AQUA INTEL
AOTEAROA
Insights and actions for sustainable water use

Otago water storage: options and opportunities assessment

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Aqua Intel Aotearoa Report June 2021

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CONTENTS

FIGURES

TABLES

APPENDICES

APPENDIX TABLES

APPENDIX FIGURES

EXECUTIVE SUMMARY

Investment in water storage can provide a significant means of increasing prosperity for many regions. The Government has set up a science platform – Aqua Intel Aotearoa – to explore regional water storage needs and opportunities and consider the potential for water storage to support a lift in sustainable regional production.

PDU-GNS platform: Regional Water Needs Assessments

Aqua Intel Aotearoa will identify how water availability constrains sustainable land development, explore means for overcoming these constraints and identify initial scientific investigations that could progress water storage for the regions. The Government is particularly interested in investigating opportunities to support Māori land being brought into production. Aqua Intel Aotearoa is working with four regions within this programme – Northland / Te Tai Tokerau, Gisborne/Tairāwhiti, Otago and Southland.

Otago's Water and Land

Otago has a large variety of surface water bodies, including several lakes, two large rivers – Clutha River / Mata-Au and the Taieri River – and several large wetland systems. The Otago region has only a few large regional aquifers, such as the Lower Waitaki Plains Aquifer, and most of the aquifers are hosted in disconnected basins.

Otago has the most diverse climate and the most extreme temperatures of New Zealand. Despite the large water volumes present in the region, parts of Otago are among the driest areas in the country. The Southern Alps act as a barrier between New Zealand's wettest areas and New Zealand's driest lands (i.e. the West Coast and Central Otago, respectively). Rainfall decreases from the western ranges to the east and the coast, with Central Otago receiving very low rainfall. Otago experiences extreme weather events, with heavy rainfall and flooding. Snowfall and frost events are relatively frequent.

Primary production occupies most of Otago's land area, with pasture and exotic forest covering 47% and 4% of the region, respectively. Agriculture earns 12.5% of Otago's regional GDP. Irrigation is the region's dominant water use (excluding hydropower use). Otago has the second-largest area of irrigated land in New Zealand after Canterbury. This area increased by 50% over the past 15 years. The availability of water is a growing challenge. Allocated groundwater has reached or exceeded the maximum allocation limits in a number of aquifers.

Otago Regional Council (ORC) is undertaking a review of its Water Regional Plan and aims to notify a new Land and Water Regional Plan (LWRP) by 31 December 2023. This plan will reflect the latest regulatory requirements, including the National Policy Statement for Freshwater Management 2020 and Te Mana o te Wai concepts. Te Mana o te Wai is the integrated and holistic wellbeing of freshwater bodies, which supports the health and wellbeing of people and the environment. In Otago, ORC works with Ngāi Tahu to deliver Te Mana o te Wai.

A unique feature of the Otago regulatory framework is the use of 'Deemed Permits' / miners' rights. These were established from 1858 to give gold miners access to water for sluicing and were later re-purposed for farm irrigation. With the introduction of the RMA, 'Deemed Permits' will expire on 1 October 2021. ORC is currently working through the replacement of these permits in the lead up to their expiry (Proposed Plan Change 7 being part of this process).

Investing in Water Storage to Sustain Otago's Land Productivity and Water Quality

For over a century, Otago has made significant investments in water-related infrastructure to support its productive sectors – initially mining, later farming and forestry and most recently dairy. Over time, these activities have placed pressure on the ecological health of Otago's catchments.

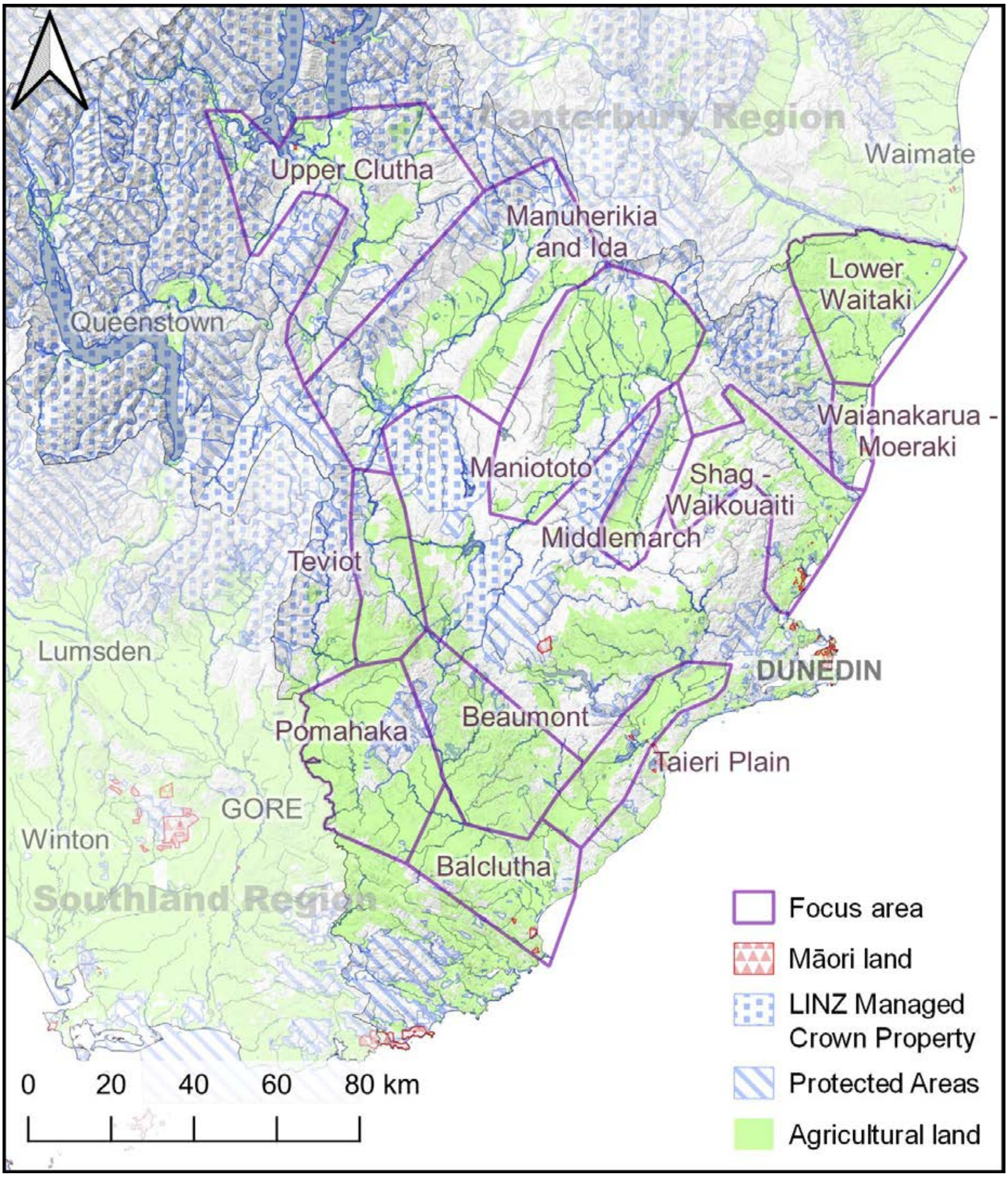
The region is considering a Land and Water Regional Plan that will address the impact of water use through changes to minimum flow requirements and allocation. Ngāi Tahu ki Murihiku, in regard to the Clutha River / Mata-Au catchment, and Otago iwi see the achievement of Te Mana o te Wai as the priority for water use, i.e. placing the needs of the water bodies first (Te Ao Marama 2021). They also see priorities for phasing out over-allocation and the maintenance of existing economic activities, rather than land-use intensification.

Water storage options could bring potential benefits in shifting some of the current activities to higher-value land uses (e.g. crops that requires less nutrients). In some locations, this will only be possible if water storage is provided, as most crops will need reliable water supply through the growing season. Currently, there is limited information available on alternative high-value land uses for these catchments that could support improved environmental outcomes.

A priority for the region in accessing additional water should be to maintain or improve existing water quality. The development of economic activities based on dryland or that are suitable to the existing climate conditions and associated water yields could also be investigated; however, this is out of scope of the present study.

Water Storage Focus Areas and Water Storage Approaches

Twelve focus areas were identified in the region (see map below). Potential opportunities to bring productive land into higher-value sustainable uses were considered for seven of them (Upper Clutha, Manuherekia–Ida, Maniototo, Middlemarch, Shag–Waikouaiti, Waianakarua–Moeraki and Taieri Plains).



Canterbury Region
Waimate
Upper Clutha
Manuherikia and Ida
Lower Waitaki
Queenstown
Waianakarua - Moeraki
Maniototo
Shag - Waikouaiti
Middlemarch
Teviot
Lumsden
DUNEDIN
Pomahaka
Beaumont
Taieri Plain
GORE
Winton
Balclutha
Southland Region
Focus area
Māori land
LINZ Managed Crown Property
Protected Areas
Agricultural land
0 20 40 60 80 km

Possible technical water storage options (see table below) are based on surface water and groundwater resources, e.g. hydro-storage, enhanced aquifer storage, small dams. These options were identified with a GIS approach that combines a series of maps (such as land use, soil properties, climate, geology and water allocation); see Appendix 2 and White et al. (2020).

<table>
<tr><th rowspan="2">Focus Area</th><th colspan="2">Possible Technical Water Storage Options*</th></tr>
<tr><th>Option 1</th><th>Option 2</th></tr>
<tr><td>Upper Clutha</td><td>Hydro-storage
• Gravity feeds from Lake Hawea and Roaring Meg
• Pumped storage from Lake Dunstan
• Small dam on Luggate Creek</td><td>Enhanced groundwater storage
• e.g. managed aquifer recharge (MAR)</td></tr>
<tr><td>Manuherekia–Ida</td><td>Hydro-storage
• Gravity feed from Lake Dunstan to the lower area of Manuherekia Valley
• Pumped scheme from Lake Roxburgh and Lake Onslow in parallel with the proposed Lake Onslow pumped storage scheme</td><td>Enhanced groundwater storage
• e.g. land subsoil recharge (LSR)</td></tr>
<tr><td>Maniototo</td><td rowspan="2">Hydro-storage
• Pumped-storage scheme using Lake Onslow and Loganburn Reservoir</td><td rowspan="2">Enhanced groundwater storage
• e.g. land subsoil recharge (LSR)</td></tr>
<tr><td>Middlemarch</td></tr>
<tr><td>Shag–Waikouaiti</td><td rowspan="2">Connection to NOIC Scheme
• Extension of the NOIC Scheme to provide water to Moeraki area / lower reaches of the Shag River</td><td rowspan="2">Hydro-storage
• Transport water from the proposed Lake Roxburgh / Lake Onslow pumped storage scheme, via the Taieri River, to the upper reaches of the Shag River / Moeraki area</td></tr>
<tr><td>Waianakarua–Moeraki</td></tr>
<tr><td>Taieri Plains</td><td>Groundwater</td><td>Small dams</td></tr>
</table>

NOIC: North Otago Irrigation Company.

* ‘Technical options’ will need to satisfy regulatory and cultural considerations to be further progressed.

Investigations into Water Availability

Any further investigations into water storage options that are progressed by Aqua Intel Aotearoa will relate to options that are consistent with scientific, regulatory and cultural priorities. Based on the work undertaken, investigations that could be useful to the Otago region and ORC as they develop their new regulations (e.g. LWRP) fall into the following categories:

- better characterisation of groundwater and surface water resources in the focus areas;
- feasibility studies related to the use of hydro-storage, guided by cultural considerations; and
- land-use / water demand studies to explore higher-value land uses and associated water demand. This type of investigation is outside the scope of this programme but would be beneficial to explore through other funding sources.

Discussions with Otago Regional Council and iwi (i.e. Aukaha and Te Ao Marama) indicate that options involving water transfer (e.g. new hydro-storage, managed aquifer recharge and in-stream irrigation water storage dams) are the least appealing. Ngāi Tahu ki Murihiku's preference (Te Ao Marama 2021) is for natural water storage options and for investigations that can improve the knowledge of the characteristics of water bodies to potentially 'optimise' natural storage.

Ngāi Tahu ki Murihiku would favour exploring the potential for harvesting of winter flows and off-stream structures. New water transfers between catchments are not favoured, and mixing of waters is to be generally avoided, particularly where alternatives exist.

The next step for our work will be to determine whether Aqua Intel Aotearoa can support the council in its obligations. In the short term, investigations could include:

1. Assessment of the relevance of using Glass Earth data for groundwater resource characterisation, and, if the results of this initial assessment are positive, further processing and analysis of this data could serve this purpose. This work could be implemented in the Manuherekia–Ida focus area.
2. Local complementary investigations of groundwater resources (e.g. site-specific/finer-scale geophysical investigations). This could, for example, be implemented in the Cardrona/Wanaka area.

Beyond this, Aqua Intel Aotearoa will stay abreast of progress in Otago to see whether there are further investigations that could be undertaken to support the region as it implements its LWRP.

1.0 INTRODUCTION

This report was prepared through Aqua Intel Aotearoa – the collaboration between the Provincial Development Unit (PDU) and GNS Science for undertaking investigations into regional water storage needs and opportunities. The Government has invested $10 million in Aqua Intel Aotearoa to undertake regional needs assessments and investigations of water availability in four regions – Northland, Otago, Southland and Gisborne.

Water storage is one of the most significant investments that can be made to lift regional productivity. For most of the regions, the primary sector is a major element of the local economy. Land-based production is a comparative advantage of the regions relative to urban areas and has shown itself to be a critical part of the economy through COVID-19.

The implementation of water storage infrastructure requires assessments that consider the needs for sustainable management, including natural and physical resources, as identified by the Resource Management Act 1991. PDU water storage investments anticipate these assessments with a set of investment criteria that address these needs (Appendix 1).

All PDU water storage investments are guided by a set of investment principles in line with objectives for water storage (Appendix 1), e.g. to:

- strengthen regional economies by shifting to higher-value sustainable land uses
- address disparities in Māori access to water for land development
- support micro- and medium-scale water storage projects that strengthen regional partnerships and provide wider public benefits, and
- support land uses that do not increase – and ideally reverse – negative impacts on water quality and that maintain and improve the health of waterways.

In meeting these objectives, PDU investments also consider how projects:

- contribute to a just transition to a low-carbon economy and/or to building climate-change resilience in Otago communities; and
- provide an incentive to change land use that risks degrading the environment into high-value, more sustainable, uses.

Water storage and distribution infrastructure can assist regions to optimise land production by moving to higher-value land uses or assist in transiting to more sustainable land uses. Reliable access to water can enable regions to diversify their land use and increase horticultural activities to ensure that the primary sector operates sustainably – minimising negative impacts on water quality and maintaining and improving the health of waterways.

The main focus of PDU funding for water storage is to increase economic returns by shifting some of the current activities to higher-value land uses (Section 3). There are a number of limitations on the purposes for which PDU water storage funding can be used. In general, PDU funds cannot be used for municipal water supply or Three Waters infrastructure, to provide maintenance funding for existing schemes or to support land use that leads to ruminant intensification.

Consideration is underway in other parts of government about the adequacy of water for other purposes, such as drinking water. With climate change, access to water may decline / be less reliable during the year in some regions, leading to greater deprivation for some communities. Water storage can support community resilience and incomes in this context.

Ultimately, land productivity also requires water availability in neighbouring townships to enable workers and suppliers to live nearby.

Regional water needs assessments are also relevant to the movement of water use to higher economic values. Here, secure water supplies allow users to move to more profitable land uses in response to economic drivers. For example, a longitudinal study focused on irrigated land in the Waimea Plains, Nelson, between 2003/04 and 2007/08 found that:

> *"… most irrigated land moved to higher value uses. In particular, dairy land use, with the lowest average revenue per hectare, was largely replaced by horticulture-other and market gardening with average revenues per hectare 3–7 times greater than dairy"* (White 2011).

Constraints on the development of water vary across the country. The climate is a constraint on irrigation development in east coast regions, which are typically dry. Therefore, historic demand for irrigation has been high in the east, with irrigation supplied by schemes that can transfer water over large distances. Economic conditions are also a constraint, as poor areas have less opportunity to raise capital to fund infrastructure. Regulations that aim to protect water quality from the effects of land development may restrict water storage options, but the use of storage may mitigate effects, e.g. by sustaining stream baseflow and environmental flows.

This report represents part of the results from the first two phases of the Aqua Intel Aotearoa Otago water storage assessment. As such, the report has considered potential water storage options for most of Otago region, including surface water and groundwater sources.

Extensive consultation with Otago Regional Council in 2020 and 2021 has provided very useful local information that is relevant to the storage assessment. However, the findings in this report are not endorsed by Otago Regional Council; no endorsement was sought from Council during the period of consultation and none was given. Likewise, the findings in this report do not represent Government policy. No endorsement for the report was sought from other relevant Otago corporates, including Ngāi Tahu.

1.1 Water Storage Development

The delivery of water storage infrastructure is a lengthy process that takes place over a number of years, with numerous phases leading to construction and operation (Figure 1.1 and Table 1.1).

Information about water availability and potential land use is necessary to bring water storage projects into effect. The information developed through these regional water needs assessments inform Gateway: Phase 1 – the strategic assessment of whether water storage projects could be taken through the development phase.

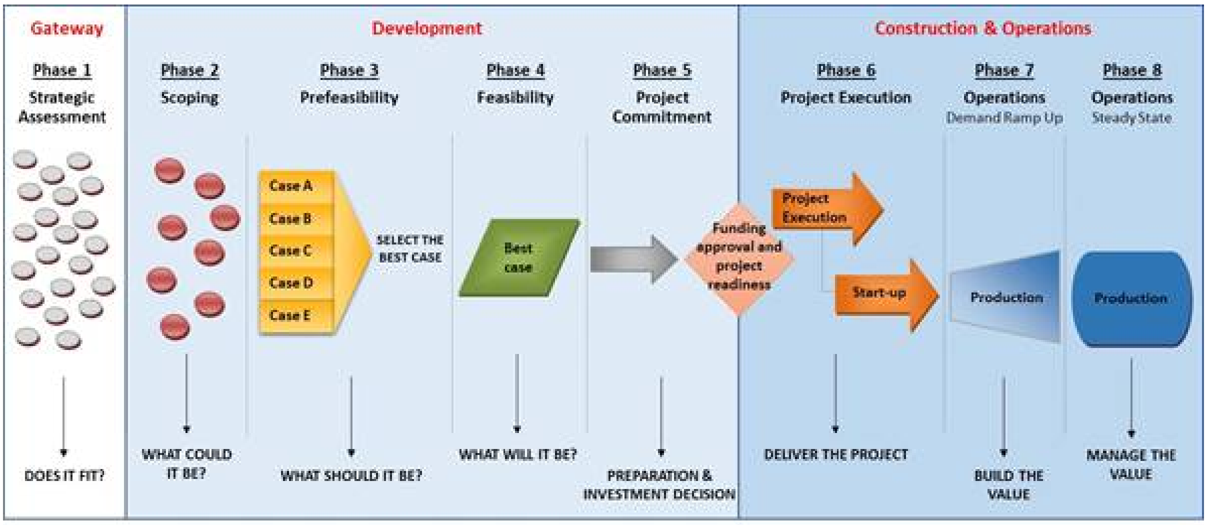


Figure 1.1 The water infrastructure development process.

The regional water needs assessments being prepared by Aqua Intel Aotearoa relate to Phase 1, i.e.:

- considering the current status of land use and water availability in focus areas within the region;
- considering potential land use and water storage approaches that could generate an increase in sustainable land development; and
- identifying and funding activities that will progress work on water availability within the focus areas, where assessments show that a viable and sustainable water storage approach is achievable and land productivity can be increased, consistent with the PDU objectives above.

The funds that are available for investment through Aqua Intel Aotearoa will be prioritised toward activities that can progress the region through to later stages of water development (as above in the diagram and below in the table). For example, the project will fund gauging of surface water in areas that are known to experience water shortage. Decisions about where to undertake gauging will be informed by local expertise from regional councils and water specialists.

1.2 Otago Considerations

This assessment of Otago water needs and opportunities considers potential water use and water availability within focus areas of the region (Figure 1.2). These areas include land in one of New Zealand's driest regions. Central Otago and coastal North Otago are particularly dry, and agriculture is dependent on access to reliable water. For example, Central Otago farming has been based on access to water via water races since mining days (through miners' privileges/rights), and coastal North Otago productive water is sourced from the Waitaki River. The demand for new water continues today, including applications to the PDU for water storage in the Strath Taieri and Manuherekia areas.

Table 1.1 Development phases for water infrastructure.

Phases	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Water Availability (Water Supply)	Identify potential sources of water and water storage approaches. Monitor availability of water, e.g. low flows and harvestable flows of water in rivers, streams and groundwater. Consider existing water supply schemes (e.g. hydro-lakes, reservoirs, networks) and potential for upgrade/extension. Determine whether sufficient sustainable water will be available to take water for productive purposes, including meeting regulatory requirements and community expectations.	Assess whether water supply will be sufficient to justify investment.	Identify potential water storage sites based on regional freshwater objectives and regulatory settings, technical feasibility and storage scale. Secure water resource consent(s).		Final site for water storage chosen.	Water storage infrastructure constructed and water becomes available to landowners.		
Land Use (Water Demand)	Identify areas for potential land-use change and what water is needed to support this (including considering land uses that require less water). Undertake preliminary discussions with landowners and potential business partners to assess potential interest in securing water.	Assess whether water demand is likely to be sufficient to meet construction costs.	Build demand from landowners, business partners and other potential owners of the infrastructure (e.g. municipal, industrial).	Secure land-based consents	Owners sign up to project.	Landowners invest funds through purchasing a share of the asset. They utilise water to increase the sustainable productivity of their land.		
Project Development	-	-	Develop a business case for infrastructure investment based on adequate supply and demand. Establish a vehicle to deliver the project.			Manage delivery of project.		

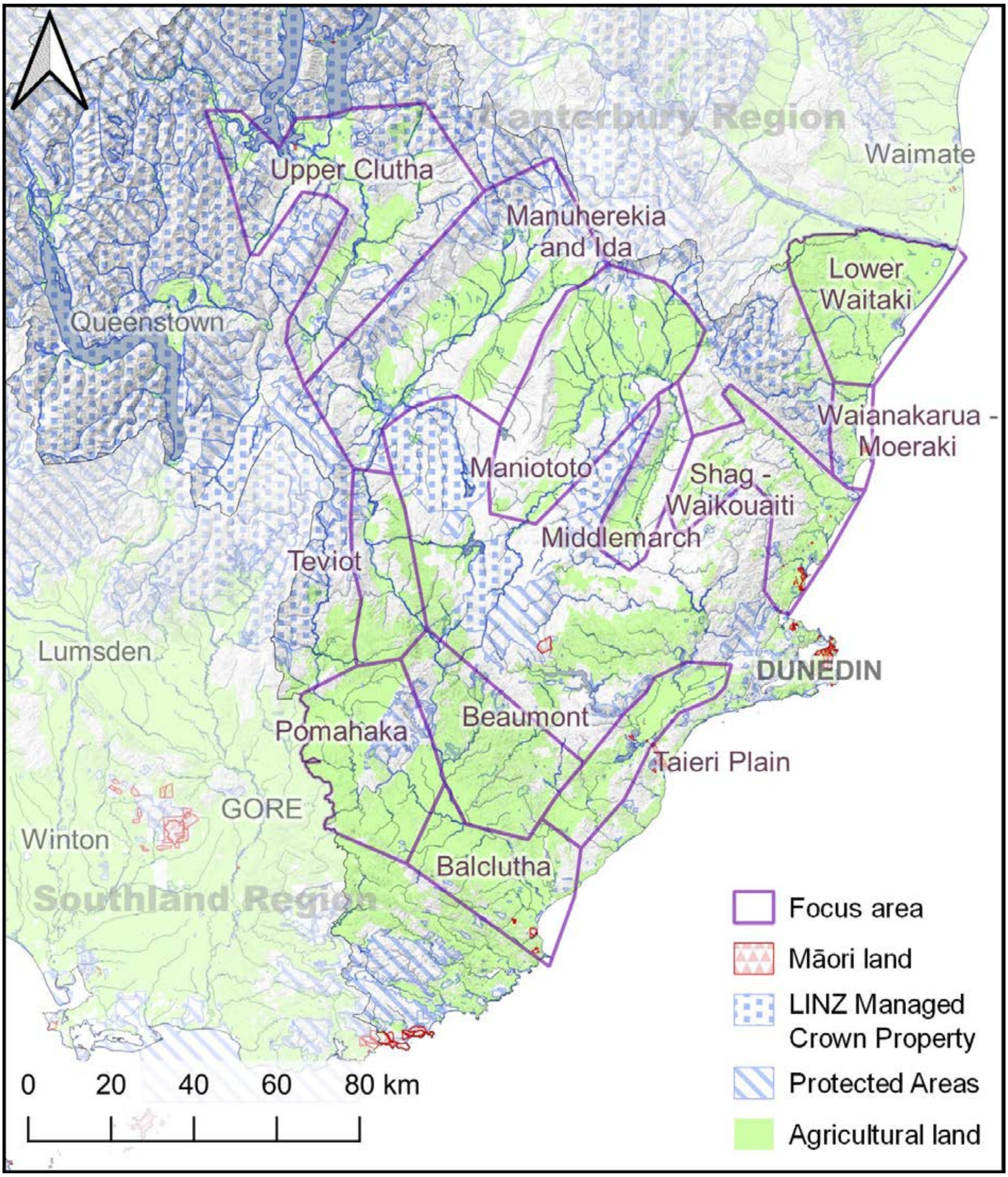


Figure 1.2 Focus areas for Otago water storage assessment.

These miners' privileges/rights, also called 'Deemed Permits', are due to expire in October 2021. De Pelsemaeker (2020) noted that:

> *"The replacement of Deemed Permits with RMA consents may reduce the levels of allocation. The environmental sustainability of allocation levels in Central Otago after miners' rights / Deemed Permits have been replaced, is currently unknown. The new Land and Water Plan (to be notified by December 2023) will propose freshwater objectives and allocation limits. Water allocated under the new RMA consents will need to be compared with these limits, to identify whether any overallocation exists."*

The Environment Court is currently considering the Proposed Plan Change 7 to the Regional Plan: Water for Otago and will decide the fate of these 'Deemed Permits' in the short to medium term (Radio New Zealand 2021).

Since 2017, the National Policy Statement for Freshwater Management (NPS-FM) requires councils to consider and recognise 'Te Mana o te Wai' in policy development related to freshwater. Te Mana o te Wai is the integrated and holistic wellbeing of freshwater bodies, which supports the health and wellbeing of people and the environment. In Otago, the regional council works with Ngāi Tahu to deliver Te Mana o te Wai (e.g. Section 2.1.2.1).

The report discusses surface water and groundwater sources (Appendix 2) with maps of suggested options in each area (Section 4). In each of the focus areas, the report comments on the potential benefits of water storage, including the benefits to regional economic development and the environment.

Land owned by Māori has been a focus for investigation in other regional assessments. However, water storage for Māori-owned land is not a key priority for this report because little such land occurs in Otago, and most of this land is covered in indigenous forest or wetlands. Focus areas with Māori-owned land (e.g. Shag–Waikouaiti, Waianakarua–Moeraki and Balclutha) contain small areas of land and therefore lack significant agricultural land expansion opportunities from the development of water storage.

2.0 OTAGO REGIONAL SUMMARY

2.1 Water

2.1.1 Freshwater Resources Overview

Otago has a large variety of surface water bodies, including several lakes, representing 23% of New Zealand's lake surface area (Otago Regional Council 2004). The largest river in terms of annual flow, Clutha River / Mata-Au, drains much of the region. Lakes Hawea, Wanaka and Wakatipu and significant tributaries (e.g. Cardrona, Lindis, Shotover, Kawarau, Manuherekia, Pomahaka) feed the Clutha River / Mata-Au catchment. The second largest catchment is associated with the Taieri River, rising from Central Otago to Taieri Mouth on the coast. Other significant rivers mainly drain coastal hills (e.g. Kakanui, Waianakarua, Shag and Waikouaiti River in the north) or rolling country (e.g. Tokomairiro River in the south). Several large wetland systems (e.g. Upper Taieri scroll plain and Waipori/Waihola wetland complexes, Lake Tuakitoto) represent significant habitat for wildlife.

The Otago region has only a few large regional aquifers (e.g. Lower Waitaki Plains Aquifer), and most of Otago's aquifers are hosted in disconnected basins that can contain multiple aquifers (e.g. Alexandra Basin, Wakatipu Basin; Heller 2001). Mainly unconfined and hosted in Quaternary outwash or recent alluvial gravel (e.g. Kakanui-Kauru Alluvial Aquifer) or volcanic units (e.g. North Otago Volcanic Aquifer), aquifers can also be (semi-) confined and found in Tertiary units (e.g. Papakaio Aquifer). For most localities, groundwater is present within the substrata, yet permeability and storage capacity can be limited in some areas as, for instance, the Ida Valley or basement rock areas.

2.1.2 Freshwater Policy and Water Allocation

> *"Balancing the need to protect the environment, provide for recreation and cultural values, and allow water to be taken for private or commercial uses is a huge challenge"* (Ministry of the Environment 2020).

2.1.2.1 Freshwater Policy Framework and Te Mana o te Wai

The Regional Plan: Water for Otago (RPW; operational since January 2004) is the primary document that manages the regional water resources by regulating environmental effects created by the use of water, activities in the water bodies or discharges of contaminants into the environment. To reflect the latest regulation requirements, including the NPS-FM 2020 and the recommendations in the matter of freshwater management (Skelton 2019), ORC is undertaking a review of the RPW and aims to notify its new Land and Water Regional Plan (LWRP) by 31 December 2023, with the following vision:

> *"In addition to the statutory requirement to review the District Plan provisions, the pressures faced within the Region have evolved over time. ORC is doing a comprehensive review of its Water Plan to ensure the Plan continues to look after the unique and treasured ecological, cultural and community values that are supported by our region's water bodies"* (Otago Regional Council c2020b).

Since 2017, the NPS-FM also requires councils to consider and recognise 'Te Mana o te Wai' in policy development related to freshwater. Te Mana o te Wai is the integrated and holistic wellbeing of freshwater bodies, which supports the health and wellbeing of people and the environment. Te Mana o te Wai can also be described as the mauri (energy and flow of life force) of water bodies and taonga species. Water is held in the highest esteem by Māori, because the welfare of the life that it contains determines the welfare of the people reliant on those resources. Regional councils and local iwi work together to determine how Te Mana o te Wai will be reflected in regional planning and consenting arrangements. This covers many aspects of water quality, including provision of clean freshwater for drinking, continuity of flow from mountain to sea, ecosystem health and biodiversity, protection of traditional cultural values, aesthetic qualities and provision of economic values.

In Otago, the regional council works with Ngāi Tahu ki Murihiku to deliver Te Mana o te Wai. While there are no agreed freshwater objectives for the region at present, mana whenua have articulated Te Mana o te Wai in working with the regional council to draft a revised Regional Policy Statement. The region is going through a transitionary period that will introduce new flow and allocation regimes, with notification of a new land and water regional plan scheduled for December 2023. The new regimes will be consistent with giving effect to Te Mana o te Wai within a ki uta ki tai framework that also seeks to manage land uses. Mana whenua consider the existing planning framework to be deficient in addressing Ngāi Tahu rights, interests and values and giving effect to Te Mana o te Wai.

Ngāi Tahu ki Murihiku interests in the Otago region are specific to the Clutha River / Mata-Au catchment from its headwaters to its coastal waters, focused on the true right tributaries, and Te Ākau Tai Toka / the Catlins area. There are a total of seven Papatipu Rūnanga with interests in the Otago region, with Kāi Tahu ki Otago interests represented by Aukaha Limited ('Aukaha' onward).

Mana whenua are seeking retirement of abstraction from tributaries in favour of taking from larger water bodies, such as lakes and main stems, in order to support Te Mana o te Wai. This is likely to require significant infrastructure change, and mana whenua would similarly support groundwater abstraction once an appropriate allocation regime is in place that gives effect to Te Mana o te Wai. Ngāi Tahu ki Murihiku considers the following factors in relation to draft freshwater and mana whenua objectives:

- Ngāi Tahu ki Murihiku economic activity includes customary practice (e.g. mahinga kai) that sustains whānau and households and is reliant upon te hauora o te wai, both in maintaining and restoring.
- Disparity is associated with degradation of water bodies and loss of mahinga kai, and review of flow and allocation regimes is about accessing water to support ahi kā, mahinga kai and kaitiakitanga rather than having a singular land development focus.
- Micro- and medium-scale projects are more likely to be helpful in contrast to larger-scale development projects.
- Land use must maintain and/or restore with reference to draft freshwater objectives.
- Just transition to a low-emissions economy and reducing risks of degrading the environment are important objectives to mana whenua.

Five Freshwater Management Units (FMU) were delineated in April 2019 for the Otago region in a close collaboration between ORC and Aukaha. They include the Clutha/Mata-Au, Taieri, North Otago, Dunedin Coastal and Catlins FMUs (Figure 2.1; Otago Regional Council 2020a). The Clutha/Mata-Au FMU is further divided into five sub-FMUs, known as rohe. It is intended that each FMU or rohe will form a chapter of the forthcoming LWRP, whereby water management is based on values determined by the communities and tangata whenua in accordance with the NPS-FM 2020.

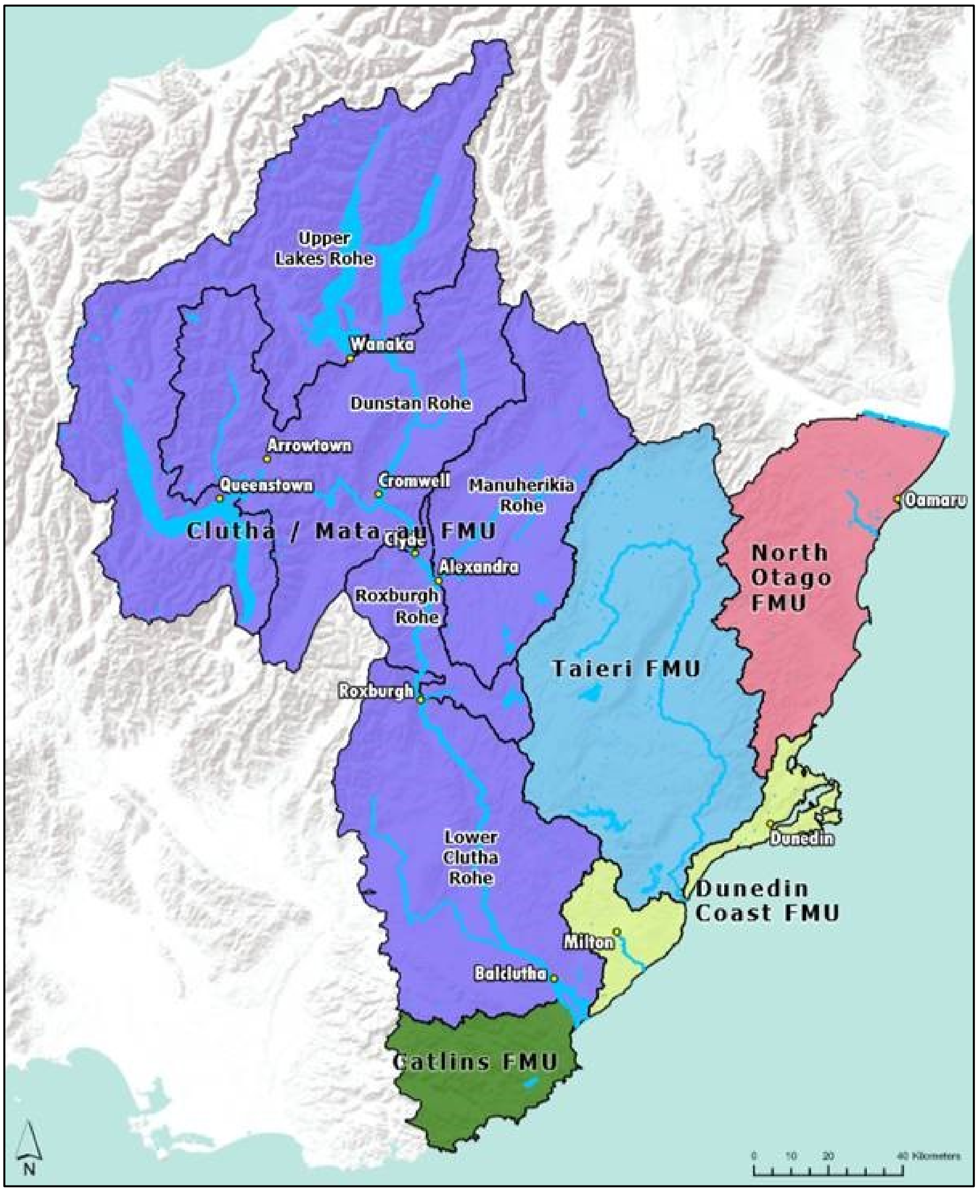


Figure 2.1 Freshwater management units and rohe in the Otago region (Otago Regional Council 2020a).

2.1.2.2 'Deemed Permits' or Miners' Rights

'Deemed Permits' / miners' rights[1] with respect to water were established from 1858, and therefore granted pre-RMA, to give gold miners access to water for sluicing and were later re-purposed for farm irrigation (Skelton 2019). With the introduction of the RMA in October 1991, 'Deemed Permits' were set to expire on 1 October 2021, with a 30-year twilight period. ORC is currently working through the replacement of these permits in the lead up to their expiry (Proposed Plan Change 7 being part of this process).

1 Mining privileges were licences issued under the Mining Act 1926, subsequent amendments and previous Acts for: water races, dry races, branch races, tail races, main tail races, drainage races, bywashes, drainage areas, dams and special sites. The RMA saw mining privileges continue as part of 'Deemed Permits'.

2.1.2.3 Water Allocation

The review of the RPW means that ORC is reviewing all existing allocation limits and minimum flows in the current plan and will set 2020 NPS-FM-compliant allocation limits and environmental flows/levels for water bodies in its Land and Water Regional Plan. This means that there is currently no certainty around future availability of water resources in the region (De Pelsemaeker 2021).

Surface water abstraction takes the largest proportion of river flow in the Manuherekia, Taieri, Fraser, Kakanui and Lindis river catchments (Figure 2.3; White et al. 2020). For the catchments where specified primary allocation limits have been introduced, the highest allocation rates are observed for the Manuherekia River and Taieri River catchments. Surface water catchments for which no further primary allocation is available under the current RPW are located in Central and North Otago and also in South West Otago (Pomahaka River) and Queenstown Lakes (e.g. Arrow River).

Currently, allocated groundwater has reached or exceeded the maximum allocation limits in the current RPW (e.g. Dunstan Flats Aquifer) or the recommended maximum allocation limits[2] for a number of aquifers (e.g. Wanaka Basin – Cardrona Gravel Aquifer and some aquifers in the Hawea Basin), which limits further abstraction from these resources (Figure 2.4; White et al. 2020). Additionally, the default groundwater allocation limit(s) at 50% of Mean Annual Recharge under the RPW has the effect of leading some groundwater basins exceeding regulatory allocation limits; however, this status would not be as obvious, as is the case with surface water (Rekker 2021).

Limitations also occur for abstracting water from aquifers classified as 'alluvial ribbon aquifers' (i.e. connected to local surface water bodies), for which groundwater take permits are considered as surface water permits and are therefore restricted for fully allocated surface water catchments (e.g. Cardrona Alluvial Ribbon Aquifer, Lindis Alluvial Ribbon Aquifer, Kakanui-Kauru Alluvium Aquifer).[3]

Despite the generally large water volumes present in the region, some parts of Otago are among the driest areas in New Zealand (Otago Regional Council 2004), and the availability of water is a growing challenge due to current high levels of abstraction and the imminent expiry of the mining privileges (a component of 'Deemed Permits'; Otago Regional Council 2020b and White et al. 2020) in October 2021 (Skelton 2019).

The NPS Renewable Energy Generation (NPS REG; Ministry for the Environment 2011) sets out objectives and policies to enable the sustainable management of renewable electricity generation under the Resource Management Act 1991. However, the NPS REG does not apply to the allocation and prioritisation of freshwater, which are currently managed locally by regional councils[4] but may be subject to the development of national guidance in the future.

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2 For some aquifers, a 'recommended allocation limit', lower than the default maximum allocation limit, has been introduced to avoid the detrimental impacts on specific values or connected water bodies.

3 Directly connected groundwater, such as alluvial ribbon aquifers, are allocated as for connected surface water bodies.

4 "There are various examples where ORC has allocated water for a variety of purposes (e.g. community or domestic supply and irrigation) from a resource that is being used to generate hydroelectricity generation. In those cases, the consents may have conditions to protect the hydro-electricity generation capacity" (De Pelsemaeker 2021).

The current RPW does not yet cover the development, operation, maintenance and upgrading of new and existing hydro-electricity generation activities; this will be addressed in the new LWRP notified by 31 December 2023 (De Pelsemaeker 2021).

2.1.3 Water Use

Water reporting for the 2017/18 year indicates that maximum annual allocation, excluding hydropower consents, was approximately 2800 million m^3/yr in Otago (Table 2.1). Most of the consented water use in the region is sourced from surface water (93.4% of the total maximum annual volume and 65.2% of total number of consents). In general, individual groundwater takes have smaller consented annual volumes than surface water takes, as they represent 6.6% in total volume but 34.8% in number.

Table 2.1 Otago water allocation for consumptive use (i.e. excluding hydropower) in the water reporting year 2017/18 (Stats NZ 2020a).

Resource Type	Maximum Consented Volume*		Consents	
	M m^3/yr	% of Total	Number	% of Total
Surface water	2589.8	93.4%	1095	65.2%
Groundwater	183.1	6.6%	585	34.8%
Total	**2772.9**	**100%**	**1680**	**100%**

'Deemed Permits' / miners' rights, with respect to water and granted pre-RMA, make up a third of Otago's authorised water permits.

Irrigation is the dominant, consumptive (i.e. excluding hydropower) water use in the region, with half of the total of consents number and almost 43% of the total maximum annual consented volume (Table 2.2). Other uses include drinking water (26.5% in volume), multiple uses (24.8% in volume) and industrial (5.9% in volume).

Otago has the second-largest area of irrigated land in New Zealand after Canterbury, with 94,200 ha in 2017 (or 13% of total New Zealand irrigated land). This irrigated land area increased by 50% in 15 years (i.e. from 60,700 ha in 2002; Stats NZ 2019).

Table 2.2 Water use for in the water reporting year 2017/18, excluding hydropower consents (Stats NZ 2020a).

Primary Use	Maximum Annual Consented Volume*		Consents	
	M m^3/yr	% of Total	Number	% of Total
Irrigation	1186.9	42.8%	885	52.7%
Drinking	735.8	26.5%	380	22.6%
Other and multiple uses	686.6	24.8%	318	18.9%
Industrial	163.6	5.9%	97	5.8%
Total	**2772.9**	**100%**	**1680**	**100%**

* Excludes hydropower consents.

Irrigated farms are mostly livestock/other rather than dairy farms and dairy/dairy-grazing farms, covering 45,900 ha and 41,400 ha of land, respectively (Figure 2.2). In Central Otago, irrigation is also important for frost fighting for horticulture and viticulture activities in the period August to November of any year.

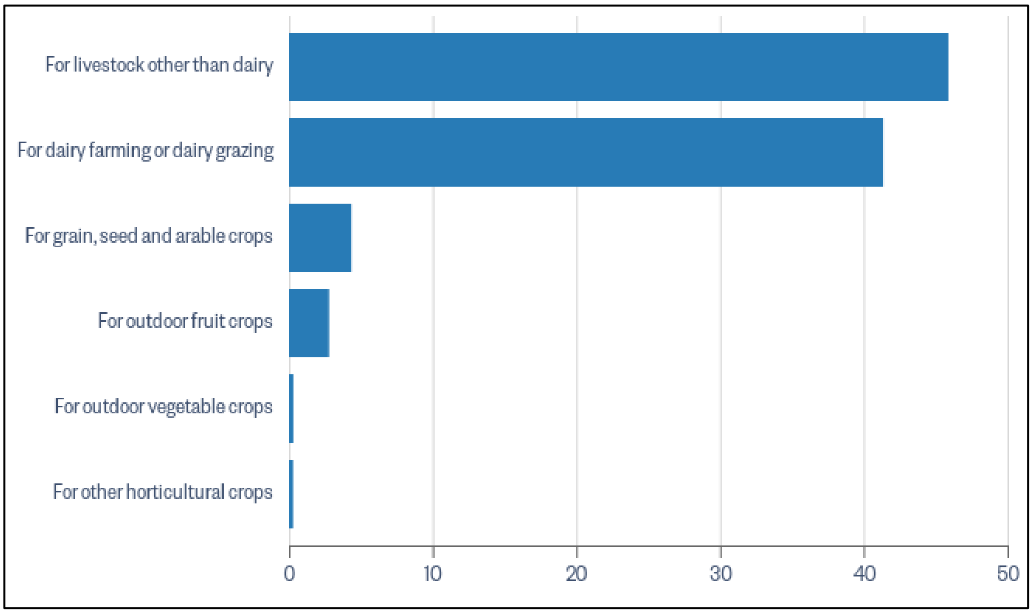

Figure 2.2 Irrigated farm area in Otago (in thousand ha) by 2017 land use (Stats NZ 2018).

2.1.4 Water Storage Project in the Context of Otago's Freshwater Policies, Allocation and Water Use

This report assesses technical water storage options that aim to shift current land uses to higher-value activities. These technical options include intra- and inter-catchment transfers of water. Further consideration of technical options should consider the following local comment on water storage in Otago.

Inland Otago is naturally arid. Therefore, opportunities for sustainable land use should be carefully considered and addressed as part of community engagement in the LWRP process that is being undertaken by ORC over the next 1–2 years. Communities have already identified visions for their FMU/rohe, and the need, desire and appropriateness for water storage and transport (or any other solutions for water security) must be considered in this context. Discussions about Te Mana o Te Wai and its application in Otago will also be part of the LWRP (see Section 2.1.2.1).

Once sustainable allocations are known and Te Mana O Te Wai priorities agreed as part of the LWRP, then sustainable land use and potential land use change and development can be discussed, along with any other options relating to water security (including better agricultural practice). This in turn can inform economic development proposals and the needs and desire for water storage, or transfer, projects.

Further requirements for data, information and investigations about options for water availability and storage, which might be needed to support discussions about land use/ development and water security, can remain an area of active engagement between the PDU and ORC.

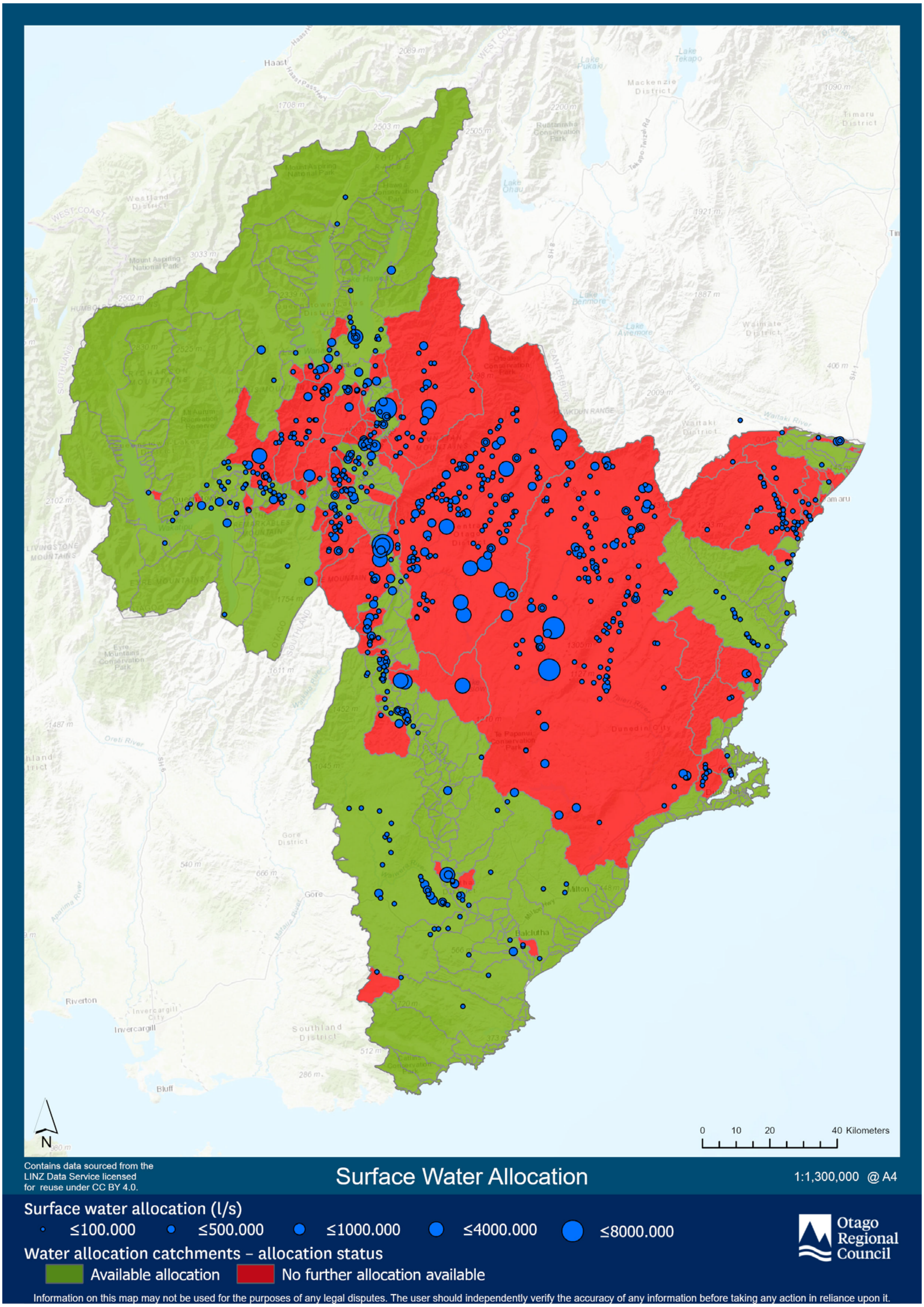

Figure 2.3 Current surface water allocation rates and surface water catchment allocation status as per August 2020 (Weir 2020).

Erratum: No further allocation is available for the Pomahaka catchment, which should be shown in red.

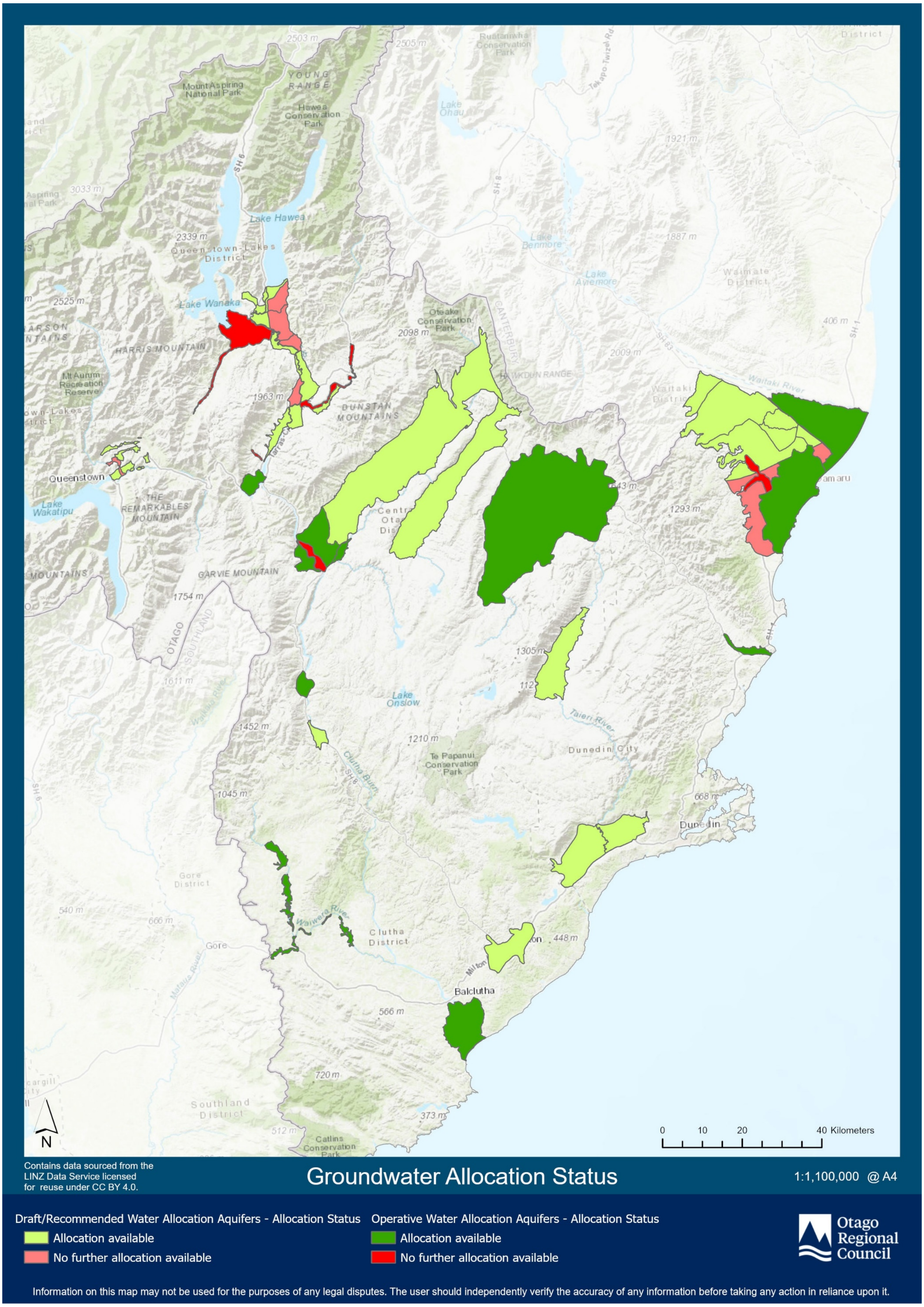

Figure 2.4 Current groundwater allocation status as per August 2020 (Weir 2020).

Note: Some of the aquifers overlap and therefore some limits are not represented (e.g. eastern Kakanui–Kauru Alluvium Aquifer in North Otago).

Erratum: There is a Draft/Recommended Maximum Allocation Limit for the Wanaka Basin – Cardrona Gravel Aquifer, which should be shown in pink.

2.1.5 Water Quality

The quality of surface water bodies is variable across Otago, with a clear spatial pattern between land use and water quality (Uytendaal and Ozanne [2018]).[5] River and stream reaches located at high/mountainous elevation with native land cover, associated with the upper catchments of large rivers (e.g. Clutha River / Mata-Au, Taieri River and Lindis River), and at the outlets of large lakes (e.g. Hawea, Wakatipu and Wanaka) have high water quality. Poorer water quality is generally observed in low-elevation and smaller streams that drain pastoral and urban catchments (e.g. intensively farmed catchments in North Otago and some tributaries of the Pomahaka River and urban streams in the Dunedin locale, respectively; Ozanne 2012).

Groundwater quality (Otago Regional Council 2008; Ministry for the Environment 2017) is generally considered as good; however, instances of elevated nitrate and faecal pathogen concentrations occur and are often linked to land use, e.g. dairy farming, market gardens, effluent and septic tank structures (e.g. Morris 2014; Otago Regional Council 2006). High concentrations of iron and/or manganese are also present in deeper and/or confined aquifers and are associated with geochemical reduced, natural conditions (e.g. Lower Taieri Basin; Rekker and Houlbrooke 2010). Rare occurrences of arsenic concentrations above drinking standards have been monitored and are inferred to be of natural or rarely anthropogenic origins (Otago Regional Council 2009).

2.2 Land Use/Cover

Primary production occupies most of Otago's land area, with pasture (high- and low-production grasslands) and exotic forest covering 47% and 4% of the region, respectively, in 2018 (Table 2.3). As there is no direct measure of productive land, land cover classes of the Land Cover Database (LCDB v5) for 2018 were used as a proxy – referred to here as 'agricultural land'. Agricultural land includes the LCDBv5 classes (with Otago land areas) of:

- high-producing exotic grassland (886,623 ha);
- short-rotation cropland (14,445 ha); and
- orchard, vineyard or other perennial crops (5421 ha).

Agriculture was the fifth-largest employment sector in Otago in 2012, earning approximately $958 million, or 12.5% of Otago's regional Gross Domestic Product (Slack et. al 2013). 'Natural' land covers are common in the region, with tall tussock grassland, indigenous forest, gravel/rock, lake/pond and manuka/kanuka classes covering up to 38% of Otago in 2018 (Table 2.3).

5 "Where trends were confidently identified, there were a greater number of increasing or degrading trends than decreasing or improving trends" (Uytendaal and Ozanne [2018]).

Table 2.3 Main land cover 2018 classes in Otago (after LRIS Portal 2020).

Main* Land Cover Classes (LCDB v5 Classes 2018)	**Area**	
	In thousand ha	**In % Total**
High-Producing Exotic Grassland	887	28
Tall Tussock Grassland	785	25
Low-Producing Grassland	622	19
Indigenous Forest	180	6
Exotic Forest	140	4
Gravel or Rock	99	3
Lake or Pond	78	3
Manuka and/or Kanuka	59	2
Short-Rotation Cropland	14	0.4
Orchard, Vineyard or other Perennial Crop	5	0.2
Sub-Total	**2800**	**90.6**
Total for Otago	3193	100

* Other classes not included in the table represent 1% or less of Otago's area, except 'Short-rotation Cropland' and 'Orchard, Vineyard or Other Perennial Crop' classes as utilised in this assessment.

Over the last two decades, Otago has seen an increase in livestock farming (largely sheep, beef and dairy), forestry and orchards, vineyards and other perennial crops, accompanied by a decrease in natural environments, such as tussock and fern, and under-productive land covered by gorse and broom (Appendix 3).

2.3 Climate

2.3.1 Current Climate

Otago has the most diverse climate of New Zealand. The Southern Alps act as a barrier between New Zealand's wettest areas and New Zealand's driest lands in the West Coast and Central Otago, respectively. Therefore, Otago weather is highly variable across the region, with strong westerlies and alpine conditions in the west and strong winds in exposed coastal locations (Macara 2015).

Rainfall distribution in the region is linked to elevation and exposure to westerlies. The western ranges have the highest rainfall, which then decreases eastward to the coast. Central Otago only receives 400 mm of rain annually, which is approximately a tenth of the precipitation (i.e. rainfall and snow) on Otago's western ranges. A rain shadow north of Dunedin results in low annual rainfall in coastal North Otago. Otago experienced numerous extreme weather events (with heavy rainfall and flooding) between 1980 and 2015 (e.g. June 2015 inundations in Dunedin; Macara 2015). Dry spells are relatively rare along the coast south of Dunedin but more frequent inland.

Temperatures in Otago are more extreme than the rest of the country. Central Otago often records New Zealand's more extreme temperatures (i.e. 38.7°C in Alexandra in January 2018 and -25.6°C in Ranfurly in July 1903). Central Otago temperatures are generally higher during summer and lower during the winter inland, compared to coastal Otago.

Snowfall and frost events are relatively frequent in Otago, e.g. an average of 12 days of snow are recorded yearly and 26 days of ground frosts monthly (July) for Queenstown (Macara 2015). South-eastern parts of Otago receive relatively low sunshine hours compared to the rest of New Zealand, e.g. Coastal South Otago is particularly cloudy and receives approximately 1500 hours of sunshine per year.

2.3.2 Climate Change

Otago temperatures are projected to increase, compared to 1995, by 0.6°C to 0.9°C in 2040 and by 0.6°C to 2.8°C by 2090 (Ministry for the Environment 2018). Frosts will become rarer (i.e. 13–45 fewer frosts per year), and the number of days with temperatures over 25°C will increase (i.e. by 4–25 days per year) by 2090. Winter and spring rainfall are generally expected to increase in Otago, e.g. extreme rainy days are likely to become more frequent. Snowfall is expected to significantly decrease, with a reduced number of snow days (i.e. a decrease of 30–40 days per year in some areas). Shorter snow cover period (especially at lower elevations) and earlier spring melt could result in a change in seasonal river flow patterns. Extremely windy days are projected to become more frequent (i.e. a 2–5% increase) and storm intensity will likely increase.

As a result of these projected changes in climate for Otago, more heavy rainfall will increase the risk of flooding and landslides. Average annual surface water flows are expected to increase across the region by the end of the century. Water flow increases (above 50%) are expected across all freshwater management units, except for the headwaters of the Taieri and North Otago, where large decreases in low flows are likely (Macara et al. 2019). More frequent droughts may also occur, and reduced snowfalls may affect water storage and water availability in summer. Coastal hazards (erosion and inundation) are expected to become more problematic, with increased storminess and sea-level rise (e.g. affecting low-lying coastal areas such as South Dunedin).

Agriculture could generally benefit from warmer temperatures and less frosts (e.g. longer growing season, better crop growing conditions). However, these benefits may be lessened by negative aspects of climate change (e.g. longer drought periods, more frequent and intense floods and storms). The projected warmer temperature and milder winters may increase the spread of pest and weeds (Ministry for the Environment 2018).

A first climate change risk assessment was issued recently for the Otago region (Hughes 2021). This assessment provides a snapshot of current and future climate scenarios, details the highest-ranked risks for the region and intends to set a baseline for the region to progressively build on and respond to climate change risks over time.

Adaption strategies to mitigate the impacts of climate change on freshwater resources include water-saving strategies, such as the utilisation of more efficient irrigation systems and water recycling, as well as adaptions of the water resources infrastructure and changes to water management (Capon 2013). Water storage infrastructure, like dams, may be relocated, upgraded or extended, or new infrastructure may be built if required. Adaption plans, infrastructure and management need regular re-visiting and review following updates of climate change projections to ensure their continued fitness for purpose.

2.4 Infrastructure

2.4.1 Existing Irrigation Scheme and Storage Infrastructure

Otago makes extensive use of small water storage/supply schemes, commonly with supply systems that date back to the mining days and shift water over large distances with much use of small dams. Early water supply systems in Central Otago were based on the mining water races (e.g. Rickard and Cossens 1973, Hamilton 2009); many of these schemes remain today, e.g. Bannockburn (The Field of Gold 2011), Earnscleugh, Hawkdun–Idaburn and the schemes in the Manuherekia Valley. Other Central Otago irrigation schemes included Government schemes such as Ardgour, Tarras, Ripponvale and Arrow (Rickard and Cossens 1968). Built reservoirs have included Falls Dam and Loganburn Reservoir (Butcher Partners Ltd 2016; Rae 2020). Gravity-fed water races take water from hydro dams (e.g. from Hawea dam for Hawea Flat).

It should be noted that the Central Otago dams relied on by the older irrigation schemes are aged infrastructure. The West Eweburn Dam was commissioned in 1901, (Upper) Manorburn Dam in 1914, Poolburn Dam in 1931, Idaburn Dam in 1931, Lower Manorburn Dam in 1934, Falls Dam in 1935, Conroys Dam in 1935, Fraser Dam in 1936 and Butchers Dam in 1937. Significant areas of highly developed agriculture and horticulture rely on these dams. Should a dam or canal failure occur, the dependent enterprises would be severely affected.

Newer infrastructure includes the use of hydro-storage dams. For example: Lake Hawea provides water to Hawea Flat for agriculture (Contact Energy c2020) and the Dairy Creek irrigation scheme is proposed[6] to take water from Lake Dunstan (Radio New Zealand 2017).

The Maniototo West Side, Maniototo East Side and Waipiata Irrigation companies take water by gravity from the Loganburn Dam and Taieri River after passing through the Paerau hydropower station. New schemes use water sources from rivers, e.g. Tarras Community Irrigation Scheme intends to abstract water from a gallery beside the Clutha River / Mata-Au to provide water to farmland near Tarras (Radio New Zealand 2011). The new Alexandra and Clyde water supply infrastructure will deliver water for domestic uses from Lake Dunstan in 2048 (Keenan 2020).

The North Otago Irrigation (NOIC) Scheme (Appendix 4) is a piped irrigation/baseflow enhancement scheme that has the potential to provide water to up to approximately 26,000 ha of North Otago (North Otago Irrigated Company Ltd c2020). The scheme, opened in 2006 and expanded in 2017, takes water from Borton’s Pond on the Waitaki River (elevation approximately 100 m above sea level) and delivers pressurised water to 250 m above sea level. Water is delivered to a straight-line distance of approximately 35 km from Borton’s Pond, e.g. to the Kakanui area. Large pumps are required by the scheme, e.g. each of four pumps in Pump Station 1 is capable of pumping water at 2 m^3/s. As part of a plan to transfer water from Enfield to Teschmakers, the scheme also includes a minimum flow condition in Waiareka Creek during the irrigation season.

Other new water transfer schemes that have been developed recently in the Otago region include the Hamnak drinking-water pipeline (Waitaki District Council c2017). This pipeline is 34 km in length and moves water from Oamaru and Hampden.

6 The Dairy Creek scheme has a water take consent but is yet to be financed and physically developed.

2.4.2 Three Waters Infrastructure

Looking beyond the scope of PDU investments to municipal water, Otago's Three Waters infrastructure is managed by five councils: Dunedin City, Central Otago, Clutha, Queenstown Lake and Waitaki, which face efficiency and sustainability operational challenges (LGNZ 2015). In July 2020, the Government announced its three-year Water Reform Programme to improve the safety and quality of the water services and environmental performance of wastewater and stormwater systems (DIA c2019). As a result, Otago will receive a regional allocation of $20.6 million and a total allocation of $41.2 million to improve Three Waters infrastructure (MacLean 2020). For instance, $10 million is allocated to Central Otago District Council for 'shovel-ready projects', including water treatment upgrades; pump station capacity upgrades in Cromwell; mains pipe upgrades in Roxburgh, Clyde and Alexandra water pressure upgrades in Omakau; flood protection for Roxburgh; an additional reservoir in Alexandra; and additional staffing to deliver the programme, as well as a contribution toward a regional work programme (Henderson 2020). Waitaki District Council will receive $6 million for new water infrastructure projects, including $1.5 million for water mains, $1 million for wastewater treatment in Palmerston and $1.4 million for wastewater treatment upgrades in Omarama (Houlahan 2020).

3.0 POTENTIAL BENEFITS FROM INVESTMENT IN WATER STORAGE

3.1 Background

For over a century, Otago has made significant investments in water-related infrastructure to support its productive sectors – initially mining, later farming and forestry and most recently dairy. Over time, these activities have placed significant pressure on the ecological health of many of Otago's catchments. The region is currently considering how to address this impact through changes to minimum flow requirements and allocation in its LWRP.

Water storage options could bring potential benefits in shifting some of the current activities to higher-value land uses (e.g. horticulture that requires less nutrients). The examples mentioned in this section do not include a detailed analysis of the policy frameworks and do not take into consideration the regulatory and cultural aspects of the proposed options. For example, development of dryland activities and activities suited to the climate are important considerations for mana whenua but are outside the scope of this study and will be considered as part of the future of economic activity in the region.

There is limited information available at this time on alternative high-value land uses that could support improved environmental outcomes in most of the focus areas. The following section outlines what is known in two catchments – Manuherekia and Strath Taieri / Middlemarch.

3.2 Potential for New Crop Production

3.2.1 Manuherekia

Production of a wide variety of crops is possible with irrigation in the Manuherekia area (Smallfield and Douglas 2005). However, production on the area's soils "needs to be tested[7] as it would be prudent to determine suitability of the soils" (Smallfield and Douglas 2005).

Potential crops, aside from pasture, include horticulture, e.g. grapes, pip and summer fruit, cherries and berry fruit; and olives. Non-traditional crops have been successfully trialled at the Redbank Research Station at Clyde, including chamomile, thyme, sage, oregano, lavender, saffron and arnica; these crops include essential oils (e.g. chamomile, thyme and sage). Other intensive crops with potential in the area include saffron, ornamental flowers and ginseng.

3.2.2 Strath Taieri / Middlemarch

Irrigation in Strath Taieri "has the potential to bring about similar land-use changes that have occurred within the Cromwell Basin over the last 20 years" in combination with tourism-related activities, such as the rail trail (Smallfield et al. 2006). Irrigation can lead to diversification of agriculture. In regard to proposed irrigation in the Strath Taieri area, local's comment (Rae 2020):

> *"While sheep and beef farming could continue with surety of supply, it could lead to other opportunities such as horticulture. 'There's a whole lot of good things we could grow here,' she said."*

7 It is likely that soil testing occurred since 2005, as there has been a significant development in horticultural and viticulture land uses.

They also comment on potential environmental effects of irrigated land development:

> *"Dairy farming would be a 'no go', built into shareholder agreements, along with certain wintering conditions in certain soils.*[8] *'There's no point getting the water here, putting it on and buggering our valley environmentally.'"*

Classes of potential crop types on irrigated land in the Strath Taieri area include arable, pastoral (not considered in this report), horticultural and ornamental (Smallfield et al. 2006). An extensive list of potential Strath Taieri arable seed crops includes:

- cereals, e.g. barley, oat and wheat;
- oils, e.g. borage, mustard and sunflower;
- pasture, e.g. clovers, lucerne and ryegrass;
- vegetables, e.g. beet, carrot and celery;
- herbs, e.g. coriander, dill and parsley, and including medicinal herb crops, e.g. ginseng, barley, chamomile, fennel and sage; and
- forage, e.g. rape, swede and turnip.

Preference would have to be given to alternative crops that do not increase and preferably reduce nutrient leaching and contribute to improve freshwater quality.

Potential fruit crops include black currant, pear and quince. However, this area is noted as a 'difficult environment for fruit tree production' because of frosts. Nut crops include hazelnut, pine nuts and walnut. Ornamental crops include Christmas lily, lavender, peony, statice and strawflower.

3.3 Alignment with Regional Planning Framework

In order to transition to alternative crops, most crops will need reliable water supply through the growing season, and this may only be possible if water storage is provided. A priority for the region in accessing additional water could be to maintain or improve its existing water quality while ensuring that water is available for new activities. The development of economic activities based on dryland or that are suitable to the existing climate conditions and associated water yields could also be investigated; however, this is out of scope of the present study. This is the key focus of the region's planning processes, with extensive engagement underway between the regional council and the community to develop approaches across all freshwater management units.

8 The Resource Management (National Environmental Standards for Freshwater) Regulations 2020 now require consent for dairy conversion. Consent for this purpose will only be granted if there is no increase in contaminant load, which is unlikely under a dairy scenario compared to status quo land use and associated losses.

4.0 FOCUS AREAS

4.1 Selection of Focus Areas

Focus areas in Otago were selected where there is productive land that could transition to higher-value uses, and preliminary assessments indicate options for water supply (White et. al. 2020). Environmental benefits from investment in water availability are considered alongside productivity potential for Otago, as no further investment in productive purposes can be made unless water quality issues are also addressed. Future work will assess water quality issues, water allocation limits and uncertainty about future water allocation.

The PDU's other key objective for investment in water availability is to support Māori-owned land being brought into higher-value uses. However, the area of Māori land in Otago is quite limited, largely as a result of the Kemp Purchase (Evison 2006). Latterly, Ngāi Tahu have purchased productive land in the Otago region (Rekker 2021).

Within these focus areas, water storage approaches are identified that meet the PDU objectives of:

- supporting micro- to medium-scale water storage projects, and
- supporting land use that does not increase – and ideally reverses – negative impacts on water quality and maintains or improves the health of waterways.

The water storage assessments do not consider options that could undermine the environmental health of freshwater bodies.

4.2 Summary of Focus Areas

This report identifies seven focus areas in the Otago region where water storage could support more productive sustainable land development.

4.2.1 Upper Clutha

Current land use within the Upper Clutha focus area (Figure 4.1) is predominantly characterised by grasslands (low-producing on sloping terrains and high-producing in the valleys), orchards, vineyards and croplands (Figure 4.3).

Water allocation maps (Figures 2.2 and 2.3) indicate that some groundwater and surface water is available under the operative Regional Water Plan but only for a relatively limited number of catchments and aquifers. Existing irrigation covers approximately 15,700 ha (Figure 4.1; Stats NZ 2019), while the maximum potential land development in the area is up to approximately 45,600 ha of agricultural land (Figure 4.1; LRIS Portal 2020), if sufficient water were available to support this level of land development.

Near Wanaka, a small area of dairy and dairy-support land use has been established over the past 10–15 years. Viticulture and horticulture also increased. Cherries in particular are grown in the wider Cromwell Basin.[9] Planting of cherries and apricots is underway in the Tarras area. This expansion of land use has largely been located along the banks of the Clutha River / Mata-Au where there has been access to reliable water that has supported a change in land use.

9 Anecdotal evidence indicates that some 200 ha of additional land was converted to cherries during 2019/20.

Current ageing irrigation infrastructure and inefficient irrigation methods, such as flood irrigation or border dyke irrigation, has declined within the Upper Clutha focus area, as higher-value land use has driven investment in more efficient irrigation methods.

Environmental issues observed in some parts of the Upper Clutha focus area include reduced stream baseflow and limited water quality issues.[10] Water investments could investigate how to support environmental improvements, as well as making water available for productive purposes.

Some storage options could come from 'technical options', e.g:

- hydro-storage (Figure 4.3; e.g. Lake Hawea, Lake Dunstan and Roaring Meg). Hydro-storage could also be used to replace ageing water race infrastructure (e.g. Bannockburn water races); and/or
- enhanced groundwater storage or managed aquifer recharge (Figure 4.4). A pre-feasibility assessment study was completed for managed aquifer recharge for the Wanaka–Cardrona area (Golder Associates 2015).

Stocker (2017) identified a number of dam sites on the tributaries of the Cardrona River and Luggate Creek. The lowest storage costs per m^3 of water capacity were assessed for dam sites located on upper Luggate Creek. Their high altitude on the Criffel and Pisa Ranges could present small hydro opportunities.

The Upper Clutha focus area includes a number of Statutory Acknowledgement Areas, tōpuni and nohoanga under the Ngāi Tahu Claims Settlement Act 1998 (NTCSA), and is an area of high cultural significance. Mana whenua preference is for options that draw water from lakes and main stem water bodies (e.g. Lake Hawea and Lake Dunstan) as opposed to tributaries (e.g. Roaring Meg, Luggate Creek) and utilise out-of-stream storage rather than in-stream storage/dams (i.e. Luggate Dam) (Te Ao Marama 2021). Mana whenua have concerns about the existing allocation and flow regime on Luggate Creek, with priority being to review the allocation and flow regime for the protection of the water body itself rather than to satisfy the water demand.

Te Ao Marama (2021) note that there are significant over-allocation issues within the Clutha River / Mata-Au catchment as a result of historic mining privileges ('Deemed Permits'), over a century old, that are reliant on run of river takes and/or old in-stream dams, often with no requirement to provide for specific in-stream flows, and these permits continue to adversely impact on mana whenua association and uses. Te Ao Marama (2021) do not support managed aquifer recharge in their takiwā.

10 For the July 2015 – June 2020 period (Otago Regional Council [2020]c), e.g. Nitrate-nitrite-Nitrogen concentrations were above the Otago Water Plan limits for Cardrona at the Mt Baker monitoring site.

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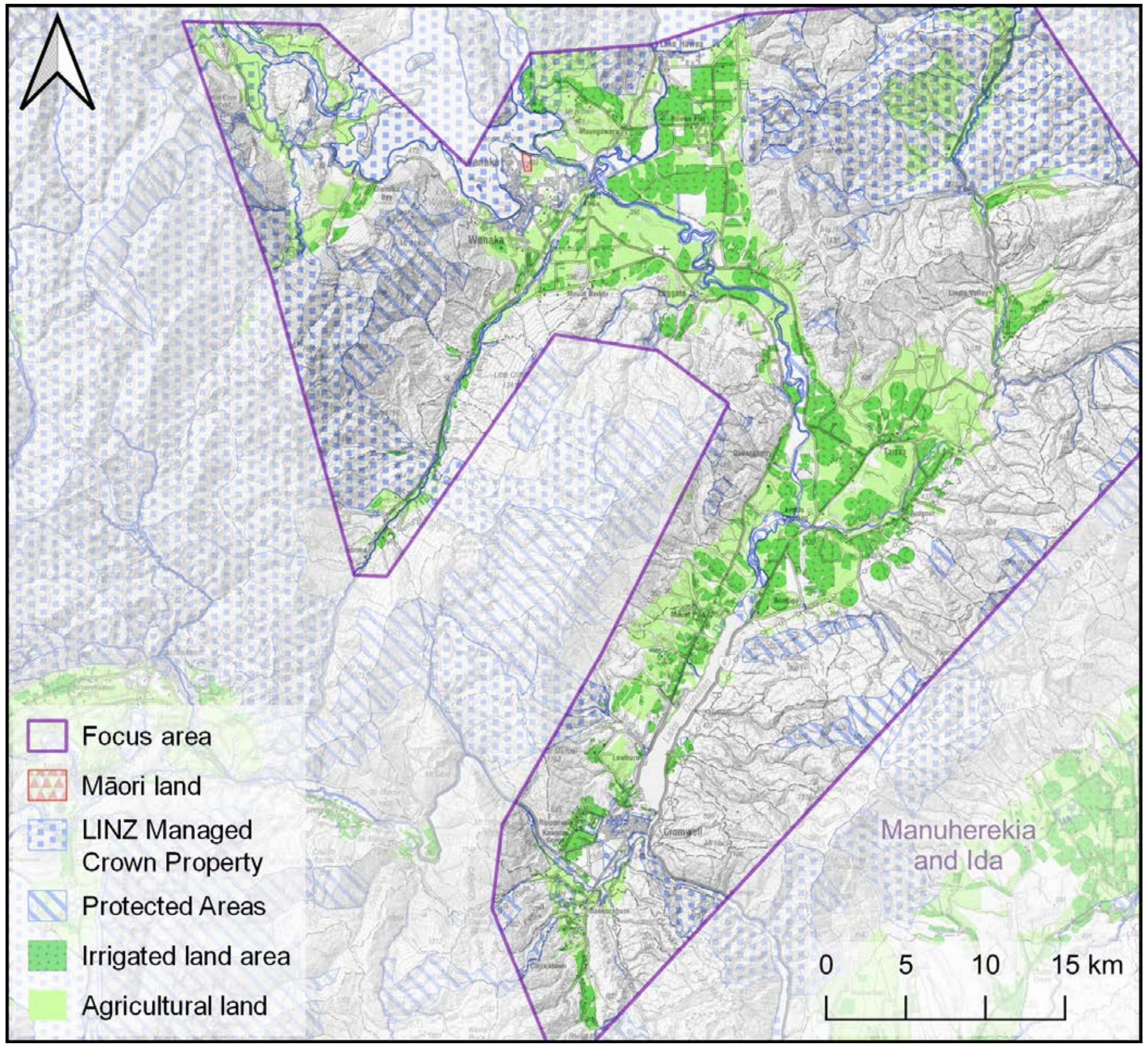

Figure 4.1 Upper Clutha focus area summary.

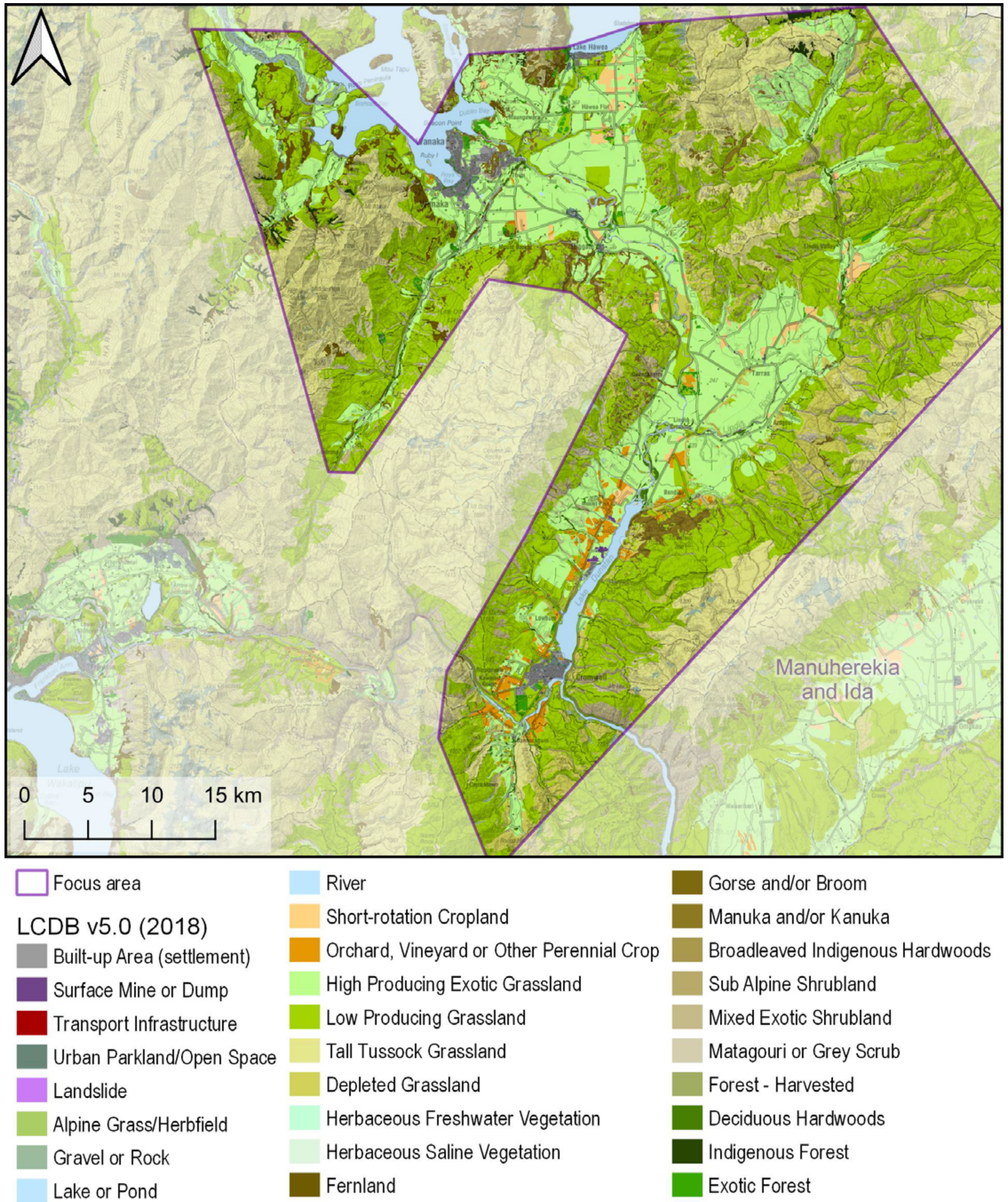

Figure 4.2 Land use/cover in 2018 for the Upper Clutha focus area (Land Cover Database [LCDB v5.0 (2018)]; LRIS Portal 2020).

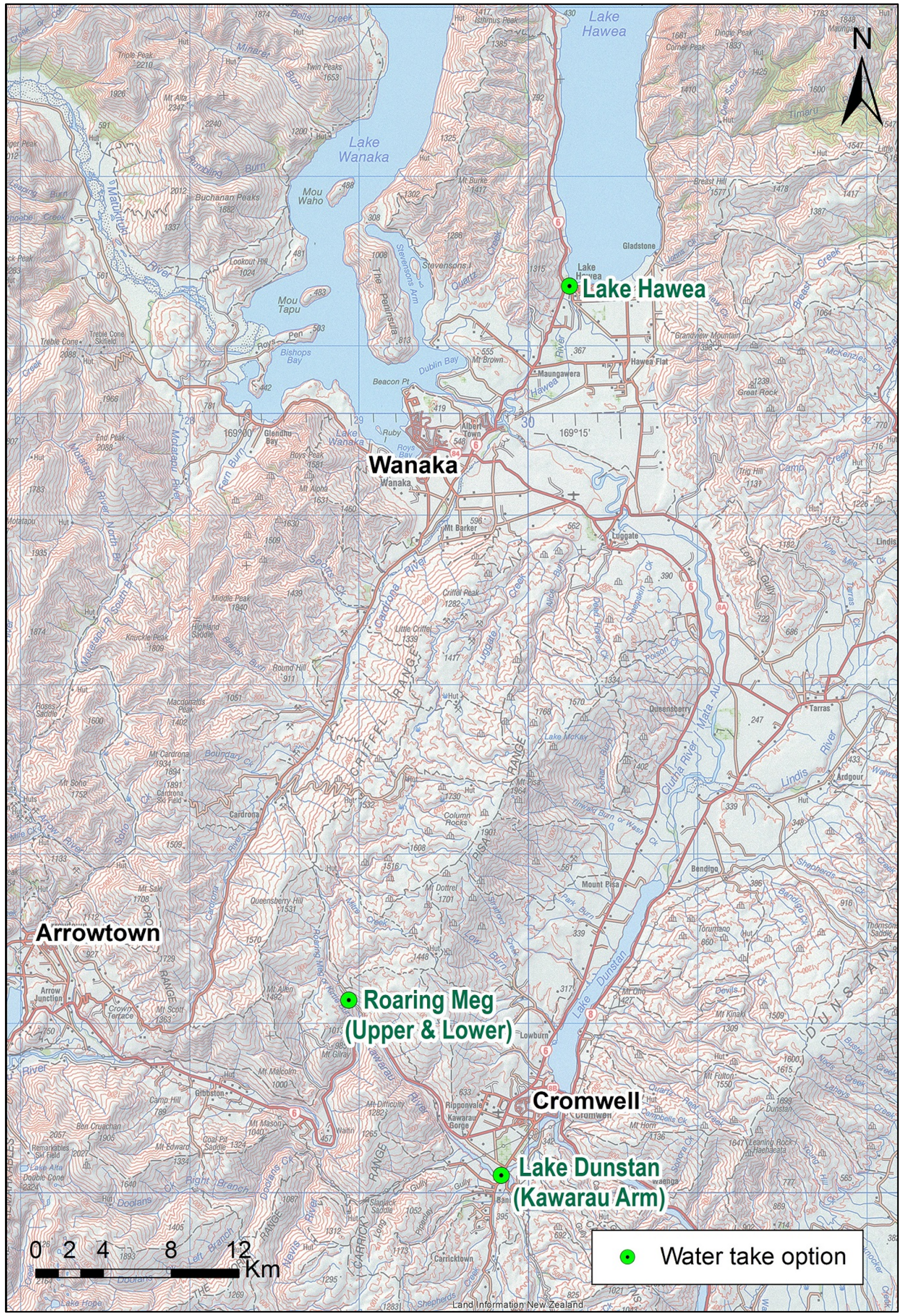

Figure 4.3 Potential technical hydro-storage options for Upper Clutha focus area.

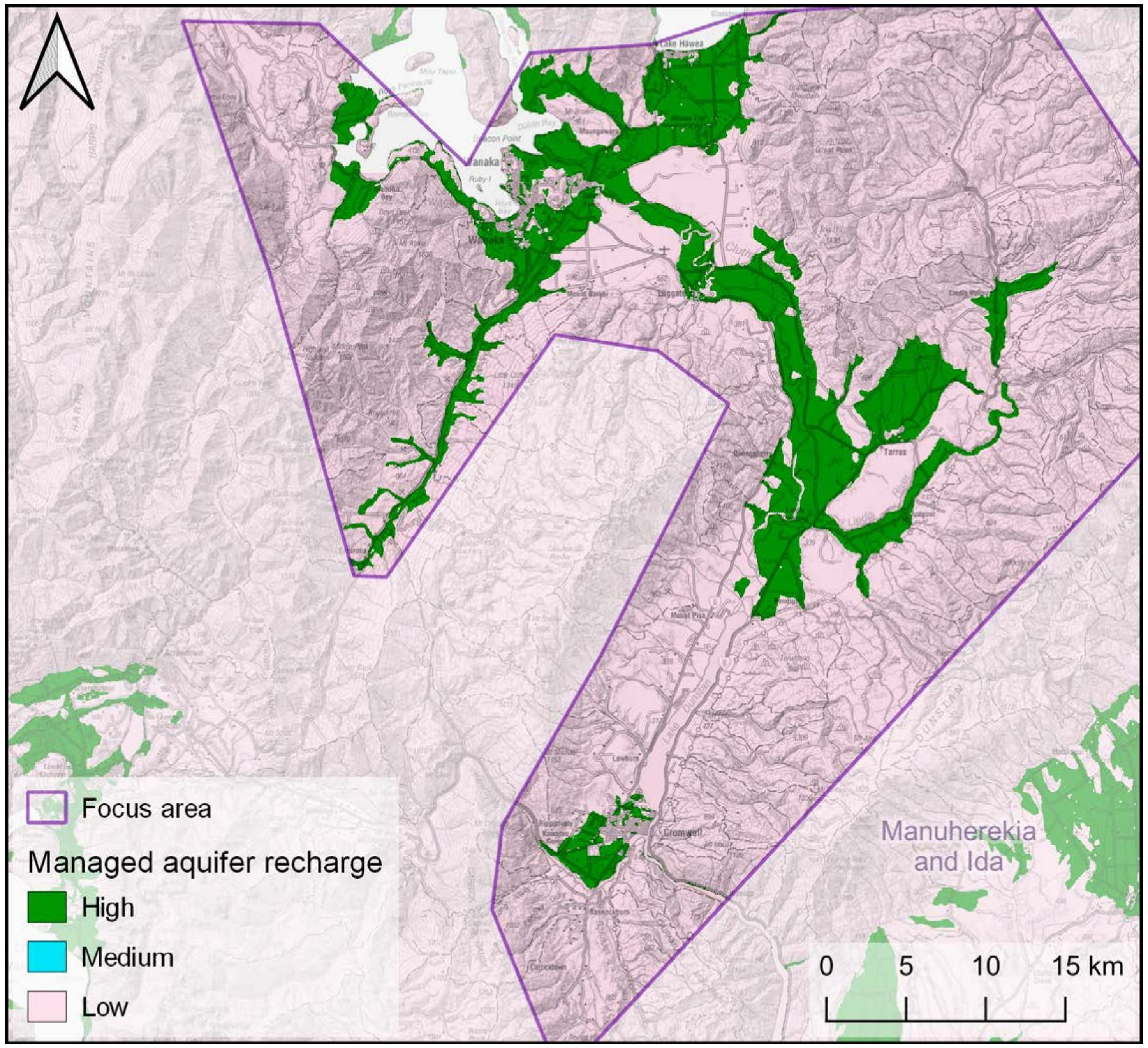

Figure 4.4 Potential for managed aquifer recharge option for Upper Clutha focus area.

4.2.2 Manuherekia–Ida

The Manuherekia–Ida focus area (Figure 4.5) is predominantly characterised by grasslands land cover (Figure 4.6). Grasslands are associated with sheep and beef farming activities, which have become more intensive as a result of irrigation efficiency gains. There has been a small increase in the number of dairy farms and dairy-support properties within the focus area during the past 10–15 years. The area also supports horticulture (stone and berry fruit), which has further expanded over the past 12–18 months (e.g. in the Waikerikeri Valley). Viticulture is also an established land use within the lower Manuherekia Valley, especially at Springvale.

There is significant potential for greater diversification of land use where reliable water supply is available, including expansion of arable/cropping land uses, including seed production, as well as potential for ongoing expansion of horticulture activities.

Existing irrigation covers approximately 17,900 ha (Figure 4.5; Stats NZ 2019). The maximum amount of land that could be brought into production in the area is approximately 67,800 ha of agricultural land (Figure 4.5; LRIS Portal 2020), if sufficient water were available to support this level of land development. However, full allocation of surface water means that water importation is required to support any further land development. Environmental issues (including low stream baseflow, limited water supply resources and degradation of water quality[11]) would need to be considered as part of any project that increased water availability for land development. Water storage may provide environmental benefits, e.g. increase in stream baseflow and surface water quality improvements.

The northern area of the Ida Valley and the Maniototo has a community irrigation and stock water supply provided by the Hawkdun Idaburn Irrigation Company Limited. This supply is based around the 108-km-long Mt Ida Water Race that captures water from numerous streams located on Mt Ida Range (in the Upper Manuherekia catchment) and transports flow through to the Taieri catchment at Naseby and then down gullies close to Kyeburn. There is limited water storage, and flows from mid-December to April are unreliable. The Hawkdun Idaburn Irrigation Company has actively investigated options for water storage and currently have preliminary geotechnical investigations underway on Wade Creek (Ida Burn North Branch) for a dam of approximately 4 M m^3. This development would not require additional distribution works.

Between 2012 and 2019, the Manuherikia Catchment Water Strategy Group undertook significant investigations to enhance irrigation in the Manuherikia and Ida valleys (MCWSG c2021). This work included pre-feasibility level studies, as well as options to upgrade or replace Falls Dam, to pump water from Lake Dunstan, to establish a new dam site in Dunstan Creek and to distribute water from Falls Dam into the upper end of the Ida Valley. The optimisation of this latest option could connect the existing Manorburn and Poolburn dams for more efficient routing of water.

Water allocation maps (Figures 2.2 and 2.3) indicate that some groundwater, but no surface water, is available for abstraction for the Manuherekia–Ida focus area. Yet, the physical ability to draw groundwater from poor aquifer property formations is the main reason that the potential allocation has not been exhausted already (Rekker 2021).

11 For the July 2015 – June 2020 period (Otago Regional Council [2020]d), e.g. E. coli and dissolved reactive phosphorus concentrations were above the Otago Water Plan limits for the Manuherekia River at the Galloway and Ophir monitoring sites.

Indeed, the Manuherekia–Ida valleys have very limited water resources due to modest rainfall, high potential evapotranspiration and little, if any, natural water storages, including a lack of significant groundwater resources. Therefore, possible storage options could come from the use of hydro-storage lakes (Dunstan and Roxburgh) and the potential pumped-storage scheme using Lake Onslow[12] (Figure 4.7) or from an enhanced groundwater storage method (e.g. land subsoil recharge; Figure 4.8).

Ngāi Tahu ki Murihiku understand land subsoil recharge to be a natural systems-based water storage option and, in that respect, find it to be a preferable approach, particularly where such recharge can be supported by increased use of indigenous land cover (e.g. tussock lands) and wetlands (Te Ao Marama 2021). Land subsoil recharge as a method for improving groundwater recharge may give effect to Te Mana o te Wai and potentially reduce the reliance on small tributary water bodies. This will be dependent upon an NPS-FM-2020-compliant allocation framework that appropriately addresses the relationship between surface water allocation and groundwater allocation or the interface between these water bodies.

12 Another option could consist of reinforcing existing storage facilities (e.g. Falls Dam and the Manorburn schemes).

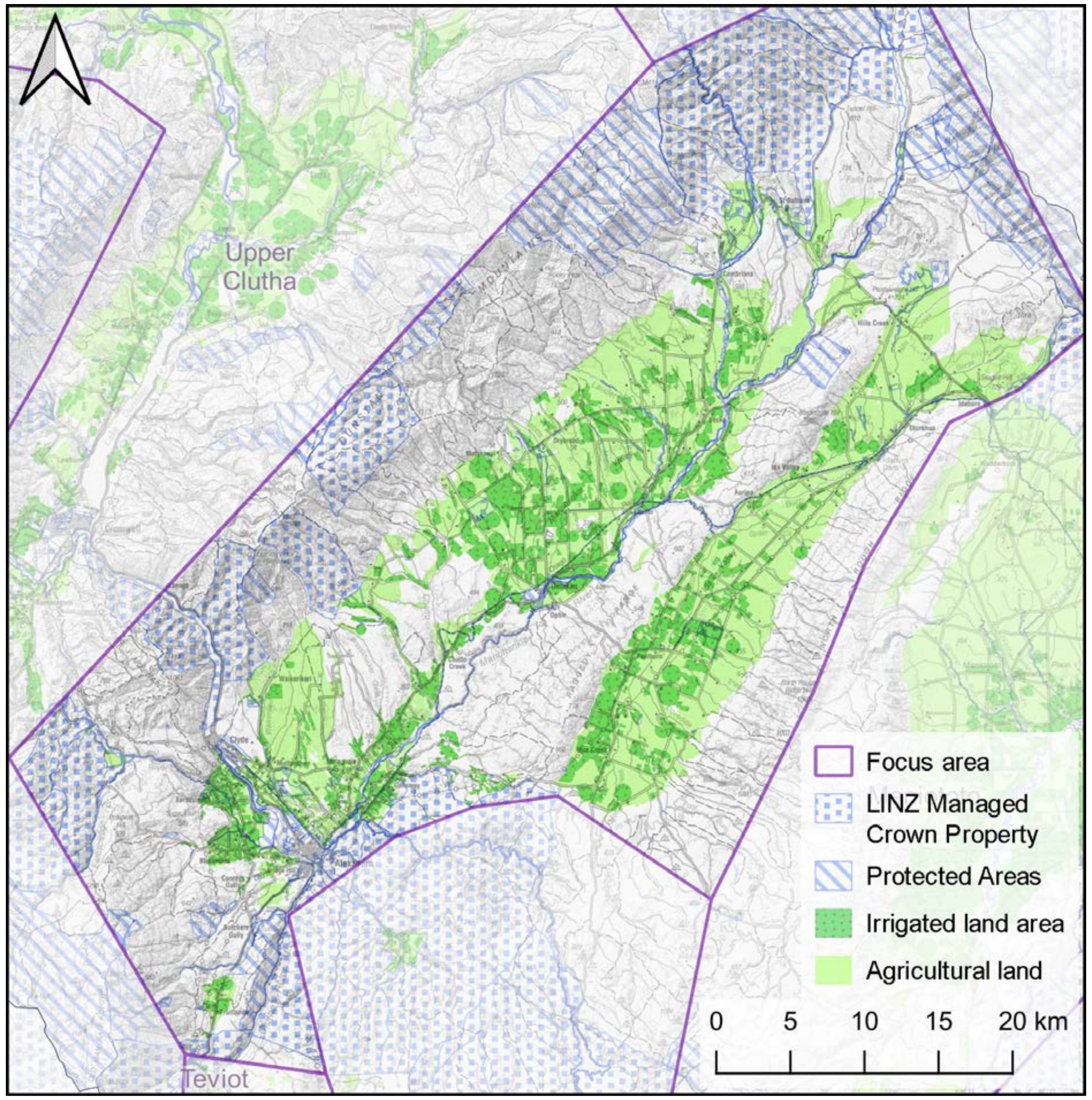

Figure 4.5 Manuherekia–Ida focus area summary.

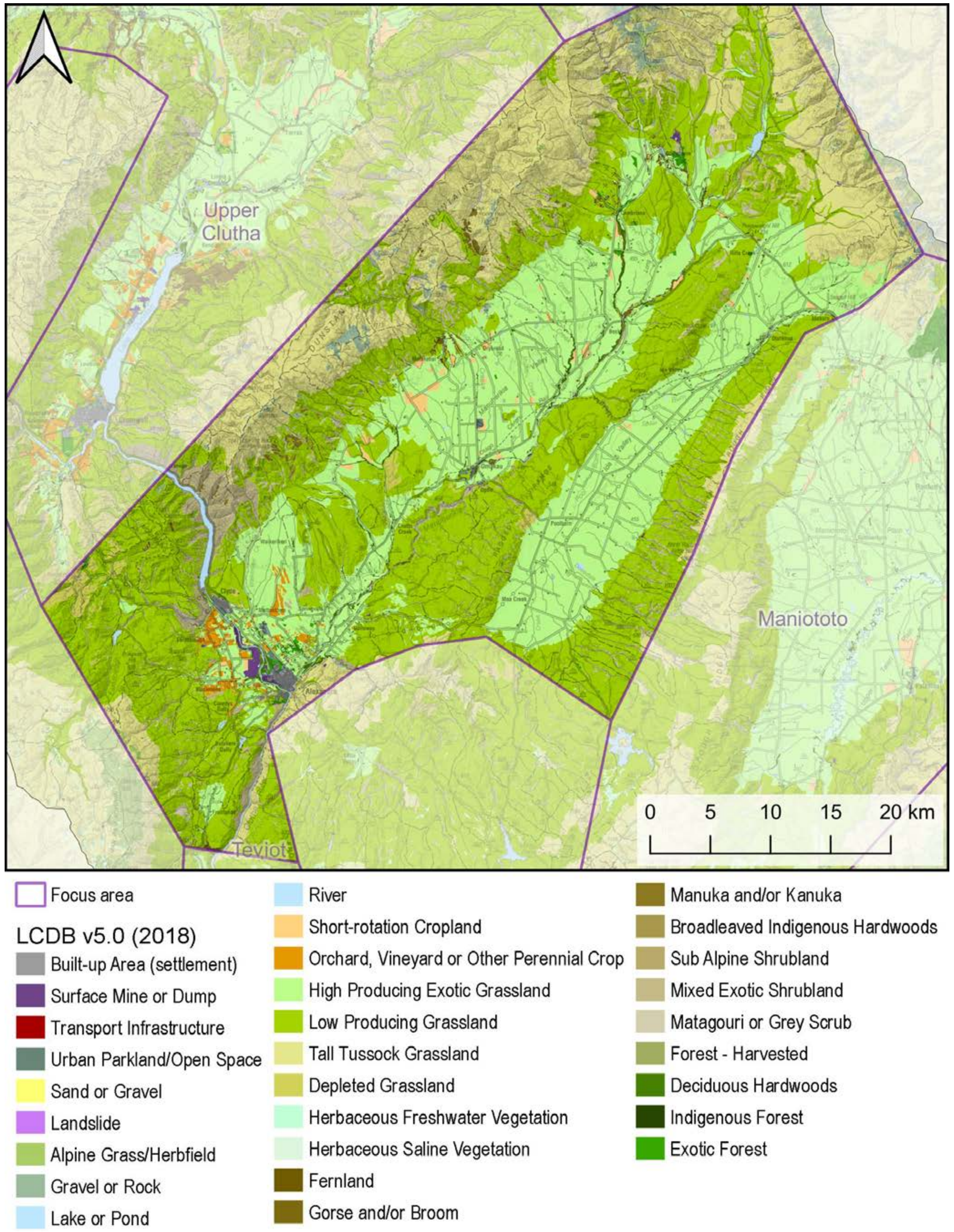

Figure 4.6 Land use/cover in 2018 for the Manuherekia–Ida focus area (Land Cover Database [LCDB v5.0 (2018)]; LRIS Portal 2020).

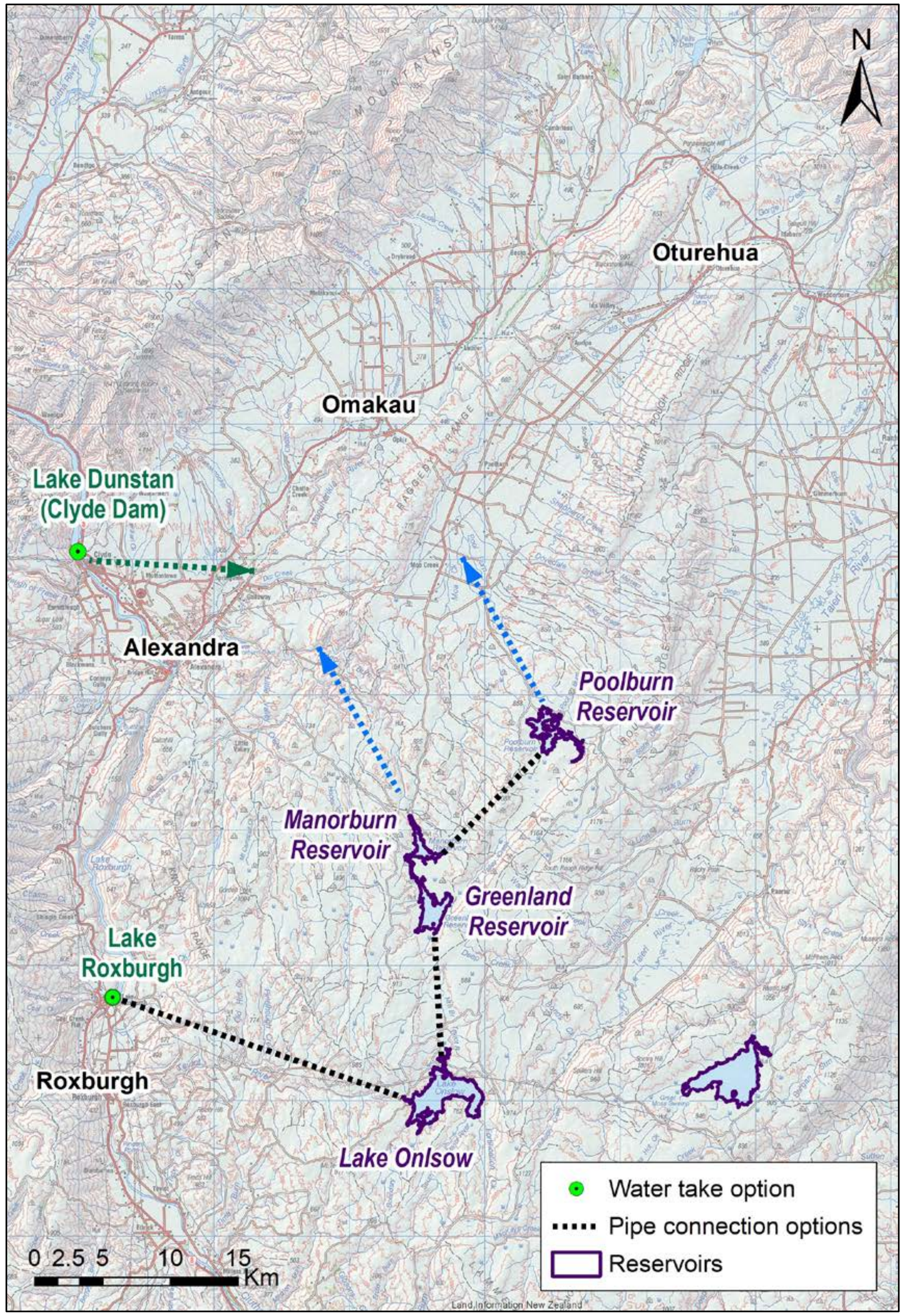

Figure 4.7 Potential technical hydro-storage options for Manuherekia–Ida focus area.

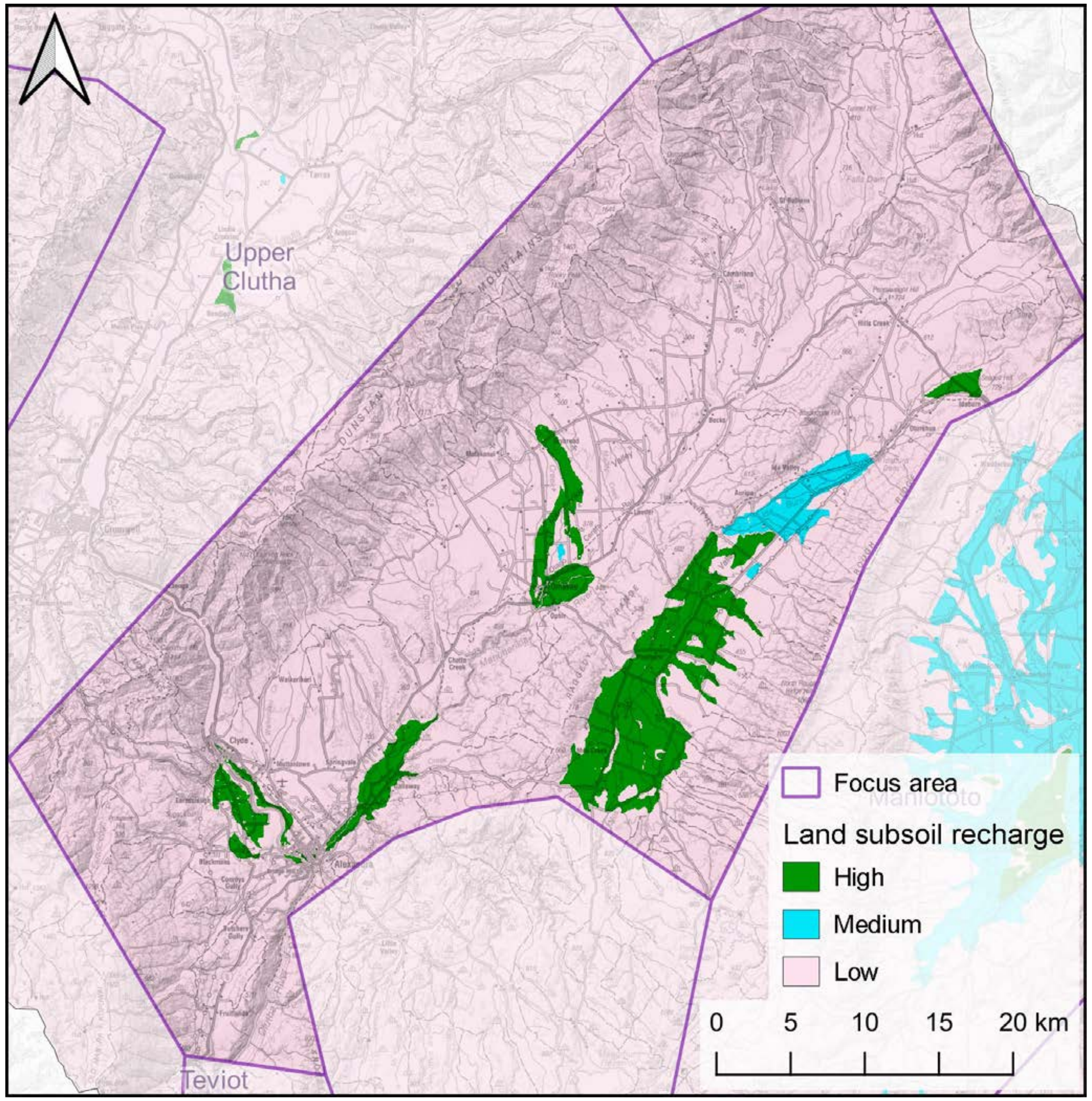

Figure 4.8 Potential for land subsoil recharge for the Manuherekia–Ida focus area.

4.2.3 Maniototo

The Maniototo focus area (Figure 4.9) is predominantly covered by grasslands, with a large proportion of high-producing grasslands (Figure 4.10). Activities are still largely dominated by sheep and beef operations, although a number of large-scale dairy operations and dairy-support uses are operational within this focus area. There is currently limited arable production in the Maniototo and no known horticulture or viticulture. Both land uses (arable and horticulture) have the potential to establish with access to reliable water, albeit other factors may still limit the establishment of such uses, including transportation barriers and shortage of skilled labour.

There appears to be little evidence of research having been undertaken to look at crop production and land-use opportunities within the Maniototo focus area, which should be taken into consideration to inform future water storage needs and opportunities.

Approximately 14,500 ha have been brought into production through irrigation (Figure 4.9; Stats NZ 2019), and up to approximately 86,800 ha could be brought into production (Figure 4.9; LRIS Portal 2020), if sufficient water were available to support this level of land development.

Environmental issues that need to be considered for this focus area are mainly low stream baseflow and water quality issues.[13]

Water allocation maps (Figures 2.2 and 2.3) indicate that some groundwater, but no surface water, is available for allocation. However, as per the Manuherekia–Ida valleys, the Maniototo focus area is naturally constrained by water availability. The rainfall is modest, the evapotranspiration high, there is very little natural water storage and there is a lack of significant groundwater resource[14] (Rekker 2021). Therefore, a potential option could be the development of a pumped-storage scheme using Lake Onslow and Loganburn Reservoir (Figure 4.11). Consultation with Ngāi Tahu on possible concerns regarding the mixing of waters is a priority before investigating this option further. The Loganburn Dam reservoir has a storage capacity of 96 M m^3 after being raised in 2014. There is potential to further raise the Loganburn Dam, but this may only be worthwhile if additional catchment area to fill the dam can be diverted. Diversions are possible from the upper Sutton Stream or upper Taieri catchments. The northern Maniototo irrigation season supply could be enhanced by the provision of additional storage above the Mt Ida Water Race, as outlined for the Manuherekia–Ida focus area.

Access to water could also be possibly improved through enhanced groundwater storage methods (e.g. land subsoil recharge; Figure 4.12).

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13 For the July 2015 – June 2020 period (Otago Regional Council [2020]e), e.g. dissolved reactive phosphorus concentrations were above the Otago Water Plan limits for the Taieri River at the Waipiata monitoring site.

14 The physical ability to draw groundwater from poor aquifer property formations seems to be the reason that the potential allocation has not been exhausted already.

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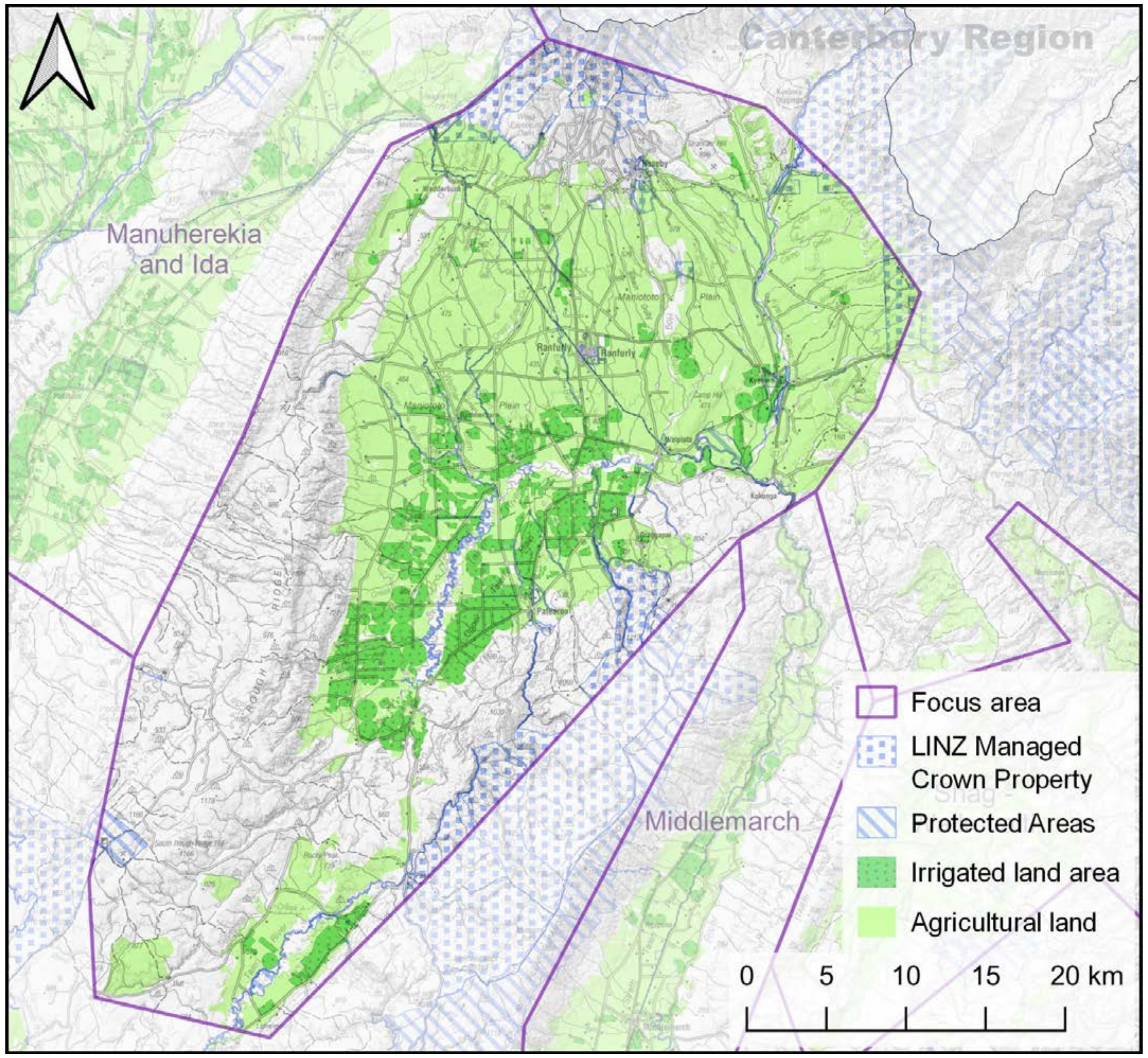

Figure 4.9 Maniototo focus area summary.

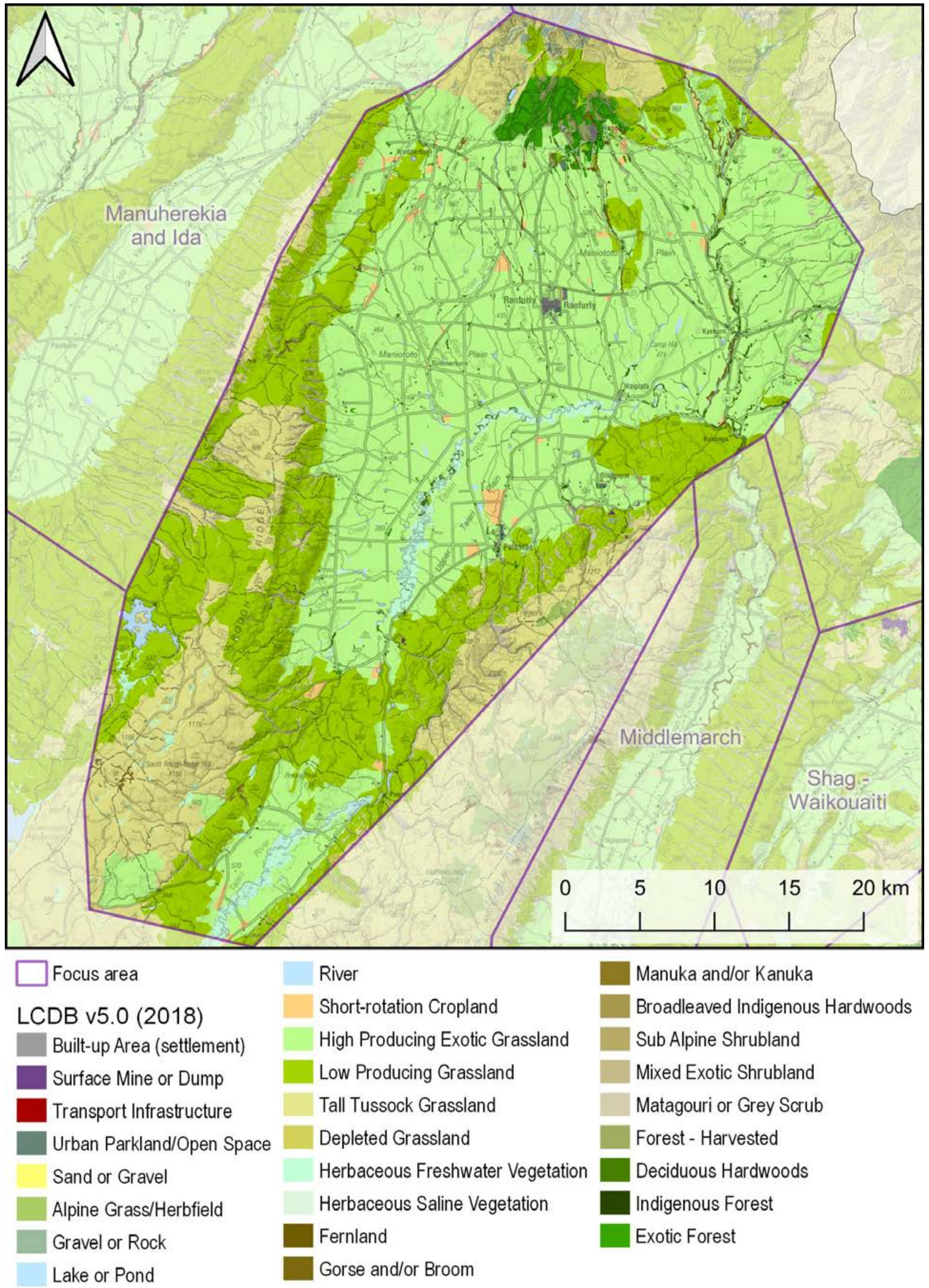

Figure 4.10 Land use/cover in 2018 for the Maniototo focus area (Land Cover Database [LCDB v5.0 (2018)]; LRIS Portal 2020).

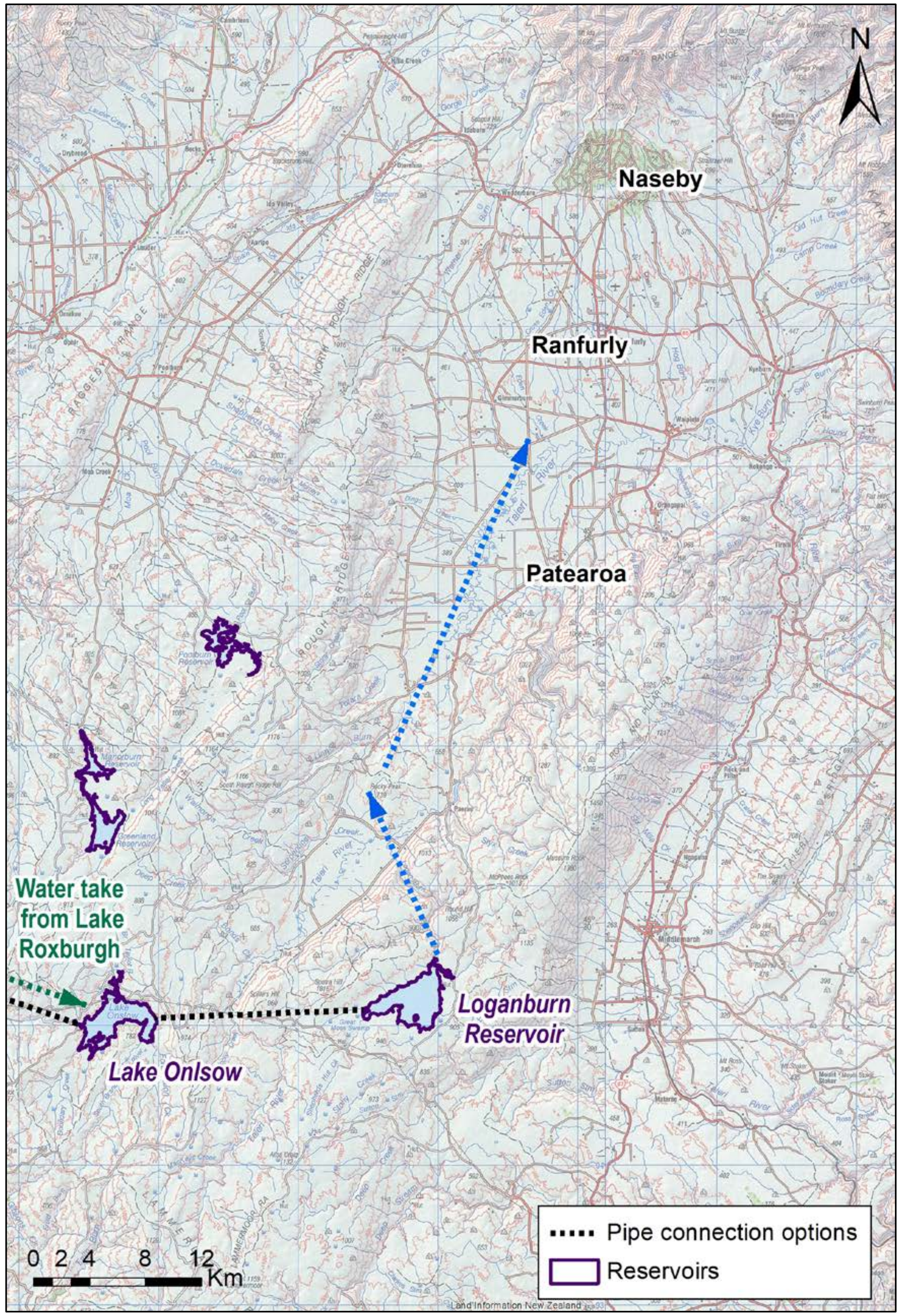

Figure 4.11 Potential technical hydro-storage options for Maniototo focus area.

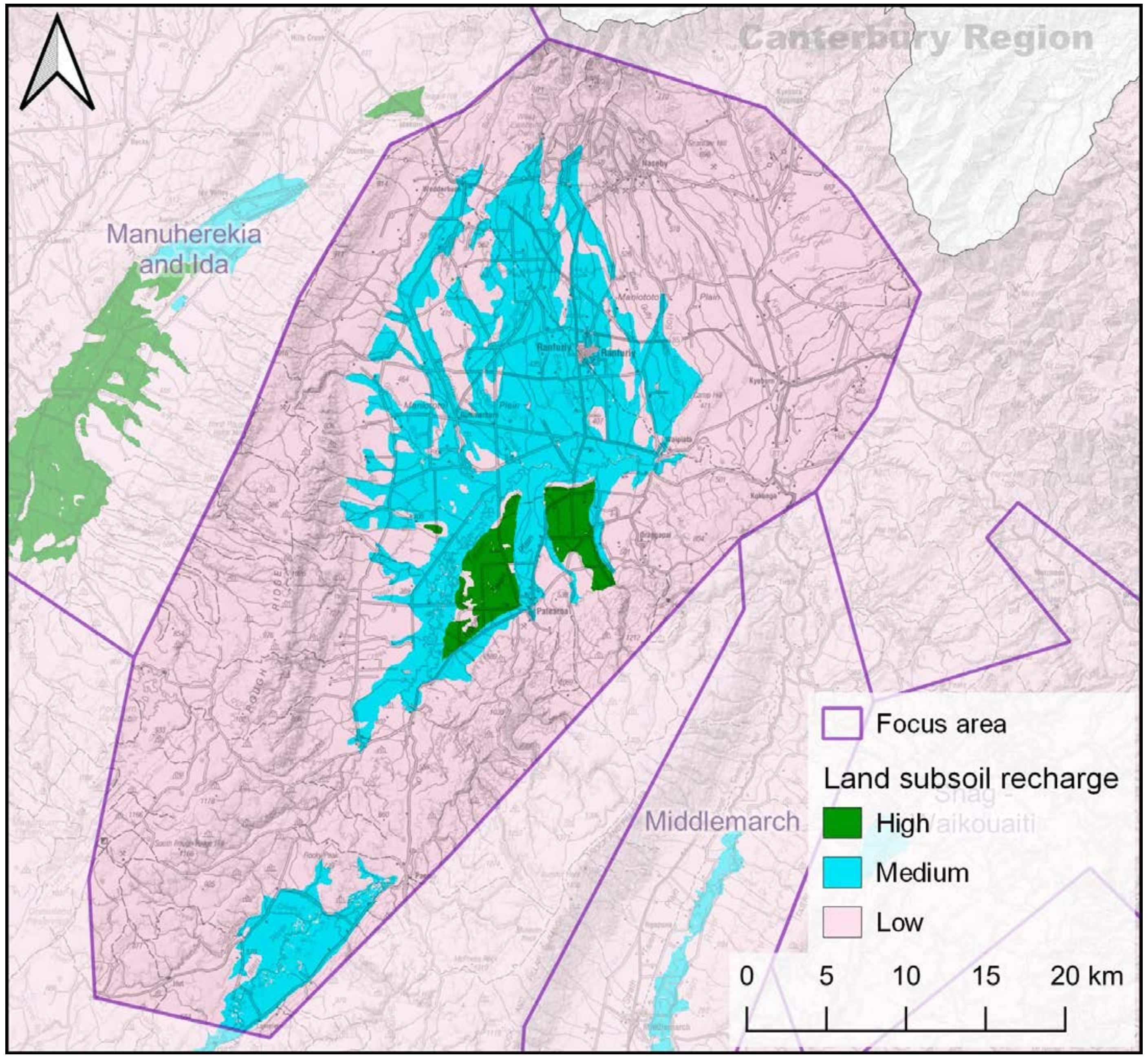

Figure 4.12 Potential for land subsoil recharge for the Maniototo focus area.

4.2.4 Middlemarch

The Middlemarch focus area (Figure 4.13) is dominantly covered by grasslands (high-producing in the valley and low-producing on sloping terrain; Figure 4.14). Associated current land use is heavily focused on pastoral farming and is largely characterised by dryland sheep and beef production with some limited areas of irrigation, which are often utilised to support winter crop production as part of a sheep and beef system.

Existing irrigation covers approximately 1880 ha (Figure 4.13; Stats NZ 2019), and the maximum irrigation potential in the area is approximately 16,500 ha (Figure 4.13; LRIS Portal 2020), if sufficient water were available to support this level of land development. Environmental issues include low stream baseflow, limited water supply resources and degradation of water quality.[15] Water storage investments could investigate how to support environmental improvements.

Soil fertility is a driver of land-use potential. In the Middlemarch focus area, soil fertility is predominantly high to medium (growOTAGO [date unknown]). Future land-use opportunities are likely to require access to a reliable source of water, although growth in manuka honey production, for example, is one such crop that could potentially thrive in the absence of reliable water.

There is currently limited research that focuses on future land-use opportunities within the focus area, although there is indication that high-value crops like quinoa could be grown in the Otago region (Gibb 2014). Quinoa is currently grown in Canterbury, Taranaki and the Manawatu without irrigation. At present (in the absence of evidence to suggest otherwise), access to reliable water is most likely to drive increased productivity within existing sheep and beef systems.

Hamilton and Associates (2006b) investigated the potential to divert the headwaters of Sutton Stream (from Stony Creek and Burgan Stream) into the Loganburn Dam (Appendix 4; Figure A4.1) and to further raise Loganburn Dam to provide an additional 10 M m^3 of storage. Outflows for the Strath Taieri could flow through the Paerau hydro power station and down about 130 km of the Taieri River, enhancing streamflow, to the Middlemarch area where a community irrigation scheme could be established. Potential reliable irrigation flows could be provided to 1500–2000 ha.

The Middlemarch focus area has very limited water resources. Water allocation maps (Figures 2.2 and 2.3) indicate that some groundwater, but no surface water, is available for allocation. Again, this may not be representative of the actual groundwater availability but rather represent low rainfall, high evapotranspiration, limited water storage and the absence of a large groundwater resource. Therefore, a potential option could include a pumped-storage scheme using Lake Onslow and Loganburn Reservoir (Figure 4.15). Consultation with Ngāi Tahu on possible concerns regarding the mixing of water will be a priority before further investigations are undertaken. Enhanced groundwater storage (e.g. land subsoil recharge; Figure 4.16) might also be an option, even though the potential seems limited.

15 For the July 2015 – June 2020 period (Otago Regional Council [2020]g), e.g. E. coli and dissolved reactive phosphorus concentrations were above the Otago Water Plan limits for the Taieri River at the Sutton monitoring site.

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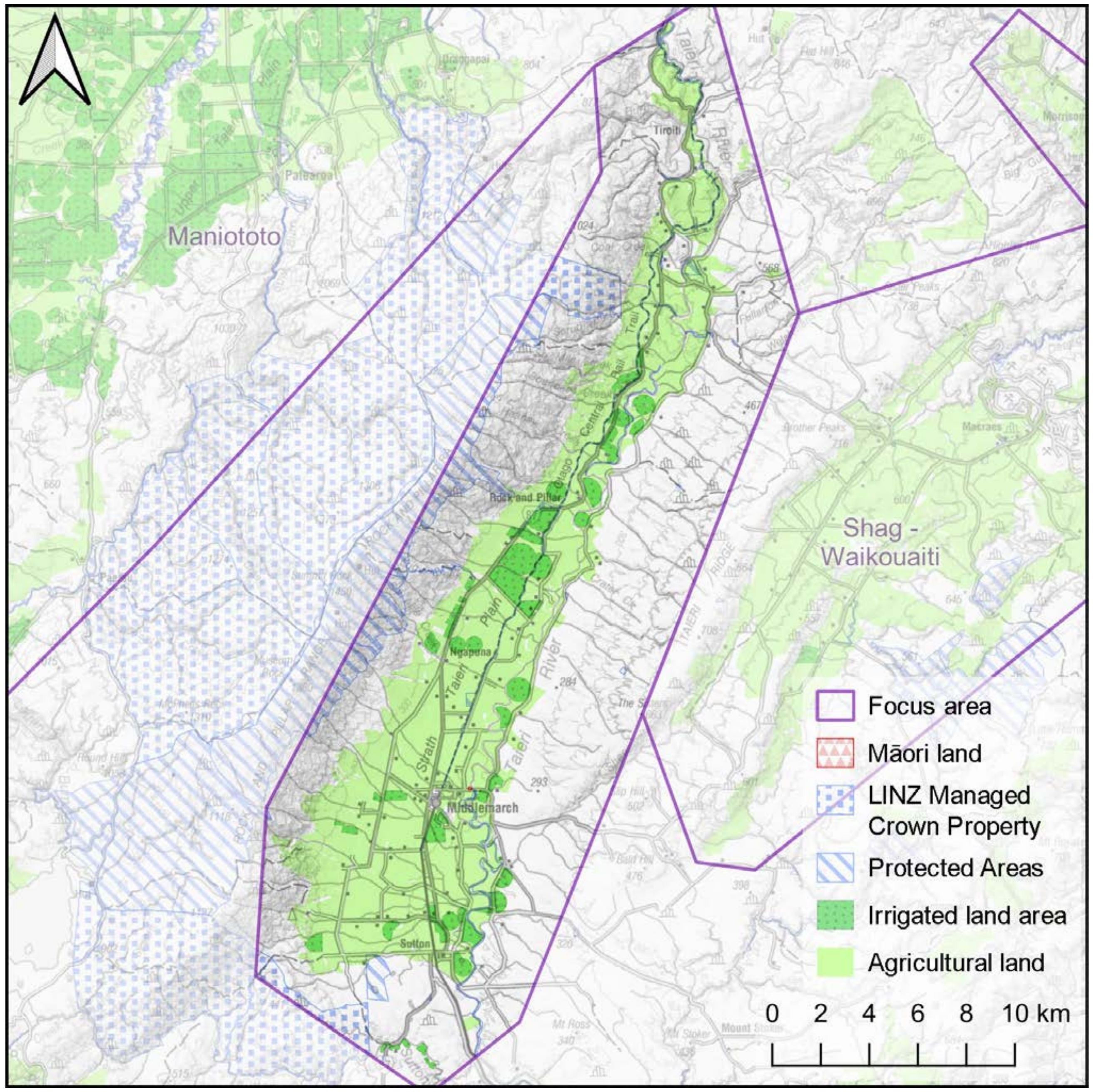

Figure 4.13 Middlemarch focus area summary.

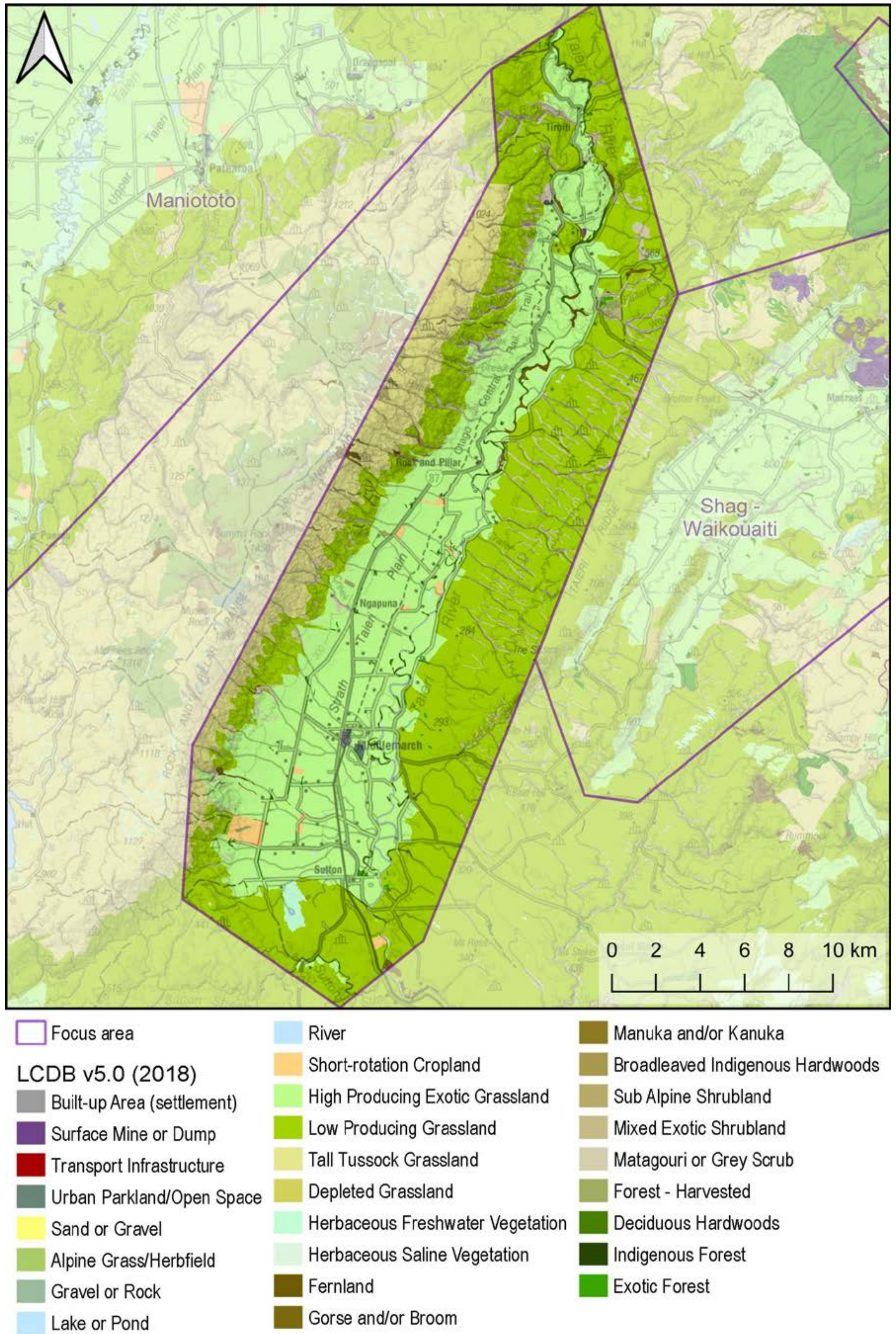

Figure 4.14 Land use/cover in 2018 for the Middlemarch focus area (Land Cover Database [LCDB v5.0 (2018)]; LRIS Portal 2020).

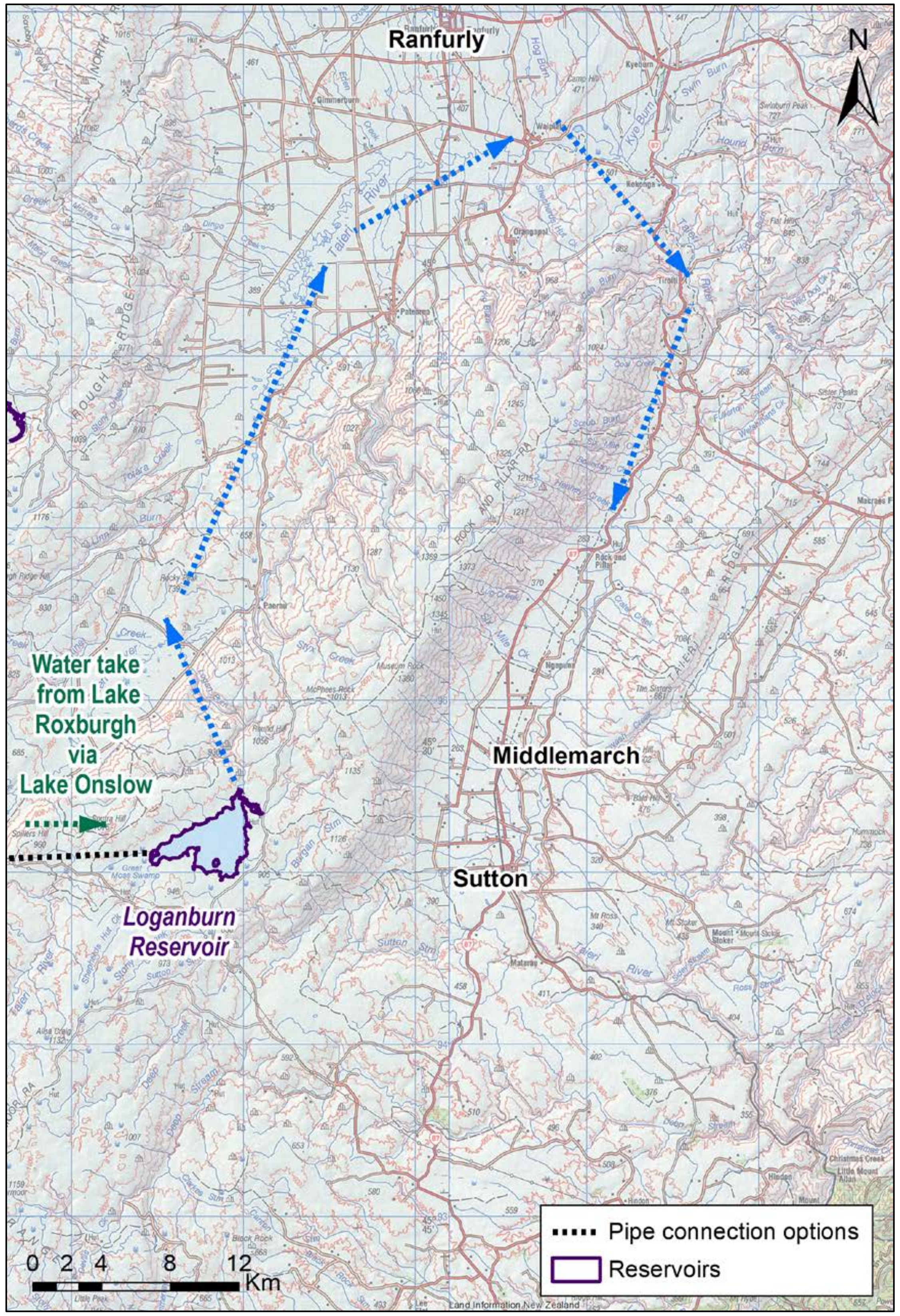

Figure 4.15 Potential technical hydro-storage options for the Middlemarch focus area.

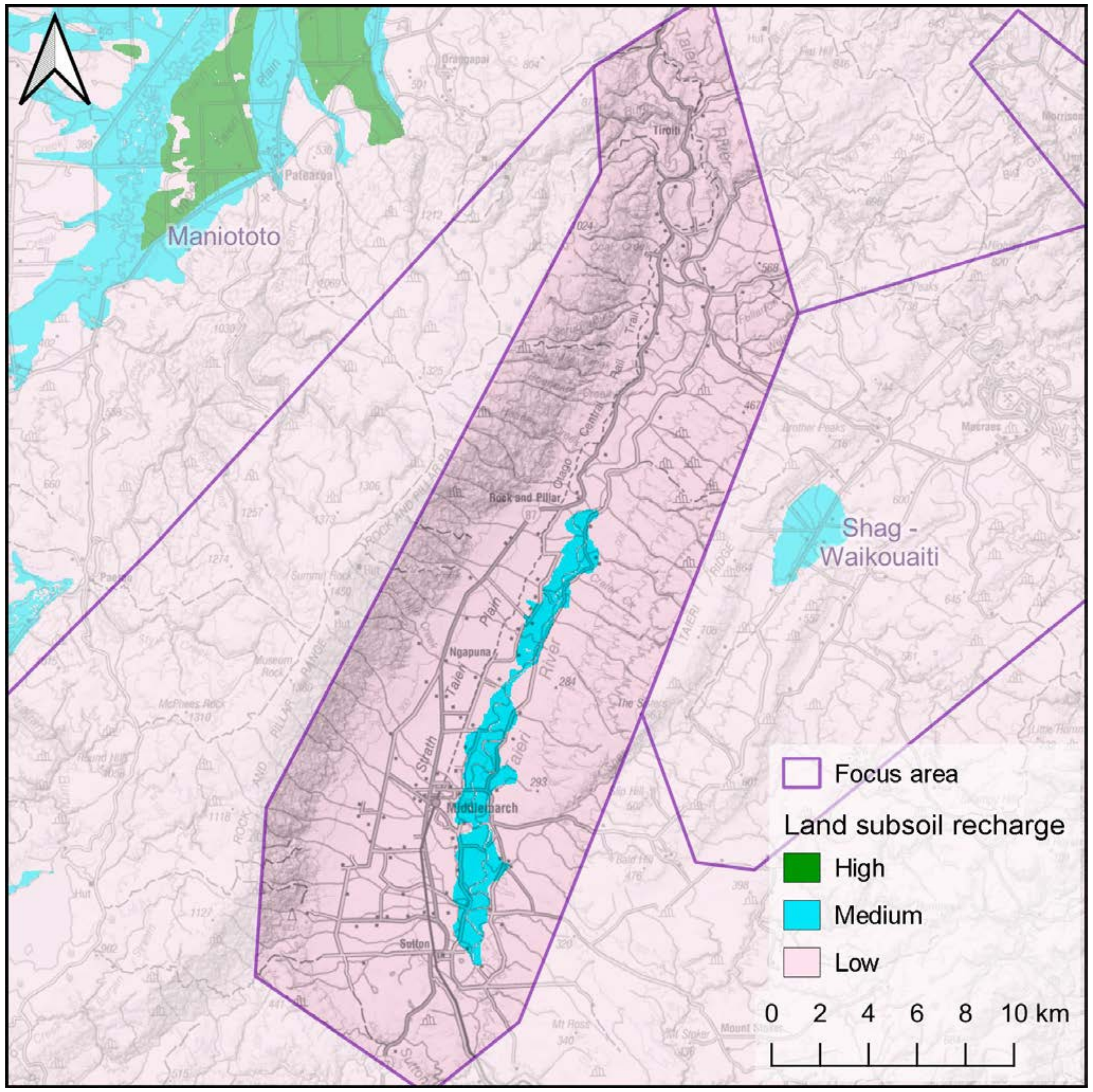

Figure 4.16 Potential for land subsoil recharge for the Middlemarch focus area.

4.2.5 Shag–Waikouaiti

The Shag–Waikouaiti focus area (Figure 4.17) is mainly covered by grasslands (high-producing in the valley flats and low-producing on steeper terrain) with some forestry, hard-rock gold mining and horticulture activities locally (Figure 4.18).

Opportunities for agriculture are severely limited in the focus area by access to reliable water supply. The underlying land is typically described as being highly fertile, with a climate that could conceivably support expansion of arable and cropping land use, including seed production, as well as an increase in horticulture. It is understood that a small amount of berry fruit is grown within the focus area at present.

A review of the available literature indicates that there has been very little exploration of future land-use/crop opportunities in the Shag area.

Existing irrigation covers approximately 320 ha (Figure 4.17; Stats NZ 2019), with maximum irrigation potential in the area of approximately 42,700 ha (Figure 4.17; LRIS Portal 2020), if sufficient water were available to support this level of land development.

The Shag–Waikouaiti focus area has very limited water resources, and previous water availability assessments have not resulted in additional water storage in the area. Water allocation maps (Figures 2.2 and 2.3) indicate that both surface water and connected groundwater are available for allocation under the current Regional Water Plan. However, this corresponds to limited opportunities (10 L/s as primary allocation), and both minimum flows and allocation limits are currently under review (De Pelsemaeker 2021).

Therefore, water importation is a potential option. Consultation with Ngāi Tahu on possible concerns regarding water transfers between catchments will be a priority before further investigation of this option is undertaken. Possible sources of water from hydro-storage could include:

- supply from the Waitaki River via a connection/extension of the NOIC Scheme (Appendix 4; Figure A4.2) from Herbert (Option A in Figure 4.19), and
- a connection to the proposed pumped-storage scheme using Lake Onslow, the Loganburn Reservoir and following the upper Taieri River and the Pigroot (Option B in Figure 4.19).

Environmental issues could benefit from the water importation with increase in stream baseflow and potential improvement in surface water quality[16] (e.g. ecological indicators); however, these need to be reconciled with cultural issues.

Formerly, Hamilton & Associates Ltd (2006a) also identified a 15 M m^3 storage reservoir, located midway up the Shag Valley (Appendix 4, Figure A4.3), that would improve low flows and enable up to 2500 ha of irrigation.

A small amount of Māori land is present in the Karitane area. This land is either residential, hobby farms or wetlands, and it appears that there are very limited opportunities for productive irrigated farming on Māori land in this area (Rekker 2021).

16 For the July 2015 – June 2020 period (Otago Regional Council [2020]f), e.g. Nitrate-nitrite-Nitrogen concentrations were above the Otago Water Plan limits for Shag River at the Craig Road and Goodwood Pump monitoring sites.

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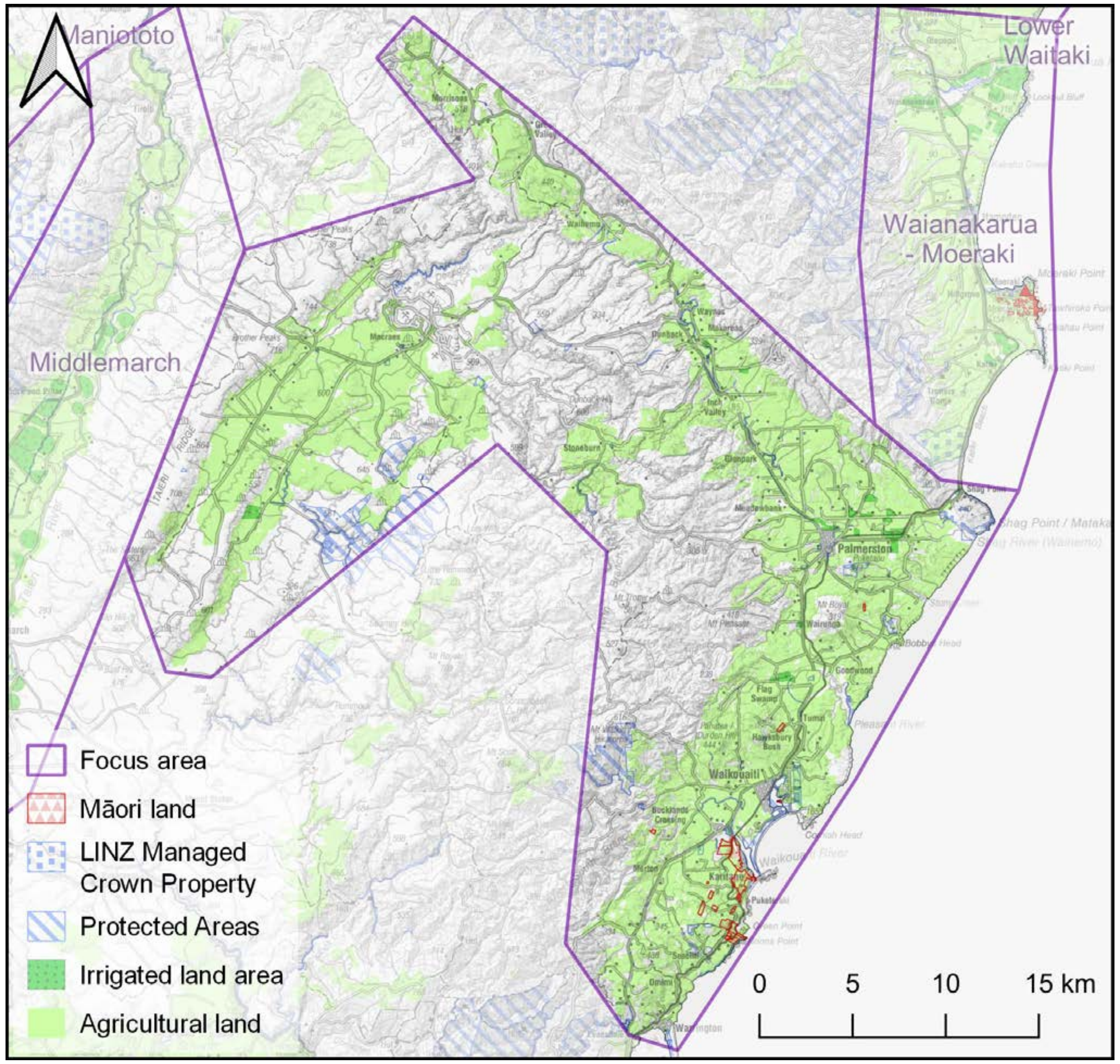

Figure 4.17 Shag–Waikouaiti focus area summary.

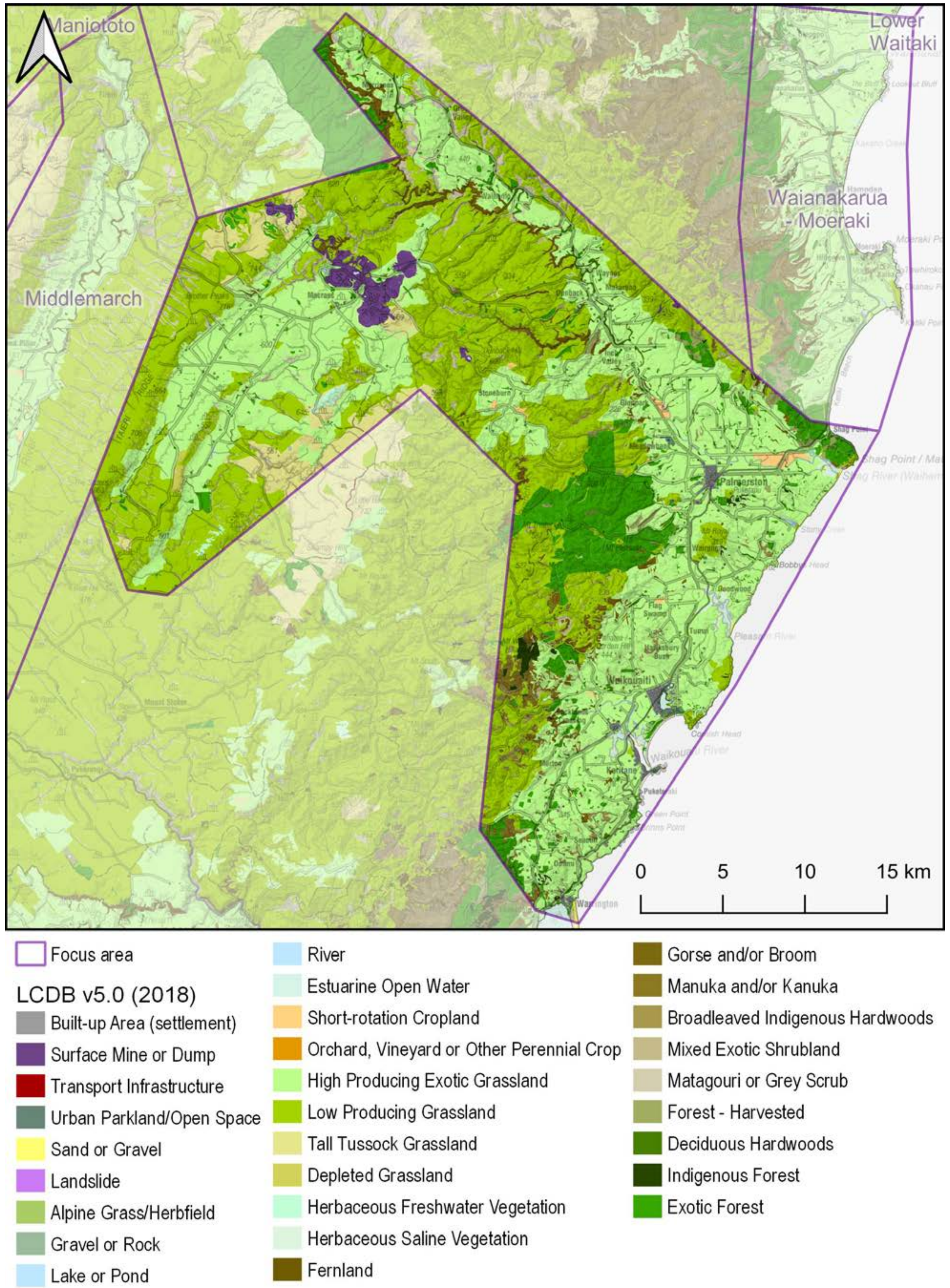

Figure 4.18 Land use/cover in 2018 for the Shag–Waikouaiti focus area (Land Cover Database [LCDB v5.0 (2018)]; LRIS Portal 2020).

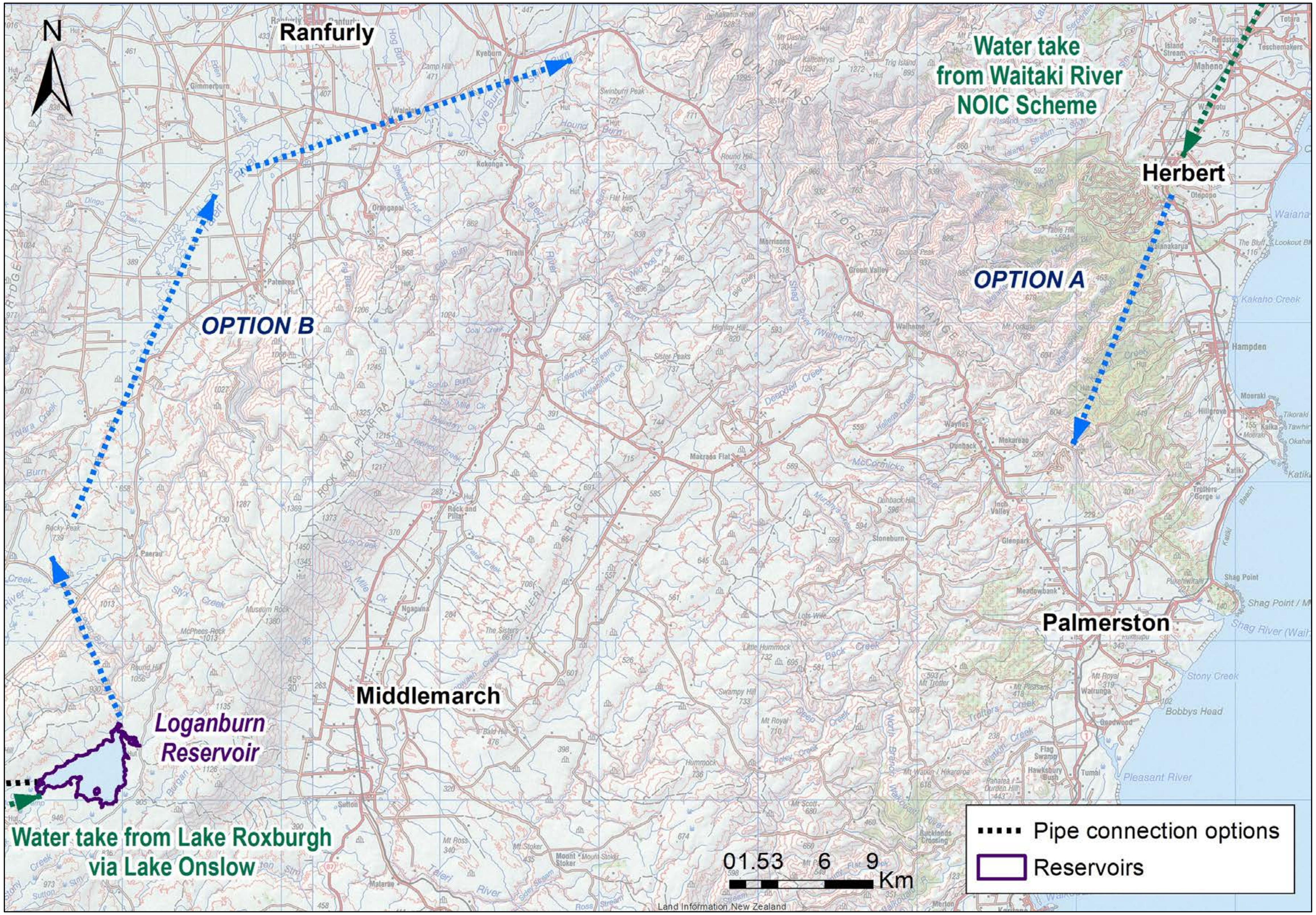

Figure 4.19 Potential technical options for the Shag Valley: North Otago Irrigation Company (NOIC) Scheme connection (A) and hydro-storage (B).

4.2.6 Waianakarua–Moeraki

The Waianakarua–Moeraki focus area (Figure 4.20) encompasses flat to undulating contour that lies between the coast and the inland hills of the Waianakarua area. Grasslands are the predominant land cover in the area and are associated with pastoral farming, including sheep, beef and small pockets of dairy/dairy-support farmland. Plantation forestry is also present on the hills of the focus area (Figure 4.21).

Existing irrigation covers approximately 960 ha (Figure 4.20; Stats NZ 2019), with a maximum potential for land development of approximately 10,100 ha (Figure 4.20; LRIS Portal 2020), if sufficient water were available to support this level of land development.

No information on alternative land uses was found for the focus area that could inform discussion on land-use change opportunities or on the value that could be derived from an expansion of irrigation within the focus area.

Water allocation maps (Figures 2.2 and 2.3) indicate that surface water is available for additional abstraction but that no mapped aquifers and associated groundwater allocation limits exist for this focus area. This is linked to the poor aquifer properties of the geological formations locally.

The Waianakarua–Moeraki focus area is water-short. The Waianakarua River and Trotters Creek are the main sources for irrigation at present, but farms are starting to use water delivered by the NOIC Scheme (Appendix 4; Figure A4.2). Therefore, water importation could be a possible option for parts of the Waianakarua–Moeraki area, if possible cultural concerns regarding the mixing or transfer of waters between catchments could be addressed. Options could include connections to an extended NOIC Scheme (Figure 4.22, Option A); or the Lake Onslow / Shag Valley, if developed (Figure 4.22, Option B).

Environmental issues could benefit from the water importation with increase in stream baseflow and potential improvement in surface water quality[17] (e.g. ecological indicators). A small amount of Māori land is present near Moeraki Point; however, it appears that there are limited opportunities for productive irrigated farming on this land.

17 For the July 2015 – June 2020 period (Otago Regional Council [2020]i), e.g. Nitrate-nitrite-Nitrogen concentrations were above the Otago Water Plan limits for Waianakarua River at the Browns and Trotters Creek at Mathesons monitoring sites.

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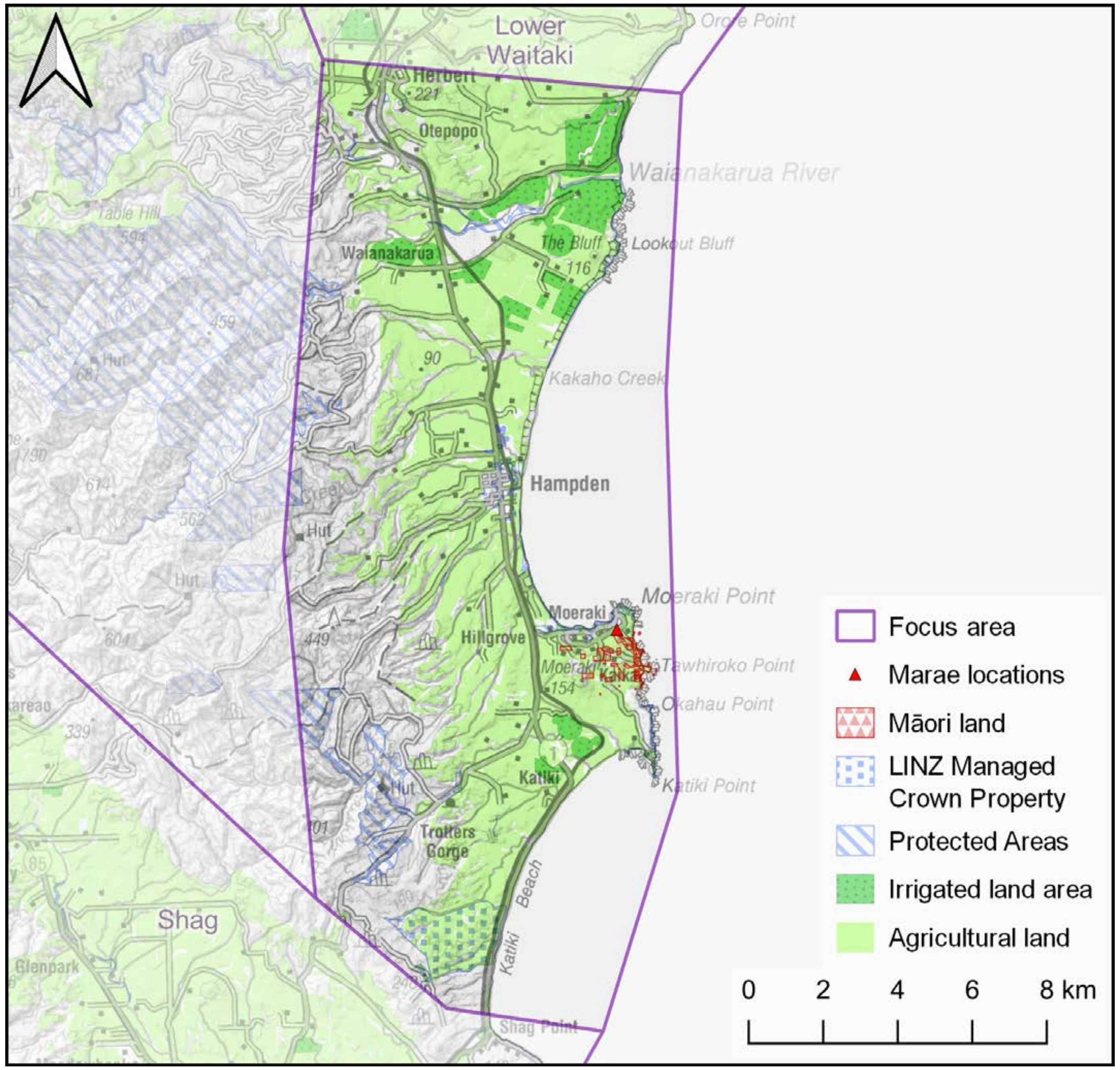

Figure 4.20 Waianakarua–Moeraki focus area summary.

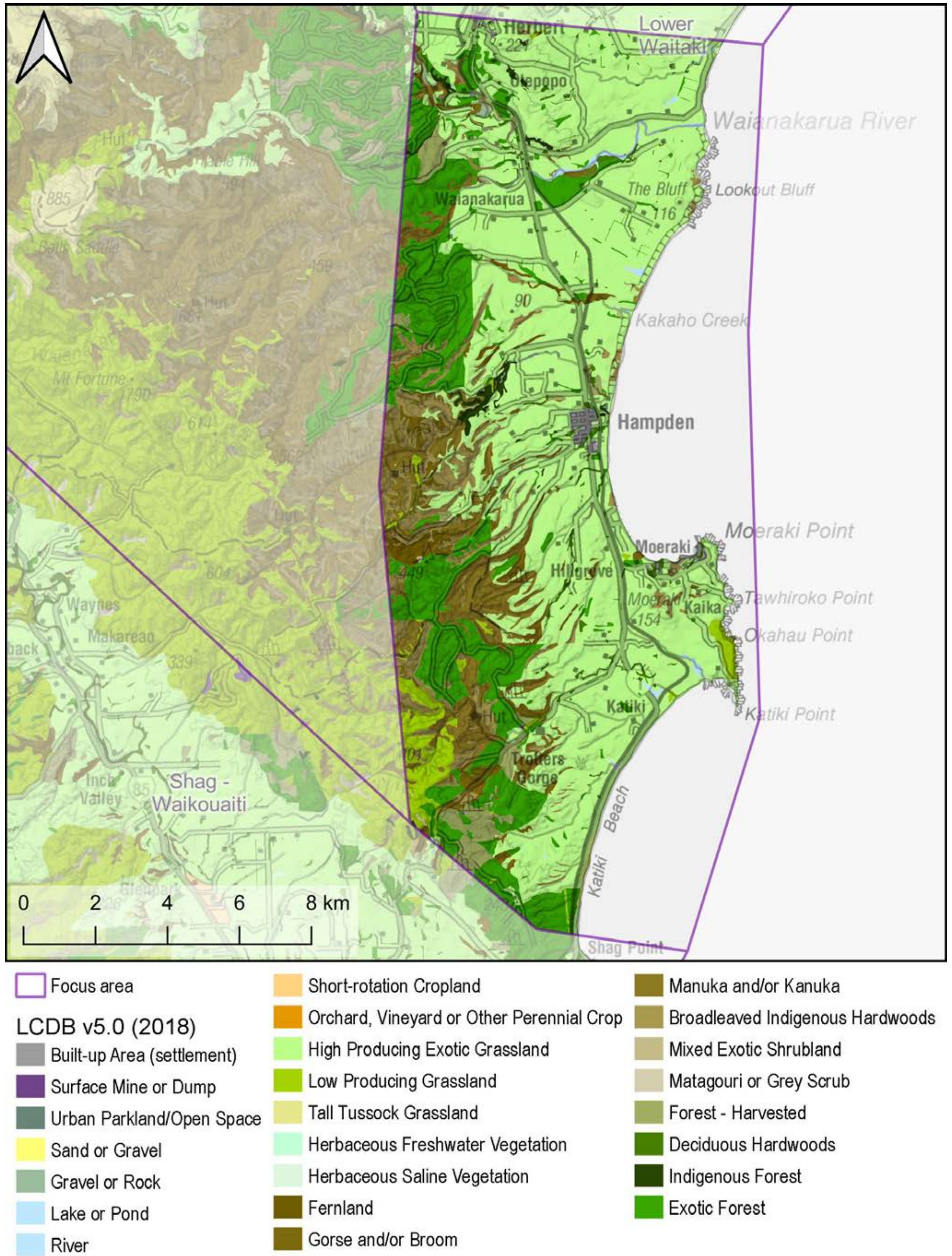

Figure 4.21 Land use/cover in 2018 for the Waianakarua–Moeraki focus area (Land Cover Database [LCDB v5.0 (2018)]; LRIS Portal 2020).

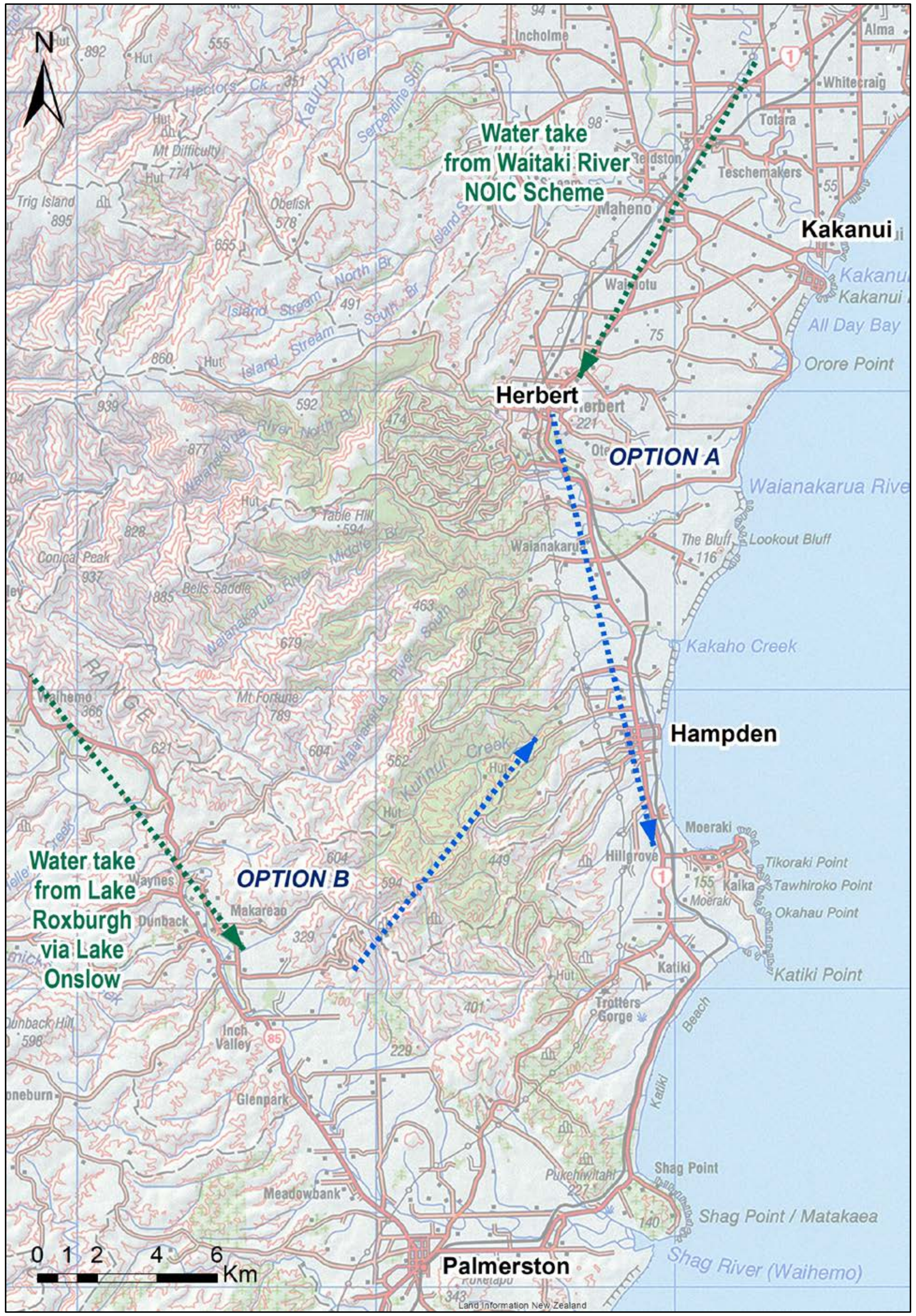

Figure 4.22 Potential technical options for the Waianakarua–Moeraki focus area: North Otago Irrigation Company (NOIC) Scheme connection (A) and hydro-storage (B).

4.2.7 Taieri Plains

The Taieri Plains focus area (Figure 4.23) is mainly covered by high-producing grasslands in the plains, with some plantation forestry on the eastern and western hill margins (Figure 4.24). The current land uses between Mosgiel and Milton are support-dairy and sheep and beef production, as well as pockets of floriculture and market gardening. The area is dominated by smaller farm units overall compared to elsewhere in Otago. The Taieri Plains have supported a broad range of agricultural land uses in the past (including carrots, cabbages, potatoes, wool, pasture, wheat, oats and barley) due the presence of nearby populations and highly suitable soils, although, more recently, some of the productive land that was historically utilised for vegetable production or pastoral use has been converted to urban and lifestyle properties, especially in the areas surrounding Mosgiel and Outram.

Seasonal water shortages can occur during summer; however, flooding is more of a problem, and extensive drainage works are required to maintain agricultural production.

Existing irrigation covers approximately 524 ha (Figure 4.23; Stats NZ 2019), and the maximum irrigation potential is approximately 41,200 ha (Figure 4.23; LRIS Portal 2020), if sufficient water was available to support this level of land development.

Leamy (1970) identified that production from Wingatui Silt Loam is capable of high yields of a wide variety of crops, including pasture, cereals and vegetables. These soils are typically associated with flat to gently undulating topography and are subject to flooding from time to time. In terms of future productive capability, there may be opportunity to return to market gardening and vegetable production, or a variety of other uses, given the highly fertile and productive nature of the underlying soils. Alternative high-value crops like quinoa or hemp may have a place in future production systems, although markets for both are still relatively small. On more intensively farmed parts of the Taieri Plains, there may be the opportunity to utilise catch crops like hemp, which not only create greater on-farm diversification but also have a functional benefit in terms of the uptake of excess nutrient. There may be options for utilising the land for less-intensive livestock farming, such as goat or sheep milk production, which, given the proximity to a relatively large population compared to other parts of Otago, could create a market advantage for local supply. There could be advantages from a food production and processing perspective.

Water allocation maps (Figures 2.2 and 2.3) indicate that, under the current Regional Plan: Water, only groundwater is available for allocation. Groundwater abstraction is partially controlled by groundwater level restriction bores of the Regional Water Plan. Possible water storage options include groundwater storage and small dams (Figures 4.25 and 4.26; respectively).

Environmental benefits of the use of storage in the area could be an increase in summer stream baseflow and surface water quality improvement.[18]

18 For the July 2015 – June 2020 period (Otago Regional Council [2020]h):

- E. coli and Nitrate-nitrite-Nitrogen (NNN) concentrations were above the Otago Water Plan limits for the Silverstream at the Taieri Depot monitoring site;
- E. coli and Dissolved Reactive Phosphorus (DRP) were above the Otago Water Plan limits for the Taieri River at the Allanton Bridge monitoring site; and
- E. coli, NNN and DRP were above the Otago Water Plan limits for Lake Waihola at the Jetty monitoring site.

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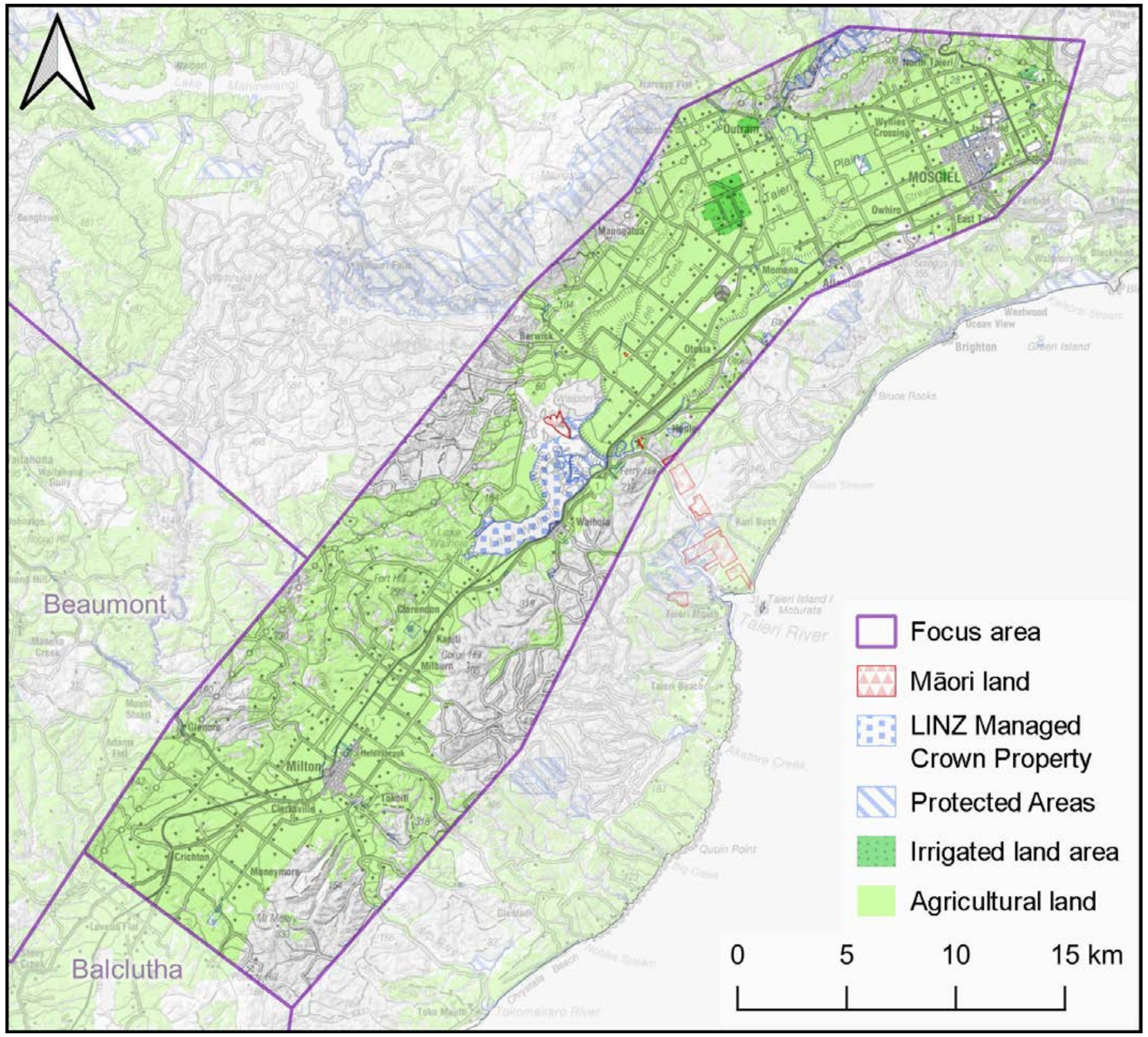

Figure 4.23 Taieri focus area summary.

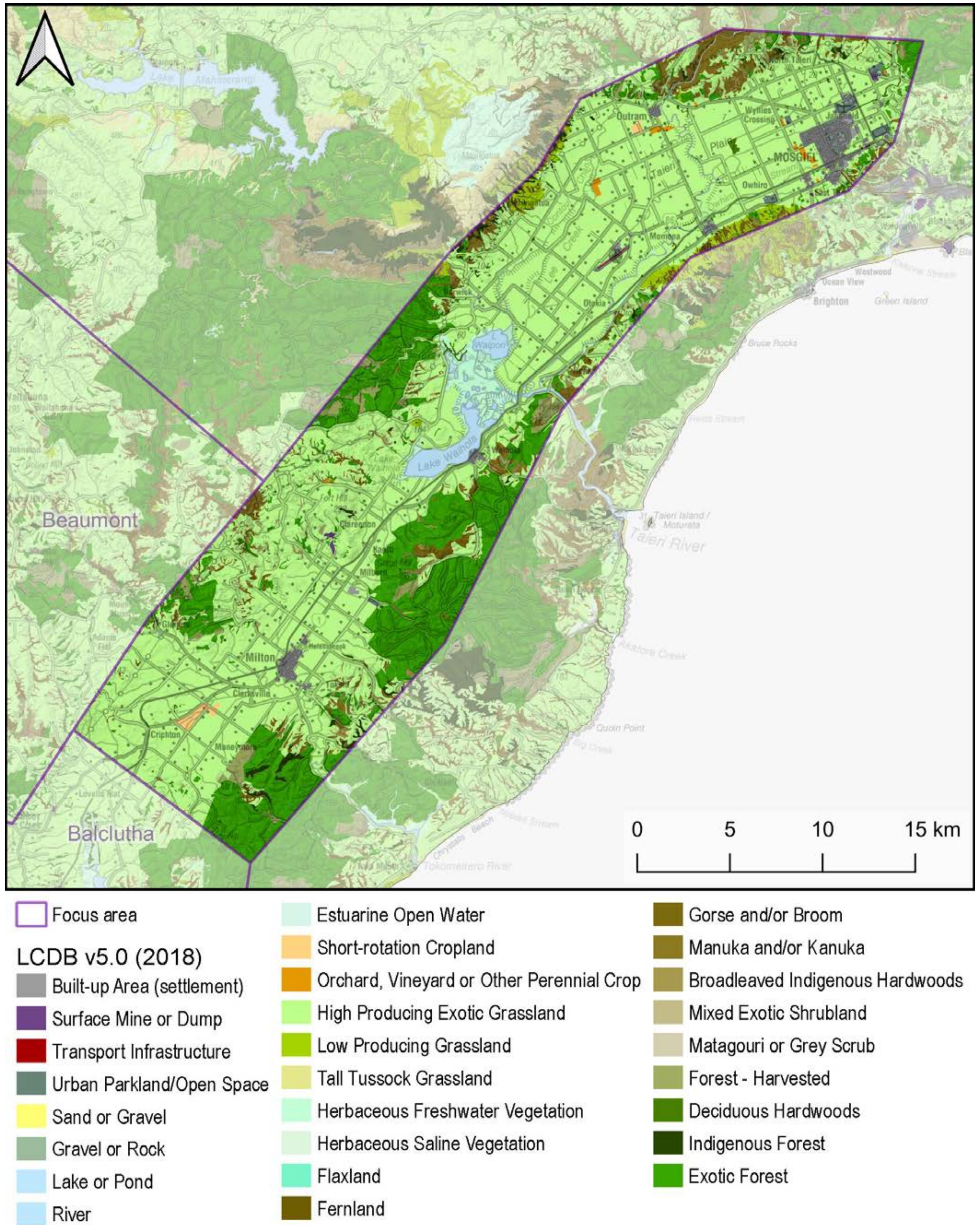

Figure 4.24 Land use/cover in 2018 for the Taieri Plains focus area (Land Cover Database [LCDB v5.0 (2018)]; LRIS Portal 2020).

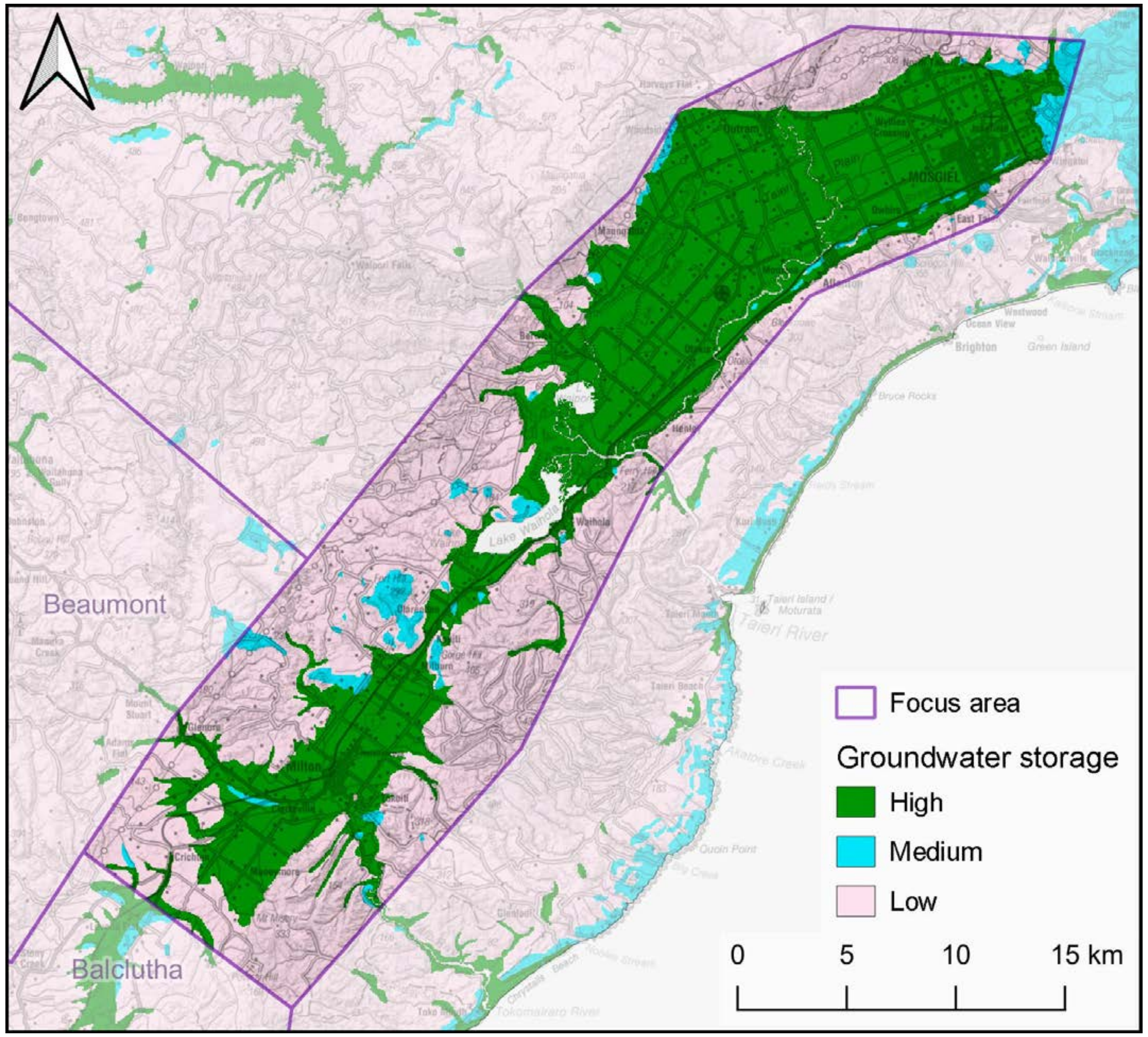

Figure 4.25 Potential for groundwater storage for the Taieri Plains focus area.

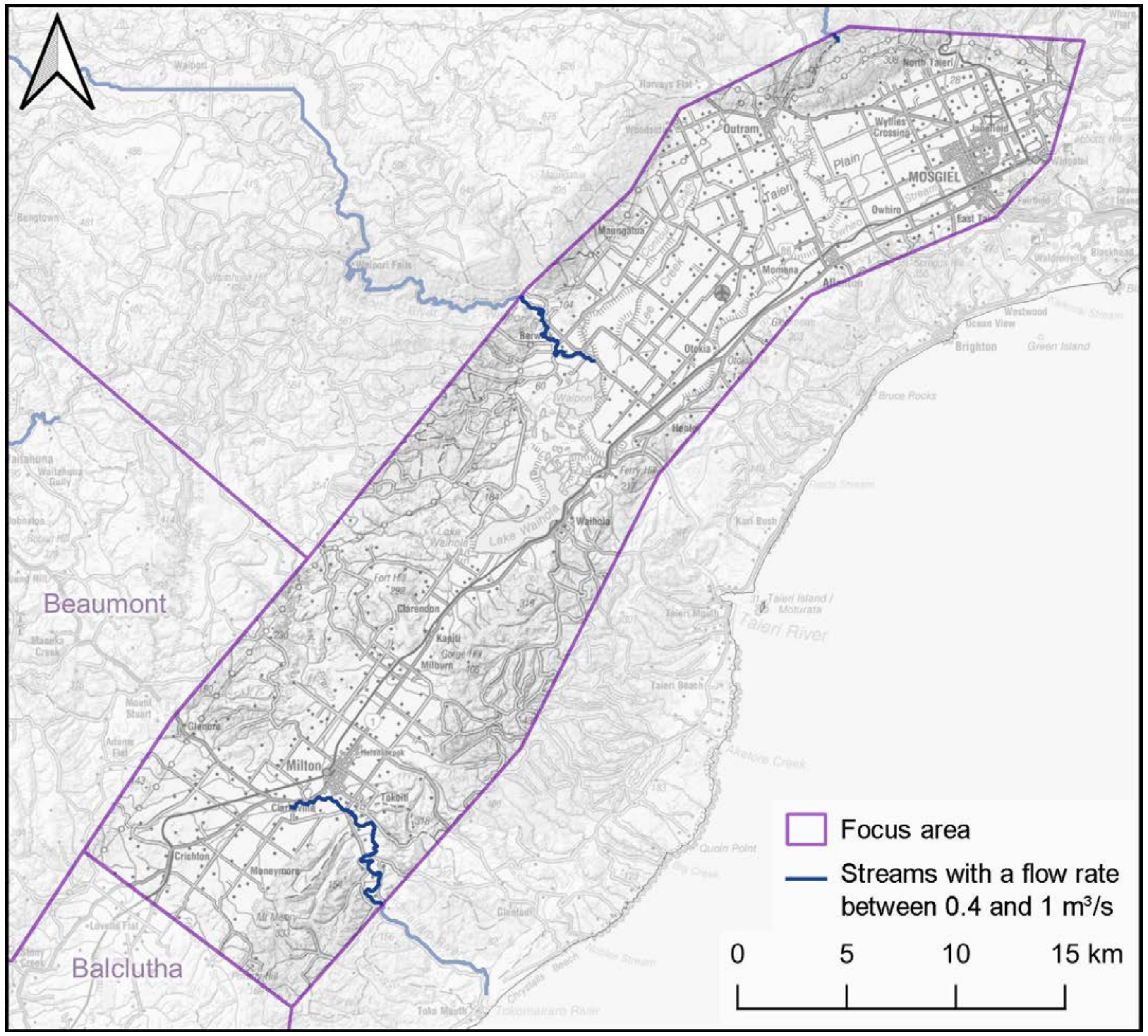

Figure 4.26 Potential for small dam option for the Taieri Plains focus area.

4.3 Summary of Technical Options

Discussions with ORC and Aukaha / Te Ao Marama (2021) indicate that many of the presented technical options (Table 4.1) and other potential technical options (Table 4.2) are unlikely to be pursued in Otago. Te Ao Marama (2021) indicated Otago iwi preference for: (i) 'natural storage' options that improve the characteristics of water bodies, (ii) exploration of the potential for increasing natural recharge and (iii) harvesting winter flows. Preference for off-stream storage rather than in-stream storage/dams was also signalled. New transfers of water between catchments are not favoured by mana whenua, particularly where alternatives exist.

Table 4.1 Priority Otago focus areas and possible water storage options.

<table>
<tr><th rowspan="2">Focus Area</th><th colspan="2">Possible Technical Water Storage Options</th></tr>
<tr><th>Option 1</th><th>Option 2</th></tr>
<tr><td>Upper Clutha</td><td>Hydro-storage
• Gravity feeds from Lake Hawea and Roaring Meg
• Pumped storage from Lake Dunstan
• Small dam on Luggate Creek</td><td>Enhanced groundwater storage
• e.g. Managed aquifer recharge (MAR)</td></tr>
<tr><td>Manuherekia–Ida</td><td>Hydro-storage
• Gravity feed from Lake Dunstan to the lower area of Manuherekia Valley
• Pumped scheme from Lake Roxburgh and Lake Onslow in parallel with the proposed Lake Onslow pumped storage scheme</td><td>Enhanced groundwater storage
• e.g. Land subsoil recharge (LSR)</td></tr>
<tr><td>Maniototo</td><td rowspan="2">Hydro-storage
• Pumped-storage scheme using Lake Onslow and Loganburn Reservoir</td><td rowspan="2">Enhanced groundwater storage
• e.g. Land subsoil recharge (LSR)</td></tr>
<tr><td>Middlemarch</td></tr>
<tr><td>Shag–Waikouaiti</td><td rowspan="2">Connection to NOIC Scheme
• Extension of the NOIC Scheme to provide water to Moeraki area / lower reaches of the Shag River</td><td rowspan="2">Hydro-storage
• Transport water from the proposed Lake Roxburgh / Lake Onslow pumped storage scheme, via the Taieri River, to the upper reaches of the Shag River / Moeraki area</td></tr>
<tr><td>Waianakarua–Moeraki</td></tr>
<tr><td>Taieri Plains</td><td>Groundwater</td><td>Small dams</td></tr>
</table>

NOIC: North Otago Irrigation Company.

Table 4.2 List of other potential water storage options for the priority focus areas.

Focus Area	Other Potential Technical Water Storage Options*
Upper Clutha	• Small dam on the Lindis River (Archies Flat) [1, 2] • Increased Roaring Meg dam capacity combined with inter-catchment transfer into the upper Cardrona catchment at the low saddle between the Kawarau and Cardrona catchments [1]
Manuherekia–Ida	• Small dam on Dunstan Creek (Pauley Road) [2] • Small dam on Ida Burn (Riverside) [2]
Maniototo	• Small dam on Taieri River (Waipiata) [2] • Small dam on Kye Burn (Kyeburn Diggings) [2]
Middlemarch	• Small dam on Taieri River (Matarae) [2]
Shag–Waikouaiti	• Small dam on Deepdell Creek with civil engineering, potentially combined with hard-rock open cast mining activities [1] • Small dam on Waikouaiti River North Branch (Bucklands Crossing) [2]
Waianakarua–Moeraki	• Small dam on the Kakanui upstream of Clifton Falls + connection to the focus area [1]

[1] Rekker 2021; [2] White et al. 2020.

* Small dams may include off-channel structures.

5.0 INVESTIGATIONS INTO WATER AVAILABILITY ACROSS OTAGO

The potential water storage options identified in this assessment are based on the region's geological and hydrological characteristics and Otago's existing water infrastructure and current water allocation. Any further investigations into water storage options progressed by Aqua Intel Aotearoa will relate to options that are consistent with scientific, regulatory and cultural priorities.

5.1 Investigations of Water Needs and Opportunities

Based on the work undertaken, the investments that could be useful to ORC and the region as they develop their new regulations (e.g. LWRP) fall into the following categories of investigations:

- better characterisation of groundwater and surface water resources in the focus areas;
- feasibility studies related to the use of hydro-storage, guided by cultural considerations; and
- land-use / water demand studies to explore higher-value land uses and associated water demand. This type of investigation is outside the scope of this programme but would be beneficial to explore through other funding sources.

These investigations would improve the understanding of water availability and potential water demand and would inform water storage solutions that are most appropriate within each focus area.

5.1.1 Better Characterisation of Groundwater and Surface Water Resources

Enhanced groundwater storage and associated methods of land subsoil recharge and managed aquifer recharge are technical options for consideration in some of the focus areas; for example, Manuherekia–Ida and Upper Clutha (e.g. Golder Associates 2015). These options are relevant because groundwater is generally available in these focus areas, albeit at relatively low rates, and current surface water is often fully allocated. However, these options require surface water inputs. In some cases, water transfers from other catchments will be required.

Groundwater investigations will improve the characterisation of aquifer physical parameters (e.g. hydraulic conductivity and groundwater storage), rainfall recharge and groundwater–surface water interactions. This would enable an assessment of the long-term sustainability of the resources. This knowledge could inform the development of groundwater storage-based options, advise councils for regulatory planning processes and allow the region to gain a better understanding of their freshwater resources.

The proposed investments could cover:

1. Analysis of the existing Glass Earth geophysical data (Glass Earth airborne electromagnetic resistivity and magnetic data collected in 2007; Fugro Airborne Surveys 2007) for preliminary groundwater resource characterisation (e.g. depth of the hydrogeological basement; Westerhoff et al. 2014).
2. Complementary investigations of groundwater resources (e.g. site-specific/finer-scale geophysical investigations, drilling for calibration and aquifer testing).
3. Measurements of water flows (e.g. surface water flows, soil drainage and groundwater recharge rates).
4. Other technical assessments (e.g. soil properties characterisation and water quality).

5.1.2 Feasibility Studies for Hydro-Storage Guided by Cultural Considerations

Water transfer from hydro-storage has been identified as a potential technical option for the focus areas with pervasive soil moisture deficits (Table 4.1). This option is attractive from a technical perspective because existing hydro-reservoirs could, in principle, provide for the water needs of much land in Central Otago. New infrastructure could transport water within the Clutha River / Mata-Au catchment under gravity (e.g. Lake Hawea) or as a pumped scheme (e.g. as proposed for the Lake Onslow scheme and Manuherekia River catchment). Existing infrastructure, e.g. the NOIC Scheme, may be used for water transport to northern coastal Otago.

Ngāi Tahu ki Murihiku are interested in investigating hydro-storage transfer options where discharging water sourced from one water body does not impact on water bodies in other catchments (Te Ao Marama 2021). This is consistent with its preference for retiring abstraction from tributaries in favour of taking water from lakes and large rivers.

Further assessment of hydro-storage options would be useful. Te Ao Marama (2021) note that a feasibility assessment for gravity-fed lake water (e.g. as with the current use of Lake Hawea water to irrigate Hawea Flat) could be of benefit if it was to assist in shifting existing land and water uses to more sustainable uses in the Clutha River / Mata-Au catchment. These assessments could include pre-feasibility studies of engineering options that transfer water; cost-benefit assessment, with a strong emphasis on environmental benefits (e.g. the replacement of ‘Deemed Permits’); and effects on receiving environments such as water bodies. In addition, the assessments could include water demand, engineering feasibility, land-use options and cultural impact assessments in partnership with mana whenua.

However, Te Ao Marama (2021) advise that new transfers of water between catchments are not favoured. Regulatory planning issues also need to be assessed by the regional and district councils. The current LWRP process, and integration of community needs through FMUs (Section 2.1.2.1), will provide values that will be relevant to future water management by ORC.

5.1.3 Land-Use / Water Demand Investigations

Water storage investigations would benefit significantly from land use and associated water demand studies. These assessments could also focus on the use and promotion of efficient irrigation methods for potential development.

5.2 Summary and Next Steps

Over the next three years, ORC will focus on developing a LWRP to respond to regulation changes and address pressures on the freshwater resource in the region, with a strong focus on improving water quality. The next steps for our work will be to determine whether Aqua Intel Aotearoa can support the council in its obligations through our investigations, where these are consistent with the region’s regulatory and cultural considerations. These steps will include discussions on the types of investigations that can improve the regional understanding of the groundwater resources and their potential availability.

Iwi welcome investigations that better characterise the groundwater and surface water resources in the Clutha River / Mata-Au catchment (Te Ao Marama 2021). They see the interpretation of Glass Earth data as potentially helpful for improving the understanding of groundwater in the region. These investigations should also lead to overall improved freshwater management in the region by bringing useful insights for the development of the new LWRP and by satisfying some requirements of the NPS-FM 2020.

In the short term, investigations could include:

- Assessment of Glass Earth data for groundwater resource characterisation in the Manuherekia–Ida focus area (see Section 0, proposed investment 1) and, if the results of this initial assessment are positive, further processing and analysis of this data.
- Local investigations of groundwater resources, including site-specific/finer-scale geophysical investigations, e.g. in the Cardrona/Wanaka area.

Beyond this, Aqua Intel Aotearoa will stay abreast of progress in Otago to see whether there are further investigations that could be undertaken to support the region as it implements the LWRP.

6.0 ACKNOWLEDGMENTS

The authors thank Otago Regional Council staff for their extensive contributions to PDU consultation in 2020 and 2021. Thanks go to the following, many for their very useful comments on water storage in the Otago region: Gwyneth Elsum (General Manager Strategy, Policy and Science), Gavin Palmer (General Manager Operations), Anne Duncan (Manager Strategy), Julie Everett-Hincks (Resource Science Manager), Tom De Pelsemaeker (Team Leader Freshwater and Land), Jens Rekker (Senior Scientist – Catchment Modelling), Anita Dawe (Policy and Planning Manager), Jean-Luc Payan (Natural Hazards Manager), Richard Pettinger (Senior Analyst – Freshwater and Land), Pete Stevenson (Team Leader Environmental Monitoring), Amir Levy and Marc Ettema (Groundwater Scientists), James Weir (GIS Analyst), Pete Ravenscroft and Rachel Ozanne (Environmental Resource Scientists – Freshwater), Ciaran Campbell (Freshwater Ecologist), Sean Leslie (Systems and Information Analyst), Sylvie Leduc (Senior Strategic Analyst), David Cooper (Principal Engagement Advisor), Dolina Lee (Policy Analyst) and James Adam (Senior Policy Analyst).

Our thanks also go to Aukaha and Te Ao Marama for their time and valuable insights. Lastly, thanks to GNS Science staff for their contributions to the project, including Damon Clarke (project management), Ross Peden and Chris Worts (stakeholder engagement), Kate Robb (report formatting) and Stewart Cameron (report review).

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APPENDICES

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APPENDIX 1 PROVINCIAL GROWTH FUND WATER STORAGE INVESTMENT PRINCIPLES

Economic

- Water storage will strengthen regional economies by shifting land use to higher-value sustainable uses, while avoiding increases in livestock intensification.
- Water storage will help address disparities in Māori access to water for land development.

Community

- Small-scale community-level projects will be supported rather than mega irrigation schemes.
- There must be public benefit from government funding of a project.
- Projects will involve stronger partnerships at the local level, including with regional councils.
- The Crown Irrigation Investments Limited (CIIL)'s programme of work will not be progressed, although communities that were involved in CIIL initiatives can submit proposals that align with PDU objectives.

Environment

- Water storage proposals should demonstrate that they will support land uses that do not increase – and ideally reverse – the negative impacts on water quality.
- Projects should maintain the health of waterways.
- Water storage will not be used to increase the intensity of ruminant agriculture, or other land uses in a catchment, where this puts greater cumulative pressure on water and risks compromising water quality.
- Water storage proposals should incorporate activities that improve water quality, e.g. activities that improve E. coli levels and ecological health; restoration and protection project such as improvements in wetlands, fish and wildlife habitats, riverbanks, biodiversity activities, soil health and sediment control.

Climate Change

- Where practical, projects should contribute positively to the target of reducing greenhouse gases. Projects should also demonstrate how they will contribute to mitigating or adapting to climate change effects and to a just transition to a low-emissions economy.
- Proposals should consider the potential to contribute to climate-change resilience in communities. Strengthening municipal water supply is not an objective of PDU funding. However, the PDU will work with councils to include municipal supply as a component of wider water initiatives, if it enables councils to contribute more to regional water management.

APPENDIX 2 WATER STORAGE METHODOLOGIES

Water storage options were first broadly identified within the natural, modified-natural and artificial categories. Then, a selection of these options was used in an assessment of water storage in Otago with a GIS-based approach (White et al. 2020). This assessment had a focus on augmented and artificial water storage options, as far greater control of the engineering and construction of structures is possible when compared to modifying the natural hydrological cycle.

A2.1 Workshop

A workshop was held in Dunedin to initiate collaborative work between ORC and GNS Science staff members in relation to water storage opportunities for the Otago region. The GNS Science project team (groundwater, planning and policy expertise) presented the scope of the project and the initial storage options identified to ORC specialists from the Science (surface water and groundwater), Policy, Strategy, Natural Hazards and Engineering teams. Related discussions, focused in particular on local knowledge, constraints, ongoing projects and strategic approach, were also held to inform the next steps of the project development.

During the session, a practical policy exercise was undertaken to identify values or systems within the region that may present significant policy or other limitations to the exploration of water storage options. The preservation of outstanding natural landscapes / water bodies / character areas, high country tussock land, heritage areas and wetlands were identified as the potential limiting factors for the use of different water storage options. Other systems or identified features that present limitations include catchments where damming is prohibited (in the RMA sense), conservation estate, statutory acknowledgements and groundwater protection zones.

A2.2 GIS Processing

A2.2.1 Datasets

A combination of national- and regional-scale datasets was used to assess water storage (Table A2.1). Individual datasets are briefly described in the sections below.

Table A2.1 New Zealand datasets and associated references used within this work.

Coverage	Dataset	Description	References
National	Depth to basement	This dataset provides an update of New Zealand's depth to hydrogeological basement map. Depth to hydrogeological basement can be loosely defined as the 'base of aquifers' or, more strictly, as "the depth to where primary porosity and permeability of geological material is low enough such that flued volumes and flow rates can be considered negligible".	Westerhoff et al. 2019
National	Digital Elevation Model	The New Zealand School of Surveying Digital Elevation Model (NZSoSDEM v1.0) is a free Digital Elevation Model (DEM) covering the country at a spatial resolution of 15 m, created by the School of Surveying by interpolating the Land Information New Zealand (LINZ) topographic vector data. This DEM was created as a series of 30 maps whose extent corresponds exactly with the LINZ Topo250 topographic map series.	Columbus et al. 2011

Coverage	Dataset	Description	References
National	Equilibrium water table	The equilibrium water table dataset consists of a raster file, where the values represented modelled depth to the water table from the ground surface. The underlying model is a global-scale groundwater flow model that received national input data relevant to terrain, geology and recharge.	Westerhoff et al. 2018
National	Fundamental Soil Layer Profile Available Water	The publicly available New Zealand Fundamental Soil Layer information combines soil physical, chemical and mineralogical characteristics from the National Soils Database with physical land resource information from the New Zealand Land Resource Inventory. This dataset contains the best available estimate of Profile Available Water data, which estimates total available water for the soil profile to a depth of 0.9 m or to the potential rooting depth (whichever is the lesser). Values are weighted averages over the specified profile section (0–0.9 m) and are expressed in units of mm of water.	LRIS Portal 2000
National	Hydrogeological Systems	The Hydrogeological System digital map (1:250,000 scale) consists of two publicly available GIS files: a set of polygons defining hydrogeological systems and relevant attributes and a set of polylines defining the system boundaries and relevant attributes. Hydrogeological systems were defined as geographical areas with broadly consistent hydrogeological properties and similar resource pressures and management issues. Individual systems were mapped using geological, topographical, surface drainage and, where available, groundwater divides.	Moreau et al. 2019
National	Hydrogeological-Unit Map	The publicly available Hydrological-Unit Map (HUM) dataset consists of two GIS files: a stacked map and an outcropping unit map. This is because differently aged HUM units occur within the same area and therefore are ‘stacked’ vertically within a given land area. The HUM dataset comprises a classification of geological units in terms of their importance for groundwater flow and storage in an ArcGIS seamless digital map. HUM units are classed into four broad types of hydrogeological unit: aquifer, aquiclude, aquitard and basement, defined as follows: • Aquifer: a hydrogeological unit type defined as: “a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs … unconsolidated sands and gravels are a typical example” (Todd and Mays 2005). • Aquitard: a hydrogeological unit type defined as a saturated but poorly permeable stratum that impedes groundwater movement and does not yield water freely to wells that may transmit appreciable water to or from adjacent aquifers and, where sufficiently thick, may constitute an important groundwater storage zone; sandy clay is an example (Todd and Mays 2005).	White et al. 2019

Coverage	Dataset	Description	References
		• Aquiclude: a hydrogeological unit type defined as a saturated but relatively impermeable material that does not yield appreciable quantities of water to wells; clay is an example (Todd and Mays 2005). • Basement: a hydrogeological unit type defined as a geologic layer, or group of layers, of Cretaceous age and older. However, the definition of an aquifer includes an assessment of 'significant quantities of water', which is a regionally variable property. In the nationally consistent HUM dataset, the classification assesses what is considered 'significant quantities of water' at the national level in New Zealand (i.e. what is defined as an aquifer versus an aquitard).	
National	Land Cover Database	The New Zealand Land Cover Database (LCDB) is a publicly available multi-temporal, thematic classification of New Zealand's land cover. LCDB v5 identifies 33 mainland land cover classes (35 classes once the offshore Chatham Islands are included). Land cover features are described by a land cover code, a name per polygons at multiple time steps (summer 1996/97, summer 2001/02, summer 2008/09, summer 2012/13 and summer 2018/19). The dataset is designed to complement New Zealand's 1:50,000 topographic database in theme, scale and accuracy and is suitable for infrastructure planning.	LRIS Portal 2020
National	Mean annual actual evapotranspiration	Annual actual evapotranspiration was estimated by GIS as actual evapotranspiration from the land surface, derived from a national-scale map developed by NIWA for the period 1960–2006 without specific consideration of land use, land cover, soil type or groundwater recharge.	Woods et al. 2006; Henderson 2019
National	Mean annual rainfall	Average annual rainfall was based on a NIWA dataset derived from the rainfall measurements at individual rainfall stations, interpolated throughout New Zealand by NIWA and averaged for the period 1960–2006.	Tait et al. 2006
National	National building outlines	The publicly available 'national building outlines' GIS dataset provides building outlines within mainland New Zealand, extracted from multiple years of aerial imagery. This is a 2D representation of the roof outline of a building that has been classified from LINZ aerial imagery using a combination of automated and manual processes to extract and refine a building roof outline.	LINZ Data Service 2019
National	Regional Council boundaries	The publicly available 'Regional Council 2020 (generalised)' dataset is the definitive version of the annually released regional council boundaries for 2020, as defined by the regional councils and/or Local Government Commission and maintained by Stats NZ.	Stats NZ 2020b

Coverage	Dataset	Description	References
National	River flow data	This publicly available ‘River flow’ dataset consists of river flow statistics attributed to specific river reaches, which can be used to assess how much water is available for irrigation, drinking water, hydro-electric power generation and recreational activities such as fishing and boating. River flows are also very important for maintaining the health and form of a waterway. This dataset was created to support environmental reporting.	Booker 2015
Regional	Available Water Allocation maps (groundwater and surface water)	The ‘Available Water Allocation maps, groundwater and surface water’ dataset indicates surface water catchments and aquifer allocation status within the Otago region as recorded in July 2020. For aquifers, a distinction is made in terms of allocation between ‘operative’ allocation status aquifers (i.e. with allocation limits notified in the RPW) and ‘draft/recommended’ allocation status aquifers (i.e. with interim allocation limits).	Weir 2020

A2.2.2 GIS Engine Implementation

Source spatial datasets were provided either as vector (e.g. shapefile) or raster (e.g. GeoTIFF) files, with different extents and resolutions. To overlay the spatial information together, each dataset was rasterised or re-gridded to the same projection, extent and grid resolution for the region. Results were then stored as GeoTIFF rasters, with codes corresponding to low, medium and high assessments. For 1:250,000 map resolution, a common raster resolution of 50 m was used (i.e. 0.2 mm in print). All data were projected in New Zealand Transverse Mercator 2000. Rasterising and re-gridding were performed with GDAL-based tools from either command prompt or within a Python programming environment with NumPy.

An illustrative example of the spatial overlay method is shown in Figure A2.1 for galleries:

- (a) shows Quaternary-aged aquifers consisting of gravel, sand and/or silt; other units are excluded using the Hydrological-Unit Map (HUM) dataset (White et al. 2019).
- (b) shows median soil Profile Available Water (PAW) from the Fundamental Soil Layer (FSL) dataset (LRIS Portal 2000), with values greater than 80 mm hashed to indicate that they are a poorer soil type for galleries.
- (c) shows water table depth (WTD) estimated using the equilibrium water table dataset (Westerhoff et al. 2018), where depths greater than 2 m are too deep for infiltration galleries.
- (d) shows land cover (LRIS Portal 2020), which excludes galleries in built-up areas and standing water (among several other conditions that apply outside the figure).

The resulting map (e) was produced by assigning assessment values following a consistent method that combines the datasets listed above. Assessments are depicted using a three-colour or ‘traffic light’ scheme suitable for a colour-blind audience.

A2.3 Storage Options

Water storage options identified as having some potential for the region are described and an initial assessment of this potential as ‘high’, ‘medium’ or ‘low’ is provided (Table A2.2).

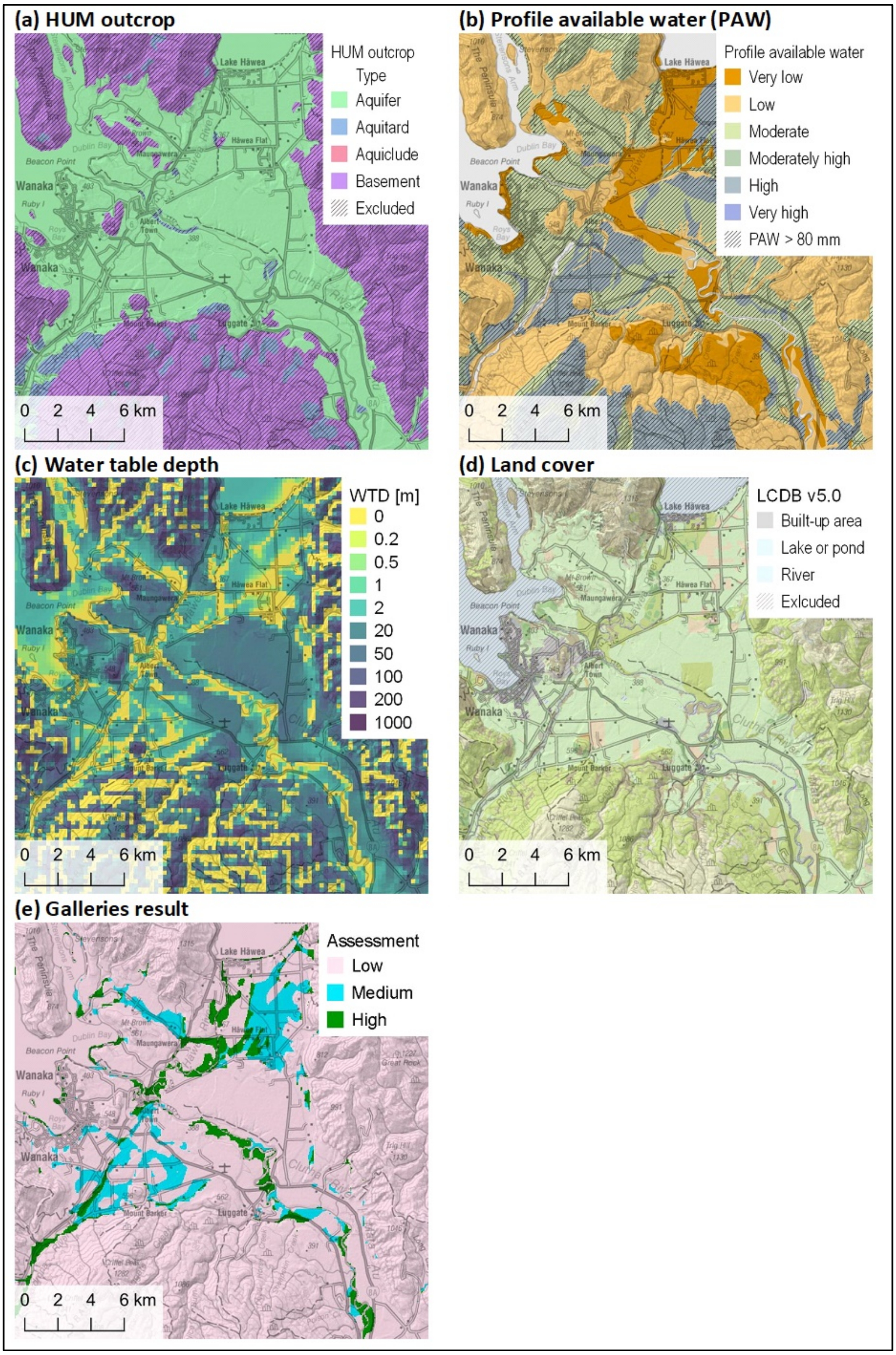

Figure A2.1 Example of a GIS overlay assessment for galleries. Acronyms used in the figure are as follows: Hydrogeological-Unit map (HUM), water table depth (WTD), Land Cover Database (LCDB).

Table A2.2 Description of assessment methods and associated datasets.

Option	Source Datasets	Description Method	Storage Assessment		
			High	High	High
Groundwater storage	Hydrogeological-Unit Map Hydrogeological Systems	The groundwater storage option was developed in five stages: 1. HUM units were subdivided using Hydrogeological Systems (HS) boundaries. 2. Stacked polygons were collapsed to a 2D dataset to identify confinement status. 3. Fixed storage coefficient values were assigned using the rules outlined in Table A2.1 to sub-HUM units, based on both the HUM_type (Aquifer/Aquitard/Aquiclude and Basement) and the aquifer confinement status (e.g. unconfined and confined). The assigned values were checked against published values (Heller 2001). 4. As part of developing the groundwater storage option, layer thicknesses were estimated using the depth to basement and equilibrium water table datasets. 5. Finally, the High/Medium/Low assessment was assigned based on groundwater storage coefficient values.	Sedimentary aquifers not fully enclosed within the Basement Hydrogeological System.	Volcanic aquifers, sedimentary aquifers fully enclosed within the Basement Hydrogeological System, aquitards.	Aquicludes and Basement.
Riverine galleries	Hydrogeological-Unit Map Hydrogeological Systems Equilibrium Water Table FSL Profile Available Water River flow data	The High/Medium/Low assessment was assigned based on outcropping lithologies (sand/silt/gravel or else), depth to the water table, proximity to a stream, river flow data, median PAW value and land cover. In addition, areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice) are classified as 'Low'.	Sediments at surface; water table less than 2 m deep; location within 100 m of stream; with a low flow greater than 0.1 m^3/s; PAW less than, or equal to, 80 mm.	Sediments at surface; water table less than 2 m deep; location within 100 m of stream; with a low flow greater than 0.1 m^3/s; PAW greater than 80 mm.	No sediments at the ground surface, and/or water table deeper than 2 m, and or unsuitable land cover type (built-up area, etc.).
Modified wetlands	Land Cover Database Mean annual precipitation Mean annual evapotranspiration Regional Council boundaries	The LCDB v5 polygons, classified as 'wetlands' in 2018, were used as an input layer for further processing to select wetlands that could potentially be modified for water storage purposes. Wetlands are usually complex systems consisting of several land cover classes, e.g. open water classed as Lakes and Ponds, areas of Herbaceous Freshwater or Saline Vegetation, Flaxland, scrub classes (Thompson et al. 2003). The saline vegetation classes of wetlands (i.e. Herbaceous Saline Vegetation and Mangrove) were excluded, as estuarine and coastal wetlands would not allow freshwater storage due to saline 'contamination'. The potential supply of water to the selected 'freshwater wetlands' was then calculated based on the difference between the long-term mean annual precipitation (P), the long-term mean annual actual evapotranspiration and on the wetland area. Adjacent wetlands (i.e. located within 50 m) were considered as part of the same wetland for this exercise. The freshwater wetlands allowing a water supply greater or equal to 50 L/s were then characterised as presenting a 'High' potential for water storage, the remaining freshwater wetlands as 'Medium' potential and the other land covers as 'Low' potential.	Wetlands receiving more than 50 L/s supply of water (calculated by subtracting actual evapotranspiration from rainfall over a wetland area*).	Wetland receiving less than 50 L/s supply of water.	Area not covered by any wetlands currently or wetland with saline inputs.
Dams for baseflow enhancement	Hydrogeological-Unit Map River flow data Land Cover Database	The storage potential was assessed based on proximity and mean flow rates of perennial streams, outcropping lithologies and HS type. In addition, areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice), are classified as 'Low'.	Areas outside of townships with perennial streams that have a low flow in range 0.2–0.8 m^3/s and Q1 and Q2 sediments in the Hydrogeological system polygon.	Areas outside of townships with perennial streams that have a low flow in the range 0.2–0.8 m^3/s.	All other areas not covered by the 'High' and 'Medium' category and/or unsuitable land cover type (built-up area, etc.).
Land subsoil recharge	Hydrogeological-Unit Map Land Cover Database FSL Profile Available Water Digital Elevation Model	The storage potential was assessed based on outcropping lithologies (unconsolidated sediments have the greatest potential for groundwater augmentation), ground slope (derived from the Digital Elevation Model) and PAW. In addition, areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice) are classified as 'Low'.	Areas in the HUM outcrop file in the rock types 'GravelSandSilt' and 'Sand' categories that are outside town areas and have a slope less than, or equal to, 2% and a median PAW less than, or equal to, 80 mm.	Areas in the HUM outcrop file in the rock types 'GravelSandSilt' and 'Sand' categories that are outside town areas and have a slope less than, or equal to, 2%.	All other areas not covered by the 'High' and 'Medium' category and/or unsuitable land cover type (built-up area, etc.).
Galleries	Equilibrium Water Table Land Cover Database Hydrogeological-Unit Map FSL Profile Available Water	The water storage potential was assessed based on outcropping lithologies (sand/silt/gravel or else), depth to the water table, median PAW value and land cover. In addition, areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice) are classified as 'Low'.	Sediments at surface; water table less than 2 m deep; PAW less than, or equal to, 80 mm.	Sediments at surface; water table less than 2 m deep; PAW greater than 80 mm.	No sediments at the ground surface and or unsuitable land cover type (built-up area, etc.).
Managed aquifer recharge	Hydrogeological-Unit Map Hydrogeological Systems FSL Profile Available Water	Areas of interest for managed aquifer recharge were identified as areas underlain by unconsolidated sediments with a low gradient slope and a low median PAW value. Any areas that fulfilled all the aforementioned conditions, and also intersected with catchments or aquifers that had any surface water or groundwater water permits, respectively, were categorised as having a 'High' potential to augment groundwater resources and stream baseflow.	Sediments at surface; sediments sand or gravel; slope less than, or equal to, 5%; PAW less than,	Sediments at surface; sediments sand or gravel; slope less than, or equal to, 5%; PAW greater	No sediments at the ground surface and or unsuitable land cover type (built-up area, etc.).

Option	Source Datasets	Description Method	Storage Assessment		
			High	High	High
	Allocation maps (groundwater and surface water) Digital Elevation Model	Any areas that fulfilled the first three conditions but did not have any surface water or groundwater water permits, respectively, were categorised as having a 'Medium' potential. All areas that did not fall into either the 'High' or the 'Medium' category, or areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice), were categorised as having a 'Low' potential for managed aquifer recharge.	or equal to, 80 mm; water permits in the catchment.	than 80 mm; water permits in the catchment.	
Hydro-lake storage	Digital Elevation Model (for reservoir level information)	The Central Otago hydropower lakes offer water storage options because these lakes provide hydraulic head (i.e. the lakes are generally elevated above surrounding countryside) and water volume. Historically, much use of small dams, originally built for gold mining, has been made for irrigation and hydropower (Hamilton 2009). Large reservoirs include Lake Hawea, Lake Dunstan and Lake Roxburgh, all in the Clutha River / Mata-Au catchment. The opportunities for water use from these sources have been explored in the past. Currently, water is piped from Lake Hawea to Hawea Flat for agricultural irrigation (Contact Energy c2020). The hydraulic head of the source reservoir is determined by the dam reservoir operating range. The operating range includes a "consented minimum control level" of 338 m (Knight 2009). This level this can: • "be lowered to 336 m as an absolute minimum (previously 330 m) when the Electricity Commission determines that reserve generation should be used. • The maximum control level is 346 m. However, this can be exceeded under the Flood Management Plan" (Knight 2009). Lake Dunstan has a normal operating range of 193.5–195.5 m and Lake Roxburgh of 132–132.6 m (Otago Regional Council c2020a; Wikipedia contributors 2020). In addition, the elevations of the Roaring Meg Power Stations are estimated from topographic contours. The area with a potential for water use / receiving waters is then estimated by mapping the nearest topographic contour to the reservoir below that level (Table A2.3). For example, the Lake Hawea reservoir is approximately 338 m above sea level, and the area with the potential for water use is identified as below the 340 m elevation contour line. Generally, water delivery is operated by gravity. Some options for the use of Lake Roxburgh may include augmentation of high-level reservoirs east of the lake (Table A2.4). Water delivery could be by gravity or by pumping. Use of water from Central Otago hydropower lakes has been suggested before. For example, Bardsley (2005) proposed high-head pumping from Lake Roxburgh for the purpose of providing pumped hydropower storage. Bardsley (2005) states that "major civil engineering" would be involved in this scheme, including the construction of a "new Onslow Dam to a height of 70 metres". The options HS6 to HS9 would also require major civil engineering, particularly water pumping from Lake Roxburgh to Lake Onslow. However, the options would involve water pumping rates that are much less than envisaged by the pumped-storage scheme. Options HS6 to HS9 would require much less working storage in high-level reservoirs than are required by Bardsley (2005). The High/Medium/Low assessment was assigned based on the possible mechanism to bring water to targeted area (natural drainage, pumped).	Water from hydro-storage can be moved, mostly under gravity.	Water from hydro-storage can be moved, mostly with pumped systems.	All other areas not covered by the 'High' and 'Medium' category.
Potential small dams	River flow data and Land Cover Database	In this option, only areas of high storage assessment were identified. These areas were identified using proximity to perennial streams with medium mean flows, intersecting with high-producing farmland, i.e. short-rotation cropland, orchard, vineyard or other perennial crop, high-producing exotic grassland.	Perennial streams that have a low flow in the range of 0.4–1.0 m^3/s and that intersect with high-producing farmland, i.e. short-rotation cropland, orchard, vineyard or other perennial crop, high-producing exotic grassland.	Not applicable.	Not applicable.
Water tanks	National building outlines Mean annual precipitation.	In this option, only areas of high storage assessment were identified. These areas were identified by calculating rooftop rainfall (mean rainfall multiplied by rooftop areas). In the Otago region, 82,167 buildings were mapped, amounting to a combined rooftop area of 13.18 km^2, receiving an estimated rainfall of approximatively 620 mm/yr.	Average annual rooftop rainfall.	Not applicable.	Not applicable.

* Wetland polygons within 50 m were clustered together as one continuous wetland body.

Table A2.3 Hydropower-lake storage options: Lake Hawea, Lake Dunstan and Roaring Meg power stations.

Option	Lake/ Reservoir/ Source	Approximate Reservoir Level or Power Station Elevation (m amsl)	Water Delivery	Elevation of Receiving Waters
HS1	Lake Hawea	338	Gravity	Below the 340 m elevation contour
HS2	Lake Dunstan (Clyde)	195	Gravity	Below the 200 m elevation contour
HS3	Lake Dunstan (Cromwell)	195	Pump 45 m head	Below the 240 m elevation contour
HS4	Roaring Meg Power House (upper)	530	Gravity	Below the 530 m elevation contour east and west of the Upper Roaring Meg Power Station
HS5	Roaring Meg Power House (lower)	240	Gravity	Below the 240 m elevation contour downstream of the Lower Roaring Meg Power Station

Table A2.4 Hydropower-lake storage options: Lake Roxburgh.

Option	Lake/ Reservoir/ Source	Approximate Reservoir Level or Power Station Elevation (m amsl)	Water Delivery	Elevation of Receiving Waters
HS6	Lake Roxburgh	132	High-head pumping to Lake Onslow	Teviot River catchment
HS7	Lake Roxburgh	132	High-head pumping to Lake Onslow and Greenland Reservoir	Teviot River catchment, Manorburn and Manuherekia
HS8	Lake Roxburgh	132	High-head pumping to Lake Onslow, Greenland Reservoir and Poolburn Reservoir	Teviot River catchment, Manorburn, Ida Burn and Manuherekia
HS9	Lake Roxburgh	132	High-head pumping to Lake Onslow, Manorburn Reservoir, Poolburn Reservoir and Loganburn Reservoir	Teviot River catchment, Manorburn, Ida Burn, Manuherekia, Taieri and Maniototo catchments

APPENDIX 3 LAND COVER CHANGE IN OTAGO BETWEEN 2001 AND 2018 (LCDB v5 DATA)

Land Cover Classes* (LCDB v5 2001 and 2018)	Area (ha)		Change between 2001 and 2018**	
	2001	2018	Area (ha)	%
High-Producing Exotic Grassland	872,323	886,623	14,300	2%
Exotic Forest	129,212	139,502	10,289	8%
Forest–Harvested	8858	11,849	2991	34%
Built-up Area (settlement)	10,471	12,222	1751	17%
Orchard, Vineyard or other Perennial Crop	4156	5421	1266	30%***
Surface Mine or Dump	1657	2528	871	53%
Lake or Pond	76,902	77,518	616	1%
Urban Parkland / Open Space	2953	3120	167	6%
Landslide	781	811	30	4%
Depleted Grassland	19,114	18,917	-197	-1%
Herbaceous Freshwater Vegetation	20,091	19,856	-235	-1%
Broadleaved Indigenous Hardwoods	28,060	27,747	-313	-1%
Deciduous Hardwoods	10,649	10,274	-375	-4%
Matagouri or Grey Scrub	33,322	32,357	-965	-3%
Manuka and/or Kanuka	59,946	58,630	-1316	-2%
Low Producing Grassland	625,471	621,798	-3672	-1%
Gorse and/or Broom	28,738	24,394	-4344	-15%
Fernland	33,051	28,504	-4548	-14%
Tall Tussock Grassland	801,326	785,458	-15868	-2%

* Only land cover classes for which a change occurred between 2001 and 2018 are shown.

** Negative values indicate a loss between 2001 and 2018.

*** The area covered by this class is likely to have significantly increased between 2018 and 2020 (e.g. for cherry production).

APPENDIX 4 DESCRIPTION OF EXISTING/PROPOSED WATER SCHEMES AND INFRASTRUCTURE IN OTAGO

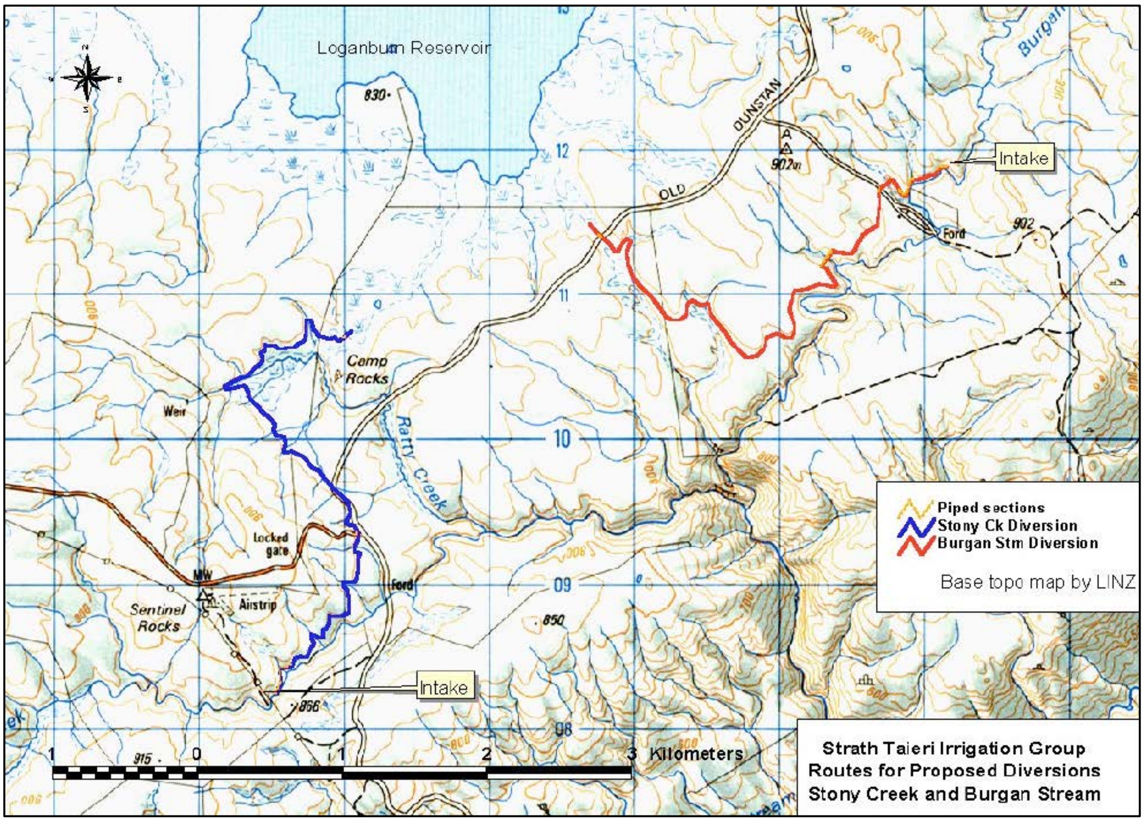

Figure A4.1 Proposed stream diversion race to supplement Loganburn Dam inflows (Hamilton & Associates Ltd 2006b).

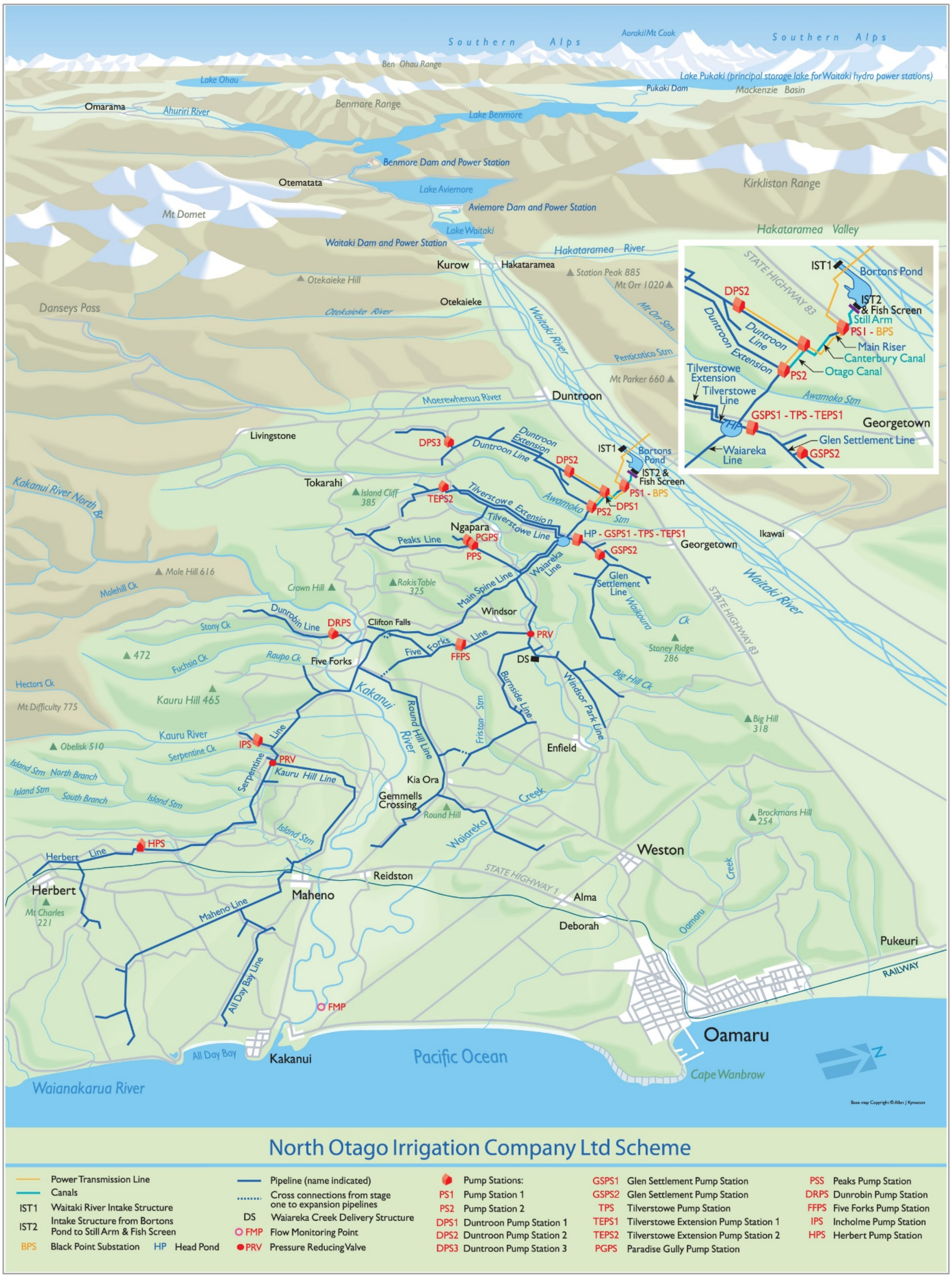

Figure A4.2 Schematic of the North Otago Irrigation Company irrigation scheme (North Otago Irrigated Company c2020).

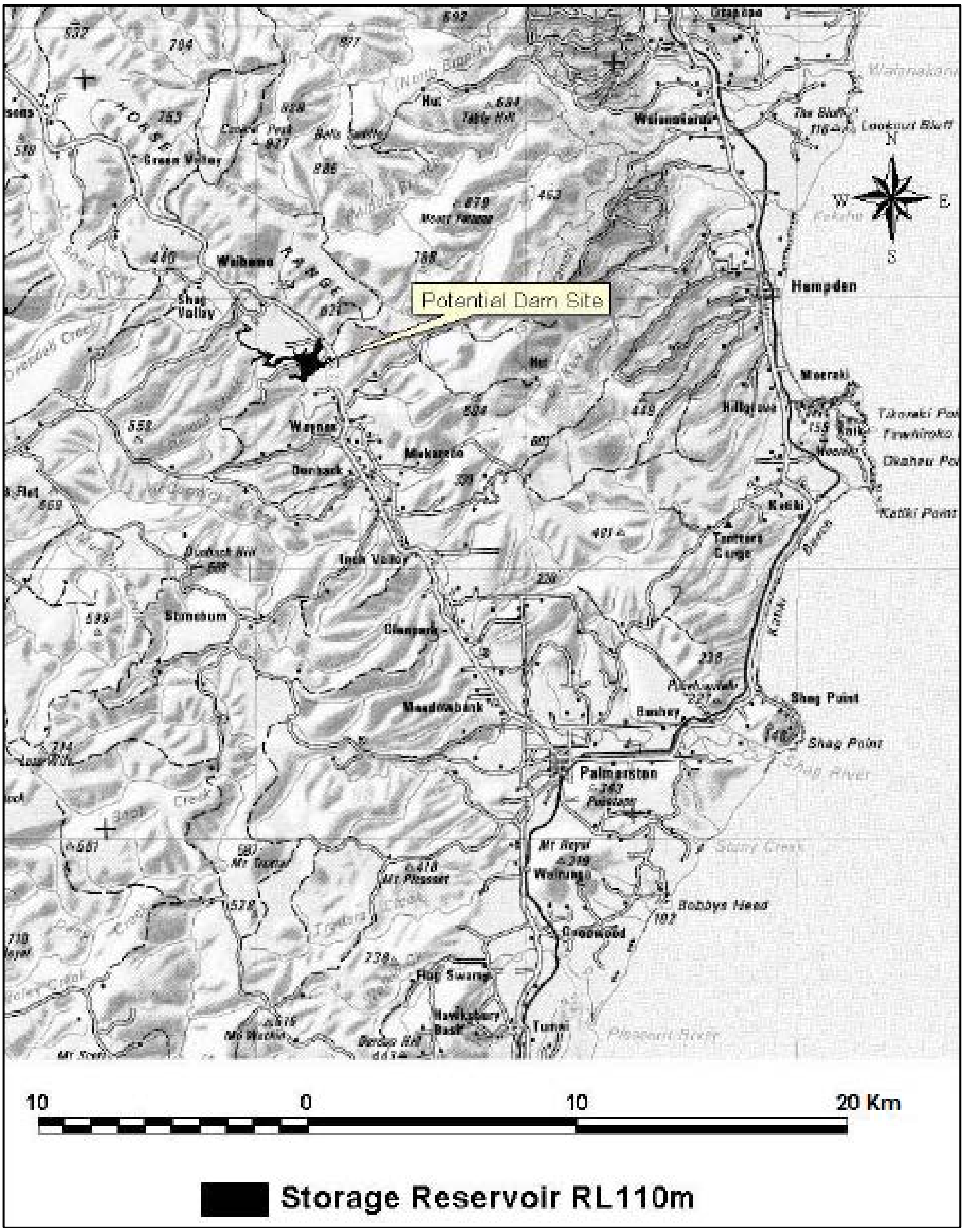

Figure A4.3 Waitaki District Council potential water storage reservoir location (Hamilton and Associates Ltd 2006a).