DDPR_feedback_0073s		
	Name	William and Penelope (Bill and Penny) Ellis
	Organisation	
	Email	[redacted]
	Response Date	Aug 31 22
	Notes	
Q1	Select the chapter you want to provide feedback on	
Q2	In general, to what extent do you support the contents of this chapter?	
Q3	Objective/Policy/Rule/Standard reference:	
Q4	Feedback/Comments	
Q5	Objective/Policy/Rule/Standard reference:	
Q6	Feedback/Comments	
Q7	Objective/Policy/Rule/Standard reference:	
Q8	Feedback/Comments	
Q9	Objective/Policy/Rule/Standard reference:	
Q10	Feedback/Comments	
Q11	supporting documents?	
	0	
Q12	If you need more space, or have any other general comments, please leave them here	

<u>Submission to the Waitaki District Council relating to the Draft District Plan</u> August 31 2022

From **Penelope and William Ellis**, (Penny and Bill), owners of

Lot 5, DP19887, 15 Ahuriri Heights, Omarama, 9412.

Property file number 26050/16004

Certificate of title map (with our property highlighted) is attached.

<u>Introduction</u>

We have concerns about some aspects of the Proposed District Plan, namely:
- the natural hazard zone maps, specifically those relating to flood and liquefaction hazard,
- the proposal to change the zoning from Rural Residential to General Rural instead of Rural Lifestyle.

<u>Background</u>

We bought our property from the developer (Arthur Budd) in October 1986. Bill and siblings played on that land as youngsters and watched this development and adjacent land for several years prior to the subdivision being formed.
As ratepayers, we recently received notice from the Waitaki Council that the District Plan was up for review and an invitation to read and make comment or submissions
After preliminary reading, we sent an email requesting information from the council planners. That email and their response is attached.

Our concerns, comments and suggestions are grouped under the following headings.

Responding to points made in the email from the council planner

- Natural hazard map flooding.
- Natural hazard map liquefaction.
- Proximity to sewage treatment ponds and best practice setbacks from sewerage related sites.
- Further residential development and efforts to lower the possible density of additional residential living.
- Is the terrace riser a good geographical delineation between the edge of the GRZ and RLZ?

Undesirable negative effects of changing zoning from RR to GRZ

- GRUZ-R13 Helicopter landing pads.
- GRUZ-S5. Setback from internal boundaries for residential buildings.
- GRUZ-S5. Setback from internal boundaries for buildings for housing animals.
- Noise-R8.

General comment.

- Shelterbelts

Summary

Appendices

- Certificate of title map (with our property highlighted
- Email correspondence with Council Planner
- Flood Hazard Assessment report by Chris Fauth, dated 26 August 2022
- GNS Liquefaction report 2020

We have used the 'AH' acronym when referring to 'Ahuriri Heights' subdivision.

<u>Addressing points raised in the email</u>

<u>Natural hazard map flooding.</u>

A broad brush approach to draw margins to the Flood Hazard Zone has resulted in the entire hill that AH is built against being included in the flood hazard zone.
Because of their elevation above the river flats, existing buildings on the hill are not at risk of being flooded.
We also consider that buildings on the flat have minimal flooding risk as their floor levels appear to have been considered (in relation to flood risk) as part of building permit or consent approval process.
And also, during the 50 plus years that Bill has been familiar with this land, he have never seen flood water inundating the land east of the water race that runs across Lot 9 of AH subdivision.

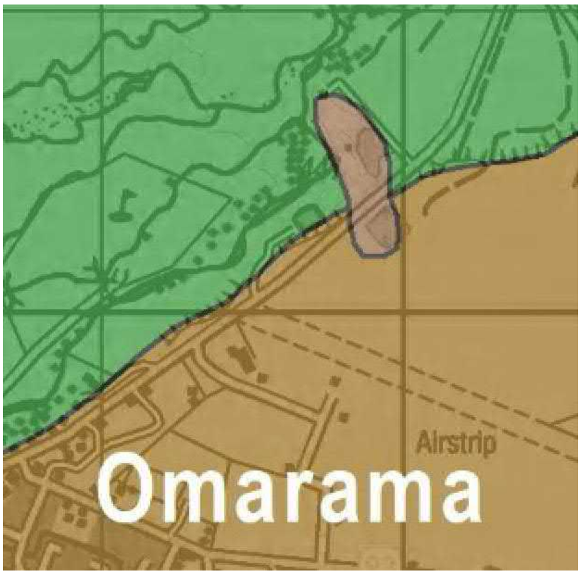
The location of a minor terrace adjacent to the water race (and its role in preventing flooding to the east of the water race) was reviewed during the past few weeks by Chris Fauth, Ecan Senior Scientist (Natural Hazards) who has suggested the District Plan natural Hazards map be amended. A copy of his report is attached.

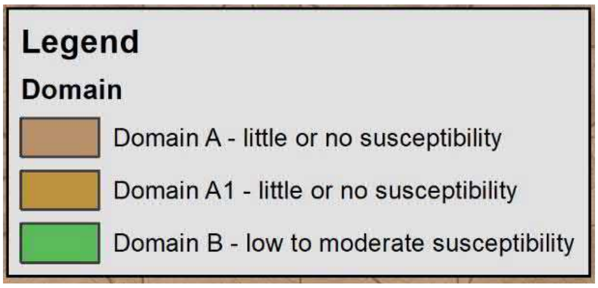
Retaining the zoning shown in the draft plan maps would have significant implications regarding the cost of future insurance for all the existing buildings, structures, fencing etc. in the AH subdivision, as well as any new buildings or structures.
News articles alert us to the conversations currently being held regarding current and future increases in insurance rates for properties in flood hazard zones, to cover the expected increase in the number and value of claims caused by climate change related flooding. My basic research has found that when insurance companies need to determine a property's flood risk they head firstly to the property file LIM, then to the District Plan maps, which is why we would like the District Plan Natural Hazard maps be updated to include the new findings outlined in Chris Fauth's report.

Natural hazard map liquefaction.

An assessment of the Liquefaction Hazards in the Waitaki District was carried out by DJA Barrell with findings published as GNS Consultancy report 2020/69, dated September 2020. A copy is attached.

A map of Omarama and surrounding area (figure 3.5 page 17) shows 3 liquefaction-susceptibility domains. The hill that AH has been built against features clearly and has been identified as being in Domain A, which has 'little or no susceptibility'. As can be seen in the clip below, all of lots 1 to 6 are included in Domain A, apart from the northern corner of Lot 1 and the eastern corner of lot 6.



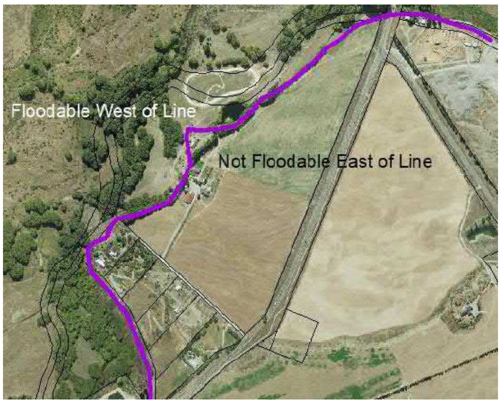


From GNS Report

From the draft District Plan maps, where the mustard coloured overlay identifies 'Liquefaction Susceptibility'.
Again, a broad brush approach appears to have been used, which has smudged the domain boundaries shown in the GNS report.

I don't wish to sound critical of the person who created the District Plan maps. I've looked at the proposed mapping of some surrounding farms that I am familiar with and an impressed with the level of detail and accurate information that is shown in the mapping.
The AH subdivision is small and remote and could be easily overlooked or not given the attention it deserves, where the Rural Residential sections have much higher per- hectare land values than the general rural farm land, and where constraints (because of the relatively small lot sizes) limit what the owners can do with their land.
For example if a farmer wants to build a structure and finds that the proposed site is in a natural hazard zone, they would probably just revise their location plans and put the structure somewhere else on their farm. Whereas when a Rural Residential property owner finds their proposed building site is in a liquefaction hazard zone where further investigation is required, they have to get geotechnical engineer to carry out an investigation which could cost in excess of $10 000. So I'd suggest that extra care should be taken when drawing zone boundaries around isolated subdivisions as a difference in position of 50 metres can result in significant extra costs.

Historical liquefaction often results in signs remaining on the ground's surface which, if not eliminated by land use practices like ploughing, can remain visible for centuries. An example is shown in figure 2.1A page 9 of the GNS report.
Old surface water courses are visible on the aerial photo that has been included in Chris Fauth's report, as well as those taken by Gavin Wills during the latest flooding events.



From Chris Fauth report


Gavin Wills photo taken during latest flooding

If historical liquefaction had occurred I would expect to see some evidence in the form of sand pods or boils but none can be seen. Bearing in mind that the water courses shown in these pictures may be hundreds of years old, when the hazard zones are for building purposes and the Building Act only has a 50 year maximum durability requirement for residential building.

<u>Proximity to sewage treatment ponds and best practice setbacks from sewerage related sites.</u>
In the time we have been involved with the AH subdivision we have never been aware of (or troubled by) smell, insect or rodent problems relating to the adjacent treatment ponds.
Midges have become more noticeable in recent years but anecdotally their increasing numbers are linked more to irrigation, dairy farm and shelter belt development than the development of the sewage treatment plant.
Lizard Hill will divert any contaminated ground and surface water (that may escape from the sewage treatment plant) around the northern end of the subdivision, though that may no longer be an issue

now that the council has installed a new effluent disposal field under the airport runway.
The large triangle of undeveloped land to the South East of the effluent ponds and Lot 4 DP21651 to the South West have been included in the Rural Lifestyle zone despite having a much smaller setback from the sewerage ponds (and would be affected more by smell and insects carried by prevailing NW and NE winds) than most of the AH properties.
Inconsistent zone change decisions again suggest a broad brush approach has been used and the existing features of the AH subdivision have not been given the attention they deserve.

Further residential development and efforts to lower the possible density of additional residential living.

GRUZ-S1 The maximum residential site density wouldn't appear to be any more restrictive than what is given in RLZ-S1 on the small (less than 1.5Ha) sections that make up the majority of AH.

"Terrace riser a good geographical delineation between the edge of the GRZ and RLZ".
Once again too broad a bush has been applied when establishing these zone boundaries. Undeveloped land to the east of AH, which is lower lying than the AH flats, has been zoned RLZ, as has the land between the Hot Pools and the sewage treatment ponds. These properties are below the more obvious terrace that was used to determine the now discredited proposed Flood Hazard boundary.

Undesirable negative effects of changing zoning from RR to GRZ

GRUZ-R13 Helicopter landing pads.
If AH was zoned GRUZ, (from my reading of the draft plan) a helicopter owner who was involved with primary production activities could set up a hanger and landing pad and take off or land their machine with no restrictions in the District Plan to the number or time of flights.
I wasn't able to find any restrictions on the location of a landing pad.
There are restrictions on what property the flight path can be over but as adjacent properties would be General Rural Zone (which isn't included in the exclusion list) it appears the permitted flight path could be over adjacent AH dwellings.
We don't consider this an appropriate approval for the AH subdivision and would welcome guidance showing me my interpretation is incorrect or incomplete, and that this activity would not be allowed to happen.

GRUZ-S5. Setback from internal boundaries for residential buildings. Our property is 60m wide so the minimum setback for a residential unit of 20m would restrict us to a building of maximum length of 20m built on the central third of our property. We consider this unnecessarily restrictive compared with what the original Rural Residential zone allowed. None of the existing residences on lots 1 to 6 would be allowed in their current positions if being planned for construction under GRUZ.

GRUZ-S5. Setback from internal boundaries for buildings for housing animals. Again with a 60m wide property, building a chook house, dog kennels, pig sty, calf or lamb shelter would all become discretionary activities. We don't consider this a realistic restriction to impose on these currently Rural Residential properties.

Noise-R8. Maximum permitted noise limits relating to noise generated from activities at the Omarama Airport are given for Residential, Rural Lifestyle, Commercial and Mixed Use Zones but not for General Rural zone.

General comment.

Shelterbelts and warning regarding wilding pines and shading could include warning of species that send root systems far into adjacent properties.
Some more anecdotal history. Maybe a decade ago we attended a workshop (about flame thrower weeding) at Lincoln University given by Professor Bob Crowder, where a 1 Ha paddock that was surrounded by Poplar shelter trees had been developed to grow onions. He commented that the biggest surprise when developing the block was that the Poplar tree roots extended under the whole 1Ha and annual ripping by heavy machinery to the perimeter of the paddock had to become a part of regular maintenance.
We have that issue on our section (to a much smaller extent) and are incorporating access for machinery along relevant boundaries so that regular root ripping can be carried out. Root ripping can however lead to increased wind throw of higher or exposed shelter trees.
Some Lifestyle block forums have discussed the issue, but the District Plan (RLZ-R2 and GRUZ-R2) could be a good place to alert future property owners to this type of hazard and possibly name species that are best avoided. Lincoln University could be a good source of information.

Summary

Zoning. We suggest that the Ahuriri Heights properties should be included in the new Rural Lifestyle zone, as the General Rural zone is not a good fit for the existing subdivision.

Flood Hazard Zone. The conclusions and findings of the review carried out by Ecan senior staff should be adopted.

Liquefaction Hazard Zone. Residents are following several different courses regarding having the liquefaction susceptibility of the AH subdivision land assessed. Unfortunately we were unable to organise investigations before the review period ended.

Bill and Penny Ellis

Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

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26 August 2022

Gavin Wills
Ahuriri Heights
Omarama

Dear Gavin

Flood Hazard Assessment
Amendment to Environment Canterbury Flood Area Mapping Ahuriri Heights, Omarama

This letter is to amend a section of flood mapping created as part of Environment Canterbury Report R20/26 – Review of the Canterbury part of the Waitaki District Plan flood hazard mapping – June 2020. This amendment came of the result of a request from members of the public who live in this area and a site visit made on 23 August 2022.

The small area of mapping in question is at the north-eastern edge of Omarama Township at Ahuriri Heights. The current District Plan maps that were used as a base layer for revising the mapping in the Environment Canterbury Report are Map 7 and Map 40.

The area in question falls onto the join/edge of the zoomed-in Map 40 and is also part of the zoomed-out Map 7. As described in the Environment Canterbury report the review of the flood mapping was carried out remotely and at a small scale using predominantly topographical information and other tools like google street view, aerial photography, historic flood photographs etc. Not every site was specifically visited and ground-truthed. In the case of this area the combination of the area involved being on the edge of the Omarama township District Council base map used and the high-level topographic information meant that higher ground in this area was simply not recognised at the time of report writing and the mapping was inaccurate.

The site visit made in August 2022, and attached flood extent line for this area, provides a much more detailed and clearer picture of potentially floodable land.

The attached August 2022 mapping is a ground-truthed amendment to the mapping that properly identifies higher and lower areas and gives a much more realistic picture of the potential for flooding. It is my view that this revision should supersede the mapping provided in Report R20/26 for this area (only the area shown) for any application for which the mapping may be applied by Environment Canterbury or Waitaki District Council.

All other comments from the 2020 Environment Canterbury report around purpose and possible applications of the mapping etc still apply.

Key Ref: 22206
Contact: Chris Fauth

When using the flood information provided in this letter it is important the following points are understood:

- The information provided is the best information Environment Canterbury has at this time. The District Council or local residents may have further information about flooding at the property.

- Environment Canterbury's understanding of flooding at the property may change in the future as further investigations are carried out and new information becomes available.

- It is assumed that flood protection works will be maintained to at least their current standard in the future.

- Flooding can occur in smaller floods if stopbanks are breached at lower than design flows. A breach can occur through lateral or internal erosion of the stopbank. The location of a stopbank breach or overtopping may affect flood depths at the property.

- Flood flow paths and depths can be affected by changes on the floodplain such as:
    - Altering swales, roads or irrigation features
    - Property development including buildings, fencing and hedges
    - Blockages in culverts, drains and bridges
    - Seasonal vegetation growth
    - Antecedent soil moisture conditions

The prediction of flood depths requires many assumptions and is not an exact science.

I hope this information is of assistance. Please do not hesitate to contact me if you require any clarification.

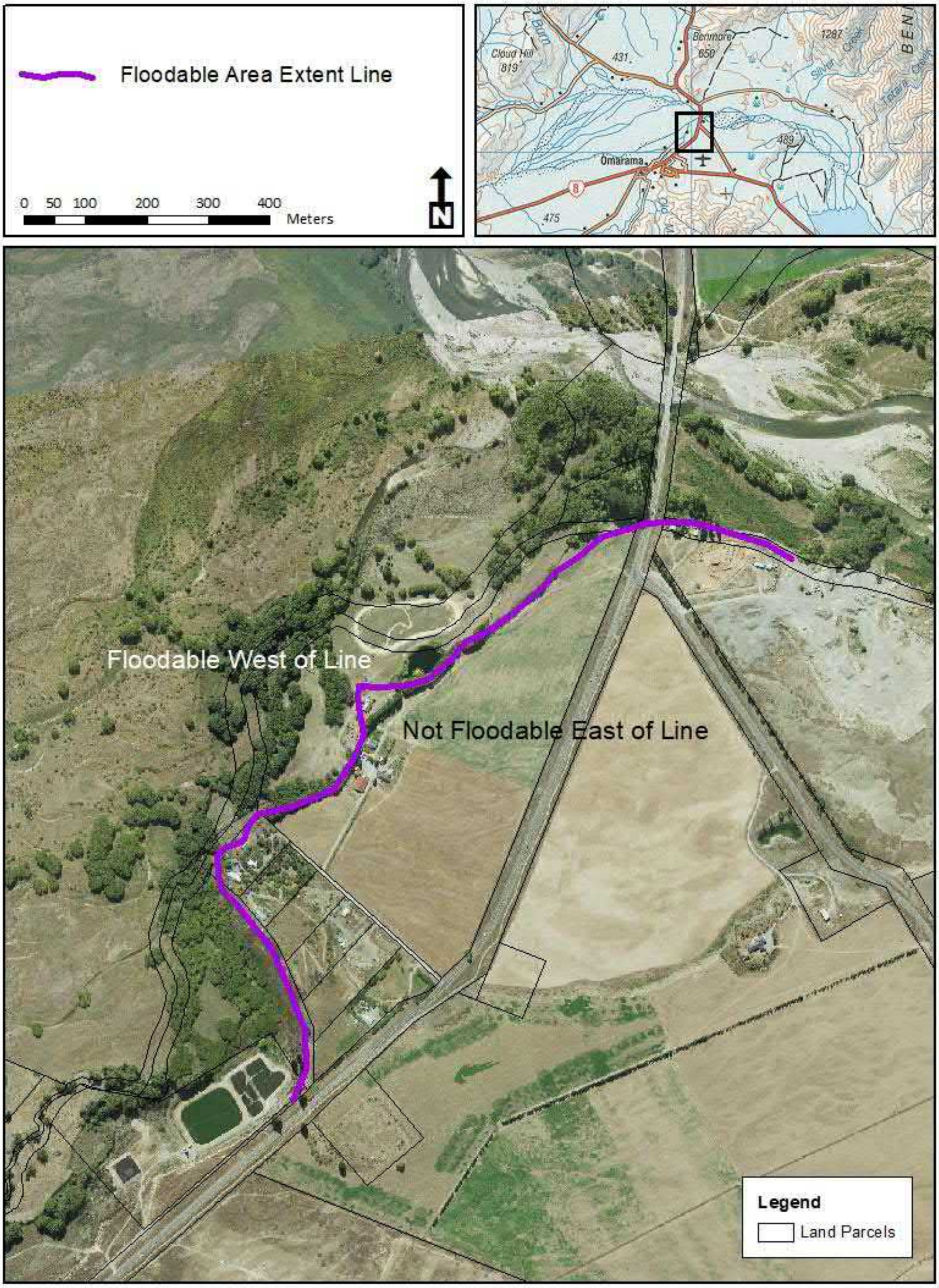
Yours sincerely

Chris Fauth
Senior Scientist (Natural Hazards)

cc: service@waitaki.govt.nz (Planning manager)
Waitaki District Council

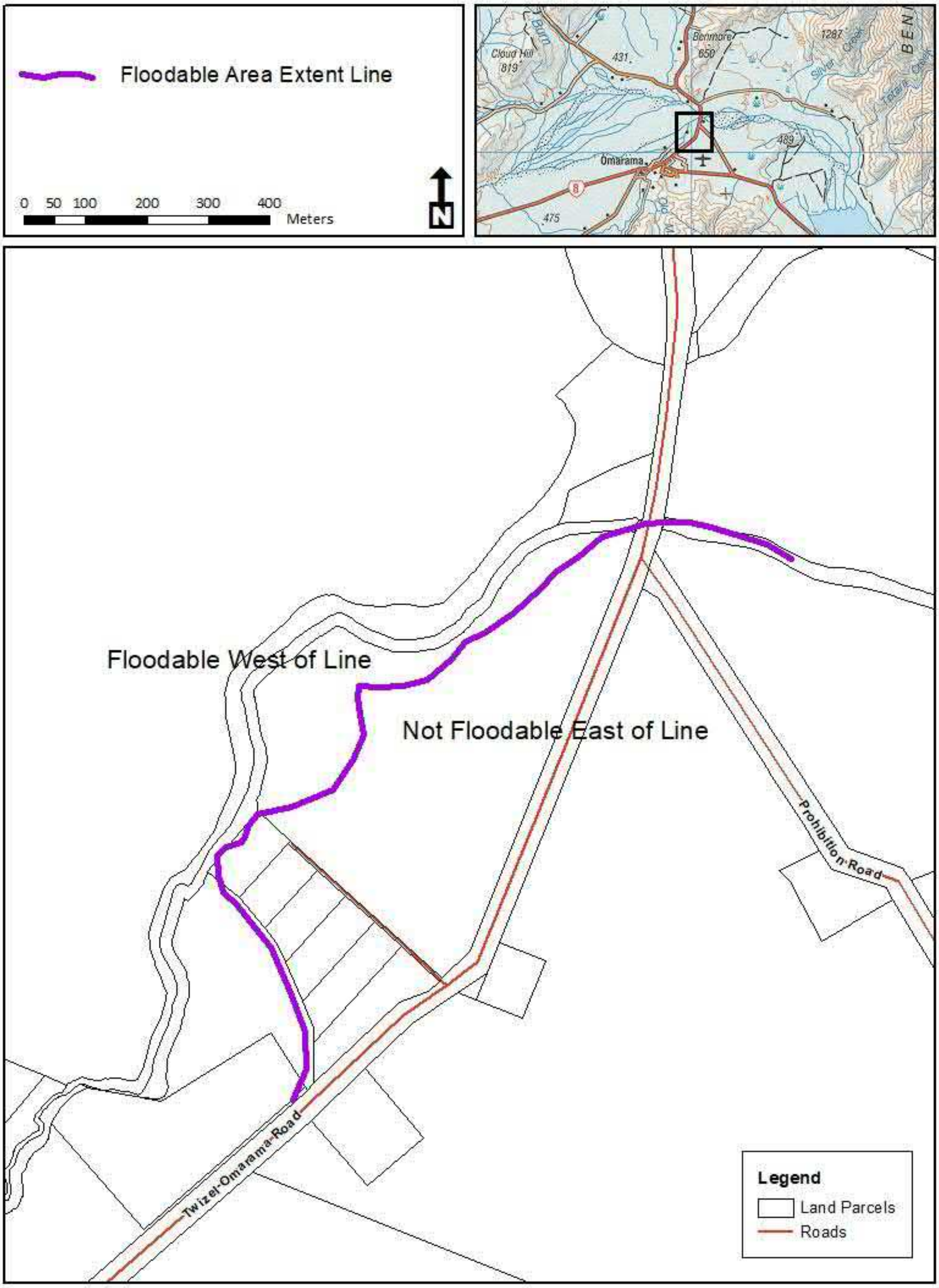
Attachments:
- Revised Ahuriri Heights floodable area extent (August 2022) on Aerial photograph
- Revised Ahuriri Heights floodable area extent (August 2022) on Topographic map
- Revised Ahuriri Heights floodable area extent (August 2022) on basic map
- Map 40 Proposed and Current flood mapping from Report R20/26 – June 2020
- Map 7 Proposed and Current flood mapping from Report R20/26 – June 2020
- Current Waitaki District Plan Map 40
- Current Waitaki District Plan Map 7

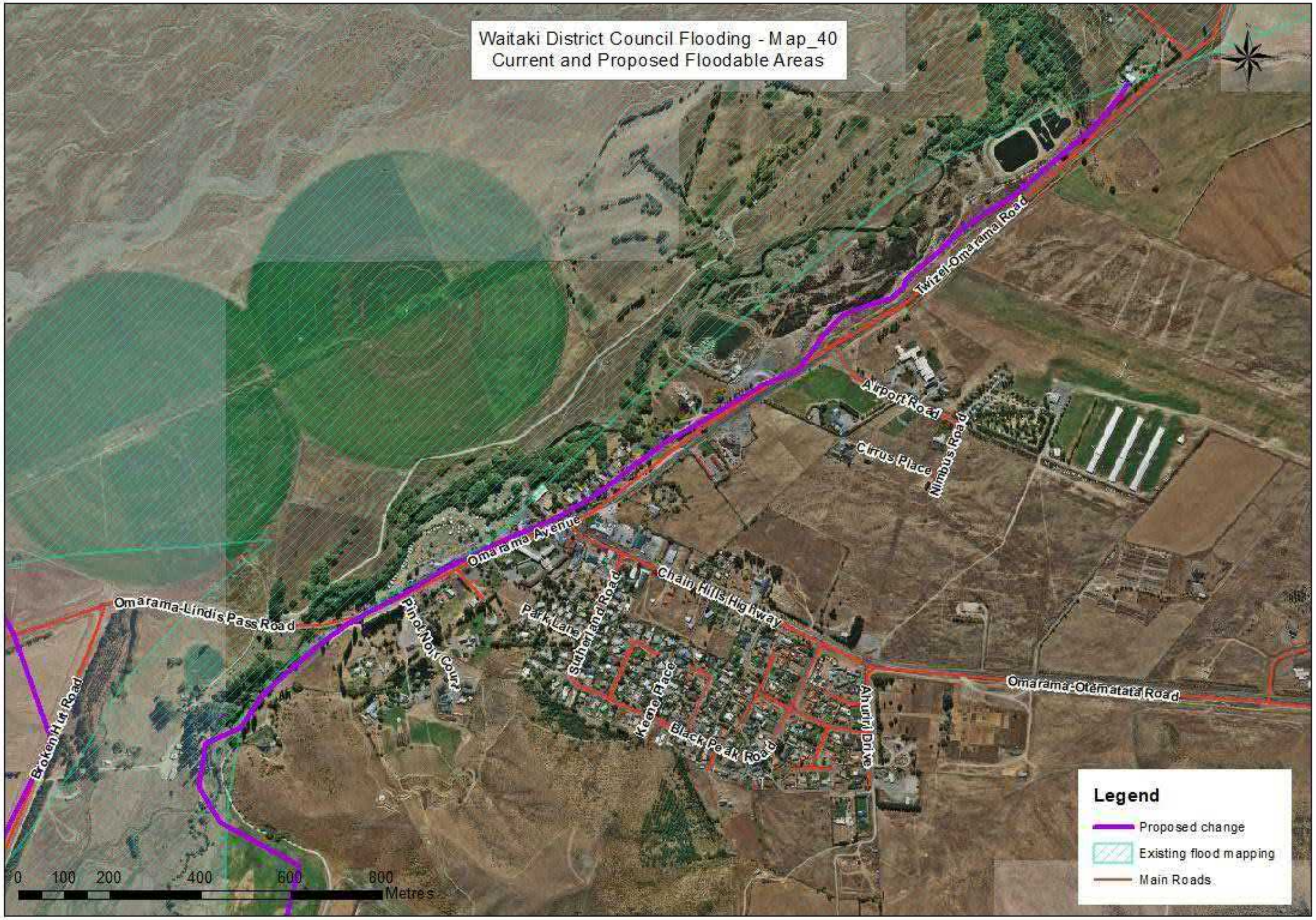
Ahuriri Heights/Lizard Hill Area - East Omarama Township - August 2022 Revision

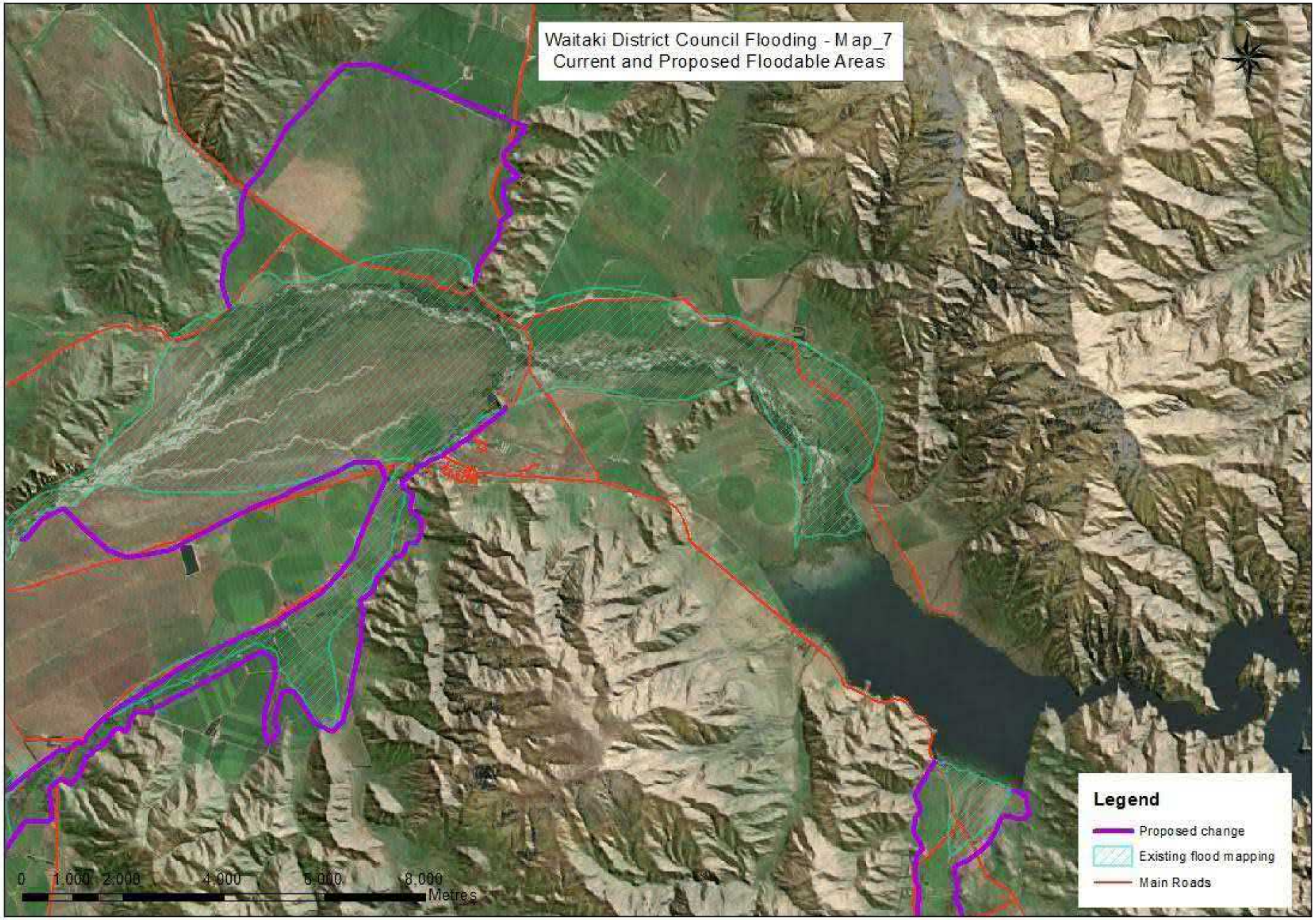


Ahuriri Heights/Lizard Hill Area - East Omarama Township - August 2022 Revision

Ahuriri Heights/Lizard Hill Area - East Omarama Township - August 2022 Revision




Waitaki District Council Flooding - Map_40
Current and Proposed Floodable Areas
Twizel-Omarama Road
Airport Road
Nimbus Road
Cirrus Place
Omarama Avenue
Chain Hills Highway
Omarama-Lindis Pass Road
Pinot Noir Court
Park Lane
Sutherland Road
Keene Place
Black Peak Road
Ahuriri Drive
Omarama-Otematata Road
Broken Hut Road
Legend
Proposed change
Existing flood mapping
Main Roads
0
100
200
400
600
800
Metres


Waitaki District Council Flooding - Map_7
Current and Proposed Floodable Areas
Legend
Proposed change
Existing flood mapping
Main Roads
0
1,000
2,000
4,000
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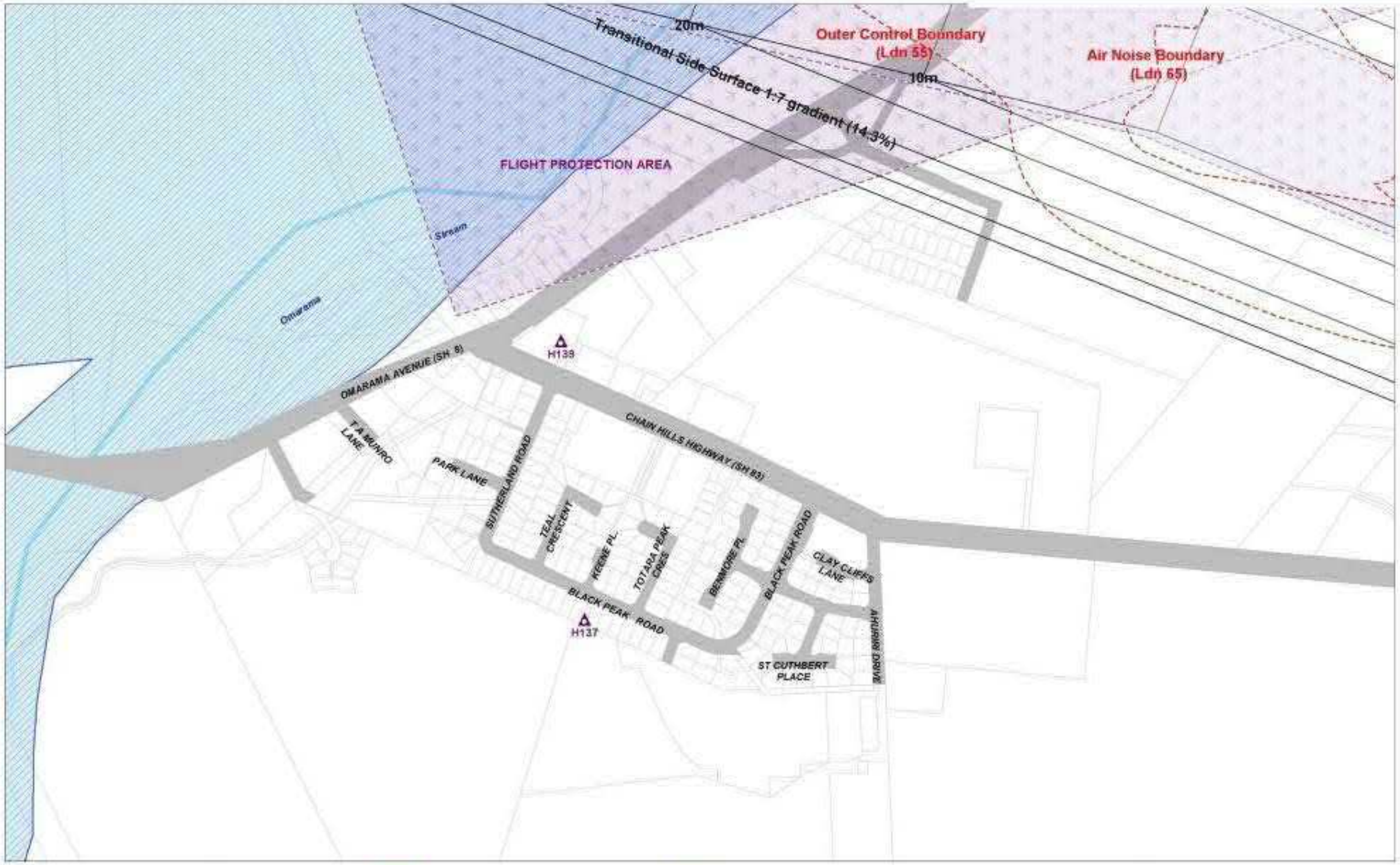
Metres

7 40

40

OMARAMA - Ahuriri

Waitaki DISTRICT COUNCIL
TE KAUNIHERA Ā ROHE O WAITAKI



Notation

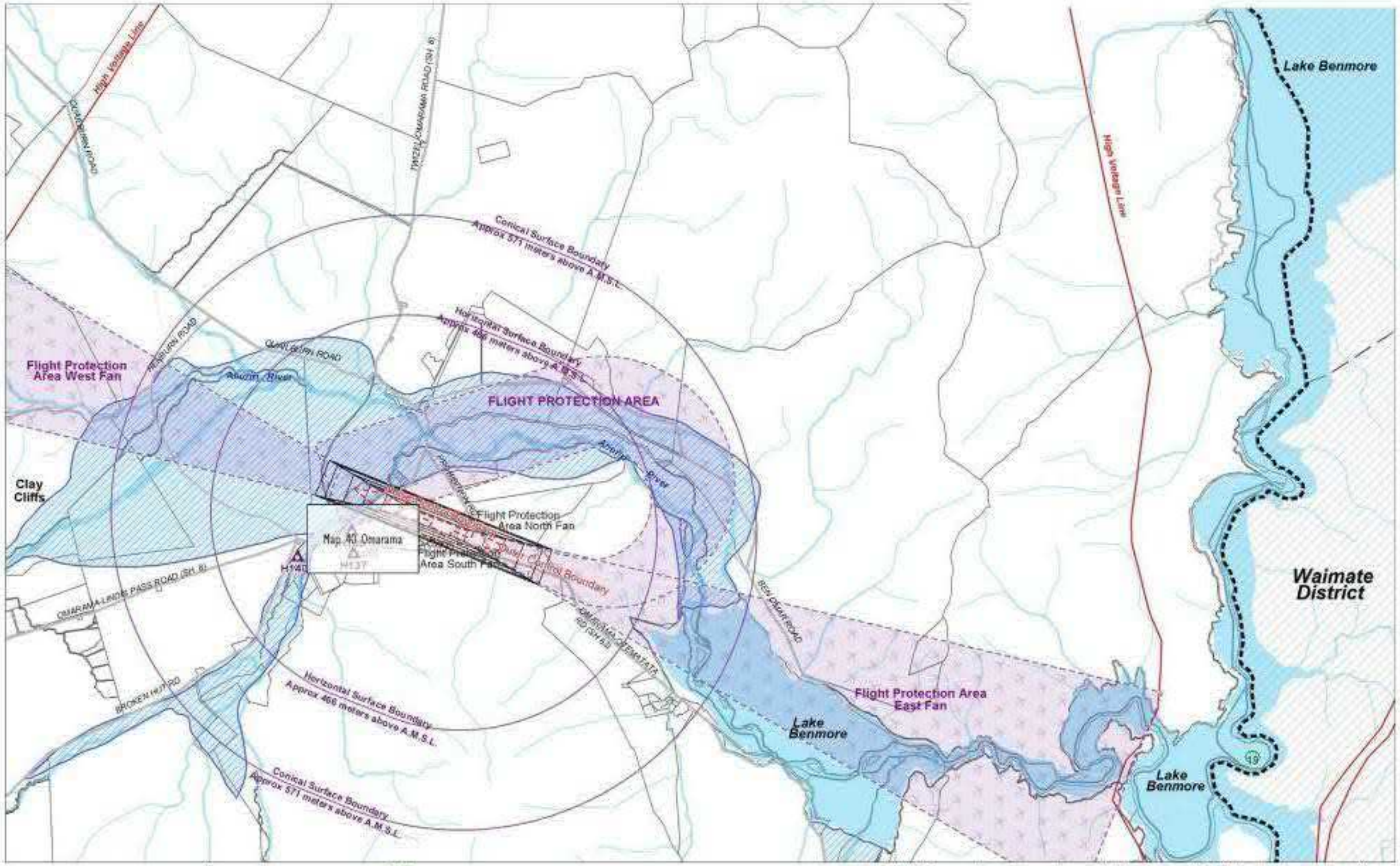
- Heritage Item
- Archaelogical Item
- Sites of Natural Significance
- Areas of Flooding Risk
- High Class Soils

4	5	
6	7	
8	9	10

7

BENMORE - Ahuriri

Waitaki
DISTRICT COUNCIL
TE KAUNIHERA Ā ROHE O WAITAKI



Notation
- Heritage Item
- Archaelogical Item
- Sites of Natural Significance
- Areas of Flooding Risk
- High Class Soils

This information is made available in good faith but its accuracy is not guaranteed. Waitaki District Council accepts no liablity for any error. Cadastral information derived from LINZ CRS Crown Copyright 2010

Gmail

bill ellis <bill.chch@gmail.com>

Query new property zoning

2 messages

bill ellis <[redacted] 15 July 2022 at 14:02
To: planreview@waitaki.govt.nz

Hi

Penny and I own the property at 15 Ahuriri Heights, Omarama.
Lot 5 DP 19887

This property has been zoned Rural Residential since the subdivision was originally developed.

We notice that the zoning on the Draft mapping shows we (and adjacent properties) have been rezoned GRu (General Rural) instead of the RL (Rural Lifestyle) we were expecting.

Is there a reason for the change to GRu or is it just an oversight that would have been picked up before the plan was finalised?

If the change was deliberate, can you please share the reasoning behind it?

Thanks

Bill Ellis

Plan Review <planreview@waitaki.govt.nz> 15 July 2022 at 16:29
To: bill ellis <[redacted]>, Plan Review <planreview@waitaki.govt.nz>

Hi Bill,

The suggested change in zoning has been a deliberate move in response to the updated natural hazard mapping which sees the mapped flood hazard extend in area. The properties in the general area (along SH8 and Ahuriri Heights) are also subject to a liquefaction susceptibility overlay. In addition to these natural hazards there is the sewerage scheme oxidation ponds in the area and further residential development in proximity to that site would likely be an ill fit with best practice setbacks from such sewerage related sites. It was considered that because of these factors the zoning of the area should change to lower the possible density of any additional residential living.

In addition to the above factors, it was considered that there is a terrace riser that makes a good geographical delineation between the edge of the General Rural Zone and the Rural Lifestyle Zone.

Hopefully the reasoning above helps to explain the suggested change in zoning.

If you would like to provide feedback for us, you can do that here – Waitaki District Council Draft District Plan | Let's Talk Waitaki

Kind regards,

Rachael Bason
Resource Management Planner – Policy

Email: rbason@waitaki.govt.nz
Web: www.waitaki.govt.nz
Tel: +64 3 433 0300

Waitaki District Council

20 Thames Street

Private Bag 50058

Oamaru

Waitaki DISTRICT COUNCIL
TE KAUNIHERA Ā ROHE O WAITAKI
Growing strong communities.

Waitaki District

Otago 9444

New Zealand

We love this place - Waitaki

From: bill ellis <[redacted]>
Sent: Friday, 15 July 2022 2:02 pm
To: Plan Review <planreview@waitaki.govt.nz>
Subject: Query new property zoning

External Email Be careful with links and attachments. Think before clicking – do I know this person and does this person's request make sense?

[Quoted text hidden]

Assessment of liquefaction hazards in the Waitaki District within the Canterbury region

DJA Barrell

GNS Science Consultancy Report 2020/69
September 2020

GNS SCIENCE
TE PŪ AO

BIBLIOGRAPHIC REFERENCE

Barrell DJA. 2020. Assessment of liquefaction hazards in the Waitaki District within the Canterbury region. Lower Hutt (NZ): GNS Science. 34 p. Consultancy Report 2020/69.

CONTENTS

FIGURES

APPENDICES

EXECUTIVE SUMMARY

The susceptibility of land to earthquake-induced liquefaction has been assessed for that part of the Waitaki District lying in the Canterbury region (the northern Waitaki District). Liquefaction is a process whereby earthquake shaking causes poorly consolidated, groundwater-saturated sediments to lose strength and stiffness due to increased groundwater pore pressure in the material. Common effects of the liquefaction of near-surface sediments are the expulsion of water, sand and silt from the ground, and associated cracking and subsidence of the ground. Liquefaction can cause severe damage to the built environment, including the breakage of foundations, differential settlement of buildings, fracturing of pipes and the buoyant rise of light buried structures, such as tanks. The closely allied phenomenon of lateral spreading involves fissuring and horizontal movement and relaxation of ground close to banks, such as the edge of a stream channel or a lake margin.

Using methods developed for liquefaction hazard evaluation in Canterbury following the 2010–2011 earthquakes, and applied across the Otago region between 2014 and 2019, including the Otago-region sector of the Waitaki District, the approach used here differentiates areas underlain by rock or firm sediments that are not susceptible to liquefaction from areas underlain by weak geological materials that may be susceptible to liquefaction if strong shaking were to occur. In order to be able to liquefy, the materials close to the ground surface need to be poorly consolidated, fine-grained (between coarse silt and fine sand) and water-saturated.

The liquefaction assessment documented in this report is an office-based evaluation of existing available information. This equates to a basic desktop assessment as defined in planning and engineering guidelines for liquefaction-prone land released in 2017 by the Ministry of Business, Innovation & Employment. The information sources included geological maps, landform and soil maps, topographic information from maps, LiDAR surveys, aerial and ground photography, geological information from borehole records and measurements of depths to groundwater.

Using that information, a liquefaction-susceptibility map for the northern Waitaki District was compiled in a Geographic Information System (GIS), and the GIS dataset is a companion to this report. The map uses the following classification of liquefaction susceptibility:

- Domain A – The ground is predominantly underlain by rock or firm sediments A sub-class, Domain A1, is applied to those areas underlain by firm sediments and poorly consolidated sediments with a deep groundwater table. In Domains A and A1, it is unlikely that damaging liquefaction could occur.
- Domain B – The ground is predominantly underlain by poorly consolidated sediments with a shallow groundwater table. There is considered to be a low to moderate likelihood of liquefaction-susceptible materials being present in some parts of the areas classified as Domain B. In Domain B, damaging liquefaction is considered to be a possibility. If liquefaction-induced ground damage were to occur, it would probably be of minor to moderate severity.

Areas mapped as Domain B are regarded as ‘liquefaction awareness areas’ and do not represent specific hazard zones. Rather, they highlight areas where there may be the possibility of a liquefaction hazard. Only 6% of the land area (excluding lakes) of the northern Waitaki District is classified as Domain B, with the remaining 94% mapped as Domain A or A1 – terrain that has little or no liquefaction susceptibility.

Information in this report is based largely on broad-scale inferences and should not be used in isolation for any purposes requiring site-specific information. The liquefaction susceptibility domains highlight areas where liquefaction hazard may warrant further scrutiny for future planning and development activities. This report and the accompanying GIS dataset provide a step toward improved awareness and management of potential liquefaction hazards.

A first step toward managing liquefaction risks is to ensure that all building and infrastructure development accords with existing standards (e.g. Resource Management Act and the Building Act). For the liquefaction awareness areas (Domain B), management or mitigation options could include the territorial authority specifying levels of geotechnical investigation to determine ground conditions and assist in the design of liquefaction-mitigating measures and foundation design. For single residential dwellings, one alternative to geotechnical investigations could be the use of strengthened foundations. A desirable future step, should the need arise for future developments, would be to establish the presence or otherwise of potentially liquefiable materials in areas mapped as Domain B and, if present, their general pattern of distribution.

1.0 INTRODUCTION

1.1 Overview

Earthquake-induced liquefaction is a potential hazard in some parts of New Zealand. Liquefaction results from the sudden loss of shear stiffness and strength of soils caused by development of excess pore pressure by cyclic shaking during an earthquake. Liquefaction may cause ground settlement, lateral spreading, loss of bearing capacity and buoyant rise of buried structures such as pipes or tanks. Extensive liquefaction damage occurred in the Christchurch area during the earthquakes of 2010–2011 (Brackley et al. 2012). Media publicity and readily accessible images have resulted in most New Zealanders now having an awareness of the nature and effects of liquefaction.

Canterbury Regional Council (ECan) contracted GNS Science to provide an assessment of liquefaction hazards for that part of the Waitaki District lying within the Canterbury region, referred to here as the northern Waitaki District (Figure 1.1). This report presents the results of that assessment, and is a companion to an assessment of liquefaction hazards in that part of the Waitaki District within the Otago region (Barrell 2019). The information in the present report is intended to assist ECan in providing advice on managing liquefaction hazards to the Waitaki District Council.

1.2 Scope of Work

The work comprised an office-based assessment of existing information for the northern Waitaki District following the methods used for assessing liquefaction hazards in the Otago region (Barrell et al. 2014; Barrell 2019).

The main components of the project were:

- review of existing relevant reports and datasets (Section 1.3);
- compilation of a liquefaction-susceptibility map; and
- preparation of an explanatory report documenting the work undertaken, accompanied by digital map files and metadata.

The report presents a geologically based assessment of information that is intended to create awareness of where liquefaction-related hazards may be present. The new mapping documented here draws upon readily available existing information, and no new site investigations were undertaken as part of this project. The approach accords with recent planning and engineering guidance for liquefaction-prone land (MBIE 2017).

The liquefaction-susceptibility domains delineated in this report are intended to highlight areas where liquefaction is a potential hazard that warrants consideration in future planning and development activities. The information is, for the most part, based on generalised assessments and broad-scale inferences rather than detailed investigations and should not be used in isolation for any purposes that require site-specific information.

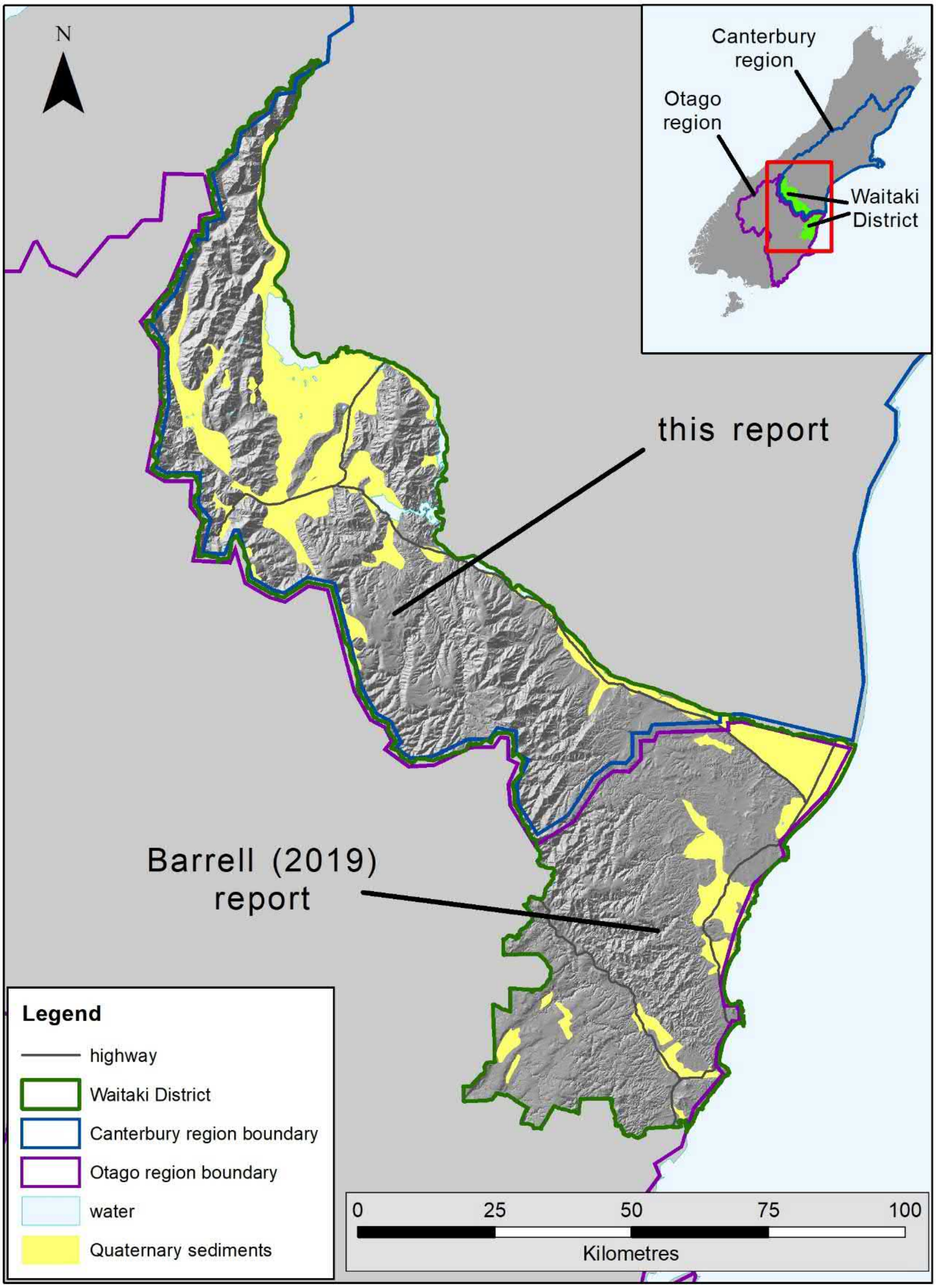


Figure 1.1 Location of the Waitaki District and its distribution of Quaternary-age sediments from the New Zealand 1:1,000,000-scale geological map (Edbrooke et al. 2014). Only those areas underlain by Quaternary sediments have any potential for the occurrence of liquefaction, and then only if the sediments are of a certain type and groundwater is close to the surface. Liquefaction in relation to that part of the Waitaki District in the Otago region is addressed in a previous report (Barrell 2019), while this report addresses the northern Waitaki District within the Canterbury region. The background is a hillshade terrain model derived from topographic map elevation data.

1.3 Liquefaction Hazard Assessment Methodology

The **liquefaction**[1] hazard evaluation reported here is a regional-scale susceptibility assessment, using methodologies similar to those previously applied in eastern Canterbury (Brackley et al. 2012) and in the Otago region (Barrell et al. 2014; Barrell 2019). Ministry of Business, Innovation & Employment guidelines for planning and engineering in relation to liquefaction-prone land (MBIE 2017) include comprehensive information on the nature of liquefaction and approaches for determining and managing risks of liquefaction damage. Interested readers should consult the MBIE (2017) report, and only a summary of the nature and occurrence of liquefaction is provided here (Section 3).

The approach used here focuses on liquefaction susceptibility. This term relates to the physical state of ground-forming materials, as to whether they have the 'ability' (suitable physical characteristics) to liquefy. The key physical characteristics are the presence of loose, water-saturated sand or silt layers or pods in the near-subsurface. The liquefaction-susceptibility mapping approach used is principally based on geomorphology. The form and origin of the ground surface (**geomorphology**) generally reflects the nature of underlying geological materials, whether solid rock or ranging through to a variety of poorly consolidated or loose sediments. Although records from the drilling of water bores, geotechnical probes or excavations provide direct information on subsurface materials, each of these points of information may lie a considerable distance apart. Thus, geomorphologic information provides an area-wide, general indication of what lies beneath the near-surface, e.g. within 10 m or so below the ground, as well as giving insights into the processes, such as erosion and deposition, that have shaped the ground surface. The aim of the mapping presented here, based on geological character and the nature of the landform, is to delineate areas where there is a possibility of liquefaction-susceptible materials being present. Areas that are assessed as having liquefaction susceptibility should also be considered to have **lateral spreading** susceptibility in areas close to 'free faces', such as river bank edges or lake shore cliffs.

In the context of the MBIE (2017) guidelines, the methodology used here equates to a 'Level A' basic desktop assessment that is aimed at distinguishing between areas where liquefaction damage is unlikely to occur versus areas where liquefaction damage is possible. This approach differs from more comprehensive classes of liquefaction evaluation listed in the MBIE (2017) guidelines (Level B – calibrated desktop assessment, Level C – detailed area-wide assessment and Level D – site-specific assessment). These more comprehensive classes of liquefaction assessment require detailed information on the geotechnical properties of near-surface sediments. Therefore, in order to make a firmer assessment of liquefaction risks, it is necessary to have site-specific **geotechnical investigation** data from drilling and down-hole testing of the ground. Generally speaking in the Waitaki District, there is insufficient information for more quantitative assessments, such as are described in the MBIE (2017) guidelines.

1.4 Data Sources and Mapping Methods

The starting point for the assessment was the GNS Science 1:250,000-scale geological database (QMAP; Heron 2018), with individual map sheets and booklets that coincide with the northern Waitaki District by Turnbull (2000; Wakatipu), Forsyth (2001; Waitaki), Cox and Barrell (2007; Aoraki) and Rattenbury et al. (2010; Haast). Liquefaction, and the associated effect of lateral spreading, are phenomena associated with young, poorly consolidated,

1 Any term that is defined in Appendix 1 is bolded at its first mention in this report.

water-saturated sediments, deposited during the **Quaternary Period** (see Figure 1.2). It is only the sediments of Late Quaternary age that are likely to have sufficiently poor consolidation and the water saturation necessary to pose a potential liquefaction hazard.

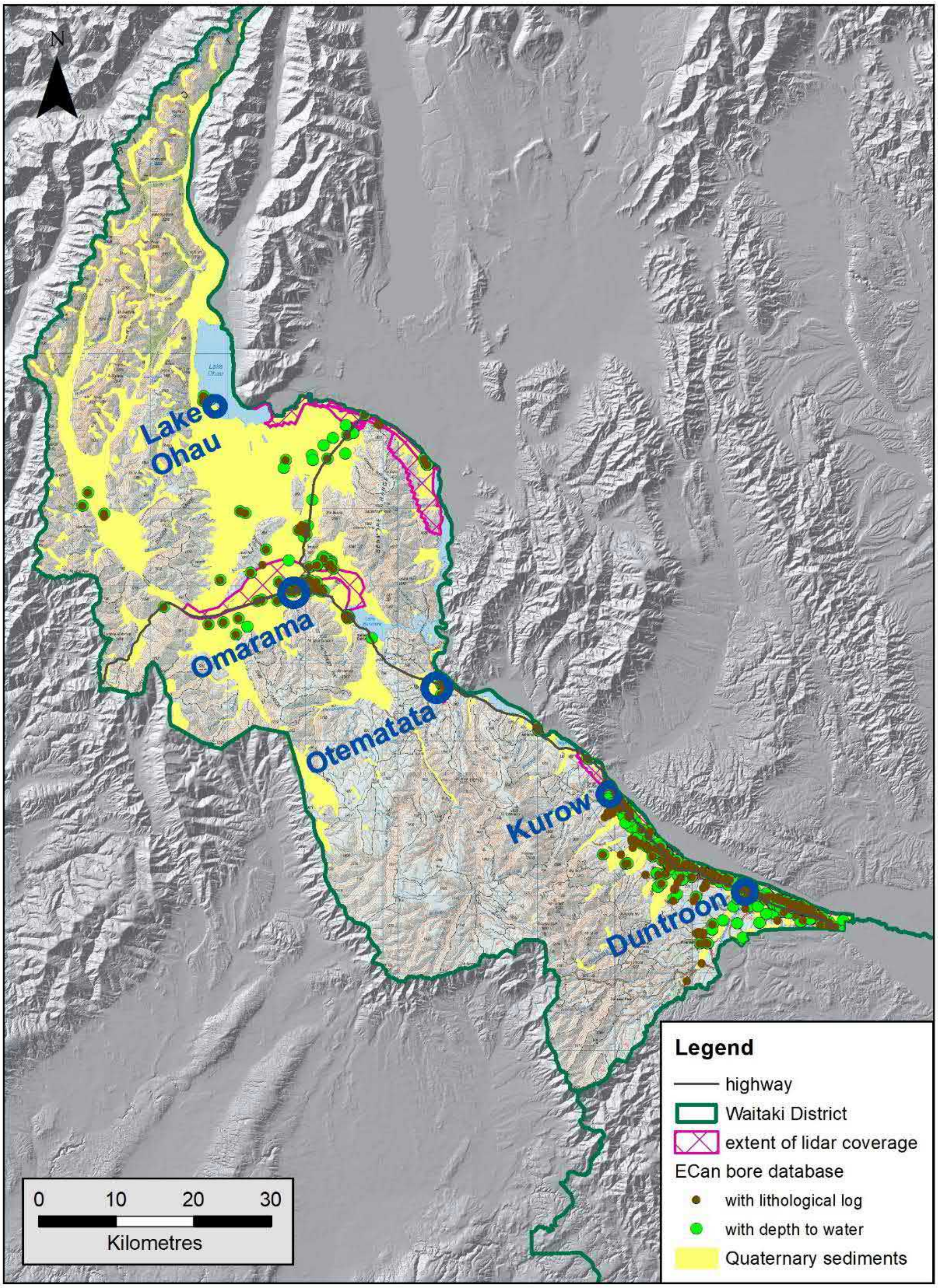


Figure 1.2 Background information sources for the northern Waitaki District. The map shows the extent of LiDAR coverage; locations of bores in the ECan database, with water-level data and/or records of geological materials (lithological logs); and the distribution of Quaternary sediments (New Zealand 1:250,000-scale geological map; Heron 2018). The coloured background is the LINZ Topo 250 map, displayed only for the northern Waitaki District.

Taking the generalised QMAP **polygons** as a guide, other information sources were used to delineate more detailed interpreted extents of **liquefaction-susceptibility awareness area** domains. The mapping was done directly with a computer using **Geographic Information System** (GIS) software (ArcGIS). Applying expert interpretation of landform features, boundaries between map polygons were positioned on-screen relative to underlying basemap information. Specific resources used for that purpose include:

- the digital topographic map of the Land Information New Zealand (LINZ) 'Topo 50' 1:50,000-scale map series;
- a high-resolution digital aerial photograph mosaic collated from images taken in 2013–2014 and accessed as a basemap layer that comes via ArcGIS;
- a digital database of borehole information made available by ECan for this project; and
- LiDAR ('laser radar') datasets, where available. These provide highly detailed information (1 m grid cells) on ground elevations, but there is only very limited coverage in the assessment area (Figure 1.2).

Other resources used to aid mapping interpretations included Google Street View, which provides 360° ground photos along all sealed roads. The writer also draws upon knowledge gained from having undertaken work on the geology and geomorphology of the Waitaki valley and its catchment over more than two decades.

1.5 Report Layout

General background information is provided in Section 2, including the geological setting and geological processes of the assessment area and the origin and context of landform features relevant to liquefaction hazards. Also provided is an overview of the general nature of liquefaction and factors influencing its occurrence, an outline of part seismicity in the assessment area and a description of the approach and methods used here for assessing liquefaction susceptibility. Section 3 describes the liquefaction-susceptibility map units (domains), defines what they mean and outlines the accuracy and limitations of the mapping. This is followed by a summary description of the liquefaction-susceptible areas. Section 4 discusses the overall findings of the assessment and the uses of the information and conclusions are set out in Section 5. Appendix 1 provides explanation of some of the technical terms used in the report. Detailed descriptions of the criteria used for mapping liquefaction-susceptibility domains at specific locations are contained in Appendix 2. The GIS dataset of the mapped liquefaction-susceptibility domains is described in Appendix 3.

2.0 BACKGROUND INFORMATION

2.1 Geological Setting

The geological sequence of the south-western part of the Canterbury region comprises, from oldest to youngest, three main categories: basement rock; cover rocks; and young, poorly consolidated deposits. The oldest underlying rock (basement rock) consists of greywacke and low-grade schist. Following its formation between 250 and 100 million years ago, erosion formed a flattish land surface across the basement rock, and this was later buried by younger sedimentary rocks (cover rocks), ranging in age from about 100 to about 2.6 million years. Since about 5 million years ago, tectonic deformation associated with movement along the boundary between the Pacific and Australian plates has produced the Southern Alps and the ranges and basins of south-western Canterbury and inland Otago. The ranges have been uplifted along geological faults, while the basins have experienced the least amount of faulting, folding or uplift. Most of the cover rocks have been eroded off the ranges, though cover rocks are still preserved in many parts of the basins. It is mainly in the basins and river valleys that Quaternary-age sediments (younger than 2.6 million years) have accumulated, and it is these sediments that may be potentially susceptible to liquefaction.

During the Quaternary Period, cyclic shifts in global climate saw periods of generally cool conditions (glaciations, or 'ice ages') separated by periods of warmer climate ('interglaciations'), such as exists today. During a glaciation, ice was not everywhere in New Zealand, but rather the climate became cool enough for extensive glaciers to form in high mountain areas. Ice from the Southern Alps formed large glaciers in the upper Ahuriri and Ohau valleys; Lake Ohau lies in the footprint of the former glacier.

During glaciations, the generally colder climate reduced the vegetation cover on the hills and mountains, encouraging erosion that delivered a general excess of sediment to the river and stream systems across the eastern South Island. This resulted in the build-up of sediment in the valley floors. The sediments of these environments tend to be dominated by gravel, but sand or silt layers or pods may be present and could be potentially susceptible to liquefaction. As the climate warmed into the present interglaciation, many rivers and streams cut down into their valley floors, producing terraces. The downcutting has tended to lower the groundwater levels beneath the terraces, resulting in lessening of any liquefaction potential there.

The retreat of ice at the end of the last glaciation brought major changes to the formerly glaciated catchments, with large volumes of **fan** and **fan-delta** sediments accumulating in and around the former glaciated valleys. These environments offer possibility for the presence of river or lake sand and silt that may have potential for liquefaction.

2.2 Seismicity

Existing information on seismicity includes general assessments of seismic hazard in the Canterbury region (Stirling et al. 2007, 2008) and an earthquake hazard assessment that includes the northern Waitaki District (Yetton and McCahon 2008). A distinction exists between 'distant' and 'nearby' seismicity. Distant seismicity relates to large earthquakes that occur on faults located as much as several hundred kilometres away from an observer but whose shaking is felt over a wide area, with less intensity the farther one is from the fault. Nearby seismicity relates to earthquakes on faults located within a few tens of kilometres of an observer. Nearby earthquakes, if sufficiently large, are particularly damaging.

Historically, southern Canterbury and North Otago have had a very low level of nearby seismicity, with very few earthquakes having **epicentres** in the area (Stirling et al. 2012). Most earthquakes that have been felt in the Waitaki District were instances of distant seismicity, centred outside the district. Recent examples of distant seismicity that may have been felt in the Waitaki area are the 2003 Fiordland Earthquake and 2009 Dusky Sound Earthquake, both centred in Fiordland, and the 2010 Darfield Earthquake and 2016 Kaikōura Earthquake, both centred in Canterbury. None caused notable damage in the northern Waitaki District.

Numerous geological faults underlie the northern Waitaki District, and several show evidence for having moved in the recent geological past (i.e. during Late Quaternary time; Appendix 1) and would have generated large earthquakes (Barrell et al. 2009; Langridge et al. 2016; Barrell 2016). These include the Stonewall, Waitangi and Fern Gully faults aligned along the Waitaki valley, and the Ostler Fault northwest of Omarama. Although the likelihood is considered low, the possibility exists for large earthquakes to be generated on geological faults in the northern Waitaki District. The September 2010 Darfield and February 2011 Christchurch earthquakes showed that damaging earthquakes can occur on faults that lie nearby, but deep underground, and whose existence is not known prior to an earthquake being generated by them.

The only known damage associated with earthquakes centred near the northern Waitaki District was from a sequence of three earthquakes in 1876 in the Oamaru area (Oamaru Earthquakes) of estimated magnitudes (M) up to 5.8 that caused some damage to chimneys and buildings there (Downes 1995). Moderate earthquakes of ~M5 occurred near Lake Benmore in 1966 and 1971, and a M5.1 earthquake occurred near Danseys Pass in 1998 (Yetton and McCahon 2008), but no damage was reported.

2.3 The Nature and Occurrence of Liquefaction and Lateral Spreading

Strong earthquake shaking is required to induce liquefaction in susceptible sediments. The 2010–2011 Canterbury earthquake sequence highlighted many of the effects and consequences of liquefaction (Brackley et al. 2012; Figure 2.1). Liquefaction can only occur in water-saturated sandy or silty materials, and therefore the depth to the groundwater table is a key factor in the occurrence of liquefaction. It was found in the Canterbury earthquake sequence that liquefaction only occurred where the depth to groundwater was less than about 5 m. For that reason, depth to groundwater has guided the interpretation of extent of liquefaction-susceptible ground mapped for this project.

A typical consequence of liquefaction is the ejection of liquefied sediment from the ground, usually along with copious amounts of groundwater. Relatively minor liquefaction may produce sand boils or sand ‘blows’, like little volcanoes (Figure 2.1A). Severe liquefaction may result in the ejection of huge volumes of water and sediment, resulting in the ground surface being buried by vast sheets of sand and silt, sometimes as much as half a metre thick (Figure 2.1B). The ejection of material commonly results in differential sagging (settlement) of the ground surface and, because liquefaction significantly reduces the strength of the soil and its supportive ability, it is likely to cause heavy structures to sink into the ground and any light or buoyant structures, particularly buried pipes or tanks, to ‘float’.

Lateral spreading is a related phenomenon resulting from earthquake-induced liquefaction of underlying sediments. Liquefaction-induced loss of strength in the subsurface causes the ground to move almost horizontally toward any nearby free-face, such as a river bank or edge of an embankment, and typically results in cracking or deep fissuring of the ground and differential ground settlement (Figure 2.1C). Lateral spreading is usually associated with coastlines, lakeshores, river channels and the margins of reclaimed ground or raised embankments.

No instances of liquefaction have been reported in the northern Waitaki District since at least the mid-1800s, when written record-keeping began. However, the anticipated major earthquake on the Alpine Fault along the western edge of the Southern Alps, and lying as close as ~90 km northwest of Omarama and ~70 km northwest of Lake Ohau village, may likely cause some liquefaction in the north-western part of the Waitaki District, such as the valley floors of the rivers draining into Lake Ohau, and in the upper Ahuriri valley. The Alpine Fault has experienced at least 27 earthquakes during the past ~8000 years. They have occurred on average once every ~300 years, although the interval between each earthquake can be as short as ~200 years or as long as ~400 years (Berryman et al. 2012). The fault has not experienced a major earthquake since about 1717 AD (303 years before 2020), based on tree ring studies. Statistical calculations indicate a 29% likelihood that the next Alpine Fault earthquake will occur within the next 50 years (Cochran et al. 2017). The more time that elapses, the more the likelihood increases.

Figure 2.1 Photos illustrating some effects of liquefaction and lateral spreading. A: Relatively minor liquefaction effects in a paddock near Tai Tapu, with pods of grey sand/silt that issued from the ground during the 2010 Darfield Earthquake. GNS Science VML ID: 1398421; DJA Barrell, 5th Sept 2010. B: Severe liquefaction effects at Ferrymead, eastern Christchurch, where vast amounts of sand/silt issued from the ground, causing localised subsidence, during the 2011 Christchurch Earthquake. EQC / GNS Science VML ID:164424; A King, 24th Feb 2011. C: Lateral spreading and ground subsidence along a river bank in Avonside, eastern Christchurch, resulting from the 2011 Christchurch Earthquake. EQC / GNS Science VML ID: 149293; RD Beetham, 4th March 2011.

3.0 ASSESSMENT OF LIQUEFACTION HAZARDS

3.1 Liquefaction-Susceptibility Domains

The focus of this project has been to identify areas that, from geological and geomorphological considerations, are underlain by sediments that may have some liquefaction susceptibility. This has included interpretation of whether groundwater levels are sufficiently close to the surface to make liquefaction possible. For this assessment, Quaternary-age sediments with an estimated groundwater table deeper than 5 m are placed in Domain A1. This depth criterion aligns with that of the MBIE (2017) guidelines, which identify a groundwater depth of more than 4 to 6 m, indicating that liquefaction damage is unlikely (Table 4.3 of the MBIE report).

The approach used here does not define hazard zones as such, but rather identifies liquefaction-susceptibility domains, as shown on the maps and contained in the associated GIS dataset. In terms of the MBIE (2017) guidelines, the project methodology equates to a 'Level A' basic desktop assessment that is aimed at distinguishing between areas where liquefaction damage is unlikely to occur (Domains A and A1) versus areas where liquefaction damage is possible (Domain B).

The liquefaction-susceptibility domains are defined as follows:

- Domain A – The ground is predominantly underlain by weak or strong rock substrate. There is little or no likelihood of damaging liquefaction occurring. In MBIE (2017) terms, liquefaction damage is unlikely.
- Domain A1 – The ground is predominantly underlain by firm to poorly consolidated sediments with a deep groundwater table. There is little or no likelihood of damaging liquefaction occurring. In MBIE (2017) terms, liquefaction damage is unlikely.
- Domain B – The ground is predominantly underlain by poorly consolidated river, stream or lake sediments with a shallow groundwater table. There is considered to be a low to moderate likelihood of liquefaction-susceptible materials being present in some parts of the areas classified as Domain B. In MBIE (2017) terms, liquefaction damage is possible.

For Domain B, the level of information is not sufficient to assign liquefaction vulnerability categories, which is a step that requires investigations at Level C or D classes (MBIE 2017).

3.2 What the Liquefaction-Susceptibility Domains Mean

3.2.1 Domains A and A1

- The geological nature of the ground is such that future earthquakes are unlikely to cause land damage from liquefaction.
- Other **geohazards** are likely to be more dominant, if present at all (see Appendix 1).
- Risks related to future earthquakes primarily relate to damage from strong ground shaking and landslide-related phenomena (if any). Those risks, and any minor residual risk from localised liquefaction, can be managed through adherence to New Zealand Building Code requirements and use of insurance.

3.2.2 Domain B

- The geological nature of the ground is such that future earthquakes may possibly cause land damage from liquefaction.
- The Domain B classification identifies what may be termed as 'liquefaction awareness areas', in which liquefaction is a possible hazard that warrants being given consideration in relation to land development, land-use intensification and infrastructure.
- Being in a liquefaction awareness area does not mean that a liquefaction hazard exists for any particular parcel of land. Rather, it indicates the possibility that a hazard may exist. Equally, site-specific investigations may show that a hazard does not exist.
- In terms of the MBIE (2017) guidelines (Table 2.2 of the MBIE report), Domain B may include at least some areas that may experience minor to moderate liquefaction-induced ground damage in response to strong earthquake shaking.
- There is little or no information on the extents of potentially liquefiable ground within the liquefaction awareness areas mapped as part of this project. It is likely that geotechnical investigations of a liquefaction awareness area (see Appendix 1) would identify some areas within Domain B where there is little or no liquefaction susceptibility (low or very low vulnerability; MBIE 2017) and some areas that have some liquefaction susceptibility (medium or high vulnerability).
- Further work, involving the collection of more geotechnical investigation information, would be necessary to undertake Level C or D liquefaction assessments for areas mapped here as Domain B, if liquefaction vulnerability maps (MBIE 2017) were to be developed. Higher-level liquefaction assessments would be useful for any proposed future urban or infrastructural development on ground mapped as Domain B.
- Based on present levels of information, consideration could be given to managing potential liquefaction risk in liquefaction awareness areas by general guidance or by regulatory provisions in district plans, for example. Options could include specifying degrees of geotechnical investigation and/or the adoption of liquefaction-mitigating structural measures (e.g. NZGS and MBIE 2016). Taking the example of a new residential house in Domain B, a possible alternative to undertaking geotechnical investigations to determine foundation requirements could simply be to use strengthened foundations. In the case of a residential subdivision development, or the construction of commercial, industrial or high-importance buildings in liquefaction awareness areas, geotechnical investigations would be an expected component of planning, design and consenting.

3.3 Accuracy and Limitations of the Liquefaction-Susceptibility Mapping

Liquefaction-susceptibility domains have been mapped based on the information sources listed in Section 1.4. The weighting of the various components of geological, geomorphological and hydrological information used to map the extent of domains is indicated, where appropriate, in Appendix 2. The domain boundaries have been drawn based on those considerations.

All of the northern Waitaki District is covered by 1:50,000-scale Topo 50 topographic maps and high-resolution colour aerial photos. In remote hill and mountain terrain, the QMAP polygons were generally adopted without modification, but elsewhere the detailed map and photographic resources were used for refining the positions of liquefaction-susceptibility polygons. Polygon boundaries drawn using topographic maps together with aerial photos should be regarded as mapped at 1:20,000-scale and accurate to plus or minus 50 m. This means that each domain polygon boundary equates to a 100-m wide zone, centred on the location where the line is drawn. In towns and villages, where Google Earth Street View was available at the time of mapping, Google Earth ground photography was accessed to help in positioning domain boundaries. In those areas, the nominated mapping scale is 1:1000, and boundaries are considered accurate at the scale of property parcels and buildings (e.g. plus or minus 10 m). The Appendix 2 commentary explains where those more detailed scales apply.

The main limitation of the liquefaction-susceptibility map is that there is considerable uncertainty in the exact nature of the subsurface sediments whose character defines the extent of Domain B. The mapped extents of each domain represent best estimates based on the interpretation of geological and geomorphological information, but the uncertainties are difficult to quantify from available data. For that reason, it is important that the GIS map of liquefaction-susceptibility domains be seen only as providing general guidance for planning, development and hazard/risk reduction. More specifically, the map's main value is to indicate areas where liquefaction is a possible hazard that may warrant consideration for matters relating to infrastructure, built assets or emergency management preparations.

3.4 Description of the Liquefaction Susceptibility Map Area

The northern Waitaki District is dominated by ground that is classified as Domains A or A1 (Figure 3.1). For the most part, ground classified as Domain B comprises the floors and lowest terraces of river and stream valleys. Inland, areas of swampy to poorly drained ground where low-gradient fans have built up at the foot of hill terrain, such as on the western sides of the Benmore Range and St Cuthbert Range, are also classified as Domain B.

There are only five notable population centres in the northern Waitaki District, identified by name in Figure 3.1, each with permanent populations of no more than a few hundred people. More detailed views of the map are provided for each population centre (Figures 3.2–3.6) and the liquefaction susceptibility mapping at each centre is described in subsections below.

In an amendment from the approach used in the Otago mapping, ECan requested that a distinction be made between areas underlain by rock substrate (Domain A) and areas underlain by sediments that are firm or poorly consolidated with a deep groundwater table, which are subdivided out as Domain A1. Although Domains A and A1 are considered to have little or no liquefaction susceptibility, this approach provides better similarity to the previous liquefaction susceptibility mapping of this area by Yetton and McCahon (2008), as discussed in Section 4. In the mapping documented here, boundaries are retained within Domain A1 between broad classes of ground, such as fans, stream valley plains, glacial moraine or outwash plains and river terraces. This detail is identified as attributes in the GIS dataset and, where relevant, is mentioned in Appendix 2.

3.4.1 Duntroon

The village of Duntroon sits on terraces and low rolling hills terrain near the confluence of the Maerewhenua and Waitaki rivers (Figure 3.1). The Duntroon Domain and camping ground, and a few houses on Livingstone Street, are on low terraces of the Waitaki and Maerewhenua river, respectively, and classified as Domain B on account of expected shallow groundwater tables. The remainder of Duntroon is on Domains A or A1. The Waitaki and Maerewhenua are gravel-bed rivers, and any liquefaction susceptibility that may exist in Domain B at this location would relate to buried pockets of sand or silt. Were any liquefaction to occur, it would likely be relatively minor, of similar character to that illustrated in Figure 2.1A.

3.4.2 Kurow

The town of Kurow sit on terraces of the Waitaki River, partly onlapped by fans from tributary streams draining from the southwest, including Kurow River (Figure 3.3). The main terrace at Kurow is assessed as having a groundwater table deeper than 5 m and is classified as Domain A1. A lower terrace alongside the Waitaki River is assessed as having a shallow groundwater table and classified as Domain B. The only existing development on that terrace is part of the Kurow Holiday Park. Any liquefaction susceptibility that may exist in Domain B at this location would relate to buried pockets of sand or silt. Were any liquefaction to occur, it would likely be relatively minor, of similar character to that illustrated in Figure 2.1A.

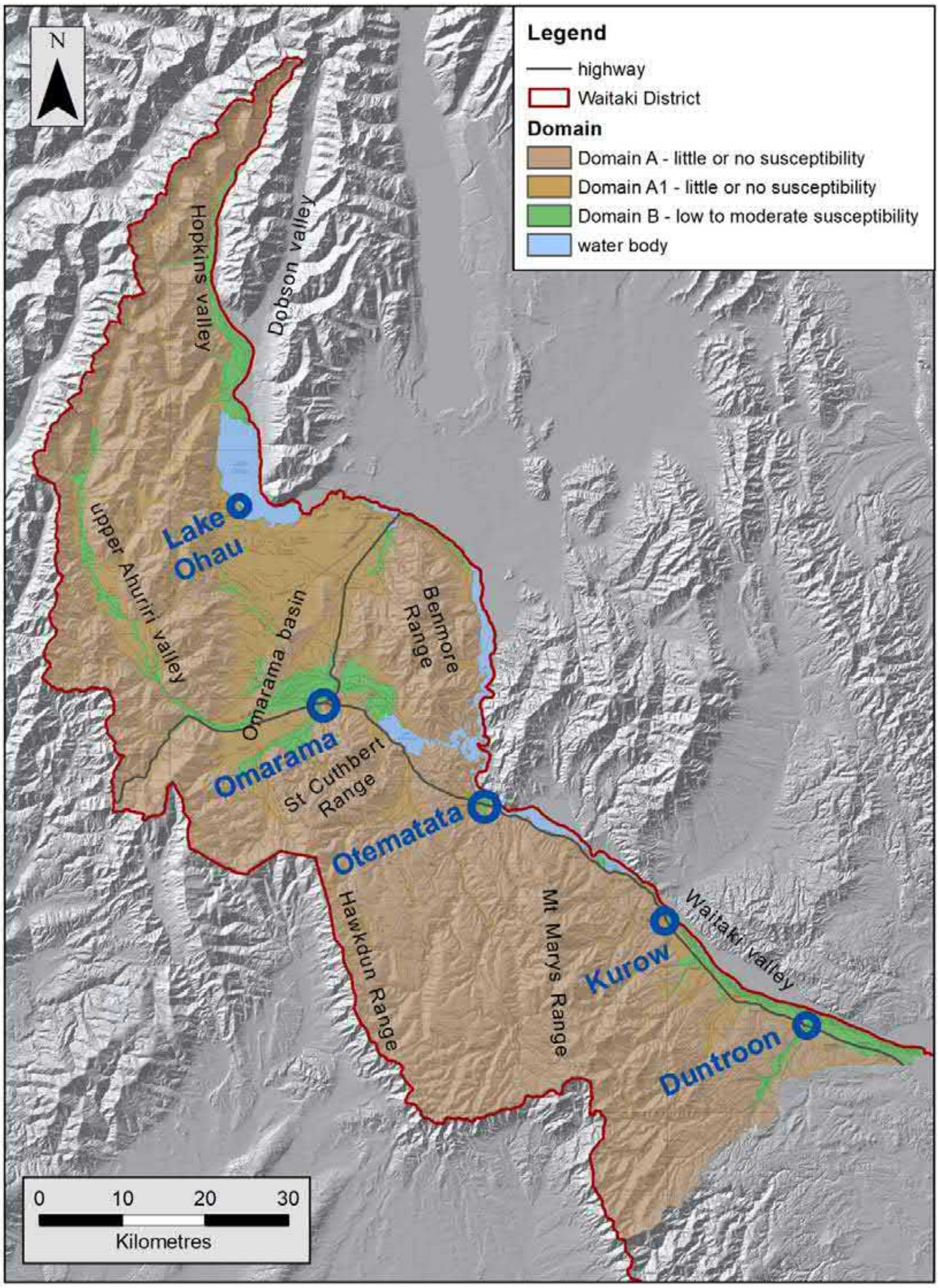


Figure 3.1 Overview map of liquefaction-susceptibility domains for the northern Waitaki District. Refer to Section 3.1 for definitions of the domains.

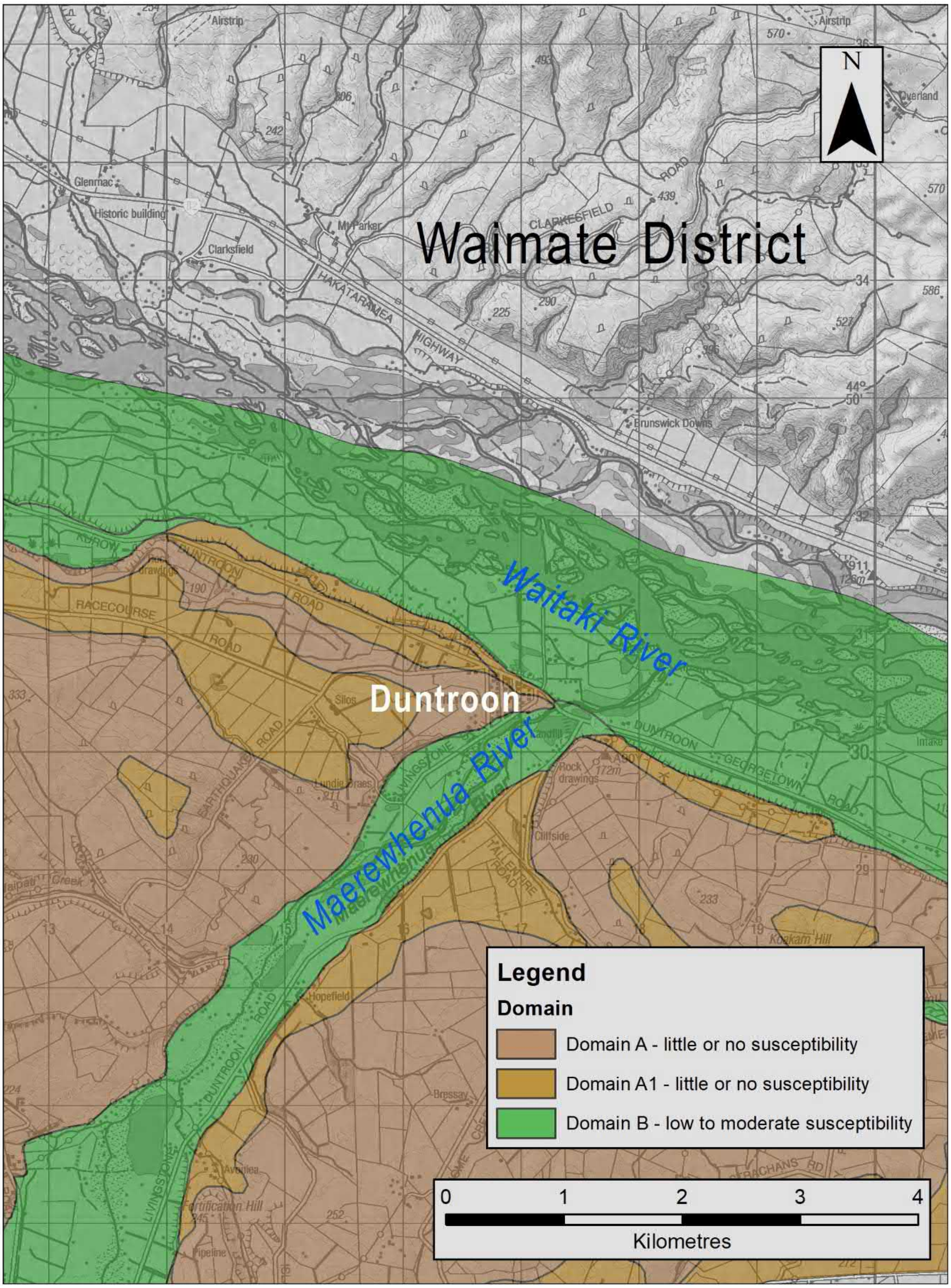


Figure 3.2 Liquefaction-susceptibility domains in the Duntroon area. The uncoloured area is the Waimate District.

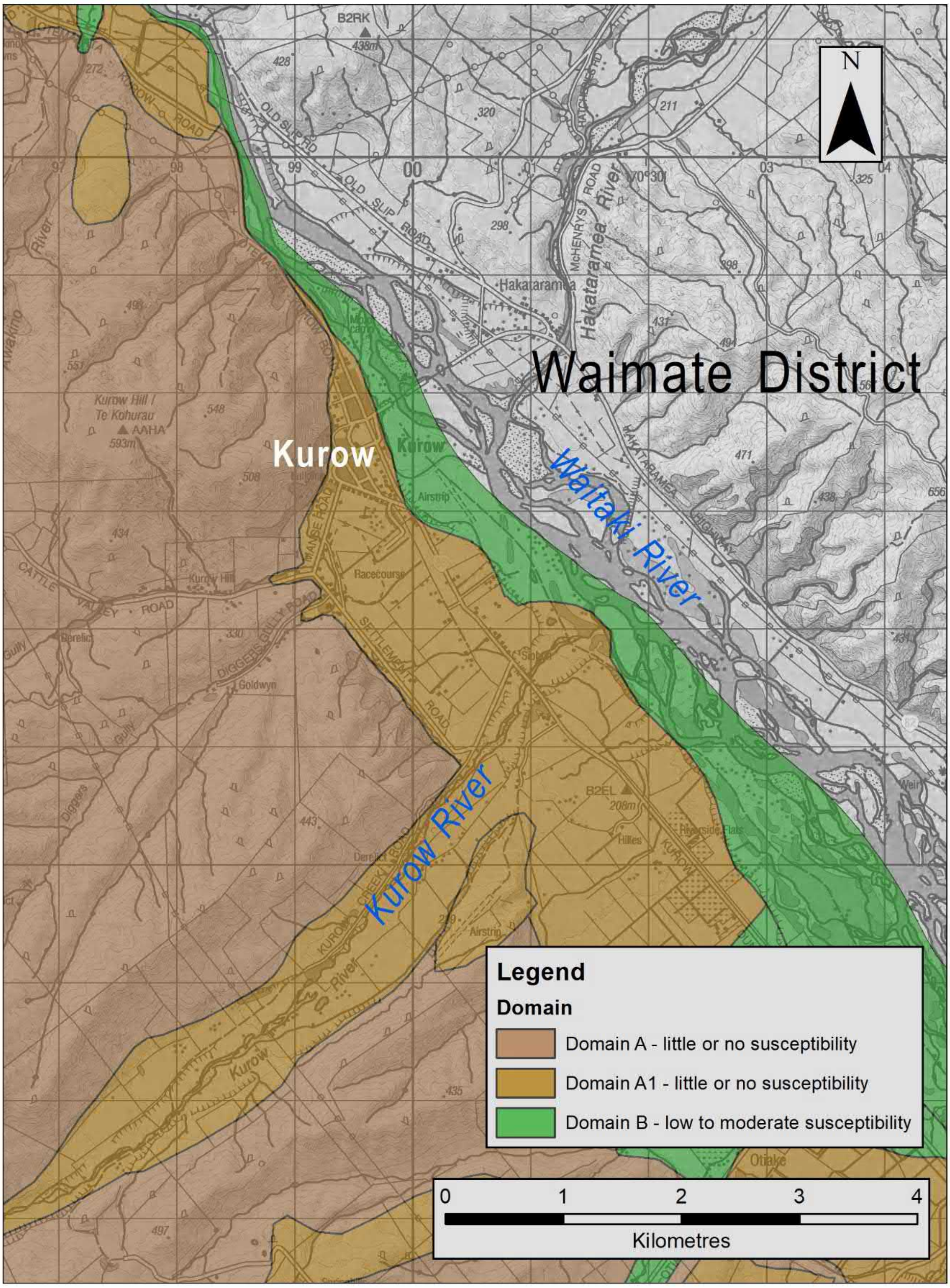


Figure 3.3 Liquefaction-susceptibility domains in the Kurow area. The uncoloured area is the Waimate District.

3.4.3 Otematata

Otematata sits on terraced alluvial fans that merge eastward onto low terraces of the Waitaki River (Figure 3.4). Since formation of Lake Aviemore in 1967–68, sediment from the Otematata River has been building a fan-delta out into the lake. Most of Otematata lies on fan terraces assessed as having a groundwater table deeper than 5 m and are mapped as Domain A1. Areas beside the Otematata River channel and low terraces beside the lake are mapped as

Domain B. The Waitaki and Otematata are gravel-bed rivers, and any liquefaction susceptibility that may exist in Domain B at this location would relate to buried pockets of sand or silt. Were any liquefaction to occur, it would likely be relatively minor, of similar character to that illustrated in Figure 2.1A. In that part of Domain B near the Otematata River mouth, another possible liquefaction-related hazard would be lateral spreading of the lower reaches of the fan-delta into the drowned Waitaki River channel now occupied by Lake Aviemore.

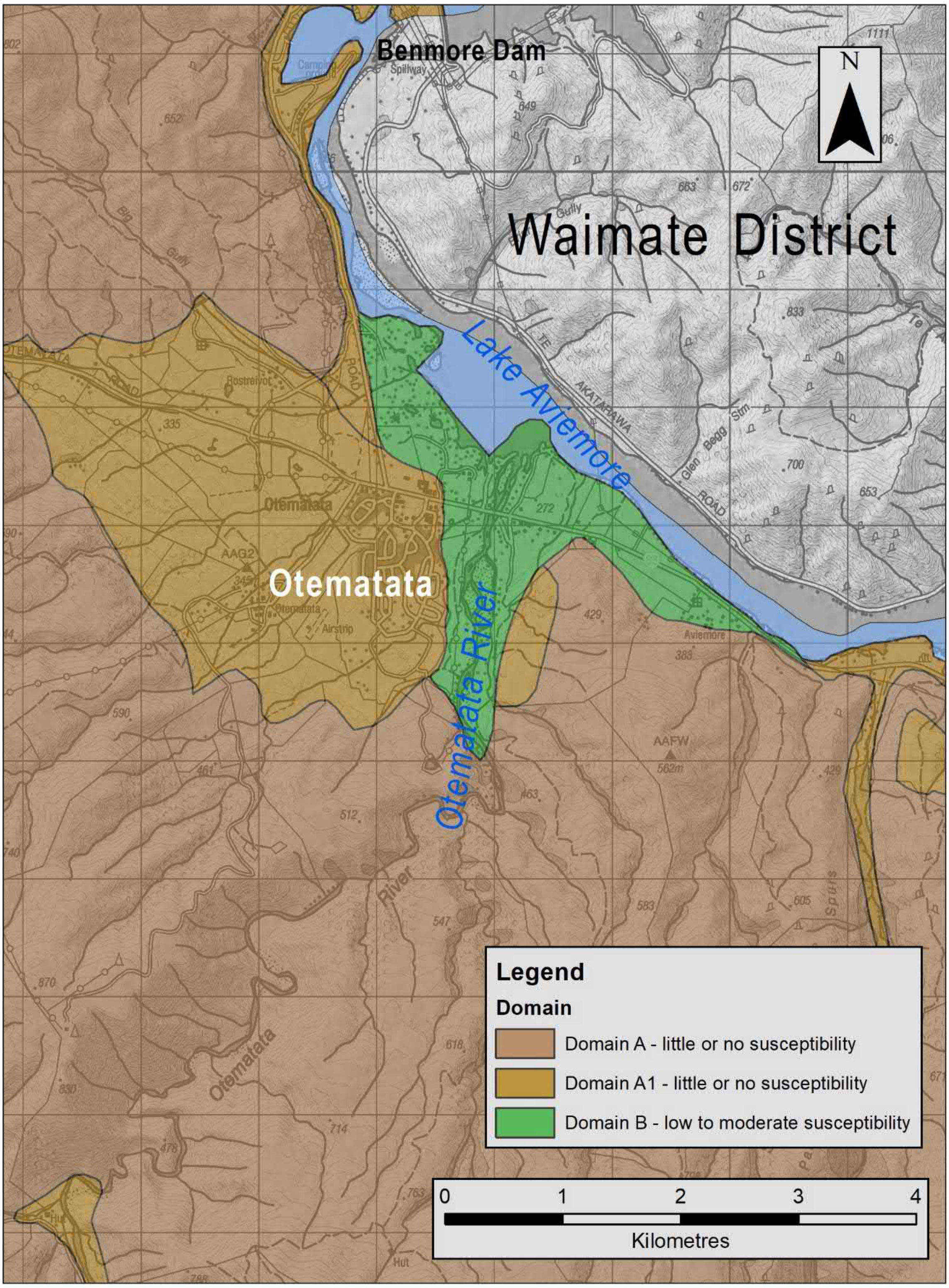


Figure 3.4 Liquefaction-susceptibility domains in the Otematata area. The uncoloured area is the Waimate District.

3.4.4 Omarama

Omarama sits on a broad terrace of the Ahuriri River, with the inset valley-floor floodplain of Omarama Stream and the Ahuriri River to the north (Figure 3.5). Groundwater bores on the broad terrace indicate a groundwater table about 5 m deep under the town. Overall, because the sediment forming this terrace is coarse-gravelly glacial outwash deposits, with lesser potential for pockets of sand or silt, a classification of Domain A1 is considered appropriate.

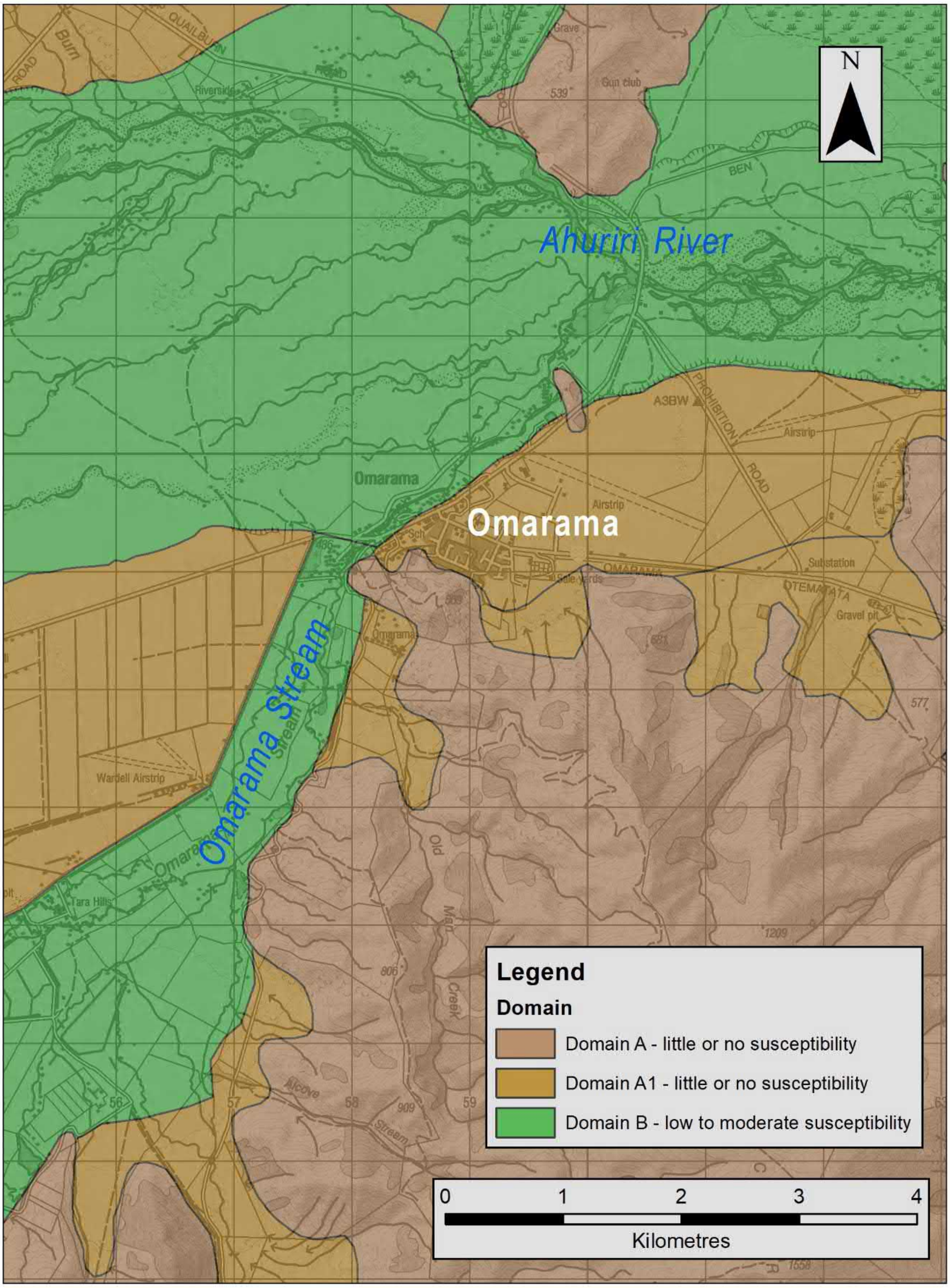


Figure 3.5 Liquefaction-susceptibility domains in the Omarama area.

The lower terrace, on which Omarama Stream flows, is assessed as having a shallow groundwater table and is mapped as Domain B. Existing development in this part of Omarama includes the sewage treatment ponds, a few houses and part of the Omarama Holiday Park. Omarama Stream has a relatively low gradient, and the part of the lower terrace on which it flows is considered to have an enhanced likelihood of being underlain by pockets of sandy or silty sediments. Any liquefaction susceptibility that may exist in Domain B at this location would relate to buried pockets of sand or silt. Were any liquefaction to occur, it would likely be relatively minor, of similar character to that illustrated in Figure 2.1A.

3.4.5 Lake Ohau village

Lake Ohau Alpine Village is a small settlement on the south-western side of Lake Ohau. The houses of the village sit in an elevated position on glacial moraine and outwash terraces, classified here as Domain A1 (Figure 3.6). At lower elevations around the perimeters of Lake Ohau, and the small enclosed water body of Lake Middleton, lake beach and lake margin deposits and a low-gradient swampy stream channel draining to Lake Middleton are placed in Domain B. Any liquefaction susceptibility that may exist in Domain B at this location would relate to buried pockets of sand or silt in the beach deposits and/or to lateral spreading towards the shoreline. Were any liquefaction to occur, it would likely be relatively minor, of similar character to that illustrated in Figure 2.1A.

3.4.6 Upper Ahuriri and upper Lake Ohau valleys

Although the only notable infrastructure in these two formerly glaciated valleys is related to high-country pastoral farming, brief mention is made because these valleys probably have greater potential for liquefaction-susceptible materials being present than elsewhere in the northern Waitaki District.

In the upper Ahuriri valley, between about 25 and 40 km northwest of Omarama (Figure 3.1), the floor of the valley is broad and generally swampy and probably marks the location of a post-glacial lake, now infilled with sediment, that formerly occupied the valley. If this interpretation is correct, large volumes of saturated sand and silt likely underlie the valley, offering considerable likelihood of liquefaction-susceptible sediments being present. Classified as Domain B, if any liquefaction were to occur, it would likely be minor to moderate, of a character intermediate between that illustrated in Figure 2.1A and Figure 2.1B.

At the north-western end of Lake Ohau, the valley floors downstream from the junction of the Hopkins and Dobson valleys forms a delta that is building out into the lake (Figure 3.1). There are likely to be large volumes of saturated sand and silt in the subsurface, presenting a considerable likelihood of liquefaction-susceptible sediments being present. The valley floor and delta are classified as Domain B. If any liquefaction were to occur, it would likely be minor to moderate, of a character intermediate between that illustrated in Figure 2.1A and Figure 2.1B. In addition, the delta margin close to the lake may have potential for lakeward lateral spread in the event of a strong earthquake.

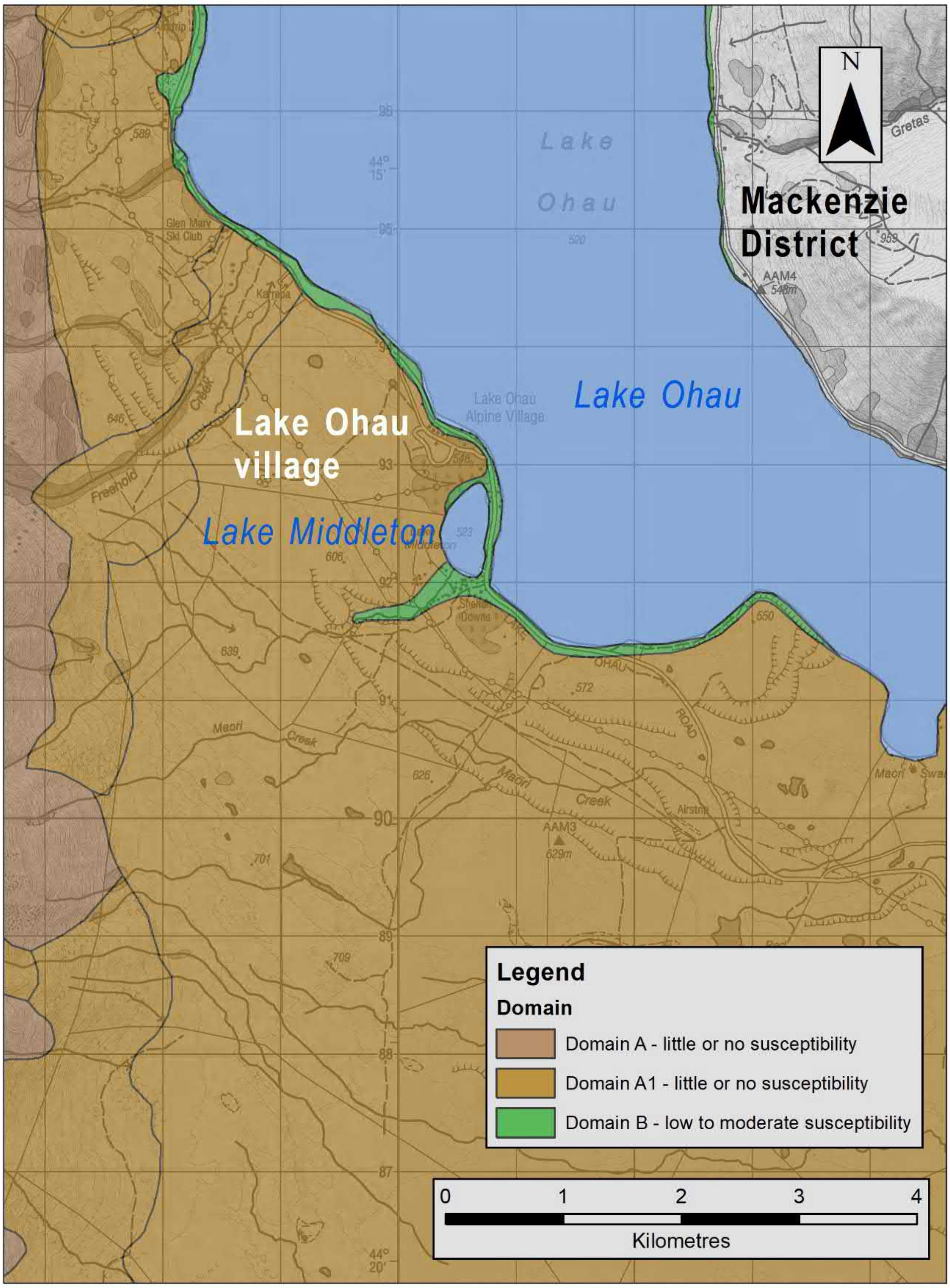


Figure 3.6 Liquefaction-susceptibility domains in the Lake Ohau village area. The uncoloured area is the Mackenzie District.

4.0 DISCUSSION

4.1 Comparison with Previous Work

In the liquefaction assessment undertaken by Yetton and McCahon (2008), a three-fold classification of 'liquefaction potential' was used. This comprised:

- Zone 1: Low potential: Areas of Holocene-age alluvium.
- Zone 2: Very low potential: Areas of alluvium older than Holocene.
- Zone 3: Nil to extremely low potential: Rock or hill soils.

That classification is closely analogous to the approach used in this report. Zones 1 to 3 are defined by similar criteria to those of Domains B, A1 and A, respectively. The difference is that the Yetton and McCahon (2008) map (Figure 7.1 of their report) is based on broad-scale geological map information, whereas the mapping described in this report also includes geomorphological and groundwater information. The new mapping is more accurate because high-quality photographic basemaps, made available since the Yetton and McCahon (2008) mapping, have been utilised. The liquefaction-susceptibility map described in this report has improved, with more accurately located boundaries, the 2008 map but not substantively changed the interpreted overall extent of liquefaction-susceptibility ground.

4.2 Overall Assessment

This project involved an evaluation of information relevant for assessing liquefaction susceptibility at a district scale. The assessment was office-based and drew upon regional-scale geological, geomorphological and hydrological information and limited subsurface information. In the terminology of the MBIE (2017) liquefaction guidelines, the approach used in this project is a 'Level A' basic desktop assessment.

The liquefaction-susceptibility domains distinguish areas where geological and/or groundwater conditions indicate that the occurrence of damaging liquefaction is unlikely (Domains A and A1) and areas where damaging liquefaction may be a possibility (Domain B). Domain B is assessed as having a low to moderate likelihood of being underlain, in part, by liquefiable materials. In total, 6% of the land area (excluding lakes) of the northern Waitaki District is classified as Domain B, with the remaining 94% mapped as Domain A or A1 – terrain that has little or no liquefaction susceptibility.

The extents of Domains A and A1 are taken largely from highly generalised geological maps, and there may conceivably be localised patches of poorly drained soft sediments, on the floors of stream valleys, for example, that do not appear on those maps. This creates a possibility that Domains A or A1 may include localised small pockets of liquefaction-susceptible sediments. In Domain B, any liquefaction-induced ground damage would probably be in the category of minor to moderate. The northern Waitaki District lacks poorly consolidated young marine or estuarine sediments that are mapped as Domain C along parts of the Otago coast and that are potentially susceptible to moderate to serious liquefaction-induced ground damage (Barrell et al. 2014; Barrell 2019).

The Domain B areas mapped in this report indicate places where liquefaction may possibly be an issue requiring consideration in relation to existing and future development. In most cases, areas classified as Domain B lack hard evidence for the existence or exact locations of potentially liquefiable ground. Rather, geological factors indicate some likelihood that liquefaction-susceptible ground may exist in parts of that domain. More sub-surface geological and geotechnical information would be needed to establish the presence or otherwise of potentially liquefiable materials in areas mapped as Domain B and, if present, their general pattern of distribution. This would enable liquefaction assessments to be advanced to Level C or D status in selected areas, should a need arise.

In areas of Domains A and A1, damaging liquefaction is unlikely to occur and, providing that any building and infrastructure development accords with existing standards (e.g. Resource Management Act and the Building Act), any residual liquefaction risk will be accepted or covered (transferred) through insurance. For liquefaction awareness areas, options range from general guidance to regulatory measures. For example, liquefaction-mitigating structural measures (e.g. NZGS and MBIE 2016) could be used for new residential houses in Domain B as an alternative to undertaking geotechnical investigations to determine foundation requirements. In the case of large-scale residential subdivision developments or the construction of commercial, industrial or high-importance buildings in liquefaction awareness areas, geotechnical investigations would be an expected component of planning, design and consenting, with an outcome of reducing the hazard through engineering or by avoiding it. The territorial authority may wish to consider requiring geotechnical investigations carried out for consenting processes to be uploaded into the New Zealand Geotechnical Database. This would allow the presence or otherwise of liquefiable materials, and their associated hazards, to be refined in the future.

Areas within Domain B that lie close to ‘free faces’, such as the banks of river or stream channels, may potentially be subject to lateral spreading hazards in the event of an occurrence of liquefaction-inducing earthquake shaking. Specific mapping of lateral spreading hazard did not form part of the present project, as that would be more appropriate as part of a more detailed level of liquefaction assessment. Information on lateral spreading assessment is provided in the MBIE (2017) guidelines. Embankments built on potentially liquefiable materials represent a hazard in liquefaction-susceptible areas, especially as many embankments may form part of transport routes (road and rail), other infrastructural elements and flood protection (river flood banks).

The information in this report and companion GIS dataset is, for the most part, based on generalised assessments and broad-scale inferences, rather than detailed investigations. It should not be used in isolation for any purposes that require site-specific information.

5.0 CONCLUSIONS

The susceptibility of land to earthquake-induced liquefaction has been assessed for the northern Waitaki district, in the Canterbury region, in an office-based evaluation of geological and landform information relevant to liquefaction hazards, supplemented where possible with borehole geological information and groundwater data. This approach equates for a 'Level A' liquefaction assessment as described in MBIE (2017) liquefaction guidelines. A GIS-format liquefaction-susceptibility map was compiled and is described in this report. The map shows areas of similar liquefaction susceptibility using a three-fold classification of liquefaction susceptibility:

- Domain A – The ground is predominantly underlain by weak to strong rock substrate. Liquefaction damage is unlikely to occur.
- Domain A1 – The ground is predominantly underlain by firm to poorly consolidated sediments with a deep groundwater table. Liquefaction damage is unlikely to occur.
- Domain B – The ground is predominantly underlain by poorly consolidated river, stream or lake sediments with a shallow groundwater table. There is considered to be a low to moderate likelihood of liquefaction-susceptible materials being present in some parts of the areas classified as Domain B. Liquefaction damage is possible. The severity of any ground damage is likely to be minor to moderate.

The liquefaction susceptibility domains are intended to highlight areas where liquefaction hazard may warrant further scrutiny for future planning and development activities. Domain B is regarded as a 'liquefaction awareness area', but does not represent a hazard zone, as such. A first step towards managing liquefaction risks is to ensure all building and infrastructure development accords with existing standards (e.g. Resource Management Act and the Building Act). For areas of Domains A or A1, any residual liquefaction risk could be managed using existing standards and insurance. For the liquefaction awareness areas (Domain B), options include specifications for levels of geotechnical investigation and foundation design (e.g. NZGS and MBIE 2016). For the case of residential properties covered by NZS 3604 (New Zealand Standard for timber-framed buildings), one alternative to geotechnical investigations would be the automatic use of strengthened foundations as per NZGS and MBIE (2016) specifications.

Areas identified as being potentially susceptible to liquefaction are restricted to low-lying places underlain by Quaternary sediments where the groundwater table is less than about 5 m deep. Approximately 94% of the land area of the northern Waitaki District is classified as either Domain A or A1 – terrain underlain by materials that are regarded as unlikely to liquefy. Domain B occupies 6% of the land area and is potentially subject to liquefaction hazards.

6.0 ACKNOWLEDGEMENTS

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APPENDICES

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APPENDIX 1 EXPLANATION OF TERMS

This appendix defines terms that are identified in the main report text by bold type at their first mention. Terms that are defined elsewhere in this appendix are italicised in bold type.

Epicentre	The epicentre is the location on the ground surface directly above the point underground where an earthquake initiated.
Fan	A fan is an accumulation of sediments that forms a sloping landform, shaped like an open fan or segment of a cone. Fans form where a valley, channel or gully meets an area that is unconfined or less confined. A typical location is where a smaller valley emerges from hill country onto a broad valley floor. Different types of fan may be recognised according to their mode of formation. Fan-shaped accumulations of river or stream (alluvial) sediments are alluvial fans; fans of debris laid down by mass flows of sediment are debris-flow fans; fans built out into a lake or the sea are ***fan-deltas***.
Fan-delta	A delta is a landform of broadly triangular extent, or alternatively lobe-like, formed where a river or stream flows into a body of standing water, such as a sea or lake. Sand and gravel cannot be transported by still water, so progressively accumulates at the shoreline and in the near-offshore to create the delta. Where the delta has been built by a relatively small stream and has a ***fan-***shaped surface, it is a fan-delta. A larger one formed by a river, with a less obvious fan shape, is often just called a delta.
Geomorphology	The scientific field dealing with the origins and characteristics of landform features.
Geohazards	Natural ground-related hazards, some examples being: • landslide or rockfall • ***liquefaction*** or ***lateral spread*** • strong ground motions from earthquake shaking • earthquake fault ground rupture • soft or compressible ground (e.g. peat) • erosion or sedimentation.
Geotechnical investigations	Geotechnical investigation refers to the process of characterising the ground subsurface conditions at a particular locality. The work must be undertaken or overseen by a ***geotechnical professional***. The work will include examination or measurements of the nature and properties of the ground-forming materials by means that include: • examination and documentation of the subsurface materials, exposed in test pits or inspection shafts or obtained from cored or non-cored bore holes; • measurements of material properties by means of probes or instruments (e.g. cone penetration tests [CPT] or standard penetration tests [SPT]); and • measurements of groundwater conditions, such as standing water levels and piezometric pressures. For house development projects, there is a minimum scope of geotechnical assessment work required, as set out in NZS3604:2011 'Timber-framed buildings', http://www.standards.co.nz/default.htm

Geotechnical professional	A suitably qualified or experienced civil engineer, geotechnical engineer or engineering geologist. Work is expected to be done according to the IPENZ (Institution of Professional Engineers of New Zealand) Code of Ethical Conduct.
GIS and polygons	A geographic information system (GIS) is a computerised mapping system designed to capture, store, manipulate, analyse, manage and present all types of geographically specific information. There are three main classes of GIS data: (1) information relating to a specific geographical point on the ground, such as a borehole (*point* data); (2) information associated with a linear feature such as a road (*line* data); and (3) information pertaining to specific areas of ground, such as a liquefaction-susceptibility map (*polygon* data).
Lateral spreading	Lateral spreading refers to the movement of ground-forming materials towards lower ground, especially where there is a well-defined step down ('free face') to the lower ground. Assessment of lateral spreading risk is possible only at site-specific scales because it not only requires information on the ground strength and liquefaction susceptibility, but also on the form and height of the 'free face' (e.g. a river channel edge). One rule of thumb is that lateral spreading can occur at a horizontal distance 20 times the height of the free face, such as a river bank.
Liquefaction	Liquefaction can be defined as 'the act or process of transforming cohesionless soils from a solid state to a liquefied state as a result of increased pore pressure and reduced effective stress'. Many people will have generated their own liquefaction when visiting sandy beaches at low tide – by standing on wet sand and wriggling one's feet, the sand becomes almost liquid and one sinks into it. But if one attempts this on a stony beach, nothing much happens. The effects of ground in the shallow subsurface include cracking of the ground and the ejection of sediment and water, resulting in uneven settlement of the ground.
Liquefaction-susceptibility awareness area (domain)	The map associated with this report ranks the ground according to the likelihood of liquefaction-susceptible materials being present in the subsurface. The map highlights areas where liquefaction may be a possible hazard to look out for rather than implying that a hazard exists.
Quaternary Period	The period of geological time spanning the past 2.6 million years. It is subdivided into the older Pleistocene Epoch (2.6 million years ago to 11,700 years ago) and the Holocene Epoch (from 11,700 years ago through to the present day). The Pleistocene is divided into Early, Middle and Late phases, with the Late Pleistocene spanning from 130,000 years ago through to the start of the Holocene. Together, the Late Pleistocene and Holocene are referred to as the Late Quaternary (130,000 years ago to present).

APPENDIX 2 COMMENTARY ON LIQUEFACTION-SUSCEPTIBILITY MAPPING

A2.1 Mapping and Interpretation Criteria

A variety of basemap information was used for the mapping. The 1:50,000 scale Topo 50 topographic maps provided a starting point, noting that the QMAP 1:250,000-scale geological map, from which the original map polygons were sourced, was originally compiled onto 1:50,000-scale topographic maps. In remote areas of hill or mountain terrain, the polygons are taken from QMAP without modification, unless noted otherwise. In those areas, a nominal scale of 1:50,000 applies, with a boundary line position accuracy of plus or minus 100 m.

However, the district-wide availability of high-resolution orthorectified colour aerial photos allowed for much more detailed scrutiny of land surface and landform features in valley floor and basin areas, which are the locus of human settlement and intensive farming. In general, this has enabled the compilation of this map at a nominal scale of 1:20,000 in valley floor and basin areas, with a boundary line position accuracy of plus or minus 50 m, unless stated otherwise. Where there is conflict between what is shown on topographic maps and what can be seen in the aerial photography, the map polygon boundaries were positioned based on the photographic information. Within towns or villages, much more detailed mapping (e.g. 1:1000-scale) has been possible with the aid of Google Street View, as described in the commentaries below.

Borehole data supplied by ECan has guided the assessment of groundwater depths. In areas with sparse or no data, geomorphic criteria have been used – notably, the height of ground above nearby waterways – to estimate groundwater depth. In general, areas underlain by river or stream deposits with groundwater shallower than 5 m are placed in Domain B, while Domain A1 is applied to areas of those deposits where the groundwater is assessed as being deeper than 5 m.

A2.2 Note on Valley Gradients

In an analogous report for the Otago region (Barrell 2019), a gradient criterion of 20 m fall per 2 km was used to differentiate lesser gradient river or stream valleys from steeper gradient ones. Lesser gradient valleys were placed in Domain B because there is more likelihood of there being sand-filled buried channels. In steeper valleys, only gravel-dominated deposition is likely, with most sand carried down-valley as suspended sediment load. The same distinction for the mapping is described here, with the proviso that the steeper gradient valleys are classified as sub-domain A1 to acknowledge the presence of Quaternary-age sediments.

An exception is applied to the gradient criterion for the case of relatively small stream catchments draining terraced or rolling-hill terrain. In such systems, the dominant sediment may be sand and silt rather than gravel. In such systems, domains are mapped primarily based on estimated depths to groundwater.

A2.3 Waitaki Valley

A2.3.1 Note on Groundwater Level Assessment

In the Waitaki River valley, river or stream sediments generally occur as relatively thin deposits sitting on the underlying bedrock. In some cases, groundwater bores penetrate the underlying bedrock, and groundwater extraction and groundwater levels relate to hydrogeological conditions in the bedrock rather than unconfined water tables in the near-surface river or stream sediments. Consideration has been given to this issue when interpreting groundwater water data from bores; it is the shallow groundwater table within near-surface sediments that is relevant to liquefaction susceptibility.

A2.4 Lower Waitaki valley

From Georgetown upstream through Black Point to Kokoamo, the Waitaki riverbed, valley-floor plain and marginal alluvial fans grading onto the plain are all included in Domain B. Boreholes with water-level information uniformly show groundwater shallower than 5 m. The Domain B area is extended a short distance up the Kokoamo Creek valley floor, the only notable right-bank tributary of this sector of the valley.

In the Duntroon to Otekaieke area, the Waitaki riverbed, valley floor and low terraces up to a few metres above river level are included in Domain B, as are the valley-floor plains and low terraces of the Maerewhenua River, whose valley gradients in less than 20 m per 2 km. The valley floor and terraces of the Otekaieke River are placed in Domain A1 because the gradient is steeper than 20 m per 2 km.

The Duntroon to Otekaieke sector of the Waitaki valley is notable for having intermediate-level terraces in many places at the valley margins. Those terraces standing 5–10 m or more above riverbed level, where data allow, typically have groundwater deeper than 5 m and are included in Domain A, identified as Domain A1 to signify that they are directly underlain by poorly consolidated river or stream sediments, with bedrock at slightly deeper levels. Another feature of this area is high-level plateau surfaces underlain by river or stream sediments; these are also placed in Domain A1. In most cases, the mapped extent of Domain A1 is taken from the QMAP 1:250,000-scale geological map database, with little or no modification.

In Duntroon village, the boundaries of Domains A, A1 and B are drawn at a scale of 1:1000, with the aid of Google Street View. Boundary lines through the built-up area are considered accurate to +/- 10 m.

From the Otekaieke River upstream to Kurow, the mapping approach is the same, but a difference here is that large alluvial fans have been built out from the western margin of the valley towards the Waitaki River floodplain. The largest fans are from the Otekaieke and Otiake rivers and from Kurow River. These fans are composed of freely-draining river sediments, and the normal flows of those waterways tend to go to ground a short distance out from the valley margins. This is why dry riverbed channels characterise the lower reaches of the fans, except during wet seasons or prolonged rainstorms. As a result, the groundwater table is deeper than 5 m on many parts of the fans, resulting in those areas being included in Domain A1. Areas on low terraces close to river or stream level have shallower groundwater tables and are placed in Domain B. The broad floors of the Otiake River and Kurow Creek valleys are sufficiently steep to be placed in Domain A1. The intermediate-size Malcolms Creek also has a steep gradient but, because it drains terrace and low hill terrain and likely has a dominance of fine-grained sediments, its fan is classified as Domain B.

A2.5 Middle Waitaki valley

From Kurow up-valley to Otematata, the valley comprises a series of interconnected intermontane basins, now occupied by artificial lakes. An array of terraced alluvial fans merges eastward into the valley floor from the mountainous terrain of St Marys Range. Localised remnants of low-lying Waitaki River terraces and lower reaches of alluvial fan channels of the larger tributaries are placed in Domain B. Intermediate to high-level river terraces and alluvial fan terraces are classified as Domain A1. The alluvial fans of the smaller tributaries have steep gradients, and their sediment deposits are dominated by coarse to boulder gravel. Their depositional environments make it very unlikely that silt or sand-filled channels will be present, and they are all included in Domain A1, even close to the artificial lakeshores, where groundwater is likely to be shallow. Domain B is applied only to some of the relatively lower-gradient larger tributary streams.

The Otematata basin floor has three main elements: low-level terraces of the Waitaki River, the terraced fan of the Otematata River and a complex of overlapping and terraced alluvial fans in the western sector of the basin. In that latter area, there was some modification of the landscape for extraction of construction materials for Benmore Dam, but locations and extents of the modification are poorly documented. The inset sector of the Otematata fan and lowest Waitaki terraces are placed in Domain B. All remaining areas of fan are assessed on geomorphic grounds as typically having groundwater deeper than about 5 m and are classified as Domain A1.

The next basin inland is occupied by the Ahuriri Arm of Lake Benmore, which drowned the former Ahuriri river valley. The main tributary of this valley sector is the Otamatapaio River, which drains the north-eastern part of the Hawkdun Range. Near Lake Benmore, the river flows on a broad gravel plain with a relatively steep gradient (20 m fall per 1.2 km). On that basis, the Otamatapaio valley floor and terraces are placed in Domain A1, which acknowledges that they are underlain by poorly consolidated sediment, but it is unlikely that damaging liquefaction would be possible. Furthermore, prior to the filling of Lake Benmore, the meeting of the relatively steep plain of the Otamatapaio River and the low-gradient Ahuriri River plain was near the original valley axis, about 2 km east of the current artificial lake shore. Therefore, any lessening of grade of the Otamatapaio plain approaching the Ahuriri River plain, which may have been of relevance in relation to liquefaction susceptibility, is drowned well below lake level.

A2.6 Lower Ahuriri valley and Omarama basin

The main river terrace on which most of Omarama township lies is assessed as being borderline between a classification of Domain B or A1. Most bores show groundwater level between 5 and 6 m, with generally compact gravel, typically described in drillers logs as ‘claybound’. As much of the area is likely to be well-drained, on account of proximity to the inset Ahuriri River floodplain/valley-floor terrace, assignment of the Omarama township terrace to Domain A1 is considered on balance the most appropriate.

The floodplain and lowest terraces of the Ahuriri River are included in Domain B. These include all the plains downstream of the Chain Hills gorge and the Ahuriri delta into Lake Benmore, out the margins of adjacent, relatively steep alluvial fans.

The low-gradient plain of Omarama Stream, running along the south-eastern side of the Omarama basin, is locally swampy and poorly drained. There are only two borehole records in that area and they indicate a groundwater table depth of the order of 2 m. The north-western margin of Domain B is placed about 100 m onto the fringing main surface of the Ahuriri Plain, on the presumption that the relatively deep groundwater under that plain (see below) shallows approaching the Omarama Stream plain. That approximates the position of Broken Hut Road, so the boundary is placed along the road carriageway for the ~9 km distance between SH8 and the Berwen and Twin Peaks homesteads. Southwest of there, the boundary is placed around the perimeter of low-lying or swampy ground in the intersection zone between the Omarama Stream and Manuka Stream alluvial fans. Upstream of there, the fans have gradients steeper than 20 m fall per 2 km and are classified as Domain A1.

The remainder of the plains of the Ahuriri River forming the basin floor upstream from Omarama are glacial outwash, and the few bores in the area indicate deep groundwater. The river floodplain and lowest terraces are placed in Domain B, and the remainder are mapped as Domain A1.

A2.7 Upper Ahuriri valley

Separated from the Omarama basin by a rocky gorge, the upper Ahuriri valley is relatively broad on account of having been shaped by glacier action. In the downstream part of the valley, the river is now well-inset below moraines and outwash plains. Upstream of terminal moraines adjacent to Ben Avon homestead, the valley floor becomes wider and swampy and is likely the infilled trough of a former post-glacial lake. Alluvial fans have encroached across the valley floor from tributary catchments.

The valley floor and lowest terraces (within a few metres of river level) are placed in Domain B, as are the lower reaches of tributary valley floors where their gradients are less than 20 m fall per 2 km.

The remainder of the Quaternary-age deposits are placed in Domain A1. For clarity in this relatively complicated landscape environment, Domain A1 polygons are differentiated to highlight their nature, such as whether they are (i) glacial moraine or outwash deposits, (ii) alluvial fan deposits, (iii) stream plain or terraces with steep gradients or (iv) glacial moraine deposits in high mountain terrain. This information is provided in the ‘Justification’ field of the dataset. Except in a few areas adjacent to the Ahuriri valley floor, the polygon extents are unmodified from QMAP.

A2.8 Northern part of the Omarama basin and the Ohau valley

The commentary on the mapping proceeds from south to north.

The Ahuriri tributaries of Hen Burn and Quail Burn have their valley floors and lowest terraces mapped as Domain B, where they are of low gradient. An exception is the broad fan of Quail Burn immediately north of the Ahuriri River and east of the Ostler Fault, because the stream loses its surface flow after exiting the Cloud Hill bedrock gorge, indicating that groundwater is deep.

On the western foot of the Benmore Range, strips of low-lying and poorly drained ground within 3.5 km of the Ahuriri River, and along Wairepo Creek within 6 km of the Wairepo Arm of Lake Ruataniwha, are placed in Domain B. Otherwise, the extensive outwash plains, terraces, moraines and alluvial fans south of Lake Ohau are mapped as Domain A1, with differentiation provided as described above for the upper Ahuriri valley.

The inset floor of the Ohau River downstream of Ruataniwha Dam, and localised areas of low terrace adjacent to artificial Lake Ruataniwha, are included in Domain B on account of likely shallow groundwater. Upstream of Lake Ruataniwha, the Ohau River valley floor and lowest terrace deposits are extremely bouldery, and Domain A1 is assessed as being the appropriate classification.

Along the shores of the main, north–south-oriented sector of Lake Ohau, raised beach deposits flank the shore, up to several metres above the modern lake storm beaches, rising to as much as 8 m or so towards the northwest end of the lake, probably reflecting greater rates of uplift towards the axis of the Southern Alps. For simplicity, all of the beach deposits, and some raised fan-deltas at the lake margin, are placed in Domain B. Lake Ohau has a natural water-level range of about 2.5 m, and this will likely be mirrored in groundwater level within fringing beach deposits. An added consideration at Ohau is that lake-margin or stream delta settings have enhanced likelihood of lateral spreading into the lake basin; hence, a reasonably conservative approach has been applied. The lower reaches of a minor tributary stream fan entering Lake Middleton has been included in Domain B.

The mapping of the Hopkins catchment (that part lying in Waitaki District) is analogous to that of the upper Ahuriri valley, with the river valley floor and lowest margins of fringing alluvial fans placed in Domain B, including low-gradient sectors of the valley floors of major tributaries. All other areas of Quaternary-age sediments are placed in Domain A1, except close to valley floors, where the Domain B/A1 boundaries are positioned at a nominal scale of 1:10,000 based on high-resolution aerial photography; the A1 polygons elsewhere are from QMAP, without modification.

APPENDIX 3 DESCRIPTION OF THE GIS DATASET

The GIS dataset referred to in this report comprises an ArcGIS file geodatabase, containing one Feature Class:

- ECan_WaitakiLiquefactionSusceptibility_2020

This feature class comprises an interpretation of the extent of ground that is potentially susceptible to earthquake-induced liquefaction in that part of the Waitaki District lying within the Canterbury region. This map dataset is based on an office-based (i.e. 'desktop') assessment of available information on geology, geomorphology (i.e. landforms), groundwater conditions and other data, where relevant. This feature class contains areas (polygons) representing the interpreted extent of potentially liquefaction-susceptible ground.

The feature class contains five attribute fields that provide information on each mapped polygon. The DOMAIN field classifies the polygon into one of the three liquefaction-susceptibility domains (A, A1 and B) or a fourth category of water body, as described in the report text. The DESCRIPTION field provides a generalised interpretation of the geological character of the ground beneath the polygon (except where the polygon is a water body). The JUSTIFICATION field provides a brief statement on the landform and/or geographic character of the polygon. The CREATOR field identifies, by initials, or author of a source publication, the person or people who made the geological and/or landform interpretation and drew the polygon. The SOURCE field lists the information sources used to map and interpret the polygon.

The positioning of boundaries between domain polygons is based largely on landform features. Where taken directly from the 1:250,000-scale QMAP dataset, a nominal mapping scale and boundary line accuracy of ± 100 m applies. In the main areas of human settlement and intensive farming, close to valley or basin floors, the QMAP polygons have been refined or revised using the 1:50,000-scale LINZ Topo 50 map series and high-resolution colour aerial photos, accessed digitally through the ArcGIS software. The general mapping scale in these areas is 1:20,000, and the boundary line between each domain polygon should be regarded as having ± 50 m accuracy, thus representing a 100-m-wide zone rather than a line. In towns and villages, where Google Earth Street View was available at the time of mapping, Google Earth ground photography was accessed to help in positioning domain boundaries. In those areas, the assigned mapping scale is 1:1000, and boundaries are considered accurate at the scale of property parcels and buildings (e.g. plus or minus 10 m). The commentary in Appendix 2 of this report indicates where these more detailed scales apply.

The geographic coordinate system for the data is New Zealand Geodetic Datum 2000 NZ Transverse Mercator.

The dataset is based largely on broad-scale inferences and should not be used in isolation for any purposes requiring site-specific information. The main purpose of the dataset is to delineate areas where liquefaction hazard may warrant further scrutiny for future planning and development activities.

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