [40]

Restoration of the ecological and cultural values of degraded waters is recognised as a fundamental principle of Māori environmental management in the Otago Regional Plan: Water.[41] Similarly, the Otago Regional Plan: Water notes that many wetlands of significance to Kai Tahu have been lost, and their loss could continue. [42]

Dunedin District Plan

Objectives and policies in the Dunedin District Plan seek to maintain or enhance biodiversity values, including by encouraging conservation activity across the district. [43] The clearance of vegetation within setbacks from wetlands is managed to ensure biodiversity values are maintained or enhanced and that there is no reduction in the extent of natural wetlands. [44]

Waitaki District Plan

The Waitaki District Plan identifies ongoing modification and degradation of nature conservation values in the district as one of the key issues within the Rural parts of the district.[45] Related objectives seek to maintain biodiversity, nature conservation values and ecosystem functioning; as well as the quality of water, wetlands, lakes, rivers and their margins. [46]

Overall, wetland restoration and construction would be generally consistent with the policy direction of the NPS-FM; Regional Plan: Water; the Waitaki District Plan; and the Dunedin District Plan.

---

[33] NPS-FM Policy 4
[34] NPS-FM Policy 6
[35] NPS-IB Policy 13
[36] NPS-IB Policy 14
[37] Otago Regional Plan: Water, Objectives 10.3.1 and 10.3.2
[38] Otago Regional Plan: Water, Policies 10.4.1 – 10.4.2.A
[39] Otago Regional Plan: Water, Policy 10.4.6
[40] Otago Regional Plan: Water, Objective 8.3.4
[41] Otago Regional Plan: Water, Clause 4.13.8
[42] Otago Regional Plan: Water, Clause 4.13.6
[43] Dunedin District Plan Objective 10.2.1 and Policy 10.2.1.5
[44] Dunedin District Plan Policy 10.2.1.Z
[45] Waitaki District Plan Issue 8
[46] Waitaki District Plan Objectives 16.9.2(1) and (2)

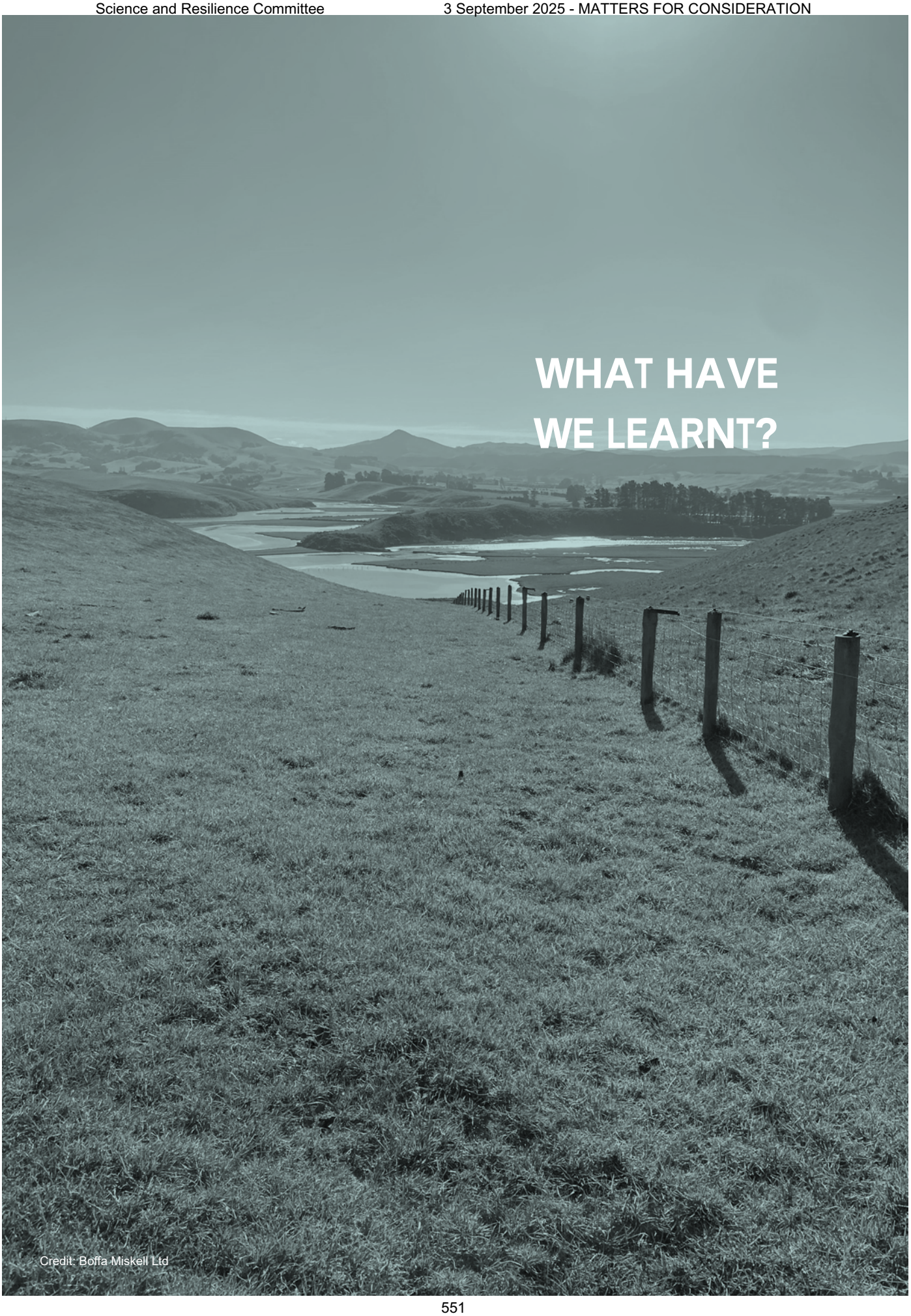
5.3.8 Summary of wetland restoration and construction as a nature-based solution

Opportunities

- This NbS intervention at sufficient scale would effectively accommodate excess flood flows in areas amenable to hydrological restoration and reduce contaminants entering the lower estuary wetland complex.
- With the creation of water retention and detention ponds, wetland areas can buffer downstream flows during flood and drought conditions.
- Provide habitat for greater ranges and larger populations of native species, including mahika kai species, and support the retreat of aquatic species from the impacts of sea-level rise.
- Wetland restoration and construction can provide for blue carbon and biodiversity credit opportunities in emerging markets by creating measurable enhancements in carbon storage and biodiversity values.
- The NbS is broadly consistent with national and local policy and planning direction, although requiring potentially complex consenting requirements when working in waterways.

Challenges

- With sedimentation pressures in the catchment, wetland areas would require bi-annual maintenance of sediment ponds to ensure functionality is retained.
- Wetland areas can often be highly invaded by aggressive pest plant and fish species, diminishing biodiversity values.
- Without cost-benefit sharing or realisation of nature-based market opportunities, would cause loss of economic value to landowner.
- Would require action of up to 17 landowners to be implemented across lower catchment.


WHAT HAVE
WE LEARNT?
Credit: Boffa Miskell Ltd

6. WHAT HAVE WE LEARNT?

6.1 FEASIBILITY OF NATURE-BASED SOLUTIONS FOR FLOOD MANAGEMENT

NbS present an integrated solution to effectively address the interconnected challenges of flood hazards, biodiversity loss, and land degradation within Te Hakapupu catchment. As a large and highly modified coastal Otago catchment, Rapid Flood Hazard Modelling developed for this feasibility study projects flood waters to be quickly transported from the steeper upper catchment areas, along well-entrenched waterways, to cause surface flooding in historically drained wetland areas in the lower catchment. With the upper catchment of Te Hakapupu dominated by exotic plantation forestry and mid catchment predominantly pastoral farming land uses, flood waters transport contaminants, causing additional flood-related impacts as they discharge into the ecologically and culturally significant Te Hakapupu Estuary Wetland Complex

The NbS tested in this feasibility study considered interventions that worked with the natural landscape and catchment hydrology to address flood hazards in a sustainable way and at scale. The NbS tested were all assessed to effectively mitigate flood-related hazards within the catchment, while possessing the potential to deliver benefits to biodiversity values, cultural values, natural landscape character, and local community catchment management plan targets. Additionally, these NbS were assessed to broadly align with national and local policy and planning requirements, although likely requiring potentially complex consenting requirements particularly when working in water ways.

While NbS interventions have been tested to be technically feasible and beneficial for addressing flood hazard and other challenges experienced within Te Hakapupu catchment, their potential use likely faces significant social and economic barriers. Requiring cooperation of over twenty or more individual landowners, all NbS require a substantial change in land use from productive agricultural or forestry uses.

Given the flood-related hazards are modelled to occurring in the mid and lower Te Hakapupu catchment locations, under current governance practices the direct economic costs incurred to individual landowners in implementing a NbS do not often generate a direct individual benefit. This is expected to create inequities in sharing the costs and benefits across effected landowners within the catchment. The sharing of economic costs and benefits is a common challenge experience by NbS practitioners globally and requires careful attention to ensure NbS are used sustainably and equitably.

Accordingly, any undertaking of NbS for flood hazard mitigation within Te Hakapupu catchment must first ensure that the governance framework for any intervention is well defined and economic incentives are available through alignment with nature-based market opportunities as much as practicable.

6.2 FEASIBILITY STUDY KEY FINDINGS

NbS are technically feasible in Te Hakapupu/Pleasant River catchment

Nature based solutions are technically feasible as methods for the management of flooding and associated hazards in Te Hakapupu/Pleasant River catchment and across the wider Otago region. NbS will work to influence the natural processes across the catchment to effectively control and accommodate floodwater, and their use should be promoted as a method of flood risk mitigation.

Landcover management in the upper catchment is the first step

Implementing land cover management NbS in areas of the upper Te Hakapupu/Pleasant River catchment is crucial for reducing flood-related risks, which tend to increase during forestry activities, such as forestry harvesting and replanting. While addressing the current level of hazards is essential, it is equally important to prevent conditions from worsening. Without permanently restoring and maintaining the hydrology of the upper catchment, through land management practices, the flood risk in the Te Hakapupu/Pleasant River catchment is expected to increase significantly, recurring in line with harvest and replanting 'windows of vulnerability'.

NbS work most successfully when applied at scale

In a large catchment like Te Hakapupu/Pleasant River, to sufficiently manage flooding and associated hazards NbS should be applied at a suitably large scale. NbS are most effective when implemented over larger areas or broader contexts, and while small-scale NbS projects can be useful, scaling them up maximises their ecological, economic, and social benefits. This would require large land use changes from farming and forestry in Te Hakapupu/Pleasant River catchment. In general, small-scale interventions will cost more per hectare and generate less benefits that a large-scale intervention.

Integrated NbS provide enhanced benefits

Nature-based solutions (NbS), such as river naturalisation and wetland construction, need to function in an integrated manner, from Ki Uta Ki Tai (mountains to the sea), across the catchment, connecting with each other and with surrounding land uses. At scale, interconnected nature-based solutions are essential for effectively managing flood hazards, working as a cohesive network to maximise their impact. Integrated NbS also provide significant benefits for biodiversity, landscape, amenity, and recreation, while also contributing to regional climate change adaptation and mitigation goals.

Innovation is required to ensure NbS are economically viable

The current economic and funding framework presents one of the greatest challenges to NbS implementation across Te Hakapupu/Pleasant River catchment. The direct cost and financial burden to landowners of implementing NbS, coupled with the resulting loss of productive land currently used for forestry and farming, makes at large-scale NbS financially unviable for many forestry and farming landowners in the catchment.

To support large-scale adoption of NbS and to help landowners benefit financially from NbS, especially across areas of productive forestry and farming land use like Te Hakapupu/Pleasant River catchment, innovative economic approaches are needed. This will require strong governance and political backing, as well as economic support and financial assistance, from both the private and public sectors. This could involve financial incentives for landowners, such as payments for environmental benefits and cost sharing initiatives and programmes.

6.3 RECOMMENDED ACTIONS

The following actions are recommended to facilitate the practical implementation of NbS in Te Hakapupu/Pleasant River catchment and other similar catchments across the Otago region.

The recommended actions consist of actions that ORC can lead and deliver at a regional scale; however, most would benefit from engagement and collaboration with other parties, including central government agencies to ensure national consistency, financial institutions, and funding partners to help address economic barriers, and landowners, mana whenua, district council within the Otago Region and local communities to ensure local buy-in.

Action 1: Strengthen NbS governance and partnerships

Develop and apply robust governance and partnership approaches for NbS alongside landowners, businesses, mana whenua and financial institutions to ensure the costs and decisions for NbS design and implementation are shared fairly.

To support the national and regional policy direction relating to NbS use in the Otago region, NbS governance and partnership approaches should seek to achieve the following outcomes:

- Define how the direct costs and benefits from NbS that span different locations, land uses, tenures, and vested interests will be equitably shared
- Define how under-represented groups and effected people will be engaged throughout NbS development processes
- Identify private and public financial investment opportunities, including green bonds and sustainability-linked loans
- Define clear decision-making process and accountabilities for NbS development and ongoing maintenance, where NbS span different locations, land uses, tenures, and vested interests

The development and application of robust governance and partnership approaches for NbS that can be applied in the Otago region would help address the economic barriers that limit the practical feasibility of NbS use.

This recommended action would ensure that individual landowners are not overburdened by the costs of establishing and maintaining NbS on their land, particularly given the primary beneficiaries of NbS for hazard management are often not the direct landowner. Additionally, robust governance practices would ensure any economic benefits gained from NbS are appropriately attributed to the parties that invested their land, time, and money.

Action 2: Facilitate economic incentives for landowners

To address the potential economic impacts that may be experienced when landowners change land uses, particularly from changing primary production lands to NbS land uses (e.g. retiring productive farmland to become wetland), a model for economic incentives should be considered. Develop and implementing a model that provides economic incentives to landowners could include mechanisms such as payments for ecosystem services, grants, tax incentives, carbon credit sales and revenue from ecotourism.

Internationally, economic incentives are successfully used at national and regional scales to financially support landowners to undertake capital works and land management activities for the purposes of natural hazard mitigation and conservation.

Examples of these include:

- The Scottish Rural Development Programme, where government bodies offer funding packages for projects where land is used or maintained to provide benefits for water or biodiversity.[47] Funding packages are target high value areas to support landowners to undertake capital works and land management for environmental purposes, such as woodland afforestation. Funding is provided as either a one-off payment for capital works, or annual payments for specific land management options (e.g. floodplain management).

- The U.S Department of Agriculture's Agricultural Conservation Easement Programme helps landowners, land trusts, and other entities protect, restore, and enhance wetlands or protect working farms and ranches through conservation easements.[48] This supports landowners to restore and protect areas from the impacts of farming and development through the creation of easements. The government agency funds up to 100% of the easement value for the purchase of the easement and help funds restoration costs on the easement.

The development of similar economic incentive models for the Otago Region would provide significant benefits to overcoming the economic challenges currently facing NbS implementation. Additionally, the targeted application of a regional economic incentive model that focuses on areas of high risk or of high biodiversity value, could support the use of NbS in priority locations, helping to achieve other environmental benefits.

[47] Scottish Rural Development Programme (SRDP) - Agricultural payments: Common Agricultural Policy (CAP) - gov.scot
[48] Agricultural Conservation Easement Program | Natural Resources Conservation Service

Action 3: Promote nature-based credit markets

This recommended action aims to increase understanding and use of nature-based markets for ecosystem services, helping to attract private investment in NbS across Otago. One example is enabling private companies to "purchase" NbS and associated carbon and biodiversity credits to offset their carbon emissions.

To improve financial incentives for NbS and boost private investment in the region, efforts are needed to build greater recognition and trust in these nature-based markets for landowners. While central government is already working to enhance the New Zealand Emissions Trading Scheme (ETS) for afforestation, exploring other carbon removal methods, and supporting a biodiversity credit system, regional efforts will further advance these initiatives.

In addition, established catchment or landscape-scale restoration projects, like Toitū Te Hakapupu Restoration Project, could serve as pilot sites to test and scale nature-based credit market opportunities in New Zealand.

Actions to support use of nature-based credit markets at the Otago catchment scale could also include:

- Identification of biodiversity credit pilot opportunities for existing well-established landscape scale restoration project across the Otago region, along with the monitoring and reporting requirement likely required to meet biodiversity credit market verification standards.
- Assessment of afforestation carbon values across a catchment and identification of opportunities for carbon credits either through the New Zealand ETS or via credible Voluntary Carbon Markets.
- Building on the indicative outcomes from DairyNZ and NIWA’s assessment of productive riparian areas, conduct an assessment at catchment or district scale of the potential applications of productive riparian areas on Otago farms to understand the likely costs, economic opportunities, and optimal application of establishing economically productive riparian buffer areas on farm.
- Catchment scale analysis of saltmarsh and wetland areas to understand the blue carbon stock currently held within the catchment wetland and estuarine environments, and blue carbons stock change potential under different wetland restoration and enhancement scenarios.

Using nature-based credit markets to encourage landowners to invest in NbS will be crucial for overcoming the economic barriers that currently limit the adoption and long-term maintenance of these solutions.

Action 4: Develop regional NbS policy, standards, and guidance

Otago NbS practice standards, guidance and policy should be developed to support private landowners to actively adopt and implement NbS on their own properties. Standardised NbS practice and guidance would ensure that NbS used by a landowner are applied consistently across the Otago region, allowing NbS to function in an integrated manner to deliver greater benefits. This includes providing comprehensive guidance for NbS planning, addressing the required consenting pathways to streamline implementation.

Examples of Otago NbS practice policy, standards, guidance could include:

- Identification of the common NbS that can be used to mitigate natural hazards experienced in the Otago region and within a catchment.
- Promoting benefits of wide scale application if NbS and embedding information regarding the outcomes that can be provided by NbS into relevant regional policy
- NbS design standards and criteria to inform how they are implemented
- Guidance of the relevant policy and consenting requirements for common NbS, particularly for interventions in and around waterways, and support to facilitate NbS planning progress through the relevant consenting pathways
- Links to available NbS design and implementation tools and resources, including regional GIS resources and funding opportunities.

Otago NbS practice policy, standards and guidance would help community users to ensure their NbS work cohesively across the catchment and are able to function in an interconnected way to generate greater benefits. Additionally, by providing NbS policy and planning guidance, NbS users would be supported to navigate the required consenting needs to implement NbS in alignment with national and local policy direction.

Action 5: Integrate NbS into catchment scale management and planning

Nature base solutions should be planned for and integrated within the Te Hakapupu Catchment Action Plan, and for other similar Otago region catchments through Integrated Catchment Management Planning (ICMP) processes.

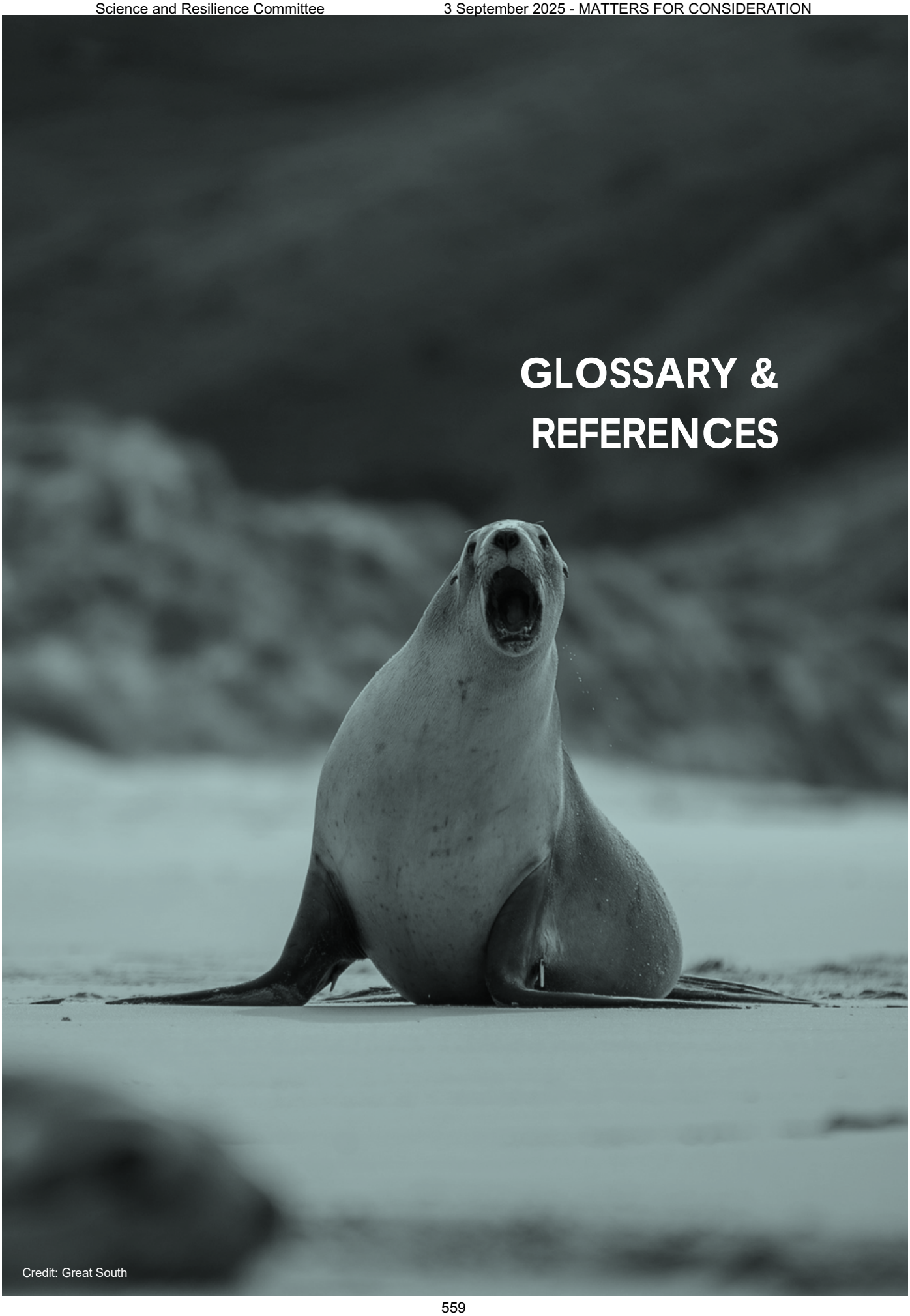
ICMP's are intended to be tools for managing natural resources on a catchment scale, looking at the ecosystems and land uses from the mountains to the sea. Accordingly, the integration of NbS planning within ICM programmes will be effective to ensuring NbS are designed and enabled at the correct scale to address natural hazards and work cohesively with catchment land uses and community values.

Key aspects of NbS integration within ICMP processes could include:

- Hydrology modelling of the catchment to understand the flood hazard characteristics under a diversity of climate change scenarios and timeframes (including a do-nothing scenario). Scenarios should consider the impacts of extreme rainfall events, relative sea-level rise, and coastal inundation events to people, property, and ecosystems.
- Spatial analysis of the catchment to identify the location, extent, and type of remnant indigenous vegetation present in the upper, mid, and lower catchment. Remnant indigenous vegetation areas identified should be assessed to understand their potential for indigenous habitat expansion through protection and enhancement measures.
- Identification of the type, scale, and optimal locations of NbS required to effectively mitigate natural hazards present in the catchment. This should include identification of where NbS should be applied as a single large intervention, or where they can be applied as a series of smaller interconnected solutions.

Integration of NbS within ICM programmes will help ensure NbS interventions are planned and implemented at an appropriate scale, relative to the size of the catchment and magnitude of the hazards and are able to function in an interconnected way to generate greater benefits.

GLOSSARY & REFERENCES



Credit: Great South

7. GLOSSARY

Table 7: Glossary to key terms relating to Nature-based Solutions

TERM	DEFINITION
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects. (IPCC, 2022)
Biodiversity	The variability among living organisms from all sources, including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. (Convention on Biological Diversity, 2006)
Biodiversity Credits	A type of economic instrument that recognises in a consistent way projects or activities that provide positive outcomes for biodiversity, against which 'nature-positive' claims can be made. (MfE, 2023)
Blue Carbon	Blue carbon is the carbon stored in coastal and marine ecosystems. Coastal ecosystems such as mangroves, tidal marshes and seagrass meadows sequester and store more carbon per unit area than terrestrial forests and are now being recognised for their role in mitigating climate change. (IUCN, 2017)
Climate Change	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. (IPCC, 2022)
Exposure	The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected. (IPCC, 2022)
Green Infrastructure	A strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings (UNEP Glossary)
Grey Infrastructure	Term used to describe engineered water and hazard management structures such as reservoirs, embankments, pipes, pumps, water treatment plants, and canals (NIWA, 2024)
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. (IPCC, 2022)

Impact	The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial. (IPCC, 2022)
Maladaptation	Any changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead. (IPCC, 2022)
Nature	A holistic term that encompasses the living environment (te Taiao), which includes all living organisms and the ecological processes that sustain them. By this definition, people are a significant part of nature. This document uses the term 'biodiversity' to refer to biological diversity and 'nature' for the wider processes, functions, and connections in the natural environment, of which biodiversity is a part. (MfE, 2023)
Resilience	The capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation. (IPCC, 2022)
Risk	The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social, and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure, and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making. (IPCC, 2022)
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. (IPCC, 2022)
Water Sensitive Urban Design	Water Sensitive Urban Design - an approach used in urban greening which adopts nature-based solutions (NBS) and ecosystem-based adaptation (NIWA, 2024)

8. REFERENCES

Ahikā Consulting Limited, 2023: Toitū Te Hakapupu – Pleasant River Catchment Restoration Project: Initial mapping of sediment sources, movement pathways and deposition areas of the Te Hakapupu catchment, eastern Otago. Report prepared by Ahikā Consulting Ltd for Otago Regional Council

Ahikā Consulting Limited, 2023: Toitū Te Hakapupu/Pleasant River Restoration Project: Results of monitoring up to 30 June 2023. Report prepared by Ahikā Consulting Ltd for Otago Regional Council

Ahikā Consulting Limited, 2024: Toitū Te Hakapupu/Pleasant River Restoration Project: Forestry Action Plan. Report prepared by Ahikā Consulting Ltd for Otago Regional Council

Beef & Lamb New Zealand, & Federated Farmers, 2020: Factsheet: B+LNZ & Federated Farmers' assessment of the new essential freshwater rules.

Claes, J., Hopman, D., Jaegar, G., & Rogers, M. 2022: Blue Carbon: The potential of coastal and oceanic climate action. Report prepared for McKinsey and Company.

Climate Change Commission. 2021d: Ināia tonu nei: A low-emissions future for Aotearoa. https://www.climatecommission.govt.nz/public/Inaia-tonu-nei-a-low-emissionsfuture-for-Aotearoa/Inaia-tonu-nei-a-low-emissions-future-for-Aotearoa

Climate Change Commission, 2024: Progress report: National Adaptation Plan – Assessing progress on the implementation and effectiveness of the Government's first national adaptation plan (August 2024)

Daigneault, A. J., Eppink, F. V., & Lee, G. W. 2017: A national riparian restoration programme in New Zealand: Is it value for money? Journal of Environmental Management, Volume 187, 2017, Pages 166-177, ISSN 0301-4797. https://doi.org/10.1016/j.jenvman.2016.11.013.

Dale. M & Rata te Raki. J, 2024: Fish Passage Assessment of the Hakapupu (pleasant) River. Report prepared by Waterscape Connections Ltd for Kāti Huirapa Rūnaka ki Puketeraki.

de Lange, P. J., Rolfe, J. R., Barkla, J. W., Courtney, S. P., Champion, P. D., Perrie, L. R., Beadel, S. M., Ford, K. A., Breitwieser, I., Schönberger, I., Hindmarsh-Walls, P. B., Heenan, P. B., & Ladley, K. 2018: Conservation status of New Zealand indigenous vascular plants, 2017 (New Zealand Threat Classification Series No. 22). Department of Conservation.

Egan, E., Woolley, JM., Williams, E. 2020: Climate Change Vulnerability Assessment of selected taonga freshwater species. Report prepared by NIWA for Te Wai Māori Trust.

Extreme sea level flood maps (1% AEP and up to 2m sea-level rise) for Aotearoa by referencing this publication as appropriate: Paulik, R., Wild, A., Stephens, S., Welsh, R., Wadhwa, S. 2023: National assessment of extreme sea-level driven inundation under rising sea levels. Frontiers in Environmental Science, 10, 2633, https://doi.org/10.3389/fenvs.2022.1045743.

Forrest BM, Roberts, KL, Stevens LM. 2022. Fine Scale Intertidal Monitoring of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 093, prepared for Otago Regional Council, June 2022. 29p.

Griffiths. J., Semadeni-Davies. A., Borne. K., & Tanner. C. 2024: Nature-based solutions for flood management: Literature Review. Report prepared by NIWA for Envirolink

International Union for Conservation of Nature (IUCN), 2024: State of ENACT NbS goals report: Year one roadmap. International Union for Conservation of Nature and Natural Resources Produced by: Climate Change Team - Centre for Economy and Finance

IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

IUCN (2020). Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First edition. Gland, Switzerland: IUCN

Jacobs Ltd, Environmental Accounting Services, Anderson Lloyd, and Conservation International. 2024: Coastal Wetland and Blue Carbon Policy Research in Aotearoa. Report prepared by Jacobs for The Nature Conservancy and Ministry for the Environment.

Leathwick, J., Mcglone, M., Walker, S., 2012: New Zealand's Potential Vegetation Pattern, Landcare Research

Leathwick, J., West, D., Gerbeaux, P., Kelly, D., Robertson, H., Brown, D., Chadderton, W., & Ausseil, A.-G. 2010: Freshwater Ecosystems of New Zealand (FENZ) Geodatabase Version One—August 2010 User Guide

Macara. G., Woolley. JM., Zammit. C., Pearce. P., Stuart. S., Wadhwa. S., Sood. A., & Collins. D, 2019: Climate change projections for the Otago Region. Report prepared by NIWA for Otago Regional Council

Matthews, Y., & Matheson, F. 2021: Productive Riparian Buffers Cost Benefit Analysis. Report prepared by NIWA for DiaryNZ

McKergow, L., Matheson, F., Goeller, B., Woodward, B. 2022: Riparian buffer design guide: Design to meet water quality objectives. NIWA Information Series 103. 16pp

Ministry for Primary Industries. 2023: A redesigned NZ ETS Permanent Forest Category: A discussion document on proposals to redesign the permanent forest category in the New Zealand Emissions Trading Scheme (NZ ETS). Wellington: Ministry for Primary Industries

Ministry for the Environment. 2024. Helping nature and people thrive: Exploring a biodiversity credit system for Aotearoa New Zealand – Summary of submissions. Wellington: Ministry for the Environment

Ministry for the Environment. 2024. New Zealand's Greenhouse Gas Inventory 1990–2022. Wellington: Ministry for the Environment

NZILA (2022) Te Tangi a te Manu Aotearoa New Zealand Landscape Assessment Guidelines.

Pohatu, P., O'Brien, S., & Mercer, L. 2020: Challenges and opportunities with native forestry on Māori land. Motu Economic and Public Policy Research. https://motuwww.motu.org.nz/wpapers/20_1

Roberts KL, Stevens LM, Forrest BM. 2022. Broadscale Intertidal Habitat Mapping of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 086, prepared for Otago Regional Council, June 2022. 57p.

Ross, F. W. R., Clark, D. E., Albot, O., Berthelsen, A., Bulmer, R., Crawshaw, J., & Macreadie, P. I. 2023: A preliminary estimate of the contribution of coastal blue carbon to climate change mitigation in New Zealand. New Zealand Journal of Marine and Freshwater Research, 58(3), 530–540. https://doi.org/10.1080/00288330.2023.2245770

Swales. A., Olsen. G., Handley. S., Ovenden. S., Marriner. A., & Brown. J. 2023: Sources of sediment depositing in the Pleasant River (Te Hakapupu) Catchment and Estuary. Report prepared by NIWA for Otago Regional Council

Tanner, C., Sukias, J., & Woodward, B. 2021: Technical guidelines for constructed wetland treatment of pastoral farm run-off. Report prepared by NIWA for DairyNZ

Tanner, C.C.; Depree, C.V.; Sukias, J.P.S.; Wright-Stow, A. E.; Burger, D.F.; Goeller, B.C. 2022: Constructed Wetland Practitioners Guide: Design and Performance Estimates. DairyNZ/NIWA, Hamilton, New Zealand.

Vigerstol K., N. Karres, S. Kang, N. Lilly, M. Massey-Bierman. 2023: Accelerating Adaptation: the promise and limitations of Nature-based Solutions in the race to adapt to increasing floods and droughts. The Nature Conservancy, Arlington, VA, USA

Williams, P. A., Wiser, S. K., Clarkson, B. R., & Stanley, M. C. 2007: New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework. New Zealand Journal of Ecology, 31(2), 119–128.

World Wildlife Foundation. 2022: Living Planet Report 2022 – Building a nature-positive society. Almond, R.E.A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (Eds). WWF, Gland, Switzerland.

World Wildlife Foundation & The International Labour Organization, 2020: Nature Hires - How Nature-based Solutions can power a green jobs recovery. WWF, Gland, Switzerland

World Wildlife Foundation New Zealand. 2024: A Nature Positive Aotearoa – Economic Analysis of Aotearoa New Zealand's Nature Opportunity. Report prepared by EY Limited for WWF

Yang, Y. & Cardwell, R. 2023: Otago Region Economic Profile for Land and Water. Otago Regional Council (LWRP Economic Work Programme), Dunedin.

Young D, Afoa E, Meijer K, Wagenhoff A, Utech C. 2013: Temperature as a contaminant in streams in the Auckland region, stormwater issues and management options. Prepared by Morphum Environmental Ltd for Auckland Council. Auckland Council technical report, TR2013/044

Together. Shaping Better Places.

Boffa Miskell is a leading New Zealand environmental consultancy with nine offices throughout Aotearoa. We work with a wide range of local, international private and public sector clients in the areas of planning, urban design, landscape architecture, landscape planning, ecology, biosecurity, Te Hīhiri (cultural advisory), engagement, transport advisory, climate change, graphics, and mapping. Over the past five decades we have built a reputation for creativity, professionalism, innovation, and excellence by understanding each project's interconnections with the wider environmental, social, cultural, and economic context.

www.boffamiskell.co.nz

Whangarei	Auckland	Hamilton	Tauranga	Wellington	Nelson	Christchurch	Queenstown	Dunedin
09 358 2526	09 358 2526	07 960 0006	07 571 5511	04 385 9315	03 548 8551	03 366 8891	03 441 1670	03 470 0460

Boffa Miskell

APPENDIX 1: NATURE-BASED SOLUTIONS

TECHNICAL SPECIFICATION

MARCH 2024

Boffa Miskell is proudly a
Toitū net carbonzero certified consultancy

DOCUMENT QUALITY ASSURANCE

BIBLIOGRAPHIC REFERENCE FOR CITATION:

Boffa Miskell, 2020. *APPENDIX 1: Nature-based Solutions Technical Specification*. Report by Boffa Miskell Limited for Otago Regional Council.

PREPARED BY:	Sam Parsons Climate Change Specialist Boffa Miskell Ltd	
REVIEWED BY:	Rachael Eaton Senior Principal | Landscape Design Boffa Miskell Ltd	
STATUS: FINAL	Revision / version: 1	Issue date: March 2024

Cover photograph: Te Hakapupu Catchment, © Boffa Miskell, 2023

CONTENTS

INTRODUCTION 3
DEFINITION 4
STANDARDS 4
FUNCTIONAL CRITERIA & PERFORMANCE INDICATORS 4
CRITERION 1 5
CRITERION 2 6
CRITERION 3 7
CRITERION 4 8
CRITERION 5 9
CRITERION 6 10
CRITERION 7 11
CRITERION 8 12

INTRODUCTION

The interest in Nature-based Solutions (NbS), particularly in addressing major challenges emerging from climate change, is growing in New Zealand and worldwide. This is evident in the growing number of investments in NbS development, and the inclusion of NbS in national strategies and international policy agreements, emphasising their importance in addressing the dual climate change and biodiversity crises.

Over the last decade, NbS have gained momentum internationally in research, policy, and practice, with greater recognition of the benefits these approaches can deliver to biodiversity and human wellbeing whilst addressing major societal challenges. NbS have become prominent through inclusion in the Ramsar Convention, UNFCCC, UNCCD (through COP 28) and the Convention on Biological Diversity – in particular the inclusion of two NbS targets in the Kunming – Montreal Global Biodiversity Framework. Nationally, NbS have become visible through inclusion as goals within Te Mana o Te Taiao - Aotearoa New Zealand Biodiversity Strategy 2020, and actions within New Zealand's National Adaptation Plan and Emissions Reduction Plan.

The purpose of this '*Nature-based Solution Technical Specification'* is to help achieve well-functioning and high quality NbS in New Zealand that are well integrated into environments. The specification has been developed in alignment with global standards and international agreements related to NbS to ensure solutions designed and implemented within New Zealand reflect existing best practices and facilitate reporting to relevant international agreements (i.e., the Kunming – Montreal Global Biodiversity Framework).

Two key outcomes are achieved within this specification:

- **Nature-based Solution Definition:** While internationally, agreement has been reached regarding the definition of NbS, nationally, a variety of definitions exist within strategy documents to-date creating ongoing misunderstandings and misinterpretations of NbS by decision-makers and stakeholders. Coherence and alignment of NbS definition on a global scale allows greater oversight and accountability of NbS use and benefits. Additionally, definition alignment supports the reduction of financing barriers of NbS.
- **Nature-based Solution Standards:** Without adherence to robust planning and implementation standards for NbS projects, significant maladaptation or unintended consequences may exist for local communities, mana whenua, national economies, and the resilience of indigenous biodiversity. NbS Standards, fit for New Zealand's unique environment, ensures NbS can be designed and implemented to address the specific requirements of local communities whilst delivering co-benefits.

Figure 1: Nature-based Solutions values - IUCN Global Standard for Nature-based Solutions 2020

DEFINITION

Nature-based Solutions are defined as **'actions to protect, sustainably manage, and restore natural and modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits.'**

- The global definition of Nature-based Solutions was formally agreed by governments at the United Nations Environment Assembly (UNEA) March 2022 (UNEA Resolution 5.5). The definition builds upon the International Union for Conservation of Nature (IUCN) definition of Nature-based Solutions, previously adopted at the 2016 World Conservation Congress and Member's Assembly.
- According to the IUCN, the social, economic, and environmental challenges that Nature-based Solutions can address include ensuring food security, water security, social and economic development, human health, climate change adaptation, and climate change mitigation.
- To differentiate a Nature-based Solution action from a conservation initiative, a Nature-based Solution that addresses biodiversity loss and ecosystem degradation should also address an additional societal challenge.

STANDARDS

The **'IUCN Global Standard for Nature-based Solutions, first edition'** is the most prominent global framework available to support the implementation of Nature-based Solutions. The Global Standard was adopted by 128 state and subnational members at the 2021 World Conservation Congress.

- The 'IUCN Global Standard for Nature-based Solutions' provides a common basis of understanding for Nature-based Solutions and provides a robust framework for Nature-based Solution intervention design, assessment, and implementation at scale.
- The 'IUCN Global Standard for Nature-based Solutions' is adaptable to the local, regional, and national social and ecological contexts, and focuses on achieving environmental, social, and economic goals in an integrated manner.
- The 'IUCN Global Standard for Nature-based Solutions' align with the UNEA definition for Nature-based Solutions, are assessed as a suitable operational framework for global implementation.

FUNCTIONAL CRITERIA & PERFORMANCE INDICATORS

Based on the '**IUCN Global Standard for Nature-based Solutions, first edition'**, the proceeding functional criteria for NbS and the performance indicators outline the standard NbS should seek to align with to ensure rigorous planning and monitoring has been conducted throughout the design and implementation of NbS.

- The Criteria and Performance indicators largely align with the IUCN Global Standards, with language and terminology adapted where appropriate to reflect New Zealand's context.
- The criteria provide measures to ensure all values and qualities are considered throughout NbS design and maladaptation and unintended consequences are mitigated, however this standard acknowledges that not all criteria will be achieved in all cases due to scale of projects and available resources.

CRITERION 1 NATURE-BASED SOLUTIONS EFFECTIVELY ADDRESS SOCIETAL CHALLENGES

Guidance: The purpose of Criterion 1 is to ensure that the NbS is designed as a response to societal challenges that has been identified as a priority by those who are or will be directly affected by the challenges. All stakeholders, especially mana whenua, land holders, and beneficiaries of the NbS, must be involved in the decision-making process used for identifying the priority challenges

CRITERIA 1 PERFORMANCE INDICATORS

Indicator 1.1 The most pressing societal challenges for mana whenua, land holders, and beneficiaries are prioritised

Guidance: The NbS intervention must address clearly specified challenges that have significant and demonstrable impacts on society. Identification of the most pressing societal challenges is best informed by a transparent and inclusive consultation process, as opinions may differ between external stakeholders and local populations and vice versa

Indicator 1.2 The societal challenges addressed are clearly understood and documented

Guidance: Establishing a clear understanding and rationale of the challenges to be addressed, and ensuring these are documented, is important for future accountability and optimising those strategies to contribute to human well-being outcomes. An NbS often yields multiple societal benefits, such as job creation or increased flow of ecosystem services, and the societal challenges these additional benefits address should also be documented.

Indicator 1.3 Human well-being outcomes arising from the NbS are identified, benchmarked, and periodically assessed

Guidance: NbS must deliver tangible and substantive benefits to human well-being. Specific, measurable, attainable, realistic, and timely (SMART) targets should be used as appropriate, as they are important for accountability and informing adaptive management

CRITERION 2 DESIGN OF NATURE-BASED SOLUTIONS IS INFORMED BY SCALE

Guidance: The purpose of this Criterion is to encourage NbS designs that recognise the complexity and uncertainty that occur in living dynamic land/seascapes. Scale applies not only to the biophysical or geographic perspective but also to the influence of economic systems, policy frameworks and the importance of cultural perspectives. Understanding the interactions which affect attributes like cultural values, laws, soils, forests, and water are important in this regard, as they are relevant to the assessment of the risk of undesirable change, or the probability of creating desirable change. NbS design seeks to maintain the productive capacity of ecosystems as well as the production of benefits necessary for human well-being (e.g., food production).

CRITERIA 2 PERFORMANCE INDICATORS

Indicator 2.1 The design of the NbS recognises and responds to interactions between the economy, society, and ecosystems

Guidance: The success of an NbS will be determined not only by the quality of the technical intervention but, critically, how well the interactions between people, the economy and the ecosystem are understood and responded to. For the solutions to be durable and sustainable, the design of NbS requires a “systems” framing that acknowledges and addresses these types of interactions and builds them into the decision-making process

Indicator 2.2 The design of the NbS is integrated with other complementary interventions and seeks synergies across sectors

Guidance: NbS will seek to work with and compliment other types of interventions, such as engineering projects, information technology, financial instruments, etc. Such complementary actions will inherently require the identification of synergies across different sectors according to the specifics and context of each situation

Indicator 2.3 The design of the NbS incorporates risk identification and risk management beyond the intervention site

Guidance: NbS has the potential to either positively or negatively impact, or be impacted by, stakeholders, interests, and ecosystems outside the immediate intervention area. For the solution to be durable and sustainable, such types of interactions both within and around the intervention area need to be understood and accounted for in the decision-making processes. Appropriate risk management options should be incorporated into the intervention design

CRITERION 3 NBS RESULT IN A NET GAIN TO BIODIVERSITY AND ECOSYSTEM INTEGRITY

Guidance: NbS are derived as goods and services from ecosystems, therefore strongly depend on the health of an ecosystem. Biodiversity loss and ecosystem change can have significant impacts on the functioning and integrity of the system. Therefore, NbS design and implementation must avoid undermining the integrity of the system and instead, proactively seek to enhance the functionality and connectivity of the ecosystem. Doing so can also ensure the long-term resilience and durability of the NbS

CRITERIA 3 PERFORMANCE INDICATORS

Indicator 3.1 The NbS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

Guidance: To develop a solution using nature, one must have a well-founded understanding of the current state of the ecosystems concerned. The baseline assessment needs to be broad enough to characterise ecological state, drivers for ecosystem loss and options for net improvements, making use of both local knowledge and scientific understanding where possible.

Indicator 3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked, and periodically assessed

Guidance: In order to inform the design, monitoring, and assessment of an NbS, targets for enhancing key biodiversity values should be established. For each NbS, the type of target may differ; for example, the target could be the percentage of ecosystem area restored or the return of a keystone species.

Indicator 3.3 Monitoring includes periodic assessments of unintended adverse consequences on nature arising from the NbS

Guidance: Ecosystems are complex with interdependent components and processes. There will always be a level of uncertainty in how they will react to specific interventions or other external changes. Therefore, NbS should be designed and monitored to minimise and mitigate unanticipated risks that might undermine the ecological foundations of the solution itself

Indicator 3.4 Opportunities to enhance ecosystem integrity and connectivity are identified and incorporated into the NbS strategy

Guidance: Utilising NbS can provide an opportunity to enhance biodiversity conservation and ecosystem management efforts in ways that other types of intervention, in isolation (such as engineering), will not be able to achieve. If solutions are to be implemented close to natural ecosystems that are managed explicitly for conservation outcomes, the NbS should be designed to enable greater ecosystem connectivity. Furthermore, they could be designed to re-introduce lost components of an existing ecosystem, for example, by deliberately choosing formerly existing species of vegetation when restoring

CRITERION 4 NBS ARE ECONOMICALLY VIABLE

Guidance: The return on investment, the efficiency and effectiveness of the intervention, and equity in the distribution of benefits and costs are key determinants of success for an NbS. This Criterion requires that sufficient consideration is given to the economic viability of the intervention, both at the design stage and through monitoring the implementation. If the economic feasibility is not adequately addressed, NbS run the risk of being short-term projects, where, after closing, the solution and benefits provided cease to exist, potentially leaving the landscape and communities worse off than before

CRITERIA 4 PERFORMANCE INDICATORS

Indicator 4.1 The direct and indirect benefits and costs associated with the NbS, who pays and who benefits, are identified, and documented

Guidance: Identification and documentation of the main benefits derived, including their direct and indirect, financial and non-financial elements are key components for assessing the economic feasibility of the intervention, over time. This information should be differentiated according to who receives the benefits and who bears the costs

Indicator 4.2 Cost-effectiveness is considered to support the choice of NbS

Guidance: Investing heavily in upfront costs without considering the longer-term economic and financial sustainability can negatively impact the intervention's viability. A cost-effectiveness study not only enables an examination of the upfront and recurring costs against the anticipated longer-term benefits of the proposed intervention(s) over time but also allows key (or hidden) assumptions to be made explicit, tested and verified

Indicator 4.3 The effectiveness of the NbS design is justified against available alternative solutions

Guidance: A key attribute of an NbS is that it is capable of addressing at least one societal challenge in a manner that is both economically viable and efficient. This means that the cost-effectiveness and affordability of the solution must be tested against viable alternatives. Alternative solutions may include a different nature-based solution (for example watershed catchment management rather than floodplain management), a different combination of conventional and nature-based solutions, or substitution of the nature-based solution entirely with a more conventional approach such as engineered infrastructure

Indicator 4.4 NbS design considers a portfolio of resourcing options and actions to support regulatory compliance

Guidance: The fact that NbS simultaneously offers multiple benefits to different stakeholders may place limits on some sources of financing, thereby undermining the interventions long-term viability. For example, private investors may not wish to bear the cost of delivering public goods or public authorities may be reluctant to cover costs for benefits that will accrue privately. This may require a resourcing package that integrates a range of financial mechanisms. Sources of investment can include public sector grants, incentives and low interest loans, private-sector loans and equity, blended public-private partnerships as well as philanthropic and voluntary contributions or combinations of the above, reflecting an equitable distribution of both the risks and returns

CRITERION 5 NBS ARE BASED ON INCLUSIVE, TRANSPARENT, AND EMPOWERING GOVERNANCE PROCESSES

Guidance: This criterion requires that NbS acknowledge, involve, and respond to the concerns of a variety of stakeholders, especially mana whenua and land holders. Good governance arrangements are proven to not only reduce an intervention's sustainability risks, but also to enhance its social 'license to operate'. At a minimum, NbS must adhere to and align with the prevailing legal and regulatory provisions, being clear on where legal responsibilities and liabilities lie. However, as often is the case with natural resources, basic compliance will need to be complemented with ancillary mechanisms that actively engage and empower mana whenua and local communities.

CRITERIA 5 PERFORMANCE INDICATORS

Indicator 5.1 Participation is based on mutual respect and equality, regardless of gender, age, or social status, upholds the right of mana whenua, and uphold the principles of the Treaty of Waitangi

Guidance: In order that governance arrangements function effectively, all affected stakeholders need to be equipped with the right information at the right time and the inputs they provide need to be meaningfully addressed. In doing so, a conscious effort is required to ensure that traditionally excluded groups are actively brought into the process in a manner that upholds their dignity and encourages their participation.

Indicator 5.2 Stakeholders who are directly and indirectly affected by the NbS have been identified and involved in all processes of the NbS intervention

Guidance: Stakeholder mapping and analysis identifies those who may be directly and indirectly, positively, or negatively, affected by the NbS. This allows the intervention to afford opportunities to affected stakeholders to engage with and participate in the design and implementation, advocate clearly to uphold their own rights and interests, and where necessary, prevent further marginalisation

Indicator 5.3 Decision-making processes document and respond to the rights and interests of all participating and affected stakeholders

Guidance: It is important that transparent and accessible documentation records key steps in NbS decision-making procedures. This helps enhance accountability and provides a strong basis for recourse in the case of any disputes or disagreements. Specific attention should be paid to noting which stakeholders where involved in decision-making and the role they played. This is particularly important where extreme inequity persists so that processes can be adapted to encourage meaningful and effective participation

Indicator 5.4 Where the scale of the NbS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making of the stakeholder in the affected jurisdictions

Guidance: Ecosystems do not follow political and administrative borders. Where appropriate, transboundary cooperation agreements between relevant authorities underpin NbS planning and implementation across frontiers to help ensure coherency and consistency of approach and desired outcomes

CRITERION 6 NBS EQUITABLY BALANCE TRADE-OFFS BETWEEN ACHIEVEMENT OF THEIR PRIMARY GOAL(S) AND THE CONTINUED PROVISION OF MULTIPLE BENEFITS

Guidance: Trade-offs in land and natural resource management is inevitable. Ecosystems provide a wealth of different benefits and not everyone values each of them in the same way. While trade-offs cannot be avoided, they can be effectively and equitably managed. This Criterion requires that NbS proponents acknowledge these trade-offs and follow a fair, transparent, and inclusive process to balance and manage them over both time and geographic space.

CRITERIA 6 PERFORMANCE INDICATORS

Indicator 6.1 The potential costs and benefits of associated trade-offs of the NbS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

Guidance: All trades-off are accompanied with an associated set of costs and benefits which may be subject to change over the entire NbS lifecycle. A key function of NbS safeguards is to ensure that necessary trade-offs do not negatively impact the most disadvantaged elements of society or, equally, that they are denied access to the intervention's benefits. It is therefore important that the costs and benefits of trade-off arrangements are fully understood, widely shared among affected stakeholders, and periodically revisited

Indicator 6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders, are acknowledged and respected

Guidance: The legal and customary rights to access, use and control management over land and natural resources, particularly of vulnerable and marginalised groups, needs to be respected and upheld. Rights, use and responsibilities of stakeholder groups in relation to the NbS should be analysed and assessed, using appropriate tools and by building upon the outcomes of stakeholder analysis or mapping. This is particularly important when working in partnership with mana whenua where the principles of the Treaty of Waitangi must be upheld

Indicator 6.3 The established safeguards are periodically reviewed to ensure that mutually agreed trade-off limits are respected and do not destabilise the entire NbS

Guidance: Where risk is unavoidable, safeguards must be in place and periodically reviewed to anticipate and avoid adverse consequences of interventions, especially considering that inequity in trade-offs may change over time and that not all stakeholders may be equally affected. Therefore, NbS design and strategy needs to be explicit about whose benefits and whose costs will be addressed, including when and how this will be reviewed

CRITERION 7 NBS ARE MANAGED ADAPTIVELY, BASED ON EVIDENCE

Guidance: This Criterion requires that NbS implementation plans include provisions to enable adaptive management as a response to uncertainty and as an option to effectively harness ecosystem resilience. A degree of uncertainty is inherent when managing most ecosystems due to their complex, dynamic and self-organising nature. This also means that ecosystems have greater resilience which confers a wider range of options to respond to unanticipated social, economic or climate events. The foundation of adaptive management is the evidence-base provided by regular monitoring and evaluation, drawing on scientific understanding as well as indigenous, traditional, and local knowledge. By proactively adopting an adaptive management approach, the NbS can continue to be relevant through the lifecycle of the intervention and the risk of redundancy and stranded investments minimised.

CRITERIA 7 PERFORMANCE INDICATORS

Indicator 7.1 A NbS strategy is established and used as a basis for regular monitoring and evaluation of the intervention

Guidance: An NbS strategy, at its most basic, includes the reasoning behind the NbS, a precise articulation of the intended outcomes and clear understanding of how these should be achieved through the actions taken. It should be informed by the prevailing economic, social, and ecological conditions, and clearly state the assumptions as to whether and how they are expected to change

Indicator 7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

Guidance: A monitoring and evaluation plan is a key requirement to understand whether the NbS strategy effectively delivers the intended outcomes and, thereby addressing the societal challenge; and, whether risks or unexpected impacts mean a change in strategy or action is required. Where NbS have synergies with other interventions or approaches, these should be included in the monitoring and evaluation plan. Observed and sustained deviations from the key elements of the NBS strategy should trigger an adaptive management response

Indicator 7.3 A framework that enables adaptive management is applied throughout the intervention lifecycle

Guidance: Learning based on evidence should drive NbS management. Furthermore, iterative learning is essential in informing adaptive management actions, in order to respond to the factors influencing NbS interventions. For this Criterion, indicators 7.1 and 7.2 provide a continuous feedback loop to learn and adapt the NbS intervention.

CRITERION 8 NBS ARE SUSTAINABLE AND MAINSTREAMED WITHIN AN APPROPRIATE JURISDICTIONAL CONTEXT

Guidance: This Criterion requires that NbS interventions are designed and managed with a view to long-term sustainability and that they take account of work with and align with sector, national, and other policy frameworks. There are various approaches to mainstreaming NbS; however, all rely on strategic communications and outreach. Audiences to consider include mana whenua, individuals (e.g. the public, academics), and institutions (e.g. local and central government bodies, businesses, and non-government organisations)

CRITERIA 8 PERFORMANCE INDICATORS

Indicator 8.1 The NbS design, implementation and lessons learnt are shared to trigger transformative change

Guidance: Transformative change can be characterised by scaling up (policy or programme mainstreaming), scaling out (expansion at the geographical or sectoral level) or replication of the NbS. Consequently, it is important that the process of design and implementation captures, documents, and makes available lessons learnt to individuals and stakeholders interested in replicating the process. This includes decision makers, investors and other NbS users from the public and private sectors

Indicator 8.2 The NbS is informed by the facilitating policy and regulation frameworks to support its uptake and mainstreaming

Guidance: The implementation of NbS is subject to a range of pre-existing policies, laws, and sectoral regulations, some of which may not be consistent or mutually reinforcing. In some situations, inconsistent policies and regulations may limit the effective rollout of NBS or, worse, actually contribute to the loss of important ecosystem functions over time. In such situations, it is important to a) be aware of policy, regulatory and legal limitations, and b) work with local and/or national decision makers as well as other key stakeholders, to highlight such obstacles and identify effective responses or other enabling solutions

Indicator 8.3 Where relevant, the NbS contributes to national and global targets for human well-being, climate change, biodiversity, and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples

Guidance: NbS can make significant contributions to national economic, social and conservation targets and help achieve national commitments to international processes on climate change, human rights, human development, and biodiversity. Making these linkages explicit, documenting and communicating them, help further reinforce the profile and role of NbS nationally, secure broad-based and durable political commitment as well as societal support, thereby enhancing the long-term sustainability of the intervention

Together. Shaping Better Places.

Boffa Miskell is a leading New Zealand environmental consultancy with nine offices throughout Aotearoa. We work with a wide range of local, international private and public sector clients in the areas of planning, urban design, landscape architecture, landscape planning, ecology, biosecurity, Te Hīhiri (cultural advisory), engagement, transport advisory, climate change, graphics, and mapping. Over the past five decades we have built a reputation for creativity, professionalism, innovation, and excellence by understanding each project's interconnections with the wider environmental, social, cultural, and economic context.

www.boffamiskell.co.nz

Whangarei	Auckland	Hamilton	Tauranga	Wellington	Nelson	Christchurch	Queenstown	Dunedin
09 358 2526	09 358 2526	07 960 0006	07 571 5511	04 385 9315	03 548 8551	03 366 8891	03 441 1670	03 470 0460

APPENDIX 2

Te Hakapupu - Nature Based Solutions

Rapid Flood Hazard Model Build Report

Boffa Miskell

10 December 2024

→ **The Power of Commitment**

Project name		Te Hakapupu - Nature Based Interventions						
Document title		Te Hakapupu - Nature Based Solutions | Rapid Flood Hazard Model Build Report						
Project number		12627855						
File name		12627855-RPT-Te Hakapupu Model Build Report.docx						
Status Code	**Revision**	**Author**	**Reviewer**		**Approved for issue**			
			Name	**Signature**	**Name**	**Signature**	**Date**	
S3	A	William Lay	Habib Ahsan		Mary Wood	Approval on file	18 April 2024	
S4	0	William Lay	Mary Wood		Mary Wood	Approval on file	8 July 2024	
S4	1	William Lay Mary Wood	Scott Wilkinson		Mary Wood		10 December 2024	

GHD Limited
27 Napier Street, GHD Centre Level 3
Freemans Bay, Auckland 1010, New Zealand
T +64 9 370 8000 | **F** +64 9 370 8001 | **E** aklmail@ghd.com | **ghd.com**

[Compliance statement]© *GHD 2024*
This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

→ The Power of Commitment

Executive Summary

GHD was engaged by Boffa Miskell on behalf of Otago Regional Council (ORC) to undertake Rapid Flood Hazard Mapping (RFHM) of the Te Hakapupu Pleasant River Catchment (Te Hakapupu) to understand the initial flood risk in the catchment.

The purpose of this report is to document the stormwater modelling methodology for the Te Hakapupu catchment and present high level RFHM results for the existing development (ED) with future rainfall and climate change to identify flood risks in the catchment. This report summarises the modelling methodology and the assessment of results. Flood maps for the 100-year ARI storm event with future climate changes allowances and existing land use flood extents, level, depth and speed in the catchment form part of this report.

The following conclusions can be derived from this flood assessment:

– The hydrology assessment was undertaken using HEC-HMS and the hydraulic modelling was undertaken using InfoWorks ICM.
– The upper catchment was divided into seven sub-catchments of various sizes to generate inflow boundary for the lower catchment.
– A minimum grid size of 9m^2 was used for the 2D domain of the lower catchment in InfoWorks ICM.
– A constant downstream tidal boundary of 3.15mRL was used based on MHWS of 2.15mRL at Port Chalmers plus an additional metre to account for the sea level rise due to climate changes.
– The 2D InfoWorks ICM model has been set up for the 100-year ARI and 10-year ARI 24-hour storm duration events. Model has been simulated for the 100-year ARI 24-hour storm event at this stage.
– The maximum depth of flooding in the lower catchment was predicted to be about 5m mainly along the river system.

Contents

1. Introduction 1
1.1 Purpose of this report 1
1.2 Scope 1
1.3 Limitations 1
1.4 Assumptions 2
1.5 Background 2
2. Model Build 4
2.1 Modelling Software 4
2.1.1 Topographical Data 4
2.1.2 Catchment Delineation 4
2.2 HEC-HMS Model 5
2.2.1 Hydrological Parameters 5
2.2.2 Elevation Profile of Flowpath 7
2.2.3 Temporal Design Storm Pattern 7
2.2.3.1 Lower Catchment Rainfall Intensity Profile 7
2.2.4 Upper Catchment Inflows 8
2.3 The 2D Hydraulic Model 9
2.3.1 2D Surface Flow Model 9
2.3.2 Locations of Upper Catchment Inflows 9
2.3.3 Tidal Boundary 10
2.3.4 10-year ARI 24-hour Storm Duration 10
3. Model Results 10
3.1 Existing Scenario 11
4. Integration with Nature Based Solutions 14
4.1 Land use 14
4.2 River Modification 15
4.3 Additional floodplain storage 15
4.4 Next steps 15
5. Conclusions 17

Table index

Table 1 Te Hakapupu catchment geological classifications and curve numbers (Source: Guidelines for stormwater runoff modelling in the Auckland Region, Auckland Council April 1999) 6
Table 2 Weighted Average Curve Numbers for each Upper incoming Catchment 7
Table 3 Upper incoming catchment peak flows and rainfall for the 100-year ARI 24-hour storm duration event 8
Table 4 100-year ARI 24-hour storm duration (RCP 8.5 climate change) peak flows from the upper catchments under different land coverage scenarios 14

Figure index

Figure 1	Te Hakapupu | Pleasant River Catchment Boundary	3
Figure 2	Delineated Upper Catchments and Lower 2D Model Boundary	5
Figure 3	Geological Units within the Upper incoming Catchments of the Te Hakapupu Catchment	6
Figure 4	Lower Catchment Rainfall Intensity Profile showing Total, Loss and Excess Rainfall	8
Figure 5	Location of incoming Flows into the Lower side of the Te Hakapupu Catchment	9
Figure 6	Location of the Tidal Boundary within the 2D Model	10
Figure 7	Predicted Peak Flood level during 100-year ARI Event	11
Figure 8	Predicted Peak Flood depth during 100-year ARI Event	12
Figure 9	Predicted Peak Flow speed during 100-year ARI Event	13

1. Introduction

GHD was engaged by Boffa Miskell on behalf of Otago Regional Council (ORC) to undertake Rapid Flood Hazard Mapping (RFHM) of the Te Hakapupu Pleasant River Catchment (Te Hakapupu) to understand the initial flood risk in the catchment.

1.1 Purpose of this report

The purpose of this report is to document the stormwater modelling methodology for the Te Hakapupu catchment and present high level RFHM results for the existing development (ED) with future rainfall and climate change to identify flood risks in the catchment.

This report summarises the modelling methodology and presents the results. Flood maps showing the maximum flood level, depth, and speed in the catchment form part of this report.

1.2 Scope

The scope of work includes the following:

– Development of a simple HEC-HMS catchment-based model for the steep upper catchments to provide hydrological boundary conditions to the lower catchment.
– Develop a 2D hydraulic model for the lower downstream area using InfoWorks ICM with suitable mesh size to achieve a reasonable model run time.
– Determine rainfall profiles based on NIWA's High Intensity Rainfall Design System (HIRDS) v4.0 and climate change RCP 8.5 scenarios and a future climate change adjusted tidal boundary using published data.
– Set up the 2D hydraulic model to simulate the 100-year ARI and 10-year ARI 24-hour duration storm events.
– Provide model outputs (floodplain extent) for the future climate change 100-year ARI 24-hour duration storm event with existing land use.
– Summarise the outcomes in a report.

1.3 Limitations

GHD has prepared this report on the basis of information provided by Boffa Miskell and others who provided information to GHD, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

This report: has been prepared by GHD for Boffa Miskell and may only be used and relied on by Boffa Miskell for the purpose agreed between GHD and Boffa Miskell as set out section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Boffa Miskell arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this RFHM assessments for, and for the benefit and sole use of, Boffa Miskell to support their delivery of the Te Hakapupu Stage 1 Feasibility Study and must not be used for any other purpose or by any other person.

The information, data and assumptions (“Inputs”) used as inputs into the Model are from publicly available sources or provided by or on behalf of the Boffa Miskell, (including possibly through stakeholder engagements). GHD has not independently verified or checked Inputs beyond its agreed scope of work. GHD’s scope of work does not include review or update of the Model as further Inputs becomes available.

1.4 Assumptions

The following assumptions were made for this study:

– The RFHM assessment is based on the Te Hakapupu catchment topography only. The 1D pipe network, if any, has been excluded in this modelling assessment.
– All provided and sourced information (LiDAR data, catchment boundaries, GIS inputs) used for the development of the model have been assumed to be correct and accurate.
– The design storms and rainfall patterns have been generated using NIWA’s HIRDS v4.0 and climate change RCP 8.5 scenarios for the future scenario (2081-2100).
– Upper catchments have been assumed to be completely pervious whereas the lower catchment has been assumed to have 1% imperviousness.
– No validation of the model results using historical data has been undertaken.

1.5 Background

ORC are currently partnering with Kāti Huirapa Rūnaka ki Puketeraki to deliver Toitū Te Hakapupu. Toitū Te Hakapupu for a multi-million-dollar catchment restoration project in the Te Hakapupu catchment, focusing on improvements to water quality and biodiversity. The project aims to improve the wider ecosystem, reduce sediment and nutrient inputs, and promote the use of modern-day knowledge to sustain current efforts. Completed and ongoing work on the Te Hakapupu catchment includes understanding water quality issues, developing environmental baselines, fence implementation and planting works.

The Te Hakapupu catchment is primarily rural covering approximately 12,800 hectares of land and is situated in East Otago at the immediate south of the Palmerston township (Figure 1).

Figure 1 Te Hakapupu | Pleasant River Catchment Boundary

The current study is one of two studies occurring in parallel and involves a feasibility study into flood mitigation opportunities for the Te Hakapupu catchment, with particular emphasis on nature-based interventions (restored and constructed wetlands). Intervention options that provide co-benefits for water quality and the environment are preferred. Nature-based flood hazard mitigation opportunities are to be investigated by are:

– Modelling the hydrology of the Te Hakapupu catchment under different rainfall events
– Developing key design criteria for nature-based flood mitigation opportunities
– Identifying suitable locations for intervention opportunities with respect to potential benefits, implementation costs, land ownership, and consenting requirements

The second study is an engagement study intended to complement the feasibility study and seeks to develop understanding of the opportunities and barriers to communities, particularly landowners for which the natured based intervention options will be adopted on their land. The two studies together aim to facilitate informed evidence-based decision making for mana whenua, ORC, and the East Otago community by providing an improved understanding of the potential natured-based interventions and perspectives of the community surrounding these interventions.

ORC currently requires technical advice about the implementation of nature-based flood hazard intervention opportunities in the Te Hakapupu catchment and has engaged Boffa Miskell to complete the stage 1 feasibility study.

Boffa Miskell have engaged GHD to support the hydrological modelling component of the above feasibility study. This entails the development of a rapid flood hazard model to identify initial flood risk.

2. Model Build

2.1 Modelling Software

HEC-HMS v4.10 was used to undertake hydrological analysis while InfoWorks ICM v2023.2 was used to complete a two-dimensional (2D) hydraulic assessment.

2.1.1 Topographical Data

Two Digital Elevation Models (DEMs) – 1m Otago DEM and 8m NZ DEM were downloaded from the freely available LINZ website and used in the model build process. To bypass software limitations, the 8m DEM was used to determine the boundary conditions from the upper catchment for the lower Te Hakapupu catchment. Differences between using the 8m and 1m DEMs for the upper catchment were considered negligible. Once the boundary conditions were identified, the 1m LiDAR DEM was used to develop the 2D model using InfoWorks ICM. The vertical datum of the 1m LiDAR DEM is NZVD2016 while horizontal projection is based on New Zealand Transverse Mercator 2000.

2.1.2 Catchment Delineation

The model has been structured based on considering potential flood risk. Additionally as per the scope of works, the Te Hakapupu catchment was divided into an upper catchment and lower catchment to achieve reasonable computation times for the lower 2D model domain. Due to the elevated topography in the west of the Te Hakapupu catchment, drainage channels were generally expected to drain from west to east towards the lower catchment and the ocean. Areas with the greatest risk of flooding would be expected to be at low elevation/flat land. The split between the upper catchment and lower catchment was therefore taken from the base of the hills.

The relevant upper catchment areas (west of the hills) were determined using the 8m DEM. The upper catchment within Te Hakapupu was divided into seven hydrologic catchments based on the topography and therefore drainage channels within the catchment (Figure 2). Catchments were delineated to estimate the incoming flows from the upper catchments into the lower half of the Te Hakapupu catchment. Each catchment represents the area that drains into the lower catchment. The longest flow path for each of the upper catchments were determined to estimate the time of concentration for the flows discharging into the lower catchment.

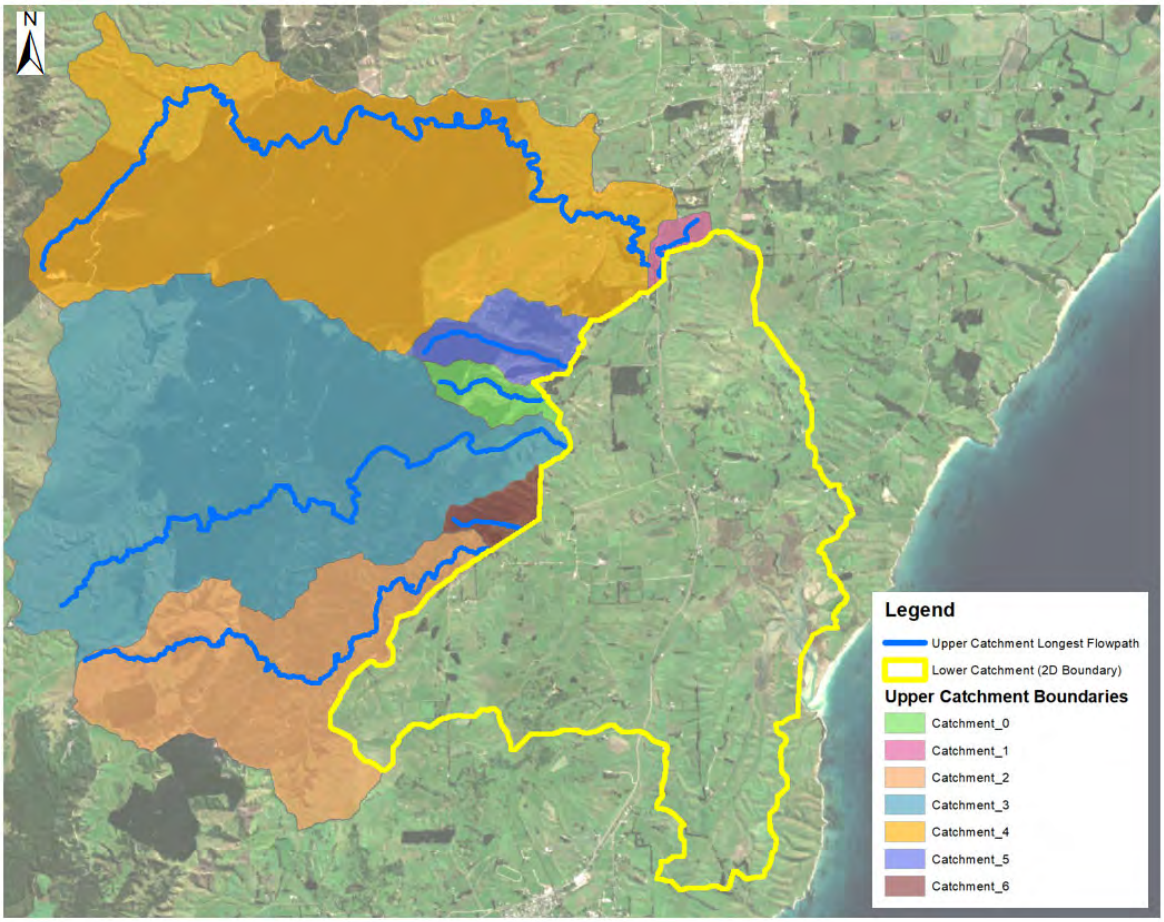


Figure 2 Delineated Upper Catchments and Lower 2D Model Boundary

2.2 HEC-HMS Model

HEC-HMS 4.10 was used to determine the boundary flow conditions from the upper catchment into the lower Te Hakapupu catchment.

2.2.1 Hydrological Parameters

A review of published geological map of the catchment (Institute of Geological and Nuclear Sciences, 1:250,000 Geological Maps, 2001) indicates that the Te Hakapupu catchment is made primarily of siltstone, sandstone, and schist, with smaller amounts of basalt, gravel, and sand (Figure 3).

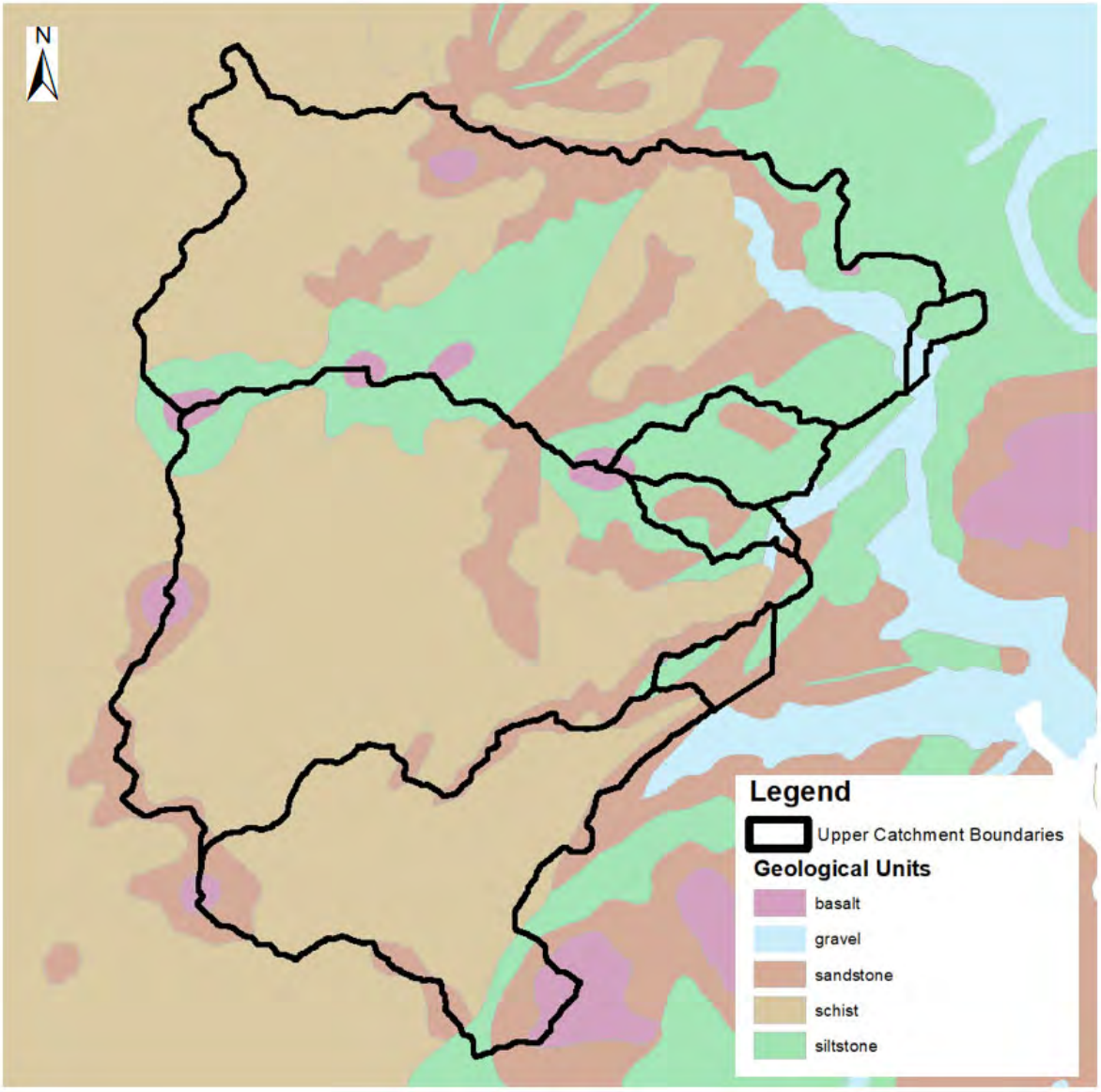


Figure 3 *Geological Units within the Upper incoming Catchments of the Te Hakapupu Catchment*

Each geological unit was classified and assigned a curve number based on Auckland Council's "Guidelines for stormwater runoff modelling in the Auckland Region". This is summarised in Table 1.

Table 1 *Te Hakapupu catchment geological classifications and curve numbers (Source: Guidelines for stormwater runoff modelling in the Auckland Region, Auckland Council April 1999)*

Geological Unit	Hydrological Soil Classification	Curve Number
Siltstone	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Sandstone	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Schist	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Basalt	Granular volcanic loam (ash, tuff, scoria)	39
Gravel	Granular volcanic loam (ash, tuff, scoria)	39

Geological Unit	Hydrological Soil Classification	Curve Number
Sand	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Unknown	-	74*

* A curve number of 74 was used for unidentified geological units as this was considered a more conservative value than 39.

The geological units of each upper catchment (Figure 2) were identified and their areas were calculated. The areas were then used to estimate a weighted average Curve Number (CN) for each upper catchment. The final weighted average CN numbers are provided below in Table 2.

Table 2 Weighted Average Curve Numbers for each Upper incoming Catchment

Catchment Number	Weighted Average Curve Number
Catchment_0	73
Catchment_1	64
Catchment_2	73
Catchment_3	74
Catchment_4	72
Catchment _5	73
Catchment _6	74

2.2.2 Elevation Profile of Flowpath

The elevation profile of each longest flow path was plotted out based on the river chainage across the 1m LiDAR DEM. In combination with the catchment area, the weighted CN as shown in Table 2, the elevation profile was used to estimate the time of concentration for each upper catchment.

2.2.3 Temporal Design Storm Pattern

The centre coordinates of the upper incoming catchment were calculated and input into NIWA's HIRDS v4.0 to determine rainfall depths for the 100-year ARI 24-hour storm duration. Together with NIWA's design parameters, the rainfall depths were used to generate the temporal storm pattern for each catchment for input into the HEC-HMS model for both upper and lower catchments.

2.2.3.1 Lower Catchment Rainfall Intensity Profile

The rainfall intensity profile applied was also developed in the HEC-HMS model, following a similar process as above using a time of concentration, initial losses and temporal design storm pattern specific to the lower catchment. The rainfall intensity profile represents the net rainfall (total rainfall minus losses) calculated in the HEC-HMS model. The net rainfall intensity profile of the lower catchment is illustrated in Figure 4 and was applied as rain-on-grid .into the entire 2D domain of the lower catchment.

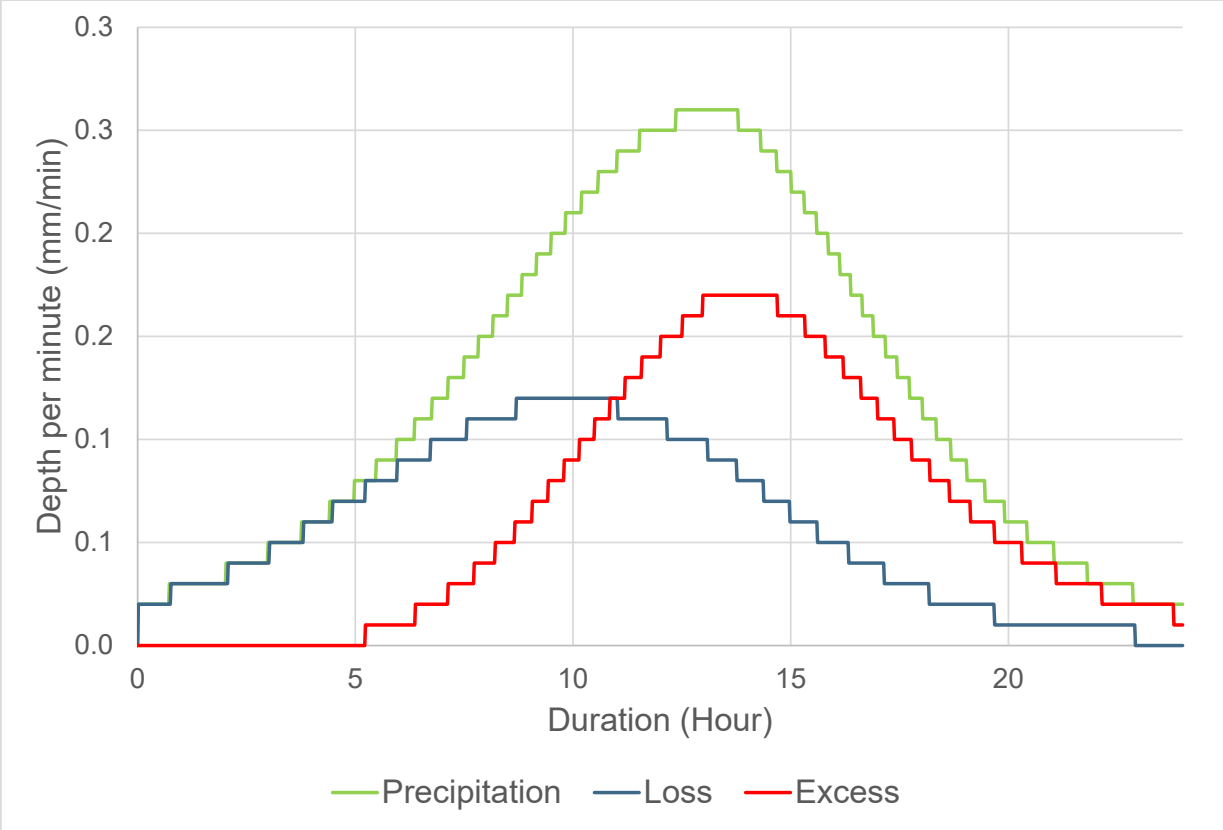


Figure 4 Lower Catchment Rainfall Intensity Profile showing Total, Loss and Excess Rainfall

2.2.4 Upper Catchment Inflows

Rainfall depths for the 100-year ARI 24 hour storm duration event with RCP 8.5 climate change were taken from HIRDS v4.0 at the centre of each of the seven upper catchments. This was used to determine the temporal design storm pattern for each upper catchment. The time of concentration and temporal design storm pattern for each upper catchment was then inputted into a rudimentary HEC-HMS model to simulate the incoming flows into the lower catchment. Upper catchment peak flows and rainfall are provided below in Table 3.

Table 3 Upper incoming catchment peak flows and rainfall for the 100-year ARI 24-hour storm duration event

Catchment Number	Total Rainfall (mm)	Total Loss (mm)	Total Excess (mm)	Peak Flow (m^3/S)
Catchment_0	180.93	70.47	110.38	4.50
Catchment_1	176.02	86.72	89.09	1.60
Catchment_2	190.02	71.41	118.02	48.10
Catchment_3	187.93	69.38	118.37	110.40
Catchment_4	190.02	73.06	116.23	107.50
Catchment_5	184.94	70.92	114.01	9.00
Catchment_6	176.02	67.97	108.14	3.60

The flow profile over the 24-hour duration for each upper catchment was extracted from HEC-HMS model and inputted as a boundary inflow to the InfoWorks ICM 2D model of lower catchment.

2.3 The 2D Hydraulic Model

The 2D hydraulic model was built in InfoWorks ICM v2023.2 after determining the boundary conditions in the HEC-HMS model. The 2D model boundary extends from the western hills within the Te Hakapupu catchment and covers the lower catchment area in the east up to the outfall of the river into the sea.

2.3.1 2D Surface Flow Model

The 2D model was developed and used to describe the overland flows within the 2D model domain. The ground surface within the 2D domain was represented by a minimum grid cell of 9 m^2 mesh generated in InfoWorks ICM using the 1m Otago DEM. A Manning's n-value of 0.06 was conservatively used for the entire 2D model domain.

2.3.2 Locations of Upper Catchment Inflows

The generated flow hydrographs as described in Section 2.2.4 above were loaded directly onto a node (Figure 5) near the downstream end of the upper catchment and the edge of the 2D model zone boundary, thus representing the discharge location of inflows into the lower catchment.

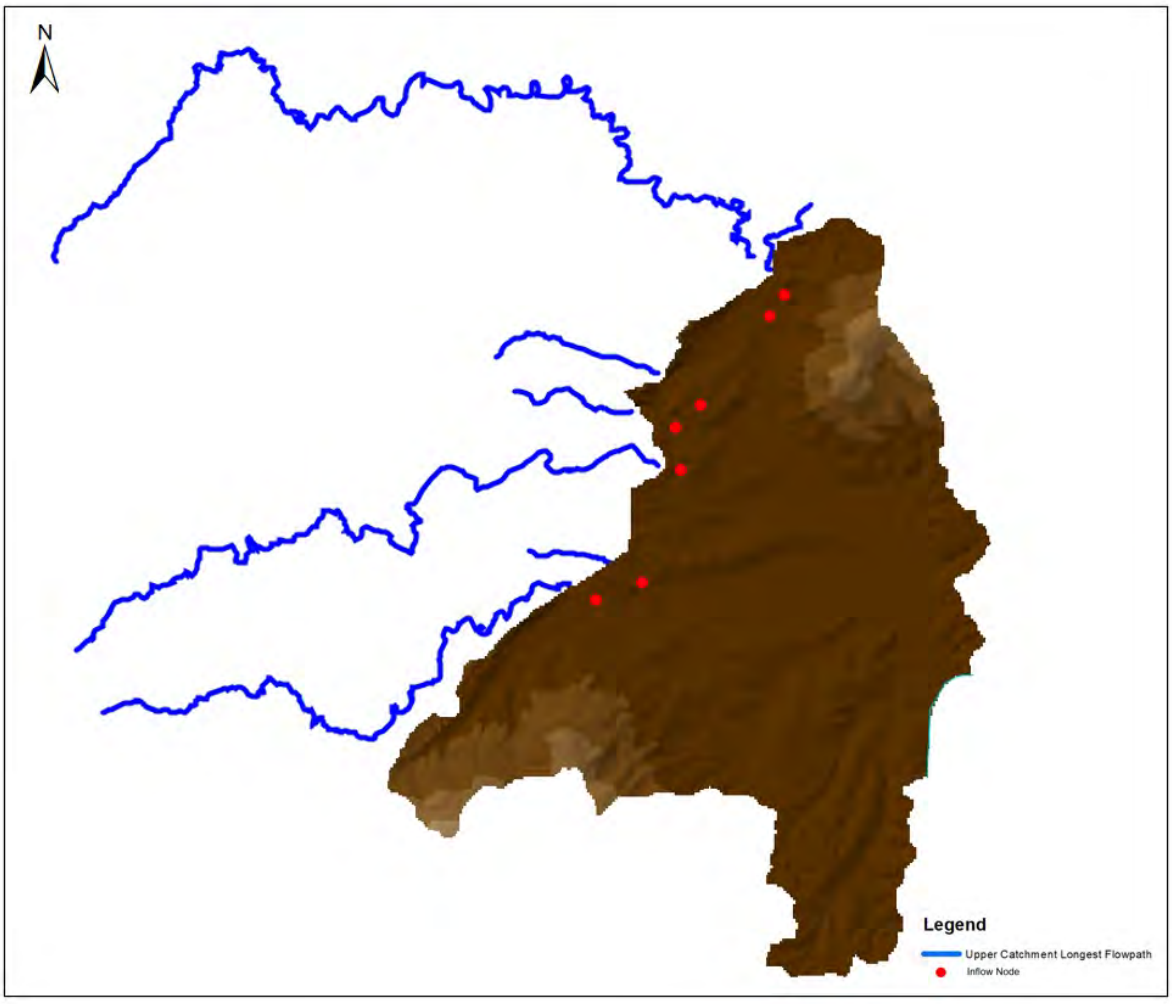


Figure 5 Location of incoming Flows into the Lower side of the Te Hakapupu Catchment

2.3.3 Tidal Boundary

The tidal boundary at the outfall of the Te Hakapupu River was derived from the nearest Port Chalmers tide data. The tidal boundary (see Figure 6) was set at 3.15 m based on the Mean High Water Spring (MHWS) level of 2.15mRL at Port Chalmers plus an additional one metre to account for future sea level rise due to climate changes.

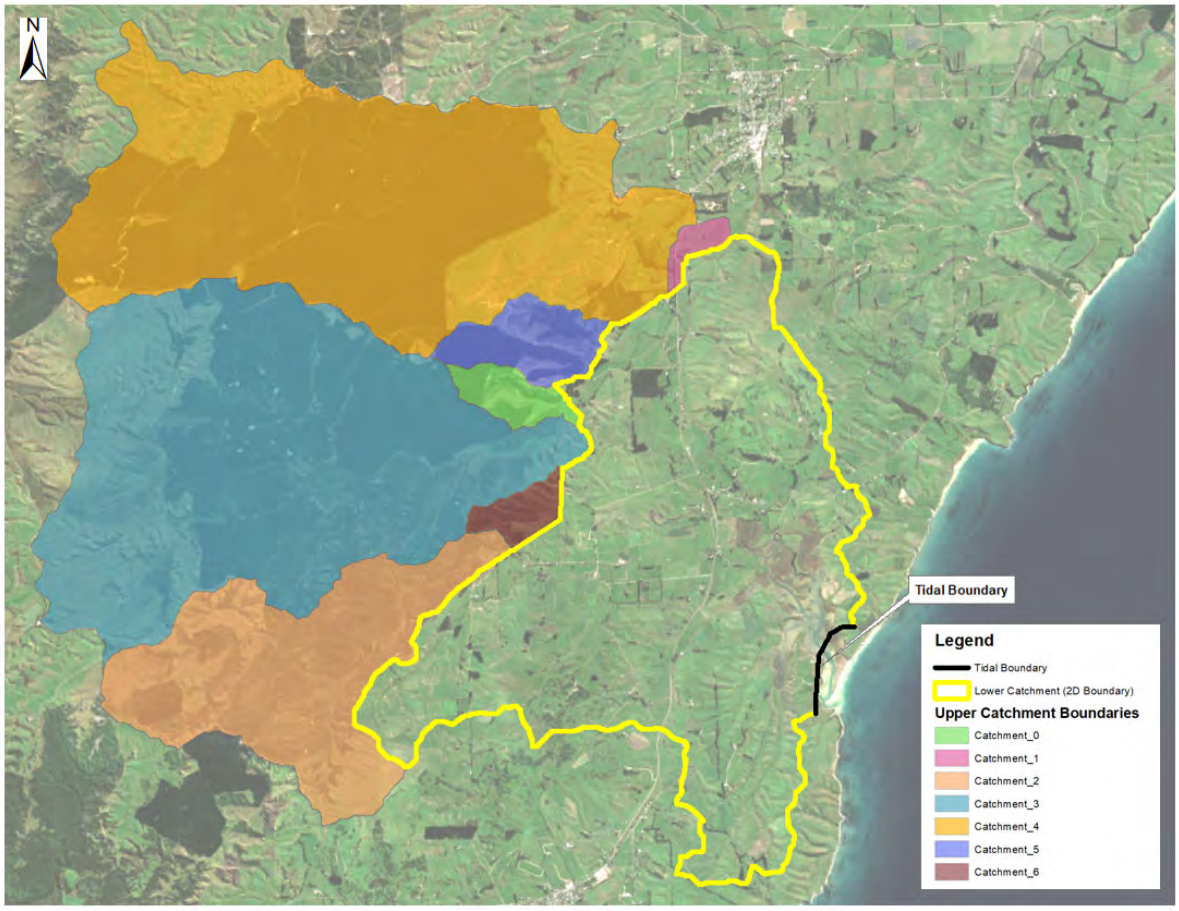


Figure 6 Location of the Tidal Boundary within the 2D Model

2.3.4 10-year ARI 24-hour Storm Duration

A scenario for the 10-year ARI 24-hour storm duration was set up following a similar process as the above. The HEC-HMS model was run using a temporal design storm pattern specific to the 10-year ARI 24-hour event. This enabled the HEC-HMS model to simulate peak flows and a rainfall intensity profile specific to the 10-year ARI 24-hour storm duration. The flow profiles and rainfall intensity profile were substituted in the 100-year ARI 24-hour scenario to set up the 10-year ARI 24-hour scenario. However, we haven't undertaken simulation of 10-year event at this stage.

3. Model Results

This section presents preliminary model results for the 100-year ARI 24-hour storm duration event prior to any model validation.

3.1 Existing Scenario

The predicted peak flood levels (Figure 7), peak depths (Figure 8) and peak speed (Figure 9) for the existing scenario 100-year ARI event are provided below for the lower catchment bounded in yellow. We have excluded 50mm depth from the predicted depth which is considered to be within the error margin of modelling software.

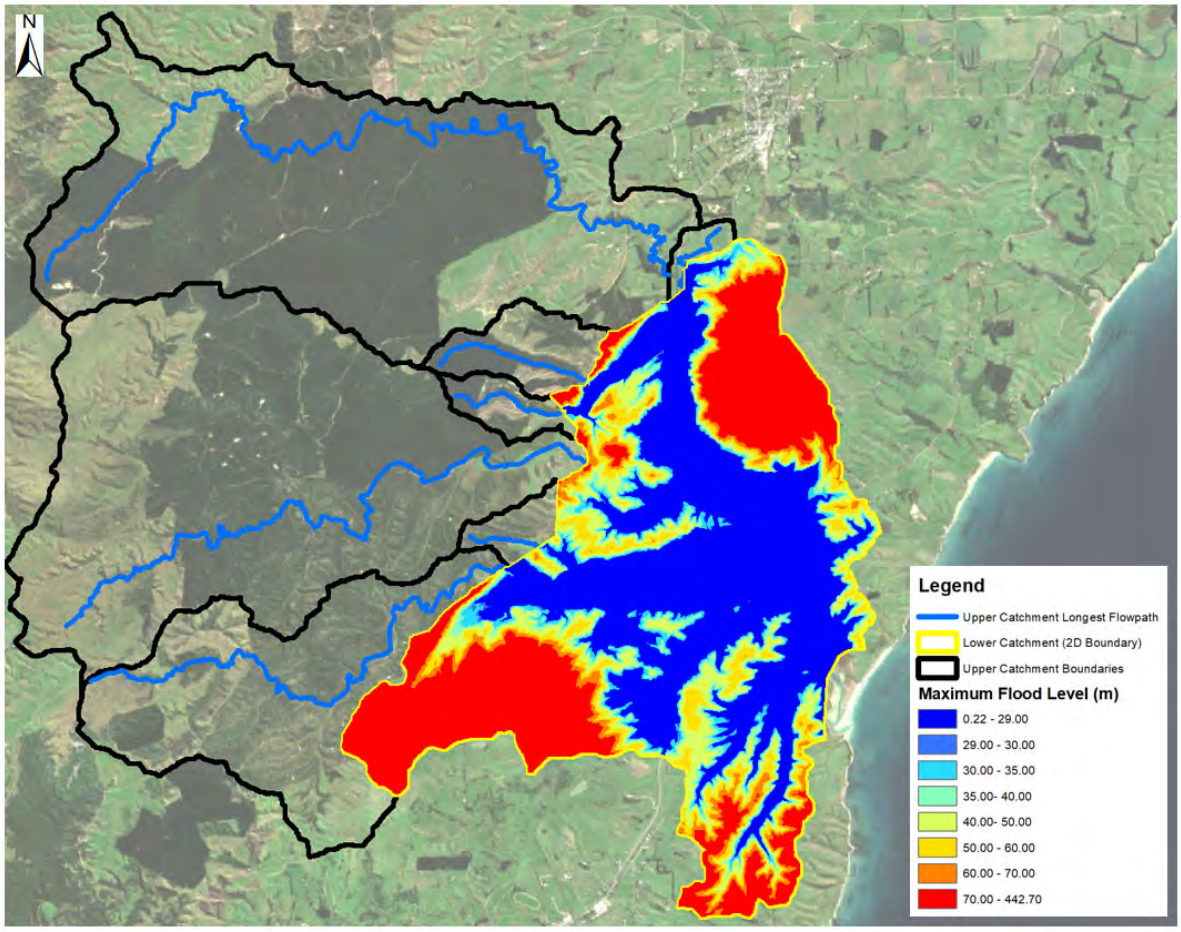


Figure 7 Predicted Peak Flood level during 100-year ARI Event

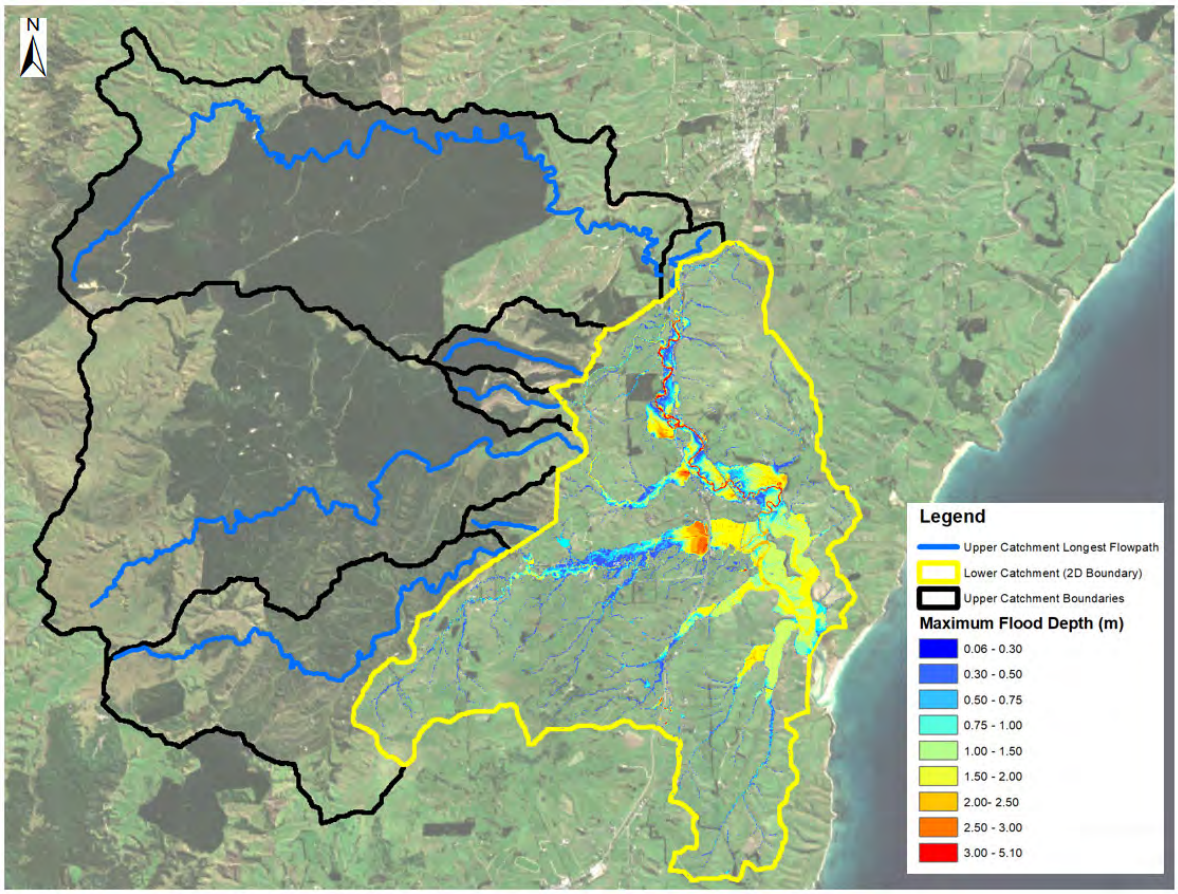


Figure 8 *Predicted Peak Flood depth during 100-year ARI Event*

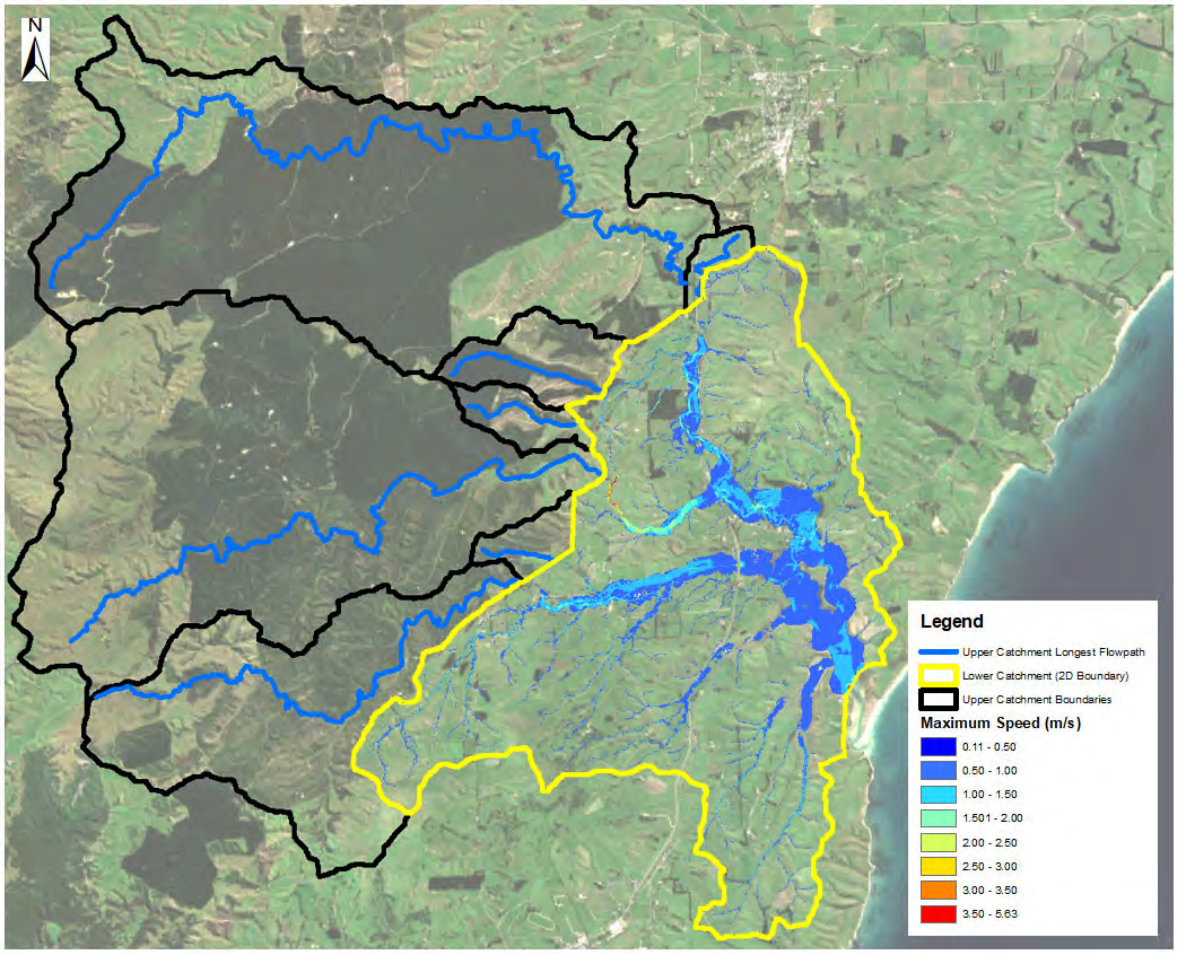


Figure 9 ***Predicted Peak Flow speed during 100-year ARI Event***

4. Integration with Nature Based Solutions

For the Te Hakapupu catchment, opportunities to implement nature-based solutions will depend on ORC priorities and the specific issues and locations of concern within the catchment. From discussions with ORC it is understood that concerns relate to:

– Sediment generation risk from harvesting in the upper catchment
– The ability to modify the current river channel to modify flood levels
– The ability to implement storage within the catchment (delivered in the form of wetland areas or similar)

4.1 Land Use

The model can be used to test some aspects of potential policy decisions within the catchment, such as land use / land coverage.

The upper catchments are largely covered by a mixture of forestry. The upper catchment models (HEC HMS components) were run with different runoff characteristics to frame out the relative change in outflow that could occur:

1. immediately following wide-spread harvest; or
2. with the land reverted to native forest.

The following changes were made to the CN values for the models:

1. Poor/bare coverage that would result immediately following forestry harvest

– CN 74 changed to CN **90** (residual crop cover, poor hydrologic condition, group C soils)
– CN 39 changed to **68** (grass, poor hydrologic condition, group A soils)

2. Improved coverage that would (eventually) result if the land was allowed to return to native forest

– CN 74 changed to CN **70** (woods, good hydrologic condition, group C soils)
– CN 39 changed to **30** (woods, good hydrologic condition, group A soils)

It should be noted that the CN values are impacted by the underlying soils as well as the type of vegetation and are empirical values.

The results have been compared to the original values (as provided in Table 3) and are summarised in Table 4 below.

Table 4 100-year ARI 24-hour storm duration (RCP 8.5 climate change) peak flows from the upper catchments under different land coverage scenarios

Catchment Number	Original Peak Flow (m^3/s)	Post Harvest Peak Flow (m^3/s)	Native Bush Peak Flow (m^3/s)
Catchment_0	4.5	5.6	4.2
Catchment_1	1.6	2.3	1.5
Catchment_2	48.1	60.2	45
Catchment_3	110.4	138.3	102.9
Catchment_4	107.5	138.5	99.9
Catchment_5	9	11.3	8.5
Catchment_6	3.6	4.5	3.4

Overall, in a 100-year ARI event with the post-harvest scenario, the model indicates that there could be increase in flow from the upper catchments in the order of 25% or more from the current forestry coverage. If the current forestry block was transitioned back to a full native bush coverage then a potential reduction in the order of 6-7% in 100-year ARI flows from these catchments could be possible compared to the current forestry coverage.

The values above are not absolute but instead provide an indication of the relative scale of change in flow (not flood extent) in the upper catchments, in a large event with future climate change projections included. Results in smaller events may be less pronounced. That said, the results indicate:

– A risk of increased rate of runoff post harvest
– Post-harvest sedimentation risk (resulting from increased runoff and potentially increased velocity and scour) in some catchments in the event of large rainfall events.

4.2 River Modification

In terms of flooding, the form of the river and the channel capacity will obviously impact flood depths as well as the frequency of spilling outside of the main channel and flood extents. In larger events, however, the capacity of the wider floodplain becomes more important.

One option considered was increasing naturalisation of the river channel and assessing how this could be beneficial in reducing flood risk. Options for naturalisation include channel modification (including reverting back to a more sinuous channel), increased planting and floodplain protection / modification.

At a high level, while there is evidence of channel modification through diverting and straightening through some properties, the channel itself is largely still that of a braided river system – so there would only be localised opportunities to implement changes. Compounding this, the flood extent shown in Figure 8 is significant. Naturalisation of these localised areas (through reinstating a more sinuous channel form and increasing floodplain storage) would be unlikely to be of a scale that would make a significant change in flood extent.

Vegetation measures may achieve benefits in terms of erosion management and protection of channel banks, but also may result in increased channel roughness and reduced channel capacity. The current model is not sufficiently detailed for assessment of erosion management options.

4.3 Additional Floodplain Storage

While additional floodplain storage was one of the options initially considered as an approach to manage flood extent, the scale and depth of flooding in the 100-year ARI event suggest that the results will depend on where this storage is provided (and what scale of flood reduction would be targeted). A large volume of storage would be necessary to achieve a material reduction, given that there are flood depths of more than 1.5m across most of the floodplain. In addition, flows are entering the main floodplain from a number of different reaches means that multiple basins could be necessary across the catchment.

It is important to note that flooding is a natural process and that it is not unexpected that there will be flooding in a widespread area in the event of a 100-year ARI event. There will be a need to consider the cost and trade-offs between the scale of purchase of land for provision of flood storage in upper branches compared to purchase of properties that might already be impacted by flooding in the first instance.

As some of the current flow depths and flood extent appear to be impacted by some of the current road levels then further survey is recommended to confirm road crest levels as well as identification of critical properties and location of dwellings to allow solutions to be considered in a more targeted manner. This particularly applies to State Highway 1 which is cutting across the floodplain in a number of areas.

4.4 Next Steps

While further information is necessary to enable the model to be used to develop possible nature-based solutions in more detail, including the size and location of possible options, in its current form the model gives an indication of the scale of solutions that would need to be developed to result in a reduction in floodplain level / extent.

It is recommended that the following steps be considered going forward:

- ORC consider assessment of smaller ARI flooding events as this may offer opportunities to manage flooding at a scale more frequently experienced by property owners.
- Consideration of development of the 1D component of the model to enable smaller scenario runs to be considered in future.
- Survey of road crest and culvert details around State Highway 1
- Dwelling extents may be worth incorporating into the flood maps for future assessment to support assessment of risk to people.
- Review specific areas around State Highway 1 and discuss with NZ Transport Agency Waka Kotahi future plans around road improvements.

5. Conclusions

The following conclusions can be derived from this flood assessment:

– The hydrology assessment was undertaken using HEC-HMS and the hydraulic modelling was undertaken using InfoWorks ICM.

– The upper catchment was divided into seven sub-catchments of various sizes to generate inflow boundary for the lower catchment.

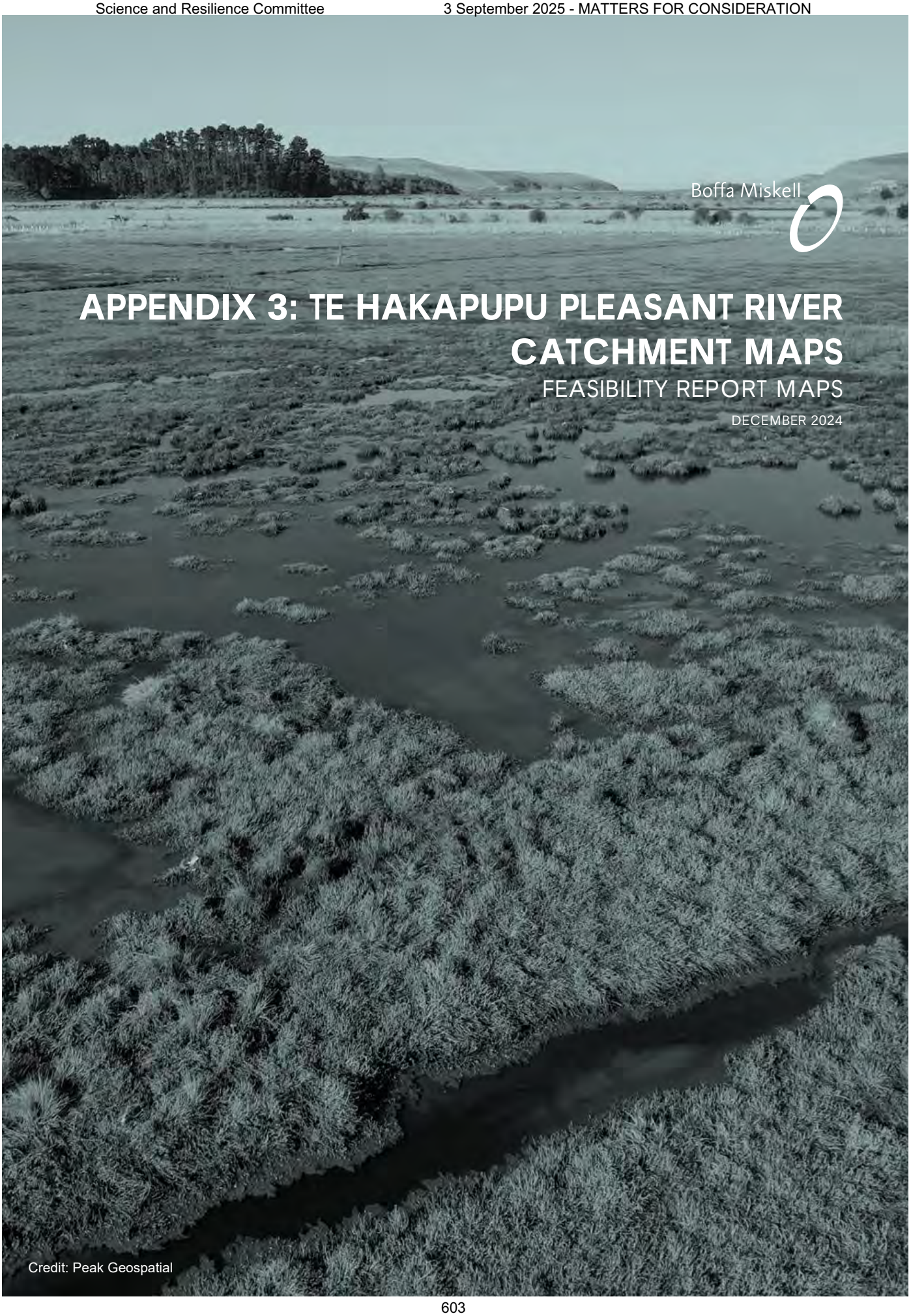
– A minimum grid size of 9m^2 was used for the 2D domain of the lower catchment in InfoWorks ICM.

– A constant downstream tidal boundary of 3.15mRL was used based on MHWS of 2.15mRL at Port Chalmers plus an additional metre to account for the sea level rise due to climate changes.

– The 2D InfoWorks ICM model has been set up for the 100-year ARI and 10-year ARI 24-hour storm duration events. Model has been simulated for the 100-year ARI 24-hour storm event at this stage.

– The maximum depth of flooding in the lower catchment was predicted to be about 5m mainly along the river system.

ghd.com → **The Power of Commitment**

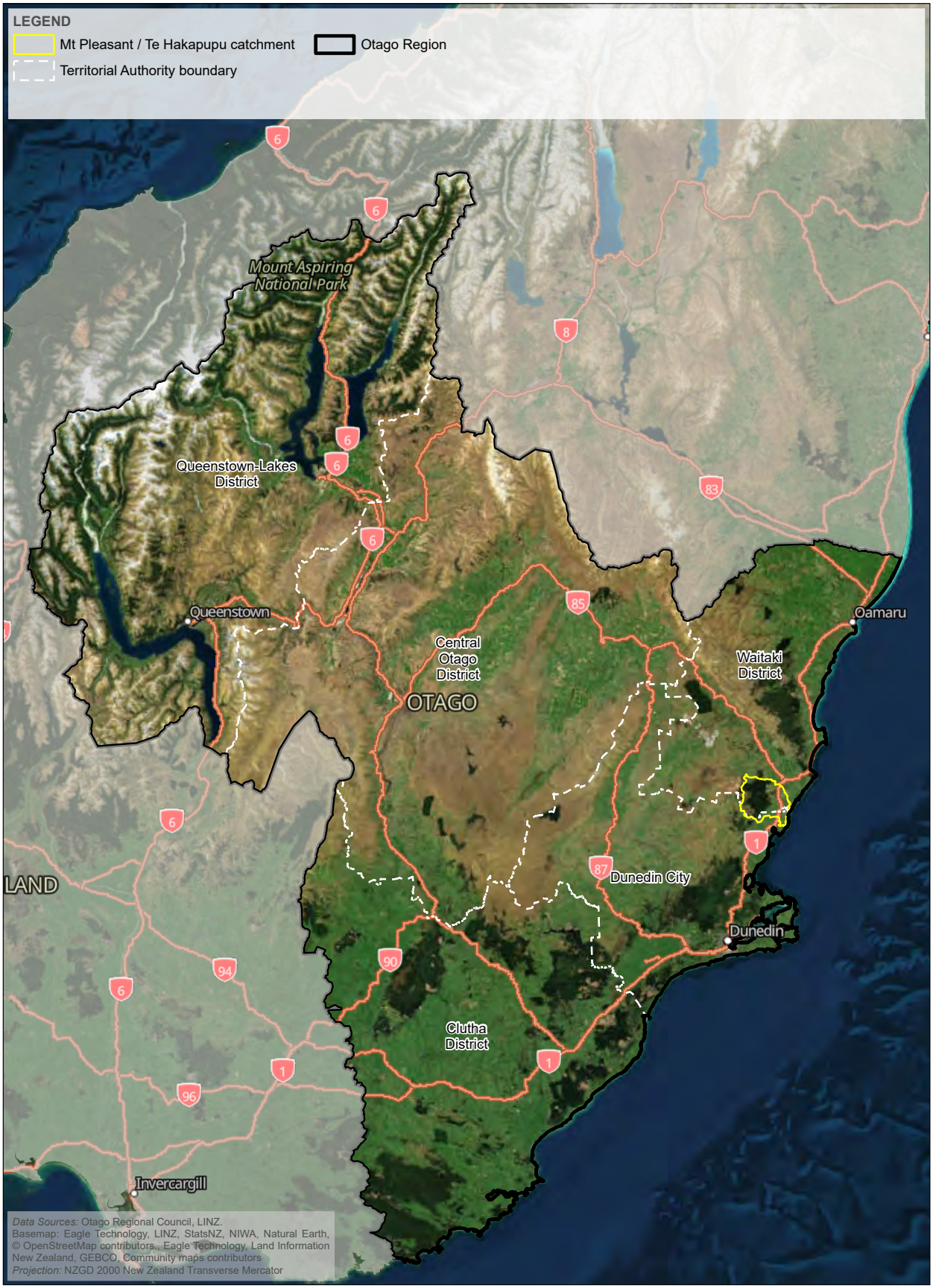


APPENDIX 3: TE HAKAPUPU PLEASANT RIVER CATCHMENT MAPS

FEASIBILITY REPORT MAPS

DECEMBER 2024

Credit: Peak Geospatial



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 20 km
1:1,350,000 @ A4

TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

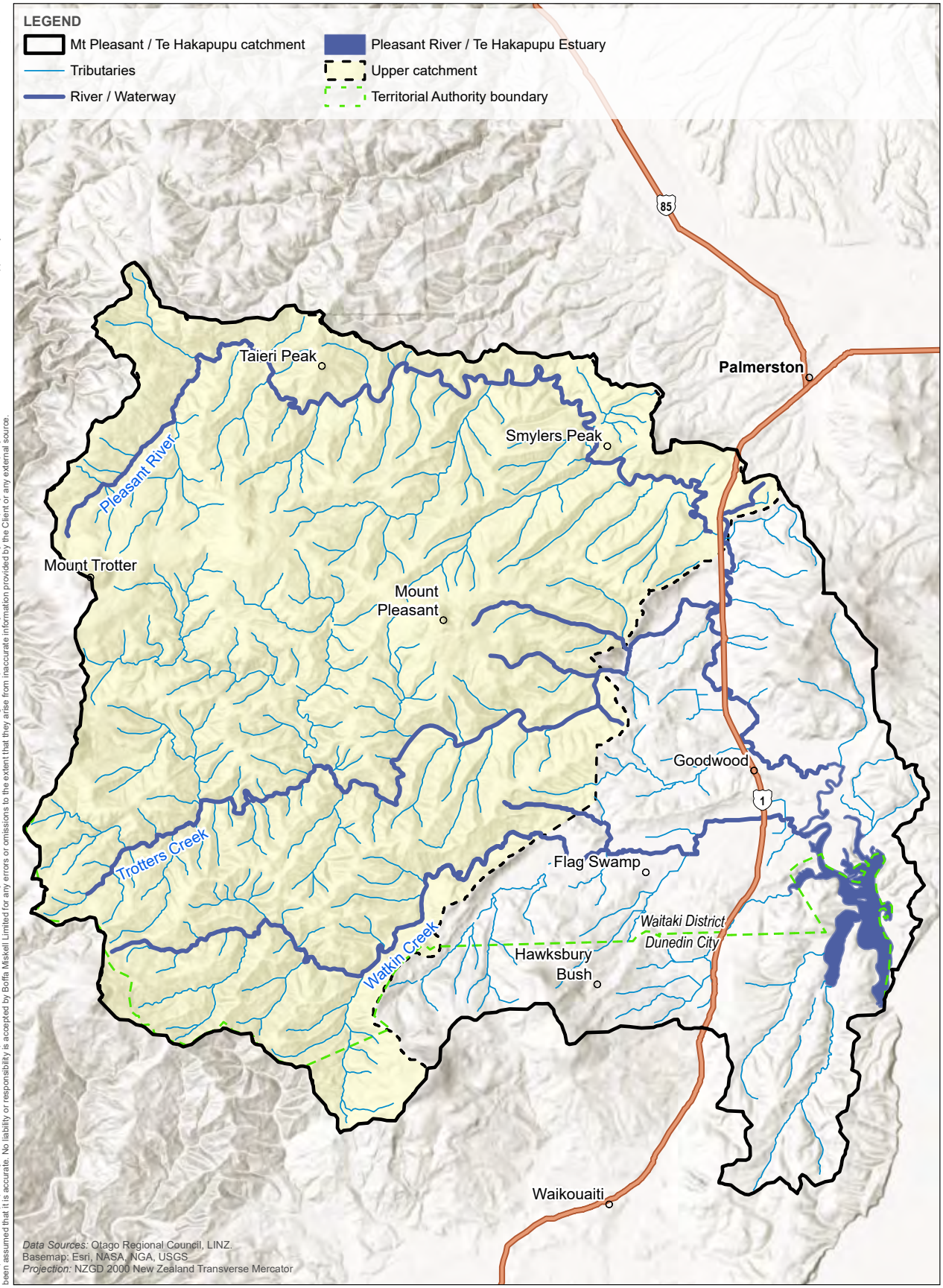
Catchment Location

Date: 04 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 1



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

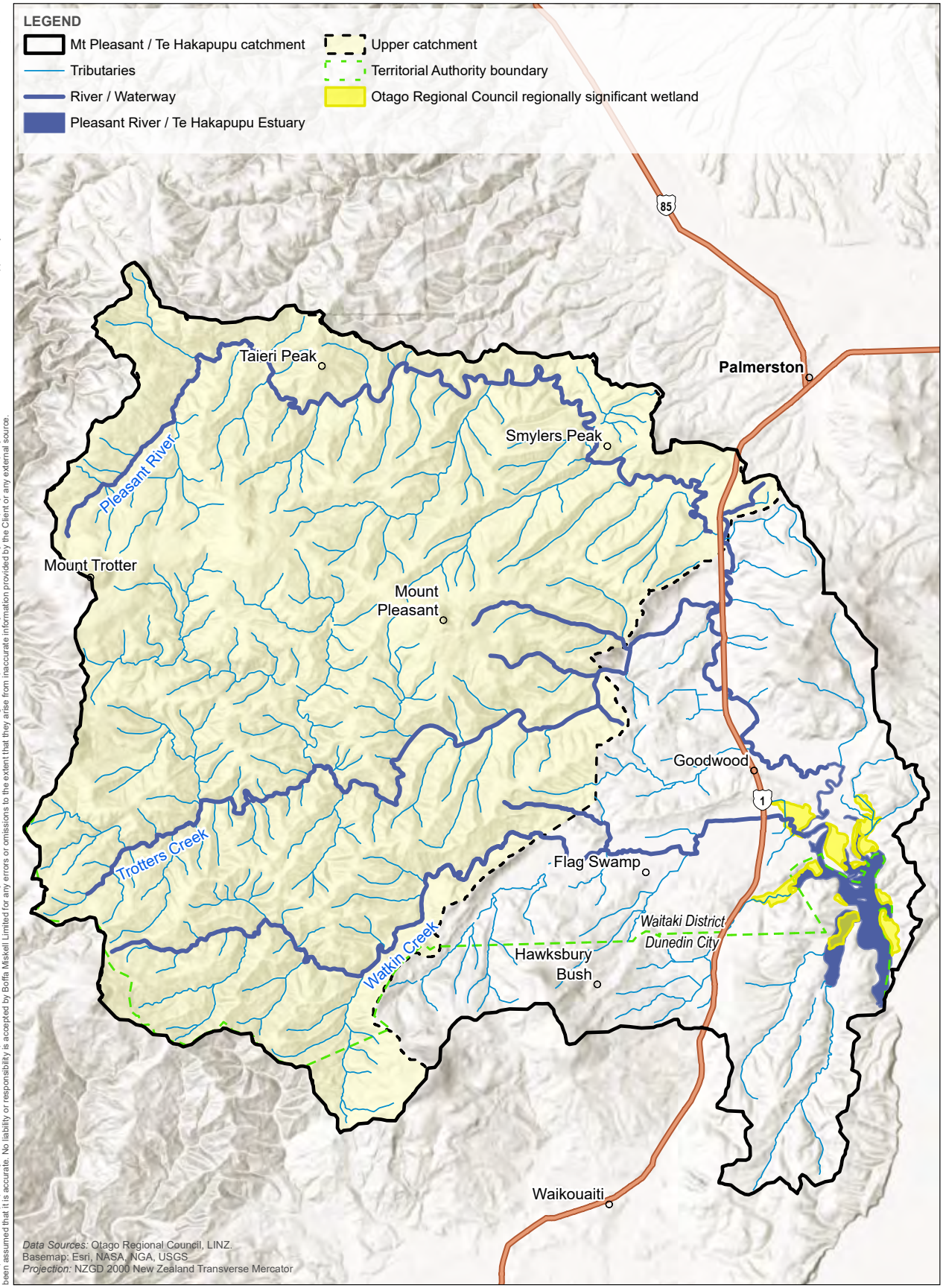
Feasibility Study

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 2



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

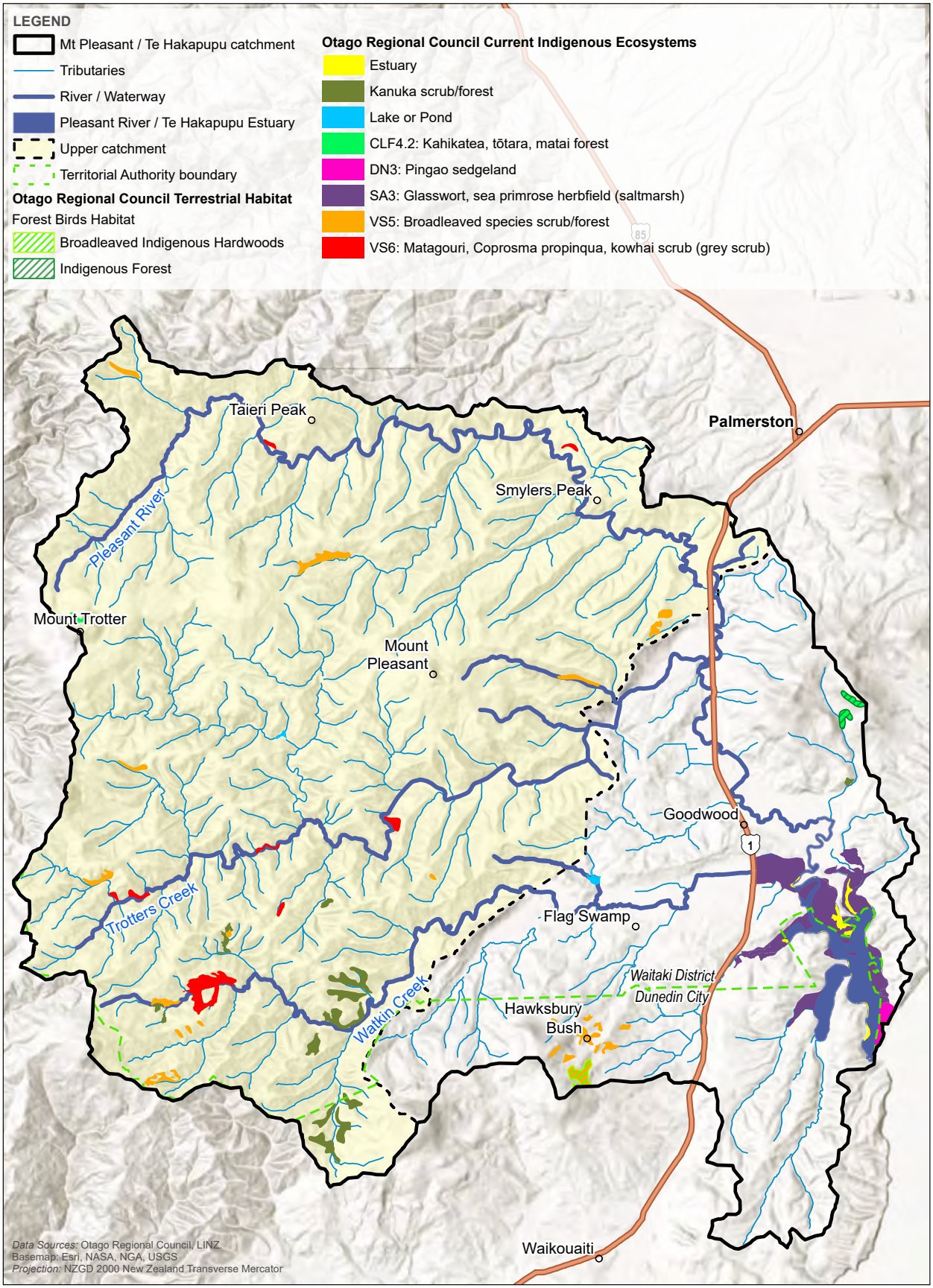
Waterways and Wetlands

Date: 06 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 3



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

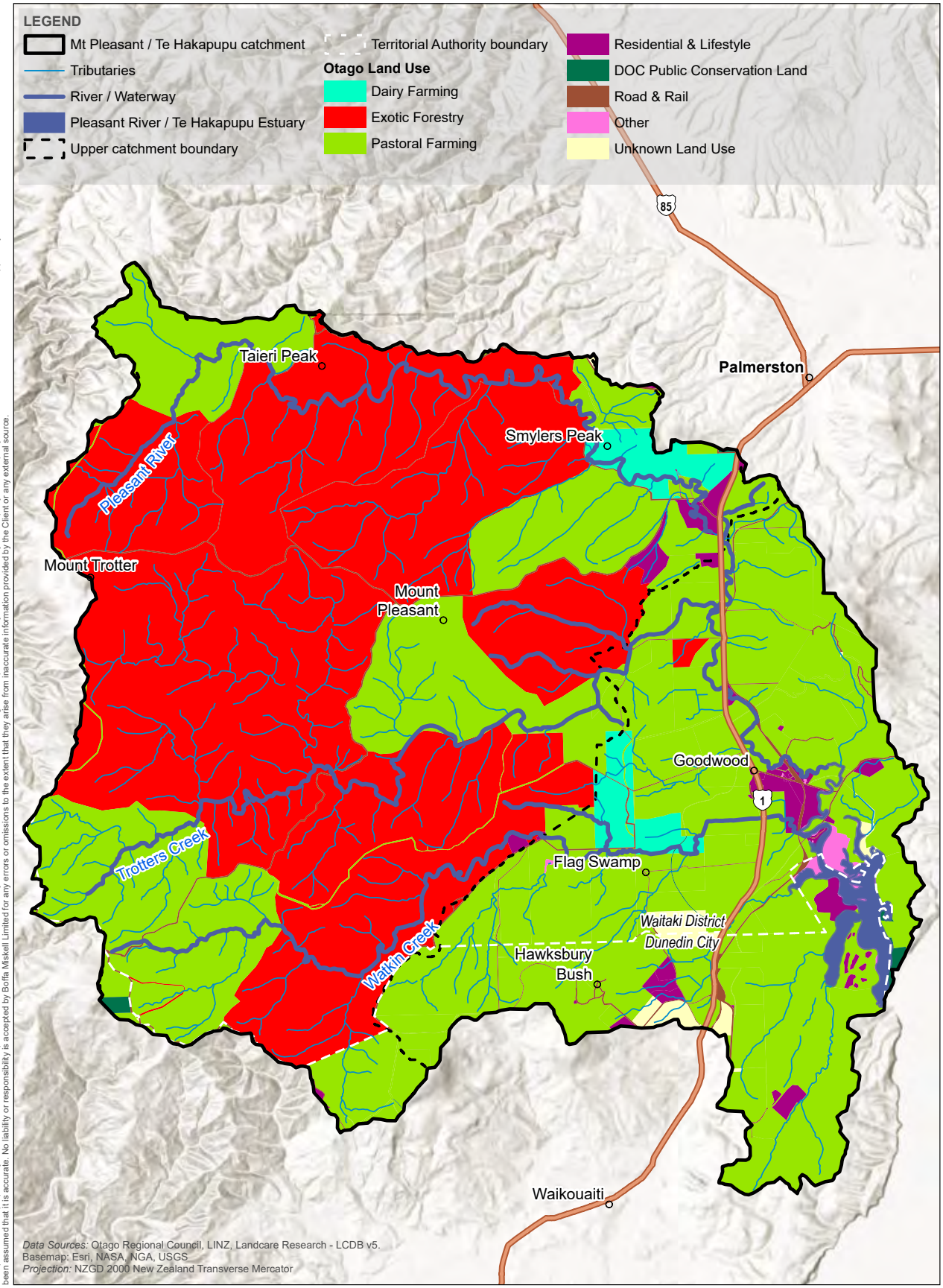
Ecosystems and Habitat

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 4



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

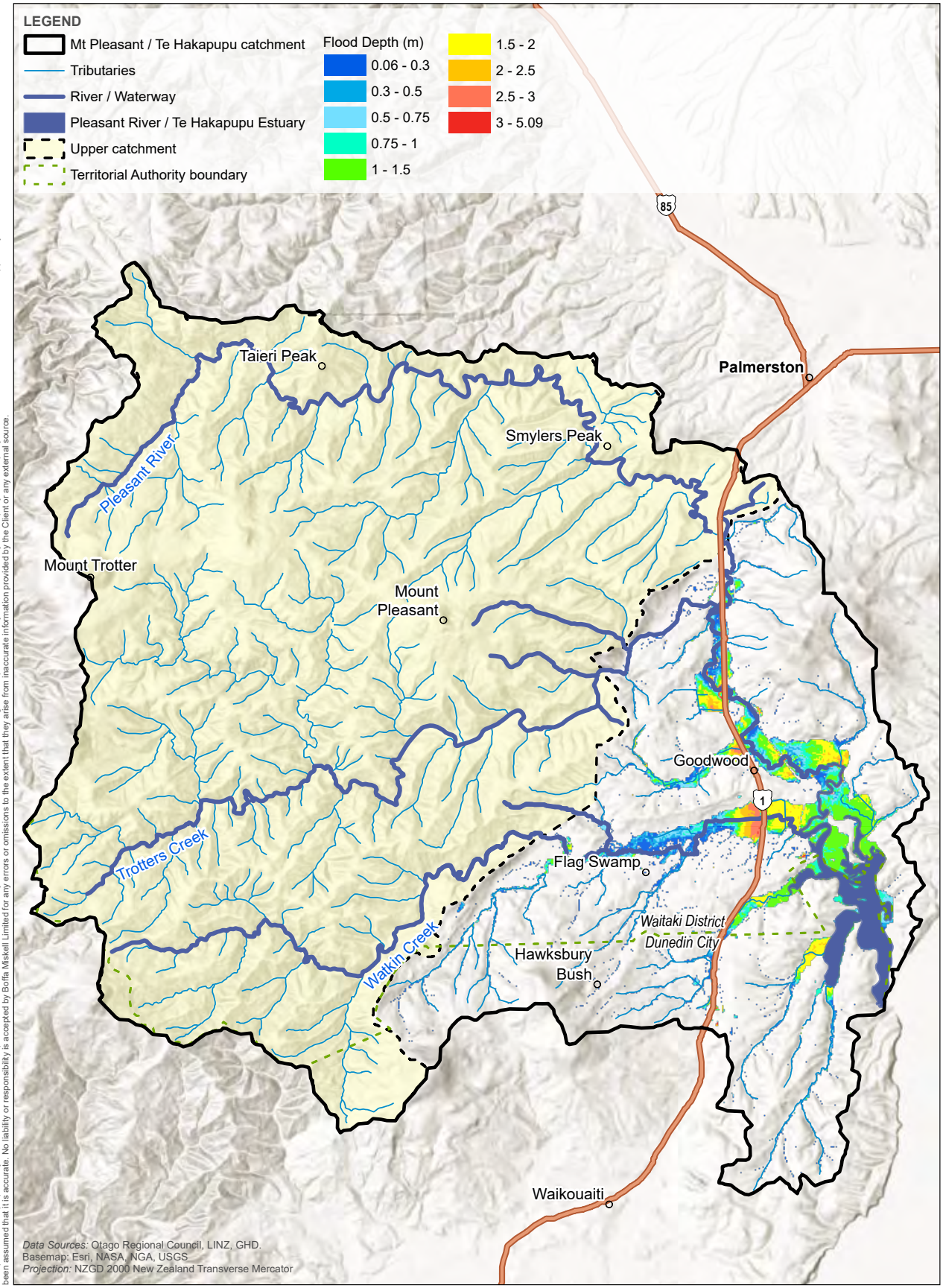
Land Use

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 5



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

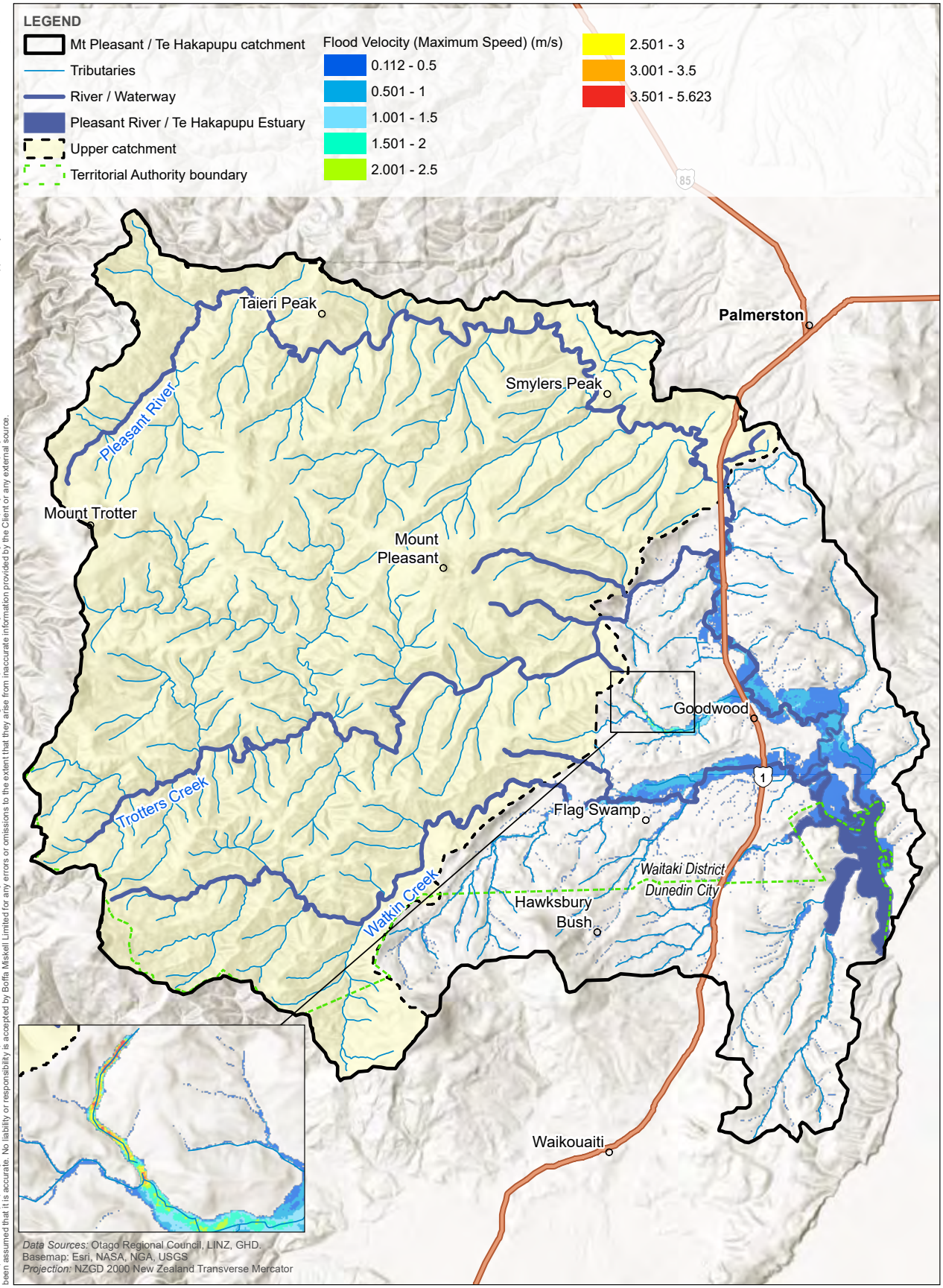
Flood Depth

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 6



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Data Sources: Otago Regional Council, LINZ, GHD.
Basemap: Esri, NASA, NGA, USGS
Projection: NZGD 2000 New Zealand Transverse Mercator

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

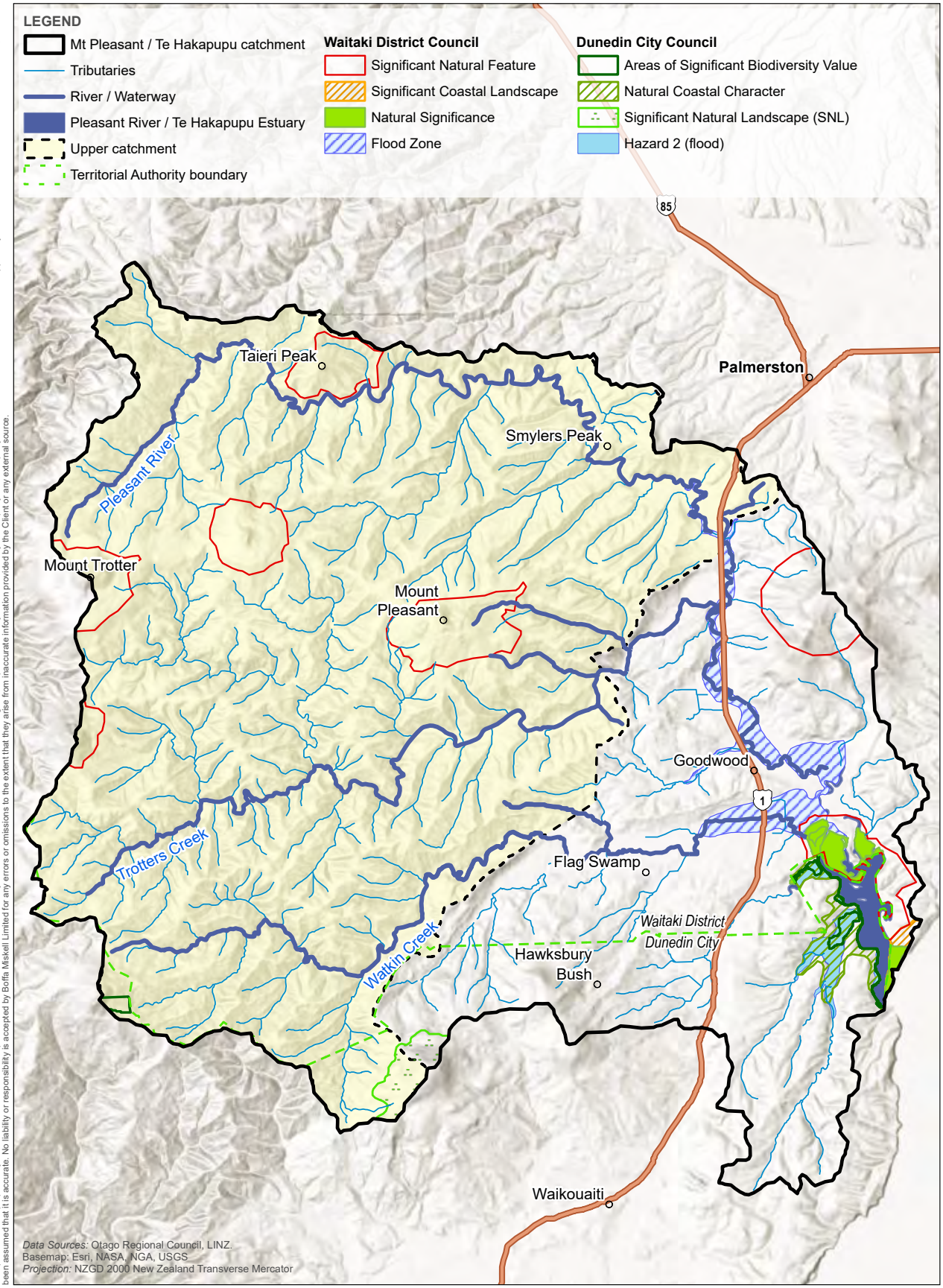
Flood Velocity

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 7



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

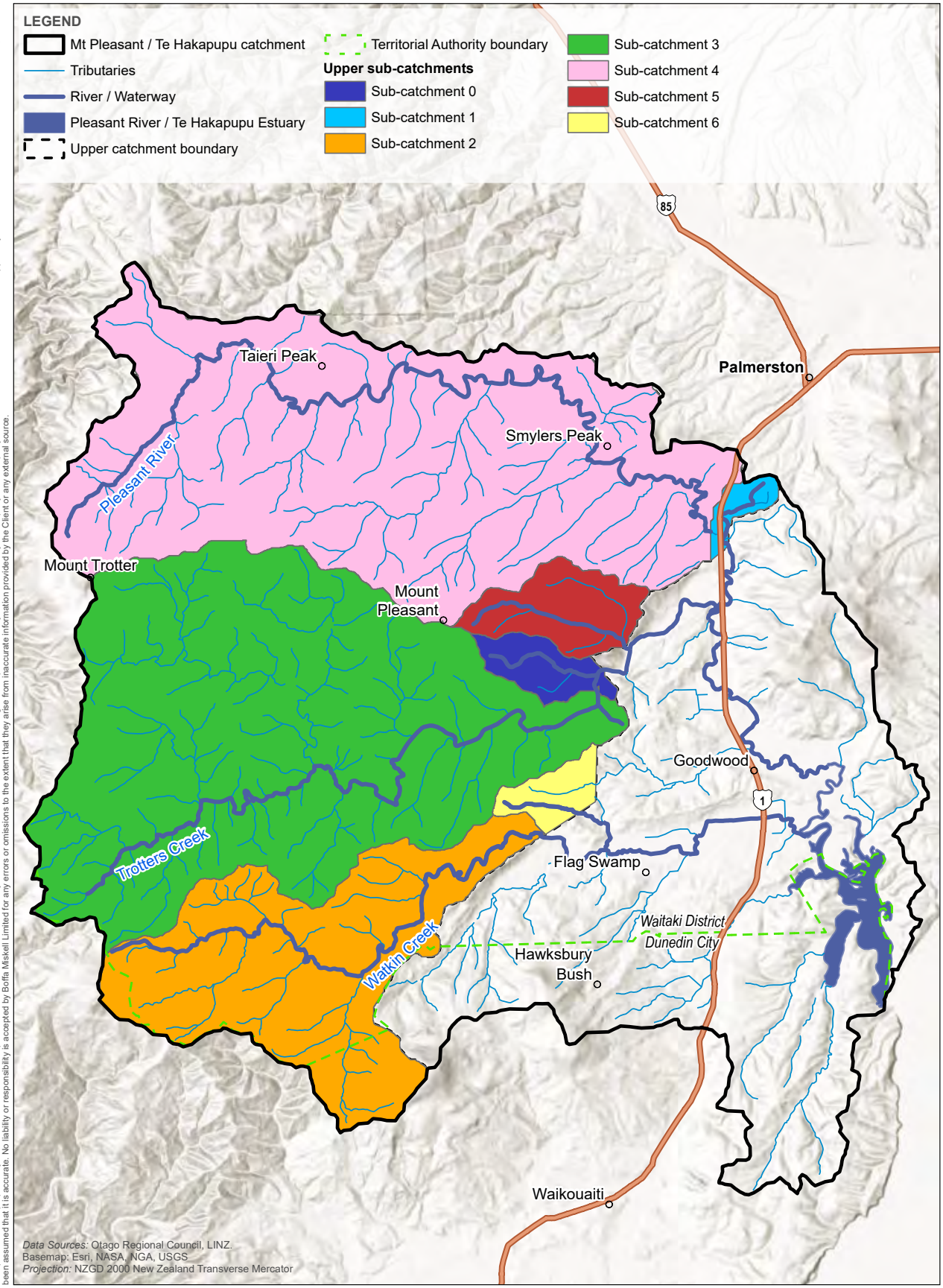
Dunedin City and Waitaki District Plans

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 8



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

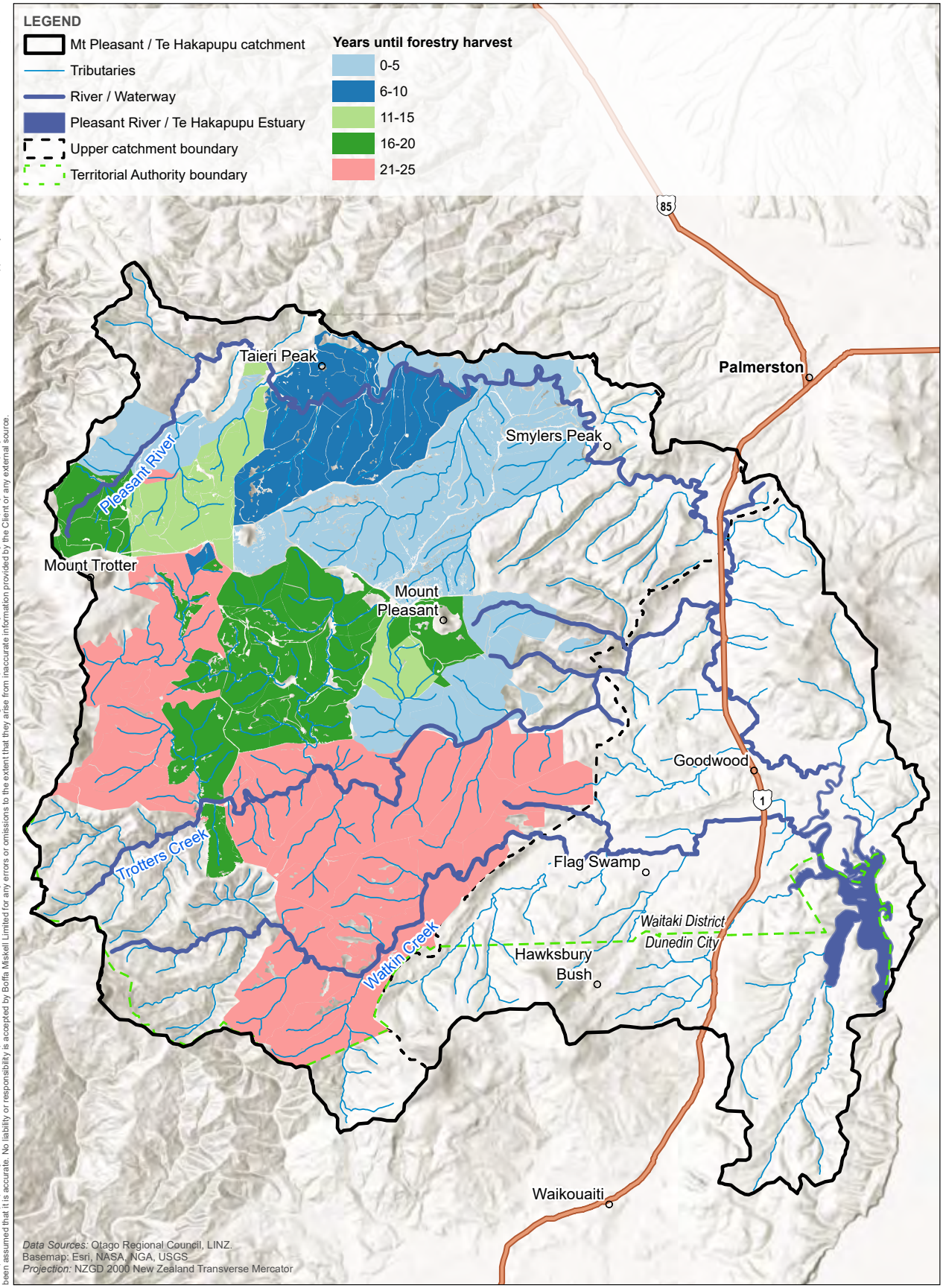
Catchment Map

Date: 06 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 9



This plan has been prepared by Boffa Miskell Limited on the specific instructions of our Client. It is solely for our Client's use in accordance with the agreed scope of work. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate. No liability or responsibility is accepted by Boffa Miskell Limited for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

Boffa Miskell
www.boffamiskell.co.nz

0 2 km
1:75,000 @ A4

PLEASANT RIVER / TE HAKAPUPU CATCHMENT NATURE-BASED SOLUTIONS

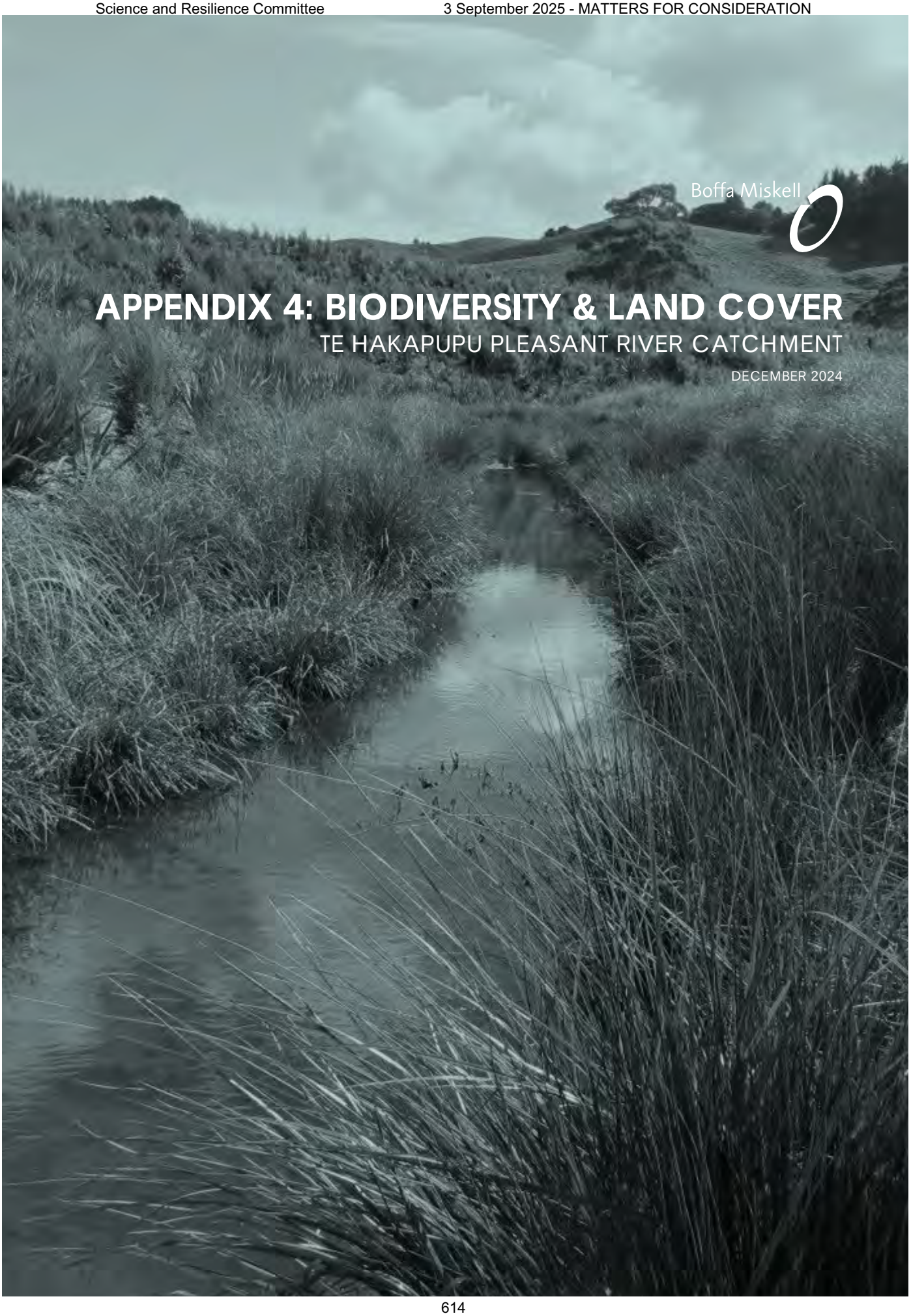
Forestry Harvest Timing

Date: 05 December 2024 | Revision: 0

Plan prepared for Otago Regional Council by Boffa Miskell Limited

Project Manager: Rachael.Eaton@boffamiskell.co.nz | Drawn: LJa | Checked: SPa

MAP 10



Boffa Miskell

APPENDIX 4: BIODIVERSITY & LAND COVER

TE HAKAPUPU PLEASANT RIVER CATCHMENT

DECEMBER 2024

BIODIVERSITY & LAND COVER CONTEXT

LAND COVER & CONSERVATION

The vegetation cover in Te Hakapupu catchment that may have existed prior to human arrival was likely dominated by forest species such as mataī, tōtara, and kahikatea, with mild climate forest types present in lower elevations and wetland surrounding the upper estuary (Leathwick *et al,* 2012). Today, indigenous forest / scrub areas consisting of kānuka, mānuka, matagouri, and other grey shrub species collectively cover approximately 1% of the catchment. These remnants of indigenous forest are mostly clustered in areas surrounding the estuary and through steeper parts of the south-eastern aspect of the catchment. Threatened and At-Risk plant species previously recorded in the catchment include climbing groundsel and desert broom (both At Risk – Declining; de Lange et al. 2018; Ahikā Consulting Ltd, 2023).

Hawkesbury Bush represents the only moderately large QEII covenant in the catchment, covering 10 hectares of native forest remnants located near the southern extent of the catchment. Restoration planting undertaken by ORC, Kāti Huirapa Rūnaka ki Puketeraki, and the local landowners as part of the Toitū Te Hakapupu project has established approximately 68,000 plants and 27 km of fencing for freshwater enhancement, contributing to the biodiversity values in the area.[1]

ESTUARY WETLAND BIODIVERSITY

The wetland and estuary, known as Te Hakapupu Pleasant River estuary wetland complex, is predominantly an estuarine system covering approx. 84 hectares (~0.6% of the catchment). The estuary wetland complex comprises of mostly salt marsh, saltmeadow, mud flat, and sandspit, supporting vegetation including glasswort (*Salicornia quinqueflora*), saltgrass (*Puccinellia* spp.), rekoreko (*Selliera radicans*), sea primrose (*Samolus repens*), and saltmarsh ribbonwood (*Plagianthus divaricatus*). It is the largest wetland in the North Otago Freshwater Management Unit, and, as an estuary, is a naturally uncommon ecosystem (Williams et al. 2007; Ahikā Consulting Ltd, 2023).

eDNA analysis of fish species in the three main tributaries within the catchment indicated ten species of freshwater fish and seven estuarine / marine species. Of these species, four freshwater fish are considered mahika kai species (īnaka and tuna / longfin eel; At Risk-Declining; and banded kōkopu, and tuna / shortfin eel; Not Threatened). All three estuarine species are considered mahika kai species (kahawai, pātiki / sand flounder, and aua / yellow-eyed mullet).

The estuary and wetland complex provides important habitat for birdlife within the catchment, including kuaka / bar-tailed godwit, pohowera / banded dotterel, tōrea / South Island pied oystercatcher, tarāpuka / black-billed gull and tara / white-fronted tern (all At Risk – Declining), tōrea pango / variable oystercatcher (At Risk - Recovering), as well as poaka / pied stilt and matuku moana / white-faced heron (both Not Threatened; Ahikā Consulting Ltd. 2023).

[1] Toitū Te Hakapupu planting and fencing figures are based on ORC reporting for December 2024 – Successes: planting, fences, and sediment traps.

Table 1: Fish species of the Hakapupu catchment, threat status based on the New Zealand Threat Classification system, and mahika kai status

	SPECIES	THREAT CLASSIFICATION	MAHIKA KAI
Freshwater Migratory	Banded kōkopu	Not Threatened	✓
	Bluegill bully	At Risk – Declining	
	Common bully	Not Threatened	
	Īnaka (inanga)	At Risk – Declining	✓
	Tuna / longfin eel	At Risk – Declining	✓
	Redfin bully	Not Threatened	
	Tuna / shortfin eel	Not Threatened	✓
Freshwater Non-Migratory	Upland bully	Not Threatened	
	Brown trout	Introduced	
	European perch	Introduced	
Marine Estuary	Estuary clingfish	Not assessed	
	Kahawai	Not assessed	✓
	Pātiki / sand flounder	Not assessed	✓
	Spotty	Not assessed	
	Thornfish	Not assessed	
	Aua / yellow-eye mullet	Not Threatened	✓

FISH PASSAGE

An assessment of potential fish passage barriers in the Hakapupu catchment was conducted by Kāti Huirapa Rūnaka Puketeraki and ORC in 2024 (Dale & Rata te Raki, 2024). In total, 20 instream structures were assessed for fish passage across the Hakapupu catchment, with 7 structures considered to be of high priority for replacement or remediation. The Toitū Te Hakapupu project is currently working to improve or replace five of these high priority structures to improve fish passage.

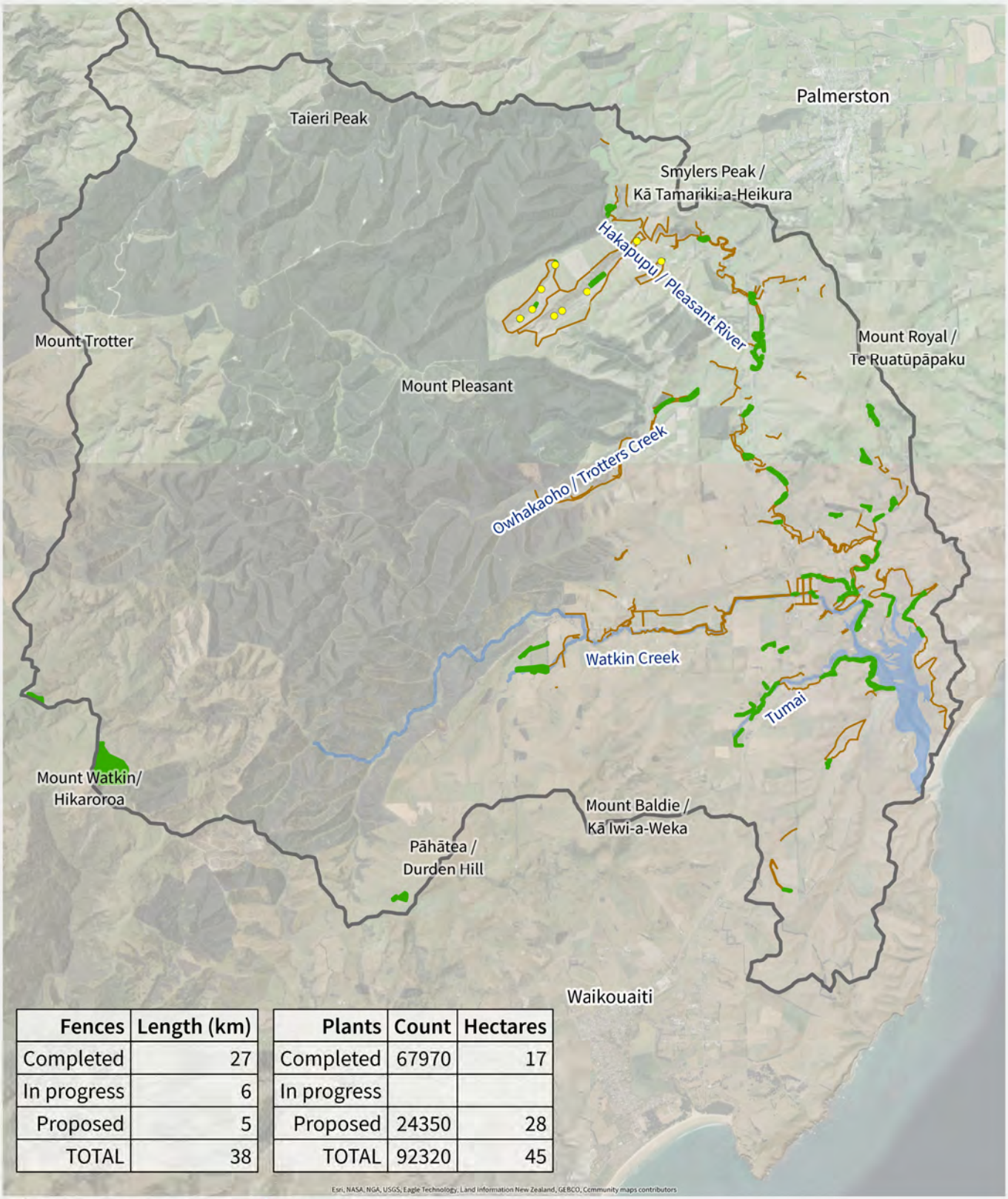
PEST SPECIES

The most prominent pest plants in the wider catchment include gorse and broom. Within the estuarine area, vast meadows of spartina can form causing a build-up of sediment, increasing flood risk. ORC undertakes spartina control work but can also issue notices requiring occupiers to eliminate spartina infestations on their land. Other pests include willows and alders, which disrupt the natural flow characteristics of the waterways under high flow conditions, exacerbating flooding. However, these species are also valued by some in the local community, on the basis that these trees provide riparian shade, stabilise riverbanks and reduce bank erosion. Community feedback has also described high number of pigs and deer coming out of forestry areas in the upper catchment, causing damage to pasture.

Toitū Te Hakapupu

Successes: plantings, fences and sediment traps

Otago Regional Council



Fences	Length (km)
Completed	27
In progress	6
Proposed	5
TOTAL	38

Plants	Count	Hectares
Completed	67970	17
In progress		
Proposed	24350	28
TOTAL	92320	45

Pleasant River Catchment
Plantings
Fences
Completed Sediment Traps (9)

0 1.5 3
kilometres

Information on this map may not be used for the purposes of any legal disputes. The user should independently verify the accuracy of any information before taking any action in reliance upon it.
This map was generated for A3 printing on 5/12/2024 at the scale of 1:50,000.

Boffa Miskell

APPENDIX 5: LANDSCAPE CONTEXT

TE HAKAPUPU PLEASANT RIVER CATCHMENT

DECEMBER 2024

LANDSCAPE CONTEXT

The concept of 'landscape' forms a foundation through which Nature-based Solution (NbS) interventions in Te Hakapupu Pleasant River catchment have been considered within this feasibility study.

Current professional best practice landscape guidance (Te Tangi a Te Manu, NZILA, 2022) sets out the following understanding of landscape in terms of the nature of relationships between people and place conceptualised as three overlapping dimensions:

- **Physical:** the physical environment—its collective natural and built components and processes
- **Perceptual:** how we perceive and experience places
- **Associative**: the meanings and values we associate with places

This guidance also notes that character and value are different but interdependent and that all landscapes have character and value.[1] Identifying each landscape's values is fundamental to its management.

VISUAL AMENITY

Visual matters are integral to landscape. As set out in Te Tangi a Te Manu, the concept of landscape is relevant to both the quality of the environment and amenity values. Terms such as 'visual amenity' and 'rural amenity', refer to landscape values that contribute to amenity values.

It is also noted that sections 7(c) and 7(f) of the RMA refer to maintenance and enhancement, providing for positive effects including restoration and rehabilitation.[2]

NATURAL CHARACTER

Natural character is the term used to describe the degree of naturalness in an area, and includes the natural elements, patterns, processes, and experiential qualities attributes of an environment. The natural character of the coastal environment, and freshwater bodies and their margins, is comprised of a number of key attributes which include:

- **Abiotic systems**: physical processes, geomorphology, topography, landform, and water quantity/quality
- **Biotic systems:** species, communities, habitats, and ecological processes

Experiential attributes - the ways in which people, including tangata whenua, experience the natural elements, patterns, and processes.

The degree of natural character present in an area is commonly described on a continuum. Areas of very high natural character are due to the lack of human induced modification. In other areas, there may be little natural character remaining due to extensive human modification.

[1] Ibid, para 5.28
[2] Ibid, paras 5.56-5.58

POLICY FRAMEWORK

RESOURCE MANAGEMENT ACT 1991

The assessment of landscape, natural character and visual effects addresses the following relevant Resource Management Act 1991 (RMA) matters:

- **Section 6(a):** Preserving the natural character of wetlands, streams, rivers, and their margins
- **Section 6(b):** Protection of outstanding natural features and landscapes
- **Section 7(c):** Maintain and enhance amenity values
- **Section 7(f):** Maintain and enhance the quality of the environment

OTAGO REGIONAL PLANS

The Te Hakapupu Pleasant River catchment is subject to provisions in the following Plans:

- Partially Operative Otago RPS 2019
- Proposed Regional Policy Statement 2021
- Regional Plan: Water for Otago

Provisions most relevant to landscape matters are summarised below.

- **Partially Operative Otago RPS 2019**
  Objective 3.1 of the Partially Operative Otago RPS (PORPS) relates to recognising, maintaining, or enhancing where degraded, the values of natural resources.

  The values (including intrinsic values) of ecosystems and natural resources are recognised and maintained or enhanced where degraded.

This is supported by the following relevant landscape-related policies:

Policy 3.1.11 Natural features, landscapes, and seascapes
Recognise the values of natural features, landscapes and seascapes are derived from the biophysical, sensory and associative attributes in Schedule 3.

Schedule 3 provides a list of criteria for the identification of natural features, landscapes and seascapes based on the dimensions recommended in Te Tangi a Te Manu:

1. Biophysical attributes

a. Natural science factors, including geological, topographical, ecological and dynamic components

b. The presence of water including in seas, lakes, rivers and streams

c. Vegetation (native and exotic)

2. Sensory attributes a. Legibility or expressiveness—how obviously the feature or landscape demonstrates its formative processes

b. Aesthetic values including memorability and naturalness

c. Transient values including presence of wildlife or other values at certain times of the day or year

d. Wild or scenic values

3. Associative attributes

a. Whether the values are shared and recognised

b. Cultural and spiritual values for Kāi Tahu, identified by working, as far as practicable, in accordance with tikanga Māori; including their expression as cultural landscapes and features

c. Historical and heritage associations

Policy 3.1.12 Natural character in the coastal environment
Recognise the values of natural character in the coastal environment are derived from one or more

of the following attributes:

a) Natural elements, processes and patterns;

b) Biophysical, ecological, geological and geomorphological aspects;

c) Natural landforms such as headlands, peninsulas, cliffs, dunes, wetlands, estuaries, reefs,

freshwater springs and surf breaks;

d) The natural movement of water and sediment;

e) The natural darkness of the night sky;

f) Places or areas that are wild or scenic;

g) A range of natural character from pristine to modified;

h) Experiential attributes, including the sounds and smell of the sea; and their context or setting.

Objective 3.2 relates to the identification of significant and highly valued resources and their protection or enhancement where degraded. Policies 3.2.3 and 3.2.5 relates to identifying outstanding natural features landscapes (RMA Section 6b) and highly valued natural features and landscapes.

The Hakapupu catchment is not identified as part of any outstanding natural feature or landscape however Te Hakapupu Pleasant River estuary wetland complex is identified as a Regionally Significant Wetland in the Regional Water Plan (summarised below).

The PORPS has been developed to give effect to the National Policy Statement for Freshwater Management (NPSFW) requirements. PORPS policy 3.1.1 requires freshwater to be managed to *"maintain or enhance as far as practicable"*, amenity and landscape values of rivers and wetlands among other matters.

PROPOSED REGIONAL POLICY STATEMENT 2021

Objective CE–O2 relates to maintaining or enhancing highly valued natural features and landscapes areas of the coastal environment.

Objective CE–O3 relates to protecting areas of natural character, natural features, landscapes and seascapes within the coastal environment and encouraging restoration is encouraged where the values of these areas have been compromised.

Objective NFL-O1 of the Proposed Regional Policy Statement (Proposed RPS 21) relates to the protection of outstanding natural features and landscapes and maintenance and enhancement of highly valued natural features and landscapes, including promoting restoration where those areas or values have been reduced or lost.

REGIONAL PLAN: WATER FOR OTAGO

Work is currently underway to prepare a new Land and Water Regional Plan (LWRP) for the Otago region however, at the time of writing, this plan has yet to be notified.

There are a number of key provisions relevant to this assessment that relate to the preservation of the natural character of waterbodies and their margins and protection from inappropriate use and development (RMA Section 6.a). These include protecting their natural character, maintaining, or enhancing their amenity values, having particular regard to features such as natural flow characteristics, water colour and clarity, aesthetic values, and recreational opportunities among others.

Policy 8.7.1 directs the promotion of the creation, retention, and enhancement of appropriate riparian vegetation.

DISTRICT PLANS

Te Hakapupu Pleasant River catchment is mostly within the Waitaki District Plan, apart from an area to the south of the estuary and part of Mt Watkin which are within the Dunedin 2nd Generation District Plan.

Within the Waitaki District, the catchment is largely within the rural zone, with some inland areas within the ‘rural scenic’ zone. Catchment areas within the Dunedin District Plan are also largely within the rural zone, except for a small rural residential area to the south of the estuary. The six volcanic peaks within the catchment are identified as Significant Natural Features in the Waitaki District Plan.

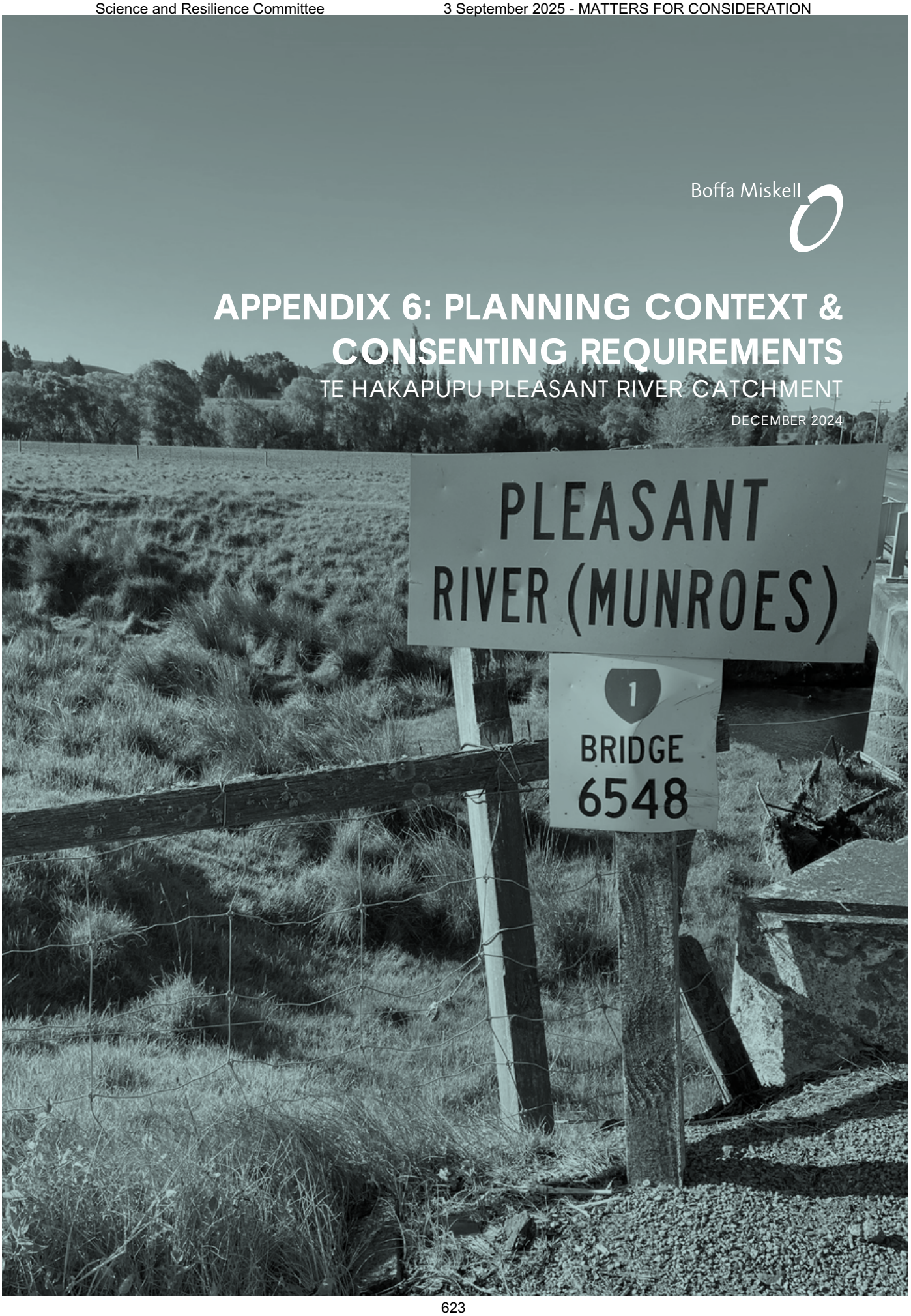
Te Hakapupu Pleasant River estuary wetland complex is identified as a Significant Natural Feature and an Area of Significant Nature Conservation Value under the Waitaki District Plan. The estuary wetland complex contains a range of values, including habitat for threatened species and mahika kai species, recreational opportunities, and landscape aesthetic qualities. Additionally, mana whenua values are associated with the estuary wetland complex.

Boffa Miskell

APPENDIX 6: PLANNING CONTEXT & CONSENTING REQUIREMENTS

TE HAKAPUPU PLEASANT RIVER CATCHMENT

DECEMBER 2024



PLANNING CONTEXT & CONSENTING REQUIREMENTS

PLANNING REQUIREMENTS

There are a range of potential regulatory requirements that may require various consents and authorisations to be obtained in order to enable the types of activities that relate to the Nature-based Solution (NbS) interventions considered in this feasibility report.

Most of these requirements stem from regulatory documents under the Resource Management Act (RMA), but other authorisations may be required under statutes such as the Wildlife Act 1953, the Building Act 2004, and the Conservation Act 1987.

A high-level overview of the regulatory instruments under the RMA that are likely to be relevant to the NbS under consideration in Te Hakapupu Pleasant River catchment is set out below. Further details about the potential consents and authorisations that would be required for the individual NbS solutions are provided later in this report.

RESOURCE MANAGEMENT ACT 1991

The Resource Management Act (RMA) is New Zealand's principal environmental statute. It sets the scene as to how the use and development of land, air and water should be managed, and a range of regulatory instruments are promulgated under the RMA, including National Policy Statements (NPS); National Environmental Standards (NES); Regional; and District Plans.

Any resource consents that are required to authorise the proposed NbS will be assessed in terms of the provisions of the Resource Management Act and the relevant regulatory instruments. The following matters are likely to be relevant for NbS in terms of the regulatory framework established under the RMA:

- The restoration and enhancement of indigenous biodiversity; wetlands; and freshwater environments.
- Managing the effects of climate change and natural hazards.
- Taking, using, damming, and diverting water.
- Introduction of planting into the beds of lakes and rivers, riparian margins, and wetlands.
- Remediation of barriers to fish passage.
- Earthworks and the associated management of sediment discharges.
- Managing contaminated land.

NATIONAL POLICY STATEMENTS

NPS are intended to provide national direction for matters of national significance which are related to achieving the sustainable management purpose of the RMA. Consent authorities are also required to have regard to any relevant national policy statement when considering an application for a resource consent. NPS do not include rules.

The policy direction set out in NPS is relevant to informing the consenting strategy for the proposed works as they inform the way in which the use and development of land, water, and other resources should be undertaken. Of the NPS currently in effect, the following are likely to be of most relevance to the NbS under consideration:

- National Policy Statement for Freshwater Management 2020 (NPS-FM)
- National Policy Statement for Indigenous Biodiversity 2023 (NPS-IB)
- National Policy Statement for Highly Productive Land 2022 (NPS-HPL)

NATIONAL ENVIRONMENTAL STANDARDS

National Environmental Standards (NES) are regulations made under the RMA and set out technical standards, methods or requirements relating to certain activities and their effects that apply throughout the country. They contain rules that must be complied with, and consents are required if compliance cannot be achieved. These standards do not include any policy provisions.

Of the NES currently in effect, the following are likely to be of most relevance to the NbS under consideration:

- National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health 2011 (NES-CS)
- National Environmental Standards for Freshwater 2020 (NES-F)
- National Environmental Standards for Commercial Forestry 2017 (as amended in 2023) (NES-CF)
- National Environmental Standards for Sources of Human Drinking Water (NES-DW)
- Freshwater Farm Plans Regulations 2023
- Stock Exclusion Regulations 2020

A NOTE ON RESOURCE MANAGEMENT LAW REFORM

Resource management law has been subject to ongoing reform over the past few years and is continuing to face reform under the current Government. Various amendments to the RMA have already been proposed and are currently going through the parliamentary process, with further amendments yet to come. Ultimately the current Government has signalled that it will seek to repeal the RMA and replace it with a statute based on the enjoyment of private property rights. In this context, it will be important to keep abreast of legislative changes that may affect the delivery of the NbS outlined in this report.

OTHER REGULATORY REQUIREMENTS

There is the potential for the NbS to require authorisations under other legislative requirements as follows:

- A wildlife permit under the Wildlife Act 1953
- An archaeological authority to damage, destroy or modify any archaeological sites that may be unearthed during the course of any project works
- Ensuring that any instream structures meet the relevant regulatory requirements in relation to fish passage; and
- A requirement for any dams to obtain consent under the Building Act 2004.

NATURE-BASED SOLUTIONS CONSENTING REQUIREMENTS

Based on a high-level assessment of the likely works associated with each NbS intervention within Te Hakapupu Pleasant River catchment, a summary of the potential consenting requirements associated with these activities under the relevant regulatory instruments is set out in the tables below.

LAND COVER MANAGEMENT

Table 1: Potential consenting requirements associated with landcover management. Potential consenting requirement identified are coloured green where they activities are permitted, yellow where activities are controlled, orange where activities are discretionary, and red where activities are prohibited.

ACTIVITY COMPONENT	WAITAKI DISTRICT PLAN	DUNEDIN DISTRICT PLAN
Earthworks		
Within riparian area	Discretionary activity for earthworks in riparian areas in rural zones.[1]	Restricted discretionary activity within various riparian areas. [2]
Other locations	Permitted or controlled in the rural zone depending on scale and location.[3]	Permitted or restricted discretionary depending on scale and location, and subject to conditions.[4]
Vegetation planting		
Within riparian areas	Potential permitted activity pathway provided that: No exotic tree planting or amenity tree planting in specified riparian areas. [5] Limits to planting trees within 15m of a neighbouring site boundary without their permission. [6] Tree planting is required to not shade roads or residential units.[7]	‘Conservation’ activities in the Rural Zone are generally permitted. [8]
Other areas		

[1] Waitaki District Plan Rule 4.4.7(2)
[2] Dunedin District Plan Rule 10.3.3
[3] Waitaki District Plan Rules 4.3.1(14) and 4.3.2(1)
[4] Dunedin District Plan Rules in chapter 8A
[5] Waitaki District Plan Rule 4.4.7
[6] Waitaki District Plan Rule 4.4.9
[7] Waitaki District Plan Rule 4.5.2
[8] Dunedin District Plan Rule 16.3.3.32.
‘Conservation’ is defined in the District Plan as “the use of land for the establishment, maintenance or enhancement of indigenous vegetation and/or habitat for indigenous fauna. Examples of component activities of conservation are:

- restoration planting
- pest and weed control
- track construction and maintenance; and
- fencing.

RIVER & STREAM NATURALISATION

Table 2: Potential consenting requirements associated with river naturalisation in Te Hakapupu catchment. Potential consenting requirement identified are coloured green where they activities are permitted, yellow where activities are controlled, orange where activities are discretionary, and red where activities are prohibited.

ACTIVITY COMPONENT	WAITAKI DISTRICT PLAN	DUNEDIN DISTRICT PLAN
Vegetation removal/ clearance		
Within riparian areas	Could be permitted in rural zone depending on scale, vegetation type, and location.[9] Generally limits on clearance of indigenous vegetation.	Ranging from permitted to restricted discretionary depending on scale, vegetation affected, and location. [10]
Earthworks		
Within riparian area	Discretionary activity for earthworks in riparian areas in rural zones.[11]	Restricted discretionary activity within various riparian areas. [12]
Other locations	Permitted or controlled in the rural zone depending on scale and location.[13]	Permitted or restricted discretionary depending on scale and location, and subject to conditions.[14]
Vegetation planting		
Within riparian areas	Potential permitted activity pathway provided that: No exotic tree planting or amenity tree planting in specified riparian areas. [15] Limits to planting trees within 15m of a neighbouring site boundary without their permission. [16] Tree planting is required to not shade roads or residential units.[17]	'Conservation' activities in the Rural Zone are generally permitted. [18]
Other areas		

[9] Waitaki District Plan Rule 4.4.7 and 4.4.8
[10] Dunedin District Plan Standards in chapter 10, Rules in 16.3.4; and standards in 16.6.11
[11] Waitaki District Plan Rule 4.4.7(2)
[12] Dunedin District Plan Rule 10.3.3
[13] Waitaki District Plan Rules 4.3.1(14) and 4.3.2(1)
[14] Dunedin District Plan Rules in chapter 8A
[15] Waitaki District Plan Rule 4.4.7
[16] Waitaki District Plan Rule 4.4.9
[17] Waitaki District Plan Rule 4.5.2
[18] Dunedin District Plan Rule 16.3.3.32.
'Conservation' is defined in the District Plan as "the use of land for the establishment, maintenance or enhancement of indigenous vegetation and/or habitat for indigenous fauna. Examples of component activities of conservation are:

- restoration planting
- pest and weed control
- track construction and maintenance; and
- fencing.

WETLAND RESTORATION & CONSTRUCTION

Table 3: Summary of potential consenting requirements associated with wetland restoration and construction. Potential consenting requirement identified are coloured grey where they are not applicable or not stated, green where they activities are permitted, yellow where activities are controlled, orange where activities are discretionary, and red where activities are prohibited.

ACTIVITY COMPONENT	NES-F	ORC REGIONAL PLAN: WATER	WAITAKI DISTRICT PLAN	DUNEDIN DISTRICT PLAN
Restoration and enhancement of the existing wetland	See specific rules below but generally permissive consenting pathway for associated activities.	Not applicable	Not applicable	'Conservation' activities in the Rural Zone are generally permitted. [19]
Construction of new wetland areas	N/A	Not applicable	Not applicable	
Earthworks				
Within wetland	Permitted subject to conditions[20]	Not applicable	Discretionary activity for earthworks in riparian areas in rural zones.[21]	Restricted discretionary activity within various riparian areas. [22]
Within riparian area				
Other locations	Not applicable		Permitted or controlled in the rural zone depending on scale and location.[23]	Permitted or restricted discretionary depending on scale and location, and subject to conditions.[24]

[19] Dunedin District Plan Rule 16.3.3.32
'Conservation' is defined in the District Plan as "the use of land for the establishment, maintenance or enhancement of indigenous vegetation and/or habitat for indigenous fauna. Examples of component activities of conservation are:

- restoration planting
- pest and weed control
- track construction and maintenance; and
- fencing.

[20] NES-F Regulation 38(2)
[21] Waitaki District Plan Rule 4.4.7(2)
[22] Dunedin District Plan Rule 10.3.3
[23] Waitaki District Plan Rules 4.3.1(14) and 4.3.2(1)
[24] Dunedin District Plan Rules in chapter 8A

ACTIVITY COMPONENT	NES-F	ORC REGIONAL PLAN: WATER	WAITAKI DISTRICT PLAN	DUNEDIN DISTRICT PLAN
Vegetation removal/ clearance				
Within wetland	Permitted subject to conditions[25]	Permitted subject to conditions.[26]	Could be permitted in rural zone depending on scale, vegetation type, and location.[27]	Ranging from permitted to restricted discretionary depending on scale, vegetation affected, and location. [28]
Within riparian areas		Not applicable		
Aquatic pest plant removal - rivers	Not applicable	Permitted subject to conditions, certain species.[29]		
Aquatic pest plant removal – wetlands		Controlled subject to conditions, certain species.[30]		
Vegetation planting				
Within wetland	Not applicable	Permitted subject to conditions.[31]	Not applicable	Not applicable
Within river	Not applicable	Permitted subject to conditions. [32]	Not applicable	Not applicable
Within riparian areas	Not applicable	Not applicable		*See Conservation activities above*
Other areas	Not applicable	Not applicable		
Introduction of listed pest plant species (including aquatic plants)	Not applicable	Certain species are prohibited.[33]		Includes rules limiting certain tree species being planted. [34]
Pest management				
Aquatic pest plants	Not applicable	Disturbance of the bed of a lake or river and associated discharge – permitted subject to conditions.[35]	Not stated	Not stated

[25] NES-F Regulation 38(1)
[26] Otago Regional Plan: Water, Rule 13.5.1.5A
[27] Waitaki District Plan Rule 4.4.7 and 4.4.8
[28] Dunedin District Plan Standards in chapter 10, Rules in 16.3.4; and standards in 16.6.11
[29] Otago Regional Plan: Water, Rule 13.7.1.1
[30] Otago Regional Plan: Water, Rule 13.7.2.1
[31] Otago Regional Plan: Water, Rule 13.5.1.5A
[32] Otago Regional Plan: Water, Rule 13.6.2.1
[33] Otago Regional Plan: Water, Rule 13.6.1.1
[34] Dunedin District Plan Rule 10.3.4
[35] Otago Regional Plan: Water, Rule 13.5.1.5

ACTIVITY COMPONENT	NES-F	ORC REGIONAL PLAN: WATER	WAITAKI DISTRICT PLAN	DUNEDIN DISTRICT PLAN
Taking, using, damming, diversion, and discharges of water				
Taking, using, damming, or diverting water	**Taking, using, damming or diverting water** associated with wetland restoration and enhancement permitted subject to conditions[36]	**Damming and diversion** permitted subject to conditions (but must not be in a regionally significant wetland). [37]	Not applicable	Not applicable
Discharging water	Permitted subject to conditions[38]	Not applicable		

[36] NES-F Regulation 38(3)
[37] Otago Regional Plan: Water, Rule 12.3.2.1
[38] NES-F Regulation 38(3)

Nature-based Solutions for Flood Resilience

Engagement Study

July 2025

Exploring landowner perspectives, barriers and opportunities around Nature-Based Solutions (NbS) implementation in Otago.

Beca

Prepared by

Natalie Dixon, Engagement specialist, Beca Ltd

Contributors

Emma Content, Nature-based Solutions specialist, Beca Ltd

James Taylor, Senior Associate - Planning, Beca Ltd

Status: Version 2

Acknowledgements

We sincerely thank everyone who generously contributed their time and insights to the Engagement Study.

Contents

This report shares findings from the ORC Nature-based Solutions Engagement Study. It is designed to inform planning and thinking around Nature-based Solutions activity and support the national shift toward climate-resilient solutions.

4. **Executive summary**
   Key findings and recommendations at a glance

6. **Introduction and context**
   Why this study matters – locally, nationally and globally

7. **What are Nature-based Solutions?**
   Deeper explanation and an information graphic

10. **Case studies**
    Examples of how governments and private landowners work together across the world

11. **Gathering insights - how we engaged**
    Engagement strategy

12. **What people told us**
    Direct feedback from Otago landowners and stakeholders

14. **Survey snapshot**
    Key insights from the digital survey

16. **Key findings**
    Barriers to implementation and opportunities

22. **From insight to action: Embedding Nature-based Solutions**
    Ideas and recommendations to enable implementation

26. **Conclusion**

THIS DOCUMENT MAY BE REFERENCED AS:

Beca Ltd, 2025. Nature-based Solutions for Flood Mitigation: Exploring landowner perspectives, barriers and opportunities around Nature-Based Solutions (NbS) implementation in Otago.

Prepared by Beca for the Otago Regional Council.

Executive summary

Around the world, Nature-based Solutions have been credited with saving billions of dollars in flood damage costs - by working with nature instead of trying to control it.

Nature-based Solutions are practical approaches that harness nature's own processes to address climate challenges. They include restoring wetlands to absorb floodwaters and filter pollutants, using bioretention techniques that combine plants and specialised soils to soak up rainfall, planting to prevent erosion, and naturalising rivers and streams to improve water flow and stability.

Nature-based solutions are embedded in key global and national frameworks, and are included in ORC's guiding framework (Strategic Directions 2024 - 2034) as tools for climate resilience, ecosystem restoration, and community wellbeing.

There is an opportunity, and growing expectation, for the Otago Regional Council (ORC) and other councils to play a role in regional delivery.

This report is part of the ORC's efforts to explore how Nature-based Solutions could play a part in reducing the effects of flooding in Otago, helping to protect people, infrastructure and property.

It is part of a wider Nature-based Solutions Study - 'Wai i te reporepo, wai i te wao: What Nature tells us about how to understand and prepare for flooding' and was funded through the Ministry for the Environment's Essential Freshwater Fund and Jobs for Nature programme.

This report highlights the value of working with willing partners, embedding nature-led responses, and unlocking co-benefits through integrated planning, funding and leadership.

By enabling locally led delivery, aligning policy and funding streams, and actively brokering partnerships, ORC can help transform exploratory interest into measurable results. The opportunity now is to move from insights to action – building a more resilient Otago through shared leadership, transparent co-investment and nature-based design.

Engagement study purpose

Around the world, Nature-based Solutions are implemented across both public and private land. Collaborative projects involving landowners, government, iwi, and community groups deliver benefits that extend beyond property boundaries —protecting ecosystems, infrastructure, and people.

This Engagement Study is part of a national Ministry for the Environment (MfE) initiative exploring how Nature-based Solutions could support flood mitigation across Aotearoa New Zealand. Focusing on Otago, the study sought to understand landowner perspectives and uncover challenges and opportunities for implementing Nature-based Solutions on private land.

The study is exploratory —not formal consultation — and is designed to inform. Through interviews, surveys, and review of existing reports, it builds a regional picture of awareness, motivation, barriers, and opportunities.

This report offers a starting point for future collaboration, consultation, and initiatives that support the further integration of Nature-based Solutions into Otago Regional Council (ORC) strategies and actions.

Readers are encouraged to consider how these findings might support regional planning, partnership and funding development, and policy design — and to reflect on their role in enabling Nature-based Solutions for flood resilience.

Findings

The Engagement Study highlighted the region's strong history and shared commitment to working with natural systems to solve challenges.

People are aware of the flood risks and are interested and open to having a conversation about Nature-based Solutions for flood mitigation. Almost everyone could see the benefits and supported ORC investigating them further.

Most people were either open to having a hypothetical Nature-based Solution on their property or interested in discussing it further. They wanted to understand costs and funding, maintenance or access agreements, and to better understand data and modelling. Some landowners indicated they had land they were ready to offer for discussion and potential implementation now, signalling strong early-stage interest.

There were firm ideas about who should lead future work, with the majority suggesting a catchment- or community-led approach, and ORC's role being to provide a regulatory framework, funding, and technical advice.

Some preferred ORC to take the lead, noting the in-house technical expertise that exists.

There were also suggestions to form regional or catchment-level partnership groups, including mana whenua, landowners, non-government organisations (NGOs), and private organisations—that could contribute funding, technology solutions (e.g., AI), and technical expertise to overcome challenges.

The study revealed significant opportunities to 'work with the willing' and build on the region's enthusiasm for natural solutions. There are significant opportunities to weave Mātauranga Māori and contemporary science together. Co-designing processes that pair cultural indicators (tohu) with scientific datasets would unlock deeper, place-based understanding of flood resilience.

By fostering collaboration and addressing gaps in funding, governance, and technical expertise, Nature-based Solutions could begin to be implemented on privately owned land - helping to create a more resilient and adaptable Otago.

The following themes, along with others, are explored further in this report.

Barriers

Awareness gap (flood benefits): People already value the environmental benefits of Nature-based Solutions however initial awareness of their potential for flood mitigation is low.

Technical language: Technical terms, including 'Nature-based Solutions', and unfamiliar phrasing can be a roadblock to understanding. People suggested talking about individual solutions (wetlands, river naturalisation) rather than using the term 'Nature-based Solutions. Graphics and images were seen as helpful.

Trust and relationships: Building trust with landowners is key to implementing Nature-based Solutions. ORC could consider partnering with third party groups, like NZ Landcare Trust, to support engagement.

Regulatory uncertainty: Inconsistent and evolving regulations create challenges and pessimism, with landowners seeking stability and set rules to enable long-term planning and investment.

Lack of local evidence: A lack of local data, modelling, and New Zealand case studies undermines confidence in Nature-based Solutions for flood management.

Expert advice: Free or subsidised access to technical experts could help landowners confidently implement Nature-based Solutions.

Financial constraints: Compensation was not a primary driver for all landowners, with both productive and unproductive land already being fenced off or offered for projects led by catchment groups and other organisations. For some, however, cost-related concerns remain a significant barrier.

Land access and maintenance concerns: Some people want to discuss possible access, maintenance, and reporting agreements with ORC before considering Nature-based Solutions on their property.

Opportunities

Mātauranga Māori and contemporary science: Conversations with members of the Ōtākou and Puketēraki hapū and whānau highlighted the need to merge Māori environmental knowledge and science. Co-designing processes and pairing cultural indicators (tohu) with contemporary datasets can unlock a deeper understanding of flood resilience.

Build on existing enthusiasm: Many landowners are already engaged with wetland and planting projects and are open to future initiatives, if supported with clear guidance and funding.

Scalable implementation: A tiered approach, where ORC leads high-risk interventions and community groups manage smaller or medium-sized projects, could create a balanced strategy. Identifying natural areas to protect can be as important as finding areas to create new projects.

Clear communications campaign and case studies: Providing local case studies will build confidence and interest among landowners. People emphasised the need for short non-technical documents and videos they could understand quickly. A communications campaign was suggested by some landowners.

Strengthen strategic partnerships: Nature-based Solutions can help various people meet their goals - from flood resilience, water quality, biodiversity to building social licence. Partnering with diverse groups can open up new pathways for implementing Nature-based Solutions.

Crown landowners and larger Otago landowners: Focus on Crown landowners such as NZ Transport Agency Waka Kotahi (NZTA), Department of Conservation (DOC), Pamu and other councils, along with larger Otago landowners such as Ngāi Tahu / Kāi Tahu, forestry, stations and those with land in the upper catchments to scale-up Nature-based Solutions.

Provide clear, practical guidance: Developing plain language resources that explain the benefits, planning and consent processes, and practical steps for implementing Nature-based Solutions will help landowners navigate implementation.

'Normalise' Nature-based Solutions: Integrate Nature-based Solutions into council functions. Prioritise or include green infrastructure in investment decisions and ensure funding supports delivery.

Innovative funding and co-investment: Explore new ways to fund projects, including private investment, co-funding and alternative government funding.

Introduction and context

The climate is changing and so must our responses. Globally and in Aotearoa, more frequent and intense weather systems are already impacting communities and ecosystems.

Local landscapes, coastal systems, and freshwater catchments are facing pressure, and the interconnected risks of climate change, biodiversity loss, and land degradation demand integrated solutions.

Nature-based Solutions are recognised, nationally and globally, as effective tools for climate adaptation. Often described as 'Indigenous knowledge in action', they offer practical and adaptable additions to complement traditional and often rigid 'hard engineering' flood mitigation options.

They are included in national direction, with Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy, the National Adaptation Plan, and the Climate Change Strategy all calling for their integration into adaptation planning. Globally, they are aligned with frameworks such as the Kunming–Montreal Global Biodiversity Framework, which prioritises equitable, nature-led responses to climate impacts. They are also highlighted in ORC's Strategic Directions 2024–2034 as key tools for building climate resilience, restoring ecosystems, and supporting community wellbeing across Otago.

Strengthening climate responses through nature

In late 2023, the Ministry for the Environment provided funding to allow 15 councils to explore how nature-based interventions might be used to mitigate river or coastal flood risk.

The Otago Regional Council (ORC) commissioned two related studies:

- a **Feasibility Study**, modelling the potential flood mitigation benefits of three Nature-based Solutions interventions in Te Hakapupu / Pleasant River catchment, and
- this **Engagement Study**, exploring landowner perspectives on implementing Nature-based Solutions on private land.

The Engagement Study and this report build insight from surveys, interviews, and existing reports. It reveals high interest in exploring Nature-based Solutions for flood mitigation but also highlights where systems are not yet ready—whether due to the lack of national direction, policy and funding, policy ambiguity, lack of knowledge and technical guidance, or gaps in long-term funding pathways.

The focus is primarily on freehold land, though the findings may have relevance for leasehold, Māori land, and Crown-owned areas, particularly where collaborative or catchment-level approaches are possible.

The study, and this report is intended to start conversations and inform ORC's strategic planning and investment, support region-wide implementation efforts, and contribute to the broader national conversation about how systemically enabled, locally led Nature-based Solutions can build climate resilience in Aotearoa.

Facing the future

Flooding is Otago's most frequent Civil Defence emergency, threatening homes, land, infrastructure, and the environment. ORC is seeking smarter, more sustainable ways to manage and reduce this risk.

For generations, iwi, landowners and communities in Otago have worked with nature—restoring wetlands, planting, and managing land—to protect waterways and biodiversity. While not always aimed at flood resilience, these efforts show a strong local legacy of using natural systems to solve complex challenges.

ORC's strategy already blends hard infrastructure (like culverts and floodbanks) with natural tools (like planting and river restoration), supported by drainage management, community education, and emergency response.

As climate change intensifies flood risks, traditional engineered solutions alone won't be enough. They'll need to be supported by adaptable approaches - like Nature-based Solutions - that can flex, absorb, and respond to a changing environment.

Flooding is Otago's most frequent Civil Defence emergency—putting homes, land, and infrastructure at risk.

What are Nature-based Solutions?

Nature-based Solutions harness the power of nature to tackle environmental challenges like flooding, erosion, and water quality issues.

By working with natural systems instead of trying to control or override them, Nature-based Solutions offer practical, sustainable ways to help protect people, property, and ecosystems.

These solutions involve actions like restoring wetlands to soak up floodwater, planting trees to stabilise soil and reduce sediment runoff into rivers and estuaries or creating riparian buffers to protect riverbanks from erosion and improve water quality. But they don't stop there, Nature-based Solutions often bring extra benefits, like boosting biodiversity, creating habitats for native species, and even supporting new economic opportunities through eco-tourism or sustainable farming.

Nature-Based Solutions don't just manage water, they can help restore mahinga kai, enhance biodiversity, and regenerate native habitats. They also support opportunities for eco-tourism and regenerative farming.

Flood mitigation

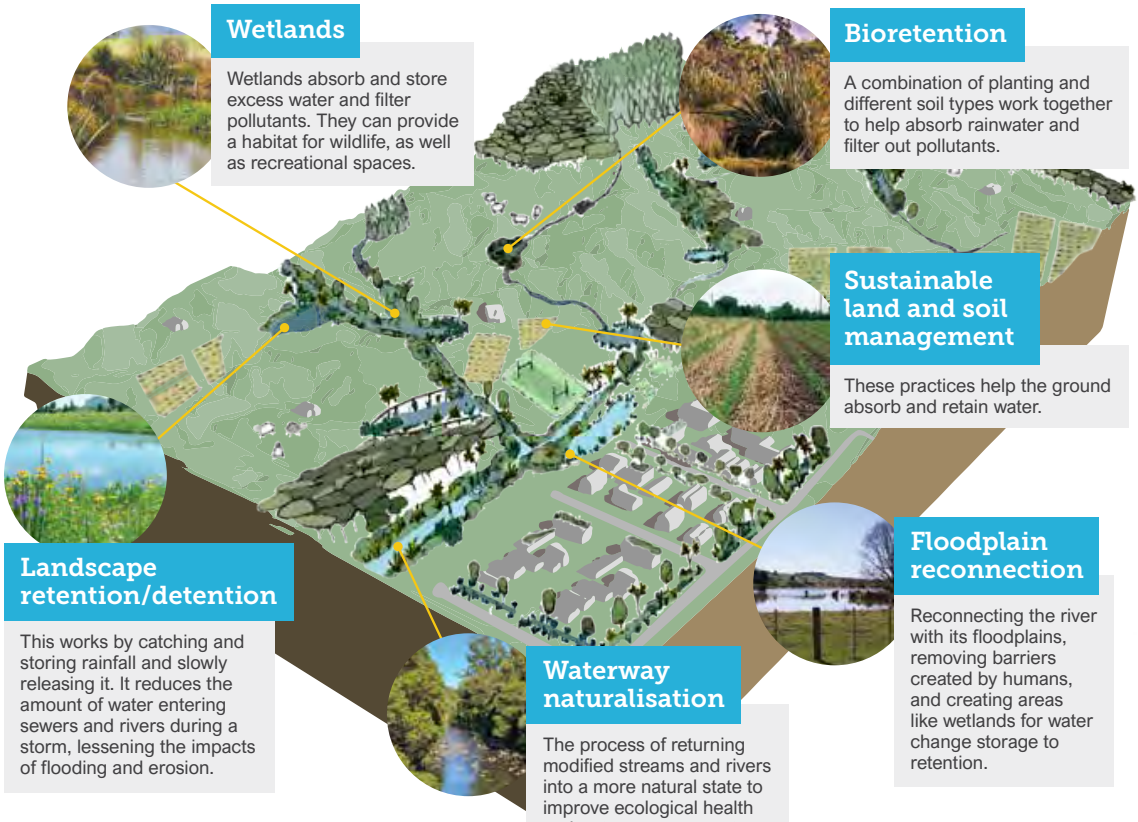
Flood mitigation is a prime example of how Nature-based Solutions can be put into action. These solutions work by harnessing ecosystem services (the benefits provided by healthy natural systems) to manage water flow, reduce flood risks, and protect people, property, and infrastructure.

Examples of Nature-based Solutions for flood mitigation include:

- **Wetland restoration:** Wetlands act as natural sponges, absorbing excess water during heavy rainfall and reducing flood peaks downstream.
- **Planting trees:** Trees in catchment areas help slow water runoff, stabilise soil, and reduce the impacts of flash floods.
- **River naturalisation:** Restoring rivers to their natural courses allows them to meander and overflow into floodplains, reducing the impact of flooding downstream.

A nature-based approach to flood resilience in Otago

The diagram below, shared with participants during the Engagement Study, highlights the types of Nature-based Solutions that could support flood mitigation in Otago.



Potential additional benefits

Nature-based Solutions improve water and air quality and enhance biodiversity by creating space for threatened native species. Internationally, we've seen benefits to farmers and communities, and opportunities in areas such as restoration, sustainable farming and eco-tourism.

Elasticity in flood management

Unlike traditional flood infrastructure, which is built for fixed capacity, Nature-based Solutions are integrated into the landscape and designed to absorb, store, and redirect excess water. While they also have a maximum capacity, their placement often means that overflow affects less critical areas, such as fields or pasture, rather than infrastructure, homes and businesses. They can work alone or alongside floodbanks, drains, and other hard-engineered structures, easing pressure on these systems during intense rainfall. This layered approach reinforces existing flood defences, helping them cope with changing conditions while reducing long-term damage. By working with natural processes, it can also make flood management more durable, cost-effective, and environmentally sustainable.

Adaptive resilience means strengthening existing flood defences so they can respond to change—not just withstand it. It's about bending with the pressure, absorbing shocks and adjusting to reduce long-term costs and damage.

The official definition

Ministry for the Environment
Manatū Mō Te Taiao

Te Mana o te Taiao-Aotearoa New Zealand Biodiversity Strategy 2020 defines Nature based Solutions as "solutions that are inspired and supported by nature, cost effective and simultaneously provide environmental, social and economic benefits and help build resilience."

UN environment assembly

Internationally, the Fifth Session of the United Nations Environment Assembly formally adopted (in its UNEA-5 resolution) the definition of Nature-based Solutions as "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits". The UNEA recognises that Nature-based Solutions "respect social and environmental safeguards, including those for local communities and Indigenous Peoples".

Case studies

There are hundreds of case studies globally which showcase how governments and landowners have collaborated to significantly reduce flood risks.

Websites such as this provide an overview: www.nature4climate.org/nature-in-action/case-studies/

This image of a digital case study map from the Nature4Climate website showcases global examples of nature-led flood mitigation.

Whangārei Urban Awa Project – New Zealand

Lead agency

Northland Regional Council (in partnership with Whangārei District Council, hapū, and community groups

Approach

Collaborative urban stream restoration using riparian planting, fencing, and landowner engagement to improve water quality and flood resilience.

Land use

Mix of public and private land across four urban catchments, with up to 80% subsidies offered to landowners for fencing and planting.

Outcome

Improved flood buffering, reduced sediment and nutrient runoff, enhanced biodiversity, and strong community ownership of local waterways.

Lower Danube Green Corridor – Bulgaria, Romania, Ukraine, Moldova

Lead agencies

World Wildlife Fund (WWF) and four national governments

Approach

A multi-country restoration of floodplains and wetlands along the Danube River to reduce flood risk and support local economies.

Land use

Governments worked with landowners to re-flood former agricultural lands, often through voluntary agreements or compensation to re-introduce natural flooding patterns in areas that were previously drained.

Outcome

Over 600,000 ha of floodplain restored or protected, reducing flood peaks, improving water retention, and boosting biodiversity across four countries.

Wallasea Island Wild Coast Project – United Kingdom

Lead agency

Royal Society for the Protection of Birds (RSPB) in partnership with UK government and Crossrail

Approach

Managed realignment of coastal land to create wetlands, mudflats, and saltmarshes for flood protection.

Land use

Agricultural land was purchased and repurposed for habitat restoration and flood mitigation.

Outcome

It's one of Europe's largest coastal habitat restoration projects, reducing flood risk while enhancing biodiversity.

Darkwoods Forest Carbon Project – Canada

Lead agency

Nature Conservancy of Canada

Approach

Large-scale land purchase to prevent development and restore natural forest and watershed functions.

Land use

Privately owned land was purchased to protect 17 watersheds and improve flood resilience.

Outcome

Enhanced water regulation and biodiversity protection across 54,000+ hectares.

Gathering insights - how we engaged

This engagement study set out to capture a high-level snapshot of perspectives on Nature-based Solutions.

Rather than aiming to represent every stakeholder or landowner, the study gathered indicative insights to inform next steps and spark further conversations and collaboration.

Because of the exploratory nature of the project our engagement strategy was to:

- Build on the relationships ORC has in Te Hakapupu / Pleasant River catchment and work with the Partnership Group.
- Involve organisations or individuals already working with ORC, within catchment groups or on regional projects such as Hill Country Erosion and Wetland Mapping.
- Ask people we interviewed to share the survey and suggest others to take part in interviews.
- Include larger landowners or organisations ORC might want to partner with in the future.
- Share information via ORC and partner communication channels, encouraging people interested in taking part to contact us.

A targeted list of landowners, individual members of the Ōtākou and Puketēraki hapū and whānau and key organisations was developed with ORC staff and catchment advisors. Of those approached, most agreed to take part, resulting in 26 interviews.

Responses have been anonymised and grouped into key themes. This ensures individual privacy while still reflecting the valuable insights shared during the engagement process.

A digital survey was shared via ORC channels such as Onstream and to individual landowners via the catchment coordinators, with 18 people filling in the survey. Some of the individuals who were interviewed also shared the survey with contacts and other individual landowners. The survey was live from January until 30 June 2025.

Interviews

In-depth interviews with landowners and regional stakeholder representatives.

Digital survey

Shared via catchment groups, people we interviewed and targeted landowners.

Communication channels

- ORC and partner newsletters
- Social media posts
- Media release

Past insights, present perspectives

This report also draws on insights from past engagement and existing reports.

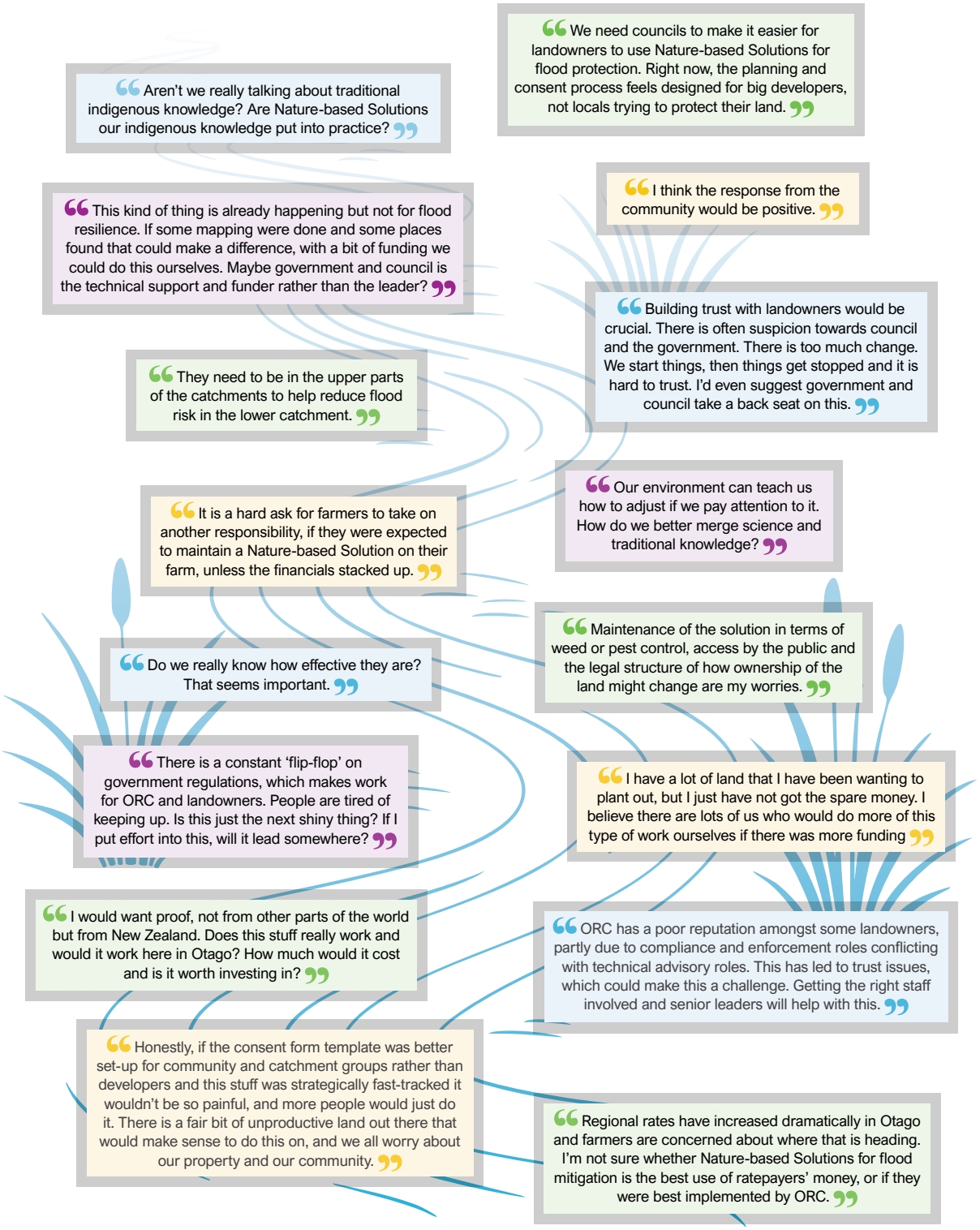
Sources reviewed include:

- Toitū Te Hakapupu Restoration Project
- Otago Catchment Stories Summary Report
- Forestry Catchment Plan
- Indigenous Pacific Approaches to Climate Change: Aotearoa/New Zealand (2018)
- NIWA Literature Review
- MfE NbS for Flood Mitigation Workshop Summary
- ORC NbS Engineering Approach and Strategic Plans

Insights from hapū: Foundations for collaboration

Insights were gathered from individual members of the Ōtākou and Puketēraki hapū and whānau, contributing personal perspectives to the engagement process. While these voices reflect lived experience and local knowledge, further co-design and consultation with Iwi and hapū will be required.

What people told us



What people told us

Survey snapshot

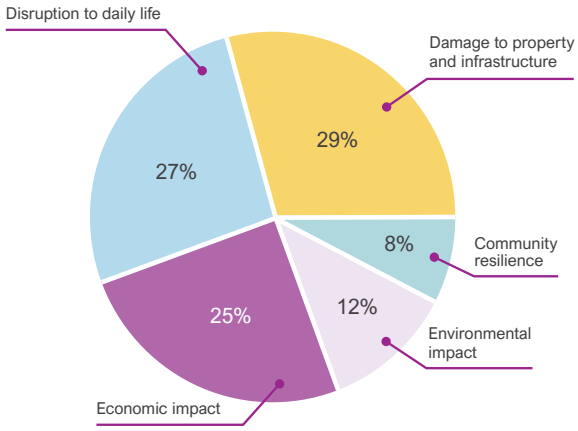
These graphs highlight some of the insights from the digital survey.

Most participants have experienced flooding on their property and expressed support for a variety of Nature-Based Solutions. People felt Nature-based Solutions could work together with existing or new flood infrastructure.

Many also showed interest in participating in education initiatives or pilot projects, in collaboration with iwi and community groups.

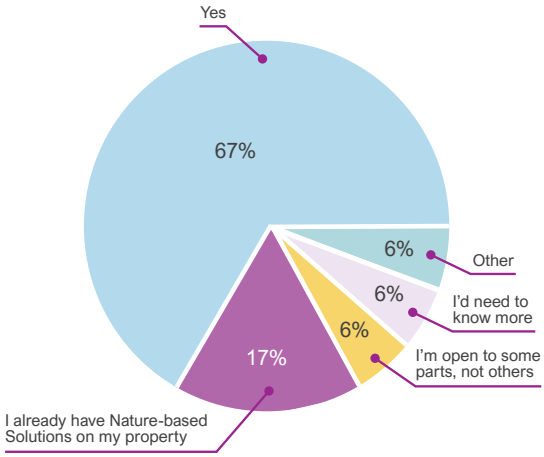
What specific concern(s) do you have about flooding and its impact on you or your community?

The most frequently selected concerns included damage to homes, businesses, infrastructure, and public facilities, power outages, and general disruption. Most participants were less concerned about environmental impacts and biodiversity loss. Highlighting how Nature-Based Solutions can help protect homes and infrastructure by slowing and holding water could help ORC gain support for future projects.



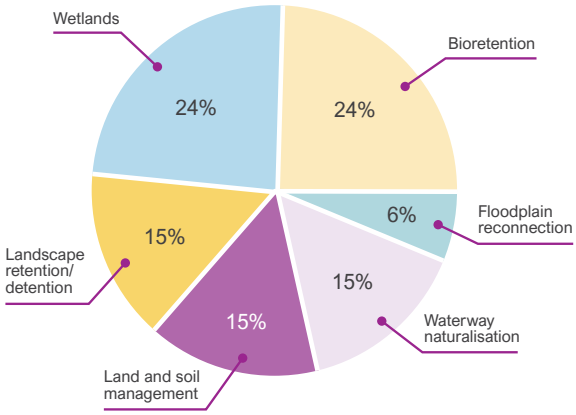
Assuming you were adequately compensated, would you consider making some of your land available for Nature-based Solutions, if it could help reduce flood impacts in the Otago region?

The majority of people would consider making land available, if they were adequately compensated.



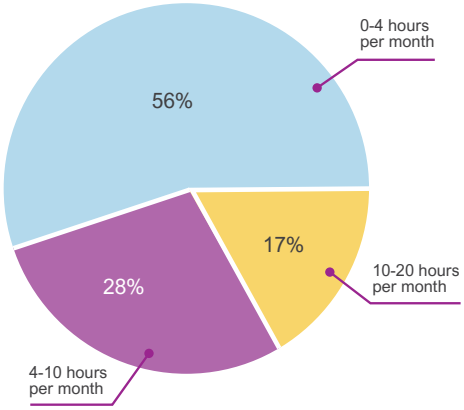
What types of Nature-based Solutions (e.g. wetlands, riparian buffers) might you be open to having on your property?

People shared the kinds of Nature-based Solutions they'd be open to on their land, revealing openness across a range of options.



Assuming you were adequately compensated, how much time and effort would you be willing to put into maintaining a Nature-based Solution(s) on your property?

Most people would be happy to put in their own time to maintain a project on their property. More than half of participants felt that up to four hours a month would be fair, with others happy to do more. Answers to another question in the survey showed more than half of the respondents would be open to allowing council staff or volunteers onto their property to maintain a Nature-based Solution for flood mitigation.



Key findings: Barriers

Limited awareness of flood mitigation benefits

Most landowners were familiar with the environmental benefits of Nature-based Solutions and the various approaches (bioretention systems, wetlands and planting) but some were unaware of or had not considered their flood mitigation potential.

During the interviews and conversations, it did not take long to build understanding, especially with those who work with catchment groups or who had experienced flooding.

Private property access, liability and maintenance

Access, liability, and ongoing maintenance present significant barriers to implementation on certain lands, particularly for forestry and farms. Concerns centre on legal and safety implications when permitting external activities. Some landowners prefer to establish formal agreements - such as MOUs - outlining liability, safety, and maintenance responsibilities before considering access for projects. Others are open to exploring existing models, highlighting successful private land projects and agreements as reference points. Developing clear frameworks that address these concerns collaboratively will be essential.

Lack of local evidence

Locally relevant data, modelling, and case studies were important to some landowners. They are interested in finding out more about global case studies, but the lack of local 'proof' limits some landowners' confidence in adopting Nature-based Solutions for flood management.

Some landowners expressed a desire to see modelling to better understand value.

Some suggested modelling existing projects not originally meant for flood mitigation to gather data about benefits.

Others felt it was more important to be outcomes-focused and 'just get on with it'. There were concerns about spending money on constant investigations when funding could go towards interventions and pilot projects.

Financial considerations

Some landowners highlighted the need for financial incentives to offset the upfront costs associated with implementation. They expressed interest in grant programs, rates relief, subsidies, or tax breaks that could help reduce any financial burden.

Others need to see clear financial benefits or financial support to justify any kind of participation, even future engagement.

Some people raised concerns about loss of income from productive land, issues with future buyers if they sold their land and the cost of their time if they got involved. Some landowners noted that they already engage with ORC and other groups for free, when others are paid for their time.

However, compensation was not a primary driver for all landowners. In Otago, land is proactively being fenced off or offered to catchment groups for projects.

Some landowners we spoke to have land that they would discuss giving up for a Nature-based Solutions to benefit the wider community if there was help to cover the costs of implementation (materials, some labour and professional expertise).

Regulatory uncertainty

New, complex and changing regulations from central and local government, and the uncertainty and complexity they create is a real challenge.

> ***"Look over here, now look over here, now this way. No, back here now."***

Inconsistent and evolving regulations create challenges and pessimism, with landowners seeking stability and clear, consistent strategy and policies around Nature-based Solutions to enable long-term planning.

Councils are not seen as always being equipped to provide the necessary technical support and guidance because central government changes so often. The cost of this to ratepayers and councils, along with wasted time and effort was highlighted often, with landowners commenting on how tired they are.

Accessing technical expertise

Landowners highlighted the complexity of implementing Nature-based Solutions, particularly when involving technical aspects like soil management, wetland restoration, or riparian planting. Some lack the knowledge and skills to effectively design and implement these.

Some people would like to 'get stuck in' but want to check things first to avoid wasting money.

Having access to technical experts quickly and in a more casual environment would be helpful. MfE's Access to Experts, which offered free technical advice, was seen as a successful tool in the Otago region.

Councils are not always seen as equipped to provide the necessary technical support and guidance needed. Or if they are, there are not enough staff to go around. Some landowners noted that ORC staff had the technical ability but some felt that they could not provide advice due to liability issues. Clarifying the type of technical advice ORC staff can give, and which staff can offer expert advice would be beneficial.

> ***"Sometimes I just want to have a 10-minute coffee with someone to check that I'm on the right path. It can be hard to find the right person and I don't want to wait for months or end up with a $20,000 report. I've moved on already."***

Technical language

Many people find the term Nature-based Solutions confusing or too technical. They suggested using plain language and focusing on specific examples such as wetlands, river naturalisation, native planting, or bioretention. Clear, community-friendly definitions, supported by visuals and video, were seen as essential for effective communication.

Different landowners are motivated by different outcomes: some by resilience, property protection, and cost-effectiveness; others by water quality and biodiversity. Tailoring messages to reflect what people care about, and avoiding jargon, will support better understanding and uptake.

> ***"We have enough in our heads, please don't make us learn a new language. Help us understand quickly and we will be keen."***

Trust and relationships

Building more trust and being transparent with landowners is crucial. Suspicion towards the government, ORC and other regulatory bodies could hinder collaboration.

Many individual ORC staff are highly trusted and have good relationships in the community but there is some distrust towards the organisation as a whole.

Landowners are open to discussing Nature-based Solutions further but some fear regulatory repercussions or loss of control over their land if they participate in future projects. Someone asked if ORC or the government could take a role as funders and let community or catchment groups, or an organisation like Landcare take the lead on implementing Nature-based Solutions.

There is a need to foster long-term relationships with key landowners and build trust to get support. ORC could choose staff with solid existing relationships to lead the work or collaborate with trusted third parties or organisations, such as NZ Landcare Trust, Fish & Game or catchment groups and allow them to take the lead on landowner engagement.

Bureaucratic challenges or perceptions of challenges

Regulatory processes are complex and not always fit for purpose.

Landowners said that consent forms and paperwork often feel designed for developers, not for community groups or individuals. Even the perception of difficulty can deter action. Some had tried and found it hard; others had not looked into it because it seemed too complex.

People asked whether councils could make it easier to get approval for projects that protect land and communities from flooding. Suggestions included simplifying guidelines, updating templates, and exploring fast-tracking for Nature-based Solutions. The Fast-track Approvals Act 2024 was mentioned as a missed opportunity, with some wondering why Nature-based Solutions aren't included.

Developing catchment-wide consents for Nature-based Solutions such as planting and wetland restoration was suggested.

Key findings: Opportunities

Leverage existing networks and allow others to lead

People emphasised the importance of leveraging existing networks and community groups to facilitate outreach and support for Nature-based Solutions.

Organisations like Fonterra, Landcare, Ravensdown, Fish & Game are already working in this space, and are well respected and connected.

People noted that allowing others to own relationships, working with catchment advisors and catchment groups, or using trusted third parties can make projects move faster.

Some believe initiatives should be community-led or driven entirely by catchment groups.

Embed Māori environmental knowledge

> ***“This is not new to us. It is a return to what was.”***

Insights were gathered from individual Ōtākou and Puketēraki hapū and whānau members, who emphasised the importance of incorporating mātauraka Māori into decision-making from the outset. Meaningful integration requires involving Māori leaders in strategy development and working alongside Māori researchers and institutions from the start.

Participants highlighted the need to acknowledge whakapapa and honour the deep ancestral relationships Māori hold with land, water, and ecosystems. These connections should guide how Nature-based Solutions are designed and implemented.

There is strong interest in partnering with Otago Regional Council to explore ways of weaving contemporary science with Māori environmental knowledge, unlocking a deeper, more holistic understanding of flood resilience.

> ***“It is not science or traditional environmental knowledge - it is science AND traditional environmental knowledge together.”***

RAG the region

Some landowners and community groups are ready to take action, especially in lower-risk areas with the appropriate support. ORC’s existing RAG (Red-Amber-Green) framework offers a practical way to prioritise catchments by risk level. This could be strengthened by explicitly integrating Nature-based Solutions.

- **Red Areas (High Risk):** ORC takes the lead in managing NbS projects in critical zones with high exposure to natural hazards, such as flood-prone areas near infrastructure or dense populations.
- **Amber Areas (Moderate Risk):** ORC collaborates with trusted groups like catchment organisations, iwi, and environmental groups to co-design and implement NbS projects.
- **Green Areas (Low Risk):** Community groups, landowners, and organisations lead initiatives, with ORC providing guidance, resources, and occasional oversight.

Funding and technical assistance would be tailored to risk levels, empowering landowners to take action while ensuring ORC’s resources are focused where they are most needed. This aligns with global best practices that advocate for a diverse portfolio of Nature-based Solutions to address various scales and contexts of flood risk.

Clear and consistent strategy and regulations

There is a need for clear, consistent policies that support Nature-based Solutions.

Some people suggested that Nature-based Solutions be added to Regional and District Plans and make them the go-to option for resource consents. Others emphasised the need for regulatory certainty and alignment across planning functions.

> ***“I would help, but not if there is a paperwork hurdle around every corner from council or government – the very people asking me to do it. Clear the path for us.”***

ORC has started reviewing policy and strategy frameworks to better support Nature-based Solutions.

GIS and data

People noted the amount of data that is readily available which could help identify high-priority sites for future intervention:

- **Wetland and riparian areas** – Existing wetlands, potential restoration sites, and buffer zones.
- **Flood-prone locations** – Historic flood data, hydrology models, and floodplain maps.
- **Historic wetlands** – GIS layers identifying historic wetlands that could be restored to act as natural buffers
- **Catchment insights** – Land use, soil permeability, terrain, and water flow patterns.
- **Interested landowners** – Mapping those keen to take part in Nature-based Solutions projects.
- **Existing research** – Studies like Dr. Sami Khan's wetland work for Otago and Hill Country Erosion.
- **Mātauranga Māori perspectives** – Incorporating Māori knowledge of ancestral flood pathways, wetlands, and traditional ecological indicators to align NbS efforts with cultural and environmental values.

By combining these layers and partnering with Crown and private researchers, ORC could pinpoint priority sites for wetland restoration, reforestation, and river naturalisation—creating a targeted, data-backed plan for flood resilience.

A spatial planning and prioritisation approach, underpinned by GIS tools, would help ORC pilot projects, guide funding decisions, and collaborate effectively with landowners, catchment groups, and experts.

Work with the willing

Many landowners already contribute land and their own funds to wetland and planting projects for biodiversity and water quality.

People said the existing willingness could be expanded to include Nature-based Solutions for flood mitigation with the right guidance, regulatory support and funding.

Catchment groups and organisations such as Fish & Game, Landcare and Fonterra have put out Expressions of Interest for partially funded projects and have been inundated with interested landowners, who in some cases have invested their own time and money to fence off areas and maintain wetlands and other projects.

Explore what exists

People highlighted available resources and existing information that could help implement Nature-based Solutions for flood mitigation, including:

- The University of Canterbury are developing tools to enhance the accuracy and efficiency of flood modelling: **New flood technology to prepare communities | University of Canterbury**
- Other crown researchers (Scion, NZTA) who have flood modelling and data to build a bigger picture.
- $5 from each hunting licence goes towards projects like wetlands, why not expand it to flood resilience - Fish & Game
- Can resilience funding be expanded to include Nature-based Solutions, or can projects be retrofitted to gather proof for future work?
- Expanding the carbon trading system to wetlands and flood resilience projects.
- Opportunities to add flood modelling into wetland projects to act as case studies.
- Focus on natural areas we have already that may play a part in flood mitigation and protect them.

Build awareness and understanding

Landowners emphasised the need for clear and concise information about the potential benefits of Nature-based Solutions. They noted that information is often hard to find, long winded and technical and does not suit the audience. Others noted that information was often in numerous places online.

> ***"I don't want to go looking for it and read these huge reports that are written for some technical expert's ego. I want to talk to someone, watch a 2-minute video or read something short and helpful that fits the situation I am in."***

People suggested the ORC work with others to agree a one-stop shop to host information and compile best practice, case studies and evidence from MfE pilot studies. This should be led by non-technical people or communications experts, who will focus on the audience needs.

Social licence and community perception

Social licence remains a challenge for industries such as insurance, banking, farming, engineering, and infrastructure and forestry. People wondered if Nature-based Solutions could offer an opportunity for these groups to build and strengthen trust and social licence by delivering visible environmental benefits and responding to community concerns.

By actively contributing to (land, expertise or other) or funding Nature-based Solutions projects or research, these groups could be positioned as partners in regional resilience, benefiting them and Otago communities.

Landowner-led Community of Practice

There was strong interest in connecting with other landowners to share knowledge and experiences. Many saw value in learning from both the successes and challenges of others, and expressed support for fostering a community of practice around nature-based solutions (NbS).

Participants were keen to build this community through pilot projects, local and national case studies, and peer-led events. Practical formats such as on-land gatherings, webinars, and 'lunch and learn' sessions were seen as especially useful for encouraging engagement and shared learning.

Normalise Nature-based Solutions

People asked if or how ORC would make Nature-based Solutions an everyday core part of council functions.

One interviewee, who has past experience working in local government, highlighted the importance of embedding Nature-based Solutions in regional and district plans, prioritising them in long-term investment planning and procurement, and ensuring funding streams support delivery.

> ***"It needs to become so normal, so second nature that we do not even name it. That starts from the inside out and flow through every part of government and council."***

Larger landowners and crown land

People discussed larger landowners in Otago and how they could get involved in large scale projects. Some people felt it would be better for ORC to concentrate on these groups, although it was noted that the formal agreements required could slow things down.

The Crown, Ngāi Tahu, privately owned forestry companies, University of Canterbury, and University of Dunedin along with Dunedin City Council (including council-owned City Forests Limited) are some of the larger landowners in Otago.

This 2019 RNZ article provides a comprehensive list of the type of information that is publicly available, and which could support future research: https://www.rnz.co.nz/news/in-depth/401186/nz-s-top50-private-landowners-revealed

Address the finer details

People talked about the need to start looking into the practical things early - like possible access, maintenance, safe access and financial agreements.

There was interest in reviewing global case studies and further engagement to begin to explore possible frameworks, MOU agreements and ideas together.

It was noted that some Otago catchment groups and organisations such as NZ Landcare have experience in this space and can share what works.

For some landowners, less formal agreements were considered suitable, while others (such as forestry) will require formal agreements covering access, liability and other aspects.

Explore financial incentives with landowners

People encouraged ORC to look into funding options—grants, tax breaks, and compensation schemes—that would make it easier for landowners to adopt Nature-based Solutions. A focus group was suggested as a good way to figure out what could work.

Many felt that aligning council funding with Nature-based Solutions would help, with ideas to include them in existing grants, biodiversity funds, and budgets.

Some pointed out that the way funding is structured now makes it harder for landowners to get involved, and that criteria and project evaluation processes need updating.

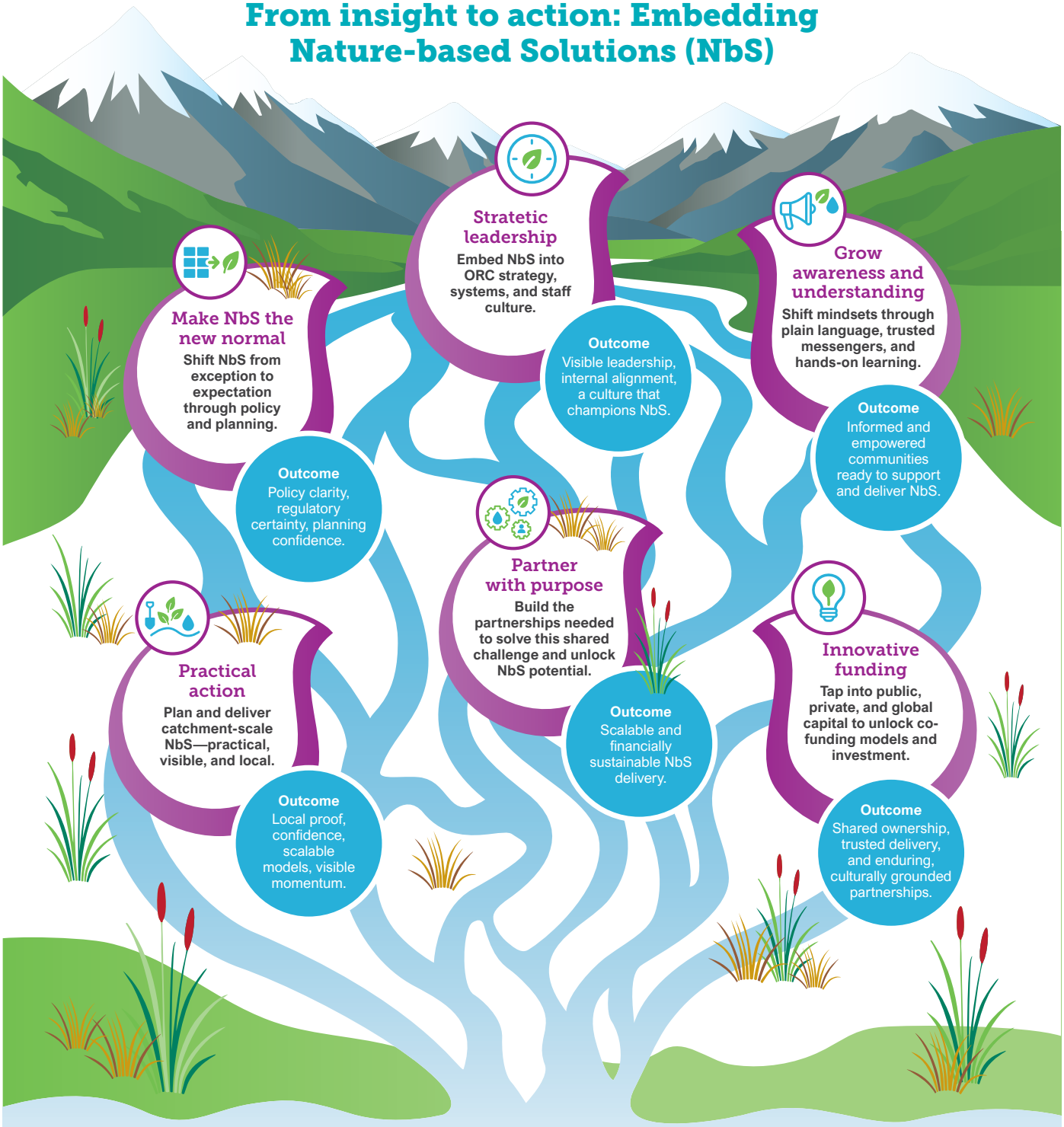
Expanding Nature-based Solutions eligibility in resilience, climate adaptation, biodiversity, and water quality funding was also mentioned, along with a review of community funding sources like the EcoFund.

Innovative ideas

People highlighted ideas for the government or council to consider, which have been built on below:

- Develop data-driven flood mitigation strategies, combining Mātauranga Māori insights, GIS and AI modelling, and hydrological research
- A region-wide approach to funding applications to access both government and private streams.
- Landowners join a regional flood resilience co-op where councils or government provide equipment, seedlings, hydrology modelling, and technical expertise for projects.
- Councils or government collaborate with insurers to create Nature-based Solutions-linked discounts for landowners who implement flood-mitigation projects.
- Wetlands and riparian buffers reduce flood risks, so insurers could offer lower premiums or risk-sharing incentives for private properties that contribute to resilience.
- Councils or universities help track data and prove effectiveness, making it easier to get funding.

From insight to action: Embedding Nature-based Solutions (NbS)



Shaped by Otago voices and global insight, these six streams show what's needed to enable Nature-based Solutions (NbS). Like Otago's braided rivers, they must flow together to support a resilient future. They offer a framework to guide ORC's alignment, partnerships, and future investment in flood resilience.

Strategic leadership

Align ORC strategy, capability, and culture

ORC must lead by example—embedding NbS into its own systems, strategies, and staff culture.

Outcome
Visible leadership, internal alignment, a culture that champions NbS.

Key actions

- Establish a cross-departmental governance group and community of practice with mana whenua representation
- Embed NbS into the LTP, infrastructure strategies, and flood risk frameworks with dual knowledge systems (mātauranga Māori and contemporary science)
- Build internal capability through training, secondments, and shared language across teams.
- Identify ORC-owned land or upcoming projects to demonstrate NbS for flood mitigation
- Draft a relationship matrix for key stakeholders and landowners (compliance and engagement focus) to build trust and clarify roles

Mātauranga Māori is not an add-on

Māori knowledge systems are holistic, place-based, and relational—offering critical insights into land, water, and climate grounded in whakapapa and whenua.

Conversations delete with mana whenua highlighted how place names, oral histories and mātauranga Māori offer critical insights into flood behaviour and land use.

For NbS to be effective, mātauranga Māori must be embedded from the outset, alongside contemporary science, in strategy, planning, and the design processes.

ORC is committed to mana whenua partnership, as outlined in the Significance, Engagement and Māori Participation Policy. Embedding mātauranga Māori into strategy and operationalising it will be a key shift. A move towards NbS and a review of existing systems, and evaluation frameworks alongside mana whenua could support this.

Make NbS the new normal

Shift NbS from exception to expectation through policy, planning and investment.

Outcome
Policy clarity, regulatory certainty, planning confidence.

Key actions

- Integrate NbS into the Land and Water Regional Plan, floodplain strategies, and catchment management frameworks
- Ensure NbS is eligible across climate adaptation, biodiversity, and water quality funding streams
- Prioritise green infrastructure in consenting and infrastructure investment decisions
- Explore a regional catchment strategy using a RAG (Red-Amber-Green) rating system, prioritising high-risk flood zones for larger ORC-led interventions, identify areas where others can lead
- Explore global consents and revise templates to support community- and catchment-scale NbS
- Advocate for a national NbS strategy and long-term regulatory certainty
- Review evaluation frameworks to align with international standards (e.g. IUCN Global Standard) and mātauranga Māori

Grow awareness and understanding

Shift mindsets through plain language, trusted messengers, and hands-on learning.

Outcome
Informed and empowered communities ready to support and deliver NbS.

Key actions

- Launch a regional NbS communications campaign using plain language, local imagery, and relatable stories
- Co-develop "how-to" resources tailored to different audiences, with mana whenua
- Enable on-land learning through training days, drop-in sessions, and peer-to-peer exchanges
- Share case studies and modelling through ORC and trusted partner channels
- Celebrate local leadership through profiles and media opportunities
- Monitor public understanding and support - use the digital survey as a base to track shifts in awareness
- Align with national and other regional campaigns to reinforce messages

Practical action

Plan and implement NbS across whole catchments—integrating hydrology, land use, and community values.

Outcome
Local proof, confidence, scalable models, visible momentum.

Key actions

- Map catchment-wide opportunities (wetland mapping, GIS layers, existing data)
- Retrofit existing biodiversity or water quality projects to include flood resilience outcomes
- Prioritise pilots in upper catchments on large properties to maximise scale, visibility, and co-benefits
- Co-design pilots with landowners and mana whenua; test delivery system (access, maintenance, co-investment)
- Align catchment planning with infrastructure upgrades, climate adaptation, and biodiversity strategies
- Monitor, evaluate, and adapt each pilot to refine policy and delivery models

Partner with purpose

This is a shared problem and strategic partners are essential.

Outcome
Shared ownership, trusted delivery, and enduring, culturally grounded partnerships.

Key actions

- Establish a regional NbS Partnership Forum including mana whenua, Crown landowners (e.g. DoC, NZTA, MfE, LINZ, Kānoa – MBIE, Pamu, private sector and landowners
- Partner with large landowners - Crown, other councils, Ngāi Tahu, universities, stations, forestry and private industry (Santana Minerals) to unlock scale and mutually beneficial opportunities
- Establish catchment-level groups to co-design and co-deliver NbS locally
- Explore flexible leadership models (mana whenua-led, ORC-led, community-led)
- Develop partnership charters or MOUs to guide shared delivery and governance

Innovative funding

Innovative funding and co-investment

Tap into public, private, and global capital to unlock co-funding models and long-term investment

Outcome
Scalable and financially sustainable NbS delivery.

Key actions

- Establish a regional NbS Investment Roundtable with crown, philanthropic, and private sector partners and explore co-investment models and required measurable outcomes
- Host an annual “NbS Investment Forum” with iwi, insurers, philanthropic funders, and businesses to share data, pilot learnings, and co-design funding streams
- Explore co-investment models, ESG-aligned finance, and developer-funded offset schemes
- Co-fund projects with insurers to deliver NbS that reduce flood claims
- Work with central government to apply for global climate grants for large-scale projects (e.g. UNDP, World Bank, Green Climate Fund)
- Identify projects that could be community-led and broker access to funding streams
- Align ORC community funding, and biodiversity/climate grants with NbS outcomes
- Update procurement policies to prioritise NbS and contractors/suppliers who deliver them
- Incorporate climate finance literacy into council and community training
- Bundle projects across multiple catchments. Combine high-risk and medium-risk sites into multi-site funding proposals that attract larger investment pools and demonstrate system-wide impact
- Develop a regional NbS financing roadmap Set out pathways for co-investment, including timelines, partner roles, ROI projections (environmental and financial), and scalability options
- Pilot outcome-based payments and long-term maintenance support for landowners
- Allocate dedicated funding for mana whenua-led NbS projects and monitoring frameworks

Conclusion

On giants' shoulders - building on regional expertise and energy

Iwi, hapū, the ORC and local communities have a long history of working with natural systems to solve challenges in Otago.

While Nature-based Solutions have traditionally been used more to support water quality, erosion control, and biodiversity, this initial engagement shows there is clear interest in scaling up Nature-based Solutions on private property as part of the regional flood resilience strategy.

With some landowners already discussing potential sites on their properties and Nature-based Solutions embedded in national policy, ORC is well positioned to begin to move from exploration and strategy into partnership and delivery.

This is a chance to build on Otago's ecological legacy, enabling practical, locally led solutions through collaboration, innovation, and environmental leadership.

Our clients do incredible things every day. They are transforming communities and changing lives, and we are right there beside them.

Beca is one of Asia Pacific's largest independent advisory, design and engineering consultancies. After a century of operation, we have grown from a family-owned New Zealand business to one of the most progressive, client-centric professional services consultancies in our region. We have more than 4,000 employees in 24 offices around the world and have delivered projects in more than 70 countries.

'Creative people together transforming our world' is our vision. It reflects our culture, our aspirations and our purpose - to make everyday better.

We create value through understanding and delivering successful solutions, exceptional service and our enduring relationships and use our skills and systems to empower innovation; helping our clients shape communities, optimise their assets and streamline their operations.

Beca

www.beca.com