Environmental Offsets and Water Resource Opportunities with Lake Onslow Pumped Storage

A thesis

Submitted in fulfilment of

The requirement for the degree of

Master in Science and Engineering

at

The University of Waikato

by

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THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2024

Abstract

As part of its transition toward an aspirational goal of 100% renewable electricity generation, New Zealand had been investigating an option of replacing the need for dry-year fossil fuel power generation with the world's largest pumped storage scheme by energy storage measure. The scheme was to be located at Lake Onslow in the southern South Island. It would have an energy storage capacity up to 5 TWh for a construction cost of 16 billion dollars. However, the 2023 change of government means the scheme is not presently under active evaluation. Evaluation may well be restarted with a subsequent change of government, depending on party policy.

While aiding emission reduction, there would be local environmental impact from expanding the existing Lake Onslow reservoir, which will flood over nearby wetlands.

This study considers a range of potential environmental mitigation measures that might counterbalance the scheme's ecological impact. Consideration is also given to the large water volume in the Onslow reservoir potentially able to act as insurance against future extreme regional droughts that may arise from climate change.

The possible offsets include the restoration of two existing scenic hydro storage lakes – Lake Monowai and Lake Hawea. An argument is made that the large amount of new hydro storage capacity at Lake Onslow means that the relatively small storage contributions of these two lakes no longer justifies their inundation environmental impact. This would start a change in national thinking because to date no hydro storage lake in New Zealand has been restored for purely environmental reasons.

In addition to lake restoration, discussion is also presented about the possibility of a hypothetical partial flow restoration of the depleted Waiau River. It was New Zealand's second largest river by discharge prior to diversion into the Manapouri power station. It is tentatively suggested that new wind power in Southland buffered by Onslow pumped storage would enable partial closure of the Manapouri station, restoring about half of the original flow the lower Waiau River downstream of Lake Manapouri.

Onslow water storage would involve cubic kilometres of water, so some water could be used to offset extreme droughts without impeding pumped storage energy functionality. A narrow-diameter rock tunnel could also be constructed between the expanded Lake Onslow and the Dunedin city water intake at Deep Creek. This would

make Dunedin drought-resilient against climate change because presently the city water supply is derived just from small local catchments with little storage.

Some Onslow water might also be used to maintain water flow of the eastern Otago Taieri River in an extreme drought. However, this would raise cultural and ecological issues that would need to be considered prior to any water release.

Acknowledgements

I am immensely thankful for the unwavering guidance and support provided by my supervisor, Associate Professor Earl Bardsley. His continuous encouragement throughout my Master journey and related research has been invaluable. His insightful remarks and suggestions have greatly enriched my work. His patience, motivation, and profound knowledge have been instrumental in shaping both my research and writing process. I am truly grateful for his mentorship, which has been a cornerstone of my academic growth. Completing this study would have been an insurmountable task without his exceptional assistance and unwavering support.

Thank you to Dr. Willem de Lange and Dr. Ali Shokri from the Faculty of Science and Engineering University of Waikato.

Gratitude is expressed to various organisations for kindly providing data used in this study. Manawa Energy supplied Deep Stream discharge data and the Otago Regional Council provided various discharge and rainfall data. Meridian Energy provided Lake Pukaki water levels and Waiau River discharge data. Contact Energy supplied a record of Lake Hawea water levels and lake inflows. NIWA provided Taieri River discharge data for the Canadian Flat flow site. A big thank you to farmer Tom Waldron who took us to the potential future confluence of Onslow water released to the upper Taieri River near Canadian Flat. Data and other information were provided on the usual basis of support for student research work. There is no implication of any institutional or corporate agreement with any part of this thesis.

Finally, I would like to thank my dearest Mom and brother for their support and encouragement. They stood by my side and stayed connected to me no matter the hardships they experienced back in Iran whilst I was in New Zealand. Their positive encouragement always kept me optimistic during very difficult periods during my study. Without their support, I would not have completed this thesis.

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Chapter One: Introduction and Motivation

1.1 Background

Pumped storage at Lake Onslow in Central Otago was one of two options being evaluated by the previous Labour government to provide an emission-free alternative to maintain a future green and electrified New Zealand economy through dry years.

Most government investigation funding ($23 million) was spent on evaluating the Onslow option. The scheme would likely have been in conjunction with a component involving biomass power generation or geothermal reserve. The change of government in the October 2023 election resulted in instructions being given not to complete the dry year options report, with dry year policy reverting to gas and coal by default. However, a further government change in future is likely to see the report completed, which could lead to Onslow pumped storage site development.

The Onslow scheme has national environmental advantages toward reduced emissions. Nonetheless, at the regional level, it represents a continuation of a long history of environmental impacts from hydropower development in the Otago-Southland region.

This thesis study is not concerned with the Onslow scheme directly but instead seeks to identify a selection of possible regional environmental offsets and water resource add-ons that could give some mitigation with respect to both the Onslow scheme and also the hydro schemes that have gone before in Otago and Southland.

Such regional considerations have not been investigated to date as part of Lake Onslow study by the New Zealand government, which has been more concerned with engineering evaluations and identifying at site environmental, social, and cultural impacts (Indicative Business Plan, MBIE, 2023).

The next section briefly reviews past impacts of hydropower development in Otago and Southland. This is followed by a description of the physical environment in the Central Otago upland region extending out from Lake Onslow. The main environmental impacts of the Onslow scheme are then summarised, followed by specific thesis goals and chapter overviews.

1.2 Southern South Island: a brief history of hydropower impacts

The southern South Island has a long history of environmental impacts from hydropower schemes, both large and small. Two of the most evident environmental impacts of the hydro schemes are flooding of river valleys and shoreline disruption from raised storage lakes. The latter includes wave erosion of soft sediments at high lake levels and extensive lakebed exposure at maximum lake drawdowns. Some schemes and their impacts are noted below.

- A well-known early example of hydro environmental impact is Lake Monowai in what is now Fiordland National Park. The lake was raised in 1926 to provide storage water for the small Monowai Power Station. The station itself has a mean power output of less than 5 MW. However, raising the lake created a massive environmental impact by flooding 50 km of lakeshore native forest and lake beaches. There are regions of standing dead trees still present today. (Mark et al. 2009).
- Another early example is the raising of Lake Hawea in the Clutha catchment. Lake Hawea was raised 20 m in 1958 to provide some limited storage for the Roxburgh power station. The lake’s raising caused the beech forests of the lower Hunter Valley to the north of the lake to be largely submerged. As with Lake Monowai, there are still flooded forest remnants protruding above the raised lake today.
- A more recent example is the Lake Dunstan flooding of the iconic Cromwell Gorge and the river confluence at Cromwell, as a consequence of building the Clyde Dam (Figure 1.1).
- Arguably, the greatest environmental impact of any hydropower scheme in New Zealand is the 1969 diversion of Southland’s significant Waiau River into the Manapouri power scheme.
- The large Waitaki River hydropower scheme has had the environmental impact of the greatest spatial extent. This includes raising Lakes Tekapo and Pukaki for the scheme’s hydro storage, diversion of the Tekapo and Pukaki rivers into hydro canals, and a change in the seasonal flow regime of the lower Waitaki River down to the sea.

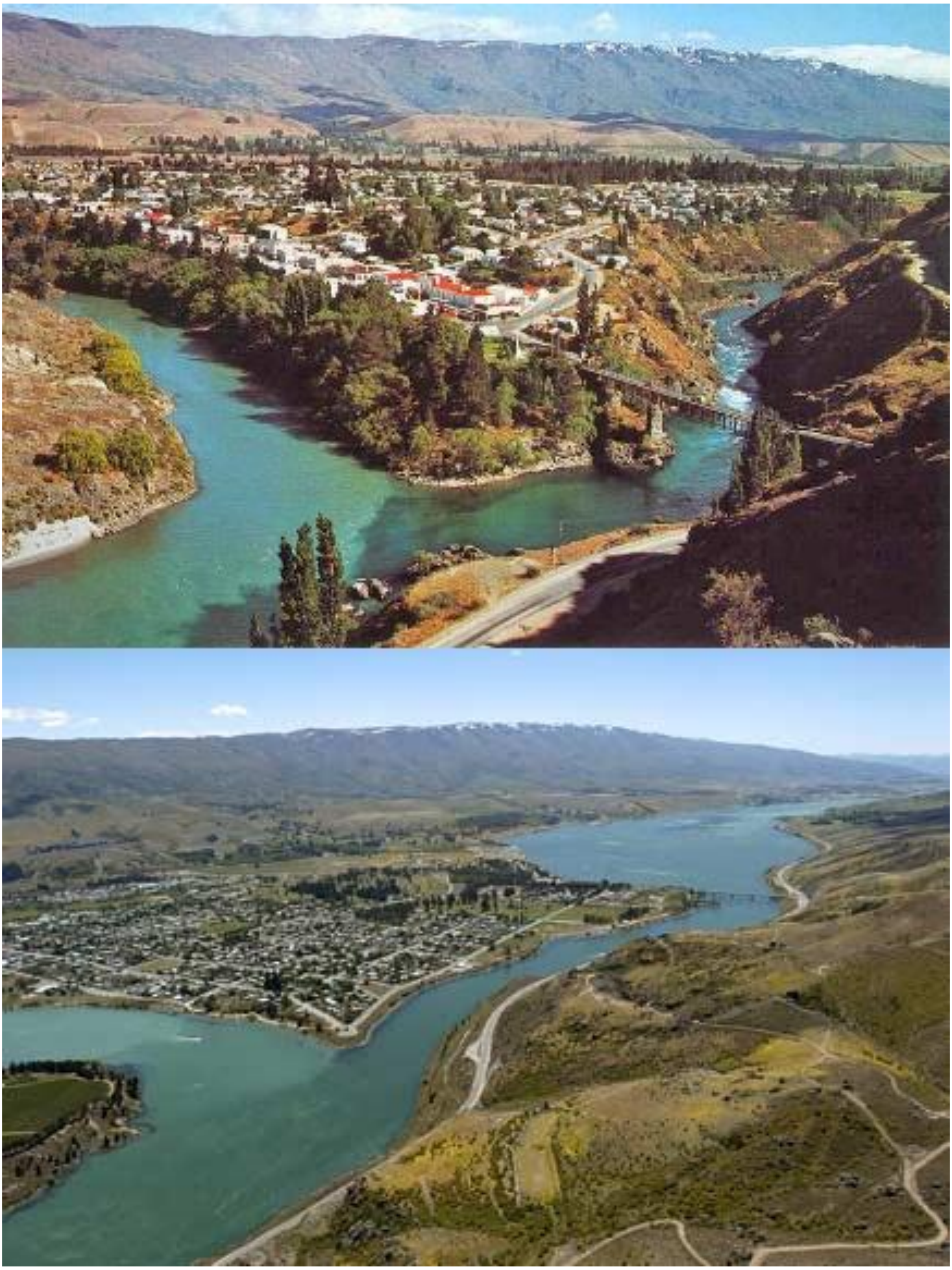


Figure1.1 Cromwell confluence before and after creating Lake Dunstan behind the Clyde Dam (Source: Lewis Verduyn).

Figure 1.2 Lake Tekapo lakebed exposed by water level lowering in a dry year, August 30, 2021 (Source: George Empson).

Figure 1.3 Release of water into the Pukaki hydro canal from Lake Pukaki. The canal water previously flowed down the Pukaki River (Source: Mark Oliver Dittrich).

Some of the hydro impacts outlined above are potentially amenable to environmental improvement as environmental offsets to the Onslow scheme. This is discussed further in Chapter 3.

1.3 Lake Onslow in the Otago upland environment

1.3.1 The physical environment

Lake Onslow is located in the Central Otago eastern upland region among open rolling hills with crags and tors of schist bedrock. The natural vegetation of the region around the lake is dominated by red tussock and alpine snow tussock (Davie *et al*., 2006).

The lake discharges into the Teviot River which flows down the Teviot Gorge and into the Clutha River some 600 m below. Its mean discharge is approximately 3.7 m^3s^{-1}.

The Teviot catchment (Figure 1.6) is primarily made up of grazed tussock hill land with some pasture grass conversion. Less than 4% of the catchment area is occupied by Lake Onslow.

Precipitation varies over the Teviot River catchment. Lake Onslow is situated between a wetter area in the higher uplands to the south and a drier area to the north (Macara, 2015). The wetter zone receives 1-1.2 m of annual precipitation (Duncan & Thomas, 2004). Annual rainfall at Lake Onslow itself is about 0.6 m. (Bardsley *et al*., 2022). Annual evaporation loss at Lake Onslow has recently been estimated by NIWA as 0.7 m (Indicative Business Plan, MBIE, 2023).

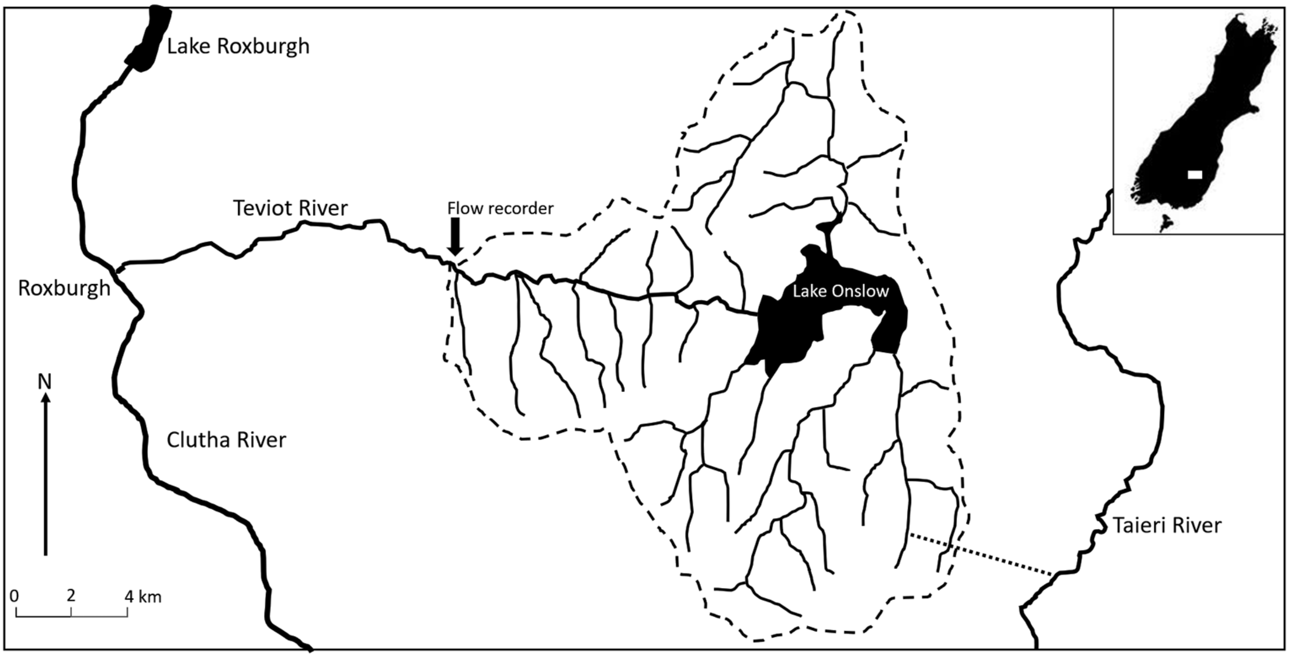


Figure 1.4 Lake Onslow and the Teviot River catchment (dashed line), as defined from upstream of the Bridge Hunts Road flow recording site (vertical arrow). The dotted line is a possible tunnel that might be used for transfer of some winter water from the Taieri River into the Lake Onslow basin (Chapter 5).

1.3.2 Adjacent Reservoirs

There are three irrigation reservoirs in the Onslow vicinity: Poolburn, Loganburn, and Upper Manorburn / Greenland (Figure 1.5).

The Upper Manorburn / Greenland reservoir is defined here as a single reservoir because the two components are linked through a narrow gorge. It is the nearest reservoir to Lake Onslow and is about 14 km in total length. It has developed into a rainbow trout fishery (Couper, 2022). However, it is presently difficult to access.

In addition to supplying irrigation water for the Maniototo region, the Loganburn Reservoir also provides storage for two small hydropower stations operated by Manawa Energy. The reservoir was created at the expense of flooding most of the former Great Moss Swamp wetland.

Of all the reservoirs, Lake Onslow is most easily accessible for recreation purposes.

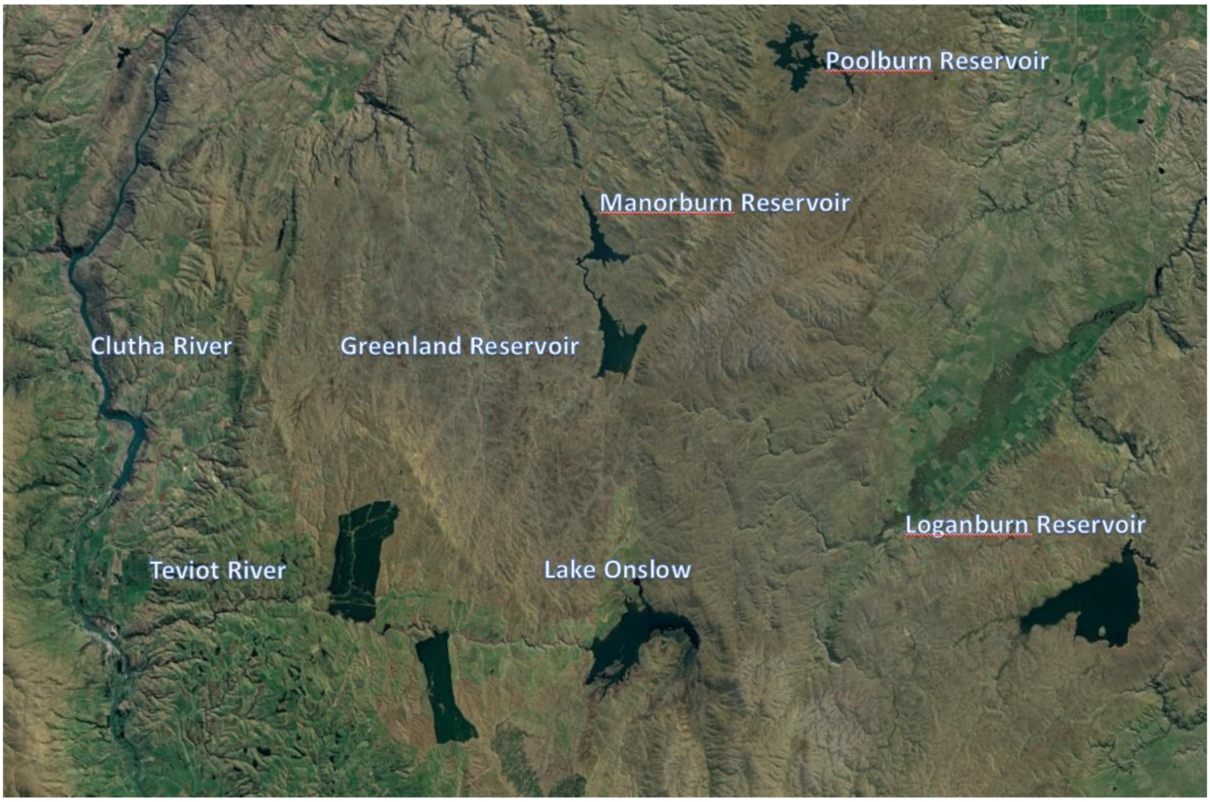


Figure 1.5. Water reservoirs in the Lake Onslow vicinity in Central Otago (Map source: Google Earth).

1.3.3 Lake Onslow

Lake Onslow is an 8 km^2 artificial reservoir at 685 m asl (Figure 1.6). It is located at the northwest end of the Lammerlaw Range, east of Lake Roxburgh, and south of Alexandra.

The lake was first created in 1890 by damming the Teviot River and flooding Dismal Swamp, which was then in an undeveloped high-country catchment (Lawa, 2022). In 1982 a new 14.6 m concrete dam (Figure 1.7) increased the lake area from the previous 3.7 km^2 to its present 8.3 km^2, giving a water storage capacity of 46 million cubic metres. Portions of the former Dismal Swamp scroll plain are still visible around the lake margins. The lake is shallow, being much less than 10 m over most of its extent.

In addition to supplying irrigation water for the Teviot Irrigation scheme, the lake also allows the controlled release of water to Pioneer Energy’s small 12 MW hydro scheme on the Teviot River (Hamilton, 2009).

Figure 1.6 Left: Lake Onslow in February 2023 (Source: Yasaman Karaminik). Right: collection of fishing hunts at Lake Onslow (Source: Allen Dick).

Figure 1.7 Onslow dam. The water discharge is the starting point of the Teviot River. (Source: Yasaman Karaminik).

1.4 Proposed expansion of Lake Onslow for 5 TWh of energy storage.

The IDP (Indicative Business Plan, MBIE, 2023) considers two scenarios for raising Lake Onslow for energy storage via a pumped storage tunnel from the Clutha River. One is based on 3 TWh of energy storage capacity and the other on 5 TWh. Both options will involve about 1000 MW of installed pump / generating capacity.

Only the 5 TWh case is considered here as being the more likely to proceed and having the greatest environmental impact. In this case, the IDP envisages an upper operating level 765 m asl, with a large permitted dry year drawdown to 695 m asl (Figure 1.8).

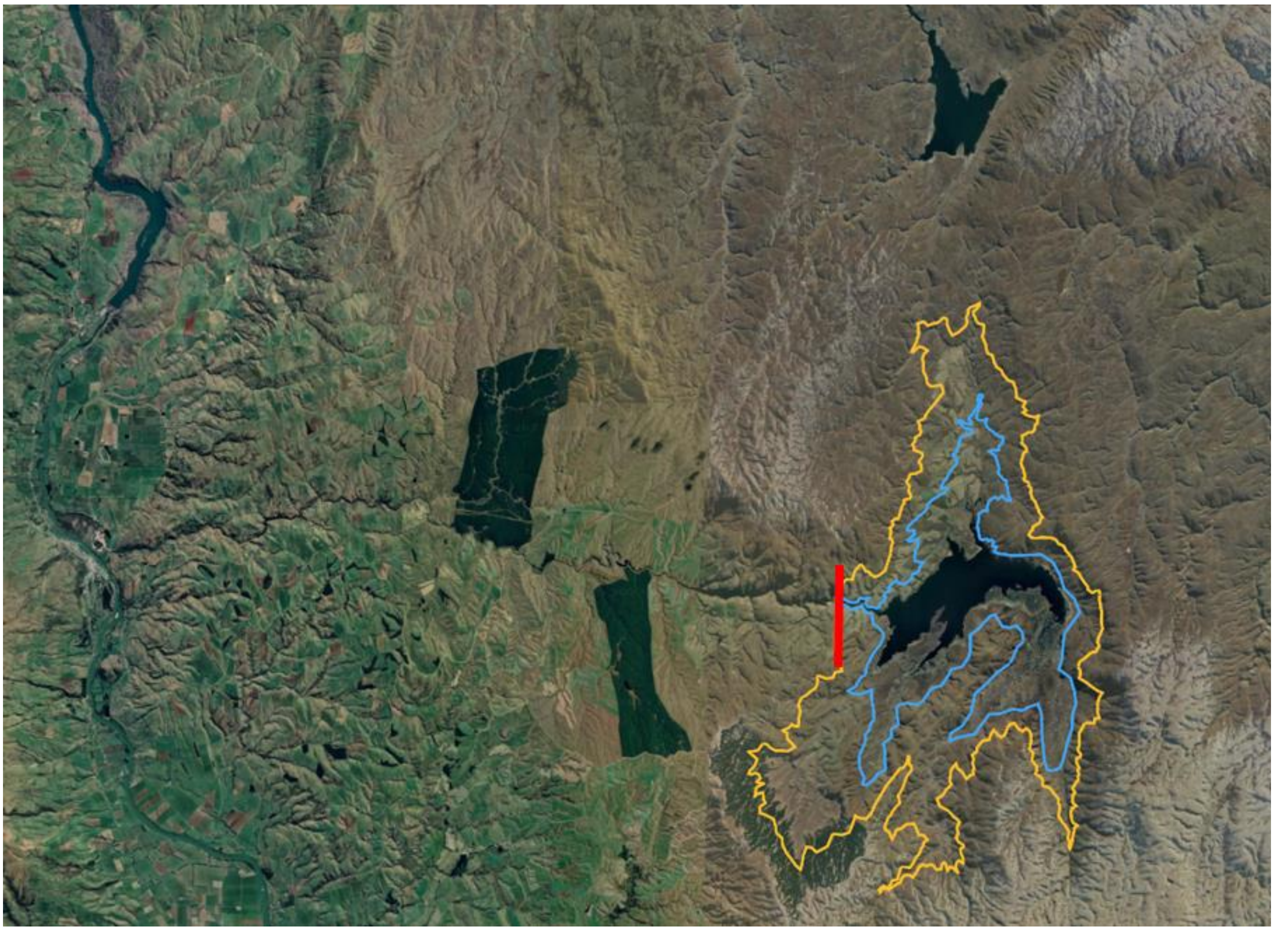


Figure 1.8 The Onslow Basin with a superimposed configuration for 5 TWh of energy storage capacity between a lower water level of 695 m (blue contour) and an upper water level of 765 m (yellow contour). The red bar indicates the approximate location of the new Onslow dam (Map source: Google Earth).

The large drawdown enables the significant 5 TWh energy storage capacity. This would be the largest energy storage in the world achieved from a pure pumped storage scheme that is independent of coupled hydro generation. However, the water level range also produces environmental impact. Upper and lower water levels incorporate a land area of about 60 km^2, that would be exposed if the lake was drawn down to its maximum extent in an extreme dry year.

In addition, the land area inundated by Lake Onslow will expand from the present 8 km^2 to a maximum of almost 70 km^2 at the highest water level (Figure 1.8). Part of this will involve permanent flooding of the scroll plain wetlands around the streams entering the southern shoreline of Lake Onslow (Figure 1.9).

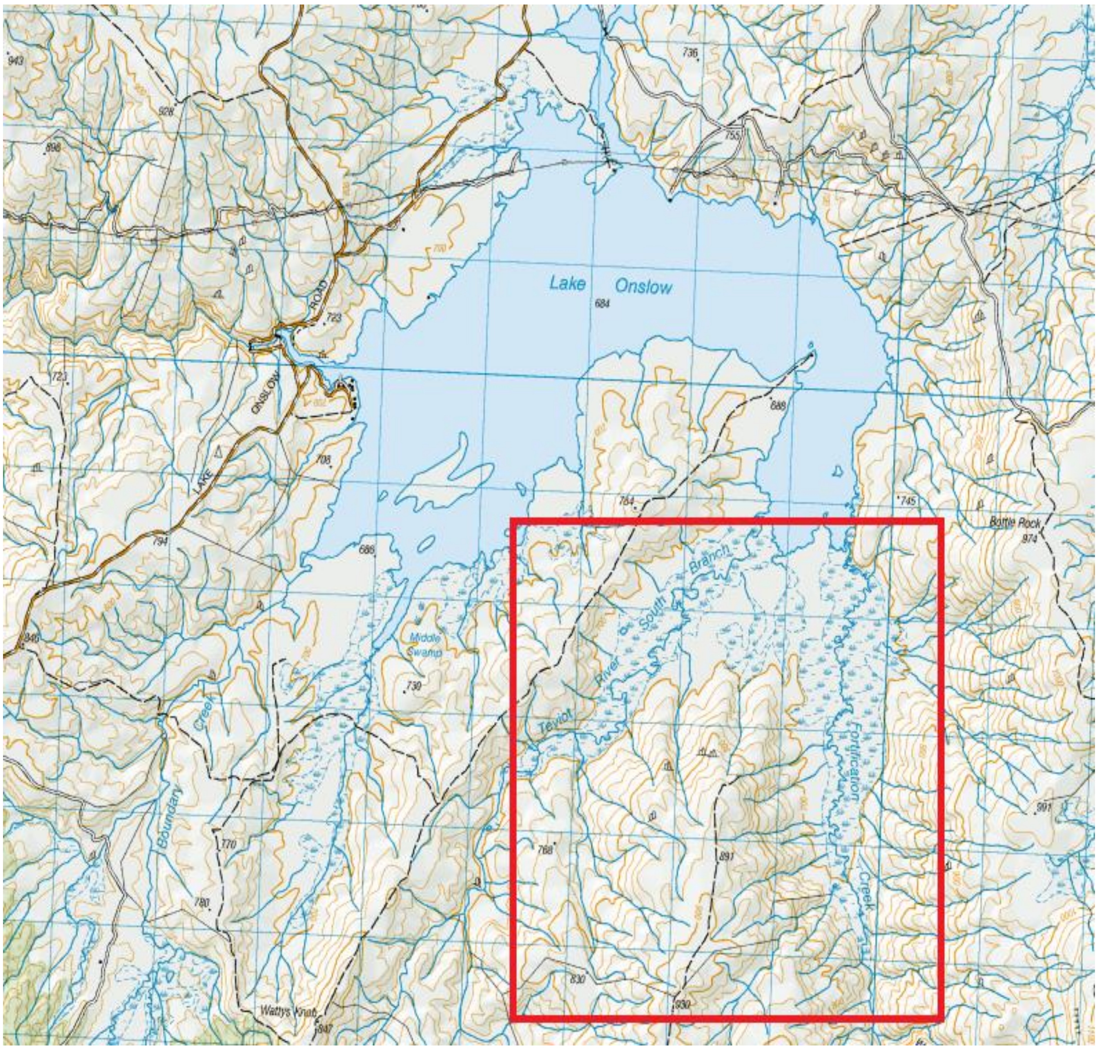


Figure 1.9 The main wetland region on the southeast of Lake Onslow, draining into the present lake. (Map source: LINZ).

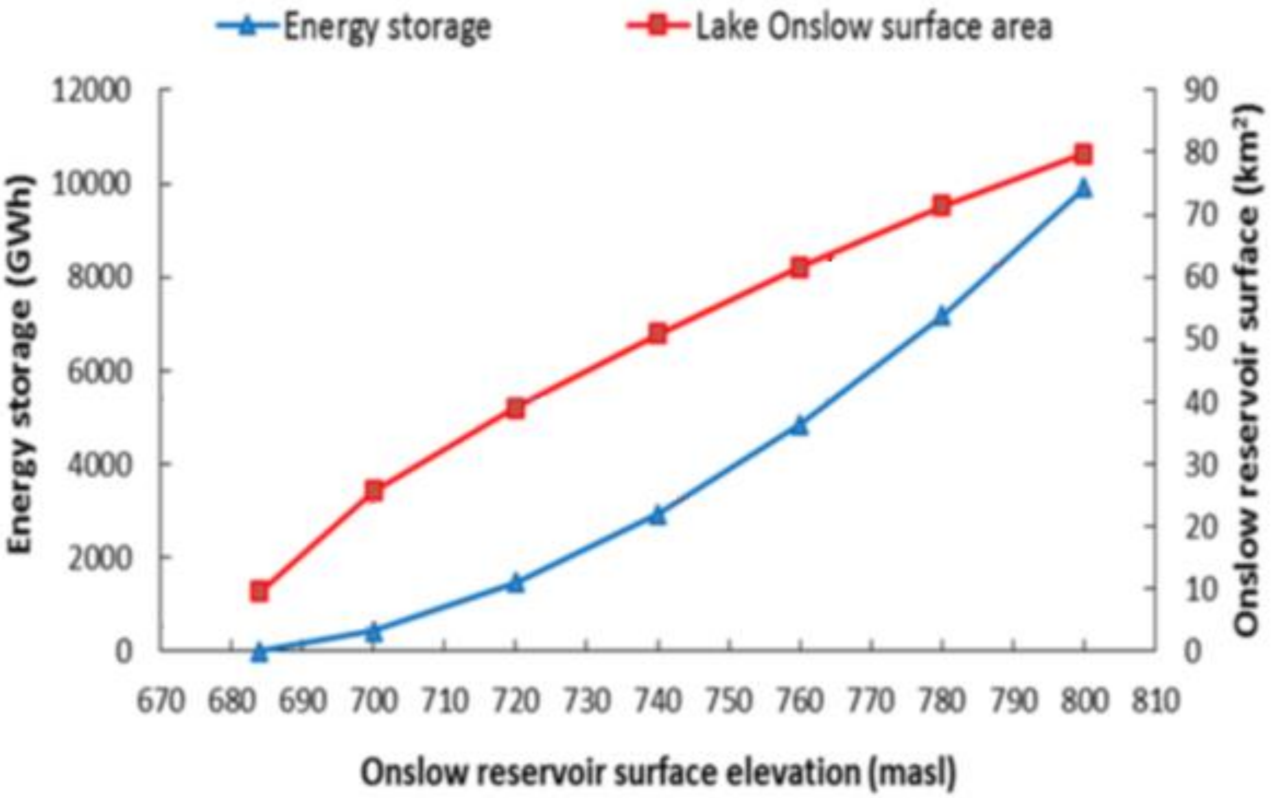


Figure 1.10 Lake Onslow energy storage and lake area as a function of surface elevation of the expanded lake. The gravitational potential energy shown here is referenced to the original lake level of 685 m asl. (After Majeed, 2019).

Another consideration is the issue of Lake Onslow for recreational fishing. Lake Onslow is a popular location for trout fishing. The lake's tributaries have good brown trout spawning grounds as well as important juvenile rearing habitats. The Lake Onslow proposal would dramatically expand the lake's maximum area and inundate tributaries (Figure 1.11). At the same time, the lake's depth is anticipated to increase by roughly 76 m, raising the final elevation to as high as 765 m asl (Couper, 2022).

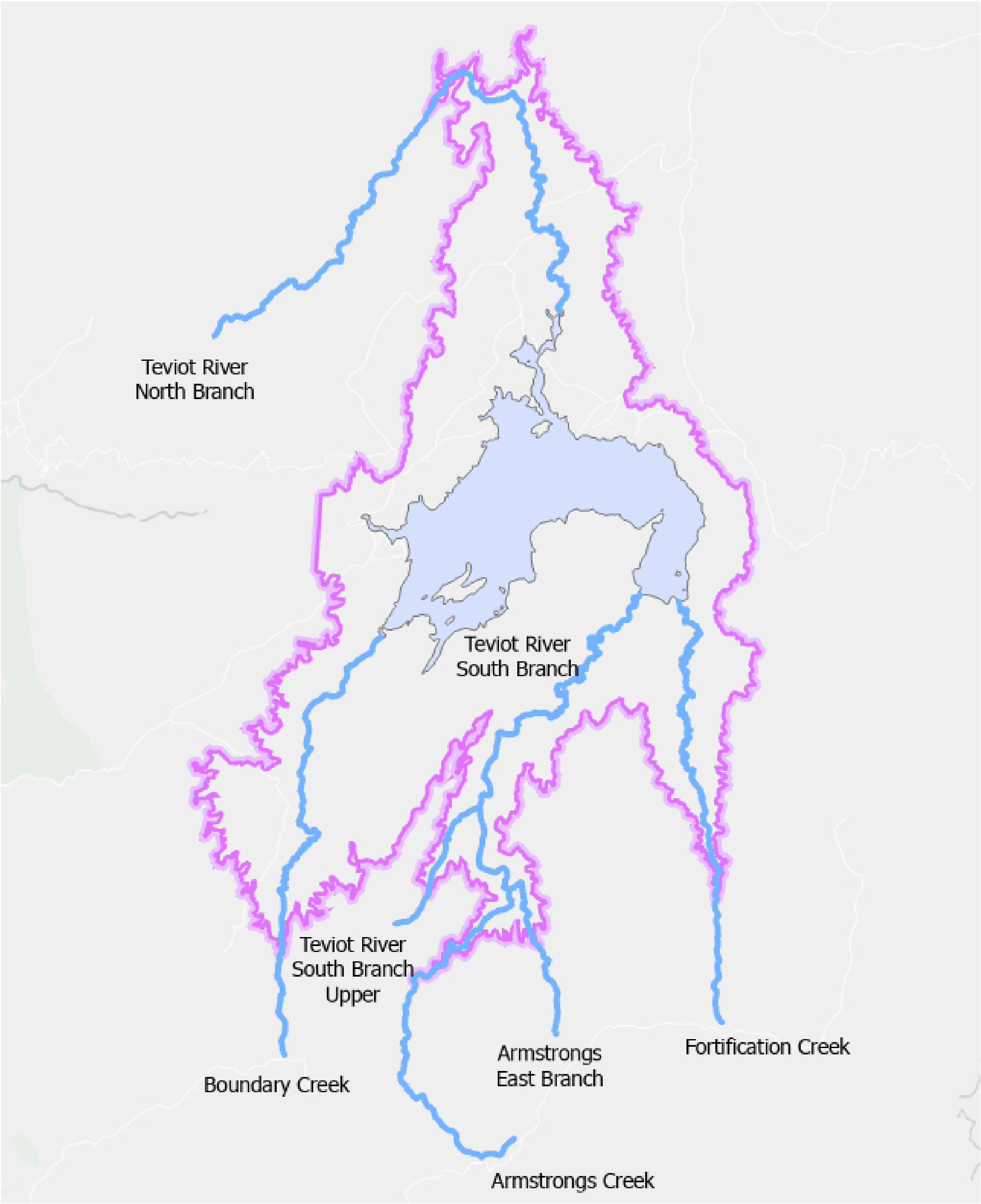


Figure 1.11 Lake Onslow and tributaries. The present lake is shown in blue and the proposed maximum lake extent is shown in purple (after Couper, 2022).

Almost all the fish spawning gravel is near the lake's present elevation; even a 20 m rise in lake height to 700 m asl would cause a spawning gravel reduction of about 84 percent (Figure 1.12). It is anticipated that lake-dwelling trout would have access to only about 0.38 percent of the spawning gravel if the lake were enlarged to 760 m (Couper, 2022).

Another matter of related concern is protection of the native Teviot Flathead population. Barriers might need to be set up on the inflowing streams to prevent predatory trout from migrating up the streams from the raised lake into Flathead habitats.

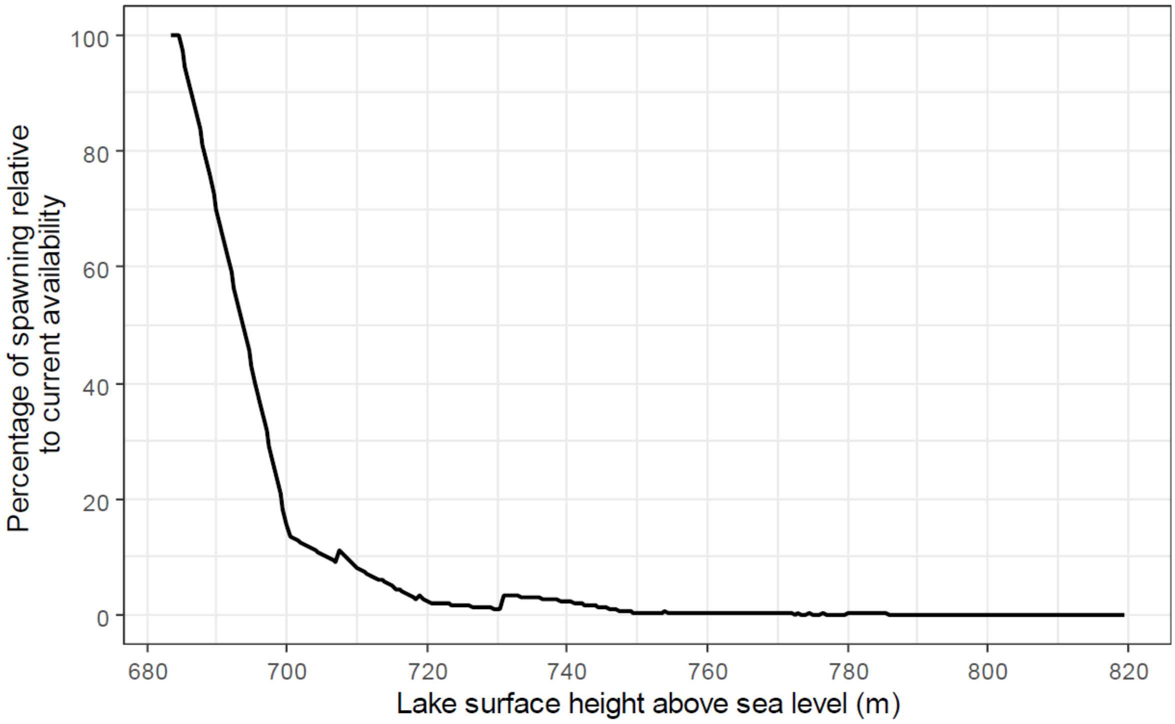


Figure 1.12 The percentage of spawning in all tributaries combined, at differing lake heights relative to what is currently available (After Couper, 2022).

1.5 Thesis objectives

In light of the expected impacts, the aim of this study is to present some mitigating possibilities with respect to the Onslow scheme, also recognising that no mitigations were undertaken with respect to the many past hydro schemes in the Otago-Southland region generally.

The various mitigations are simply proposals that might be considered and are not intended to be exhaustive or obligatory. Possible funding may be considered as part of the Onslow construction budget or derived from other alternative sources, should the scheme proceed.

The two overarching study objectives are with respect to environmental offsetting and new water resource possibilities:

- Identify a range of environmental offset possibilities over the Otago-Southland region.
- Identify climate change adaptation opportunities, especially drought resilience, arising from the massively expanded water storage volume at Lake Onslow.

This first chapter has served to introduce the thesis, the remaining chapters are organised as follows:

Chapter 2: Large-scale overview

Environmental offsets and mitigation concepts are examined.

Chapter 3: Local environmental offsets and mitigation options.

An outline is given of possible local lake recreation alternatives.

Chapter 4**:** Possible lake and river restorations as Onslow environmental offsets

The wider Otago-Southland region's prospective restoration opportunities are evaluated in this chapter as potential Onslow scheme offsets.

Chapter 5: Lake Onslow water storage against regional droughts

This chapter provides an overview of some drought mitigation water resource possibilities that the enlarged Lake Onslow may make possible.

Chapter 6: Discussion and Conclusion

Chapter 2: Large-scale Overview

This chapter serves as an overview of two important concepts within environmental science: environmental offsets and environmental mitigations, along with their fundamental distinctions. Environmental offsets and mitigation strategies play useful roles in making decisions to implement many construction and development projects.

2.1 Environmental Offset

Environmental offset refers to the process of compensating for unavoidable adverse impacts of a development project, by providing equivalent ecological benefits elsewhere. It involves the restoration, enhancement, or protection of ecosystems or habitats in a different location to counterbalance the environmental losses caused by the development. Environmental offset is often implemented through measures such as habitat restoration, the creation of protected areas, or investment in conservation projects. The idea is that the negative impact on the environment caused by a development project is balanced out by an equivalent positive impact in a different location or at a different time.

In the context of environmental offset, the ideal scenario entails the establishment of an ecologically identical ecosystem in a different location to compensate for the ecological losses caused by a development project. However, in practice, achieving such a perfect offset is often infeasible. Therefore, offsets are often implemented as environmental protection and conservation projects that aim to enhance the overall environmental quality. For instance, in cases where a wetland is impacted by the construction of a hydropower facility, the ideal offset would involve the creation of a new wetland elsewhere. However, due to practical constraints, this may not always be possible. Consequently, offsets encompass any environmental initiatives that generate positive impacts in the vicinity of the project.

The Deepdell project at Macrases gold mine serves as an illustrative case of environmental offsets, as outlined in the Appendix. Chapter 3 includes examples of some specific local environmental offsets in Otago.

2.1.1 Environmental Restoration

Environmental restoration is a form of environmental offset and refers to the deliberate process of repairing, rehabilitating, or re-establishing ecosystems and their natural functions and values that have been degraded, damaged, or destroyed by human activities or natural disturbances. It involves a range of activities aimed at reversing or mitigating the negative impacts on the environment and promoting the recovery of ecosystems to a more natural or desired state. Environmental restoration can take place in various types of ecosystems, including forests, wetlands, grasslands, coastal areas, lake, and freshwater systems.

The goals of environmental restoration typically include:

- ***Restoring biodiversity**:* Environmental restoration aims to enhance and promote the recovery of plant and animal species, including rare, threatened, or endangered ones. The process involves restoring habitat conditions, providing suitable resources for wildlife, and promoting ecological connectivity.
- ***Rehabilitating ecosystem functions**:* Restoration efforts focus on reinstating key ecological processes such as nutrient cycling, water purification, pollination, and seed dispersal. These functions are for maintaining the health and resilience of ecosystems.
- ***Improving ecosystem services**:* Environmental restoration aims to enhance the benefits that ecosystems provide to humans, such as clean air and water, carbon sequestration, erosion control, and recreational opportunities.
- ***Enhancing resilience**:* Restoration projects often aim to increase the resilience of ecosystems to future disturbances, including climate change impacts. This may involve restoring natural buffer zones, improving ecosystem connectivity, or introducing climate-resilient species.

The process of environmental restoration typically involves several steps, including assessing the extent and causes of degradation, setting restoration goals and objectives, designing and implementing restoration plans, monitoring progress, and adjusting strategies as necessary.

Overall, environmental restoration plays a role in conserving biodiversity, improving ecosystem health, and fostering sustainable development by addressing the impacts of human activities and supporting the recovery of degraded ecosystems.

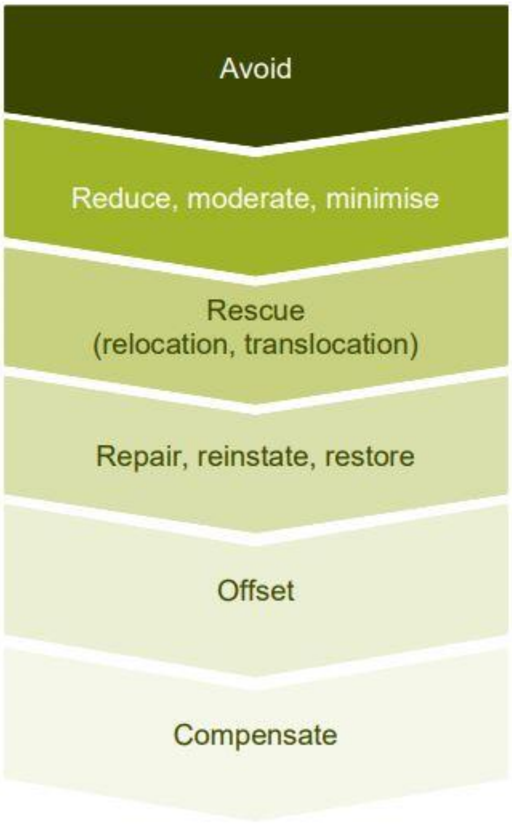


Figure 2.1. The conservative hierarchy (LLP, 2010)

LLP (2010) showed in their research that offset, mitigation, and restoration are the steps in the conservative hierarchy (Figure 2.1), which comprises the steps ‘avoid’, ‘remedy’, and ‘mitigate’, followed by ‘offset’ and ‘compensation’, and requires each lower stage to be completed as far as feasible before the next stage is attempted, thereby creating a hierarchy of preference (LLP, 2010).

In the context of the above, Chapter 4 provides some recommendations for Onslow-related environmental restoration projects, focusing on restoration of rivers and lakes.

2.2 Environmental Mitigation

Environmental mitigation involves the implementation of measures to reduce, prevent, or minimize the negative impacts of human activities on the environment. Mitigation aims to address the root causes of environmental degradation or harm by implementing specific actions or strategies that can mitigate or alleviate the adverse effects. It focuses on reducing the magnitude or severity of the impact, rather than compensating for the impact through alternative actions. Environmental mitigation can include practices such as pollution control, waste management, habitat restoration, or the adoption of sustainable practices to minimize environmental harm and reduction of site impacts.

Riparian buffer zones along the banks of rivers, streams, and other water bodies, green infrastructure, and fish ways in many hydropower stations are examples of environmental mitigations. Examples with respect to the Onslow scheme are considered in Chapter 3.

2.3 Distinguishing between environmental offset and environmental mitigation

Environmental offset and environmental mitigation both aim at addressing the negative impacts of human activities on the environment. However, they differ in their focus and the strategies used to achieve their goals.

The key difference between environmental offset and environmental mitigation lies in their objectives and approaches. Environmental offset seeks to compensate for environmental losses caused by a development project by providing equivalent benefits elsewhere, while environmental mitigation aims to reduce or minimize the negative impacts of human activities through various measures and strategies. Both approaches contribute to environmental conservation and sustainability, but they address different aspects of impact management and ecological restoration.

2.4 Climate change adaptation in water resources

Climate change adaptation in water resources refers to the implementation of strategies and measures to manage and respond to the impacts of climate change on water availability, quality, and related ecosystems. It involves adjusting water management practices and infrastructure to cope with changing climate conditions and to ensure the sustainable use of water resources in the face of climate-related challenges.

In scientific terms, climate change adaptation in water resources entails:

Hydrological Assessment: Conducting thorough assessments of hydrological systems to understand the potential impacts of climate change on water resources. This includes analysing changes in precipitation patterns, evaporation rates, snowmelt, river flows, groundwater recharge, and other hydrological parameters.

Water Resource Planning: Developing robust and flexible water resource management plans that account for climate change projections. This involves considering future scenarios of water availability, demand, and variability to ensure long-term sustainability and resilience in water allocation and distribution.

Infrastructure Adaptation: Modifying or upgrading water infrastructure, such as reservoirs, dams, canals, and drainage systems, to withstand extreme weather events, changing runoff patterns, and increased variability in water supply. This may involve improving storage capacity, enhancing flood protection measures, and incorporating climate resilience into the design and operation of water infrastructure.

Water Use Efficiency: Promoting efficient water use practices and technologies to optimize water allocation and reduce water demand. This includes implementing water conservation measures, promoting water-efficient irrigation techniques, and encouraging water recycling and reuse.

In this context, Chapter 5 provides specific suggestions for climate change adaptation possibilities with specific reference to future Otago droughts that may arise from climate change.

Summary

Environmental offset involves compensating for the negative impacts of a development project by providing equivalent environmental benefits elsewhere. This is achieved through the restoration, enhancement, or protection of ecosystems or habitats in a different location. While the ideal offset would involve establishing an identical ecosystem elsewhere, practical constraints often lead to the implementation of environmental protection and conservation projects that enhance overall environmental quality. Environmental mitigation, on the other hand, aims to reduce or prevent the negative impacts of human activities on the environment by implementing specific actions or strategies.

Furthermore, environmental restoration, a form of mitigation, involves repairing or rehabilitating degraded ecosystems to promote their recovery. Climate change adaptation in water resources entails strategies and measures to manage and respond to the impacts of climate change on water availability, quality, and related ecosystems. This includes hydrological assessment, water resource planning, infrastructure adaptation, and promoting water use efficiency.

Chapter Three: Local Environmental offsets and Mitigation options

The local community around Roxburgh and Teviot Valley has expressed concern about local impacts around Lake Onslow (Taylor et al., 2022). In particular, the loss of present lake recreational opportunities and wetland loss. This chapter overviews some possible local alternatives if the Onslow scheme proceeds.

3.1 Alternative Lake Recreation Options from Roxburgh Township

Two alternative lake recreation possibilities are considered here: a constructed road access to the Greenland Reservoir and the creation of a new lake and reserve in the upper Bonds Creek catchment.

3.1.1 Alternative new road to Greenland Reservoir

The Greenland Reservoir might serve as an alternative lake recreational resource. It is already a trout fishing resource but is currently not possible to access it from Roxburgh due to the absence of a public road link. Subject to landowner agreements, it might be possible to relocate the present Onslow fishing hunts to the Greenland Reservoir.

Combined with the Upper Manorburn reservoir, there would be some 14 km length of waterway of recreational boating available.

An access possibility from Roxburgh is to extend the existing road end through to the reservoir. The extension shown in Figure 3.1 is tentative only but serves as an indicative starting point. A detailed road route evaluation and landowner engagement would be required if the Greenland Reservoir access option were to be considered further.

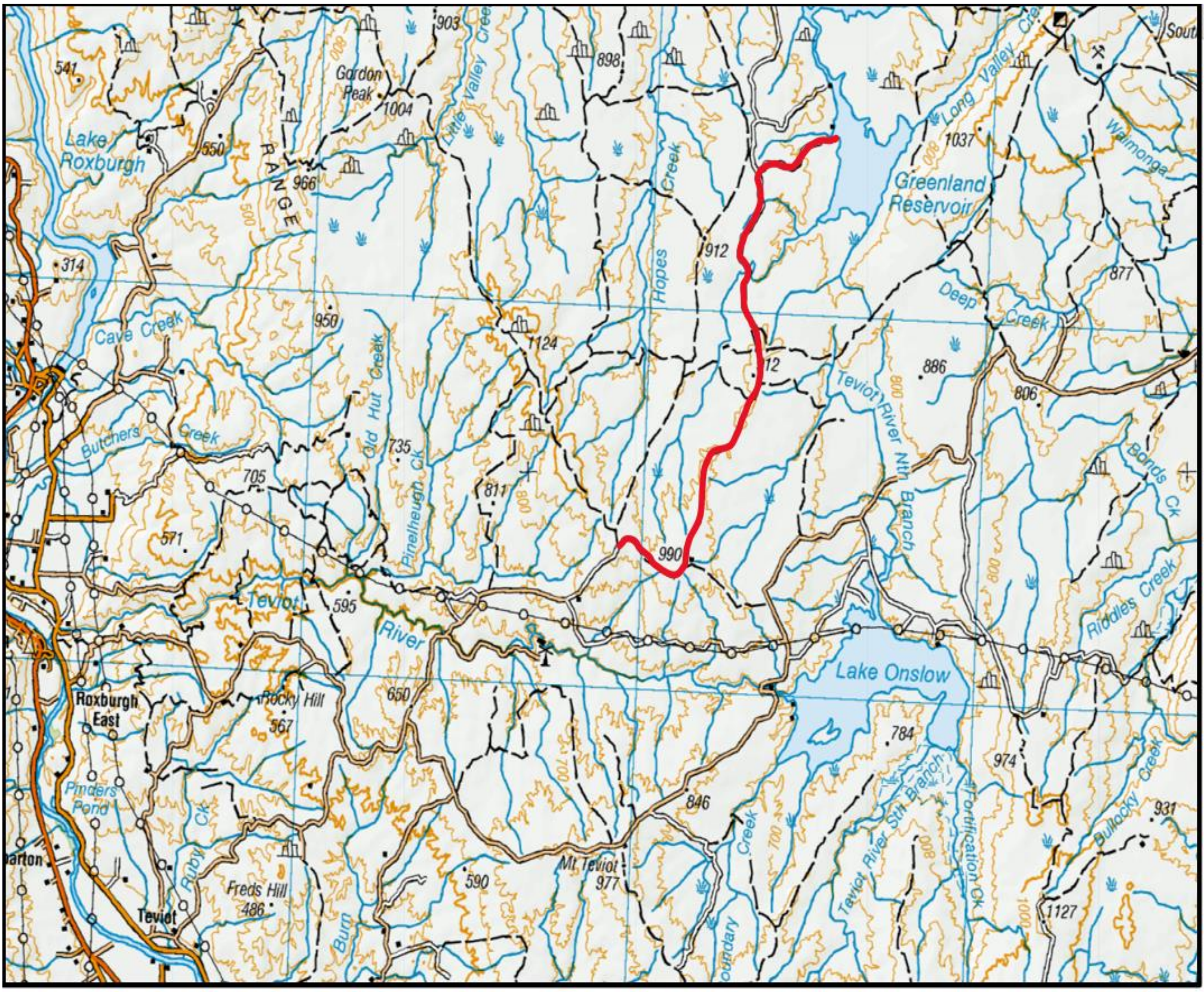


Figure 3.1 Tentative new road link (red) for access to the Greenland Reservoir from Roxburgh township (Map source: LINZ).

3.1.2 Potential new lake and upland reserve at Bonds Creek

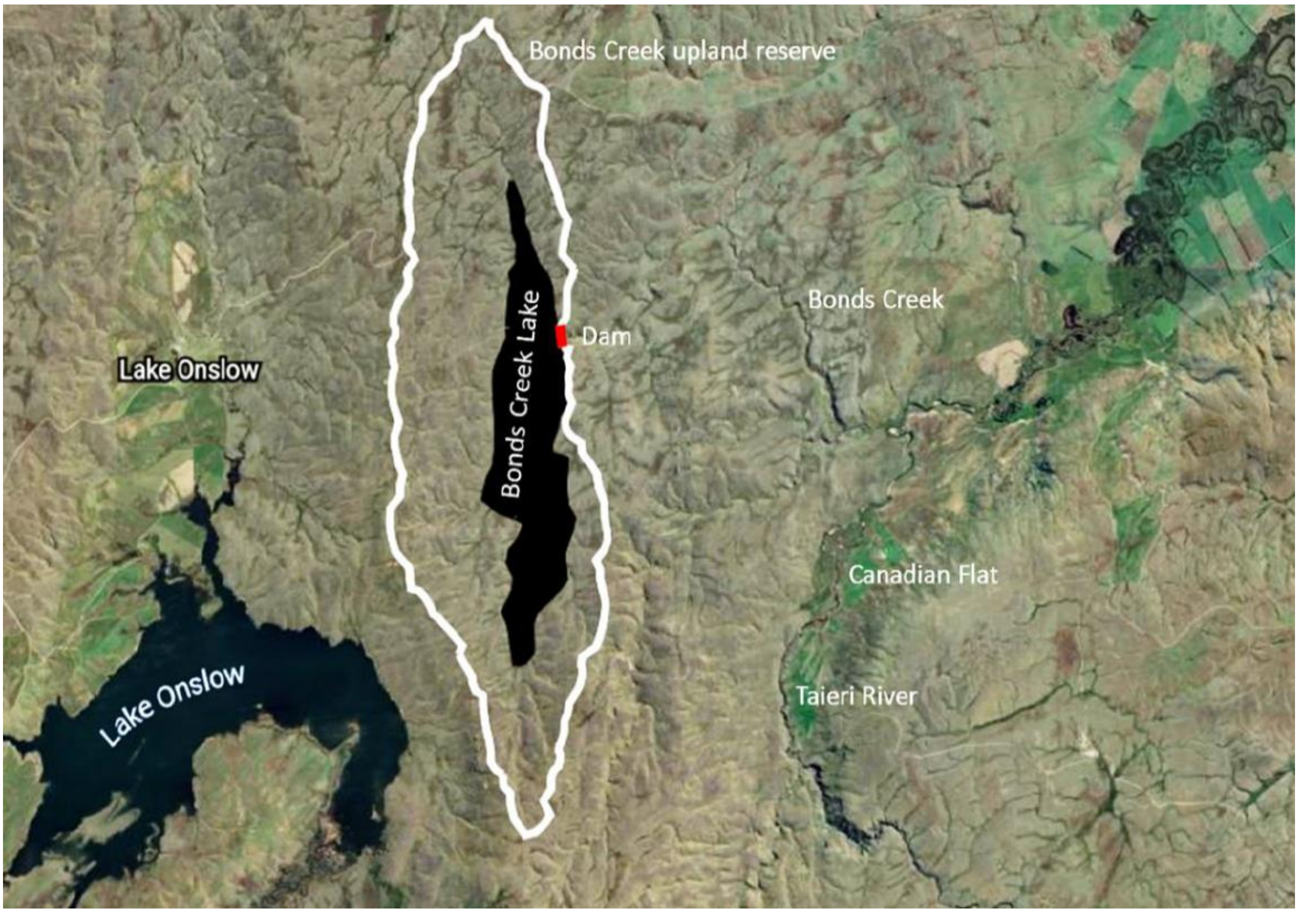


Figure 3.2. Potential Bonds Creek upland tussock reserve with a new recreational lake. The white line is the lake catchment boundary that would also serve as the boundary of the reserve (Map source: Google Earth).

A 40 m dam in the Bonds Creek headwaters would create an extended new lake with a 13 km shoreline at 760 m elevation. Subject to securing landowner agreement for land purchases, the catchment of the lake could be set up as a protected tussock upland reserve extending over some 15 km^2 (Figure 3.2). A predator-proof fence might be constructed on the reserve boundary.

As with the present Lake Onslow, the lake would have shallow water around its margins. This would encourage new wetland development and possible trout spawning on the lower tributary streams.

The new lake would be some 100 m higher than the present Lake Onslow, possibly being more favourable for trout because of colder water. In keeping with reserve status, hydraulic barriers would need to be installed on streams to provide permanent safeguard for Teviot Flathead populations against trout predation.

The new lake would function hydrologically as a natural water body, unlike the present Lake Onslow reservoir. That is, the dam would just be a weir waterfall with no possibility for controlled water release.

Like the Greenland Reservoir, the new lake would have the remote feel of the present Lake Onslow and new road access would need to be designed.

It would be desirable if the Greenland and/or Bonds Lake options were established prior to construction starting at Lake Onslow, which will become something of an industrial zone for an extended period of time during the Onslow scheme construction.

3.2 Local environmental mitigation at Lake Onslow

Three possible suggestions are raised with respect to an expanded Lake Onslow.

(i) Floating wetland
(ii) Waterfall Fish Barriers
(iii) Drawdown mitigation

3.2.1 Floating wetland possibility

The main environmental concern of Lake Onslow pumped storage is that around 8 km^2 of existing wetlands would be flooded.

For the wetland bird population's protection, a predator-proof fence might be built around the entire Lake Onslow area. Additionally, a constructed floating wetland with intricate waterways suitable for eco-tourist operations could be built on perhaps 16 km^2 of the new lake.

If constructed, the new wetland would in part make up for both the southern and Dismal Swamp wetlands losses. A demonstration square kilometre floating wetland might be created on the present lake Onslow to give a sense of the eventual wetland's appearance.

Lake Onslow is an elevated location that is exposed to strong winds from time to time. Any constructed long-term floating wetland structure would therefore need special boundary strengthening against wave erosion and perhaps set in a location with reduced wave fetch.

The Lake Rotorua failed wetland experiment gives a warning example of the consequences of poor wetland design against wind waves (Figures 3.3, 3.4).

Figure 3.3 Floating wetland as originally set up in Lake Rotorua to improve water quality and provide a bird habitat (Source: Rotorua Daily post).

Figure 3.4 Rotorua floating wetland damaged after a storm (Source: Rotorua Daily post).

3.2.2 Fish barrier construction on Lake Onslow tributary streams

One of the local native fish species at risk from raising Lake Onslow is the Teviot Flathead galaxiid (MacDonald, 2022). A protective action would be to create small dams with artificial waterfalls to block trout migration from progressing further upstream.

Some examples of existing barriers of this type in Otago and Canterbury are shown in Figures 3.5, 3.6, and 3.7.

Figure 3.5 Swinburn Creek barrier in Central Otago. A built barrier has been installed onto a natural waterfall to protect Central Otago roundhead galaxiid populations, after brown trout gained access upstream when stream conditions changed (Source: Department of Conservation, 2018).

Figure 3.6 Akatore Creek barrier in Otago. A built barrier has been installed onto a natural waterfall to protect Taieri flathead galaxias, after brown trout gained access upstream when conditions changed (Source: Department of Conservation, 2018).

Figure 3.7 Built barrier installed in Cabbage Tree Gully, South Canterbury. The barrier was built to prevent trout accessing a key lowland longjaw galaxias population, Canterbury (Source: Department of Conservation, 2018).

3.2.3 Onslow drawdown mitigations

A raised Lake Onslow would differ from other New Zealand hydro lakes in having a very large potential maximum drawdown of around 45 m.

This raises the issue of blown dust from extensive areas of drying soil when lake levels decline.

Blown dust was an issue in the early years of Lake Hawea operation when drawdowns almost back to the original lake level caused fine river silt derived from the exposed Timaru Creek delta to be blown over Hawea township.

The Lake Onslow situation is different in that soil rather than river silt would be the source of dust. Research is required into this environmental aspect of Onslow operation. One possibility would be to pre-clean the shallow soils from the underlying schist rock over the most likely range of water level fluctuation. There is also a need to investigate the extent to which wave action on the raised lake might remove the remnant soil.

Drawdown will have the most visible impact at the north end of the lake where the water level will fluctuate over a region of gentle gradient in the vicinity of the north branch Teviot tributary. One possibility here might be to use the river flow to maintain ephemeral lakes which appear as the lake level falls. This would involve constructing weirs along the lower portion of the Teviot north branch stream. The weirs would be submerged at high lake level but would create small lakes when the level falls. This would result in the loss of some energy storage capacity of Lake Onslow, but the water volumes involved would be minimal relative to the Onslow total volumetric storage capacity.

Summary

Chapter 3 has considered aspects of local environmental offsets and mitigation strategies in the context of the proposed Lake Onslow pumped storage scheme.

The exploration of alternative lake recreation possibilities, such as the potential use of Greenland Reservoir and the creation of a new lake and upland reserve at Bonds Creek, highlights the need to preserve recreational and ecological values valued by the local community.

Chapter Four: Possible Lake and River Restorations as Onslow Offsets

This chapter presents an assessment of selected restoration possibilities in the Otago-Southland region as potential Onslow scheme offsets. The restoration suggestions for the most part involve significant changes and should be taken only in the spirit of opening discussions.

The restoration initiatives are evaluated based on their perceived viability, with priority given to the restoration of Lake Monowai, Lake Hawea, and the lower Manuherikia River. In addition, attention is drawn to a partial restoration of the seasonal flow regime of the lower Waitaki River that will arise independently as a consequence of Lake Onslow pumped storage operating in the electricity market. In addition, a more speculative long-term suggestion is raised about how Onslow combined with new Southland wind power could enable considerable flow to increase in the lower Waiau River.

4.1 Restoration of Lake Monowai

Lake Monowai (31 km^2) is a forest-surrounded lake in the southern region of Fiordland National Park. Prior to the formation of the national park, the lake was raised 2.13 m in 1926 to give storage for a small power station that provided needed electricity at the time for western Southland.

The Monowai power scheme was officially opened in 1925 and is presently operated by Pioneer Energy. Water is released from Lake Monowai, flowing down the Monowai River and diverted into a headrace some distance downstream outside of the National Park (Figure 4.1). The headrace water is then transferred into penstocks extending down to the small 6 MW Monowai power station (Figure 4.2). The station discharges into the Waiau River. Its mean power output is about 4 MW.

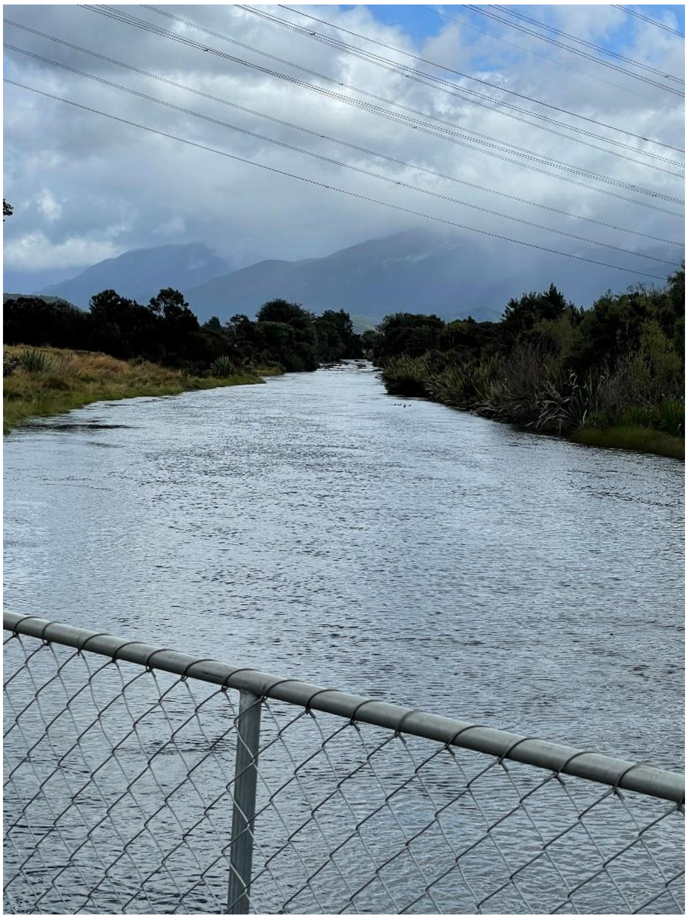


Figure 4.1 Start of Monowai power station headrace (Source: Yasaman Karaminik).

Figure 4.2 Monowai power station (Source: Pioneer Energy).

Given its small power output, the Monowai scheme is arguably the most environmentally destructive in New Zealand for benefit gained. Raising Lake Monowai for seasonal storage drowned the original natural lake beaches and the lake margin beech forest. This resulted in what is now a national park lake being characterised by 57 km of shoreline comprised of dead tree remnants and submerged logs (Figure 4.3).

The lake stands in sharp contrast to nearby Lake Hauroko, which shows how the Lake Monowai shoreline once was (Figure 4.4).

Figure 4.3 Section of Lake Monowai shoreline with exposed stumps of the former forest (Source: Yasaman Karaminik).

Figure 4.4 Shoreline beach at natural Lake Hauroko, near Lake Monowai (Source: Kayak Fishing Otago).

Restoration of Lake Monowai to its original state would be a relatively cost-effective partial environmental offset to the flooding of the Onslow wetlands, despite being located some distance away and of different environmental character.

The process would be that the government would first purchase the Monowai power scheme from Pioneer Energy and remove the small dam at the lake exit point. This would restore the lake to its original level with no further control. The power station would be reconfigured with turbines optimised to run of the river operating mode and sold – perhaps back to Pioneer Energy.

Part of the reconfiguration might involve increased penstock diameter and headrace discharge capacity to capture more of the peak natural flows from the lake. Any such works would not impact Fiordland National Park because the locations involved are all outside of the park boundary.

Subsequent to lowering the lake back to its natural level, there would need to be replanting of the lake shore beech forest to slowly cover over what will be initially a somewhat desolate lakeside zone of exposed logs and stumps of the former forest.

The growing forest would be eligible for carbon credits, which would contribute to the restoration cost.

Restoration of Lake Monowai would be of national significance well beyond the lake itself. This is because it would be the first time in New Zealand that former hydro storage has been reverted back to its original natural state for environmental reasons.

4.2 Restoration of Lake Hawea

Lake Hawea was raised in 1958 to provide some seasonal water storage for the Roxburgh power station (and now for the Clyde station also). The lake is presently managed by Contact Energy as part of its Clutha Power Scheme (Figure 4.5), comprising the Roxburgh and Clyde stations. It remains the only managed seasonal hydro storage lake in the Clutha River catchment.

4.2.1 Environmental impact of lake raising

Lake Hawea was raised 18 m from its original level of 327.6 m asl. (Figure 4.6). The Hawea Dam discharges lake water into the Hawea River, with a currently permitted discharge range of 10 - 200 m^{3}s^{-1}.

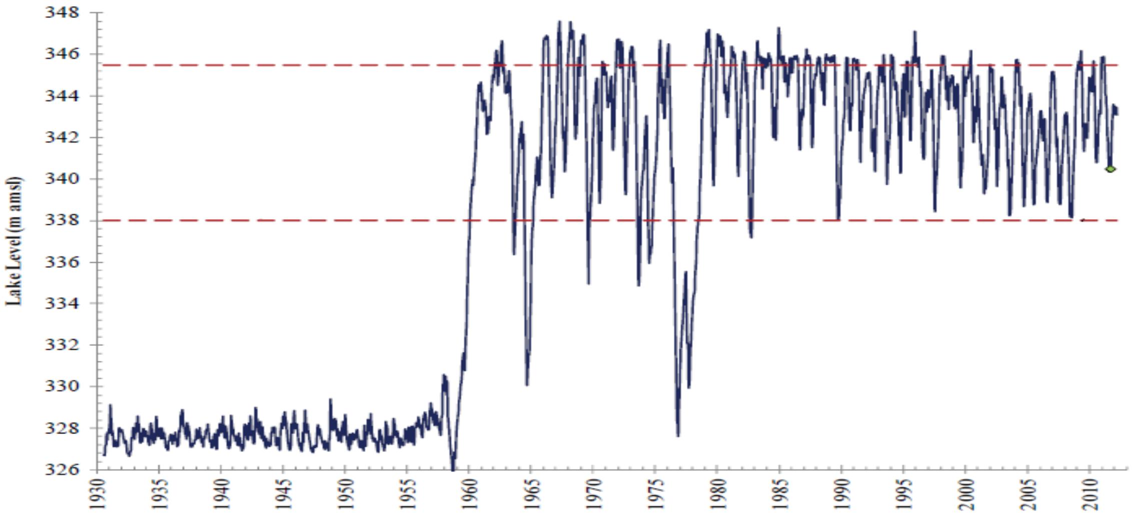


Figure 4.6 Lake Hawea water levels 1930-2010, showing lake raising with subsequent increased seasonal water level variation as a consequence of hydro operation. From 1985 the lake's permitted operating range is 338-346 m asl. (After Wilson, 2012).

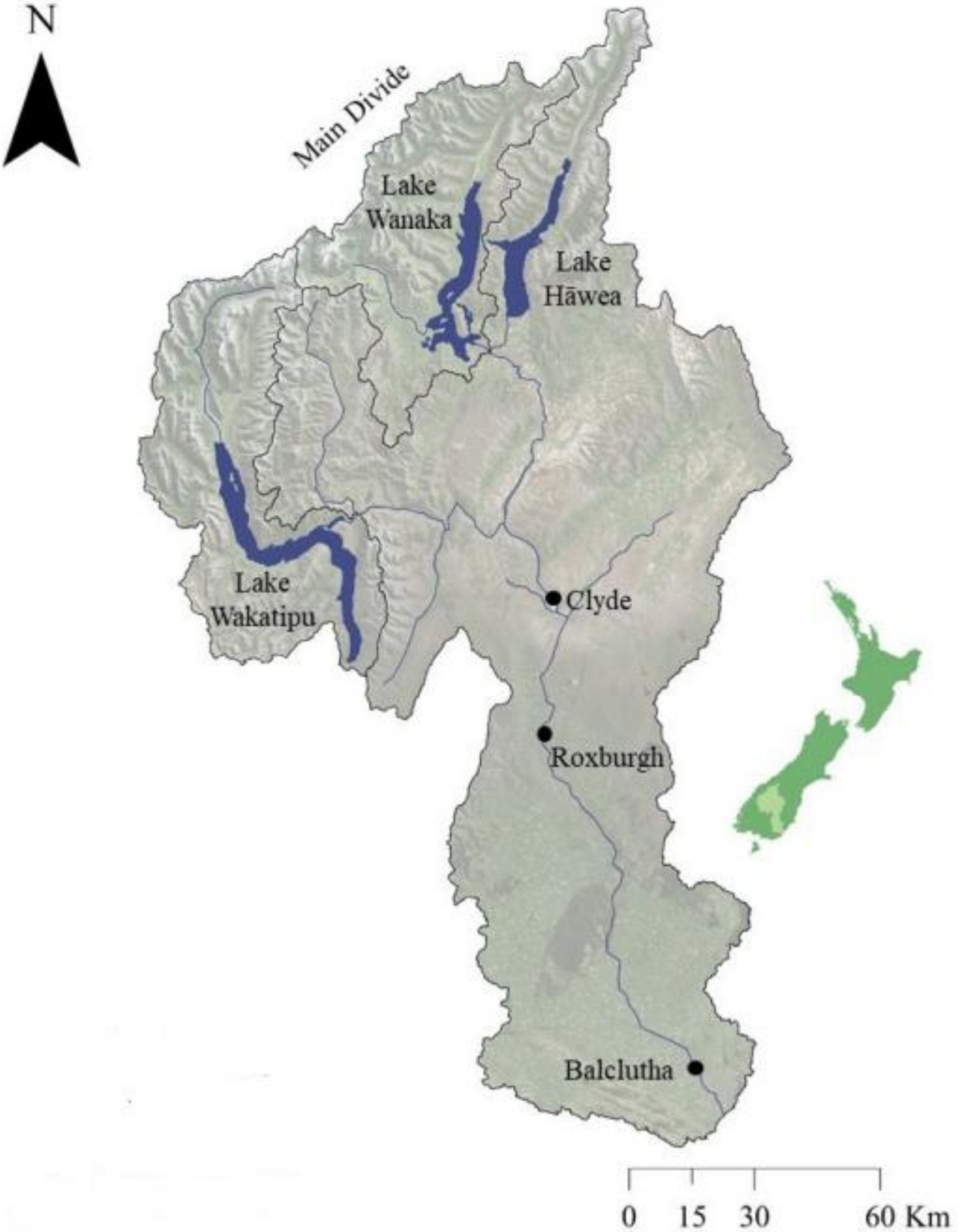


Figure 4.5 Clutha Mata-Au River catchment with Lake Hawea in the north.

The main regions of land flooded from raising Lake Hawea are shown in Figure 4.7.

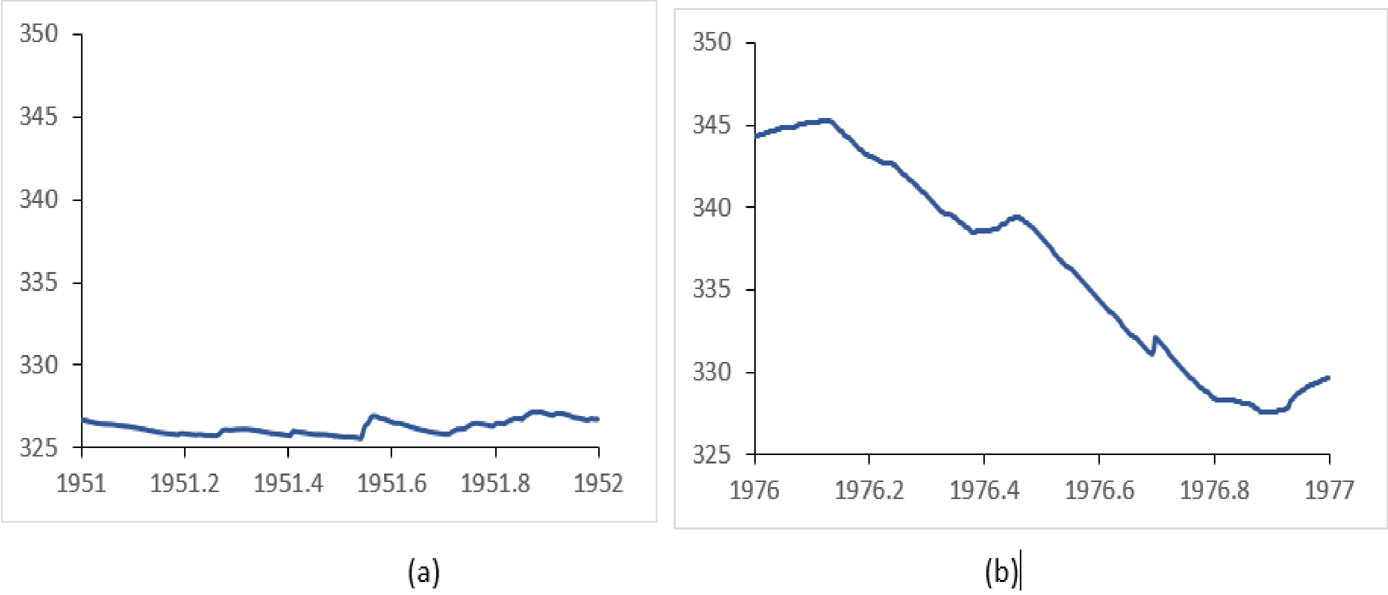
Figure 4.7 Main locations, shown in green, that were submerged by raising Lake Hawea (Map source LINZ).

The major environmental impact of the lake raising was destruction of the native beech forests of the lower Hunter River, at the north end of the lake. The dead remnants of some of the trees can still be seen protruding above the lake surface (Figure 4.8).

Figure 4.8 Flooded forest at Lake Hawea, showing the topmost branches of the drowned lower Hunter River beech forest (Source: Benjamin Jones).

The lake's hydroelectric operation has forced a seasonal water level variation of up to 8 m. This contrasts with the earlier, short-duration natural fluctuations, which were about 1 m in amplitude. The large seasonal variation (Figure 4.10) combined with episodic wave erosion at maximum water levels produces a sluicing effect that creates unstable retreating lakeshore cliffs in some locations (Figure 4.9).

Figure 4.9 Eroding lakeshore cliffs in soft glacial till, Lake Hawea (Source: Varvara Vetrova).



(a)

(b)

Figure 4.10 Hawea lake level variation over the course of two selected years, 1951 and 1976, illustrating the changed nature of lake level fluctuations before and after lake raising, respectively.

4.2.2 Potential for Lake Hawea restoration to its original level

Hydropower implications

In a hydropower sense, the raising of Lake Hawea could be regarded as an unfortunate accident of history. If 5 TWh pumped storage had been emplaced at Onslow first, there would have been strong environmental protests at the prospect of drowning the lower Hunter beech forest for the sake of just a 4% increase in national energy storage capacity.

Another factor is that Lake Hawea storage does not enable much seasonal control of Clutha River flow at Contact’s Roxburgh and Clyde stations in any case (Figure 4.11). This is because most of the water passing through these stations is derived from the outflow from the uncontrolled lakes Wanaka and Wakatipu. With or without Lake Hawea's seasonal storage, the seasonal power output from the two stations would not be greatly affected relative to the environmental gain of Lake Hawea restoration.

An additional factor is that Onslow pumped storage in operation will have a considerable smoothing effect in reducing the amplitude of seasonal price variations (Kelly, 2023). This means that stored water in hydro lakes over summer will have less value for winter power generation. The question is then raised as to whether keeping Lake Hawea in a flooded state can be justified.

Having an Onslow-induced summer floor price for wholesale electricity is likely to be beneficial to the economics of the Roxburgh and Clyde stations. This is because the stations are run of the river for practical purposes, presently generating most output when water flows are high and wholesale prices are relatively low.

One negative factor in terms of hydropower generation with a restored Lake Hawea is that there would no longer be potential to add a small power station to the Hawea Dam. However, Contact Energy does not see this as a high priority presently.

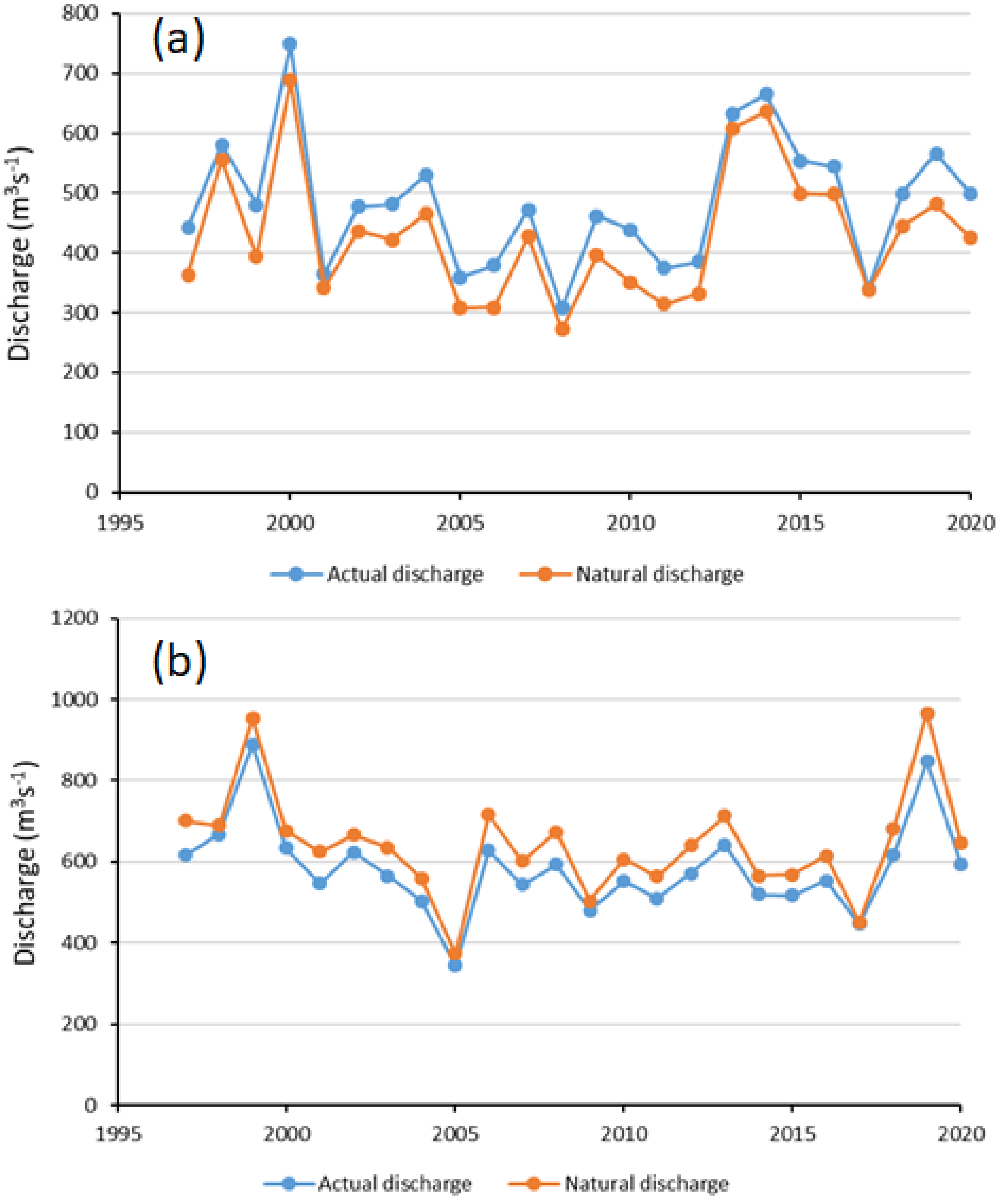


Figure 4.11 Mean 3-monthly Clutha flow as recorded at Clyde (blue), and natural mean 3-monthly Clutha flow at Clyde in the absence of Lake Hawea storage (obtained from Lake Hawea inflows). (a) Flow means for June, July, and August, (b) Flow means for October, November, and December.

It might be possible to keep some discharge control in a restored Lake Hawea. That is, high inflows might be held back for a short period and the lake levels permitted to rise briefly. This would reduce the impact of flood peaks on the Hawea River and sometimes enable some spill reduction at the Clyde and Roxburgh stations.

A crude model was constructed along these lines, while still keeping the simulated Hawea River flow within its consented range. The model operates on an equilibrium basis, where inflows and outflows are presumed to be exactly balanced, resulting in no change in the restored lake's 328 m water level. However, this equilibrium is disrupted in the model during high flow in the Clutha or Kawerau rivers. Water is then retained in Lake Hawea while still ensuring a minimum water release of 15 m^3s^{-1}. Conversely, in situations of low inflow conditions, the model releases some water from Lake Hawea to maintain a steady flow of 15 m^3s^{-1} in the Hawea River.

Figures 4.12 and 4.13 show the model output. The simulated lake level hydrograph is mostly at a constant 328 m elevation, broken at times by rapid rises and falls for brief storage at times of high flow in the Clutha and Kawarau Rivers. A more general flow model would enable quantification of Clyde and Roxburgh spill reduction as a function of acceptable water rises of short duration in Lake Hawea.

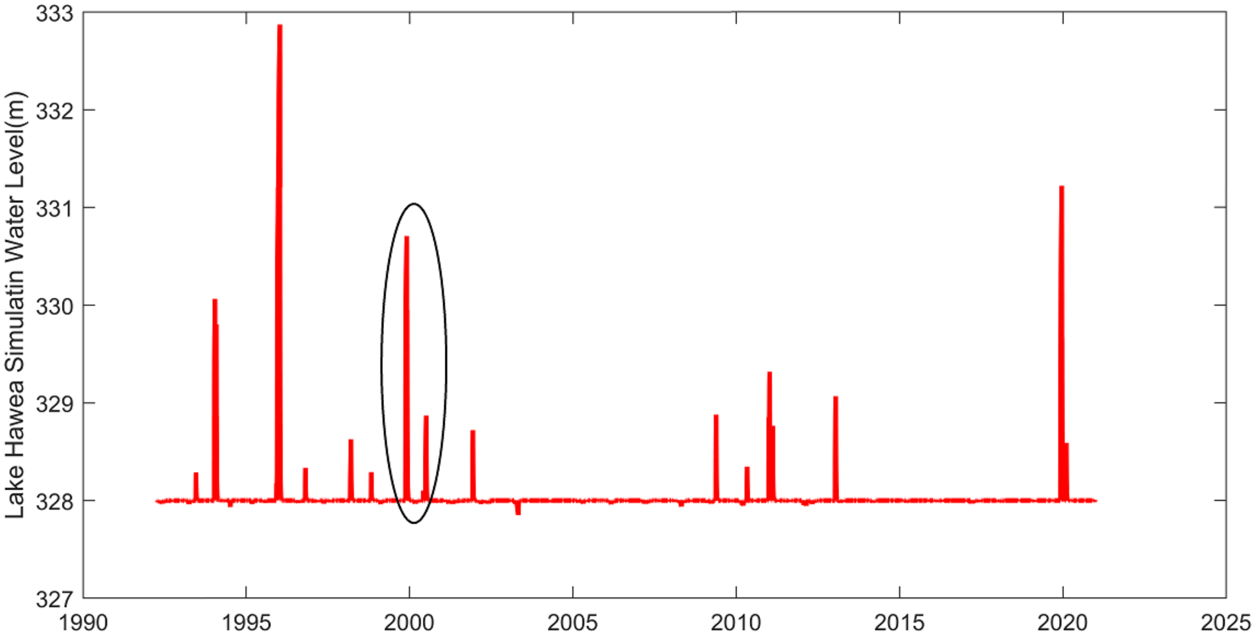


Figure 4.12 Restored Lake Hawea water level simulation model from 1992 – 2020, with the lake set at its original area (125 km^2). The model keeps the water level at 328 m except for some high-water levels from holding back flood inflows. The indicated region is expanded in Figure 4.13.

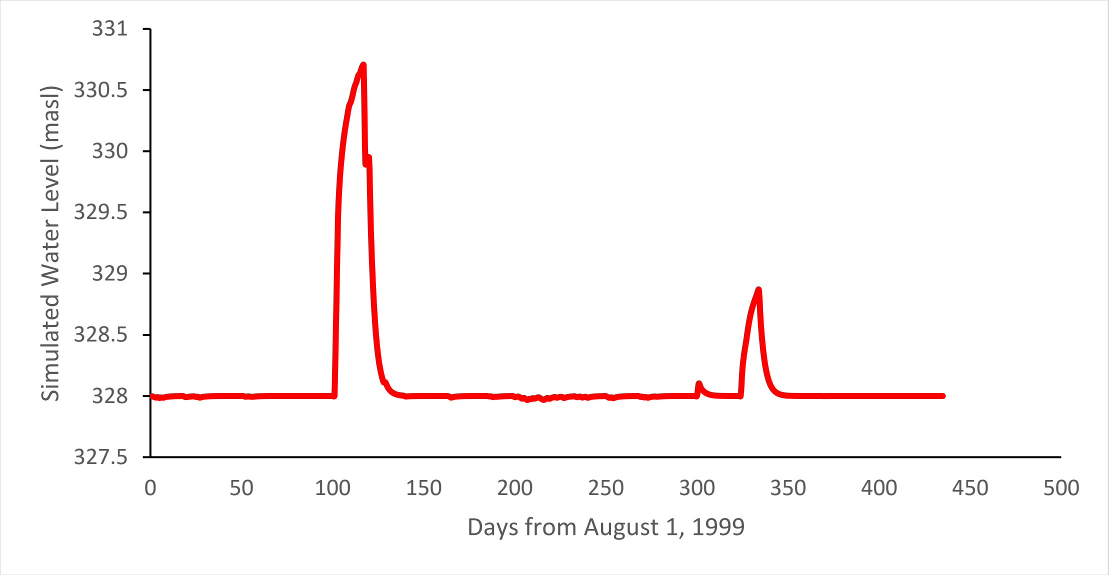


Figure 4.13. Expansion of model output over the indicated period in Figure 4.12.

A further development of the model would be to evaluate the ecological impact of high water levels of various durations.

4.2.3 Groundwater implications for lake level restoration

Groundwater wells provide water supply for Hawea Township and irrigation on the nearby Hawea Flat. Concerns about the possibility of falling well water levels are likely to be expressed over any suggestion of lake level restoration back down to the original natural water level.

The extent of any linkage between Lake Hawea water level and nearby well water levels has been a subject of debate and will depend on the degree of hydraulic connection between the local aquifer and the lake. An available record of groundwater levels from a monitoring bore located at Loach Road was utilised here (Figure 4.14).

Figure 4.15 shows some tendency for high and low groundwater levels to follow lake levels with about a two-month lag.

However, Figure 4.16 also shows a degree of association between local rainfall and lake level. The delay in groundwater response might therefore reflect the time for vertical rainfall percolation to groundwater. That is, rainfall could be driving both groundwater recharge and lake level through fast-response Lake Hawea river inflows.

There is therefore uncertainty as to whether a lowered lake level would in fact result in reduced well water levels. Further modelling and groundwater monitoring would be required.

The lake lowering would proceed in stages if restoration went ahead. If groundwater lowering is detected then there would be an argument for provision of deeper supply wells. Similarly, loss of the Hawea syphon might be compensated by pumping Hawea River water for irrigation.

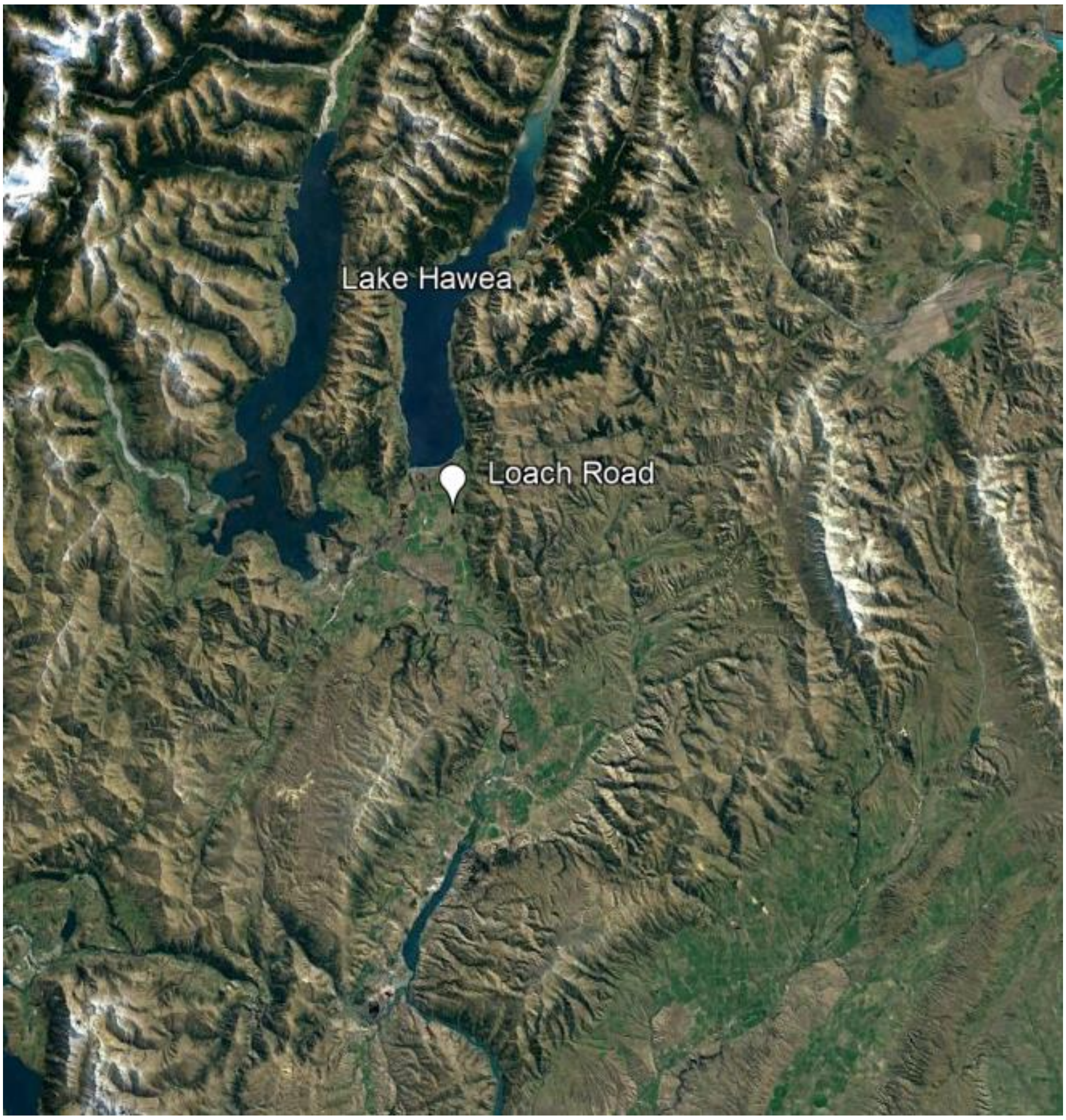


Figure 4.14 Loach Road groundwater monitoring site location (Map Source: Google Earth).

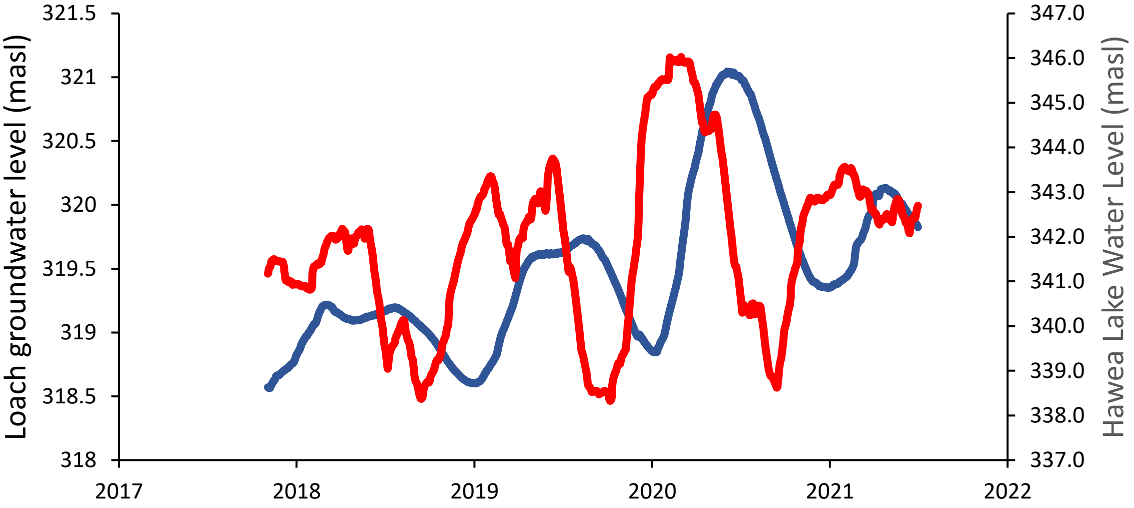


Figure 4.15 Loach Road groundwater level (blue) and Lake Hawea water level (red).

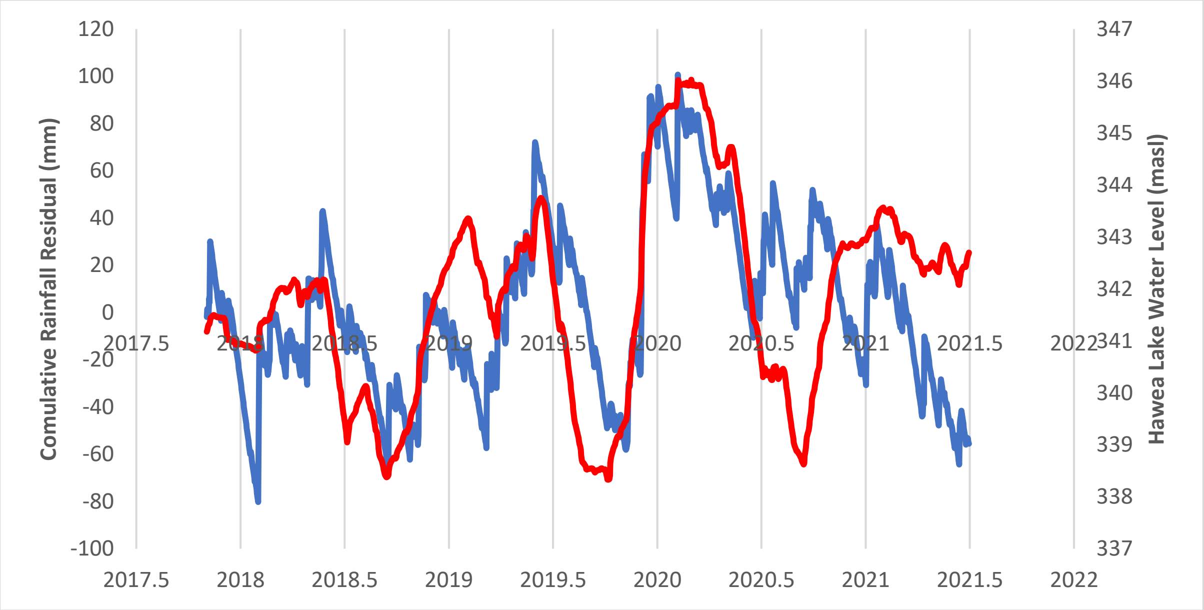


Figure 4.16 Lake Hawea water level (red) and rainfall cumulative residual (blue).

4.2.4 The restoration process

If the lake level was to be restored, restoration would take place by lowering the lake level in discrete steps with some grass planting to prevent dust-related problems. Most of the newly emergent land will be at the north end of the lake in the lower Hunter Valley.

Replanting of forest in the lower Hunter Valley would also proceed in increments, establishing new trees between the old logs of the original forest. As with Lake Monowai, carbon credits would help to offset reforestation costs.

4.3 Partial restoration of lower Waitaki River summer flow

The operation of Onslow pumped storage will result in a partial return of the lower Waitaki River flow toward its pre-hydro seasonal flow regime of higher spring-summer flows and lower flows for the rest of the year. This return toward the natural state has merit in itself but will also enhance recreational activity and reduce the impact of present water abstractions for irrigation.

The new flow regime will arise from a market-derived different commercial operation of the Waitaki power scheme. Onslow will pump mostly in spring-summer when the wholesale electricity prices are lower and the Clutha River flows are high. Often the purchased power for pumping will be derived from the Waitaki power scheme, with water releases from Lake Pukaki providing the flow through the Waitaki stations and therefore increasing the present spring-summer discharge through the braided lower Waitaki River (Figure 4.17).

It is difficult, however, to quantify the extent of the return to the natural seasonal flow regime of the lower Waitaki River. This is because it would involve attempting to simulate the operation of the Waitaki power scheme in the New Zealand electricity market with Onslow in operation.

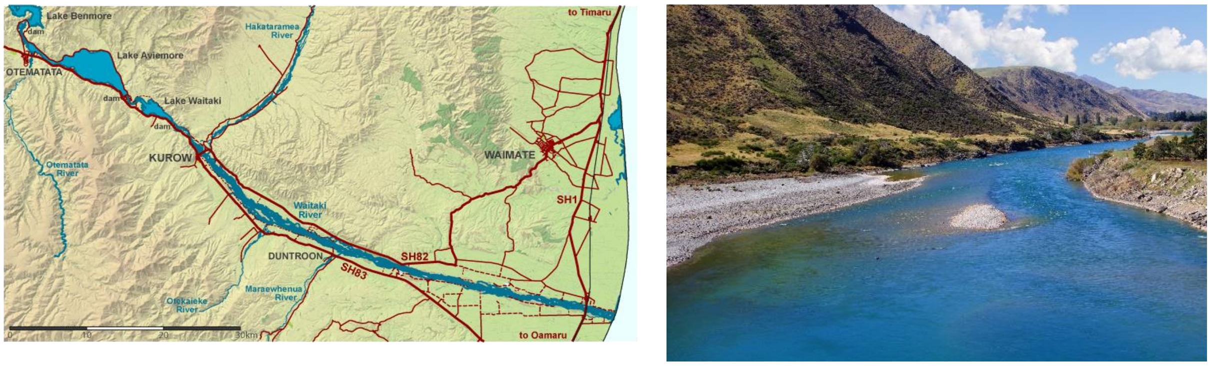


Figure 4.17 Lower Waitaki River (left). The Waitaki River below the Waitaki power station (right) marks the start of the Lower Waitaki River, which carries on to the sea. (RNZ).

An indication of at least the potential for change in the flow regime can be seen in Figure 4.18. This shows mean monthly discharge increases or decreases in the lower Waitaki River that would occur in the absence of any storage effect from Lake Pukaki. In reality, even an uncontrolled Lake Pukaki would still have some element of natural storage. However, this would be small compared to the large controlled seasonal storage effect for hydro operation.

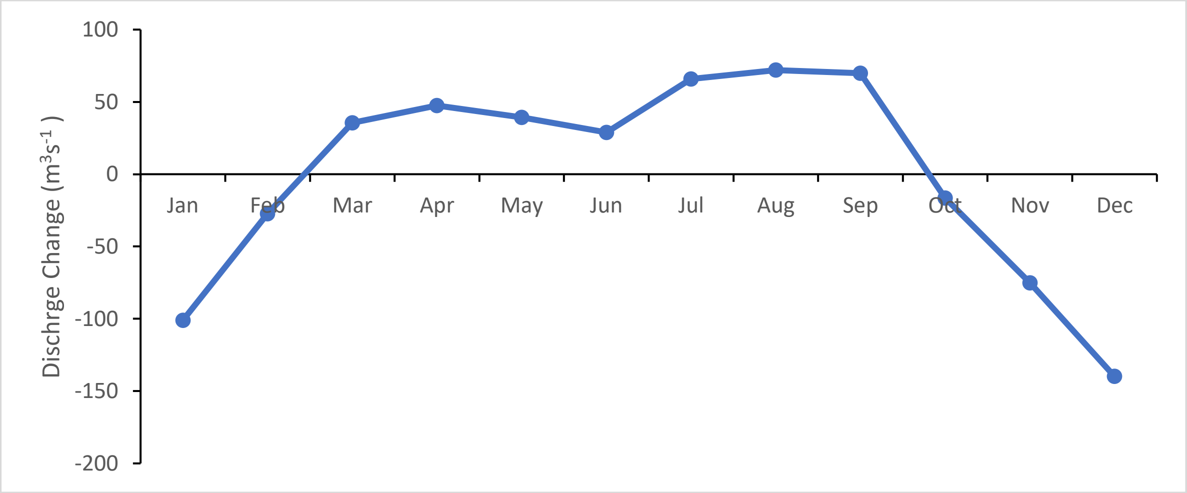


Figure 4.18 Estimated change in mean monthly flows in the lower Waitaki River arising as a consequence of hydro storage operation in Lake Pukaki, as averaged over 1985-2023. Hydro operation has reduced the flows over November, December and January, with increases from March to September. The large mean flow reduction in December is particularly evident.

In addition to commercially-related changes in the lower Waitaki flow, the presence of pumped storage at Lake Onslow would enable imposition of new consents requiring higher minimum river flows. This would ensure some increase in minimum water release from Lake Pukaki as part of Meridian Energy operations.

At the other flow extreme of the Waitaki River, Majeed (2019) has noted that the new operating regime of the Waitaki hydro lakes would result in some reduction in flood peaks on the lower Waitaki. This is because a reduced frequency of high lake levels translates to reduced spill events at the Waitaki power stations.

4.4 Restoration of the Manuherikia River

The Manuherikia River (Figure 4.19) has its headwaters in the Hawkdun Ranges of Central Otago, flowing southwest to join the Clutha River at Alexandra (Figure 4.19). The Manuherikia catchment is a dry region and there has been significant water diversion for irrigation, such that there is a general decline in river discharge downstream. Figure 4.20 shows visible river flows for various discharges at a site near Alexandra.

The reduced summer flow of the Manuherikia River at Alexandra has given rise to local controversy as to what should be the minimum required discharge at Alexandra (Figure 4.21) (Otago Daily Times, 8 June 2021). Low flows can result in warmer water with associated quality issues. However, higher minimum flows would prevent water takes from some existing irrigation users.

Despite numerous past reports, there is unlikely to be a resolution between the competing recreational and irrigation requirements of the river users in this dry environment. This has recently come to a head with the release of the final scientific report on the Manuherikia, recommending no less than 2 m^3s^{-1} of minimum flow near Alexandra. This could force the termination of some irrigation with local economic implications (Otago Daily Times August 23, 2023).

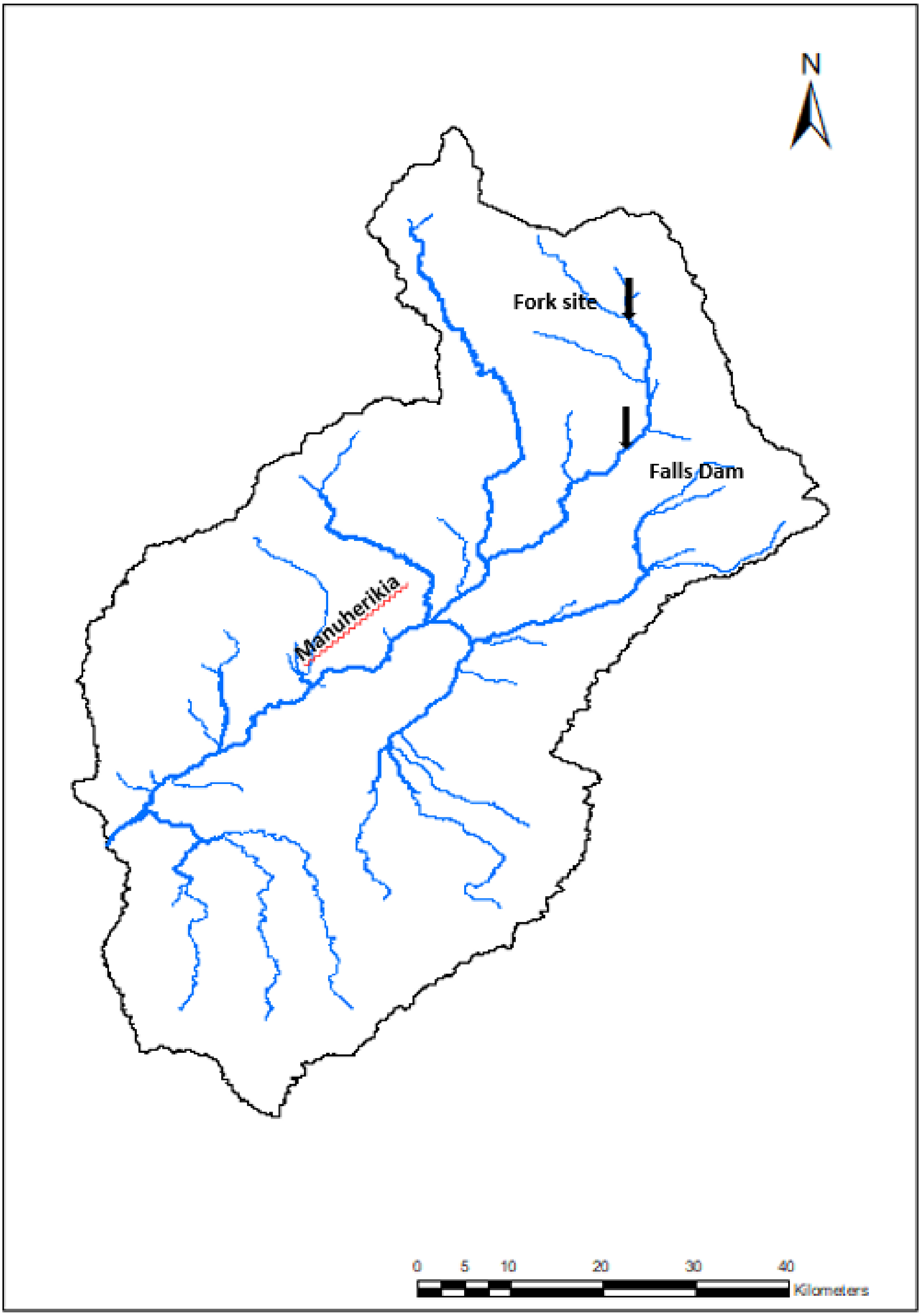


Figure 4.19 Manuherikia River catchment with location of Fork flow recording site and Falls Dam.

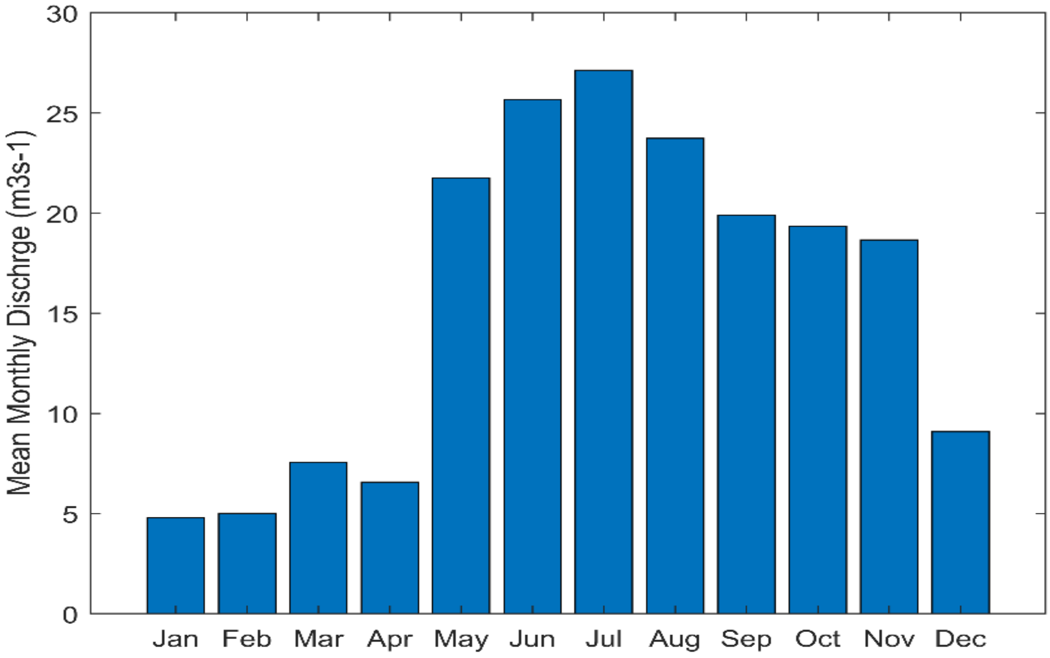
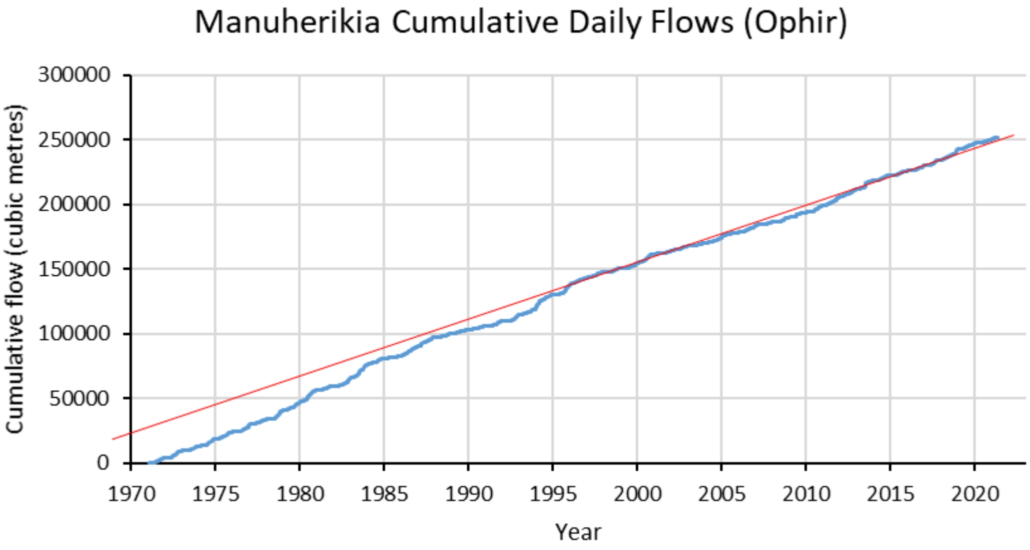


Figure 4.20 Mean monthly discharge of the Manuherikia River near the Alexandra Campground

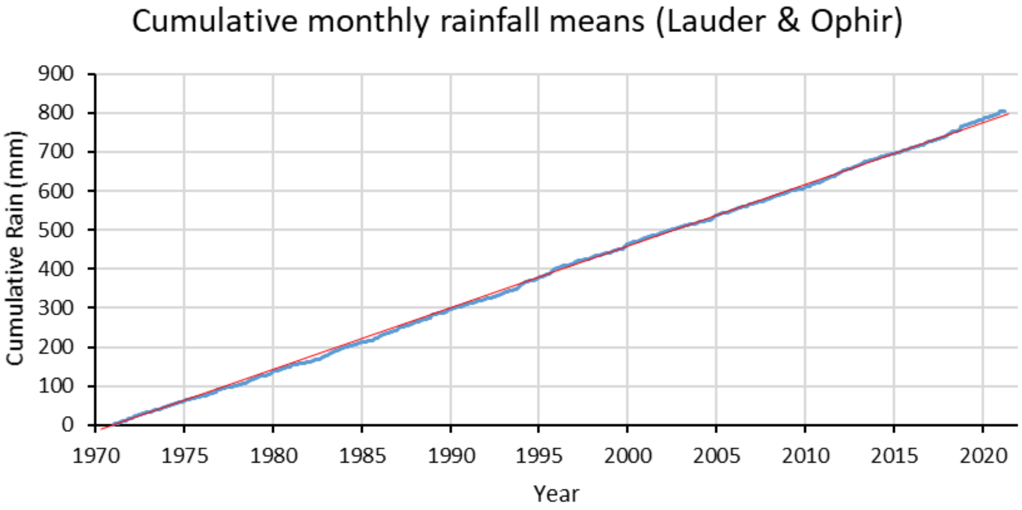
Figure 4.21 Manuherikia River, near Campground at different flow levels (Source: Otago Daily Times, 8 June 2021).

There has been ongoing dispute about the Manuherikia River. Since 1995, its flow at Ophir seems to have diminished (Figure 4.22a).

Mean flow declined from 14.9 m^3s^{-1} (pre-1995) to 12.6 m^3s^{-1} (post-1995) throughout the time period depicted in Figure 5, a difference of 2.3 m^3s^{-1}. Because the local rainfall does not exhibit a similar break in slope, this looks to be a result of more water-intensive land use (Figure 4.22b). It would be necessary for headwater rainfall investigations to verify this.



a)



b)

Figure 4.22 a,b Manuherikia River discharge and local rainfall. The rainfall time series is a composite of the Lauder and Ophir stations, to allow for missing data.

One possibility that has been suggested from time to time is the raising of the Falls Dam (Figure 4.23) in the catchment headwaters. The seasonal hydrograph of the inflow water to Falls Dam illustrates that sufficiently large storage at Falls Dam might enable higher flows in August-December (Figure 4.24) to be held back and released later to give higher flows over January-April. This would give higher minimum flows at Alexandra without imposing further restriction on current irrigation use.

The Falls Dam solution has attraction but the considerable cost of a higher or new dam has prevented serious consideration of this option.

Raising Falls Dam might therefore be considered as a possible government contribution as a partial offset for the environmental impact of flooding the Onslow wetlands. Part of any government contribution would be the requirement that the additional low-flow water would be for environmental purposes only, without permitting increased irrigation takes.

Figure 4.23 Morning glory spillway with water loss from the Falls Dam reservoir (Source: Bill Hatcher/ National Geographic Stock).

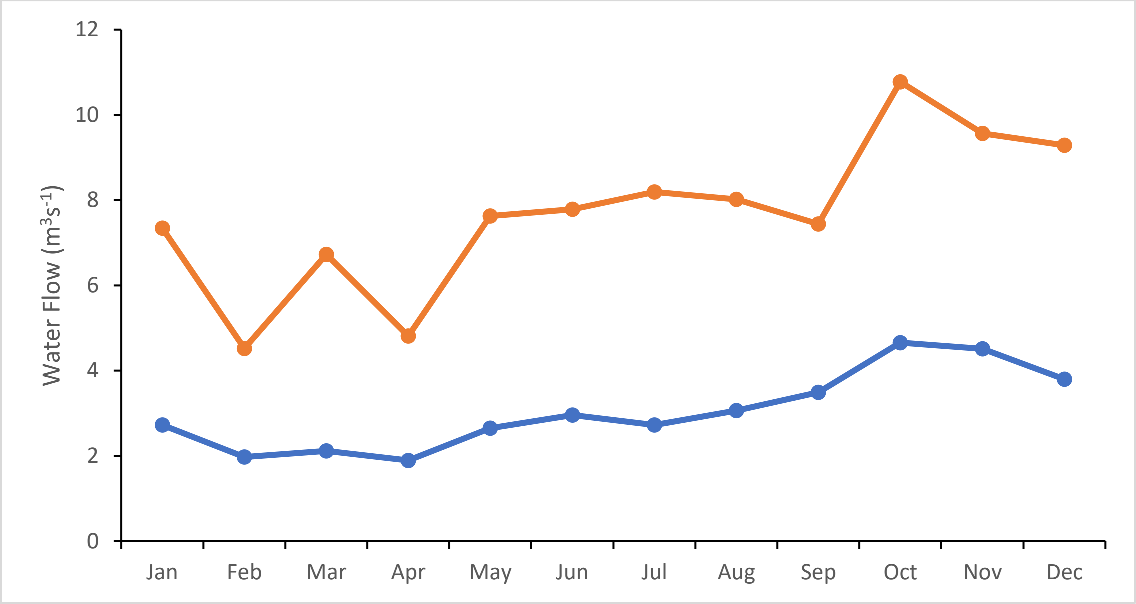


Figure 4.24 Mean monthly maximum flow (orange) and average monthly flow (blue) at Forks site upstream of Falls Dam (Manuherikia River).

Detailed river discharge models already exist for the Manuherikia catchment and would be possible to quickly determine the extent of minimum flow increase that could be achieved for various levels of enhanced storage at the Falls Reservoir.

4.5 Partial flow restoration of the Waiau River

The Waiau River in the western Southland (Figure 4.25) has arguably suffered the greatest hydropower impact of any New Zealand river.

The lower Waiau River (450 m^3s^{-1}) was second only to the Clutha River by mean discharge.

From 1971, most of the Waiau flow that was previously discharged from Lake Manapouri was diverted into the Manapouri Power Station and then to Doubtful Sound (Figure 4.26). Summer flows now are less than 60 m^3s^{-1} for over 50% of the time.

The power scheme was constructed to provide electricity for the Tiwai Point aluminum smelter at Bluff, having the positive economic contribution of giving direct and indirect employment to about 1,000 people.

Concerns are frequently expressed about the visible state of the lower Waiau River between Lake Manapouri and the sea (Figure 4.27). The low flows create water quality issues also. In the summer of 2019 the Southland Regional Council issued a warning that tourists on the Waiau River should avoid skin contact with the water. However, if the smelter is to continue operation there is no clear alternative power source.

It would be a dramatic change, but in principle Onslow pumped storage could enable the smelter to continue operation with partial closure of the Manapouri Power station to allow significant flow to be restored to the Waiau River.

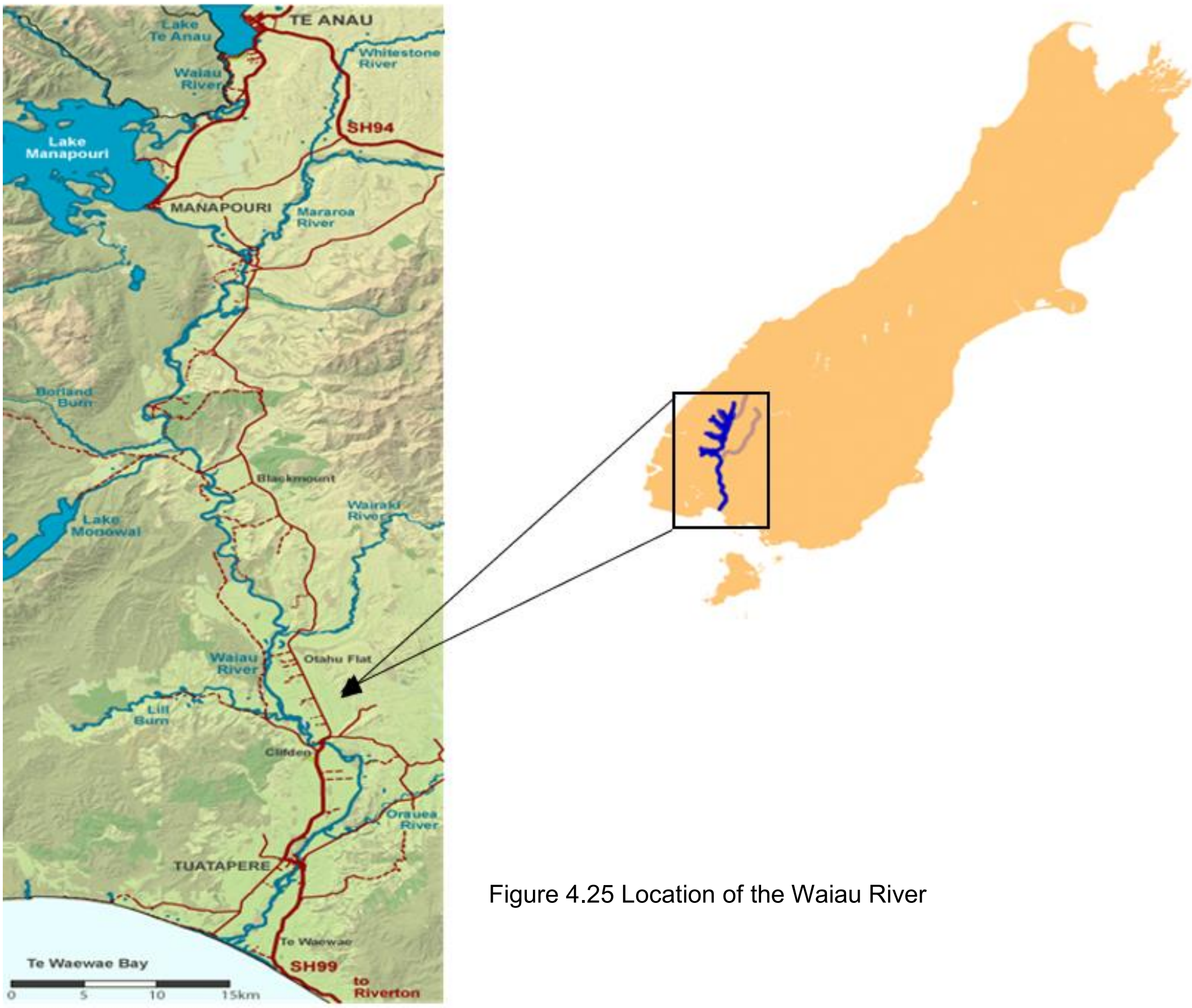


Figure 4.25 Location of the Waiau River

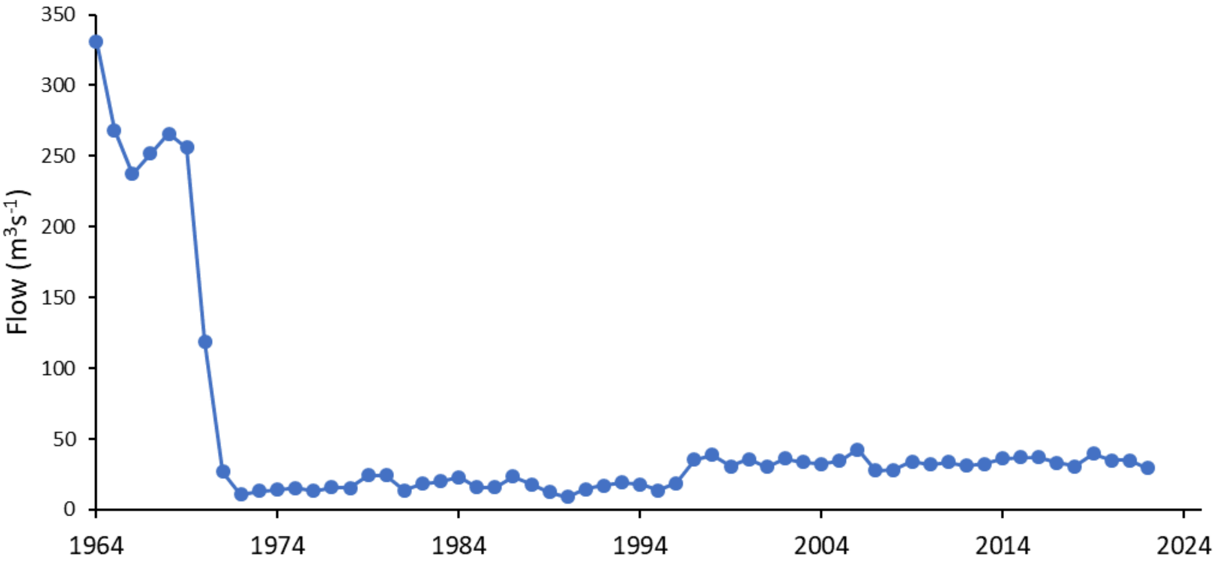


Figure 4.26 Waiau River at Tuatapere: Annual minimum flows 1964 -2022, showing the impact of the Manapouri Power Station water diversion.

Figure 4.27 Depleted Waiau River (gravel zone on left) visible downstream of the Waiau River control structure at Mararoa. (Source: Yasaman Karaminik).

The mechanism for the additional power would be to utilise some of significant wind resource of southern Southland. It has long been recognised that wind speeds rapidly increase with height above land surface around Foveaux Strait (Bardsley et al, 2022). This would enable large generators to produce a significant mean power output, with the intermittency buffered by pumped storage at Onslow. The anticipated 1000 MW of pumped storage at Onslow could buffer up to 2000 MW of new Southland wind energy.

If 170 MW of new Onslow-buffered wind power was constructed in Southland, this would enable setting a minimum Lake Manapouri outflow to the Waiau River of 125 m^3s^{-1}. This would involve closure of two of the Manapouri Power Station's seven generators, other than for use in emergency situations or where there are flood flows into Lake Manapouri.

This mixture of power to the smelter from wind, Onslow, and the Manapouri Power Station would be beneficial to the smelter operation because it could continue operation through dry years.

An overbuild of wind power for environmental purposes is a new concept but could be achieved by Meridian Energy without great difficulty, given sufficient advance warning of a change in the Waiau River water consents.

Summary

This chapter has explored various possibilities for lake and river restorations in the Otago-Southland region, focusing on utilising Onslow scheme offsets. The restoration initiatives discussed, namely Lake Monowai, Lake Hawea, the lower Manuherikia River, the Waitaki River summer flow, and the Waiau River, have all been tentatively evaluated based on their viability and potential environmental impact.

The restoration of Lake Monowai to its original natural state is an achievable and significant partial environmental offset for the flooding of Onslow wetlands. Importantly, it could also represent the start of the reconfiguration of renewable energy development, such that wind and solar power could enable the retirement of parts of the worst New Zealand hydropower schemes as measured by their present environmental impact.

Chapter Five: Lake Onslow water storage against regional droughts

The large additional volume of water that would be stored in Lake Onslow represents energy storage against a hydro dry year. However, the water volumes involved are so large that some water could also be released for rare but intense future regional droughts that may arise from climate change. The southern South Island is surrounded by ocean, but this does not give security against major droughts, as seen in 2018 in Cape Town where that major city came close to running out of water.

This chapter overviews sequentially some water resource options that could be considered from the expanded Lake Onslow. Various river and rainfall recording sites are mentioned in the discussions and are shown together in Figure 5.1 for convenience.

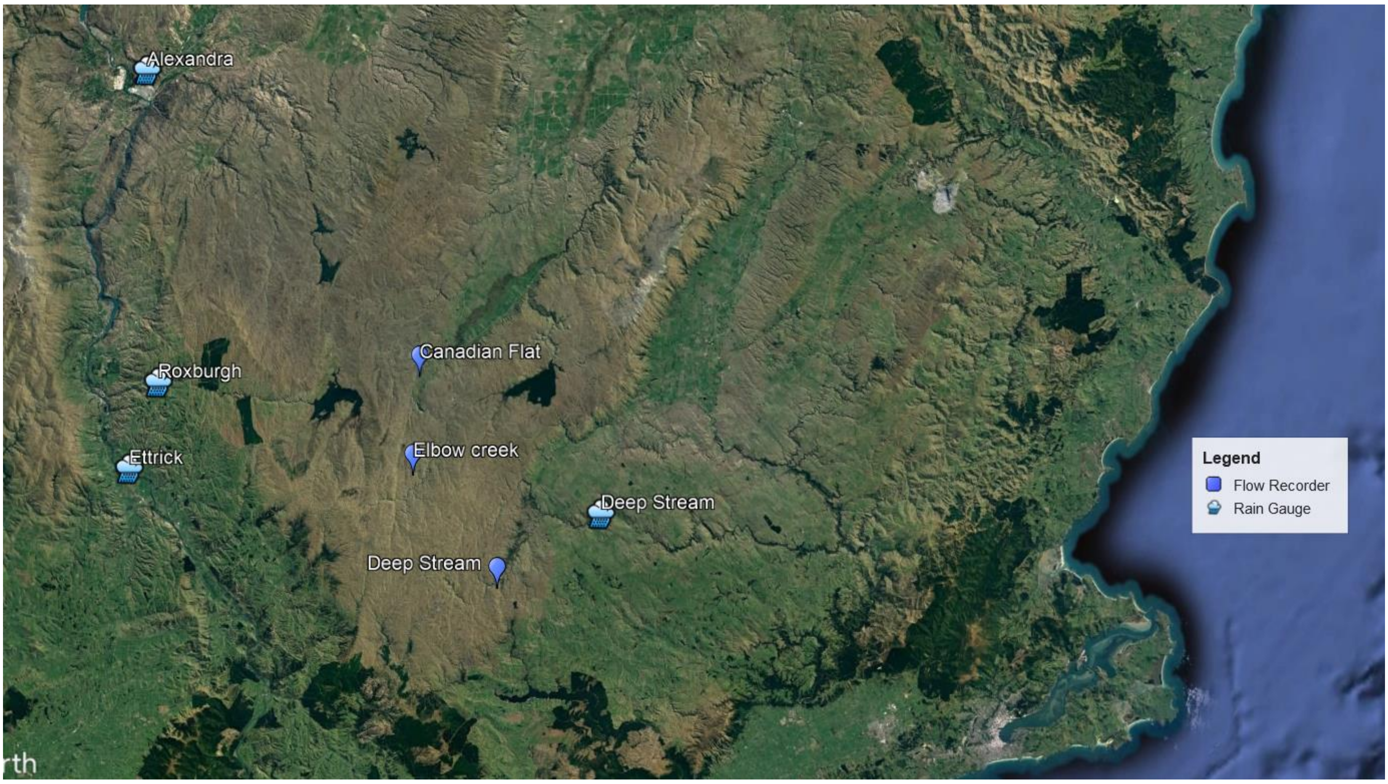


Figure 5.1 Rainfall sites (blue), flow sites (dark blue) location (Map Source: Google Earth).

5.1 Teviot River Irrigation Security

In addition to its use for hydropower by Pioneer Energy, the Teviot River provides gravity flow water for the Teviot irrigation scheme. The presence of the expanded Lake Onslow and the associated new dam means that the Teviot River flow can be seasonally regulated to coincide with times of maximum irrigation need.

The large storage capacity of the new dam also means that there can be multi-year storage in the Onslow basin of water from the streams flowing into the lake. This allows security against extended periods of low local rainfall which could increase irrigation demands. Figure 5.2 and 5.3 suggests that a period of reduced rainfall started in the Roxburgh-Ettrick region from about the year 2000, emphasising the need for irrigation.

The enhanced Onslow storage capacity would also allow the possibility of some winter water transfer from the upper Taieri River into Lake Onslow via a short tunnel starting on the Taieri River near the Elbow Creek confluence (Figure 5.4). However, this would involve the cultural issue of mixing water from different drainage basins and there would be some income loss from the two small Manawa power stations on the Taieri River.

The various aspects of Teviot irrigation security are independent of the pumped storage and there is no implication of any energy loss to the scheme. The presence of a small new power station on the Onslow dam and the eliminated Teviot spill loss will result in some increase in mean power output from Pioneer’s Teviot power scheme.

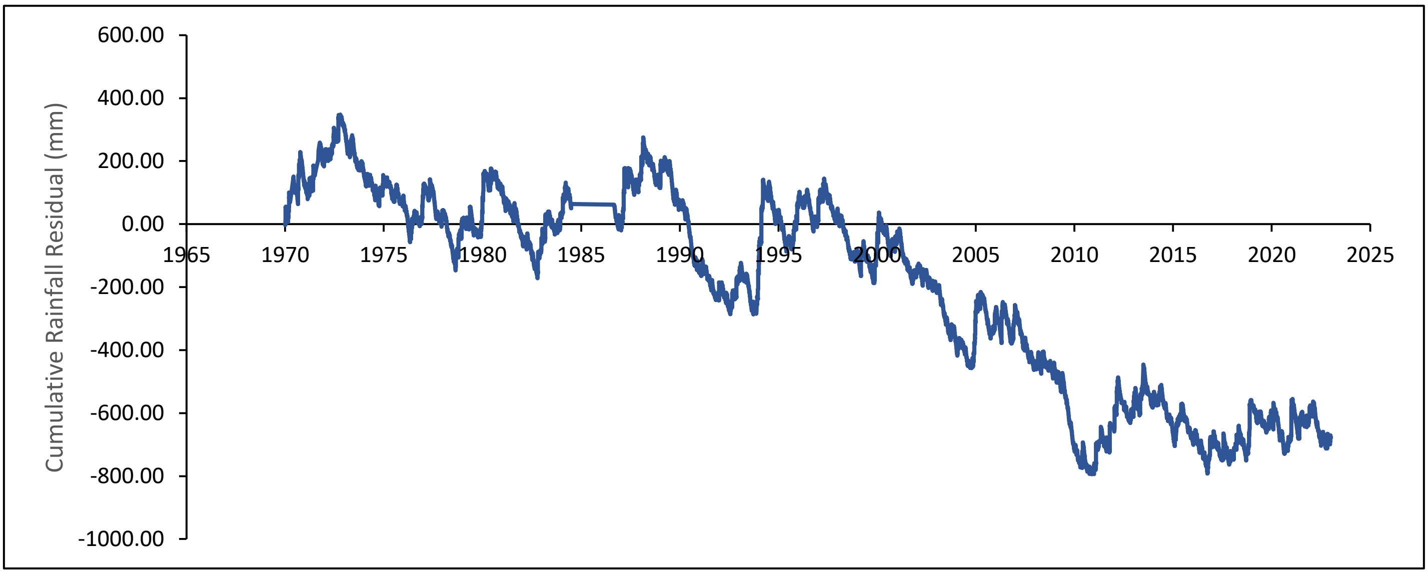


Figure 5.2 Roxburgh cumulative daily rainfall residuals 1970 – 2022. The reference mean was calculated over 1970-2001.

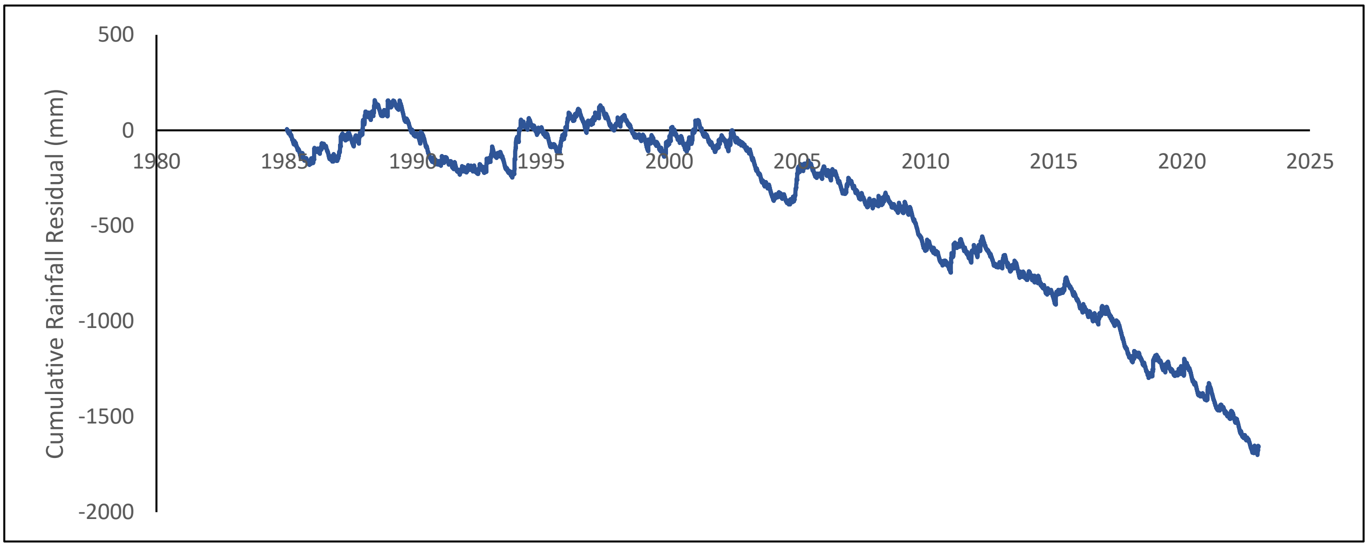


Figure 5.3 Ettrick cumulative daily rainfall residuals, 1984 – 2021. The reference mean was calculated over 1984-2002.

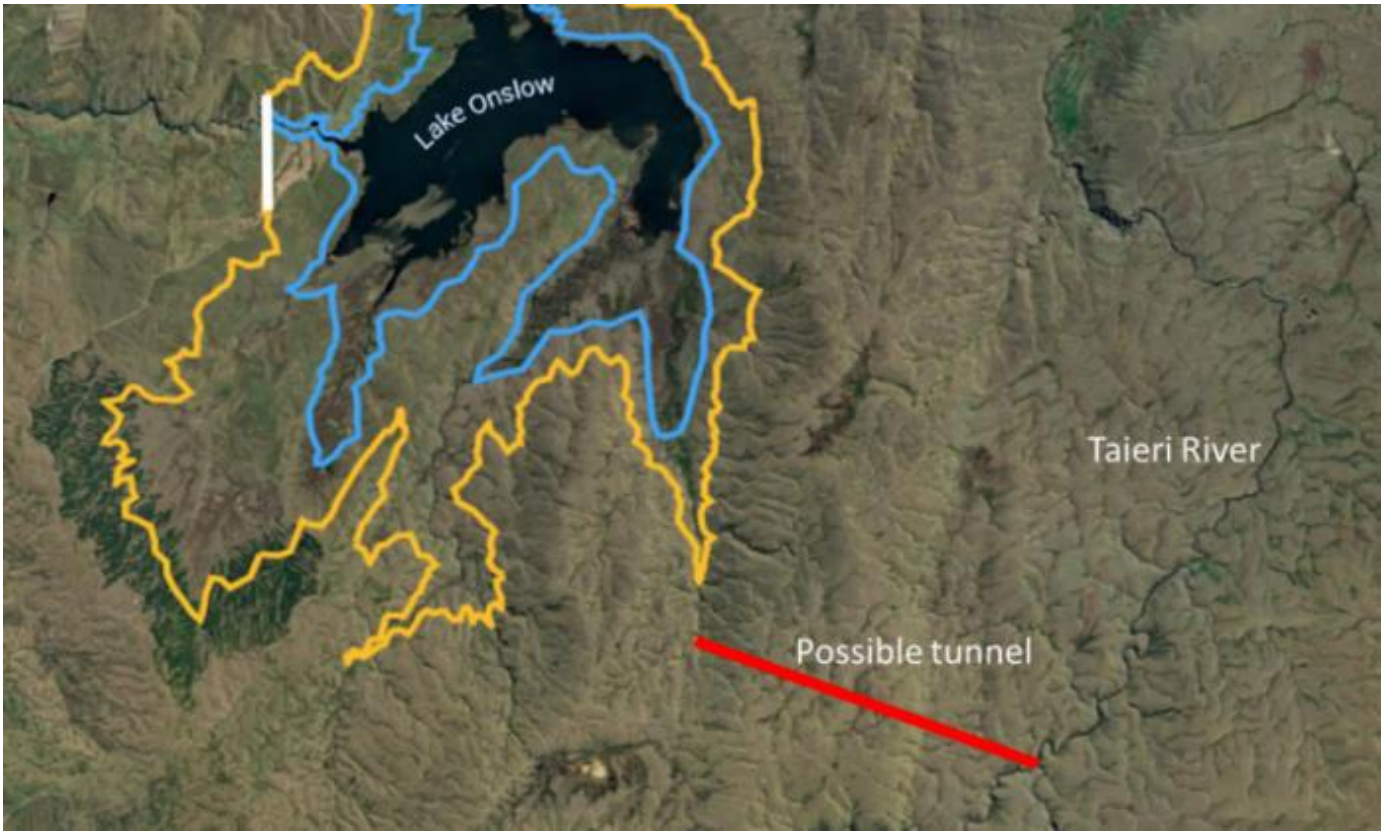


Figure 5.4 Possible 5.3 km tunnel at 860 metres asl for gravity flow transfer of some upper Taieri River winter water to an expanded Lake Onslow. Discharge is into Fortification Creek. Blue and orange lines are likely upper (765) and lower (695) lake level operating limits for pumped storage operation. White bar is the probable location of the new Onslow dam (Map source: Google Earth).

5.2 Onslow water augmentation for the Poolburn Stream and lower Manuherikia River

A low saddle separates the Lake Onslow drainage basin from the Greenland-Manorburn basin to the north. A short 4 km tunnel through the saddle at about 750 m elevation could be constructed to link the two basins (Figure 5.5). During a drought emergency, the tunnel would allow gravity flow of Onslow water into the Greenland reservoir. The water would then be released via the Upper Manorburn reservoir to provide supplementary irrigation support through existing water races to farms along the Poolburn Stream and then the lower Manuherikia valley. Gravity flow in this case would require the Lake Onslow water level at the time to be higher than the Greenland reservoir level.

Outside of hydro dry years it is likely that the raised Lake Onslow will be higher than 750 m. Lake Onslow lowering will coincide with South Island hydro drought with low rainfalls in the Southern Alps. However, this will not necessarily coincide with local drought in Central Otago. A valve control would be required in the tunnel so there is not reverse flow back to Lake Onslow when its level goes below 750 m.

Irrigation supplementary water in this way is likely to be used only in situations of extreme drought. This is because the water would need to be purchased from the Lake Onslow operators, who would need to recover the costs of pumping up from the Clutha River.

The tunnel would ideally be constructed prior to Lake Onslow being raised past 750 metres asl during the filling process.

Figure 5.5 Location of 4 km tunnel (red) enabling drought emergency water transfer by gravity flow from raised Lake Onslow into the Greenland Reservoir (Map source: LINZ).

5.3 Potential for Lake Onslow water to maintain Taieri River flows in extreme drought

The Taieri River is the main river of eastern Otago, following a 288 km convoluted course to the coast. The river rises in Central Otago near Lake Onslow and thus has no wet Southern Alps water source like the Clutha or Canterbury rivers.

Apart from the small Loganburn Reservoir, there is no controlled water storage in the Taieri catchment. There are also only limited groundwater aquifers to maintain river baseflow. This means that an extended period of low rainfall causes a relatively rapid decline in river baseflows (Figure 5.6).

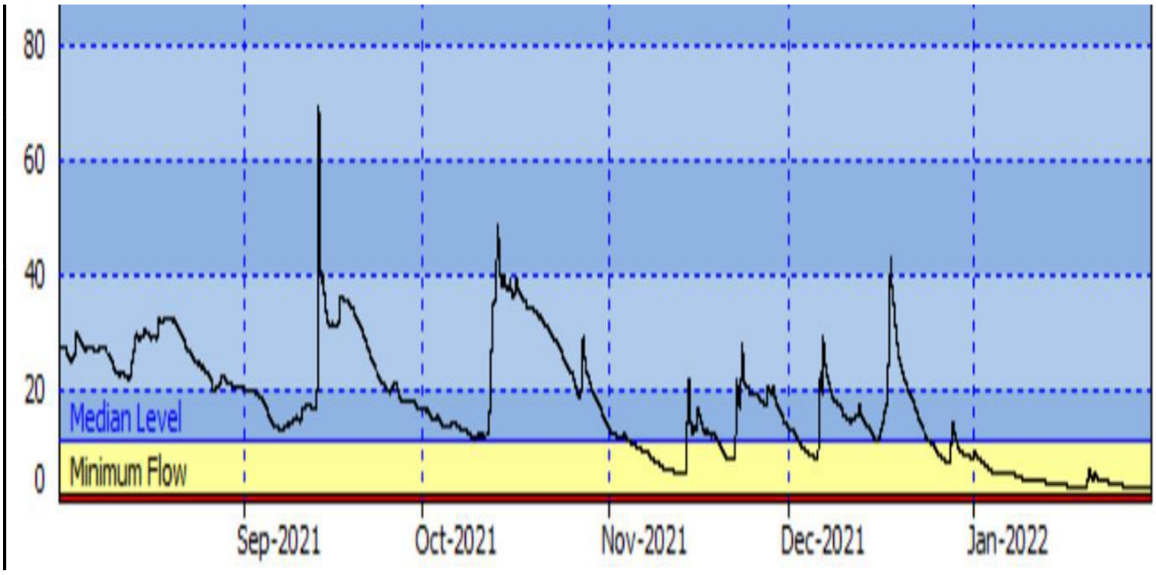


Figure 5.6 Taieri River flow at Sutton to January 29, 2022, showing baseflow decline from January 1 (Source: Otago Regional Council).

The Taieri River provides water for various irrigation schemes (Figure 5.7) and townships, which are all vulnerable to a future intense Otago drought arising from climate change.

Figure 5.7 Taieri River meanders (right) and irrigated land (left) in the Maniototo, Central Otago (Map Source: Google Earth image).

In what may be the first indication of a drying trend with climate change, summer lowest flows in the Taieri headwaters appear to be declining relative to the previous flows prior to 2000 (Figure 5.8) The Canadian Flat and Elbow Creek recording stations (Figure 5.9) are in Taieri headwater sites not subject to human modification of flows.

When required, Onslow water could be released into the upper Taieri via a short 3.1 km rock tunnel at 720 m elevation to Riddles Creek (Figure 5.9). Riddles Creek flows into the lower Bonds Stream which in turn flows into the upper Taieri River (Figure 5.10).

In terms of the volume of water released, Lake Onslow could easily maintain the Taieri River flow through an intense drought without compromising its pumped storage role. If Lake Onslow was 60 km^2 in surface area then it would only fall 50 cm to provide 5 m^3s^{-1} flow into the Taieri River for 10 weeks.

It might happen that a guaranteed flow of water would be made freely available to the Taieri River on the basis of a certain maximum total water volume available in, say, any 10-year period.

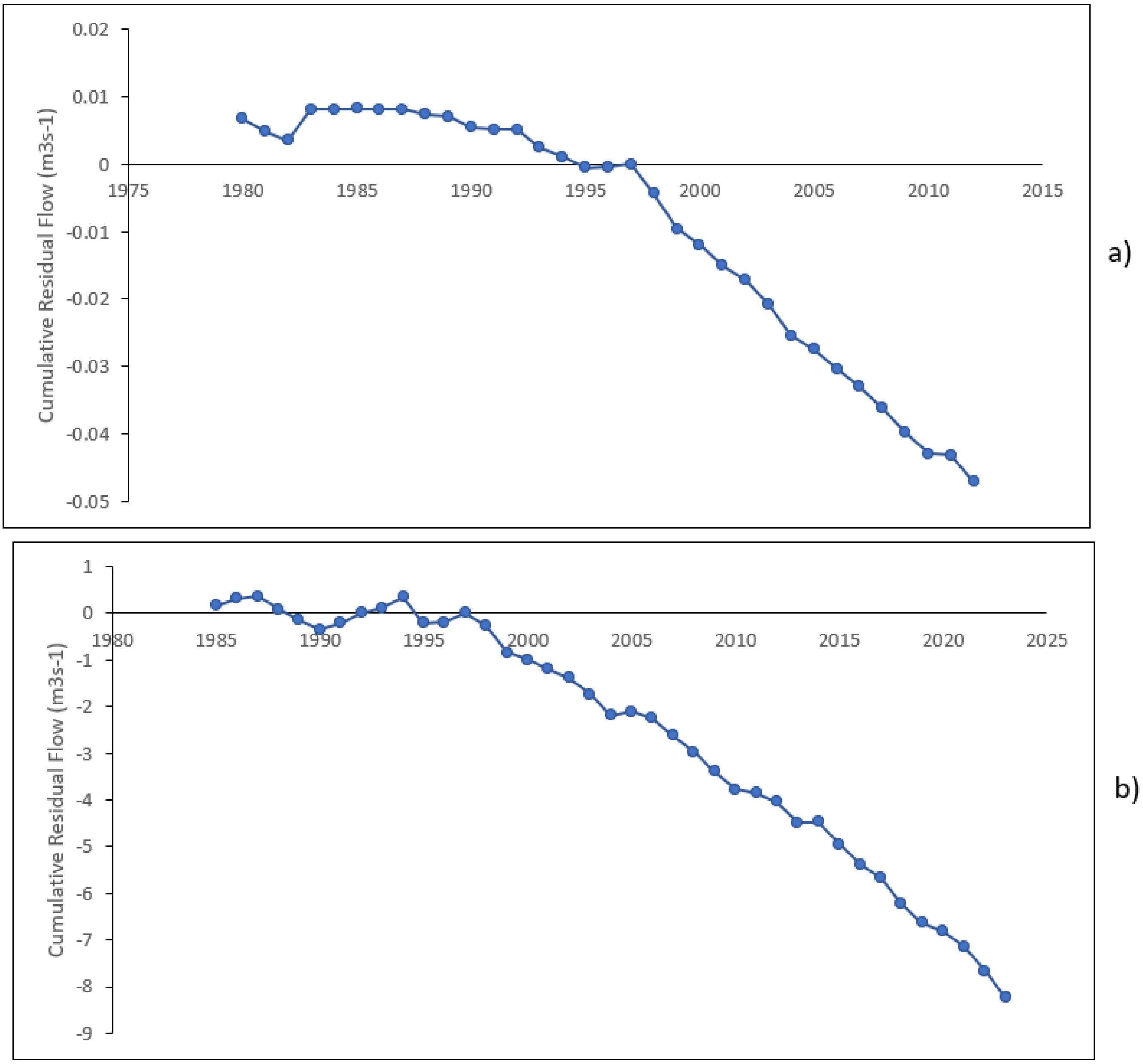


Figure 5.8 Cumulative residual values for the 7-day minimum flow for January-March (3 months) for Elbow Creek (a) and Canadian Flat (b). Elbow Creek flow residuals are over the period 1980-2012, with the reference mean residual value calculated for 1980-1997. Canadian Flat flow residuals are from 1985 to 2023, with the reference mean residual also calculated for 1980-1997.

Figure 5.9. Possible tunnel connection (red) at 720 m elevation between a future expanded Lake Onslow and the Riddles Creek Taieri headwater, which flows into the upper Taieri River via Bonds Stream (Figure 5.10).

Despite its economic value in a drought, Onslow water would only be released to the Taieri in a dire drought emergency. This is because the new water would result in didymo and other weeds becoming established along the length of the Taieri River, if not already present at that time. There would also be cultural considerations because there is a transfer of water from one drainage basin to another.

Such concerns could mean that the supplementary water is never used. There is nonetheless an advantage in having the tunnel in place because future generations will then have the option of using Onslow water if they deem it necessary for economic survival. If it was to be constructed, the tunnel would need to be completed prior to Onslow water reaching 720 m during the initial fill.

Figure 5.10. Confluence of the Taieri River (left) and Bonds Stream (right) (Source: Yasaman Karaminik).

5.4 Onslow water for Dunedin city water supply drought resilience

Reduced water supply due to droughts has impacted a number of southern hemisphere cities in recent years – Cape Town in South Africa (2018), Santiago in Chile (2022), and Montevideo in Uraguay (2023).

A city without domestic water represents a major climatic social impact because it is difficult to quickly find an alternative supply. A better approach is to evaluate the risk and likely impact, then carry out whatever infrastructure is required before the event happens.

Unlike Balclutha and Christchurch, Dunedin's water supply is not connected to rivers with headwaters in the Southern Alps. Instead, most of Dunedin's water is derived from local small upland catchments to its west – Deep Stream and Deep Creek (Figure 5.11).

The small extent of these catchments gives rise to vulnerability with respect to both fire impact and extended periods of local low rainfall.

A grassland fire removed the Deep Stream water supply catchment for a time in 2019, causing some restrictions on water use. The same drying trend that is evident in the Taieri River upland headwaters appears to extend into the Dunedin water supply catchments (Figure 5.12, 5.13), which might indicate increased likelihood of a major future drought event.

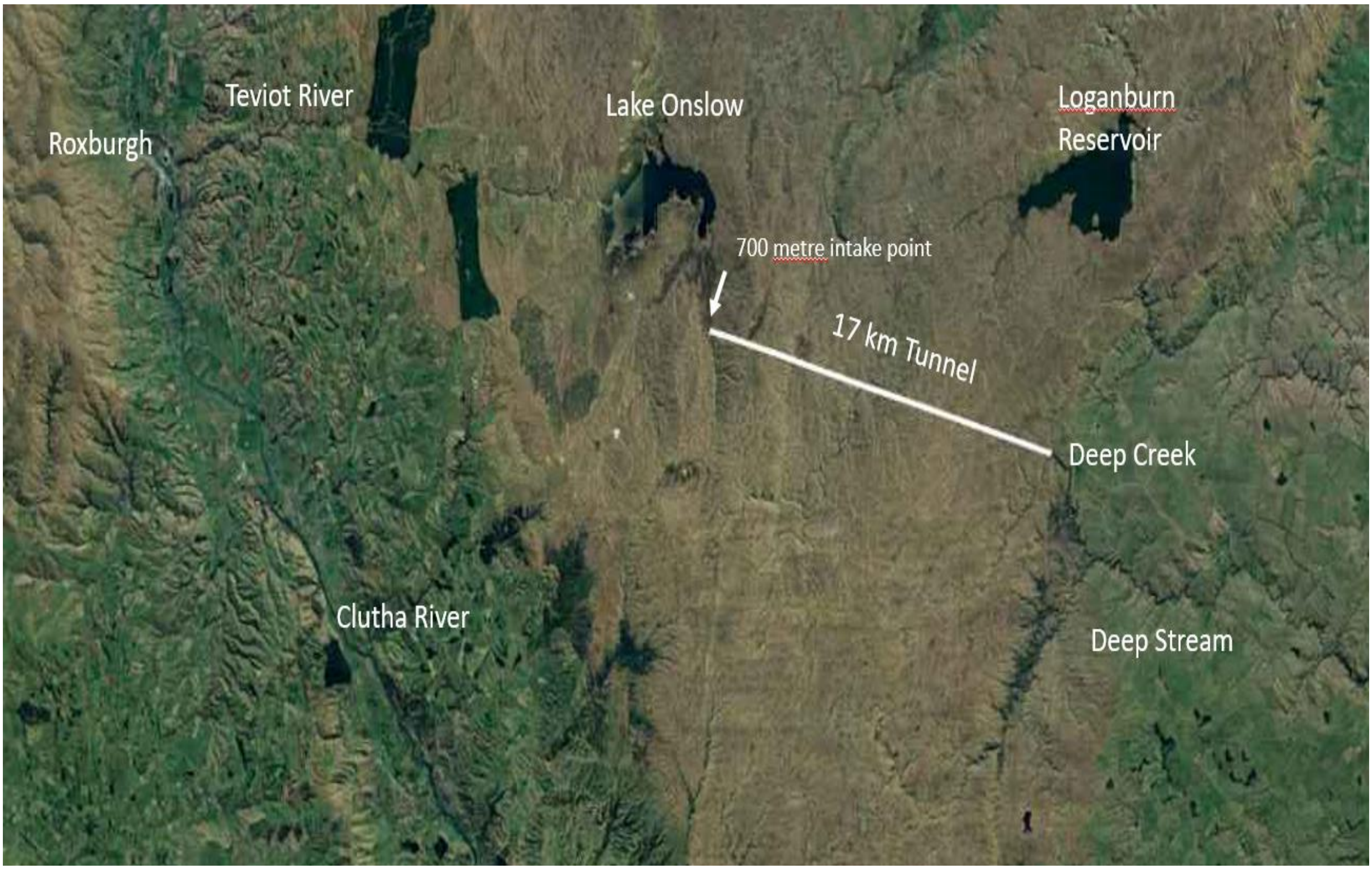


Figure 5.11 Location of a possible 17 km water supply tunnel linking a raised Lake Onslow with the existing Dunedin city water supply intake point at Deep Creek (Map source: Google Earth).

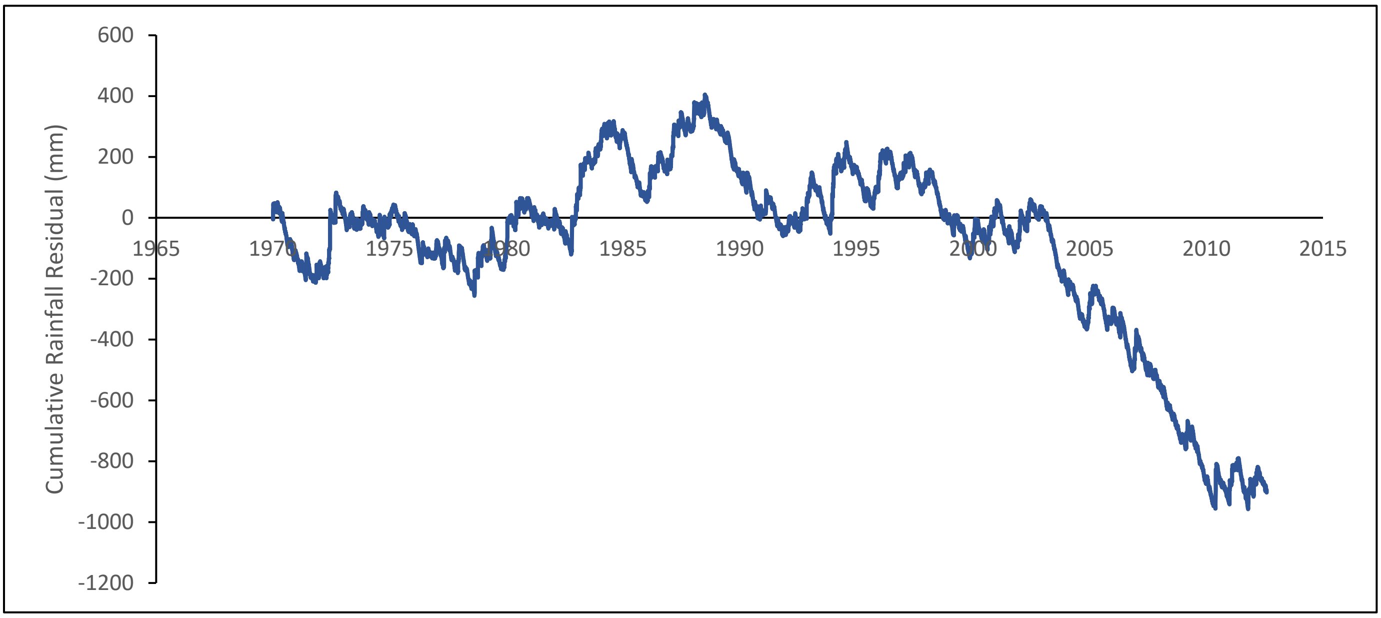


Figure 5.12 Deep Stream cumulative daily rainfall residuals 1968 – 2012. Reference mean is over 1968-2002.

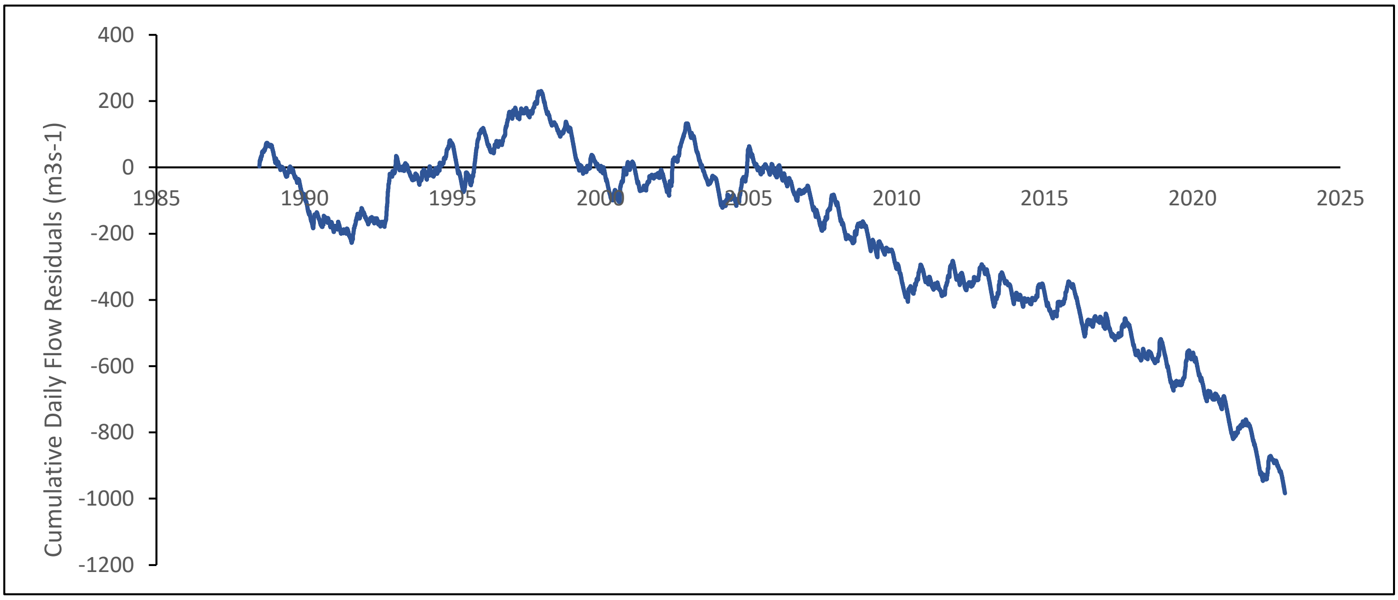


Figure 5.13 Deep Stream cumulative daily flow residuals from 1968 - 2012. Reference mean is from 1968-2006. NIWA flow recording site 7444) upstream from the tunnel water diversion.

It would be possible to provide needed climatic resilience to the Dunedin city water supply by constructing a 17 km gravity-flow rock tunnel at 700 m elevation, linking an expanded Lake Onslow to the Dunedin Deep Creek water intake. (Figure 5.14, 5.15). Lake Onslow would appear to be the only reliable water supply option as both the upper Taieri River and Loganburn Reservoir would have minimal water in an extended drought.

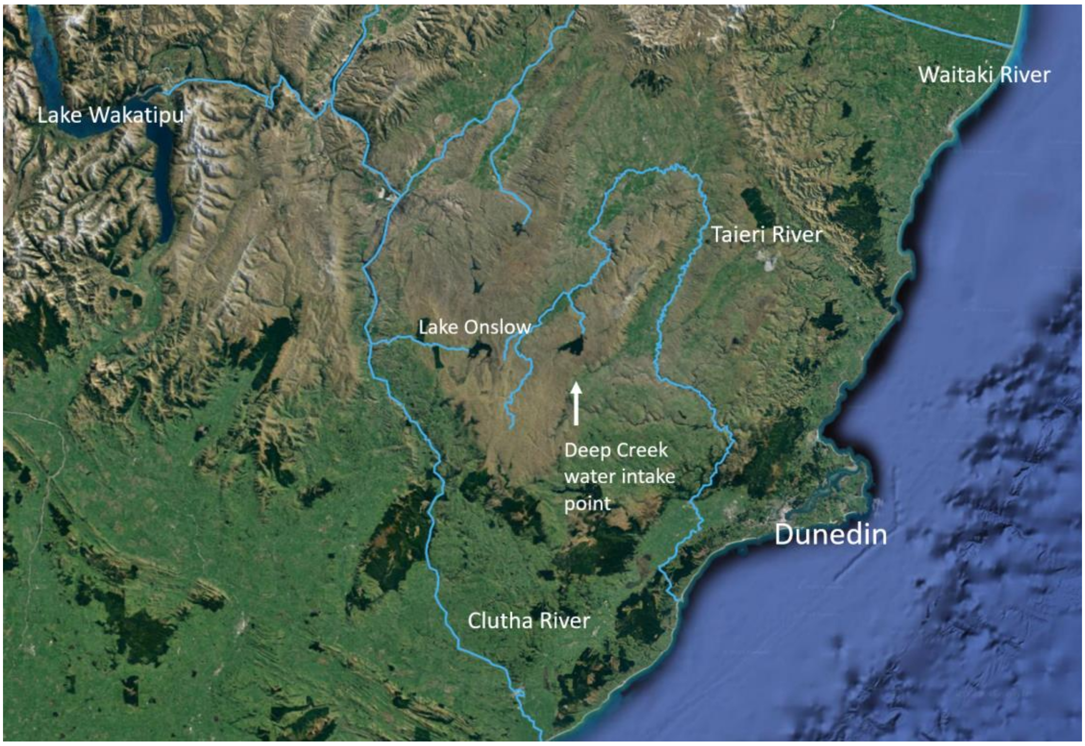


Figure 5.14 Location of the Deep Creek water intake point for Dunedin City water supply (source map: Google Earth).

Figure 5.15 Deep Creek Dunedin city water supply intake point. The approximate 700 metre elevation is also indicated. (Source: Taieri Recreational Tramping Club).

Dunedin city uses only about 0.5 m^3s^{-1} as a water supply mean, so the city supply could be future-proofed by a small-diameter tunnel that was capable of transferring just 2 m^3s^{-1}. This would not be major engineering as the tunnel would be more like a horizontal mine shaft. It would need to be constructed prior to first pumping into Lake Onslow. As with the Taieri River flow augmentation, the water volumes are relatively small and occasional use would not impact the Onslow pumped storage operation.

It could happen that the Onslow water tunnel connection remains unused for many years. However, it would provide water supply insurance against a low probability / extreme impact Otago drought.

Summary

Otago water resources are vulnerable to climate change, particularly with respect to droughts of greater magnitude than experienced in the past record. A raised Lake Onslow offers water resource buffering against extreme drought in a number of respects. The Taieri River augmentation would be of particular value but also carries with it significant cultural and environmental impacts. Rather than make the decision now, a more pragmatic approach would be to have the necessary tunnel constructed so later generations have that water supply choice available.

There are other more minor water risk mitigations associated with the Onslow scheme as well. In particular, diverting some Clutha flood flow by pumping into Lake Onslow would have a slight lowering effect on flood peaks at Balclutha. The impact on a typical Clutha flood would not be great but could make the difference in an extreme flood between a flood bank being overtopped or not.

Chapter Six: Conclusion

This study has examined a range of alternative lake recreation options, environmental mitigations, and potential restoration projects in the context of hydropower operations and environmental impacts. The key findings and implications from the analysis of the different options and scenarios are summarised below.

6.1 Alternative Lake Recreation Options

Two alternative lake recreation possibilities were considered: constructed road access to the Greenland Reservoir and the creation of a new lake and reserve in the upper Bonds Creek catchment. The analysis indicated that both options have the potential to provide valuable recreational resources, including fishing, boating, and wetland environments. The Greenland Reservoir, when combined with Upper Manorburn, could offer trout fishing and boating activities. The creation of a new lake and upland reserve at Bonds Creek would provide opportunities for wetland development, possible trout spawning, and a protected tussock upland reserve. Detailed road route evaluations, landowner engagement, and environmental impact assessments would be required for further consideration of these options.

6.2 Local Environmental Mitigation at Lake Onslow

Three environmental mitigation suggestions were raised for the Lake Onslow project: the possibility of a floating wetland, construction of fish barriers on selected streams, and addressing drawdown mitigations. The proposed floating wetland could help offset the loss of wetlands due to flooding, with a focus on protecting wetland bird populations and promoting eco-tourism activities. Fish barriers on selected streams would protect native fish species from the impact of trout migration resulting from lake raising. Drawdown mitigations are crucial to address potential environmental issues related to soil dust and changing water levels. Further research and engineering assessments are needed to implement these mitigations effectively.

6.3 Restoration Projects

Several restoration projects were considered, including the restoration of Lake Monowai, Lake Hawea, Waitaki River summer flows, the Manuherikia River, and partial flow restoration of the Waiau River. These restoration projects aim to address the environmental impacts caused by hydropower operations and enhance natural flows. Restoration of Lake Monowai and Lake Hawea would revert hydro storage to their original natural states, providing environmental offsets for the Onslow project. The restoration of flows in the Waitaki, Manuherikia, and Waiau Rivers would improve river health, enhance recreational activities, and provide irrigation security during droughts.

6.4 Onslow Water Augmentation and Drought Resilience

The study also explored the potential for using Onslow water for various water augmentation purposes, including maintaining river flows in the Taieri and Manuherikia Rivers, as well as enhancing the Dunedin city water supply drought resilience. These options have the potential to provide additional water resources during drought emergencies, enhancing both environmental and societal resilience.

6.5 Overall Implications

The findings from this study highlight the interaction between Onslow pump storage operations, environmental impacts, and potential restoration and mitigation measures. The various options and scenarios examined illustrate the importance of balancing energy generation, environmental protection, and societal needs. The implementation of these options would require careful planning, stakeholder engagement, environmental assessments and further investigations.

It is difficult to rank the various options in terms of preference and relative viability because this would involve community feeling as well as economic evaluation. The lower Waitaki River shift toward more natural seasonal variation would happen in any case without intervention. The most readily achieved would be the restoration of Lake Monowai, which is desirable in any case because it is a national anachronism in a Fiordland National Park.

A public road extension through to the Greenland Reservoir would be appreciated by the people of Roxburgh to offset the loss of the Lake Onslow environment during scheme construction. That would involve negotiating some land purchase but would be at less cost than a significant new high country reserve in the Bonds Creek catchment, which could only proceed with landowner agreement.

The most expensive of the more likely offsets would probably also be the most popular – raising the Falls Dam or creating a new dam. This is because the lower Manuherikia summer flow is arguably the most contentious water-related environmental issue in Central Otago and there seems no resolution short of at least a contribution by government toward Falls Dam engineering.

With respect to water resources, buffering the Teviot irrigation scheme through an extended drought will happen in any case without additional cost, assuming the mean flow of the Teviot River is a consenting requirement. The various water supply tunnel options would have small total cost relative the estimated $16b cost of the Onslow scheme. The issue here would arise more at a later date when an extreme drought would require decisions over whether water supply should take precedence of cultural and ecological considerations.

In conclusion, the study has identified a range of alternative lake recreation options, restoration projects, and environmental mitigations that have the potential to the balance between hydropower generation and environmental considerations. Each option presents its challenges and opportunities, and the feasibility of implementation depends on a variety of factors, including engineering feasibility, environmental impact, stakeholder input, public interaction and regulatory approvals.

The various topics considered here are obviously tentative and dependent in various situations on good will, at least partial government funding support, and further research work in all cases. The suggestions are not exclusive and may prompt further considerations of mitigation and adaptation in the event of the Onslow pumped storage scheme going ahead.

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Appendix: Environmental Offset Example

In New Zealand one of the current studies is the Deepdell North pit development at Macraes gold mine in East Otago (Figure a.1). The Deepdell North pit (Figure a.2) construction is the most recent in a series of achievements in nature preservation environmental offsets.

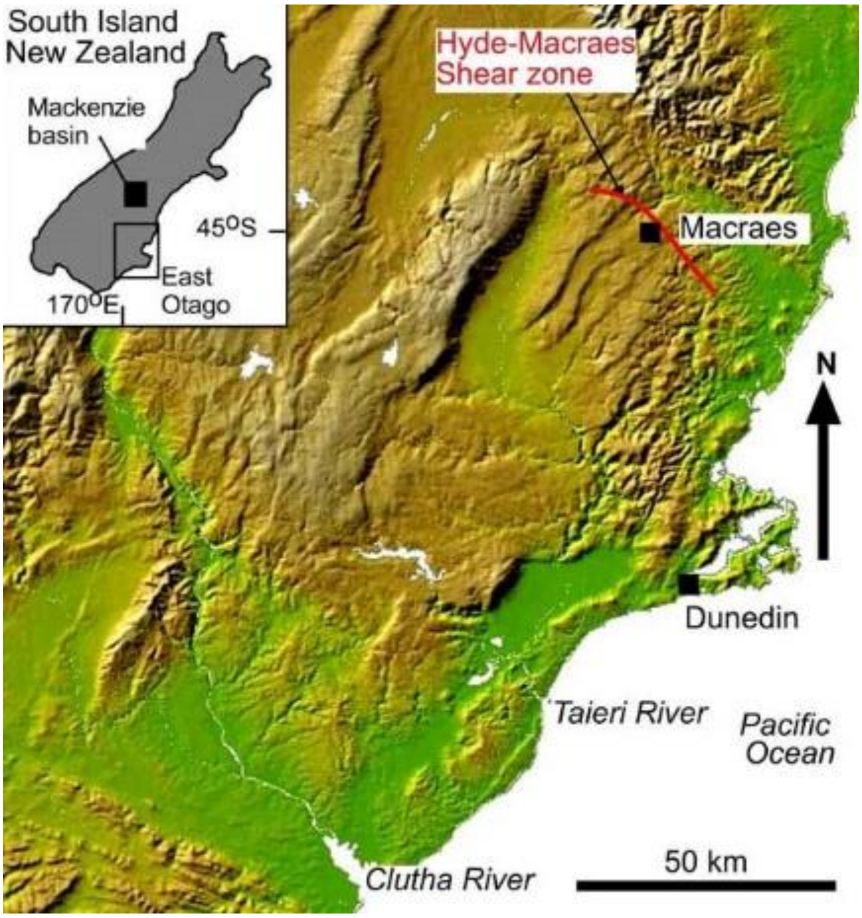

Figure a.1 The Macraes mine is developed in a regionally continuous structural feature, the Hyde-Macraes Shear Zone

The opencast Macraes mine (Figure a.2) in East Otago is the largest gold mine in New Zealand and has been operated by OceanaGold since 1990. The company follows the "effects management hierarchy" in its approach to environmental management at each of its locations, which is a step-by-step procedure for avoiding, remedying (repairing), and then mitigating (making less severe) environmental effects. For any residual effects, the company uses offsets and compensation to improve biodiversity and wetlands at other locations.

Between operations winding down in some areas of Macraes and the beginning of new operations, such as the Golden Point underground mine, there is a two-year transition period provided by the Deepdell pit. Deepdell poses a problem for handling excess rock, as well as for the preservation of wetlands, shrubland, and lizards.

Figure a.2 Macraes open pit – the Deepdell project (Straterra, 2021).

The non-bearing rock that a mine operator must remove to have access to gold-mining resources is typically the mine's greatest waste stream. There must be a place for this extra rock (Straterra, 2021).

One of three additional projects approved in late 2020 will extend Macraes' mine life until at least 2028. Comprises extending the current backfilled open pit and building a new rock stack. This project is called Deepdell North Stage Three. This plan avoids impacts on heritage sites, avoids impacts on the Taieri flathead galaxiid habitat, and eliminates the need for freshwater management at the rock stack site, which is now located at a high point in the terrain/watershed. It also spares a single 200-year-old tree daisy (Olearia fimbriata), which is listed as Nationally Vulnerable (Straterra, 2021).

Six ephemeral wetlands on pasture land are impacted by the Deepdell development as mentioned above and despite efforts to minimise substantial biological values. OceanaGold showed that although being listed as Critically Endangered and Naturally Uncommon environments, these ecosystems are widely distributed throughout the

Macraes Ecological District and are severely degraded. OceanaGold is offsetting a nearby 5.4ha wetland on a nearby farm (the largest of its kind in Otago) to mitigate the disturbance and loss of 0.3 ha of wetlands. The offset's objective is to increase the wetland's native biodiversity over the course of ten years in order to achieve 50% cover in 15 native plant species, including five ephemeral wetland species of national conservation concern and at least 10 species that are characteristic of Macraes ephemeral wetlands (Figure a.3) (Straterra, 2021).

The improvement of terrestrial habitat across 50 ha of covenanted land, which includes stock exclusion, conversion of tussock land to native shrubland, and a 50-year commitment to administer the site through a community trust supported by money, is the second component of the offset package (Straterra, 2021).

Figure 2.3 Ephemeral wetland offset – October 2019 Central Otago (Straterra, 2021).

The offset impacts on 3.75 ha (15 plant species) of shrubland across 4.23 ha (22 species) and expanding shrubland to 10 hectares with 18 species and 75% canopy cover is the 10-year objective (Straterra, 2021).

The offset also affects 0.07 ha (700 m^2) of the seepage wetland over 0.82 ha. The 10-year objective is to add the Naturally Uncommon reed species *Juncus distegus* and to raise the dominance of indigenous species by 20% (Straterra, 2021).

As a result, the corporation created a comprehensive compensation plan that comprises four study streams looking into lizard conservation issues lasting seven to ten years (Straterra, 2021).