Technical Committee - 31 January 2018 Attachments

Otago Regional Council

Minutes of a meeting of the Technical Committee held in the Council Chambers at Otago Regional Council on Wednesday 29 November 2017, commencing at 4:12 pm

Membership

Cr Andrew Noone	*(Chairperson)*
Cr Ella Lawton	*(Deputy Chairperson)*
Cr Graeme Bell	
Cr Doug Brown	
Cr Michael Deaker	
Cr Carmen Hope	
Cr Trevor Kempton	
Cr Michael Laws	
Cr Sam Neill	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Stephen Woodhead	

1. APOLOGIES

Resolution

That the apologies for Crs Kempton and Woodhead be accepted.

Moved: Cr Noone
Seconded: Cr Lawton
CARRIED

2. LEAVE OF ABSENCE

A Leave of Absence for Cr Laws noted.

3. ATTENDANCE

Nick Donnelly, *(Acting CE, Director Corporate Services)*
Sian Sutton, *(Director Stakeholder Engagement)*
Tanya Winter, *(Director Policy, Planning & Resource Management)*
Gavin Palmer, *(Director Engineering, Hazards and Science)*
Lauren McDonald, *(Committee Secretary)*
Ian McCabe, *(Executive Officer)*

For our future

4. CONFIRMATION OF AGENDA

The agenda as tabled was confirmed.

5. CONFLICT OF INTEREST

No conflicts of interest were advised.

6. PUBLIC FORUM

No public forum was held.

7. PRESENTATIONS

No presentations were held.

8. CONFIRMATION OF MINUTES

Resolution

That the minutes of the meeting held on 18 October 2017 be received and confirmed as a true and accurate record.

Moved: Cr Lawton
Seconded: Cr Hope
CARRIED

9. ACTIONS

(Status report on the resolutions of the Technical Committee).
No current items for action.

10. MATTERS FOR COUNCIL DECISION

Nil.

11. MATTERS FOR NOTING

11.1. Director's Report on Progress

The report provided an update on: the climate, river flow and groundwater situation and outlook for Otago; the review undertaken by NIWA of the weather which caused the July 2017 coastal Otago flood event; progress with key actions arising from the event, and progress with the design and construction of the Leith Flood Protection Scheme.

Dr Payan, Manager Natural Hazards provided an overview and key findings from the NIWA report.

Resolution

That this report is received and noted.

Moved: Cr Hope
Seconded: Cr Deaker
CARRIED

11.2. Rangitaiki River Scheme Review - April 2017 Flood Event
The report summarised the independent review commissioned by the Bay of Plenty Regional Council on the 6 April 2017 breach of the Rangitaiki River floodwall at Edgecumbe and the key issues for the Otago region arising from the review.

Resolution

a) *This report is received and noted.*

b) *The findings presented in the report Rangitaiki River Scheme Review - April 2017 Flood Event are noted.*

Moved: Cr Deaker
Seconded: Cr Hope
CARRIED

11.3. 2017 Air Quality Results
The report outlined the year-round State of the Environment (SoE) ambient air quality monitoring of PM10 for the towns of Alexandra, Arrowtown, Mosgiel and Central Dunedin, and the towns of Balclutha, Milton, Clyde and Cromwell for the period 1 May to 31 August. The report described the state of Otago air quality for the 2017 year, using key air quality indicators against current standards. The status of the National Environmental Standards - Air Quality (NESAQ) review was also provided.

Dr Mills responded to questions from councilors and discussion was held on the impediments to improving air quality in the region.

Resolution

a) *That this report be received.*

b) *That the state of air quality in Otago be noted.*

c) *That a report back be provided on the reduction of the use of coal achieved in other areas of New Zealand.*

Moved: Cr Deaker
Seconded: Cr Scott
CARRIED

11.4. Continuous Environmental Monitoring: Opportunities and Challenges
The report outlined the environmental monitoring and data collection technologies used by the Otago Regional Council to measure water quality and quantity. It also outlined ORC's involvement in bringing emerging technologies to the Otago region.

Resolution

a) That this report is received.
b) That the ideas presented in this report be considered for inclusion into the Long-term Plan.

Moved: Cr Robertson
Seconded: Cr Scott
CARRIED

11.5. Management flow reports for the Cardrona and Arrow Rivers
The reported provided an update to the original 2011 report entitled "Integrated Water Resource Management for the Cardrona River" and the 2012 report "Management flows for aquatic ecosystems in the Arrow River". The update provided additional information on the Cardrona and Arrow catchments including: hydrology and existing water allocation; the in-stream aquatic values; presentation, analysis and interpretation of the results on instream habitat modeling undertaken by NIWA to estimate the flows required to maintain aquatic, ecological and natural character values.

Resolution

The technical reports are received and noted.

Moved: Cr Hope
Seconded: Cr Lawton
CARRIED

12. NOTICES OF MOTION

NIL

13. CLOSURE

Cr Robertson left the room at 5:05pm.

The meeting was declared closed at 5:11pm.

<u>Chairperson</u>

Report	**Meeting Date**	**Action**	**Status**
2017 Air Quality Results	29/11/17	That a report back be provided on the reduction of the use of coal achieved in other areas of New Zealand	CLOSED ITEM 11.3 OF AGENDA

Adapting to Climate Change in New Zealand

Stocktake Report from the Climate Change Adaptation Technical Working Group

The information provided in this report represents the best information available to the Group and our expert judgement. The gaps in knowledge and work programmes signify those present as of 31 May 2017.

This Stocktake Report constitutes the Interim Report of the Climate Change Adaptation Technical Working Group as per their terms of reference.

Published in December 2017 by the
Climate Change Adaptation Technical Working Group
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This document is available on the Ministry for the Environment website: www.mfe.govt.nz.

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Executive summary

Global climate has already changed as a result of greenhouse gas emissions from human activities and it will continue to do so. While we are uncertain about the exact speed and scale of change, we know that planning for the future means planning for a different climate.

In New Zealand we will experience increased frequency and intensity of extreme events such as higher temperatures flooding, droughts and wildfires, increased sea-level rise, and warmer and more acidic oceans. This will threaten our coastal communities, cities, infrastructure, human health, biodiversity, oceans and resource-based economy (Intergovernmental Panel on Climate Change (IPCC), 2014). These changes may also bring opportunities and we need to plan how we can best position ourselves to take advantage of these.

In November 2016 the Minister for Climate Change Issues established the Climate Change Adaptation Technical Working Group and asked us to advise the Government on New Zealand's choices for how to build resilience to the effects of climate change. This stocktake report summarises the expected impacts of climate change on New Zealand over the medium and long term, takes stock of existing work on adaptation, and identifies gaps in knowledge and work programmes. This report is a stepping-stone and has informed our second report on New Zealand's options for building resilience to the effects of climate change.

What is adaptation?

Adaptation is an ongoing process of adjusting to the actual and expected changes in the environment resulting from greenhouse gas emissions already released into the atmosphere and those that may be released in the future. Adaptation is an ongoing process as the climate will continue to change throughout this century and beyond. It is different from but linked to *mitigation*, which is about reducing greenhouse gas emissions to limit further climate change, and increasing the ability of natural processes to absorb emissions, for example, by planting trees.

This report focuses on adaptation but acknowledges that the two are closely linked, as the extent of adaptation required in the long term will depend on the global level of mitigation achieved in the future. Adaptation and mitigation can be mutually reinforcing.

By ratifying the Paris Agreement in 2016, New Zealand confirmed it will *plan for* and *take action* to adapt to the impacts of climate change.

We have options for how we can adapt. Decisions we make today about infrastructure, urban development, biodiversity, and land and water management will have implications for how our future generations can adapt. Many activities that build resilience in the short term may have immediate co-benefits. For example, restoring wetlands and mangroves will help provide coastal protection from sea-level rise for a time, while also contributing to biodiversity conservation goals.

Finding the most appropriate adaptation actions will, however, be a delicate balancing act. It is therefore important to consider and be ready to manage downstream consequences – co-benefits may be temporary or increase vulnerability rather than resilience in the long term. For example, planting more trees in areas exposed to more rainfall can help protect the land from soil erosion and at the same time absorb emissions. On the other hand, such measures could increase our exposure to pests, wildfire and water stress. So regardless of how we approach our adaptation to a changing climate it needs to be deliberate and well planned.

Climate-related changes New Zealand can expect

Natural variations have always played a part in New Zealand's climate, and will continue to do so. Climate change is expected to shift the range and the pattern of this variability. This will be driven by the greenhouse effect changing the temperature range, the greater water-holding capacity of the atmosphere resulting in more intense rainfall, and by an accelerating rate of sea-level rise from the polar ice sheets. Sea-level rise is one of the major and most certain consequences of climate change. Over the last 100 years, the sea level around New Zealand has risen at an average rate of 1.8 mm per year. Since satellite measurements began in 1993, the average global sea level has risen by about 3.3 mm per year. The IPCC Fifth Assessment Report projects that global sea level will rise by 0.2–0.4 m by 2060 and 0.3–1.0m by 2100, depending on the emissions scenario. However, the collapse of parts of the Antarctic ice sheets could substantially increase this range. The acceleration of sea-level rise will have implications on the ability of natural and human systems to adapt. The following table outlines the changes we can expect to see to our climate and oceans over the medium and long term.

Projected magnitude and variation of climate-related changes for New Zealand[1]

Climate variable	Description of change	Timeframe of change[2]		
		Now	**2040**	**2090**
Average temperature	Only for low carbon scenario does warming peak and then decline slightly during the 21st century Warming greatest at higher elevations. Warming greatest summer/autumn & least winter/spring	New Zealand has already warmed by 0.9°C	+0.7°C to +1.0°C	+0.7°C to +3.0°C 2110: +0.7°C to +3.7°C
Daily temperature extremes: frosts	Decrease in cold nights (0°C or lower) Number of days of frost decrease greatest in the coldest regions	Significant reduction in frequency of cold nights in many locations	30% to 50% decrease	30% to 90% decrease
Daily temperature extremes: hot days	Increase in hot days (maximum temperature of 25°C or higher)	No significant changes observed yet	40% to 100% increase	40% to 300% increase
Ocean warming[3]	Progressive increase Higher temperature increase in north Tasman Sea (projected to exceed 3°C by 2100)	1909–2009: warmed 0.71°C		Mean sea surface expected to increase by 2.5°C [RCP8.5]
Ocean acidification (lowering pH)	Increase, with a rate of change that is unprecedented in the last 25 million years	Increasingly acidic Subantarctic waters (since 1998)		pH surface water will decline by 0.33 [RCP8.5]
Sea-level rise	Progressive increase faster than over the last century, and continuing for many centuries Relative sea-level rise will vary at different locations around New Zealand.	1915–2015: rate of 1.8 mm per year on average	2060: 0.2 m to 0.4 m rise 2100: 0.3 m to 1.0 m rise The collapse of parts of the Antarctic ice sheets could substantially increase the upper end of this range	
Average rainfall	Varies around the country and with season. Annual pattern of increases in west/south of New Zealand, and decreases in north and east Winter decrease: Gisborne, Hawke's Bay and Canterbury Winter increase: Nelson, West Coast, Otago and Southland	Rainfall decrease in Northland and rainfall increase in the SW South Island.	Substantial variation around the country, increasing in magnitude with increasing emissions.	

1 Ministry for the Environment, 2016, *Climate Change Projections for New Zealand*.

2 Magnitude of change considers scenarios based on Representative Concentration Pathways (RCPs) Four scenarios are considered ranging from a low emissions world where net anthropogenic global carbon dioxide emissions stop after 2080 (RCP2.6) to a high emissions, no mitigation scenario (RCP8.5). Changes are relative to 1995 levels.

3 Law, C.S., Rickard, G.J., Mikaloff-Fletcher, S.E., Pinkerton, M.H., Gorman, R., Behrens, E., Chiswell, S.M., Bostock, H.C., Anderson, O. and Currie, K. (2016) *The New Zealand EEZ and South West Pacific. Synthesis Report RA2, Marine Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100*. MBIE contract C01X1225. 41pp.

Climate variable	Description of change	Timeframe of change[2]		
		Now	2040	2090
Daily rainfall extremes: dry days[4]	More dry days throughout North Island, and in inland South Island Dry days most marked in north and east of North Island (winter and spring)	More dry days in Northland. Fewer dry days in SW South Island (since 1930)		Up to 10 or more dry days per year (~5% increase).
Daily rainfall extremes: very wet days	Increased extreme daily rainfall, especially where mean rainfall increases Strongest increases in western regions, and in south of South Island	Increases in the west of both islands, decreases in the east and Northland (since 1930)		More than 20% increase in 99th percentile of daily rainfall [RCP8.5] in SW of South Island
Snow and Ice	Decrease Large decreases confined to high altitude or southern regions of the South Island	Decrease in the length of many New Zealand glaciers		Snow days per year reduce by 30 days or more [RCP8.5]. Loss of many glaciers [RCP8.5]
Drought	Increase in severity and frequency Increases most marked in already dry areas	Increase in the risk of severe drought in some areas. The worst drought in the New Zealand record occurred in summer 2012–13.		Up to 50 mm+ increase per year, on average, in July–June potential evapotranspiration deficit (PED) [RCP8.5]
Extreme wind speeds	Increases in southern half of North Island and the South Island		Up to 10% or more in parts of the country	
Storms	Poleward shift of mid-latitude cyclones and possible small reduction in frequency. The most severe Ex-tropical cyclones are expected to be stronger. Their frequency is expected to decrease slightly or remain unchanged.	More analysis needed		

The impacts of climate-related changes for New Zealand

Changes to our climate and oceans pose a number of risks and opportunities to our people, infrastructure, natural environment and economy.

4 Defined as days with precipitation below 1 millimetre/day. Salinger, M.J. and Griffiths, G.M. (2001), Trends in New Zealand daily temperature and rainfall extremes. *International Journal of Climatology*, 21: 1437–1452. Porteous, A. and Mullan, B. (2013), *The 2012–13 drought: an assessment and historical perspective*. NIWA client report for Ministry for Primary Industries, June 2013, 57p.

In terms of risks, climate change will amplify existing risks and create new risks which will be unevenly distributed across natural and human systems (IPCC 2014). Applied to a climate setting, these risks depend on:

- how **exposed** people, infrastructure, the natural environment and the economy are to the change.
- their **vulnerability** to those hazards, that is their ability to cope and adapt to the change.

The implications of climate change for New Zealand's economy and society over the long term will depend on what actions we take now. Adaptation has the potential to reduce the risks from climate change.

Impacts on the natural environment

Climate change could have a significant impact on our terrestrial, freshwater, coastal and marine ecosystems, which are already under pressure from existing stressors (such as land use intensification). The range of ecosystems and species will change, as well as the timing of annual and seasonal events (eg, beech masting), and ecosystem functions (eg, food webs). Native species that have highly specialised habitat requirements, such as frogs and lizards, are particularly at risk. Indirectly, climate change will increase the extent and abundance of invasive species, already a key driver of extinction in New Zealand.

Climate change will also impact on essential ecosystem services we rely on, including the availability of clean fresh water, access to kai moana, soil stability, flood protection, pollination, carbon storage and coastal protection.

Impacts on the built environment

Most of New Zealand's major urban centres and the majority of our population are located on the coast or floodplains of major rivers. Our communities, homes, commercial assets and infrastructure are exposed to flooding, sea-level rise, storm surge and inundation from rising ground water levels.

The mid-range projected sea-level rise over the next 50 years is 30 cm. Such a rise in sea level would have impacts on all coastal areas to varying extents. Under this scenario, in Wellington a one in 100 year inundation event would become an annual event, in Dunedin this would become a one in two year event, and in Auckland a one in four year event. We can also expect to see more damage and disruption to assets and critical infrastructure in parts of these areas. This is significant considering central and local government own over $200 billion in infrastructure assets.

Impacts on society and culture

Climate change is increasingly being recognised as a serious emerging risk to public health. Some of the potential impacts will be direct, such as injury and illness from extreme weather events, while others will be indirect, such as increased incidences of existing and new diseases.

For Māori, their reliance on the environment as a cultural, social and economic resource makes them exposed to climate change impacts. Different iwi face different risks, and some are more vulnerable than others. There are numerous marae, cultural heritage and food gathering sites in coastal low-lying areas that are at risk of being lost by sea erosion and inundation.

There will be some groups and locations in New Zealand that will be more vulnerable to climate-related risks and have less capacity to adapt. More research is needed to understand which these groups are and where such hotspots are located.

Impacts on the economy

Agriculture, fisheries, forestry and tourism are significant contributors to New Zealand's economy, and are all dependent on climate-sensitive natural resources. These sectors are exposed to the direct impacts of a changing climate (eg, changes to water availability and quality) as well as indirect impacts that compound and cascade through the economy (eg, increased biosecurity threats and disruption to supply chains). In addition, many of our industries are trade-intensive. The IPCC (2014) suggest that the flow-on effects of climate change impacts and responses outside our region could outweigh some of the direct impacts within New Zealand. More research is needed on this.

Climate change will also impact on the insurance and finance sector which will have broader economic implications. More extreme weather events will raise the number and value of claims insurers pay, which will inevitably be reflected in the premiums charged and willingness to provide cover. For banks, this could result in the offer of shorter term mortgages which may become less affordable. Unavailability or unaffordability of insurance cover will reshape the distribution of vulnerable groups.[5]

Businesses, such as manufacturing and retail, are expected to be indirectly affected through changes to consumer behaviour, disruption to supply of products and services, and/or damage to commercial assets. But climate change can also present new business opportunities. For example, regions may be able to sustain different types of crops than they have been able to grow previously, although climate ranges will be continually changing.

While the potential costs of climate change impacts on the New Zealand economy are not known, we do know our exposure to the impacts are high in many areas (eg, in coastal floodplains and to our major economic sectors), and as such the costs are likely to be significant. For example, the economic impact of the 2012–13 drought, which climate change is assessed to have made a

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5 2013 and 2014 were among the most expensive years for weather-related events.

contribution, is estimated to be a minimum of $1.5 billion. Another example shows the costs of weather events to our land transport network in the last 10 years have increased from $20 million per annum to over $90 million per annum.

Defining effective adaptation

While the potential impacts of climate change may appear overwhelming, well-planned adaptation can substantially reduce these risks, avoid losses and maximise opportunities. This can be achieved by taking action to reduce the exposure of our natural, built, social and economic systems to the impacts; and ensuring these systems have sufficient capacity to adapt.

To review what New Zealand is currently doing to adapt we have developed a framework identifying key characteristics and attributes of an effective adaptation approach. The characteristics include that we are:

- **informed** about how our climate is changing and what it means for us
- **organised** in our approach
- taking **dynamic action** to proactively manage the environmental, economic and social risks.

We then assessed the information provided by sector representatives against the key characteristics of effective adaptation. For each sector, we rated each characteristic as ‘maintain’, ‘more work required’, ‘significant work required’, or ‘not present’.

Stocktake of what New Zealand sectors are doing to adapt to climate change

Our Terms of Reference require us to undertake a stocktake of existing work on adaptation by central and local government. In addition to this, we have also drawn on our expertise within the Group to consider what other sectors of society are doing on adaptation. We chose to extend the scope of the stocktake as we recognise that New Zealand will not successfully adapt through central and local government alone.

Central and local government on behalf of communities is responsible for managing risks to public goods and assets (including the environment), delivering government services, and creating the institutional, market and regulatory frameworks that can promote resilience and adaptation.

Central government has played a key role in funding research which provides the basis for building New Zealanders’ understanding of climate-related changes and the impacts on different sectors of society. Central government agencies’ understanding of how climate change will impact on their responsibilities and operations are less clear.

There is some misalignment in how climate change adaptation and resilience objectives are incorporated into legislation and policy. As a result, the response of central government agencies to adaptation is not coordinated and there is little alignment of legislation, adaptation goals or agreement of priorities.

Agencies consider and act on the impacts of climate change to varying degrees – some have taken positive initial steps (eg, the National Infrastructure Plan and National Civil Defence Emergency Management Plan both highlight the importance of integrating climate risks into decision-making). Other government activities are running the risk of increasing New Zealand's future vulnerability as climate impacts are not being considered (eg, accelerated urban development). In general, most of central government's action on adaptation has been reactive to climate-related events and principally within a natural hazard management response framework, when ongoing impacts will also encompass wider considerations such as human and natural ecosystems health.

Local government has responsibilities for preparing communities for and managing the risks of climate change. However, this brings with it inefficiencies when central government statutory frameworks and national adaptation goals and priorities are not aligned or missing.

The majority of councils appear to have a good understanding of climate change and are able to clearly articulate the potential impacts on their responsibilities.

The extent and scope of action on adaptation varies considerably. For example, some regions are already experiencing difficult climate-related impacts, including significant flooding risks in South Dunedin and coastal erosion and inundation impacts in the Hawke's Bay. Overall, councils are at different stages of planning, and have different approaches to managing climate risks which can create confusion for the public, and result in litigation of decisions.

Many councils realise the importance of acting on adaptation and would like to do more, but identified barriers including lack of leadership and support from central government; limited community buy-in; and resourcing constraints (funding, capacity and capability). There are a few councils that are starting to innovate with community processes and tools for managing climate risks.

Infrastructure providers include private and/or public organisations responsible for the design, construction, operation and maintenance of electricity generation and transmission; water, wastewater and stormwater (three waters); flood management; and communications and transportation networks (including ports and airports). Infrastructure assets generally have a long design life. It is the provider's responsibility to ensure they consider climate-related change and the long-term impacts this will have.

A good level of information is available to infrastructure providers on climate change through climate projections supplied by government, and applied through industry standards. Some providers have displayed a good understanding of the risks, however many consider climate change adaptation as part of a broader goal around resilience to natural hazards. This limits the consideration of the changing nature of climate-related risks.

Given the long lifetime of infrastructure, it is important that climate change adaptation is factored into infrastructure decisions now. Many local authorities, which are significant providers of infrastructure assets, are approaching a period of infrastructure renewal. This is an opportunity to integrate consideration of climate change impacts and their consequences over the lifetime of the assets.

In the majority of cases, infrastructure decisions do not currently consider climate change impacts. There are a number of challenges to incorporating climate change adaptation into infrastructure decision-making. These include: most approaches to addressing service provision involving 'locked in' practices and measures developed over the last century, and a perception that climate change adaptation will cost more, even though it may not be significant compared with the large capital costs and longevity of infrastructure investment.

The finance and insurance sector includes New Zealand's insurance, banking and investment providers. The sector is experienced in dealing with natural hazards and understands that climate change will exacerbate this. It is calling for a more coordinated and proactive response focused on reducing the potential impact of disasters before they strike.

The mismatch in the duration of insurance cover (annual) and lending (spanning decades) creates complexity in creating a coordinated response for businesses and homeowners in locations significantly affected by climate change. While the sector has not yet implemented any direct measures to deal with climate change impacts, it knows how insurance products would be changed when risks become too large. A key concern for the insurance industry is that action taken on a specific risk can result in precipitous action by others in the industry and some government policy settings, for example the Earthquake Commission (EQC).

The health sector is becoming increasingly aware of the risks of climate change on public health in New Zealand, but more work is needed. The sector is not organised for adapting to climate change with no clear goals or understanding of what is expected of them and no plan for how to go about adaptation. Some District Health Boards are addressing the impacts of climate change on public health in their planning and decision-making. This has mainly been through their emergency response and infrastructure planning.

For the **primary sector**, there is a lot of information available on the impacts and implications of climate change. This has helped facilitate a basic understanding of climate change for the sector. However, there are gaps in research on some of the impacts, for example, pests and diseases. The sector has a long history of adapting to seasonal and annual variability in climate-related conditions, including coping with the current frequency of extreme events. The challenge the sector will face as a result of climate change is increased range in that variability, changes to baseline rainfall and temperatures and an increase in the frequency of extreme events. Where measures that increase resilience have been incorporated, climate change is often not a key driver.

In the remaining **business sector**, the majority of businesses surveyed understand the future trends in climate that New Zealand can expect to experience.

While no overall plans for adaptation in this sector were indicated, the majority of survey respondents noted intent to manage climate change impacts in the future. However, information on how they intend to do this was not supplied.

Some businesses have an understanding of climate change risks, but often due to uncertainty and perceived costs involved, more immediate issues take priority. The private sector is driven by market conditions and as such has the ability to respond much more quickly to change, compared with the government. Increased range in climate variability may however challenge that agility.

Many **iwi/hapū** organisations recognise that if this generation does not take action then a higher burden will fall on future generations. Considerable work has been undertaken by Māori authorities and governance structures in generating iwi and hapū plans that identify climate change issues and implications. However, few of these have been mainstreamed by local government. Supporting vulnerable whānau and Māori land owners and business to adapt to climate change is a key area of focus for iwi.

In **civil society**, academics and the research community (funded by government) supply information to all sectors of society to help enable proactive and purposeful adaptation. Current research includes refinement of the range of expected impacts and how to implement appropriate adaptation. More work is required to understand if and how civil society can adapt to climate change.

A stocktake of current gaps in knowledge and work programmes

For effective adaptation to develop in New Zealand three characteristics and their attributes need to be in place – being **informed** about how our climate is changing and what this means for us; being **organised;** and taking **dynamic action,** to proactively reduce exposure to the environmental, economic and social and cultural consequence of climate change. Once each of these steps have started it is important that they continue. As our climate continually evolves, so must our adaptation approach.

The stocktake shows that New Zealand is in the early stages of planning for climate change impacts, with many positive initial steps being taken across nearly all sectors. The majority of sectors appear to be in the phase of becoming informed about the potential impacts and understanding what it means for them, while others have progressed to the organised phase.

Informed

New Zealand has generated a significant amount of information about what is happening to our climate, but the challenge is for this information to be readily available to sectors in forms that are relevant to their decision-making. There are gaps in our knowledge, including the potential costs to the economy over the medium and long term if no action is taken to adapt now, potential biosecurity threats to our sectors and natural systems and the impacts of climate change on pluvial flooding.

The lack of a nationwide assessment of the climate-related risks means that it is difficult for New Zealand to develop a planned approach for climate change adaptation because priorities for action cannot yet be articulated. This would be the first step towards an aligned approach across all sectors to help stimulate action in a systematic way.

Organised

Climate change adaptation is not currently integrated into many central government agency objectives. In the absence of coordinated leadership on climate change adaptation, other sectors operate within regulatory frameworks and policies which are not well aligned. This makes it difficult for central and local government and sectors to proactively organise themselves and take action.

Additional organisation gaps identified include:

- An overarching strategy or plan for how New Zealand can adapt to climate change.
- Coordinating mechanism(s) across and within sectors on climate change adaptation.
- Enabling tools to help facilitate adaptation, including the use of national direction tools.
- Resource scarcity, including expertise and funding across all sectors.
- Role clarity within and across sectors.

Dynamic action

We have seen a few examples of proactive adaptive action where there is high exposure and potentially large costs (eg, investment in flood risk management and some roading projects). However, overall there is limited evidence of proactive action that reduces medium and long-term risks. In most cases, actions have been reactive and part of a sector's natural hazard management response, rather than considering wider impacts, their changing characteristics and their compounding and cascading effects within and across sectors.

Next steps

The next step is to use this stocktake report as a basis for our second report on options for how New Zealand can address the challenges identified and build resilience to the effects of climate change while growing our economy sustainably.

1 New Zealand's climate is changing

New Zealand is already being affected by climate change. Changes to our environment will increase in magnitude and frequency over time. This will affect all of us in some way during our lifetimes, and our response will directly affect future generations.

Global climate has already changed as a result of greenhouse gas emissions from human activities, and it will continue to do so. While we are uncertain about the exact speed and scale of change, we know that planning for the future means planning for a different climate.

In New Zealand we will experience increased frequency and intensity of extreme events such as flooding, droughts and wildfires, increased sea-level rise, and warmer and more acidic oceans. This will threaten our coastal communities, cities, infrastructure, human health, biodiversity, oceans and resource-based economy (Intergovernmental Panel on Climate Change (IPCC), 2014). These changes may also bring opportunities and we need to plan how we can best position ourselves to take advantage of these.

1.1 What is climate change adaptation?

There are two important and complementary approaches to New Zealand's response to climate change.

- **Mitigation** – about reducing greenhouse gas emissions to limit further climate change and increasing sinks, such as planting trees, which absorb these gases.
- **Adaptation** – about an ongoing process of adjusting to the actual and expected changes in the environment resulting from greenhouse gas emissions which have already been released into the atmosphere, and those that may be released in the future. Adaptation is an ongoing process as the climate will continue to change throughout this century and beyond.

This report focuses on adaptation but acknowledges that the two parts are closely linked because:

- the extent of adaptation we need in the long term, will depend on the global level of mitigation achieved in the future
- the way we adapt may affect mitigation efforts. For example, planting more trees in areas exposed to more rainfall can help protect the land from soil erosion and at the same time absorb emissions. On the other hand, such measures could also increase our exposure to pests, wildfire and water stress. So regardless of how we approach our response to a changing climate it needs to be deliberate and well planned.

1.2 How can New Zealand adapt to climate change?

By ratifying the Paris Agreement in 2016 New Zealand confirmed it will 'plan for' and 'take action' to adapt to the impacts of climate change.

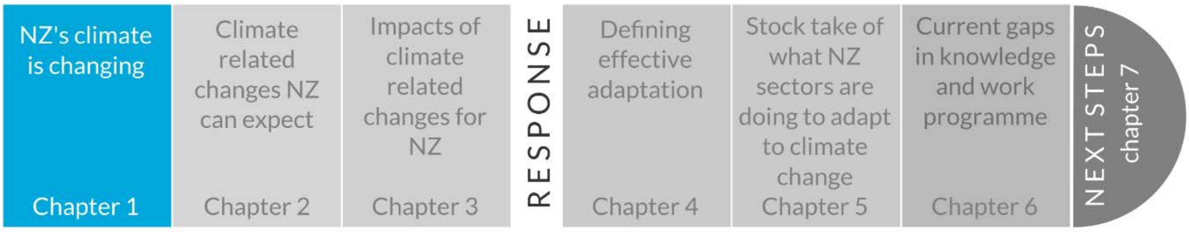
We have choices about how we can adapt. Decisions we make today about infrastructure, urban development, biodiversity and land and water management will have implications for how our future generations can adapt.

Many activities that build resilience in the short term may have immediate co-benefits (eg, flood protection work can reduce present economic losses). But it can be a delicate balancing act and we need to consider or be ready to manage downstream consequences – co-benefits may be temporary or increase vulnerability rather than resilience in the long term. For example, investment in irrigation can reduce short-term vulnerability to drought but in the long term may encourage land intensification thereby placing greater pressure on water resources. Structural protection works may also build a false sense of security and further demands for protection thus locking in exposure to risk over the long term.

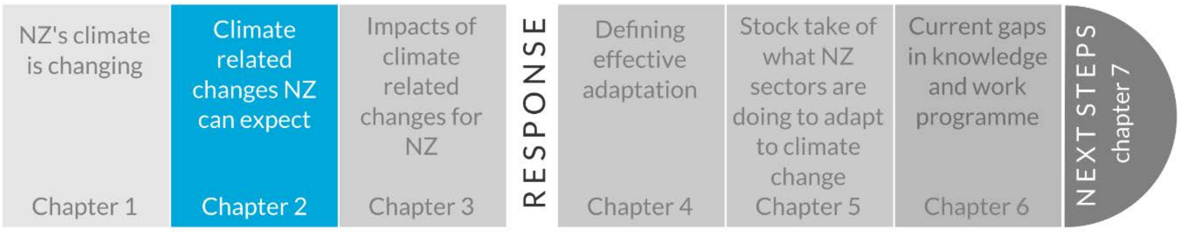
In November 2016 the Minister for Climate Change Issues established the Climate Change Adaptation Technical Working Group and asked us to advise the Government on the options New Zealand has for how to build resilience to the effects of climate change. This is our first report where we:

- **look at the climate-related changes New Zealand can expect over the medium and long term (Chapter 2), and the potential impacts this will have on the natural and built environment, the economy and society (Chapter 3).** For example, climate change driven sea-level rise will intensify coastal erosion and inundation. This may lead to low-lying areas being covered by water, seawaters entering some of our groundwater resources, and increased damage to properties and infrastructure near the coast
- **define the key characteristics and attributes of effective adaptation (Chapter 4)**
- **take stock of the existing work on adaptation by central and local government (Chapter 5).** Our Terms of Reference requires us to undertake a stocktake of existing work on adaptation by central and local government. In addition to this, we have also drawn on our expertise within the Group to consider what other sectors of society are doing on adaptation. We chose to extend the scope of the stocktake as we recognise that New Zealand will not successfully adapt through central and local government alone
- **outline gaps in knowledge and work programmes (Chapter 6)** based on the stocktake. This information provided in this DRAFT report represents the best information available to the Group and our expert judgement. The gaps in knowledge and work programmes identified are a work in progress. We propose to test this information with key, targeted groups
- **outline what will come next (Chapter 7).**

This report is a stepping-stone that will inform our second report, a draft of which will be produced in November 2017 with the final report due to the Minister of Climate Change Issues in March 2018. Our second report will consider and provide recommendations on what New Zealand's choices are for building resilience to the effects of climate change (see Appendix 1 for the Group's Terms of Reference). The report is organised as follows:



2 Climate-related changes New Zealand can expect



New Zealand's average temperature has increased by around 1°C over the last century, and will continue to increase. This section summarises the climate-related changes New Zealand can expect as a result, over the medium and long term. The information in this section comes from a variety of sources, including the Ministry for the Environment's 2016 report *Climate Change Projections for New Zealand*[6] and the IPCC Fifth Assessment Report.[7]

2.1 Climate-related changes over the medium and long term

Table 2.1 and Figure 2.1 show the projected changes in climate-related variables as a result of climate change, and the spatial distribution of these changes. Where possible, we have set out the projected impact across time, with a snapshot of now, 2040 and 2090. More detailed regional impacts of climate change can be found on the Ministry for the Environment's website.[8]

6 http://www.mfe.govt.nz/publications/climate-change/climate-change-projections-new-zealand

7 https://www.ipcc.ch/report/ar5/

8 http://www.mfe.govt.nz/climate-change/how-climate-change-affects-nz/how-might-climate-change-affect-my-region

Table 2.1: Projected magnitude and variation of climate-related changes for New Zealand[9]

Climate variable	Description of change	Timeframe of change[10]		
		Now	**2040**	**2090**
Average temperature	Only for low carbon scenario does warming peak and then decline slightly during the 21st century Warming greatest at higher elevations. Warming greatest summer/autumn & least winter/spring	New Zealand has already warmed by 0.9°C	+0.7°C to +1.0°C	+0.7°C to +3.0°C 2110: +0.7°C to +3.7°C
Daily temperature extremes: frosts	Decrease in cold nights (0°C or lower) Number of days of frost decrease greatest in the coldest regions	Significant reduction in frequency of cold nights in many locations	30% to 50% decrease	30% to 90% decrease
Daily temperature extremes: hot days	Increase in hot days (maximum temperature of 25°C or higher)	No significant changes observed yet	40% to 100% increase	40% to 300% increase
Ocean warming[11]	Progressive increase Higher temperature increase in north Tasman Sea (projected to exceed 3°C by 2100)	1909–2009: warmed 0.71°C		Mean sea surface expected to increase by 2.5°C [RCP8.5]
Ocean acidification (lowering pH)	Increase, with a rate of change that is unprecedented in the last 25 million years	Increasingly acidic Subantarctic waters (since 1998)		pH surface water will decline by 0.33 [RCP8.5]
Sea-level rise	Progressive increase faster than over the last century, and continuing for many centuries Relative sea-level rise will vary at different locations around New Zealand	1915–2015: rate of 1.8 mm per year on average	2060: 0.2 m to 0.4 m rise 2100: 0.3 m to 1.0 m rise. The collapse of parts of the Antarctic ice sheets could substantially increase the upper end of this range.	
Average rainfall	Varies around the country and with season. Annual pattern of increases in west/south of New Zealand, and decreases in north & east Winter decrease: Gisborne, Hawke's Bay and Canterbury Winter increase: Nelson, West Coast, Otago and Southland	Rainfall decrease in Northland and rainfall increase in the SW South Island	Substantial variation around the country, increasing in magnitude with increasing emissions	

9 Ministry for the Environment, 2016, *Climate Change Projections for New Zealand*.

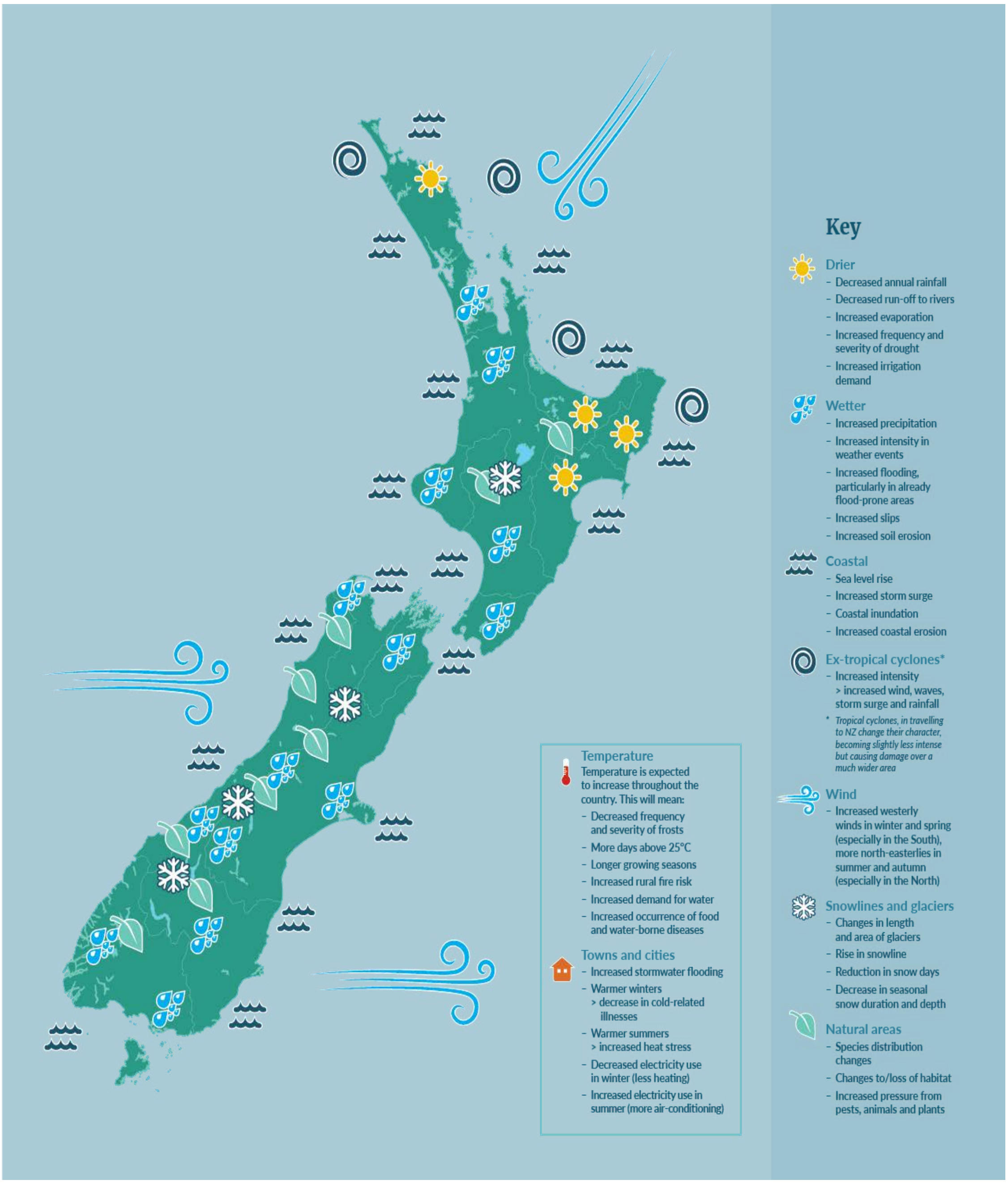
10 Magnitude of change considers scenarios based on Representative Concentration Pathways (RCPs). Four scenarios are considered ranging from a low emissions world where net anthropogenic global carbon dioxide emissions stop after 2080 (RCP2.6) to a high emissions, no mitigation scenario (RCP8.5). Changes are relative to 1995 levels.

11 Law, C.S., Rickard, G.J., Mikaloff-Fletcher, S.E., Pinkerton, M.H., Gorman, R., Behrens, E., Chiswell, S.M., Bostock, H.C., Anderson, O. and Currie, K. (2016) *The New Zealand EEZ and South West Pacific. Synthesis Report RA2, Marine Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100*. MBIE contract C01X1225. 41pp.

Climate variable	Description of change	Timeframe of change[10]		
		Now	2040	2090
Daily rainfall extremes: dry days[12]	More dry days throughout North Island, and in inland South Island Dry days most marked in north and east of North Island (winter and spring)	More dry days in Northland. Fewer dry days in SW South Island (since 1930)		Up to 10 or more dry days per year (~5% increase)
Daily rainfall extremes: very wet days	Increased extreme daily rainfall, especially where mean rainfall increases Strongest increases in western regions, and in south of South Island	Increases in the west of both islands, decreases in the east and Northland (since 1930)		More than 20% increase in 99th percentile of daily rainfall [RCP8.5] in SW of South Island
Snow and Ice	Decrease Large decreases confined to high altitude or southern regions of the South Island	Decrease in the length of many New Zealand glaciers		Snow days per year reduce by 30 days or more [RCP8.5] Loss of many glaciers [RCP8.5]
Drought	Increase in severity and frequency Increases most marked in already dry areas	Increase in the risk of severe drought in some areas. The worst drought in the New Zealand record occurred in summer 2012–13		Up to 50 mm+ increase per year, on average, in July–June potential evapotranspiratio n deficit (PED) [RCP8.5]
Extreme wind speeds	Increases in southern half of North Island and the South Island		Up to 10% or more in parts of the country	
Storms	Poleward shift of mid-latitude cyclones and possible small reduction in frequency. The most severe Ex-tropical cyclones are expected to be stronger. Their frequency is expected to decrease slightly or remain unchanged.	More analysis needed		

12 Defined as days with precipitation below 1 millimetre/day. Salinger, M.J. and Griffiths, G.M. (2001), Trends in New Zealand daily temperature and rainfall extremes. *International Journal of Climatology*, 21: 1437–1452. Porteous, A. and Mullan, B. (2013), *The 2012–13 drought: an assessment and historical perspective*. NIWA client report for Ministry for Primary Industries, June 2013, 57p.

Figure 2.1: Shows the spatial distribution of climate-related changes across New Zealand



2.1.1 Climate-related changes in weather patterns, oceans and coastal areas

As set out above (Chapter 1) we cannot be certain about the extent to which global emissions will reduce, and if so by how much. Therefore we work with ‘low’ and ‘high’ emissions scenarios to reflect a plausible range of outcomes.

Temperature

By 2040, New Zealand is projected to experience a temperature increase of between 0.7°C (under a low emissions scenario) and 1.0°C (under a high emissions scenario), relative to 1995. This range widens towards the end of the century, with temperatures projected to increase by up to 3.0°C by 2090 and 3.7°C by 2110 (under a high emissions scenario). Across the country, we expect to see slight differences from north to south, from east to west, and across seasons. The greatest warming will be in the northeast, and generally highest in summer and autumn and lowest in winter and spring. The frequency of hot days is expected to increase (up to 100 per cent by 2040 and up to 300 per cent by 2090, relative to 1995) and the frequency of frosts is expected to decrease (up to 50 per cent by 2040 and up to 90 per cent by 2090).

Rainfall

New Zealand will experience changing rainfall patterns as a result of climate change. These will vary around the country and with season, and are associated with changing circulation patterns (New Zealand is expected to receive more north-easterly airflow in the summer and stronger westerly flow in winter). The overall pattern for changes in annual rainfall is a reduction in the north and east of the North Island, and increases almost everywhere else, especially on the South Island West Coast. Seasonally, decreased spring rainfall is expected in the north and east of the North Island, and in the south and east of the South Island. During summer, increased rainfall is projected in the north and east of the North Island, and increased winter rainfall is expected in many parts of the South Island. The largest rainfall changes by the end of the century will be for particular seasons rather than annually. We expect New Zealand to see a decrease in the number of snow days, and to experience rising snowlines.

Oceans

Climate change is projected to drive changes to the oceans around New Zealand by increasing sea level, temperature and acidity. In terms of temperature, our ocean surface temperatures have warmed by about 0.71°C in the 100 years up to 2009, and under a high emissions scenario by 2110 the mean sea surface temperature is expected to increase by 2.5°C, and by more than 3°C in the north Tasman Sea.[13] In addition, New Zealand's sub-Antarctic waters have become more acidic since measurements were first taken in 1998, and the pH of surface water is expected to decline by 0.33 under the highest emissions scenario by 2100, a rate of change that is unprecedented in the last 25 million years.

Sea-level rise

Sea-level rise is one of the major and most certain consequences of climate change. Over the last 100 years, the sea level around New Zealand has risen at an average rate of 1.8 mm per year. Since satellite measurements began in 1993, the average global sea level has risen by about 3.3 mm per year. The IPCC Fifth Assessment Report projects that global sea level will rise by 0.2–0.4 m by 2060 and 0.3–1.0 m by 2100, depending on the emissions scenario. However, the collapse of parts

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13 CCII Marine Case Study (http://ccii.org.nz/wp-content/uploads/2017/04/RA2 MarineCaseStudySynthesisReport.pdf).

of the Antarctic ice sheets could substantially increase this range. The stability of the polar ice sheets is a very active area of research and recent developments are expected be captured in the IPCC Special report on "*the Oceans and the Cryosphere in the Context of Climate Change*" (due in 2019).

While published projections of future sea-level rise are usually the global average, the amount of sea-level rise experienced in different regions will vary. According to the IPCC Fifth Assessment Report, sea-level rise in our region is expected to be up to 10 per cent more than the global average, depending on whether more ice melts from the Greenland or Antarctic ice sheets. The melting of the Greenland ice sheet would result in New Zealand experiencing a greater sea-level rise than the global average, while the reverse is true if melting is mainly from the Antarctic ice sheet. This is because in the area around a melting ice sheet, the gravitational attraction between ice and ocean water is reduced, and the land tends to rise as the ice melts. However, in regions further away from the melting ice sheet, sea-level rise is greater than the global average.[14]

Climate change is also expected to affect New Zealand's coastal areas through:[15]

- increased coastal erosion
- more frequent and extensive coastal flooding
- higher storm surges
- saltwater intrusion into coastal aquifers and further inland in estuaries
- changes in surface water quality, groundwater characteristics and sedimentation.

2.1.2 Changes in extreme weather events

Natural variations have always played a part in New Zealand weather, and will continue to do so. Climate change is expected to shift the range and the pattern of variability.

We expect New Zealand to experience more frequent extreme weather events, such as droughts (especially in the east) and floods.

The projected change in frequency and intensity of droughts increases over time and is more pronounced under a high emissions scenario. Increased droughts may combine with strong winds, high temperatures and low humidity to produce dangerous fire weather situations. Fire risk is expected to increase as a result of climate change.

An increase in the frequency of extreme rainfall events is also projected, with the strongest increases in the west and south, and increased flooding of rivers is expected to occur as a result of this (Royal Society of New Zealand (RSNZ), 2016). Ex-tropical cyclones are expected to be stronger and cause more damage as a result of heavy rain and strong winds. Extreme wind speeds could increase by 10 per cent or more in parts of the country.

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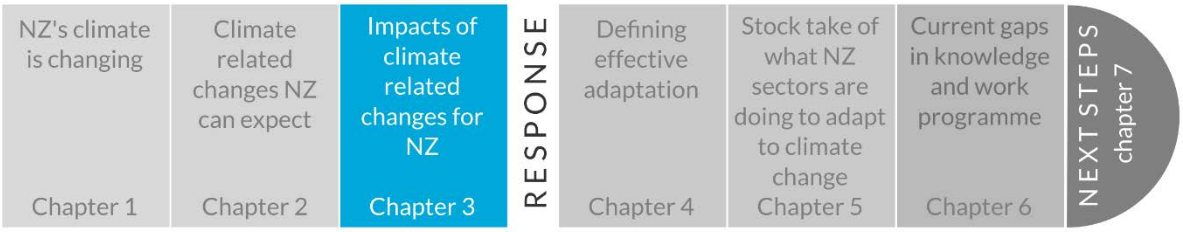
14 IPCC AR5 Working Group 1: The Physical Science Basis (https://www.ipcc.ch/report/ar5/wg1/).

15 Royal Society of New Zealand, 2016, *Climate change implications for New Zealand.*

2.1.3 Medium and long term impacts

The medium and long term impacts of climate change depend on future global emissions of greenhouse gases and, for sea-level rise, on the stability of ice sheets that are grounded below sea level (eg, West Antarctica). However, generally speaking the impacts become greatest under the highest emissions scenario as time goes on. The range of projected changes for a particular variable also widens over the long term compared to the medium term, as the difference between the low emissions scenario and the high emissions scenario becomes greater over time.

3 The impacts of climate-related changes for New Zealand



This section explores the flow-on impacts on New Zealanders resulting from the climate-related changes, across our economy and society. These impacts will be a combination of risks and some opportunities.

Risk is often expressed in terms of a combination of the consequences of an event and the likelihood of that event occurring. The IPPC describes climate risks as:

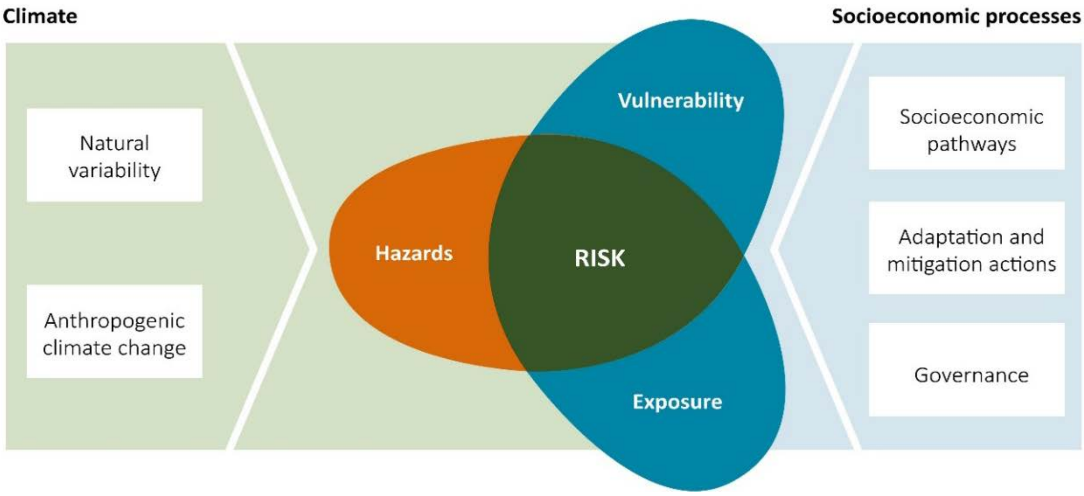
"Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development." (IPCC, 2014)

Applied to a climate setting, these factors depend on:

- how **exposed** people, infrastructure, the natural environment and the economy are to the change
- their **vulnerability** to those hazards, that is their ability to cope and adapt to the change.

This is illustrated in Figure 3.1.

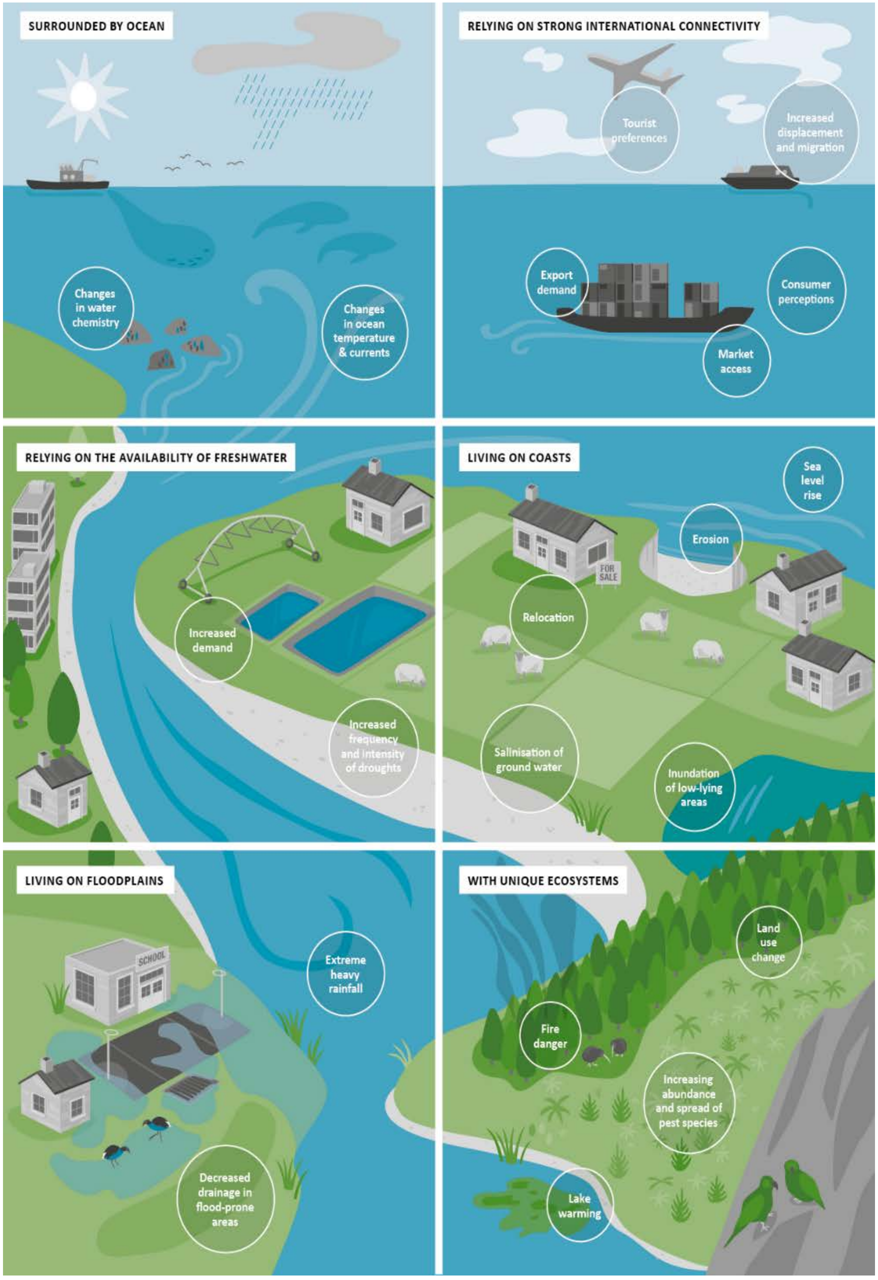
Figure 3.1: Climate change risks as the confluence of three drivers (Renwick et al (2016) based on IPCC (2014))



Although there is a large body of information on the expected changes to our climate, less is known about the impacts of these changes on our natural environment, society, communities and for the different sectors of the economy. These are gaps we have identified in our current knowledge.

The impacts of climate change on New Zealand's economy and society over the long term will depend on what actions we take now. Examples of this are illustrated in Figure 3.2. Adaptation has the potential to reduce the risks from climate change, and the more adaptation that takes place the greater this reduction will be (IPCC, 2014).

Figure 3.2: Examples of impacts of climate change for New Zealand[16]



16 Ibid.

3.1 Impacts on the natural environment

Our natural environment is already subject to multiple pressures, such as habitat loss, pollution, intense resource use and invasive species. It will be impacted substantially if it cannot cope with the increasing rate of climate change. Both the compounding effect and the interaction of climate change with other stressors, such as invasive species, has the potential to have a significant impact on our terrestrial, freshwater, coastal and marine ecosystems.

3.1.1 Biodiversity

Many aspects of New Zealand's biodiversity will be impacted by climate change in some way. New Zealand has a number of unique indigenous ecosystems, and changing temperatures and water availability as a result of climate change will have impacts on where species can survive (RSNZ, 2016). The range of ecosystems and species will change, as will the timing of annual and seasonal events (eg, beech masting), and ecosystem functions (eg, food webs).[17] Indirectly, climate change will increase the range and abundance of invasive pests and weed species which is currently a key driver of extinction.

Many of New Zealand's unique species are highly specialised (eg, tuatara[18]), limited in number (eg, takahe) and/or have specialised habitat requirements (eg, frogs and lizards). These factors will reduce their capacity to adapt to a changing climate.

There is uncertainty around where the greatest risks are, but there is a clear possibility that climate change will be a significant driver of biodiversity loss throughout this century and beyond (DOC, 2017).

There are some ecosystems that are particularly sensitive to climate change.

- **Alpine and sub-alpine ecosystems** – as temperature rises, tree lines are expected to increase in altitude. This and the introduction of invasive pests may also result in a loss of alpine species.
- **Freshwater ecosystems** – species and ecosystems will be affected by increased flood frequency, drought, sea-level rise, erosion and higher temperatures. Increased rainfall intensity will increase sedimentation and have further impacts on aquatic ecosystems.
- **Coastal ecosystems** – rising sea levels are expected to result in loss of sand dunes, wetlands, mangroves and estuaries.
- **Marine ecosystems** – increased temperature, wave action, turbidity, sedimentation and a reduction in dissolved oxygen will interact with pest invasion and ocean acidification, and threaten many marine species and ecosystem functions.

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17 For example, red-billed gulls were declared nationally vulnerable in 2014 due to climate-driven changes to the availability of krill which they feed on.

18 Warmer temperatures have resulted in changes in tuatara sex ratios to increasingly male.

3.1.2 Fresh water

The New Zealand Government Environment Report on Our Fresh Water (2017) states that climate change is projected to increase pressure on water flows and water availability. Higher temperatures and lower rainfall, along with increased frequency and intensity of droughts, are expected to reduce soil moisture, groundwater supplies and river flows for some areas. Greater variability in river flows over time is expected, as the frequency and intensity of droughts and floods are expected to increase over time (Prime Minister's Science Advisory Committee (PMCSA), 2017).[19]

Changes in seasonal rainfall patterns and extreme weather events will create secondary effects of erosion and sedimentation to waterways, affecting freshwater ecosystems. In addition, rising sea levels are expected to cause salinisation of groundwater[20] and coastal wetlands. Lower river flows in summer will raise water temperatures and exacerbate water quality problems, such as through increased algae growth leading to more algal blooms and eutrophication of lakes. Intensified stratification in deep lakes may occur, along with wind driven mixing in shallow lakes (PMCSA, 2017).

3.1.3 Oceans and coasts

The New Zealand Government's Environment Report on our Marine Environment (2016) identified ocean acidification and warming as top issues facing our oceans. It noted that marine and coastal species with carbonate shells like pāua, mussels, and oysters, and the plankton that support all life in the oceans are particularly vulnerable to climate change with increased acidity interfering with the formation of shells (Climate Changes, Impacts & Implications for New Zealand (CCII) RA2 Marine case study).[21]

Ocean warming and acidification caused by climate change pose a risk to many ecologically important species in the New Zealand region, including deepwater coral reefs that form habitat for many marine species. The north Tasman Sea is expected to experience greater warming than the rest of our surrounding ocean, and this could drive regional change in marine ecosystems in the form of fewer temperate species, increased sub-tropical species and more nutrient-poor conditions (CCII RA2 Marine case study). Some species that presently live in lower latitude regions may migrate into New Zealand waters in response to rising temperatures and changing

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19 The Prime Minister's Chief Science Advisor Sir Peter Gluckman recently released a report on freshwater which confirms the climate change impacts on our waterways. PMCSA, 2017, *New Zealand's fresh waters: Values, state, trends and human impacts.*

20 DOC, 2016, *Freshwater conservation under a changing climate*.

21 Law, C.S., Rickard, G.J., Mikaloff-Fletcher, S.E., Pinkerton, M.H., Gorman, R., Behrens, E., Chiswell, S.M., Bostock, H.C., Anderson, O. and Currie, K. (2016) *The New Zealand EEZ and South West Pacific. Synthesis Report RA2, Marine Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100*. MBIE contract C01X1225. 41pp.

ecological community structures.[22] Work is underway to characterise impacts on fish in the New Zealand region.[23]

3.1.4 Other ecosystem services

Other ecosystem services that we expect to be affected by climate change are soil stability, flood protection, pollination, carbon storage, and coastal protection.

3.2 The built environment

3.2.1 Physical infrastructure

The built environment provides the systems on which people and their activities rely for living, mobility and well-being. For example, infrastructure necessary for the transport of goods and people, energy supply, clean water, communication and emergency responses to disasters. It also encompasses communities' social and cultural assets – our homes, marae, schools, hospitals, prisons, libraries, swimming pools, nature reserves and national parks, and recreational facilities.

Most of New Zealand's major urban centres and the majority of our population are located on the coast or floodplains of major rivers.[24] Our communities, homes, commercial assets and infrastructure are exposed to flooding, sea-level rise, storm surge and inundation from rising groundwater levels. For example, as sea level continues to rise, areas of low-lying coastal land that currently flood during storms or king tides will experience more frequent and severe inundation.

The mid-range projected sea-level rise over the next 50 years is 30 cm. This 30 cm sea-level rise would have impacts on all coastal areas to varying extents. Under this scenario, in Wellington a one in 100 year inundation event would become an annual event, in Dunedin this would become a one in two year event, and in Auckland would become a one in four year event. The combination of higher sea levels and more frequent extreme rainfall events will also lead to increased flooding, in particular where rivers meet the coast. Communities can expect to see more damage caused to assets and property in parts of these areas, and consequently: increased costs to manage and maintain urban facilities; more frequent disruption to business operations; and potential

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22 Molinos G.J, Halpern B.S., Schoeman D.S., Brown C.J., Kiessling W., Moore P.J., Pandolfi J.M., Poloczanska E.S., Richardson A.J. and Burrows M.T. (2015). Climate velocity and the future global redistribution of marine biodiversity, *Nature Climate Change*, doi:10.1038/nclimate2769.

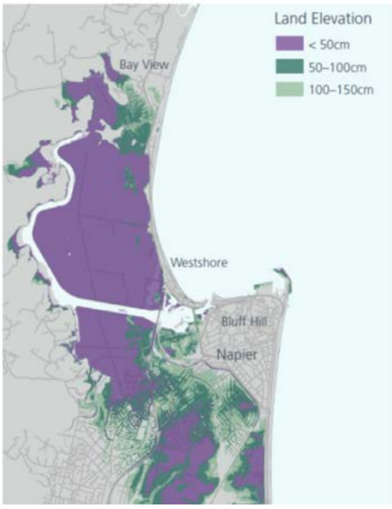
23 Renwick J.A., Hurst R.J., and Kidson J.W. (1998). Climatic influences on the recruitment of southern gemfish (Rexea solandri, Gempylidae) in New Zealand waters. *International Journal of Climatology* 18: 1655–1667; Beentjes M.P. & Renwick J.A. (2001). The relationship between red cod, *Pseudophycis bachus*, recruitment and environmental variables in New Zealand. *Environmental Biology of Fishes* 61: 315–328.; Dunn M., Hurst R., Renwick J., Francis C., Devine J., and McKenzie A. (2009). Fish abundance and climate trends in New Zealand. *New Zealand Aquatic Environment and Biodiverstiy*. Report No. 31. NIWA, Wellington.

24 Two-thirds of our population live in areas prone to flooding (Royal Society of NZ, 2016), while 75 per cent of New Zealanders live within 10 km of the coast (Statistics New Zealand, 2006, *Are New Zealanders Living closer to the coast*).

reduction in the land values. These risks will increase with ongoing development and population growth, if property and asset exposure increases. In addition, where the sea is connected to water tables and the land is reclaimed, surface ponding will increase the risk of ground settlement and liquefaction (PCE, 2015, page 40).

Figure 3.3: Houses and roads in urban areas that are less than 50 cm above mean high water spring (PCE, 2016)

Urban area	Houses	Roads (km)
Dunedin	2,683	35
Napier	1,321	37
Christchurch	901	40
Whakatane	276	9
Auckland	108	9
Wellington/Hutt	103	2
Tauranga	77	3
Nelson	64	6
Motueka	45	4



As noted in the PCE's report, this inventory (the table in Figure 3.3) is "a necessary early step in assessing what is at risk as the sea rises". The actual impact on the built environment may be larger than this. The impact of disruption to New Zealand society and businesses as a result of climate change is also not captured by this illustrative table.

3.2.2 Critical infrastructure

Critical infrastructure provides a backbone to well-functioning societies and economies, whether it is reliable electricity, clean drinking water, or transport networks. Central and local government own over $200 billion of infrastructure assets.[25] Significant elements of our critical infrastructure, including lifelines utilities,[26] are at risk of being damaged, disrupted or rendered inoperable by climate change impacts. Key impacts are identified in Table 3.1.

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[25] Treasury, 2015, *Thirty Year New Zealand Infrastructure Plan 2015* http://www.infrastructure.govt.nz/plan/2015/

[26] Organisations that provide essential infrastructure to the community for example, roads, water supply.

Table 3.1: Description of vulnerability of particular infrastructure to impacts of climate change

Infrastructure	Potential impacts
Transport – roads, rail, ports and airports	Top impacts identified by NZ Transport Agency (NZTA) (2009) are: • Sea-level rise/storm surge – increasing threat nationally to ports, airports[27] and low-lying coastal networks, with a higher risk on the western seaboard • Increased magnitude and frequency of flooding and rainfall-induced landslips, caused by heavier and/or more frequent extreme rainfall • Increased heat buckling on the rail network due to higher temperatures (highest risk predicted in the northern part of the North Island) • Stronger winds – higher risk to roads and ports in eastern coastal areas of the North and South Islands, and the Canterbury Plains.
Electricity transmission and generation	Increased intensity of storm events, snow and high wind risks damage to substations and transmission lines (CCII RA4 Synthesis Report). Over 80% of our electricity comes from climate-dependent wind and hydro generation which makes our electricity system vulnerable to a variable climate (eg, higher temperatures, and greater variability of rainfall and wind). There may be seasonal changes in both electricity demand and supply, with more demand for air conditioning in summer, but less demand for heating in winter. There is expected to be greater potential for hydro generation in winter due to increased proportion of precipitation falling as rain rather than snow (IPCC, 2014).
Water (including stormwater, flood protection and wastewater)	Sea-level rise will cause seawater to run up stormwater pipes, significantly affecting drainage capability. This could cause flooding well inland in low-lying areas. Land drainage, stormwater systems and flood protection may not cope with more intense and frequent heavy rain events. There may be overloading of sewer networks (through increased inflow/infiltration) leading to increases in wastewater overflows. There is also increased potential for inundation of pump stations located in low lying areas (Parliamentary Commissioner for the Environment (PCE), 2015).
Telecommunications	Increased intensity of storms (including flooding) and high winds risks damage to above ground structures increasing maintenance and repair costs (CCII RA4 Synthesis Report).

It is noted that an impact on any one of these services is expected to impact on another, due to the interconnected nature of our infrastructure networks. These impacts could be significant, for example, the road and three waters infrastructures comprise more than $100 billion of community assets.[28] With the exception of the 2009 NZTA report, no nation-wide assessment has been done on the risk of climate change to these assets.[29] This is a critical information gap.

3.3 Economic impacts

Agriculture, horticulture, fisheries, aquaculture, forestry and tourism sectors are all significant contributors to New Zealand's economy, and all are dependent on natural resources and the ability to function within the current climate range. They are therefore exposed to the direct impacts of climate change that are outside their ability to adapt, and to those that compound and

[27] Many of our airports are located in low lying areas, such as Wellington, Napier, Nelson and Dunedin.

[28] Office of the Auditor-General, 2014.

[29] Based on the literature reviewed as well as conversations with Treasury's National Infrastructure Unit.

cascade through the economy from other sectors. Climate change has therefore the potential to have negative impacts on New Zealand's economy as a whole.

New Zealand society will also be affected by indirect impacts of climate change, which are those that require adaptation in one place as a result of climate change somewhere else. New Zealand is an open economy which has important trading links with Europe, Australia, the US and China. Climate change-related impacts on our trading partners and on the rest of the world will affect New Zealand's ability to sell goods overseas, as well as have an effect on migration and social and cultural ties (RSNZ, 2016). For example, the primary sector may experience impacts as a result of changing demand internationally for our products, while our tourism industry may be affected by changing tourist behaviour (RSNZ, 2016). Examples of how we expect sectors of New Zealand's economy to be affected by climate change are discussed below.

3.3.1 Primary industries

The primary industries play a fundamental role in New Zealand's food security and economy, directly accounting for 6 per cent of GDP and contributing to just over half of New Zealand's export earnings.[30] The primary industries are particularly exposed to the impacts of climate change. For example, they are strongly linked to freshwater availability, and climate change is expected to increase competition for freshwater resources (RSNZ, 2016). While the severity of impacts will vary by sector and region, the risks and costs from extreme weather and wildfires are expected to increase across all land based sectors and supply chains.[31] All primary sectors will be affected by impacts which interfere with the ability to get primary products from the farm to processing facilities and then to markets or ports. Climate change impacts may affect transport (for example due to storms and slips closing routes) and also the operation of processing facilities (for example interruption to the supply of energy or water required for processing). Table 3.2 outlines key impacts for each sector.

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[30] Treasury, 2016, NZ Economic and Financial Overview.

[31] SLMACC, 2012, Impacts of climate change on land-based sectors and adaptation options – stakeholder report.

Table 3.2: Key impacts for each sector[32]

Sector	Impact
Agriculture and horticulture	• Rainfall changes, and rising humidity and temperatures are expected to shift agricultural and horticultural production zones and timing of some activities, and to reduce crop quality and yield • Some areas are expected to benefit from climate change and increases in atmospheric carbon dioxide in the short term, if farm management practices change to make the most of increased pasture production • Some regions face increased drought and flooding risk • Higher temperatures will increase the range and incidence of many pests and diseases, with a risk of new invasive species establishing • Erosion could become an increasing problem on farms • There are some short-term opportunities, particularly where impacts may be mitigated by commodity price rises[33] • Potential for increased demand for irrigation and fertiliser, leading to other downstream issues (PMCSA, 2017) • Increased temperature will lead to early flowering, increasing the chance of frost damage in spring • Increased flooding and ponding increases the risks of surface water contaminating produce
Forestry	• Foresters could benefit from increased *Pinus radiata* growth in cooler regions due to enhanced carbon dioxide levels; where other elements, water and nutrients are less limiting • Significantly increased fire risk in some areas • The impact of pests on forest health, habitat loss and unstable land have been identified as primary risks for foresters[34] • Forestry sector is more exposed than some sectors to climate risks due to the long production cycles[35]
Fisheries and aquaculture	• Primary production in open ocean surface water is projected to decline by an average of six per cent from present levels by 2100 under a high global emissions scenario, as a result of ocean warming and acidification[36] • Growers and harvesters of shellfish species, such as pāua, mussels and oysters, will be particularly vulnerable to changes in water temperature, acidification and land-based runoff[37] • Finfish aquaculture will have to adapt to rising temperatures and reduced oxygen levels
Mining	• Production affected by access to critical climate-sensitive inputs such as energy and water • Disruption to supply chain (eg, delivery of fuels and electricity)

32 Information primarily sourced from:
- NZ Climate Change Centre, 2014, IPCC Fifth Assessment Report, NZ findings
- Sustainable Land Management and Climate Change (SLMACC), 2012, *Impacts of Climate Change on Land-based Sectors and Adaptation Options*
- CCII RA4 Synthesis Report (http://ccii.org.nz/wp-content/uploads/2017/01/RA4-Synthesis-report.pdf).

33 NZ Climate Change Centre, IPCC Fifth Assessment Report, NZ findings.

34 CCII Synthesis Report R4.

35 Ibid.

36 CCII Synthesis Report: Marine Case Study.

37 Oregon and Washington State lost 80 per cent of their shellfish hatcheries' production in 2008 due to the impacts of ocean acidification caused by the upwelling of deepwaters (DoC 2017).

Biosecurity

Climate change is expected to impact New Zealand's biosecurity. Warmer average temperatures could enable new pests and diseases to establish themselves in New Zealand, should they make landfall. An increase in potential biosecurity threats has implications for New Zealand's primary industries, as well as for our native biodiversity and for human health. The potential establishment of subtropical pests is one of the biggest concerns.[38] Ministry for Primary Industries (MPI) suggest in their 2015 report that north-east Asia is expected to dominate pest import pathways in the future, but there are also increasing risks associated with India, South America and other emerging economies. Changes in climate, shipping routes, the commodities traded and international pest distributions will shape New Zealand's future biosecurity risks (MPI, 2015). Particular threats are to the forestry industry due to its long lifecycle. Changes in the timing of annual and seasonal events as a result of climate change (such as beech masting), will also have significant impacts on pest management.

The CCII research programme[39] identified biosecurity management as an area where more research is needed to test its sensitivity to climate change.

3.3.2 Tourism

Tourism, a major growth industry in New Zealand, is already one of the largest single sources of foreign-exchange revenue. The sensitivity of tourism to climate change impacts depends on a range of factors including:[40]

- how tourists respond to certain climatic conditions
- how important weather and weather-related natural hazards are to tourism businesses in terms of carrying out specific activities
- how infrastructure or wider natural resources relevant to the operation of tourism businesses might be affected by climatic events.

Much of the research on the impacts of climate change on tourist behaviour relates to the effect of climate change mitigation policies, which is out of scope for this report. Less information is available on how the impacts of climate change in a particular region will affect tourism behaviour in and of themselves. The ski industry is one of the most climate dependent tourism subsectors, and as such more information is available regarding the impacts of climate change on this subsector than on others. While it is hard to predict future tourist behaviour in the short term, climate change may bring benefits for ski tourism due to less snow in Australia. However, in the long term, higher temperatures and fewer snow days will negatively impact the industry, particularly those in lower elevation sites. Tourism at Fox and Franz Josef Glaciers will also be at

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38 MPI, 2015, *Effects of climate change on current and potential biosecurity pests and diseases in New Zealand.*

39 Lawrence, J., Blackett, P., Cradock-Henry, N., Flood, S., Greenaway, A. and Dunningham, A. (2016) *Synthesis Report RA4: Enhancing capacity and increasing coordination to support decision making. Climate Change Impacts and Implications (CCII) for New Zealand to 2100*. MBIE contract C01X1225. 74 pp.

40 A national-level screening exercise to assess tourism's vulnerability to climate change (http://www.lincoln.ac.nz/PageFiles/6750/NationalScreeningOverview.pdf).

risk as glaciers further recede. This will impact regional economies, and individuals and communities with livelihoods dependent on the industry.[41]

3.3.3 Financial and insurance services

More extreme weather events caused by climate change will raise the number and value of claims insurers pay, which will inevitably be reflected in the premiums insurers charge and their willingness to provide cover.[42] Insurance covers risks which are uncertain, and as such insurers are expected to retreat from certain locations (eg, at the coast) once the risks are sufficiently probable.[43] Households may find it difficult or more expensive to access insurance cover in the face of increased flood risk, or fruit growers may find it more expensive to insure against weather-related damage.

For banks, it is expected that this will result in the offer of shorter-term mortgages which may become less affordable. Lending to business in sectors or locations especially exposed or vulnerable will reduce. In addition, climate change could give rise to home loan defaults due to the loss of insurance cover.[44] Unavailability or unaffordability of insurance cover will reshape the distribution of vulnerable groups.[45]

Fund managers will likely factor into their investment decision the impacts of climate change on the businesses they invest in and their adaptive capacity.

Apart from the recent report by Motu and Deep South (2017) on insurance, housing and climate adaptation, there has been little detailed research on this issue in New Zealand, although there is a growing body of literature and attention overseas, for example, reinsurer Munich Re and Lloyd's London.

3.3.4 Other business

Other businesses such as production, manufacturing, and retail are expected to be indirectly affected by climate change in one way or another. This could be by: changing consumer behaviour; disruption to transport networks and supply chains of goods and services during extreme weather events; or damage to infrastructure and commercial assets by extreme weather events or sea-level rise. Climate change also has the potential to have negative impacts on New Zealand's economy as a whole, which will have flow-on effects for individual businesses.

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41 PMCSA, *New Zealand's Changing Climate and Oceans.*

42 2013 and 2014 were among the most expensive years for weather-related events.

43 *Insurance, housing and climate adaptation* (Motu and Deep South, 2017).

44 Ibid.

45 2013 and 2014 were among the most expensive years for weather-related events.

3.3.5 The cost of climate change impacts

While the potential costs of climate change impacts for New Zealand are not known, we do know that our exposure to the impacts of climate change is high, particularly in certain areas (eg, at the coast, within the built environment and to our major economic sectors), and as such the costs will be significant. For example, the value of assets that will be affected by sea-level rise is estimated to be in the billions of dollars, and the costs of weather events to the land transport network have increased in the last 10 years from about $20 million per annum to over $90 million per annum.[46] The associated costs of three extreme events in New Zealand to which climate change is assessed to have made a contribution are:[47]

- **2011 flooding in Golden Bay**: estimated cost $16.8 million
- **2012–2013 drought which affected the entire North Island and the west coast of the South Island: It was one of the most severe experienced in these areas in at least 40 years. The economic impact of the drought is estimated to be a minimum of $1.5 billion (Treasury)**
- **2014 flooding in Northland**: estimated cost $15.1 million.

The increased frequency and intensity of large extreme events has the potential to increase the scale of costs significantly, especially if the coping capacity between events is challenged. The much greater frequency of smaller events could represent an even greater cumulative cost.[48]

Overall, the costs to New Zealand of climate change impacts and adapting to them are expected to be higher than the costs of reducing greenhouse gas emissions. While adapting to climate change cannot be avoided, adaptation is not a substitute for reducing emissions.

3.4 Social and cultural impacts

Our exposure to climate change will impact on New Zealand society and culture. Climate change could lead to large changes to our society, including potential social disruption and conflict over changing patterns in the value of land in coastal areas[49] and/or increasing competition for resources, for example, access to clean water and kai moana. It may also exacerbate equity issues for at risk groups in society and for future generations.[50]

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46 MoT, Sector Report, *Managing Climate Related Risks for Land Transport Infrastructure.*

47 Figures obtained from Insurance Council of New Zealand (http://www.icnz.org.nz/statistics-data/cost-of-disaster-events-in-new-zealand/).

48 https://eos.org/scientific-press/small-storms-over-time-can-cost-more-than-extreme-events

49 Bengtsson et al., *Climate change impacts in New Zealand: a cross-disciplinary assessment of the need to adapt buildings, with focus on housing*, 2007, http://www.cmnzl.co.nz/assets/sm/2245/61/008-BENGTSSONJonas.pdf

50 New Zealand College of Public Health Medicine, 2013, *Climate Change and Health in New Zealand*, http://www.nzcphm.org.nz/media/74098/1._nzcphm_climate_change_policy__final_comms_version2_.pdf

3.4.1 Public health

Climate change is increasingly being recognised as a serious emerging risk to public health globally and in New Zealand. Some of the potential impacts will be direct, such as injury and illness from extreme weather events or increased heat-related deaths (although winter-related deaths are expected to decline).

There are also indirect risks including increased incidences of existing and new diseases.[51] Climate change brings changes to disease vectors worldwide. A warmer and wetter New Zealand means that we will experience diseases not currently present in New Zealand and potentially more frequent pandemics. These impacts will lead to intensified pressures on our health system. Other indirect risks include increasing stress and mental health issues, for example, as a consequence of extreme weather events, sea-level rise or loss of livelihoods.[52]

3.4.2 Risks to emergency services and lifelines operational capability and capacity

There will be greater resourcing pressure on our emergency services and lifelines to manage public safety with increased frequency and severity of floods, wildfires, landslips and extreme storms.[53] New Zealand is also expected to increase support to low-lying Pacific Island communities which are highly vulnerable to the impacts of climate change. Such support includes providing post-disaster recovery assistance and risk reduction for enhancing resilience.[54]

3.4.4 Cultural heritage sites

Cultural heritage will be affected by climate change, particularly through ongoing loss of coastal archaeological sites to sea erosion and inundation.[55] For example, there are numerous Māori cultural heritage and food gathering sites in coastal low-lying areas which are deeply connected with Māori identity, and these sites are more exposed to the impacts of climate change as a result of their location.

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51 For example: potential increase in food and water borne disease (such as giardiasis and salmonellosis) as a result of changing rainfall, drought and temperature patterns; potential increase in respiratory illnesses as a result of changes in the pollen season; increases in mosquito vectors establishing in warmer regions (eg, malaria).

52 New Zealand College of Public Health Medicine, 2013, *Climate Change and Health in New Zealand*, http://www.nzcphm.org.nz/media/74098/1._nzcphm_climate_change_policy__final_comms_version2_.pdf

53 NZ Defence Force, 2010, *Impact paper: Climate change and the New Zealand Defence Force*.

54 RSNZ, 2016; IPCC 2014.

55 Bickler S, Clough R & Macready S, 2013, The impact of climate change on the archaeology of New Zealand's coastline, http://www.doc.govt.nz/documents/science-and-technical/sfc322high_res.pdf

3.4.5 Vulnerable groups

The impacts of climate change will not be evenly distributed around New Zealand. Vulnerability to climate change depends on level of exposure to the change and ability to cope and adapt to the change. For example, those who live on floodplains may be more exposed to climate-related changes we can expect in the future. The most vulnerable will be those who do not have the resources to adapt. Based on this, communities we consider could be more vulnerable to the expected impacts of climate change include:

- **Māori** – their significant reliance on the environment as a cultural, social and economic resource makes Māori vulnerable to the impacts, some of which they are already experiencing,[56] as their livelihoods are exposed to the impacts of climate change on the natural environment. For example, the Māori economy relies heavily on primary industries. Different Māori communities face different climate change risks, as some communities will be more vulnerable to the impacts of climate change than others. As summarised by the Climate Change Iwi Leaders Group:

  "The climate is changing where Iwi in the South talk of the Titi (mutton birds) having today a 4 in 7 bad year where once it was 1 in 7 and they call for a much more holistic (kaitiakitanga) solution to climate change. Iwi in the East talk about their roadways being washed away and serious soil erosion. While an Iwi in the North talks about all 14 of their marae facing inundation from rising sea levels and flooding. Iwi in the West talk too about flooding while those Iwi in the Central North Island call on government to help with new afforestation. And meanwhile the science tells us that these issues are only going to get worse…… The legacy of our generations is at stake."[57]

- **communitites in low lying areas** – people living close to the coast and on floodplains are more exposed to flooding and other coastal hazards, the frequency and intensity of which are expected to increase as a result of climate change. Not all of these communities are equally vulnerable as their ability to adapt will differ

- **rural communities dependent on non-reticulated water resources (eg, rain water tanks)** – increased pressure on freshwater resources is an expected impact of climate change (RSNZ, 2016), and the effects of changing hydrological regimes on drinking water availability are expected to seriously affect these places and populations.[58]

There is very little research on which groups and locations in New Zealand are at the greatest risk from climate change impacts. This is an information gap.

56 For example, erosion at the coast revealed human bones from a sacred Māori burial site in the Waimea inlet in January of this year.

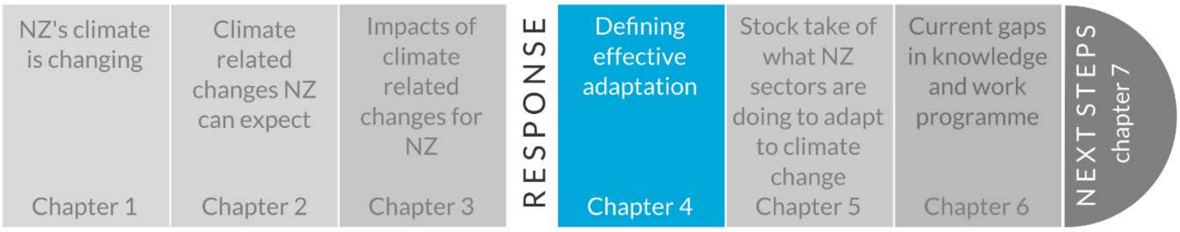
57 CCILG submission on the NZ ETS Review, 2016.

58 RSNZ 2016; MoH 2016.

3.4.6 Intergenerational equity

A significant question around climate change impacts is where the costs will fall and who will bear them – current or future generations? How we address and provide for intergenerational equity in our systems and decision-making around climate change impacts is a gap in our current understanding. What we do know is that costs of adapting will increase over this century. Not addressing these would also place a financial burden on future generations. A case study on youth perspectives in this regard can be found in Section 5.9.

4 Defining effective adaptation



We have defined effective adaptation to mean that New Zealand's current and future communities are able to reduce the risks from climate change impacts over the medium and long term by:

- reducing the exposure and vulnerability of our natural, built, economic, social and cultural systems
- maintaining or improving the capacity of our natural, built, economic and social and cultural systems to adapt.

To review what New Zealand is currently doing to adapt we have created a framework of what we consider to be key characteristics and attributes to achieve effective adaptation (Table 4.1). The framework is based on the findings of the extensive global literature on adaptation reviewed by the IPCC (2014) and the collective experience of adaptation and risk management experts on the Group. The attributes that describe these characteristics reflect the best information available to the Group and our expert judgement.

We consider being informed, organised and acting in a dynamic way are the key characteristics for effective adaptation:

Informed: Climate change will have impacts on all sectors of New Zealand society, and the social, cultural, economic and environmental cost of these impacts is potentially large. Effective adaptation involves all sectors understanding the characteristics of the impacts and what it means for them, and considering these impacts in their decision-making and planning so that they can reduce the risks and take advantage of any opportunities.

Organised: The cost of inaction or of unplanned, reactive adaptation measures is expected to be great. Some of the decisions we are making now about investments will determine the magnitude and extent of the impacts we experience in the future. For example, infrastructure assets are long-lived, and it is therefore important to consider the future impacts of climate change on these assets when investing in them. The location of green-fields urban/housing and rural developments also has long-term implications hence it is prudent to take climate change impacts into account in land use planning by not expanding into areas expected to be at risk from increased flooding, coastal erosion and inundation, and drought.

Dynamic Action: The amount of adaptation required today is built on a legacy of past infrastructure and planning decisions. It is important we remain flexible so we do not limit our ability to adapt in the future nor increase the costs of responding to adverse events.

Table 4.1: Characteristics and attributes that could contribute to effective adaptation

CHARACTERISTIC	ATTRIBUTES
INFORMED	**We understand what's happening:** the climate-related changes that New Zealand can expect in the medium and long term as a result of climate change are widely understood
	We understand the impacts of the climate-related changes and what this means for us: the consequences, connections, thresholds, vulnerabilities, risks and opportunities in the natural, built, economic, social and cultural environments in the medium and long term are widely understood
ORGANISED	**We know what's expected of us**: our roles and responsibilities are appropriate and widely understood
	We have common goals: a common set of adaptation outcomes, goals and priorities exist
	We have a planned approach: adaptation is factored into strategies, plans and decision-making allowing us to define priorities and set timeframes
	We have the tools we need: enabling frameworks, resources and coordinating mechanisms are in place to drive action, and are sufficient and effective
DYNAMIC ACTION	**We are taking anticipatory action:** proactive and purposeful in taking practical steps to adapt
	We are being flexible: goals, strategies and plans adjust though a combination of monitoring and situational awareness to deal with uncertainty and the changing risks, issues, opportunities and circumstances that emerge
	We are reducing risks by adapting: the environmental, economic and social and cultural consequences of climate change are being managed

We engaged with representatives of various sectors of society to understand how well climate change adaptation is integrated into their thinking and planning (see Appendix 2 for the division of sectors). This is in addition to an extensive review of published literature on climate change adaptation in New Zealand.

We also looked at other countries' approaches to adaptation. Regardless of the type of approach taken, there are a number of common themes. These are highlighted in the *Case Study 1: Common themes among other Countries approaches to adaptation*. An overview of adaptation initiatives in other countries is included in Appendix 6.

We then assessed the information they provided against the key characteristics of effective adaptation (identified in Table 4.1) and rated it as:

Maintain	More work required	Significant work required	Not present
There is evidence that all descriptors of the attribute are in place	There is evidence that most descriptors of the attribute are in place	There is evidence that some descriptors of the attribute are in place	There is no evidence that any descriptor of the attribute is in place

The following sections outline the conclusions of the assessment.

When reading our assessment it is important to recognise that:

- the aim of this assessment is to determine where New Zealand is now as it moves towards effective adaptation. By understanding where New Zealand is now we will be able to identify (in our next report) options for how the country can adapt to climate change
- the assessment represents a snapshot in time. Through the work of the Group it is clear that there is an emerging but increasing trend towards the consideration of climate change adaptation
- the assessment is the qualitative expert judgment of the Group, and is based on the information referenced within this report and provided by sectors
- we have experienced extreme contrasts within some sectors where a few parties are meeting the attribute and others have made little progress. In making our assessment we have made a judgment that reflects the sector as a whole.

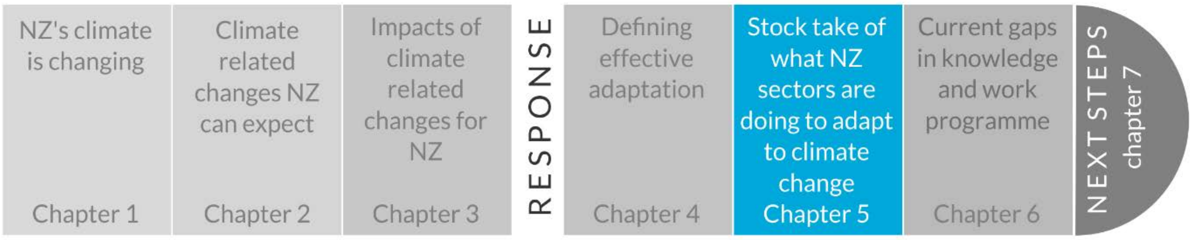
The framework considers the key attributes that could contribute towards effective adaptation for New Zealand across all sectors of society. All sectors have complementary but different roles in adapting to climate change. Some sectors will therefore have a greater role to play than others in some attributes. The greater the role in the attribute, the more advanced we would expect the sector to be. For example, central government is primarily responsible for policy frameworks. Amongst other roles, it is responsible for providing robust information on how New Zealand's environment may change, and distributing and making this accessible to other sectors.

For effective adaptation we would expect to see evidence of the attributes being addressed in a logical sequence. For example, informed attributes being addressed before a response is organised and action is widespread across all sectors. We would also expect the public sector to provide direction (information) for an organised approach, and coordinated and ongoing (dynamic) action.

CASE STUDY 1: COMMON THEMES AMONG OTHER COUNTRIES' APPROACHES TO ADAPTATION

- Having a strong scientific evidence base, providing robust information and raising awareness
- The importance of coordination, collaboration, cooperation and partnerships between central government and other levels of government, and across sectors and society. Shared responsibilities are important while acknowledging the importance of national leadership
- Identification of priority sectors, including assisting and prioritising vulnerable people and regions
- The need to anticipate the risk, be proactive and comprehensive
- Factoring and integrating climate risk into decision-making
- Taking a long-term view and building resilience
- The importance of monitoring and evaluating progress towards building resilience with feedback into review of a strategy or plan
- Looking for and taking advantage of opportunities for adaptation.

5 Stocktake of what New Zealand sectors are doing to adapt to climate change



In accordance with our Terms of Reference, we have undertaken a stocktake of existing work on adaptation by both central and local government. In addition to this, we have also drawn on our expertise within the Group to consider what other sectors of society are doing on adaptation. We chose to extend the scope of the stocktake as we recognise that New Zealand will not successfully adapt through central and local government alone. We also acknowledge that there are some sectors, for example infrastructure and transport that span both the public and private sector. Where this is the case these have been considered as a standalone sector.

5.1 Central government

Key findings

- Central government has played a key role in funding research which provides the basis for building New Zealanders' understanding of climate-related changes and the impacts this will have on different sectors of society. Central government's agencies understanding of how climate change will impact on their responsibilities and operations are less clear.
- There is some misalignment in how climate change adaptation and resilience objectives are incorporated into legislation and policy. As a result, central government agencies response to adaptation is not currently coordinated and there is little alignment of adaptation goals or agreement of priorities.
- Actions that central government agencies have taken to adapt have generally been reactive and have been part of a natural hazard management response after climate-related impacts have been felt.

5.1.1 Role in climate change adaptation

Central and local government, on behalf of communities, is responsible for managing risks to public goods and assets (including the environment), delivering government services, and creating the institutional, market and regulatory environment that promotes resilience and action.[59] Central government's main responsibilities for climate change adaptation are:

- governance in setting the statutory and policy frameworks
- funding research and ensuring it is relevant to and shared with end users
- providing information and guidance to support decision-making
- preparation for, and response to, major natural hazard events
- owning, managing and investing in major infrastructure (eg, schools, hospitals, recreational infrastructure on public conservation land)[60]
- agreeing funding decisions across policy domains
- monitoring policy effectiveness and advising on future needs.

5.1.2 Engagement undertaken

To understand what central government is currently doing on climate change adaptation, a survey was sent to 35 government agencies (see Appendix 3). We received responses from 25 of those agencies.

5.1.3 Work towards effective adaptation

Informed

Central government understand the climate-related changes New Zealand can expect in the medium and long term	**MAINTAIN**
Central government understand the impacts of the climate-related changes and what this means for them	**MORE WORK REQUIRED**

In 2015/16 the government invested a total of $50.3M in climate change-related research including $14M in Crown Research Institutes and $3.5M in the National Science Challenge[61]. Recent research programmes on adaptation include:

59 Australian Resilience Strategy, 2015.

60 Infrastructure and transport and discussed in detail in section 5.3. as these assets are owned by both the private and public (central and local government) sector.

61 New Zealand's Seventh National Communication under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, 2017 (in press).

- **Deep South National Science Challenge (2014–2019)** – the current provider of most adaptation research in New Zealand. Its mission is to transform the way New Zealanders adapt, manage risk and thrive in a changing climate
- **Resilience Science Challenge (2014–2019)** – also has projects relevant to climate change adaptation at the coast and on adaptive governance. Its mission is to inform how New Zealand will build a transformative pathway toward natural hazard resilience
- **Sustainable Land Management and Climate Change (SLMACC) programme** – aims to help the agriculture and forestry sectors address the challenges arising from climate change
- **Climate Change Impacts and Implications (CCII) programme (2012–2016)** – focused on the projected climate conditions and variability, their impacts and implications for New Zealand and their significance for and how to enhance decision-making about them.

Other research has considered climate change impacts on the tourism industry, urban infrastructure, the coastal environment and community vulnerability. In addition, we understand that Land Information New Zealand is currently working on improving its elevation data to enable better flood modelling and sea level recording. A full list of research programmes and information on adaptation is included in Appendix 4. The research undertaken is essential to help sectors (end users) make informed decisions about how to respond to a changing climate, including how to organise themselves and how to take dynamic action.

Engagement with central government has shown that this research has resulted in a relatively clear understanding of the climate-related changes New Zealand can expect but not the full implications of these for New Zealand. This understanding is similarly clear across the majority others sectors (see Sections 5.2 to 5.9).

The impact of climate change on central government agencies roles and operations is less well understood. For example, while the Department of Conservation understands that climate change will have implications on all aspects of their work (eg, pest management, maintenance of recreational infrastructure), they noted that there is limited information on where the greatest risks are. Key information gaps identified by agencies include limited information on vulnerable groups and areas in New Zealand, and limited solution-orientated research, although the latter is now being heavily invested in through the Science Challenges (which builds on past research).

Organised

Central government plays an important role in negotiating and being party to key international agreements which recognise the importance of, and need for, climate change adaptation. Central government also sets the domestic regulatory framework within which adaptation is currently considered. Table 5.1 outlines the key agreements and statutes relevant to adaptation.

Table 5.1: Key agreements and statutes relevant to adaptation

Statute/Agreement	Requirements
International	
The Paris Agreement	To plan for and take action on climate change adaptation
The Sendai Framework for Disaster Risk Reduction	Includes the consideration of climate change effects. Effective from 2015–2030.
Domestic	
The Resource Management Act 1991 (RMA)	To control the use of land in order to manage the risks of natural hazards and have particular regard to the effects of climate change. This includes the consideration of cumulative effects which arise over time or in-combination with other effects regardless of scale, intensity, duration, or frequency
The New Zealand Coastal Policy Statement 2010 (NZCPS)	Includes policies which must be given effect to for managing coastal hazards and climate change under the RMA, including sea-level rise, storm surge and wave height under storm conditions over at least a 100 year timeframe
The National Policy Statement for Freshwater Management 2011	Regional councils must have regard to the reasonably foreseeable impacts of climate change when setting freshwater quality limits and environmental flows under the RMA
The Local Government Act 2002 (LGA)	Outlines the administrative and management responsibilities of regional and district councils for matters such as land management, utility services (three waters) and the provision of services. It requires communities to prepare long-term plans that set outcomes and longer term financial planning. These plans include infrastructure strategies over at least a 30-year period
The Civil Defence Emergency Management Act 2002 (CDEMA)	A risk management approach must be taken when dealing with hazards. It provides a framework for local government to plan and coordinate hazard management. It requires lifeline utilities to be resilient
The Building Act 2004	A consent authority must refuse to grant building consent if the land on which the building work is being carried out is subject to or expected to be subject to natural hazards, unless adequate provision has or will be made to either protect the land, building work, or other property from the natural hazards or natural hazards or restore any damage to that land or other property as a result of the building work. It requires consideration of a 50-year design life, however it is silent on providing for climate change
The Soil Conservation and Rivers Control Act 1941	The objectives of the Act include the prevention and mitigation of soil erosion, and the prevention of damage by floods

There are many other statutes that are indirectly relevant to adaptation, including those that cover the management of biodiversity and public health. While we do not expect all these statutes to explicitly cover adaptation, they do need to be aligned where climate change impacts are relevant. We are currently seeing some misalignment in the regulatory framework. For example, there are inconsistencies in the timeframe for considering climate change effects, with the Building Act requiring a 50 year design life and no express consideration of climate change effects; the NZCPS using a timeframe of at least 100 years; and the LGA requiring 30 year infrastructure plans.

Central government know what is expected of them	SIGNIFICANT WORK REQUIRED

There are many different roles central government agencies take in terms of acting on climate change adaptation across different sectors. Critical agencies include:

- **Treasury and Earthquake Commission (EQC)** – have a role in taking on limited liability for physical damages from natural hazard events
- **Department of the Prime Minister and Cabinet (DPMC)** – responsible for national security including significant risk to New Zealanders, managing large scale civil defence emergencies, and ensuring coordination in disaster risk reduction across New Zealand
- **Ministry of Business, Innovation and Employment (MBIE)** – influences major infrastructure procurement and investment; and administers the Science Challenges
- **Department of Conservation (DOC)** – the lead agency for managing threats (such as climate change) to public conservation land and marine sanctuaries, as well as protecting New Zealand's native species and ecosystems
- **Ministry of Primary Industries (MPI)** – supports the primary industries sector to manage risks to help improve productivity, and coordinates New Zealand's biosecurity response
- **Ministry for the Environment (MfE)** – advises on environment risks and sets the framework for local government planning for the environment, including water management
- **Ministry of Health (MoH)** – advises on health risks and sets the framework for managing these
- **Department of Internal Affairs (DIA)** – advises on requirements for local government infrastructure strategies and asset management planning (through the Local Government Act).

All of these critical agencies are considering climate change impacts to varying degrees. There is a lack of co-ordination between agencies and clear lines of responsibility.

Central government has common goals	SIGNIFICANT WORK REQUIRED

Nearly all agencies we surveyed have a goal of building long-term 'resilience' for New Zealand. Each agency has their own view on what resilience means for them, and only some explicitly consider climate change adaptation as part of this. Currently, central government does not have a common set of outcomes, goals and priorities for climate change adaptation. This means that messages on climate change from central government are mixed or absent, appear inconsistent and create uncertainty amongst those with specific responsibilities at central and local government.

Central government has a planned approach	SIGNIFICANT WORK REQUIRED

At a national level, there are a number of strategy documents targeted at certain sectors (or parts of sectors) that highlight the importance of considering climate change in decision-making and planning. These include:

- National Civil Defence Emergency Management Plan Order (2015)
- Thirty Year New Zealand Infrastructure Plan (2015)
- Biosecurity 2025 Direction Statement (2016).

These documents do not however include a clear articulation of the priorities for action, timeframes for delivery, and how this should be monitored to ensure implementation is and remains effective.

One of the consequences of not having a planned approach is that climate change adaptation is not formally factored into decision-making. This creates a risk that new government initiatives are not able to deliver the benefits planned because they could increase New Zealand's exposure to climate risk. For example:

- **the drive to accelerate urban development and housing** – new legislation is proposed to enable major urban development projects to be built more quickly but may not adequately consider future climate change impacts on the areas selected for development
- **climate change mitigation policies** – the New Zealand Emissions Trading Scheme currently promotes planting forests and without considering potential future climate risks this activity has on the potential to increase weed pressure and water loss, particularly in dry eastern catchments
- **irrigation investment** – while investment in irrigation may help strengthen the ability of communities to cope during dry conditions, there is a risk that if adaptation is not adequately factored into allocation and planning decisions, it could increase the intensity of land use and increased vulnerability to the effects of climate change.

Central government has the tools they need	SIGNIFICANT WORK REQUIRED

Agencies we have spoken to have identified a number of gaps in the development or application of tools they have to act on adaptation, including:

- difficulty for agencies to balance immediate and long-term priorities and emphasised that short-term priorities tend to trump long-term planning
- lack of leadership across agency work programmes/responses
- capacity – the majority of agencies suggested that resourcing constraints were a significant barrier to proactive work on adaptation
- capability – including the lack of specialised skills in the interface between climate and impact modelling, and between vulnerability and risk assessment.

Central government plays an important role in providing tools for others to use to help implement adaptation measures across its relevant responsibilities:

Providing information and guidance to support decision-making

New Zealand's *Framework for Adapting to Climate Change* (2014) is based around four key pillars including information; roles and responsibilities; research; and action. This framework is very high level and in its current form does not provide enough detail to facilitate action. Some of this detail is provided in guidance to local government, including:

- Climate Change Effects and Impacts Assessment (2008)
- Coastal Hazards and Climate Change (2017)
- Tools for Estimating the Effects of Climate Change on Flood Flow (2010)
- The New Zealand Coastal Policy Statement (NZCPS) Guidance note (2010).

An *Adaptation Framework for the Conservation of Terrestrial Biodiversity in New Zealand* (2014) has also been developed by the Department of Conservation. The resourcing for its implementation is currently being considered. Appendix 5 provides a list of central government frameworks and guidance documents on adaptation and their web links.

Governance in setting statutory and policy frameworks

Central government also has a number of policy levers it can use to provide greater direction to motivate local government and private sector decisions-making on climate-related risks which are currently under-utilised. Examples include, National Policy Statements and Environmental Standards under the RMA, and the Government Policy Statement on Land Transport.

Preparation for, and response to, major natural hazard events

Recent flooding, earthquakes and tsunami threats have focused attention on improving New Zealand's regulatory frameworks to reduce disaster impacts and losses. This includes the development of the National Disaster Resilience Strategy (an update of the Civil Defence Emergency Management Strategy) which intends to explicitly cover adaptation. Complementing this is development of national direction to support councils with risk assessment and land use planning in response to changes to the RMA on natural hazards. These will all need to be aligned so there is a cohesive package to guide risk and vulnerability assessments, and ensure there are flexible management approaches for dealing with changing climate-related risk profiles over long timeframes.

It is important to keep in mind that natural hazard management does not address the full range of climate change impacts and opportunities. For example, while it may support New Zealand to prepare for increased frequency and magnitude of extreme storms, it does not address the prolonged effects of sea-level rise and changes in temperature, nor the impacts on human health and pest management.

Dynamic action

Central government is taking anticipatory action	SIGNIFICANT WORK REQUIRED

We found few examples of anticipatory action on adaptation. For example, funding assistance is mainly focused on supporting communities to recover *after* climate-related events occur, such as central government meeting 60 per cent of councils' cost of restoring infrastructure after disaster; the EQC Fund policy settings for flooding and land damage; and MPI's Adverse Events programme that helps rural communities and individuals recover from adverse events (including natural disasters, severe weather and biosecurity incursions).

Other than funding, we have seen a small number of positive examples of central government agencies taking proactive action to adapt including:

- **NZ Defence Force** – its infrastructure plans for estate regeneration include assessment of climate risks and opportunities to build resilience to climate change into new projects[62]
- **Ministry of Health** – supporting DHB public health units detect exotic mosquitoes of public health significance, and monitoring DHB emergency and business continuity plans to ensure they include risks of extreme weather events
- **Department of Conservation** – initiated the 'Battle of Our Birds' as a result of increased frequency of sudden irruptions in pest species populations caused by an increase in mast seeding events in forests.[63]

Central government is being flexible	SIGNIFICANT WORK REQUIRED

Central government's frameworks and plans are generally slow to respond to changing risks, issues and opportunities. The Climate Change Impacts and Implications Programme (2016) highlights the need for new tools and practices, including novel communication methods that engage stakeholders and practitioners. In addition, our stocktake identified a lack of formal monitoring of policy effectiveness of adaptation measures which hinders central government's ability to adjust its approach with agility.

Central government is reducing risks by adapting	NOT PRESENT

The RMA and the NZCPS stand out as the key statutory frameworks that focus on reducing climate change effects. While these have been used in some localities by local government to anticipate changing climate we found no evidence that climate change risks to New Zealand have been reduced by the actions taken by central government.

62 Approval has been given for a $1.7 billion rejuvenation of Defence buildings, infrastructure and facilities.

63 The irregular seeding of millions of hectares of beech trees, resulting in a rapid expansion of mice and rat numbers affecting wildlife, is partially driven by changes in temperature and weather events.

Overview

The sector's progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what's happening	**Maintain**
	Understand what it means for them	**More work required**
ORGANISED	Know what is expected of them	**Significant work required**
	Has common goals	**Significant work required**
	Has a planned approach	**Significant work required**
	Has the tools they need	**Significant work required**
DYNAMIC ACTION	Is taking action	**Significant work required**
	Is being flexible	**Significant work required**
	Is adapting	**Not present**

5.2 Local government

Key findings

- Local government has responsibilities to prepare communities for and manage the risks of climate change. They have devolved powers to do this as they are considered best placed to understand what is appropriate for their region (that is, the principle of subsidiarity) based on the local changes they can expect to experience. The majority of councils appear to have a good understanding of climate change and are able to clearly articulate the potential impacts on their responsibilities.
- The extent and scope of action on adaptation varies considerably. Councils are at different stages of planning, have different views on how to manage climate risks, and have different needs. These different approaches can create confusion for the public and litigation of decisions.
- Many councils realise the importance of acting on adaptation and would like to do more but identified barriers including limited community buy-in; resourcing constraints (funding, capacity and capability); and lack of leadership and support from central government. There are a few councils that are starting to innovate with community processes and tools for managing climate risks.

5.2.1 Role in climate change adaptation

Local government has responsibilities for preparing communities for and managing the risks of climate change. They have devolved powers to do this as they are considered best placed to understand what is appropriate for their region (that is, the principle of subsidiarity) based on the local changes they can expect to experience. Local government consists of regional councils, unitary and territorial authorities (city and district councils). Collectively local government is responsible for:

- resource management policy, planning and decision-making
- flood control, stormwater management, flood warning and land drainage, and emergency management
- freshwater management, including the allocation of water quantity and quality
- maintenance of indigenous biological diversity
- responding to sea-level rise and the associated risks to coastal communities
- the operation and maintenance New Zealand's major infrastructure (water, stormwater, wastewater, flood protection and roads) that provide services to communities[64]
- understanding the needs of local and regional communities, communicating directly with those communities being accountable and responding.

5.2.2 Engagement undertaken

To understand what local government is currently doing on climate change adaptation, a questionnaire was sent to 78 local authorities. We received responses from 48 of those agencies (see Appendix 3). Literature that similarly surveyed local government was also reviewed to inform this section (see Appendix 7).

5.2.3 Work towards effective adaptation

Informed

Local government understand the climate-related changes New Zealand can expect in the medium and long term	**MAINTAIN**

Local government appears to have a good understanding of the climate-related changes they can expect for their region. This understanding comes from regional climate change projections including for groundwater, sea-level rise, ocean acidification and warming; and local government funded research to develop more detailed local information.

[64] Local government owns more than $120 billion of assets and manages the bulk of New Zealand's drinking water, wastewater, stormwater (three waters); flood protection and river control infrastructure; and 88 per cent of roads. Infrastructure and transport and discussed in detail in section 5.3. as these assets are owned by both the private and public (central and local government) sector.

Local government understand the impacts of climate-related changes and what this means for them	MORE WORK REQUIRED

The majority of councils were able to articulate the potential implications on their responsibilities. However, there were a small number of district councils who noted that they do not consider climate change to be an issue for them at present, and as such adaptation was not a priority.

As well as using information provided by central government, we have seen a number of examples of councils commissioning their own research. For example, Northland Regional Council is undertaking a region-wide LiDAR project which will help assess the impact of sea-level rise. In addition, several councils have undertaken coastal hazards assessments (eg, Hawke's Bay, Kāpiti).[65]

Our survey results showed there is a desire for better data and information on local scale impacts (approximately 50 per cent raised this), and the costs of obtaining this information is a barrier to action on adaptation.

Organised

Local government know what is expected of them	MORE WORK REQUIRED

The extent to which each council considers adaptation varies. In part, this is due to the level of exposure to climate-related changes each face, and the level of resources available to them. These different approaches can create confusion for the public, and inconsistencies and litigation of decision-making.

Councils appear to have a good understanding of their responsibilities, however many noted that misalignment across legislation and policy creates confusion regarding what is expected of them in terms of adaptation. As an example, a council noted that the Housing Accords and Special Housing Areas Act 2013 appeared to put priorities on housing supply ahead of natural hazard management considerations under the RMA.

In addressing whether the role of councils is considered appropriate, some have suggested having each unit of local government attempting to adapt to the impacts of climate change using different assessment and implementation approaches is inefficient and creates duplication of effort across New Zealand as there are similar impacts occurring throughout the country (eg, sea-level rise, flooding).

Local government has common goals	SIGNIFICANT WORK REQUIRED

While there are currently no common goals to help guide action on adaptation across the 78 councils, some regional councils are developing climate change work programmes (for example Canterbury), or strategies (for example The Greater Wellington Climate Change Strategy and Implementation Plan) to help councils in their region to work in an integrated way.

65 These assessments have not comprehensively assessed climate change risks across whole regions.

In addition, central government is currently considering a proposal by local government to establish a central risk agency that pools and coordinates local government resources to lower the risk and cost of disasters. The proposal aims to harmonise risk practice, improve local government skills, share data and provide best practice risk modelling.

Local government has a planned approach	SIGNIFICANT WORK REQUIRED

In the majority of cases, councils do not have a plan for how to go about climate change adaptation. However, as established earlier we are starting to see some councils develop climate change work programmes and strategies for their region.

In addition, we are seeing councils working together to plan for climate change risks. For example, Western Bay of Plenty District Council, Tauranga City Council and Bay of Plenty Regional Council are engaging in a collaborative natural hazards work programme over the next two years.

Local government has the tools they need	SIGNIFICANT WORK REQUIRED

A number of tools are available to councils to help them implement adaptation measures in their areas but many are calling for more support, including:

- **greater public awareness** – lack of community buy-in was raised as a barrier to adaptation by over half of respondents
- **more quality data and information** – particularly in relation to local-scale impacts (approximately 50 per cent of respondents). There is incomplete coverage of land elevation (light detection and ranging (LiDAR)) data which is required for local-scale hazard and risk assessments to consistent national standards. Vulnerability assessments are also required for risk assessments to appropriately address potential social impacts
- **more support in resourcing and capacity** – the cost and/or funding of adaptation is a key barrier, including the issue of liability and who pays (close to 70 per cent of respondents),[66] while over 30 per cent raised the issue of capacity and capability
- **policies and frameworks to be more joined up** across government and better suited to the task (over 40 per cent of respondents)
- **coordinated national leadership and direction** on adaptation wanted by councils, as without it they face issues in their ability to act with a clear mandate and thus engage effectively with communities and prioritise action (approximately 60 per cent of respondents raised this as a barrier).[67]

Box 1 provides examples of councils' views on the barriers to climate change adaptation.

[66] This is consistent with the Climate Change Impacts and Implications Project (2016)[66] which found that "without the ability to fund climate change adaptation where people and assets are at risk, councils considered it unlikely that measures currently in use would be effective in reducing exposure and vulnerability to climate change".

[67] As an example, while local councils have suggested that the guidance manuals by central government are useful tools (on the proviso that they are updated regularly), many are calling for more statutory levers as guidance can easily be ignored.

Local government also plays an important role in providing tools to support their communities to adapt. This includes:

Statutory frameworks and planning

Over half the councils who responded to our survey considered climate change adaptation in their Regional Policy Statements, and District and Regional Plans. Around a third considered it in their Long Term Plans. Some examples of how adaptation is covered in plans include:

- **adaptation policies and objectives** – some councils include specific policies and objectives for adaptation to climate change in Regional Policy Statements, for example, the notified Regional Policy Statement for Otago
- **natural hazard management** – in the majority of cases, we are starting to see projected climate change impacts being considered in local hazard risk management policies and frameworks. As an example, the Horizons One Plan requires a precautionary approach when assessing the effects of climate change on the scale and frequency of natural hazards with regards to decisions on, amongst other things, water allocation and water takes
- **sea-level rise and land use management** – some councils include specific controls on land use planning and development, for example, the Auckland Unitary Plan (operative in part) places development controls related to anticipated sea-level rise 100 years in the future on both greenfield and brownfield development
- **flood risk management –** some District Plans set minimum floor levels to help protect properties from the risks of floods and/or include flood hazard maps
- **biosecurity** – all regional councils have regional pest management strategies (in accordance with the Biosecurity Act). Some of these strategies factor-in climate risks. For example, climate data is integrated into Canterbury's Proposed Regional Pest Management Plan which aims to prevent and manage new pest incursions (including those resulting from climate change).

Education

Local government also plays an important role in educating communities about climate change risks in their region. For example, Auckland Council introduced the King Tide Initiative which encourages people from the region to photograph the highest tides that naturally occur along the coastline each year. They use these photos to help visualise what their coasts may look like in the future as sea level continues to rise. Other councils provide support to initiatives such as Enviroschools, to help educate communities. Greater consistency of information provided to communities would strengthen the understanding.

Dynamic action

Local government is taking anticipatory action	**SIGNIFICANT WORK REQUIRED**

Many councils are still in an early phase of planning for adaptation and few are at the implementation stage. Specific actions councils mentioned in their survey responses vary significantly. Some examples include:

- **sea-level rise and coastal erosion control** – New Plymouth District Council is implementing erosion control measures through a Coastal Erosion Strategy which includes specific consideration of climate change
- **flood protection** – Bay of Plenty Regional Council initiated a River Scheme Sustainability Project. It sets the direction for sustainable management of its major waterways for the next 100 years including under different climate change scenarios
- **water management** – A number of councils are investigating water storage and irrigation infrastructure to help meet their community's needs as weather patterns evolve, including Greater Wellington (Water Wairarapa project), Environment Canterbury and Northland
- **biosecurity and biodiversity management** – Palmerston North City Council is partnering with communities to regenerate forest remnants and connect them via green corridors, which can increase ecosystem resilience to climate events.

Local government is being flexible	SIGNIFICANT WORK REQUIRED

The philosophy of continual change and review are well established within local government, and we understand that local government has good experience in amending their policies and practices over time based on changing environmental, economic and social conditions. This has been through the statutory requirement to review their Regional and District Plans every 10 years, and Long Term Plans every three years. To date the processes for making these changes are generally slow to respond to changing risks and opportunities, as they are time based and arbitrary rather than flexible and adaptable.

In terms of being flexible to climate risks, we are starting to see some councils shift their planning practices from static (where decisions do not consider further, future decisions that may be required) to dynamic approaches (where the options for future decisions are also considered) to help deal with uncertainty. For example, the Hutt River Floodplain Management Plan upgrade for the Hutt CBD used dynamic adaptive planning tools to assess the significance of ongoing climate changes.

Local government is reducing risks by adapting	SIGNIFICANT WORK REQUIRED

While we are seeing some positive steps being taken to adapt to climate change by some councils, they are still in early stages of development implementation for example, the *Hawke's Bay Clifton to Tangoio Coastal Hazards Strategy to 2120* and the Otago Regional Council/Dunedin City Council South Dunedin Future programme. For more information on these programmes, see *Case Study 2: Hawke's Bay – An Example of Adaptation in Practice* and *Case Study 3: South Dunedin: Responding to Climate Driven Challenges.*

Overview

The sector's progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what's happening	**Maintain**
	Understand what it means for them	**More work required**
ORGANISED	Know what is expected of them	**More work required**
	Has common goals	**Significant work required**
	Has a planned approach	**Significant work required**
	Has the tools they need	**Significant work required**
DYNAMIC ACTION	Is taking action	**Significant work required**
	Is being flexible	**Significant work required**
	Is adapting	**Significant work required**

BOX 1: COUNCILS' VIEWS ON THE BARRIERS TO CLIMATE CHANGE ADAPTATION

The following quotes from responses to our survey give a taste of the complexity of the issue as well as barriers to act on adaptation faced by local government:

> "There is currently no central government acknowledgement that significant resources will be required for climate change at a scale that local government is unlikely able to fund. The public perceptions of the risk of climate change are unlikely to be helped if there is no acknowledgement that there will be significant financial risks."
>
> "Clearer climate change jurisdictional responsibilities and a demonstration of national leadership would be beneficial, with regional and district plans being better aligned and responsive, and less politically contentious."
>
> "Lack of immediacy of threat compared to expected immediate and long term cost implications to the rate/tax payer"
>
> "It's not the front of mind issue that some others currently are."
>
> "Tyranny of the now – sea level rise and climate change is relatively slow so only truly surfaces in the city's consciousness during related emergencies. Response funding and focus often overshadows reduction strategies"
>
> "Difficult for the organisation to prioritise climate change adaptation work as other issues – including those with strong central government directives take priority – lack of a mandate."
>
> "The vague and piecemeal approach to climate change adaptation leaves Territorial Authorities without direction and authority to undertake significant adaptation."
>
> "If the public perception is that central government is not adequately acknowledging climate change, then it is very hard for local government to defend a policy position"
>
> "A stronger policy stance from central government on a precautionary approach to new development in hazard prone areas would give local government a better mandate and more robust defensible position to decline additional development, or only allow development with greater natural hazard mitigation conditions."
>
> "… we believe it needs to be a matter of urgent priority for central government to develop a government-wide approach to climate change adaptation."

CASE STUDY 2: HAWKE'S BAY – AN EXAMPLE OF ADAPTATION IN PRACTICE

Coastal erosion, flooding from the sea (inundation) and tsunami are pressing issues facing the Hawke's Bay in particular the southern stretch of the bay. These issues are being considered in the Clifton to Tangoio Coastal Hazards Strategy 2120 (the Strategy) for the next 100 years.

A Joint Committee has established two collaborative community panels to recommend appropriate responses to the identified risks using a structured decision-making process. This is being supported by a Technical Working Group and the development of an intergenerational funding model.

The region is very susceptible to changes in the climate and the coastline is also highly vulnerable to tsunamis triggered by earthquakes off Chile or in the Hikurangi Trough just off the coast. It is already experiencing disruption such as:

- storm swell events at Te Awanga, Haumoana and Westshore continually erode stretches of gravel beach
- inundation from rising sea/wave/swell levels threatens communities through overtopping the existing gravel barrier ridge.

The Joint Committee working on the Strategy facilitates the coordination of the two territorial authorities that the section of coastline falls in the jurisdiction of (Napier City Council and Hastings District Council), as well as Hawke's Bay Regional Council.

Hawke's Bay is the first region in New Zealand to take this long-term planning approach and there is little central government guidance on long-term approaches (although it is acknowledged that the Coastal Hazards Guidance is being updated). Coastal communities are being consulted on the level of risk they are prepared to live with and the associated cost of minimizing risk.

There are uncertainties with regard to ongoing insurance coverage, particularly in high-risk areas. Managing these uncertainties will require social and financial responses that will be generally perceived as fair by New Zealand community as a whole.

If local government ratepayers choose to cover costs of protecting private land from coastal hazards there may be issues around setting a precedent and unfairly allocating funds from the entire regions rates to coastal areas.

A combination of intervention, from engineering structures, beach re-nourishment and other methods, and retreat from the coast are expected to be used to enable communities to adapt to climate change and the risks of coastal hazards.

Those working on the Strategy are looking for the following from central government:

- national guidance suitable for local applications and circumstances which compliments existing work and efforts in the region
- direction and support on how local government can fund adaptation responses
- discussion of the role of central government in funding adaptation responses
- direction and support on how to manage retreat what it looks like, how to achieve it without splitting up communities, how to enable and incentivize it, how to pay for it.

CASE STUDY 3: SOUTH DUNEDIN – RESPONDING TO CLIMATE DRIVEN CHALLENGES

South Dunedin is a vibrant and diverse community, which is expected to face many issues in the future due to its low-lying location. The area was converted from marshy wetland in the mid–1800s due to strong demand for level, dry land. As a result there are nearly 2,700 homes less than 50 centimetres above the spring high tide.

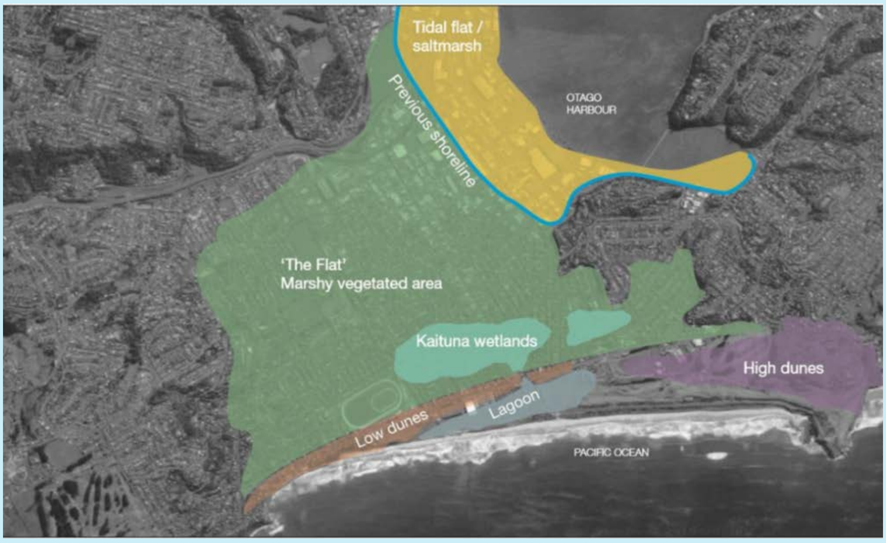


Image: Aerial map of South Dunedin overlaid with the natural features of the 1800s, Source Otago Regional Council.

A mixture of sandy and silty soils underlies South Dunedin meaning marshy conditions persist. The soil is very absorbent and the groundwater table sits close to the ground surface, in some cases less than 20cm deep. When heavy rainfall or higher tides occur, groundwater can rise quickly to, at, or even above the level of the land.

Sea level has risen about 14 cm over the last century, relative to the land. It is expected that any long-term rise in sea level will also see a rise in groundwater levels, which will eventually cause permanent ponding of water on the ground surface. This was discovered by modelling done by the Otago Regional Council.

These changes would cause damp housing conditions (leading to chronic health problems), parks and other facilities to be unusable in wet seasons due to drainage issues, and an increased risk of flooding during heavy rainfall due to limited ability for surface water to be absorbed beneath the ground. Otago Regional Council and Dunedin City Council are working together to develop and deliver a programme that responds to the climate driven challenges facing South Dunedin.

Community engagement is developing common understanding of the likelihood and nature of climate driven events as well as the potential environmental, social, cultural and economic impact. International examples of managing rising groundwater are being considered in a South Dunedin context. This information, along with the councils' own science and monitoring, will help identify viable options for the area.

Communities must be confident about the decisions they and their local authorities make about the future. This can be difficult with the current level of uncertainty. Change to the environment is slow and imperceptible in nature and the triggers for adaptation are not expected to be obvious to the public. While this gives councils and the community the benefit of time to adapt to the change it risks a prolonged period of uncertainty in which appropriate action is not taken.

5.3 Infrastructure providers

Key findings:

- A good level of information is available to infrastructure providers on climate change through climate projections supplied by government and industry standards. Some providers have displayed a good understanding of the risks, however many consider climate change adaptation as part of a broader goal around resilience to natural hazards. This limits the consideration of changing risks.
- Given the long lifetime of infrastructure, there is urgency for climate change adaptation to be factored into infrastructure decisions now. Local government, which are significant providers of roads, flood management and three waters infrastructure, are approaching a period of infrastructure renewal. This is an opportunity.
- In the majority of cases, infrastructure decisions do not currently consider climate change adaptation. There are a number of challenges in incorporating climate change adaptation into infrastructure decision-making including most approaches to addressing service provision involved 'locked in' solutions that have been developed over the last century. There is also a perception that climate change adaptation will cost more even though it may not be significant compared with the large capital costs, and longevity of infrastructure investment.

5.3.1 Role in climate change adaptation

Infrastructure providers include private and/or public organisations responsible for the design, construction, operation and maintenance of electricity generation and transmission, water, wastewater and stormwater (three waters), flood management and communications, and transportation networks (including ports and airports). Infrastructure assets generally have a long design life. It is the provider's responsibility to ensure that they consider climate-related change and the long-term impacts this will have.

5.3.2 Engagement undertaken

To understand what the infrastructure and transport sector is currently doing on climate change adaptation, we analysed the survey responses from central and local government. Survey responses were also provided by six infrastructure providers in the private sector (see Appendix 3).

5.3.3 Work towards effective adaptation

Informed

The infrastructure and transport sector understand the climate-related changes New Zealand can expect in the medium and long term	**MORE WORK REQUIRED**

The sector has a good level of information available to them about climate change through climate projections supplied by government and industry standards. The six providers who responded to our survey showed they had a good understanding of the changes New Zealand can expect. However, this is only a small sample, and we expect that there are a large number of providers within the sector that are not necessarily aware of climate change impacts or understand them in detail.

The infrastructure and transport sector understand the impacts of the climate-related changes and what this means for them	**SIGNIFICANT WORK REQUIRED**

Few infrastructure providers appear to have commissioned specific studies and assessments into climate impacts and risks. However, the consideration of climate change impacts goes beyond the service performance of any particular infrastructure. There are significant implications for long-term land use planning for the provision of infrastructure through the strategic integration of infrastructure with land use by regional councils.

Many have also commissioned their own research including:

- **Watercare Services Limited** – investing in hydrodynamic and water quality models of the Manukau Harbour to enable the running of various scenarios of sea-level rise and climate change impacts
- **Auckland Airport** – commissioned two studies to better understand and manage the risk of sea-level rise and inundation. One study is on sea-level rise (2016) and the other on the impact of sea-level inundation on their stormwater network
- **The New Zealand Transport Agency** – undertook a two year research project on climate change effects on the land transport network (2008/09). It identified and assessed the impacts of climate change on road, rail, ports and coastal shipping networks, and provided recommendations, including adaptation options, to address information gaps and risks
- **Waikato Regional Council** – developed a coastal inundation mapping tool for projected sea-level rise which informs council infrastructure decisions in the region.

Many stakeholders we spoke to within this sector highlighted they need access to up-to-date information and guidance to consider the implications to them. This includes detailed LiDAR information as well as hazards and sea-level rise data and scenarios with tools deployed that can consider future uncertainties. If tools to assess the future range of climate-related conditions are unavailable or not routinely used for infrastructure planning, inadequate consideration of future climate risks with costly consequences or no decisions being made can be expected.

Organised

The infrastructure and transport sector know what is expected of them	SIGNIFICANT WORK REQUIRED

Infrastructure providers are responsible for maintaining New Zealand's infrastructure and transport network in the face of climate change impacts over the long term. This responsibility is understood by many within the sector but focus tends to be on hazard risk management in the near term.

One stakeholder told us that priorities from central government can be unclear and it is not always obvious how policies fit together. For example, it was considered that recent policy changes to provide for additional land for housing and to improve freshwater management could better integrate considerations of climate change-related risks.

The infrastructure and transport sector has common goals	SIGNIFICANT WORK REQUIRED

The National Infrastructure Plan (NIP) (2015) establishes a goal that New Zealand's infrastructure is resilient, coordinated and contributes to a strong economy and high living standards. Adaptation is identified as a key element to achieving this. The NIP however provides no detail on how to go about this. The NIP suggests that the infrastructure response to the impacts of climate change would be explored further in the near future but we are not aware that this has been done yet.

In addition, the Government Policy Statement for Land Transport that sets out the government's priorities for expenditure from the National Land Transport Fund over the next 10 years also includes an objective on resilience in its network, but does not explicitly cover climate change impacts and adaptation. This reiterates the current focus on immediate hazard management rather than on how climate change affects infrastructure provision over its design life.

The infrastructure and transport sector has a planned approach	SIGNIFICANT WORK REQUIRED

While there is a common goal around building resilience in our infrastructure, we have seen little evidence of a plan for *how* adaptation in infrastructure investment and planning will be carried out.

The infrastructure and transport sector has the tools they need	SIGNIFICANT WORK REQUIRED

Many infrastructure providers highlighted the main tools that motivate their action on adaptation are the policies and rules in statutory documents set by central and local government. For example:

- **the Civil Defence Emergency Management Act (CDEMA)** – considers infrastructure managed by this sector as critical lifeline utilities, and is therefore much more heavily regulated for risk management compared to some sectors. While CDEMA requirements are not future focused and have no express requirement to adapt, we are seeing some instances of adaptation being integrated into emergency preparedness for natural hazards.
- **rules and policies in planning documents under the RMA** – influence where infrastructure may be built and how it is designed. For example, Watercare's projects are being designed to consider the potential for sea-level rise of one metre over the next 100 years, as established in the Auckland Unitary Plan.

Some infrastructure providers identified gaps in the tools available to them, including:

- **the lack of nation-wide science on hazards risk and climate change guidance** – with much of the current guidance out-of-date
- **limited funding, resourcing and capability** – to consider and apply climate change adaptation
- **the lack of consistent terminology** – there is a wide range of language, definitions and theory associated with related fields of risk management, resilience and climate change adaptation which reduces the potential for shared understanding and collaboration. We understand that this issue is being considered by local government as part of the proposed Local Government Risk Agency.

Dynamic action

The infrastructure and transport sector is taking anticipatory action	**SIGNIFICANT WORK REQUIRED**

We have found only a few examples of infrastructure investment decisions that directly consider climate change adaptation including:

- **the New Zealand Transport Agency** – implemented a business improvement project which aims to build resilience into the state highway network (one example is that NZTA raised and widened the State Highway 16 causeway in West Auckland based on a 50 year prediction of sea-level rise)
- **Wellington Water** – plans to increase the capacity of stormwater pipes when they are due for replacement by using climate change scenarios
- **Auckland Airport –** developing an adaptation management plan based on research it commissioned on the risks of sea-level inundation on their operations.

It's important to note that these examples are not reflective of the whole sector's response to adaptation, and we are aware that many infrastructure providers (if not the majority) do not currently integrate climate change impacts into their decision-making. For example, we have seen no evidence of the New Zealand Transport Agency's climate change impact assessment (2008/09) for land transport being used to anticipate future changes.

The infrastructure and transport sector is flexible	**SIGNIFICANT WORK REQUIRED**

We have seen some good examples of the sector implementing risk-based approaches to ensure they can be flexible to changing overtime. An example of this is included in the *Case Study 4: Transpower – Managing Transmission System Uncertainty*. In addition, providers we surveyed noted they monitor trends in climate conditions that might impair their operations which will help facilitate their ability to respond to change over time.

CASE STUDY 4: TRANSPOWER – MANAGING TRANSMISSION SYSTEM UNCERTAINTY[68]

New Zealand design standards require infrastructure to withstand specified probabilities of earthquake and wind events. These levels are then compared against the proposed function of the asset, as some assets are more critical than others. Technical and economic considerations for the asset are then taken into account.

For example, transmission lines are very robust and simple, and fast and cheap to reinstate (between 24 and 72 hours). Multiple lines run between substations and provide functional diversity. Substations are, by comparison: geographically concentrated; have more component parts that perform a single function; are very expensive; and have long replacement times. For example, delivery of a power transformer will take over a year from date of order and weighs several hundred tonnes, a significant logistical exercise to replace. Even a spare takes two to four weeks to get on site. Substations therefore have more stringent design standards than transmission lines.

Not all lines or assets are created economically equal either. The core grid (220 kV) and anything greater than 150 MW are designed to deterministic standards (two of everything), so if one part is 'lost' the other parts can continue running with no interruption. For investment in anything less than 220 kV or 150 MW, the criteria are purely economic. Sensitivity analysis of $20K/MWh (megawatt hour), $5K/MWh and $35K/MWh can be used to highlight what is at risk in the event of non-delivery due to different load concentrations.

The Research Project: *The Climate Change Impacts and Implications for New Zealand to 2100, Synthesis Report* (RA4) suggested that this same process could be used to consider climate change risk on the transmission system. For example, for heat, snow and ice, wind, sea-level rise, flood events, and related landslips. Redundancy, criticality of asset, and diversity of system design are the factors that enable Transpower to manage uncertainty and dynamic change in their system. However, distribution companies are more at risk, because they have more limited funding to manage the logistics costs of such a protocol.

The infrastructure and transport sector is reducing risks by adapting	**SIGNIFICANT WORK REQUIRED**

While our survey responses have shown some steps are being taken which will help reduce New Zealand's exposure to the risks of climate change, this is not reflective of the sector's response to adaptation as a whole. We can conclude that the majority of infrastructure providers do not currently integrate climate change impacts into their decision-making and there is limited adaptation taking place in this sector.

68 CCII Synthesis Report R4.

Overview

The sector's progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what's happening	**More work required**
	Understand what it means for them	**Significant work required**
ORGANISED	Know what is expected of them	**Significant work required**
	Has common goals	**Significant work required**
	Has a planned approach	**Significant work required**
	Has the tools they need	**Significant work required**
DYNAMIC ACTION	Is taking action	**Significant work required**
	Is being flexible	**Significant work required**
	Is adapting	**Significant work required**

5.4 Finance and insurance

Key findings:

- The sector is experienced in dealing with natural hazards and understands that climate change will exacerbate this. It is calling for a more coordinated and proactive response within and across sectors to reduce the potential impact of climate-related changes before they occur.
- The mismatch in the duration of insurance cover (annual), lending (spanning decades), infrastructure investment and planning decisions creates complexity in creating a coordinated response for businesses and homeowners in locations significantly affected by climate change.
- While the sector is quite active in mitigation, parts of the sector are also starting to implement direct measures to deal with climate change impacts. A key concern for the insurance industry is that overt action by one organisation can result in precipitous action by others in the sector and potentially affect government policy settings (EQC).

5.4.1 Role in climate change adaptation

The key responsibilities of the finance sector (including New Zealand's insurance, banking and investment providers) are:

- sharing their knowledge and expertise
- providing products that enable adaptation and recovery (for example, insurance)
- sending signals about risk through terms and availability
- influencing others through their capital management.

5.4.2 Engagement undertaken

To inform this section, we spoke to key stakeholders within the industry and reviewed relevant published literature.

5.4.3 Work towards effective adaptation

Informed

The finance and insurance sector understand the climate-related changes New Zealand can expect in the medium and long term	**MORE WORK REQUIRED**

Industry stakeholders told us they are aware of the potential climate-related changes. Increased consistency, granularity and availability of data are needed, for example, nationally consistent LiDAR.

The finance and insurance sector understand the impacts of the climate-related changes and what this means for them	**SIGNIFICANT WORK REQUIRED**

The sector also appears to understand what it means for them in general terms, but not at a sufficient level to inform their investments and market response. This reflects the broader understanding of impacts in the built and economic environments. As highlighted by Mark Carney, Governor of the Bank of England in his December 2016 speech, "without the necessary information, market adjustments to climate change will be incomplete, late, and potentially destabilising".[69]

Organised

The finance and insurance sector know what is expected of them	**SIGNIFICANT WORK REQUIRED**

Some within the finance sector have an understanding that they play a role in helping facilitate adaptation in New Zealand.

The finance and insurance sector has common goals	**SIGNIFICANT WORK REQUIRED**

There is no set of common goals for how to address climate change adaptation within the sector. However, there are calls from the insurance industry for a more coordinated strategy for managing hazard risk (including climate-related risks) that is focused on reducing the potential impact of disasters before they strike.[70]

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69 Belinda Storey, Ilan Noy, Wilbur Townsend, Suzi Kerr, Rhian Salmon, David Middleton, Olga Filippova and Vanessa James, 2017, *Insurance, Housing and Climate Adaptation: Current knowledge and Future Research*, Motu note 27.

70 Insurance Council of New Zealand, 2014, Protecting New Zealand from Natural Hazards Position paper.

Without these common goals some within the sector are concerned that competition may trigger rapid change in the availability and terms of products, especially for insurance (and therefore lending) in high risk locations. However, greater cooperation in the sector may breach competition rules.

The finance and insurance sector has a planned approach	**SIGNIFICANT WORK REQUIRED**

The sector knows what it would do in response to increasing risk and the types of changes that would be made to their products to reflect this. What it doesn't know is when and how fast these changes will need to be implemented as a result of climate change. It also recognises that these changes will have consequential impacts on other sectors and that signalling and alignment are important.

The finance and insurance sector has the tools they need	**SIGNIFICANT WORK REQUIRED**

The sector can adjust its existing products to manage increasing risks caused by climate change. Insurers can adjust their exposure to risks by increasing the minimum excess a customer has to pay which is typically their first response, and from there they could increase premiums or reduce cover. Ultimately they may not offer any cover. Given that contracts are renewed annually, insurers are able to adapt relatively quickly to changing risk profiles. *Case Study 5: Climate change adaptation and the insurance sector – Insurance Australia Group (IAG)* shows how the IAG currently addresses hazard risks in their operations.

For the banking sector, they currently view environmental risk on a case-by-case basis when determining lending decisions. In the case of coastal properties vulnerable to erosion and storm surges, the banking sector expect a gradual reduction in the extent to which they could lend against those properties and/or they would require more equity or shorter mortgage terms.[71]

Mortgages are generally granted with repayment periods spanning decades which could increase their exposure if a home is lost or significantly damaged. To reduce some of this exposure, insurance is a requirement for residential mortgages in New Zealand, and failing to maintain insurance can trigger default. However, there is a general absence of compliance checks and lack of understanding of how well properties are insured. These leave a risk that many homes may be underinsured which increases banks' exposure to losses.

Overall, the mismatch in cover and lending duration generates complexity in creating a coordinated response to businesses and homeowners in locations significantly affected by climate change.

Investment managers will likely factor into their decisions the impact of climate change on, and the adaptive capacity of the businesses they invest in.

[71] CCII project, 2016.

Stakeholders within the sector have identified the following gaps in their tools to adapt to climate change:

- lack of national direction and objectives
- lack of coordination within and across sectors – some have expressed a desire to work more in concert on this issue but in reality this is difficult due to competition.

Dynamic action

The finance and insurance sector is taking anticipatory action	SIGNIFICANT WORK REQUIRED

To date, the actions the finance sector have been focused on are the natural hazards that climate will exacerbate rather than its broader social or economic impacts. This includes:

- working with government to help get the right policy frameworks in place to support proactive action to reduce risks
- some insurers are increasingly reflecting risk in their pricing and cover (although providing cover remains their primary role) to create greater equity across high and low risk locations, and help discourage development in more hazardous locations
- some banks are starting to factor environment issues into their lending decisions.

The finance and insurance sector is being flexible	SIGNIFICANT WORK REQUIRED

The sector already has products available to them to deal with increasing risk, and the mechanisms to monitor and respond to those impacts. These are typically focused on the short term. We expect they will adapt their response relatively quickly to climate change impacts as they grow.

The finance and insurance sector is reducing risks by adapting	SIGNIFICANT WORK REQUIRED

The sector has not yet made material changes as a result of its understanding of climate change risks.

Overview

The sector's progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what's happening	**More work required**
	Understand what it means for them	**Significant work required**
ORGANISED	Know what is expected of them	**Significant work required**
	Has common goals	**Significant work required**
	Has a planned approach	**Significant work required**
	Has the tools they need	**Significant work required**
DYNAMIC ACTION	Is taking action	**Significant work required**
	Is being flexible	**Significant work required**
	Is adapting	**Significant work required**

CASE STUDY 5: CLIMATE CHANGE ADAPTATION AND THE INSURANCE SECTOR – INSURANCE AUSTRALIA GROUP (IAG)

Climate change became part of IAG’s agenda in the early 2000’s when they were exposed to a number of large losses due to weather events. IAG expects the impacts of climate change will only increase the frequency and impact of weather-related natural hazards, and will begin to have a wider effect on New Zealand homes and businesses.

IAG already builds this type of risk into its products and services. There are number of tools they can use to reflect risk while still insuring properties that are highly exposed to natural hazards. These tools include:

- applying a special excess for a specific hazard (eg, flood) so that the customer takes responsibility for the first part of any claim
- increasing the premium to reflect the known risk and to offset the costs associated with more complex and more frequent claims
- applying restrictions to the amount they will pay or what costs they will pay for when a claim arises, whether caused by the hazard or not
- excluding the hazard (eg, flood) but still providing cover for other types of loss such as fire
- downgrading cover by only insuring a house for its market value rather than replacement on a like-for-like basis.

IAG’s preferred approach is to use these tools progressively and in combination so they can continue to provide cover. It is still extremely rare that they decline cover outright and they do not expect to see that change anytime soon. If, when and how firmly these tools are used will vary across the country, reflecting the uncertain impact on natural hazards and uncertain pace and scale at which they are changing.

Some examples of specific high-risk areas within New Zealand where IAG already applies special terms to its insurance contracts are:

- Haumoana (Hawke’s Bay) – this area has a high risk to erosion and coastal inundation. In response, insurance is considered on a case-by-case basis with many risks in the most extreme locations being declined where the council is unlikely to issue consent for future building/repairs to be undertaken
- Matata (east coast of the North Island) – this area has high risk of heavy rainfall causing landslides and debris flow. In response, a combination of underwriting tools on a case-by-case basis ranging from increased excesses where the council has measures in place to remediate the risk of future events to declining cover where no remediation has been undertaken
- Ohope (eastern Bay of Plenty) – high risk of inundation and coastal erosion. In response, a combination of underwriting tools on a case-by-case basis
- Port Hills (Canterbury) – high risk of land instability and rock fall. In response, IAG decline new insurance in mass movement areas although there are currently no restrictions on insurance for existing customers.

In addition to signalling risks in the pricing of insurance, IAG has also previously worked in partnership with Thames Coromandel District Council and Environment Waikato to proactively reduce both current and future flood risks on the Thames Coast.

5.5 Health providers

Key findings:

- The health sector is becoming increasingly aware of the risks of climate change on public health in New Zealand, but more work on what this means for the sector is needed.
- The sector is not organised for adapting to climate change with no clear goals, unclear understanding of what is expected of them and no plan for how to go about adaptation.
- Some District Health Boards (DHBs) are addressing the impacts of climate change on public health in their planning and decision-making. This has mainly been through their emergency response and infrastructure planning.

5.5.1 Role in climate change adaptation

The key responsibilities of the health sector in terms of adaptation are:

- providing primary care and community services to support wellness (including physical, mental and social well-being) and prevent illness, services to help manage long-term conditions, or urgent help to deal with accidents or acute illness[72]
- understanding climate change risks on public health and critical health assets, and factoring this into planning and decision-making
- sharing knowledge on public health and equity consequences of climate change.

5.5.2 Engagement undertaken

To inform this section, we engaged with the Ministry of Health and OraTaiao[73] (the New Zealand Climate and Health Council). We also sent surveys to DHBs and received two responses.

5.5.3 Work towards effective adaptation

Informed

The health sector understand the climate-related changes New Zealand can expect in the medium and long term	**MORE WORK REQUIRED**

There is a varied level of understanding and awareness of the impacts of climate change across the health sector.

72 New Zealand Health Strategy 2016.

73 OraTaiao: The New Zealand Climate and Health Council comprises of health professionals in Aotearoa.

The health sector understand the impacts of the climate-related changes and what this means for them	MORE WORK REQUIRED

There is varied understanding of the implications of climate change on the health sector. DHBs generally appear to know very little about the implications of climate change, however some have appointed sustainability officers with part of their work focused on climate change. On the other hand, public health units which are part of DHBs, tend to hold greater institutional knowledge about climate change and health.

We are seeing some positive steps towards improving the health sector's understanding of climate change impacts on public health, with a growing body of research on this issue and the establishment of OraTaiao which runs awareness days at hospitals around the country on climate change impacts and health. However, more work and resourcing are needed to improve this understanding.

There are a number of information gaps within the sector, including:

- the impacts of climate change on existing health inequities, by ethnicity and socioeconomic status
- the extent of psychosocial impacts caused by climate change in New Zealand
- the impacts of climate change on Hauora Māori.

Organised

The health sector know what is expected of them	SIGNIFICANT WORK REQUIRED

There is limited understanding on what is expected of the sector in terms of adaptation. While we can find many examples of health organisations working towards reducing greenhouse gas emissions and waste, there is less acknowledgment for the need to implement strategies for adaptation.

The health sector has common goals	NOT PRESENT

There are no common goals for climate change adaptation and plans for how to go about it within the sector. While New Zealand's Health Strategy (2016) acknowledges that climate change has health and social consequences, it provides no other further information on this.

The health sector has a planned approach	SIGNIFICANT WORK REQUIRED

There is no requirement or direction for hospitals to be planning for the health effects of climate change. We are seeing some DHBs start to incorporate climate change into their plans, most notably Waitemata and MidCentral. However, many are yet to do so. For those that have, the key focus areas include sustainability, emergency response, food and water safety, and security.

The health sector has the tools they need	NOT PRESENT

A recent UNFCCC report on Human Health and Adaptation found there are a number of challenges in advancing climate change action to address health risks in countries. These include the availability of and access to funding for health and adaptation. This finding is consistent with messages we received from stakeholders within the sector who highlighted that resourcing and capacity are significant barriers to adaptation.

Dynamic action

The health sector is taking anticipatory action	SIGNIFICANT WORK REQUIRED

There are only a few actions being taken on adaptation in the health sector including:

- introduction of exotic mosquitos is considered by some as a priority risk in the health sector and it is acknowledged that with a changing climate this risk is elevated. DHBs including Canterbury, Nelson Marlborough, Tairāwhiti and Whanganui have mosquito monitoring in place within their region
- Waikato DHB has invested in 'virtual health' which uses a number of different media to enable access to health care. This is expected to reduce the need for travel in the delivery of health care, and shows adaptability to innovations that could assist climate change adaptation.
- The West Coast DHB has been mindful of climate change effects in the design of their new Grey Base Hospital. The ground floor of the building has been constructed to be sensitive to sea-level rise and increased rainfall depth.

The health sector is being flexible	SIGNIFICANT WORK REQUIRED
The health sector is reducing risks by adapting	SIGNIFICANT WORK REQUIRED

While we are seeing a few positive examples of steps taken to proactively address adaptation within the sector, these are limited in their response to the scope and main threats to health from climate change.

Overview

The sector's progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what's happening	**More work required**
	Understand what it means for them	**More work required**
ORGANISED	Know what is expected of them	**Significant work required**
	Has common goals	**Not present**
	Has a planned approach	**Significant work required**
	Has the tools they need	**Not present**
DYNAMIC ACTION	Is taking action	**Significant work required**
	Is being flexible	**Significant work required**
	Is adapting	**Significant work required**

5.6 Primary sector

Key findings:

- There is a lot of information available on the impacts and implications of climate change for the primary sector. This has helped facilitate a reasonable understanding of climate change for the sector. However, there are gaps in research on some of the implications, for example, economic, social, pests and diseases.
- The sector has a long history of adapting to seasonal and annual variability in climate-related conditions, including coping with extreme events. The challenge the sector will face as a result of climate change is increased range in that variability, changes to baseline rainfall and temperatures, and an increase in the frequency of extreme events.
- Where measures that increase resilience have been incorporated into practice, climate change is often not a key driver.

5.6.1 Role in climate change adaptation

An important component in considering and planning the sustainability of the farm business is understanding the risks posed by climate change on the business and farming family. It is in the interests of farmers to take responsibility for planning to protect the longer term interests of their family and business from those risks. Reducing exposure to risk also has wider societal benefits by reducing the call on government assistance for recovery from extreme events.

Industry bodies have a role (alongside government) in supporting research to facilitate climate change adaptation in their sector, and communicating the risks of climate change to their members.

A range of central government recovery assistance measures (including mentoring/advice and financial assistance) are available to farmers following localised, medium-scale and large-scale adverse events (including extreme weather events and biosecurity incursions).

5.6.2 Engagement undertaken

To understand what the primary sector is currently doing on climate change adaptation, a survey was sent to 14 primary industry bodies, businesses and representatives. We received 7 responses (see Appendix 3). Literature that considered primary industries response to climate change was also reviewed to inform this section.

5.6.3 Work towards effective adaptation

Informed

The primary sector understand the climate-related changes New Zealand can expect in the medium and long term	**MAINTAIN**

The primary sector as a whole has a reasonable understanding of expected climate-related changes.

Research on ocean-related climate change, ocean acidification and seafood sector adaptation is under current investigation by the industry.[74] The aquaculture industry is collaborating with MPI, Regional Councils and the National Institute of Water and Atmospheric Research (NIWA) to improve monitoring of seawater on a national scale.

The primary sector understand the impacts of the climate-related changes and what this means for them	**MORE WORK REQUIRED**

A wide range of central government funded research on the implications of climate change for the primary sector and options for how to adapt has been undertaken. Most of this information has been collated into one website for ease of accessibility (climate cloud).[75] There are gaps in that research. For example the economic and social implications of climate change on the primary sector and implications regarding pests and diseases are still poorly understood.

74 http://www.mpi.govt.nz/news-and-resources/science-and-research/fisheries-research/

75 http://climatecloud.co.nz/Pages/default.aspx

A review of existing research on the impacts and implications of climate change on the primary sector is currently underway to identify key messages, areas of focus, outcomes achieved to date and gaps in knowledge. This review will be completed in June 2018.[76]

Organised

The primary sector knows what is expected of them	MORE WORK REQUIRED

The role of farmers and growers in protecting their family and business from the risks of climate change is articulated in a number of government and industry body documents.

As described below there is evidence of some farmers and growers proactively adapting to climate change.[77] This suggests some are aware of this expectation, while others are not aware, or if aware, not yet prepared to take steps to adapt.

The primary sector has common goals	SIGNIFICANT WORK REQUIRED
Individuals, industry bodies and businesses in the primary sector have a planned approach	SIGNIFICANT WORK REQUIRED

At the individual, industry body and business levels within the primary sector there appears to be an ad hoc, rather than planned approach, to adaptation. A number of primary industry bodies and businesses have noted that adaptation to climate change is not always considered a priority for their sectors compared to issues around financial viability, biosecurity and more immediate environmental issues (such as water quality and availability).

The primary sector has the tools they need	MORE WORK REQUIRED

There are some enabling tools being provided. Examples include:

- **Beef and Lamb NZ's Land Environment Plans** – which encourage farmers to consider the impact of extreme weather events on whole farms systems
- **the kiwifruit industry** – developed a tool to support growers when making decisions around irrigation that incorporates forecast meteorological data.

In 2010 a five step Adaptation Toolbox was developed by government to help individuals identify and manage risks from a changing climate. This tool box has not been updated and is currently not operational.

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76 *Mind the Gaps: Synthesis and Systematic Review of Climate Change Adaptation in New Zealand's Primary Industries* study lead by Landcare Research with other collaborators assessing SLMACC adaptation research projects from 2008 to current projects, to be completed by June 2018.

77 SLMACC, 2012, Impacts of climate change on land-based sectors and adaptation options – stakeholder report.

Dynamic action

The primary sector is taking anticipatory action	**MORE WORK REQUIRED**
The primary sector is being flexible	**MORE WORK REQUIRED**

Action undertaken by the primary sector in response to climate change varies considerably across sectors and individual farmers. Adaptation to climate change is not the only driver for any action but one of a suite of drivers.

Farmers and growers continually adapt their practices to accommodate changes in the environmental conditions they experience. There is evidence of some farmers taking a longer term view to this approach. Others have suggested that they take a wait and see approach, in light of uncertainty around projections and impacts as well as the costs of adaptation measures.[78] A 2009 survey of farmers' attitudes and behaviours found 39 per cent of farmers were working to become more resilient to severe weather patterns.[79] There is no more recent survey data available.

There is investment occurring across the sector into the development of breeds and species that are more resilient to the impacts and implications of climate change (eg, increased drought tolerance, and to increased threats from pests). Some representatives of the forestry industry have noted that restrictions on genetic modification are hindering progress on some potential adaptation responses.

The primary sector is reducing risks by adapting	**MORE WORK REQUIRED**

Examples of farmers reducing current climate risk include irrigation developments and afforestation on erosion prone country, changes to livestock mix and use of improved genetics both in livestock and feed. We do not have the data/evidence to determine the extent to which this or other de-risking is occurring or has long-term efficacy under a changing climate.

Under the Primary Sector Recovery Policy, the New Zealand Government currently helps rural communities and individuals recover from adverse events, including severe weather and biosecurity incursions. This policy is currently being reviewed to ensure it is fit for purpose and is due to be completed mid–2018. This review could provide insights on the extent to which proactive adaptation responses by the primary sector reduce the need for government support.

78 CCII RA4 Synthesis Report (http://ccii.org.nz/wp-content/uploads/2017/01/RA4-Synthesis-report.pdf)

79 Reference: Neilson, 2009 Sustainable Land Management and Climate Change Technology Transfer: Setting Benchmark Measures.

Overview

The sector's progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what's happening	**Maintain**
	Understand what it means for them	**More work required**
ORGANISED	Know what is expected of them	**More work required**
	Has common goals	**Significant work required**
	Has a planned approach	**Significant work required**
	Has the tools they need	**More work required**
DYNAMIC ACTION	Is taking action	**More work required**
	Is being flexible	**More work required**
	Is adapting	**More work required**

5.7 Other business

Key findings:

- The majority of businesses surveyed understand the future trends in climate that New Zealand can expect to experience.
- While we are not aware of any overall plans for adaptation in this sector, the majority of survey respondents have noted their intent to manage climate change impacts in the future. However, we do not have information on how they intend to do this.
- The private sector is driven by market conditions and as such has the ability to respond much more quickly to change compared with the Government. Increased range in climate variability may however challenge that ability.

5.7.1 Role in climate change adaptation

Businesses have a role in understanding climate risks to their assets and activities, and are generally best placed to manage these risks.

5.7.2 Engagement undertaken

A survey on adaptation was sent to a number of businesses, primarily through Business New Zealand and the Sustainable Business Council. Seventeen responses were received from a range of business types. Sectors covered included energy, consulting, tourism, technology, manufacturing and consumer goods.

5.7.3 Work towards effective adaptation

Informed

The business sector understand the climate-related changes New Zealand can expect in the medium and long term	MORE WORK REQUIRED

Of the businesses which responded to this survey, over 85 per cent were concerned about the impacts of climate change in New Zealand. Most of those businesses which expressed concern also noted a general understanding of the future trends in climate that New Zealand can expect to experience.

The business sector understand the impacts of the climate-related changes and what this means for them	SIGNIFICANT WORK REQUIRED

In the majority of cases, businesses have not yet fully considered the implications of climate change.[80] This is confirmed through surveys undertaken in the Climate Change Impacts and Implications Project (2016) which concluded 'serious questions regarding the capacity of private interests to manage changing risk profiles over time remain largely unanswered, since they are yet to consider them'.

The lack of nationally consistent climate hazard data was noted as a gap in information for business.

Responses received from the surveys however did illustrate some understanding of the impacts of future expected changes in climate.

Organised

The business sector know what is expected of them	SIGNIFICANT WORK REQUIRED

We have seen little evidence of businesses factoring climate change impacts in their planning and decision-making. This may be because it is unclear that this is expected of them.

The business sector has common goals	NOT PRESENT

There are no common goals on adaptation for this sector.

80 In the majority of cases, the businesses that responded were more focused on climate change mitigation (including ways to reduce their emissions or how a transition to a low carbon economy may impact on their operations).

The business sector has a planned approach	**SIGNIFICANT WORK REQUIRED**

We are not aware of any overall plans for adaptation in this sector. However, 86 per cent of respondents to our survey noted they have plans to manage climate change impacts in the future. We do not have information on how they intend to do this.

The business sector has the tools they need	**SIGNIFICANT WORK REQUIRED**

Some businesses have thought about the tools they need to adapt however they have also identified barriers to acting on climate change adaptation, including:

- the perception that acting on it will cost more (rather than save money in the long run)
- resourcing insufficiencies, including time and lack of qualified support and data
- some customers do not believe that climate change will affect them
- “there is not yet a complete picture of adaptation required”.

Dynamic action

The business sector is taking anticipatory action	**SIGNIFICANT WORK REQUIRED**

We have only seen some examples of businesses actively thinking about how they could adapt to the impacts of climate change. This includes:

- educating the public on biodiversity loss and actions that can be taken to address this (Wellington Zoo)
- planning to help improve the resilience of their freight transport
- encouraging clients to factor the impacts of climate change into their planning
- advocacy, including developing education and training materials
- looking at what other business areas/opportunities they might participate in, and planning for change overtime.

While these are positive examples of early steps being taken, many of these examples are of the business helping others to adapt, for example through the work of the Sustainable Business Council. We are confident to conclude that the majority of businesses are not currently factoring climate change impacts in their decisions.

The business sector is being flexible	**NOT PRESENT**

Businesses are generally much quicker to respond to market conditions and changes compared to the public sector.

The business sector is reducing risks by adapting	NOT PRESENT

Examples of businesses adapting to climate change are generally limited to those outlined above.

Overview

The sector's progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what's happening	More work required
	Understand what it means for them	Significant work required
ORGANISED	Know what is expected of them	Significant work required
	Has common goals	Not present
	Has a planned approach	Significant work required
	Has the tools they need	Significant work required
DYNAMIC ACTION	Is taking action	Significant work required
	Is being flexible	Not present
	Is adapting	Not present

5.8 Iwi/Māori

Key findings:

- Climate change is a significant issue for iwi/hapū, with many recognising that if this generation does not take action then a higher burden will fall on future generations.
- Considerable work has been undertaken by Māori authorities and governance structures in generating iwi and hapū plans that identify climate change issues and implications.
- Supporting vulnerable whānau and Māori land owners and business to adapt to climate change is a key area of focus for iwi.

5.8.1 Role in climate change adaptation

In terms of responsibilities, there are a number of roles iwi could take on adaptation, including:

- considering climate change adaptation in their role as kaitiaki and business leaders to ensure a sustainable future
- sharing knowledge, including Māori environmental knowledge, to complement the management of climate change impacts
- understanding and managing climate change risks in marae, homes and communities, as well as considering it in business and investment decisions.

5.8.2 Engagement undertaken

To inform this section we reviewed relevant literature and engaged with the Climate Change Iwi Leaders Group and Ngāi Tahu. This does not represent all iwi.

5.8.3 Work towards effective adaptation

Informed

Iwi/Māori understand the climate-related changes New Zealand can expect in the medium and long term	**MORE WORK REQUIRED**

Although there is some isolated understanding (for example, as outlined in the case study 6 on Ngāi Tahu), overall Iwi/Māori do not appear to have a good understanding of potential climate-related changes.

Iwi/Māori understand the impacts of the climate-related changes and what this means for them	**MORE WORK REQUIRED**

Māori have a strong understanding of the intergenerational equity issues caused by climate change and the need for long-term solutions, however more work is required for Māori to understand how changes will impact them.

A number of studies have been undertaken to better understand the impacts on iwi, including:

- **NIWA** – carried out a number of studies on how they expect Māori society to be affected by climate change, including a series of place-based studies examining coastal Māori community adaptation and vulnerability
- **Ngāti Kahungunu** – working in partnership with GNS Science to explore the connections between science and mātauranga-a-iwi. The group are focusing on issues important to the Hawke’s Bay and Wairarapa iwi including the effects of climate change. Through interactive marae-based learning, participants are developing their understanding on issues critically important to iwi development, resilience, and environmental sustainability
- **the Deep South Science Challenge** – currently underway has a particular focus on Māori and adaptation. The Mātauranga science projects are built around four research themes: understanding climate change – linkages, pressure points and potential responses; exploring adaptation options for Māori communities; assistance to Māori business to aid decision-making and long-term sustainability; and products, services and systems derived from mātauranga Māori.

These studies indicate a need for further investment in science and research on the impacts on Māori and on how to enable adaptation for communities.

Organisation

Iwi/Māori know what is expected of them	**SIGNIFICANT WORK REQUIRED**

While we have seen many examples of a role being taken on adaptation, a consistent message we have heard is that there are mixed messages from government on the importance of acting on climate change adaptation which creates confusion on what is expected of them.

Iwi/Māori have common goals	**NOT PRESENT**

There is no common set of outcomes and goals for climate change adaptation across Māori.

Iwi/Māori have a planned approach	NOT PRESENT

Considerable work has been done by Māori authorities and governance structures in generating iwi and hapū plans that identify climate change issues and implications. These documents provide important mechanisms for communicating Māori approved positions, interests and visions about climate change adaptation and the wider management and protection of natural and physical resources.[81] Key themes in many of these documents are education, planning and monitoring, environmental degradation, tribal self-determination, cooperation and collaboration. However, we are not aware of an overarching plan for adaptation.

Iwi/Māori have the tools they need	**SIGNIFICANT WORK REQUIRED**

Māori have identified a number of gaps in the development or application of tools they need to adapt. These include:

- understanding of the impacts of climate change and how to enable adaptation in Māori communities
- the need for a longer term view in government policies on climate change
- consistent messages from across government on climate change adaptation
- resourcing and capacity to consider and take action onclimate change adaptation.

Dynamic action

Iwi/Māori are taking anticipatory action	**SIGNIFICANT WORK REQUIRED**

Iwi appear to be in the early stages of acting on adaptation, including collecting information on the potential impacts on them and thinking about options for how they can respond. We have not undertaken an extensive assessment of work programmes underway by iwi. However, we are aware of a few.

81 Rouse, HL, Bell RG, Lundquist CJ, Blackett PE, Hicks BM & King DN, 2016, *Coastal adaptation to climate change in Aotearoa-New Zealand.*

The Climate Change Iwi Leaders Group (CCILG)[82] has initiated a five year work programme aimed at ‘preparing our people to meet the challenges and the opportunities of climate change head on’. The project is broader than adaptation and also considers mitigation. The project is at an early stage but will include an element of education and learning programmes, research into the expected impacts at the local scale and identifying specific tools to enable resilience. Ngāi Tahu is currently developing a climate change strategy as set out in the *Case Study 6: Ngāi Tahu*.

Iwi/Māori are being flexible	SIGNIFICANT WORK REQUIRED

More work is required to understand what is needed for managing the cultural and economic impact of the risks and opportunities of climate change.

Iwi/Māori are reducing risks by adapting	NOT PRESENT

Although we can see there is a focus on thinking about adaptation and how to go about it, we have seen few examples of actions currently being taken to reduce the risks.

Overview

The sector’s progress towards an effective adaptation system is considered as:

Characteristic	Attribute	Rating
INFORMED	Understand what’s happening	More work required
	Understand what it means for them	More work required
ORGANISED	Know what is expected of them	Significant work required
	Has common goals	Not present
	Has a planned approach	Not present
	Has the tools they need	Significant work required
DYNAMIC ACTION	Is taking action	Significant work required
	Is being flexible	Significant work required
	Is adapting	Not present

82 CCILG is a national grouping with its membership identified by the Iwi Chairs Forum which is made up of the Chairs of Tribal Iwi Authorities drawn from Iwi throughout New Zealand and bisecting the country’s geographical characteristics.

CASE STUDY 6: NGĀI TAHU

In 2016 Ngāi Tahu tribal governance identified the need to develop a strategy to give Ngāi Tahu direction in ensuring resilience in the face of the impacts of climate change.

Ngāi Tahu currently has around 55,000 registered whānau members from many walks of life, and a broad range of tribal business interests. The iwi is kaitiaki of a takiwā that showcase a broad, diverse range of landscapes, freshwater and marine environments, and the species that inhabit them. This diverse set of circumstances means developing a strategy that captures all the aspects necessary to combat and adapt to climate change is no small feat. However, it is because of that diversity and the risks and opportunities posed, that makes this a high priority kaupapa for Ngāi Tahu.

Te Rūnanga o Ngāi Tahu staff began engaging with whānau to get a grasp of what particular aspects of climate change were having the greatest impact, and what pressures or opportunities were being seen across the takiwā. Parallel to this process a report by NIWA was commissioned. The report contained no unique scientific data, but applied existing knowledge to help Ngāi Tahu understand how their tūrangawaewae and the resources they rely on to sustain themselves physically, economically, and culturally are expected to be affected as the climate changes. These processes provided some indications of the current situation, some pathways forward, and direction as to the values and aspirations Ngāi Tahu whānau want to see supported.

Te Rūnanga o Ngāi Tahu are guided by the whakatauki 'Mō tātou, ā, mō kā uri, ā muri ake nei' – For us, and our children after us. This strategy will be an important step to ensuring that iwi will continue to thrive by making decisions that will sustain the growing tribal membership for generations to come.

5.9 Civil society

Key findings:

- Academics and the research community supply information to all sectors of society to help enable proactive and purposeful adaptation. Current research includes refinement of the range of expected impacts and how to implement appropriate responses.
- We do not currently have the information to determine whether community groups, Non-Government Organisations and/or the public understand the climate-related changes New Zealand can expect or the possible implications it has for them.
- Engagement with civil society is required to understand how civil society is organised to act and are acting to adapt to climate change.

5.9.1 Role in climate change adaptation

Civil society and their role in climate change adaptation include:

- **academics and the research community** – provide information through commentaries and dialogue with all sectors of society to help enable proactive and purposeful adaptation
- **community organisations and Non-Governmental Organisations (NGOs)** – have a critical place in encouraging change by raising awareness (CCII R4), as well as respond to the impacts. They are usually formed by groups of individuals that aim to promote or express a common purpose through ideas and actions from local through to international levels
- **the public** – has a key role in being informed about climate change impacts when making property purchase decisions (for example, decisions about where they live and invest). Public agencies are mandated to provide risk reduction information that inform those decisions.

5.9.2 Work towards effective adaptation

Informed

Extensive research has been undertaken on climate change adaptation, with key focus areas being on primary industries; biodiversity, biosecurity and conservation; governance and institutions that influence adaptation decision-making; and barriers and enablers to adaptation decision-making and coastal issues.

Early research on adaptation focused on establishing the expected climate-related changes (under a range of plausible scenarios of future climate) and the impacts this would have at more detailed regional scale. This basic information and its ongoing updating is a necessary foundation for action.

Research is now focused on identifying and assessing potential solutions; the decision-making processes required to implement them; and the barriers to this occurring. The current state of adaptation research includes continued refinement of the range of changes expected, together with research on how to implement appropriate responses, and some recent focus on improving understanding of the issues. This shift in research emphasis has begun to be reflected in international advice for policy makers. For example, the Intergovernmental Panel on Climate Change has introduced a larger element of social science research, risk and adaptive management approaches, and the importance of engagement with communities in its programme for the Sixth Assessment cycle (2016–2022).

Community groups, non-governmental organisations and the public have understanding of climate change but what it means for them varies significantly across the country. Recent studies on public perceptions of climate change in New Zealand show that while New Zealanders are concerned about climate change, this concern ranks lower for climate change than for other more personally or locally relevant concerns including healthcare, cost of living and education. This may be because New Zealanders consider climate change a future risk rather than something that concerns them today. Understanding what drives these priorities will be important.

Additionally, we see that that they are much more focused on climate change mitigation (and have an understanding of steps they can individually take to reduce emissions) and there is less of an understanding on adaptation (and the options available to adapt), in part because it is public authorities with their communities that will be initiating adaptation action.

Organised

The research community fulfils a role in society of independent scholarship and public commentary on societal issues and has an ongoing role with respect to climate change adaptation. Academia through its teaching programmes also builds the skills and knowledge in the next generation of researchers and practitioners. With respect to research, universities compete for programme funding just like consultants and crown research institutes do. Increasingly though they are part of teams or lead research across these research providers. They also act as independent facilitators and knowledge brokers working with practitioners to develop policy and practice solutions, able to introduce new processes and tools through access to international networks of problem solvers and scholarship. Multi-disciplinary projects will enable such new information and networks to leverage adaptation action.

The IPCC serves as a weak coordination mechanism that synthesises the peer reviewed knowledge globally on about a 7 year cycle. There is however a general lack of coordination that results from there being no national adaptation strategy to guide the research undertaken in New Zealand. While the National Science Challenges have given attention to some aspects of climate change, there is no cross-challenge climate change theme that can integrate the key Science Challenges. This would help to focus attention on the gaps in adaptation research.

Dynamic action

The greater focus from researchers on the 'how' has resulted in a number of tools being developed that enable uncertainty and changing risk profiles to be addressed. These include:

- **Urban Impacts Toolbox** – a resource to help planners, engineers, asset managers, and hazard analysts in New Zealand urban councils understand and evaluate the potential impacts of climate change in their city
- **Dynamic Adaptive Pathways Planning** – an exploratory model-based planning tool that helps design adaptive and robust strategies using different future scenarios to stress test adaptation options
- **simulation games** – to help experience decision-making under uncertainty over the long term. The Sustainable Delta Game adapted for New Zealand conditions, simulates decision-making in a river catchment or coastal setting and helps participants to learn about preparing an adaptive plan.

CASE STUDY 7: A CONVERSATION WITH YOUTH REPRESENTATIVES ABOUT CLIMATE CHANGE ADAPTATION

The Ministry for the Environment convened a meeting with youth representatives from social NGOs in Wellington to discuss their views on climate change adaptation.

A number of issues were discussed ranging from legacy issues to opportunities and enablers they see for climate change adaptation. Some of their key concerns for New Zealand's future include:

- the legacy issues they will inherit when they are decision-makers
- understanding the risks and vulnerabilities for communities (ensuring adequate future proofing for flooding, erosion, impacts on freshwater)
- future food security – increased agricultural pressures within already stressed environmental limits
- loss of biodiversity and conservation values (ability to access and enjoy the wilderness)
- the need to tell an empowering narrative for climate change – the need for the framing of climate change to be accompanied with what action can be taken and what achievable goals look like (eg, concern over youth suffering pre-traumatic stress as a result of fear for the future state)
- increased public health problems (eg, asthma, *E. coli* in water and food sources).

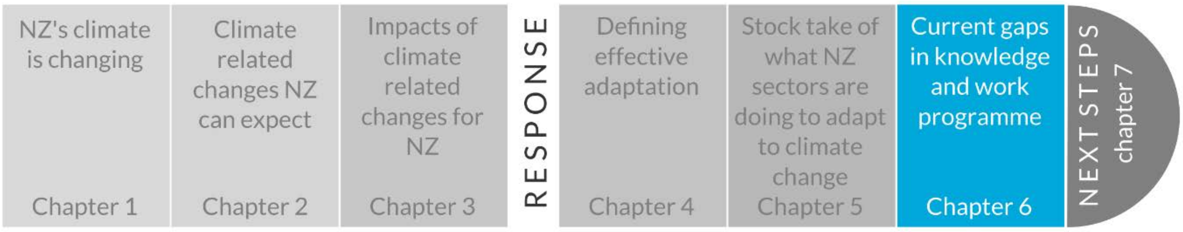
The youth representatives expressed their concerns over the action and inaction consecutive governments have taken/not taken with regard to climate change. They recognise the Paris Agreement as an achievement, but question how effective we will be at implementing it and preventing further greenhouse gas emissions. They recognise that short-term decision-making will negatively affect them and future generations, but are concerned they do not have the influence needed to advocate for government to ensure policies and action are adequate and take a long-term vision.

Compounding the issue surrounding youth and their perception of climate change adaptation, Māori youth feel like they are in an especially vulnerable position. Having already experienced land and resource losses, they believe that climate change will increase their vulnerability. Land that is returned in settlements may be unproductive in the future and there is uncertainty around how their rural communities will adapt to these changes.

Youth are taking their own action, organising themselves around issues and lobbying for the change their generation see as necessary.

They want a voice at the table on policy decisions, to be included in co-design solutions and want easier access to research and information. Above all, they want to know what they can do and task us with ensuring the narrative around climate change adaptation is empowering and inspires future generations with hope.

6 Current gaps in knowledge and work programmes and overall summary of the New Zealand stocktake



This section summarises key findings from the stocktake and identifies gaps in New Zealand's current approach to climate change adaptation.

Overall we found that New Zealand is in the early stages of planning for climate change and that many positive initial steps have been taken in some areas and sectors – it is in the informed phase, with some areas having advanced to the organised phase. However, there are considerable gaps in our current approach that act as a barrier to adaptation. New Zealand's current approach to adaptation is described in the following sections, grouped according to each of the three characteristics of effective adaptation.

6.1 Informed phase

New Zealand has developed a significant amount of information about what is happening to our climate and the impacts of a changing climate. However, this is not currently all in forms that can support adaptive decision-making. This means information is either not accessible to decision-makers, decision-makers do not have the capacity or capability to make decisions, or they are not able to prioritise adaptation action based on current information.

There are some information gaps which could hamper adaptation action, including:

- an understanding of social vulnerability and how to assess it
- the potential costs to the economy, as well as social costs, over the medium and long term if no action is taken to adapt now
- the potential biosecurity threats to the various sectors of our economy
- how pluvial flooding responds to changes in climate
- how our natural systems may respond to greater climate variability and increased intensity in climate events
- nationally-consistent standards for assessing local climate change risks and opportunities

- making existing information readily available to sectors in forms that are relevant to their decision-making.

The lack of a nationwide assessment of climate risks means that it is difficult for New Zealand to develop a planned approach for climate change adaptation because priorities for action cannot yet be articulated. This would be the first step towards an aligned approach across all sectors to help stimulate action in a systematic way.

6.2 Organised phase

New Zealand's focus on adaptation to date has mainly been on improving its information base about climate risks and opportunities. There has been less of a focus on organising ourselves, in a coordinated manner, to translate this information for decision making on adaptation. At this stage New Zealand does not have a coordinated plan for how to adapt to climate change.

A key barrier is that climate change adaptation is not currently integrated into many central government agency objectives. In the absence of coordinated leadership on climate change adaptation, other sectors operate within regulatory frameworks and policies which are not well aligned or fit for purpose for adaptation. This makes it difficult for government and sectors to proactively organise themselves and take action.

Other organisational gaps include:

- no strategy, plan or common goal for how New Zealand can adapt to climate change
- unclear roles, responsibilities and liabilities (which makes investment in resources to deliver adaptation action challenging)
- inconsistencies in timeframes and in some instances competing objectives across legislation and policies related to climate change adaptation, resilience and disaster risk reduction
- limited enabling tools to help facilitate adaptation, including the use of national direction tools
- lack of alignment in how climate change adaptation and resilience objectives are incorporated into legislation and policy.

6.3 Dynamic action phase

We have seen a few examples of proactive adaptation action where there is high exposure and potentially large costs involved (eg, investment in flood risk and coastal hazard management and some transport projects). However, overall there is limited evidence of proactive action that reduces medium- and long-term changing and increasing risk profiles. In most cases, actions have been reactive and part of a sector's natural hazard management response after extreme events occur, rather than being proactive and undertaking preventative measures which take a long-term view and consider the wider impacts.

Key gaps include:

- resource scarcity, including insufficient expertise and funding, was identified as a barrier to action by all sectors
- limited monitoring and evaluation of existing climate change adaptation measures hampering our ability to adjust our approach in response to changing risks, issues, opportunities and circumstances that emerge.

6.4 Overall summary

Table 6.1 provides a summary of each sector's current approach to climate change adaptation associated with the characteristics for effective adaptation.

Based on these findings, we can conclude that while some specific actions are being taken to adapt to climate change, the current decision-making framework does not support or incentivise effective adaptation at the scale we consider necessary for maintaining and/or improving the well-being of New Zealand's current and future communities in the face of a changing climate.

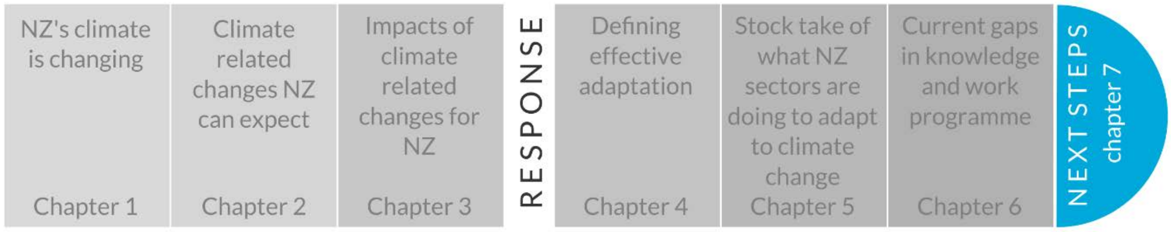
It is important that action that is being taken now is maintained and built upon. This includes work in the informed phase and specifically investment in research, for example through the Deep South and Resilience Science Challenges and other climate change-relevant programmes to understand the ongoing changes in climate that New Zealand can expect, the implications of these for our main hazards and social, economic and natural systems, tools to assess climate and social vulnerability and analytical tools to support decision-making processes. Some New Zealand communities facing significant current and ongoing impacts are more informed than others about the further changes they can expect.

Table 6.1: Overview of what New Zealand is currently doing to adapt to climate change assessed against the characteristics and attributes of effective adaptation system identified in Chapter 4

	ATTRIBUTES	PUBLIC SECTOR		PUBLIC AND PRIVATE SECTOR			PRIVATE SECTOR			CIVIL SOCIETY
		Central Government	Local Government (excluding infrastructure)	Infrastructure providers	Finance and insurance	Health providers	Primary sector	Other business	Iwi/Māori	
INFORMED	They understand what's happening									
	They understand the implications of the climate-related changes and what this means for them									
ORGANISED	They know what's expected of them									
	They have common goals									
	They have a planned approach									
	They have the tools they need									
DYNAMIC ACTION	They are taking anticipatory action									
	They are being flexible									
	They are reducing risks by adapting									

ASSESSMENT:	Maintain	More Work Required	Significant work required	Not present
	There is evidence that all descriptors of the attribute are in place	There is evidence that most descriptors of the attribute are in place	There is evidence that some descriptors of the attribute are in place	There is no evidence that any descriptor of the attribute is in place

7 Next steps



This stocktake report provides an overview of New Zealand's current progress towards developing an effective approach to adaptation.

The Group acknowledge that it has been challenging to summarise and reflect the broad range of perspectives, actions and initiatives currently being undertaken across New Zealand to adapt to climate change.

The information provided in this report represents the best information available to the Group and our expert judgement. The gaps in knowledge and work programmes signify those present as of 31 May 2017.

The next step is to use this stocktake report as a basis for our second report on options for how New Zealand can address the challenges identified and build resilience to the effects of climate change while growing our economy sustainably.

Our final report will be submitted to the Minister for Climate Change by March 2018.

Glossary

Adaptation — The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2014c, annex II).

Adaptive capacity — The resources available for adaptation to climate change and variability or other related stresses, as well as the ability of a system to use these resources effectively in pursuit of adaptation (Brooks and Adger, 2004).

Adaptive management — A structured process that addresses a changing state that is dynamic and cannot be predicted over the long term, and where the change is irreversible in human timeframes so there is no reversion to an earlier state. It is flexible decision-making that can be adjusted in the future as conditions change, thus reducing risk by avoiding lock-in of decisions that are costly to change later.

Climate-related changes — Changes to the climate and other environmental variables resulting from increased concentrations of greenhouse gases in the atmosphere. These include changes to climate variables, such as temperature and rainfall, changes to the oceans (warming, acidification and sea-level rise), and associated changes to natural hazards.

Co-benefits — Co-benefits are the added benefits of climate change adaptation, above and beyond the direct benefits of improved resilience to future climate change. For example, coastal and land use planning and flood protection work can reduce present economic losses and social and cultural impacts from floods and coastal erosion; building more resilience to drought into our agricultural and horticultural activities has immediate financial benefits for rural communities and the economy overall; reducing pests and diseases will help our ecosystems now and set them up to better cope with future changes.

Exposure — The presence of people, livelihoods, ecosystems, environmental functions, services and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by natural hazards and climate change (adapted from IPCC, 2014c, annex II).

Impacts — Effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate change or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system (IPCC, 2014c, annex II).

Mitigation Human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014c, annex II) and limit further climate change.

Resilience There are many definitions of resilience, most of which cover concepts such as the ability of a system to withstand and/or cope with disruption, disturbance or hazardous events. Some also cover the concept of adaptability and flexibility, as well as, early discovery and rapid recovery from failure. Some distinguish between bouncing 'back' and bouncing 'forward' from an event. The IPCC (2014c annex II) defines resilience as the capacity of social, cultural, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.

Risk Effect of uncertainty on objectives (AS/NZS ISO 31000:2009, Risk management standard). Risk is often expressed in terms of a combination of consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

Vulnerability The predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including: sensitivity or susceptibility to harm or damage, and lack of capacity to cope and adapt (adapted from IPCC, 2014, annex II).

Appendix 1: Terms of Reference

Climate Change Adaptation Technical Working Group

In July 2016 Cabinet agreed to the establishment of a Climate Change Adaptation Technical Working Group (the Group) to provide advice to the Government on adapting to the impacts of climate change.

Under the Paris Agreement, New Zealand is required to plan for and take action on adapting to the impacts of climate change.

1. The Group will provide to the Minister for Climate Change Issues:

   (i) An **interim report by May 2017.** This interim report should include a summary of the expected impacts of climate change on New Zealand over the medium and long term and a stocktake of existing work on adaptation, by both central and local government. The stock take should identify any gaps in knowledge and work programmes.

   (ii) A **draft final report by November 2017.** The report should identify options for how New Zealand can build resilience to the effects of climate change while growing our economy sustainably. The report should identify the benefits and limitations of New Zealand having an integrated economy-wide approach to adaptation. Any recommendations should not be policy-prescriptive,[83] should build on the findings of the interim report and provide a range of options.

   (iii) A **final report by March 2018**, with final recommendations. The recommendations are not to be policy-prescriptive and should provide a range of options for consideration.

Mode of work

2. The members of the Group are to also provide advice to technical questions from officials and Ministers throughout the process on an as needed basis.
3. Opportunities will be explored for community interaction to inform the work of the Group where appropriate.
4. The Group will be supported by a small secretariat based at the Ministry for the Environment.
5. The Group will draw upon a range of people from Government agencies and the private sector to inform specific elements of the work being undertaken.
6. The Group will not revisit New Zealand's climate change targets, look at options to mitigate climate change, get involved with international negotiations, investigate options which would replace or discontinue the New Zealand Emissions Trading Scheme, write policy, or develop regulations or legislation.

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[83] The purpose of the Group is not to draft legislative tools, but to provide advice and options for consideration by the Government.

Membership of the Climate Change Adaptation Technical Working Group

7. The members of the Group are appointed for a fixed period (November 2016 to March 2018) and the membership is listed in the Annex. However following the interim report, the membership of the Group could rotate depending on the issues identified.

8. The Group will be co-chaired by Penny Nelson, Deputy Secretary Sector Strategy, Ministry for the Environment and Dr Judy Lawrence, Victoria University Wellington.

9. The members of the Climate Change Adaptation Technical Working Group will be subject to confidentiality arrangements[84].

10. Members of the Climate Change Adaptation Technical Working Group will receive fees as appropriate and reimbursement for travel.

Meetings and reporting

11. The Climate Change Adaptation Technical Working Group will interact regularly (including meetings and using electronic means), with the frequency of meetings being not more than approximately every six weeks.

12. It is anticipated that the reports will be made publically available.

Annex 1: Membership of the Climate Change Adaptation Technical Working Group

- Dr Judy Lawrence, Senior Research Fellow, Climate Change Research Institute, Victoria University of Wellington (co-chair)
- Penny Nelson, Deputy Secretary Sector Strategy, Ministry for the Environment (co-chair)
- Frances Sullivan, Principal Policy Advisor, Local Government New Zealand
- Kirk Hope, Chief Executive, BusinessNZ
- James Hughes, Associate Director – Climate and Resilience, AECOM*
- Bryce Davies, Senior Manager Government and Stakeholder Relations, IAG
- Bruce Wills, Horticulture NZ Board, Motu Trustee and previous President of Federated Farmers
- Dr Sam Dean, Chief Scientist for the Climate and Atmosphere Centre, NIWA
- Whaimutu Dewes, Lead Advisor to the Climate Change Iwi Leaders Group
- Dr Gavin Palmer, Director Engineering, Hazards and Science, Otago Regional Council

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84 These arrangements are not intended to prevent the Group from engaging and consulting with stakeholders.
* James Hughes is now the Climate and Resilience Specialist at Tonkin + Taylor.

Appendix 2: Societal sectors and sub-sectors

Sector		Examples
PUBLIC SECTOR	Central government	*Departments and ministries* *Regulators*
	Local government	*Regional councils* *Unitary authorities* *Local councils*
PRIVATE SECTOR	Infrastructure	*Electricity generation and transmission* *Water, wastewater and stormwater* *Communications* *Roads* *Ports and airports*
	Finance	*Banking and non-bank deposit takers* *Life, health and general insurance* *Investments and funds management*
	Health	*Hospitals* *Primary care providers*
	Primary	*Agriculture* *Horticulture* *Forestry* *Fishing and aquaculture* *Mining*
	Transport (addressed within the Infrastructure section)	*Road* *Rail* *Shipping* *Air*
	Tourism	*Accommodation; food and hospitality; arts and recreation*
	Other business	*Retail; wholesale trade; manufacturing; construction; education; professional services*
PARTNERS	Iwi	
	Community organisations	
	Academia	
	The public	

Appendix 3: Stakeholders we engaged with

Central government agencies:

1	Ministry of Health NZ
2	Ministry of Social Development
3	Health Quality & Safety Commission
4	Ministry of Education
5	Ministry of Civil Defence and Emergency Management (DPMC)
6	Department of the Prime Minister and Cabinet
7	Ministry of Business, Innovation and Employment (MBIE)
8	Land Information New Zealand (LINZ)
9	Local Government New Zealand (LGNZ)
10	Ministry of Transport
11	Te Puni Kōkori
12	Ministry for Primary Industries (MPI)
13	Department of Conservation (DOC)
14	Department of Internal Affairs (DIA)
15	New Zealand Treasury
16	Ministry for the Environment (MfE)
17	Commerce Commission
18	Energy Efficiency Conservation Agency (EECA)
19	Environmental Protection Authority (EPA)
20	NZ Defence Force (NZDF)
21	Ministry for Culture and Heritage
22	Maritime NZ
23	Ministry for Pacific Peoples
24	Ministry for Women
25	Reserve Bank of New Zealand
26	Office of the Children's Commissioner
27	Health Research Council of New Zealand
28	Health Promotion Agency (HPA)
29	Social Policy Evaluation and Research Unit (SUPERU)
30	Fire Emergency New Zealand/New Zealand Fire Service
31	Ministry of Defence

32	Productivity Commission of New Zealand
33	New Zealand Tourism Board
34	Statistics New Zealand
35	Heritage New Zealand

Local government:

1	Auckland Council
2	Bay of Plenty Regional Council
3	Buller District Council
4	Canterbury Regional Council/Environment Canterbury
5	Dunedin City Council
6	Far North District Council
7	Gisborne District Council
8	Gore District Council
9	Greater Wellington Regional Council
10	Grey District Council
11	Hamilton City Council (not the template, but provided information)
12	Hastings District Council
13	Hauraki District Council
14	Horowhenua District Council
15	Hurunui District Council
16	Hutt City Council
17	Kaipara District Council
18	Manawatu District Council
19	Marlborough District Council
20	Masterton District Council
21	Matamata—Piako District Council
22	Napier City Council
23	Nelson City Council
24	New Plymouth District Council
25	Northland Regional Council
26	Opotiki District Council
27	Otago Regional Council
28	Palmerston North City Council
29	Porirua City Council
30	Rangitikei District Council
31	Ruapehu District Council
32	Selwyn District Council
33	South Taranaki District Council
34	South Waikato District Council

35	South Wairarapa District Council
36	Stratford District Council
37	Taranaki Regional Council
38	Tasman District Council
39	Taupo District Council
40	Thames—Coromandel District Council
41	Waikato District Council
42	Waikato Regional Council
43	Waipa District Council
44	Wairoa District Council
45	West Coast Regional Council
46	Western Bay of Plenty District Council
47	Westland District Council
48	Whanganui District Council

Infrastructure and transport:

In addition to relevant central and local government stakeholders who manage infrastructure, we also engaged with:

1	NZ Transport Agency
2	Kiwirail
3	Trustpower
4	Wellington Water
5	Watercare
6	Meridian Energy

Primary industries:

1	Horticulture NZ
2	Fonterra
3	Fertilizer Association
4	DairyNZ
5	Beef and Lamb NZ
6	Peter Weir (Ernslaw One)
7	Peter Clark (PF Olsen Ltd)

District health boards:

1	Waitemata District Health Board
2	Counties Manukau District Health Board

Appendix 4: Adaptation research and information

One of the most important roles central government has taken on adaptation has been on funding research and providing information to help build an understanding of the impacts and implications of climate change across New Zealand. This research and information includes:

- **The Deep South Challenge** (2015–2019) **–** a current four-year programme with a mission 'to enable New Zealanders to adapt, manage risk and thrive in a changing climate.' It has three research programmes: Processes and Observations, Earth System Modelling and Prediction, and Impacts and Implications; as well as two cross-cutting programmes: Engagement and Vision Mātauranga. The Impacts and Implications programme is the current provider of most adaptation-relevant research in New Zealand http://www.deepsouthchallenge.co.nz/along with the Resilience Science Challenge https://resiliencechallenge.nz/
- **National Science Challenges –** a number of current Challenges that are relevant to adaptation including Resilience to Nature's Challenges (which includes a 'Living at the Edge' work programme focused on communities that are highly vulnerable to natural hazards; and a Resilience Governance programme); New Zealand's Biological Heritage; Our Land and Water; Sustainable Seas; and Building Better Homes, Towns and Cities http://www.mbie.govt.nz/info-services/science-innovation/national-science-challenges
- **The Sustainable Land Management and Climate Change (SLMACC) programme –** launched in 2007 and ongoing, aims to help the agriculture and forestry sectors address the challenges arising from climate change. Much of the output of the programme has been compiled into a web-based adaptation resource http://www.climatecloud.co.nz
- **The Coastal Acidification: Rate, Impact and Management Project** (2016–2019) – will provide new knowledge on coastal acidification to enhance the protection and management of coastal ecosystems https://www.niwa.co.nz/coasts-and-oceans/research-projects/carim-coastal-acidification-rate-impacts-management
- **The Climate Change Impacts and Implications (CCII) programme** (2012–2016) – focused on the significance of considering climate change impact in decision-making and on enhancing capacity and increasing coordination to support this http://ccii.org.nz/
- **The Conservation and Environment Science Roadmap** (2017) – identifies the development of adaptation scenarios that test and demonstrate the sensitivity of New Zealand's environment, economy and society to climate-related impacts as a priority research area within the first five years http://www.mfe.govt.nz/sites/default/files/media/About/cesr-at-a-glance.pdf

- **Climate Change Projections for New Zealand** (2016) – provides updated projections of atmospheric changes in New Zealand as a result of climate change http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/nz-climate-change-projections-final.pdf
- **Environmental Health Indicators on Climate Change** (2014) – monitors New Zealand's health through a set of environmental health indicators related to climate change http://www.ehinz.ac.nz/indicators/climate-change/
- **Preparing the Tourism Sector for Climate Change Project** (2009–2012) – provides information on the impacts of climate change on the sector, and identifies adaptation strategies to increase the ability of tourism decision-makers to cope with future changes http://researcharchive.lincoln.ac.nz/handle/10182/4376?show=full
- **Impacts of Climate Change on Urban Infrastructure and the Built Environment: Toolbox Handbook** (2012) – provides information to help local councils understand and evaluate the potential impacts of climate change in their cities https://www.niwa.co.nz/sites/niwa.co.nz/files/cc_and_urban_impacts_toolbox_handbook.pdf
- **The Coastal Adaptation to Climate Change Research Project (2011)** – includes a national coastal sensitivity profile https://www.niwa.co.nz/climate/research-projects/coastal-adaptation-to-climate-change
- **Adaptation to climate variability and change** (launched in 2009) **–** this and the previous NIWA programme aimed to increase New Zealand's scientific understanding of the climate system, our ability to predict the climate, and decision-making tools to help New Zealand adapt to climate variability and change https://www.niwa.co.nz/climate/research-projects/adaptation-to-climate-variability-and-change
- **The Community Vulnerability Resilience and Adaptation to Climate Change programme** (2008–2011) – focused on developing a consistent framework for considering potential vulnerability to climate change in New Zealand, and how to build social and structural resilience. It focused on Māori community responses to climate change, local government management of the climate risks and the effects of climate change on human health. http://www.victoria.ac.nz/sgees/research-centres/ccri/research/community-vulnerability,-resilience-and-adaptation-to-climate-change,-2008-2013

Appendix 5: Central government frameworks and tools on adaptation

Central government provides some frameworks and tools on adaptation as listed below:

- Climate Change Effects and Impacts Assessment (2008)
  http://www.mfe.govt.nz/publications/climate-change/climate-change-effects-and-impacts-assessment-guidance-manual-local-6
- Coastal Hazards and Climate Change Guidance (2017)
  http://www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-local-government
- Tools for Estimating the Effects of Climate Change on Flood Flow (2010)
  http://www.mfe.govt.nz/publications/climate-change/tools-estimating-effects-climate-change-flood-flow-guidance-manual-lo-10
- New Zealand Coastal Policy Statement Guidance Note (2010) (updated pending publication)
  http://www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/policy-statement-and-guidance/
- New Zealand's Framework for Adapting to Climate Change (2014)
  http://www.mfe.govt.nz/publications/climate-change/new-zealands-framework-adapting-climate-change
- Adaptation Framework for the Conservation of Terrestrial Native Biodiversity in New Zealand (2014)
  http://www.doc.govt.nz/Documents/science-and-technical/sap257.pdf
- National Civil Defence Emergency Management Plan (2015)
  http://www.civildefence.govt.nz/cdem-sector/cdem-framework/national-civil-defence-emergency-management-plan/
- The Thirty Year New Zealand Infrastructure Plan (2015)
  http://www.infrastructure.govt.nz/plan/2015/nip-aug15.pdf
- Biosecurity 2025 Direction Statement (2016)
  https://www.mpi.govt.nz/protection-and-response/biosecurity/biosecurity-2025/

Appendix 6: What are other countries doing?

The international policy environment for climate change adaptation includes the assessment reports of the IPCC, guidance and decisions developed and adopted under the UN Framework Convention on Climate Change (UNFCCC) and most recently the Paris Agreement where Parties agreed an adaptation goal of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change.

Each Party to the Paris Agreement is to engage in adaptation planning processes and the implementation of actions. It is against this backdrop that as part of the stocktake we have looked at how a number of developed countries have advanced their approaches to climate change adaptation, bearing in mind that how each country adapts to the impacts of climate change is dependent on each country's national circumstances, including the physical environment, societal context and government structures.

As summarised in the table below, the approaches taken vary across jurisdictions.

Country	Approach/approaches to climate change adaptation at a national level
Australia	**National Climate Resilience and Adaptation Strategy** Sets out how Australia is managing the risks of a variable and changing climate; identifies a set of principles to guide effective adaptation practice and resilience building; outlines the Australian Government's vision for a climate-resilient future. Planning and action at the national and sub-national levels. Australia's investments in research provide a strong foundation for the strategy.
Canada	**Federal Adaptation Policy Framework 2011** Enables the government to take account of climate risks when making decisions. **Vancouver Declaration on Clean Growth and Climate Change (March 2016)** Canada's first ministers agreed to develop a pan-Canadian Framework to achieve Canada's commitments in the Paris Agreement. This involved setting up a working group on preparing for and responding to the impacts of climate change. The Working Group on Adaptation and Climate Resilience released its final report in December 2016 which provides conclusions and options.
Germany	**German Adaptation Strategy 2009** together with **Adaptation Action Plan of the German Strategy for Adaptation to Climate Change 2011** Aims to reduce the vulnerability of the natural, social and economic systems, and to maintain and improve their capacity to adapt to the impacts of climate change. Federal government leads the process through each sector of government, and each sector is responsible for implementing the relevant portion of the plan. The plan promotes an integrated approach that considers the interactions between sectoral and regional activities, and seeks to anchor consideration of the possible climate change impacts in all relevant sectoral policies.

Country	Approach/approaches to climate change adaptation at a national level
United Kingdom	**Climate Change Act 2008** Sets a legally binding long-term framework including a five-yearly UK-wide climate change risk assessment; and a National Adaptation Programme which sets out the Government's objectives, proposals and policies for responding to the identified risks (every five years) and also sets out how businesses and society are adapting.
United States	**President's Climate Action Plan 2013** Includes a focus on preparing the United States for the impacts of climate change, followed by an **Executive Order** This contains more detail on implementation and formalised the creation of an interagency **Council on Climate Preparedness and Resilience** (replacing an earlier 2009 Task Force). Federal agencies must facilitate communities' efforts to strengthen resilience to extreme weather and prepare for other impacts of climate change, including impacts to their own assets and operations (eg, the USEPA Climate Change Adaptation Plan 2014). The objectives of the Council are to develop, recommend and coordinate interagency efforts; support regional, State, local and tribal action; facilitate the integration of climate science in policies and planning of government agencies and the private sector.

Regardless of the type of approach taken, they have a number of common themes and these are presented in the box below.

- Having a strong scientific evidence base, providing robust information and raising awareness.
- The importance of coordination, collaboration, cooperation and partnerships between central government and other levels of government, and across sectors and society. Shared responsibilities are important while acknowledging the importance of national leadership.
- Identification of priority sectors, including assisting and prioritising vulnerable people and regions.
- The need to anticipate the risks, be proactive and comprehensive.
- Factoring and integrating climate risk into decision-making.
- Taking a long-term view and building resilience.
- The importance of monitoring and evaluating progress towards building resilience with feedback into review of a strategy or plan.
- Looking for and taking advantage of opportunities for adaptation.

Barriers to adaptation were also identified by the countries we looked at, and relate to:

- market failures
- governance/institutional arrangements
- policy/regulatory settings
- cultural/behavioural aspects
- costs of and resources needed for action

- uncertainty in or lack of information
- moral hazard.

In the material examined for this section the importance of public engagement was highlighted by all countries.

The United Nations Framework Convention on Climate Change (UNFCCC) provides guidance for development of national adaptation plans[85] focused on incorporating integrated planning, country-specific solutions, and providing continuity. While this guidance is directed at developing countries it is has relevance for all countries, regardless of their level of development. Using this guidance as a reference, NIWA has undertaken a desktop review[86] of the national adaptation plans of nine developed countries looking at possible options for the structure and various elements of a New Zealand national adaptation plan.

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85 Summarised in http://unfccc.int/files/adaptation/application/pdf/nap_poster.pdf

86 Developing a national climate change adaptation plan (NAP) for New Zealand. Scoping Report. March 2017. https://www.niwa.co.nz/climate/research-projects/developing-a-national-climate-change-adaptation-plan-for-new-zealand

Appendix 7: Climate change published reports

Published research papers on adaptation in New Zealand

There are two key documents available which describes and reviews recent literature on climate change adaptation in New Zealand. These are:

- McKim, L, 2016, *A systematic review of recent research: Implications for policy and management, and tools to support adaptation decision making in New Zealand*. Prepared for the New Zealand Climate Change Research Institute, Victoria University of Wellington as part of the Climate Change Impacts and Implications (CCII) for New Zealand to 2100 research programme. MBIE contract CO1X1225. 59pp http://ccii.org.nz/wp-content/uploads/2017/01/RA4-Review-of-recent-research.pdf
- Reisinger, A & Kitching R, 2014, *IPCC Climate Change: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Australasia (Chapter 25)* https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap25_FINAL.pdf

The following lists other relevant documents that have merged since 2016 and were not captured in the above documents.

Impacts and implications

- Ausseil AGE, Bodmin K, Daigneault A, Teixeira E, Keller ED, Baisden T, Kirschbaum MUF, Timar L, Dunningham A, Zammit C, Stephens S, Bell R, Cameron M, Blackett P, Harmsworth G, Frame B, Reisinger A, Tait A, Rutledge D, 2017, *Climate Change Impacts and Implications for New Zealand to 2100: Synthesis report RA2 lowland case study*. *Synthesis Report LC2714. Climate Change Impacts and Implications for New Zealand to 2100.* http://ccii.org.nz/wp-content/uploads/2017/03/RA2-Lowland-Case-Study-Synthesis-report.pdf

Provides a case study analysis on key pressures, critical time steps and potential responses for alpine and the lowland environment.

- Barron MC; Pech RP; Christie JE; Tait A; Byrom A & Elliot G, 2016, *Climate change impacts and implications: an integrated assessment in the alpine case study. Synthesis Report: RA2 Alpine Case Study. The beech forests of New Zealand. Climate Change Impacts and Implications for New Zealand to 2100*. MBIE contract C01X1225. http://ccii.org.nz/wp-content/uploads/2017/03/RA2-Alpine-Case-Study-Synthesis-Report.pdf

Provides a case study analysis on key pressures, critical time steps and potential responses for alpine and high elevation native forest ecosystems.

- Law, C.S; Rickard, G.J; Mikaloff-Fletcher, S.E; Pinkerton, M.H; Gorman, R; Behrens, E; Chiswell, S.M; Bostock, H.C; Anderson, O & Currie, K, 2016, *The New Zealand EEZ and South West Pacific. Synthesis Report RA2, Marine Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100*
  http://ccii.org.nz/wp-content/uploads/2016/12/RA2-Marine-Case-Study-Synthesis-report.pdf

Provides a case study analysis on key pressures, critical time steps and potential responses for alpine and the marine environment.

- McBride G; Reeve G; Pritchard M; Lundquist C; Daigneault A; Bell R; Blackett P; Swales A; Wadhwa S; Tait A & Zammit C, 2016, *The Firth of Thames and Lower Waihou River. Synthesis Report RA2, Coastal Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100*.
  http://ccii.org.nz/wp-content/uploads/2017/02/RA2-Coastal-Case-Study-Synthesis-report.pdf

Provides a case study analysis on key pressures, critical time steps and potential responses for alpine and the coastal and estuary environment.

- Tait, A; Sood, A; Mullan, B; Stuart S; Bodeker, G; Kremser S &Lewis, J, 2016, *Updated Climate Change Projections for New Zealand for Use in Impact Studies. Synthesis Report RA1. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100*. MBIE contract C01X1225.
  http://ccii.org.nz/wp-content/uploads/2016/10/RA1-Synthesis-report.pdf

Updates and improves regional-scale projections of climate trends and variability across New Zealand out to 2100 based on the latest global projections. It describes the process of updating and improving regional-scale climate projections for New Zealand and describes how users can access the new data. Work done on generating a large ensemble of temperature projections for New Zealand is also presented, as are web-based tools for exploring visualisations of the data.

Decision-making and governance

- Flood, S & Lawrence, J, 2016, *Framing conversations around risk and uncertainty. Climate Change Impacts and Implications (CCII) for New* **Z***ealand to 2100*.
  http://ccii.org.nz/wp-content/uploads/2017/01/RA4-Framing-conversations-around-risk-and-uncertainty.pdf

Explores how to effectively deal with climate change-related risk and uncertainty as well as highlight the importance of considering a range of future scenarios when making decisions that are affected by climate change.

- Frame, B & Reisinger, A, 2016, *Exploring Options for New Zealand under Different Global Climates. Synthesis Report RA5. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100*. MBIE contract C01X1225.
  http://ccii.org.nz/wp-content/uploads/2017/02/RA5-Synthesis-report.pdf

We describe a framework for establishing globally linked national-scale socio-economic scenarios for New Zealand (NZ). These were developed to enable a better understanding of potential societal changes and how those changes may interact with changing climatic conditions, to inform climate change vulnerability and adaptation research and decisions.

- Lawrence, J; Blackett, P; Cradock-Henry, N; Flood, S; Greenaway, A; & Dunningham, A, 2016, *Synthesis Report RA4: Enhancing capacity and increasing coordination to support decision making. Climate Change Impacts and Implications (CCII) for New Zealand to 2100*. MBIE contract C01X1225.
  http://ccii.org.nz/wp-content/uploads/2017/01/RA4-Synthesis-report.pdf

Presents evidence about the impacts and implications of climate change that have decision relevance for a range of stakeholders. The evidence supports the development of new practices for addressing and planning for climate change impacts and implications in New Zealand.

- Palmer, G.W.R, 2015, New Zealand's defective law on climate change, *New Zealand Journal of Public and International Law*, v. 13 n.1:p115-136.
  http://search.informit.org/documentSummary;dn=683629212907831;res=IELNZC;subject=Archaeology

Describes international efforts to combat climate change in the last twenty-five years with the view that progress has been limited. Asks how much worse will it need to get before effective change will be implemented? Examines the state of NZ law on climate change and the approach NZ is taking to international negotiations.

Insurance

- Storey B; Noy, I; Townsend, W; Kerr, S; Salmon, R; Middleton, D; Filippova, O and James, V, 2016, *Insurance, Housing and Climate Adaptation: Current Knowledge and Future Research*, Motu Note #27, funded by the Deep South Science Challenge.
  https://motu.nz/assets/Documents/our-work/environment-and-resources/climate-change-impacts/Insurance-Housing-and-Climate-Adaptation4.pdf

Discusses how insurance will adapt to a changing climate. New Zealand's current insurance institutions are surveyed; these are sufficiently unusual to limit the applicability of the international literature. Issues with the provision of climate-sensitive insurance – particularly with its pricing – are discussed, as are relationships between insurance markets and financial markets. Possible policy responses are suggested. The note concludes by proposing high-priority questions for future research.

Iwi/Māori

- Bargh, M; Sarsha-Leigh, D; Te One; A; 2014, Fostering sustainable tribal economies in a time of climate change, *New Zealand Geographer*, v.70 n.2: p. 103–115.
  http://onlinelibrary.wiley.com/wol1/doi/10.1111/nzg.12042/full

Reviews Environmental Management Plans to assess how Māori tribal organisations are proposing to move towards more sustainable tribal economies in a time of climate change. Presents a case study in the Bay of Plenty area focusing on Ngāti Kea/Ngāti Tuara. Suggests that many tribal organisations are seeking to respond to climate change and transition to becoming producers of their own food and energy needs, and are often articulating these responses in relation to specific local resources and contexts.

Health

- Metcalfe, S, 2015, Fast, fair climate action crucial for health and equity, *New Zealand Medical Journal*, v.128 n.1425: p.14–23. http://www.nzma.org.nz/journal/read-the-journal/all-issues/2010-2019/2015/vol-128-no-1425-20-november-2015/6741

Examines the threat to global health presented by climate change, and what health equity means for setting countries' greenhouse gas (GHG) emission targets, including New Zealand's share of the global effort.

- Macmillan A; Jones R & Bennett H, 2014, New Zealand health professional organisations' joint call for action on climate change and health. *New Zealand Medical Journal* (Online), v.127 n.1403: p.5–8. https://www.nzma.org.nz/journal/read-the-journal/all-issues/2010-2019/2014/vol-127-no-1403/6309

Backgrounds the world context which prompted a joint 'Call for action on climate change and health' for New Zealand issued by 10 NZ health organisations to highlight human-caused climate change as an increasingly serious and urgent threat to health and health equity. Indicates the organisations involved. Summarises the points emphasised in the call for action.

Immigration

- Tennent, D, 2015, The adverse effects of climate change, *New Zealand Law Journal*, Feb 2015; p. 23–26. http://primo-direct-apac.hosted.exlibrisgroup.com/primo_library/

Outlines the impact of climate change on such countries as Kiribati and Tuvalu, particularly the pressure of overcrowding. Queries the protection afforded people affected by climate change under current immigration legislation, if they are unable to obtain residence. Refers to the NZ Immigration and Protection Tribunal decisions in 'AF (Kiribati)' [2014] NZIPT 800413 and 'AD (Tuvalu)' [2014 NZIPT 501370–371, examining people's ability to claim refugee or protective person status, or to appeal deportation. Sets out the two main issues that require addressing in this matter.

- Cameron, M, 2013, The demographic implications of climate change for Aotearoa New Zealand: a review. *New Zealand Population Review*, v.39:p. 121–142. http://researchcommons.waikato.ac.nz/handle/10289/7979

Reviews international literature on the demographic impacts of climate change, with a particular focus on how this might affect New Zealand. Suggests expected changes will feature internal migration.

Tourism

- Hall M; Baird T; James M & Ram Y, 2015, Climate change and cultural heritage: conservation and heritage tourism in the Anthropocene. *Journal of Heritage Tourism*. http://dx.doi.org/10.1080/1743873X.2015.1082573

Reviews some of the actual and potential effects of climate change on cultural heritage and its management with special reference to heritage tourism to help identify knowledge gaps and issues in relation to different types of heritage, management strategies and policy-making, as well as enabling an understanding of the potential significance of climate change impacts in a regional, national and international setting. It is also relevant to understanding the broader pressures of environmental and global change on the management of heritage tourism sites, and cultural heritage in particular, in the Anthropocene.

Natural hazards

- Glavovic, B.C., 2014, The 2004 Manawatu Floods, New Zealand: Integrating Flood Risk Reduction and Climate Change Adaptation. *Adapting to Climate Change*, pp. 231–238. Springer Netherlands. http://link.springer.com/chapter/10.1007/978-94-017-8631-7_10

Describes the lessons learned from the 2004 floods in the Manawatu region and how these could be used for building resilience and adaptive capacity in the face of climate change. It recommends priority actions for mainstreaming climate change adaptation.

Oceans and coastal hazards

- Molinos G.J, Halpern B.S., Schoeman D.S., Brown C.J., Kiessling W., Moore P.J., Pandolfi J.M., Poloczanska E.S., Richardson A.J. and Burrows M.T. (2015). Climate velocity and the future global redistribution of marine biodiversity, *Nature Climate Change*, doi: 10.1038/nclimate2769.
- Munday P., Cheal A.J., Dixson D.L., Rummer J.L., and Fabricius K.E. (2014). Behavioural impairment in reef fishes caused by ocean acidification at CO2 seeps, *Nature Climate Change* 4, 487–492 (2014) doi: 10.1038/nclimate2195.
- Renwick J.A., Hurst R.J., and Kidson J.W. (1998). Climatic influences on the recruitment of southern gemfish (*Rexea solandri, Gempylidae*) in New Zealand waters. *International Journal of Climatology* 18: 1655–1667; Beentjes M.P. & Renwick J.A. (2001). The relationship between red cod, *Pseudophycis bachus*, recruitment and environmental variables in New Zealand. *Environmental Biology of Fishes* 61: 315–328.; Dunn M., Hurst R., Renwick J., Francis C., Devine J., and McKenzie A. (2009). Fish abundance and climate trends in New Zealand. *New Zealand Aquatic Environment and Biodiversity*. Report No. 31. NIWA, Wellington.

Ministry for the Environment
Manatū Mō Te Taiao

Preparing for coastal change

A SUMMARY OF COASTAL HAZARDS AND CLIMATE CHANGE GUIDANCE FOR LOCAL GOVERNMENT

New Zealand Government

Disclaimer

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Ministry for the Environment
Manatū Mō Te Taiao

Making Aotearoa New Zealand
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Aotearoa – he whenua mana kura mō te tangata

Contents

Introduction

Since 2001, the Ministry for the Environment has provided guidance on how to adapt to the risks from coastal hazards caused by climate change, particularly those associated with sea-level rise. The previous guidance, published in 2008, has been widely used by local government, and also by others involved in providing services and infrastructure to coastal areas. The Ministry also provides climate projections for New Zealand, a manual on climate change effects and impacts assessment, and tools for estimating the effects of climate change on flood flow.

The Coastal Hazards and Climate Change guidance (released together with this summary) is a major revision of the 2008 edition. It updates scientific understanding and the legal framework. It introduces new material on hazard, risk and vulnerability assessments, and collaborative approaches to engaging with communities. The 2017 edition also explains adaptive approaches to planning for climate change in coastal communities.

References cited in this summary can be found in the reference list of the full guidance.

Why is this guidance required?

Hazard risk is compounding in coastal areas, because hazard impacts are occurring more frequently as seas rise, while at the same time coastal development and property values are increasing. Sea level is expected to keep rising for at least several centuries, posing an ongoing challenge for us and future generations to create more sustainable coastal communities.

Coastal hazards can have impacts on a wide range of our social, cultural and economic values, as well as affecting our natural and physical environment. Acceptable solutions for adapting to the changes will vary from place to place, and for some communities will be made more complex by greater risks, greater vulnerability, and a lower ability to cope. There is no one-size-fits-all solution.

Local government faces the enduring question of how to achieve the aspirations of local communities while making (sometimes unpopular) decisions that will enable them to adapt to the impacts of a changing climate.

The guidance developed by the Ministry supports local government in this complex role.

Who is the guidance for?

This document summarises the step-by-step approach developed to help local government (and others) assess, plan for and manage the increasing risks facing coastal communities. It is intended primarily for local government and other users of the full guidance, such as those who provide services and infrastructure to coastal areas and work with local government including engineers, planners, asset developers, lawyers, insurers, community-engagement facilitators, councillors and government officials. Property owners and coastal communities may also find information in this document useful.

The full guidance is a technical document. It contains details about how to apply a risk-based, adaptive planning approach, along with additional information, case studies, and tools and techniques.

It is targeted at local government functions dealing with coastal and estuarine areas – those already affected by coastal hazard risks arising from climate change, and those potentially affected in the foreseeable future. The council functions include policy, planning, consenting, civil defence and emergency management, transport planning, asset development/ management, and building control.

Adaptive planning

The planning approach in the guidance is new. It is being recommended to local government by the Ministry for the first time.

The approach differs from previous editions, and from current coastal hazard management practice, in two significant ways – first, in how it deals with uncertainty and risk, and second, by placing community engagement at the centre of decision-making processes (see figure 3).

The approach is called *dynamic adaptive pathways planning*. As its name suggests, it identifies ways forward (*pathways*) despite uncertainty, while remaining responsive to change should this be needed (*dynamic*).

In the approach, a range of responses to climate change are tested against possible future scenarios. Pathways are mapped that will best manage, reduce or avoid risk. A plan is developed, with short-term actions and long-term options, and includes pre-defined points (triggers) where decisions can be revisited. This flexibility allows the agreed course of action to change if the need arises – such as, if new climate change information becomes available.

By accommodating future change at the outset, this approach helps avoid locking in investments that could make future adjustments difficult and costly. As such, it assists both longer-term sustainability and community resilience.

The *dynamic adaptive pathways planning* approach is a powerful process for managing and adapting to climate change. It recognises that, first, climate change effects vary from place to place, and second, that decision-makers face unavoidable uncertainty about ongoing sea-level rise. It is usually not possible, practical or sensible for them to wait until uncertainties are reduced before making decisions.

Part 1: Climate change and coastal hazards

Earth's climate is changing, mostly due to emissions of greenhouse gases from human activities, such as burning fossil fuels (eg, coal and oil), agriculture, and deforestation (where large areas of trees are cleared). The greenhouse gases we emit include carbon dioxide, methane and nitrous oxide. They warm the Earth, and one of the major and most certain consequences of warming is sea-level rise.

How much warming occurs in future will depend on global greenhouse gas emissions. Countries have agreed to limit warming to below 2°C above pre-industrial levels, but this is an ambitious aim and by no means certain to be achieved. More warming over the next few decades is inevitable, even if global emissions were to stop completely today. Because we can never be sure what will happen, in planning for this climate change we need to consider a range of possible futures, or 'scenarios'.

Climate change and sea-level rise are not in themselves hazards, but they will make worse coastal hazards already occurring due to natural processes. While sea-level rise will have the greatest effect, changes in storminess will also influence how often other impacts from coastal hazards occur, and how damaging they are. These include hazards from storm surges and waves.

Sea-level rise will increase the frequency and scale of coastal hazards. For example, as sea level rises we will experience more floods that inundate existing infrastructure, such as coastal roads. In New Zealand, by 2050–2070, extreme coastal water levels that are currently expected to be reached or exceeded only once every 100 years (on average) will occur at least once per year or more (on average) – earlier in areas with smaller tide ranges. More information is provided in section 6.4 of the guidance.

After at least a thousand years of little change, sea level around the world began to rise around the latter half of the 19th century, and increased at a rate of around 1.7 millimetres a year during the 20th century (see figure 1). Since satellite measurements began in 1993, the average global sea level has risen about 3.3 millimetres a year. The increase is due partly to natural climate variability and partly to faster sea-level rise caused by global warming.

Local responses to local changes in sea level

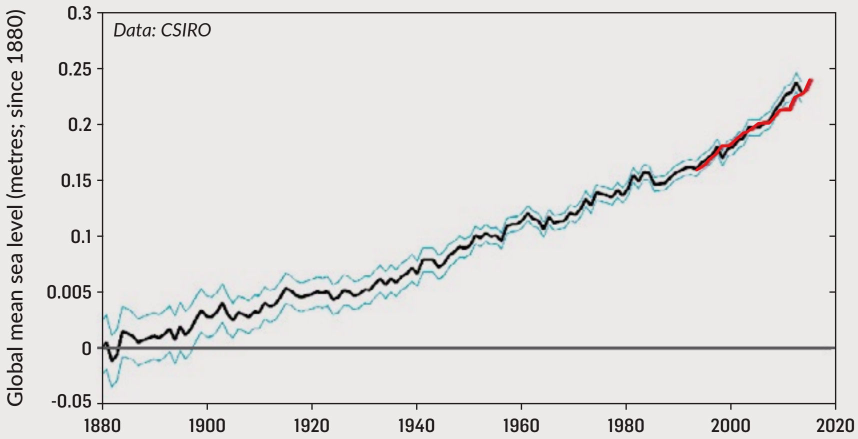
Local sea-level change may be different from the global average, because winds and currents may change and because ice meltwater added to the oceans is not distributed evenly around the world.

If the land is rising or falling, this also changes the sea level in that place. The term *relative sea-level change* describes the combined movement of both water and land (see figure 7). That is, even if sea level was constant there could still be changes in *relative sea levels* – rising land would produce a relative fall in sea level, while sinking land would produce a relative rise in sea level.

Across New Zealand, the average *relative* sea-level rise for the 100 years up to 2015 was around 1.8 millimetres a year (see figure 2). This rise means that what was an extreme high tide level in 1900 is now reached about twice as often.

While published projections of future sea-level rise are usually global, locally we need to adapt to the *relative* sea-level rise. So, for New Zealand, corrections need to be applied for differences in the regional ocean response for the southwest Pacific and for local vertical land movement.

Figure 1: Cumulative changes in global mean sea level since 1880, based on a reconstruction of long-term tide gauge measurements to the end of 2013 (black) and recent satellite measurements to the end of 2015 (red)



Note: Lighter lines are the upper and lower bounds of the likely range (± 1 standard deviation) of the mean sea level (MSL) from available tide gauges, which depends on the number of measurements collected and the precision of the methods.

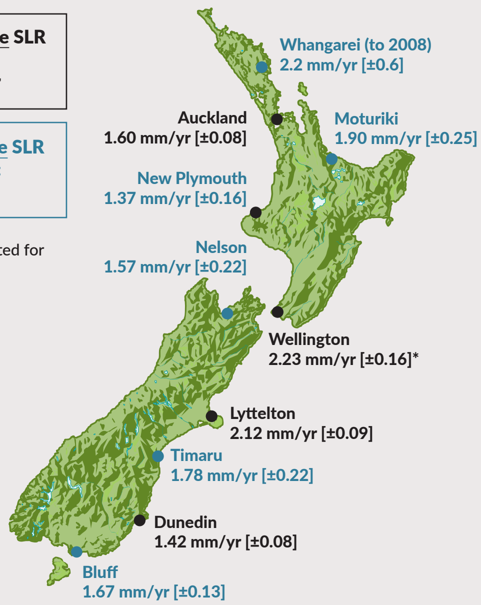
Source: Tide gauge data – Church & White (2011) updated to 2013 (United States Environmental Protection Agency, 2016); Satellite data adjusted for glacial isostatic adjustment and inverted barometer (Commonwealth Scientific and Industrial Research Organisation, 2016)

Figure 2: Relative sea-level rise (SLR) rates in New Zealand, up to and including 2015 (excluding Whangarei), determined from longer-term sea level gauge records at the four main ports

NZ average relative SLR (four main ports): 1.78 ± 0.21 mm/yr

NZ average relative SLR (all 10 gauge sites): 1.76 mm/yr

*1.97 mm/yr when adjusted for tectonic subsidence



Note: Determined from more than 100 years of gauge records at the four main ports (black circles) and inferred rates from gauge station records used in the first half of the 1900s to set the local vertical datums (see supplementary information sheet 10 in the guidance), spliced with modern records (blue circles). Standard deviations of the trend are listed in the brackets.

Source data: Analysis up to end of 2008 from Hannah & Bell (2012), updated with seven years of mean sea level data to end of 2015 (Hannah, 2016); sea level data from various port companies is acknowledged.

According to the Intergovernmental Panel on Climate Change's (IPCC)[1] Fifth Assessment Report (2013), sea-level rise in our region is expected to be up to 10 per cent more than the global average. This is accommodated in the guidance by applying a correction of up to an additional 0.05 metres by 2100.

Future warming will cause further sea-level rise due to three processes:

- expansion of the ocean's water, as it warms
- melting of mountain glaciers around the world
- melting of the polar ice sheets in Greenland and Antarctica.

However, it is not possible to make a 'best estimate' of what that future sea-level rise will be, or assign a likelihood to different possible scenarios. Instead, plausible futures are best explored using a range of scenarios of future global greenhouse gas emissions that have been developed by climate change researchers for the IPCC. Under all scenarios, sea level will continue to rise during the 21st century and beyond, and the rate of sea-level rise will very likely be faster than in the past few decades.

1 The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change, its potential impacts, and options for adaptation and mitigation.

Part 2: The decision cycle

The guidance recommends that planning for the impact of climate change on coastal hazards follow a 10-step decision cycle. The cycle is made up of elements to secure and implement a long-term strategic planning and decision-making framework for coastal areas potentially, or already, affected by coastal hazards and climate-change effects, such as sea-level rise. The 10-step process is iterative, as steps can be revisited – for example, if new climate change information becomes available.

Overview

The 10-step decision cycle (figure 3) is structured around five key questions:

A. What is happening?

B. What matters most?

C. What can we do about it?

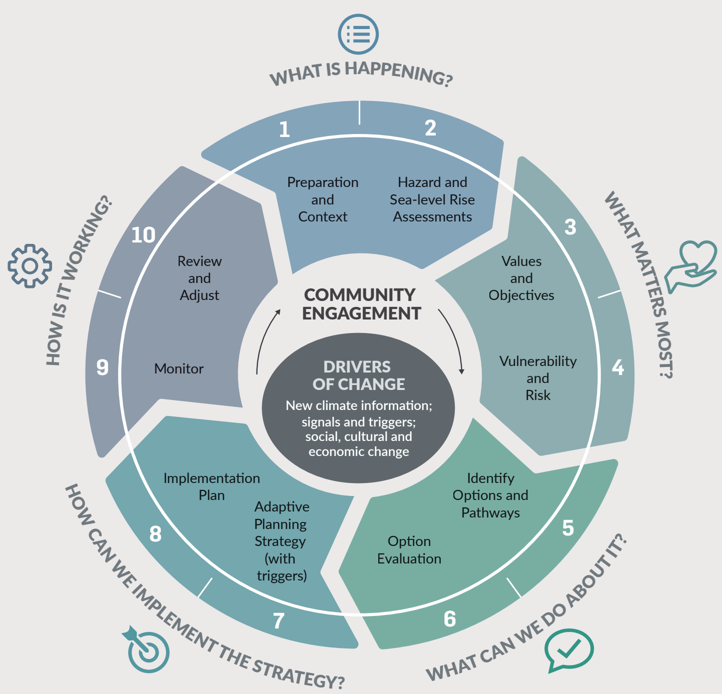
D. How can we implement the strategy?

E. How is it working?

Although the 10-step decision cycle is presented in guidance on coastal hazards and climate change, it can apply more broadly to planning under changing and uncertain conditions.

Full details of all the supporting tools and resources available are in chapter 12 of the guidance.

Figure 3: The 10-step decision cycle, grouped around five questions



Source: Adapted from Max Oulton (University of Waikato), and UN-Habitat (2014)

A. What is happening?

Step 1: Preparation and context

Setting up the team and securing resources

A multi-disciplinary team will be needed to implement the 10-step decision cycle, as navigating the coastal adaptation challenge will require a wide set of expertise, skills and knowledge. Once the team is established, much of the preparatory work will revolve around understanding the **scope** of the changing risk, and the local community **context**, before formulating and resourcing a working plan.

Preparatory tasks: Setting the context and the scope of the risk

1. Establish the team and agree on the best way to work together.
2. Establish the need to reduce coastal risk (including the effects of climate change).
   - Identify the scope of coastal hazard risk.
   - Define communities, and the factors shaping risk.
   - Perform stocktake of available information (eg, demographics, relevant plans and policies, topographic elevation data).
   - Make connections with potentially affected communities.
3. Agree how your team will engage with the community, iwi and hapū, and stakeholders.
4. Agree on the planning approach and mobilise resources.
   - From the contextual information (see box 3 in the guidance), decide on the overall approach.
   - Develop a case for the project within and between councils, and secure funding and a planning mandate.
   - Develop a work programme.

Source: Adapted from Glavovic (in press)

Changing risk

Much of New Zealand's population lives at the coast, and many of our cities are located in coastal areas. Climate change poses an increasing risk to these coastal areas, in particular because sea-level rise increases their exposure to coastal hazards. This risk is further compounded by ongoing development and population growth in coastal areas, along with rising property values.

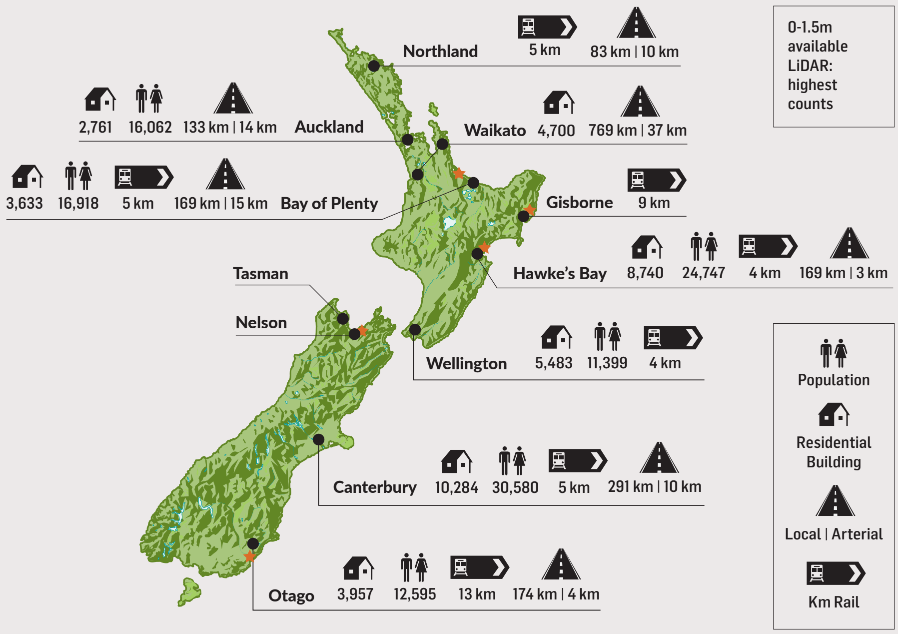
The high-level definition of risk[2] is the 'effect of uncertainty on objectives'.

- *Effect* refers to a deviation from the expected (negative or positive).
- *Objectives* can encompass a range of goals, such as financial, health and safety, resilience, and environmental goals.

Figure 4 shows levels of risk exposure in different regions, for low-lying coastal areas. Using these measures, the highest coastal risk exposure is in Canterbury and Hawke's Bay, with Waikato having the greatest length of road network exposed (mostly local roads).

2 Standard AS/NZS ISO 31000:2009 Risk Management.

Figure 4: Levels of coastal risk exposure determined by resident population, buildings, roads, railway, airports and jetties/wharves for land elevations less than 1.5 metres above mean high water spring (MHWS[3]) at the coast.



$19B (2011)
Replacement cost of all buildings

43,680
Total number of residential buildings

68,170
Total number of all buildings

133,265 (Census 2013)
Total resident population

National Infrastructure

382 critical-facility buildings

5 airports ★

1,547 jetties & wharves

2,121 km of roads (1,930 km local roads)

46 km railway

Note: The boxes above show aggregated results from regional totals where LiDAR[4] data were available.

Source: Bell et al (2015), including the infographic; Parliamentary Commissioner for the Environment (2015)

3 Mean high water spring (MHWS) describes the highest level that spring tides reach (ie, the tide just after a full or new moon), on average, over a long timescale – often 18–20 years.

4 Light Detection and Ranging (LiDAR) uses a laser scanning system, usually mounted on an aircraft, and is accurate for heights down to 0.1 metres.

Climate change will increasingly change the nature and broaden the extent of the impact from coastal hazards. Its impact will also be influenced by the vulnerability of the coastal community in question, and its coping capacity.

As exposure to coastal hazards increases over time, difficult decisions will be required around assets and infrastructure at the coast (eg, buildings and roads). Do we remove, relocate, forgo or protect these investments? The places and environments valued by people will also be exposed to increasing impacts, and vulnerable groups and those with little capacity to move will be particularly affected.

Communities, councils and infrastructure providers will need to ensure present knowledge of the increasing future risk and the evolving consequences are embedded in key private and public decisions now. The risks to future communities, and their ability to address them, should not be made worse by decisions taken now.

Local government's roles

The avoidance or mitigation of natural hazards is one of the core services to which councils must have particular regard when performing their roles. Local government will need to identify communities or coastal infrastructure or amenities that are vulnerable to the effects of sea-level rise, and address the likely consequences.

Without a planned response, adaptation could be ad-hoc and limit future options, while the risks to communities from climate change effects continue to increase over time. Local government is responsible for developing strategies to ensure current risk exposure does not increase unmanageably in the future (eg, Policy 27, New Zealand Coastal Policy Statement 2010).

Risk management and planning must recognise that:

a. the risks are changing – both from coastal hazards and the additional exposure from ongoing development, and

b. there is a high level of uncertainty about future greenhouse gas emissions and the rate of sea-level rise.

The need to replace, protect, modify or remove buildings, amenities and infrastructure in vulnerable coastal areas increasingly exposed to natural hazards, is a major responsibility, where local government (along with central government) will have leadership roles. More information is in chapter 2 and appendix A of the guidance.

Community engagement principles

Adapting to ongoing sea-level rise will require individuals, families, communities, businesses, infrastructure and utility providers, and local and central government to make choices about the future. Different interests, expectations, values and world views may result in a lack of consensus. In addition, the impacts of sea-level rise and the consequences of planning decisions will not be the same for everyone. For these reasons, it is widely accepted that community engagement will be essential and that communities should play a central role in decision-making.

It is difficult to prepare for, and to respond to, situations where the level of risk is not constant. Discussion and debate are likely to lead to a greater shared understanding of the:

- causes of the problem
- problem itself
- risks and vulnerabilities
- values at stake
- range of responses possible.

The guidance recommends that engagement be more inclusive, rather than less. Three key questions must be addressed in the early phase of establishing a programme of community engagement:

- Who should participate?
- What do we already know about the community?
- How should participation proceed?

The guidance adopts the International Association for Public Participation (IAP2) spectrum of public participation (see figure 5), which provides clear descriptions of what each type of public engagement could entail, and how decisions could be made. Using a uniform and generally accepted terminology for public participation will help align expectations and practice throughout New Zealand.

Figure 5: The International Association for Public Participation spectrum of public participation

INCREASING IMPACT ON THE DECISION

	INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
PUBLIC PARTICIPATION GOAL	To provide the public with balanced and objective information to assist them in understanding the problem, alternatives, opportunities and/or solutions.	To obtain public feedback on analysis, alternatives and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.	To place final decision making in the hands of the public.
PROMISE TO THE PUBLIC	We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision. We will seek your feedback on drafts and proposals.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will work together with you to formulate solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.

Source: International Association of Public Participation (2014) – with permission

Chapter 3 of the guidance focuses on engagement. It includes questions to help identify where on the spectrum to position engagement at various steps, and how to identify stakeholders and participants:

- What is the nature of the decision?
- What is the purpose or goal of the engagement?
- How diverse are the community, iwi, hapū, and stakeholder values?
- How are the potential impacts distributed?

More information is in section 3.3 of the guidance.

Once the level of engagement has been determined, the process can be established. The majority of the decisions made on adaptation to sea-level rise are likely to require an engagement process towards the collaborative end of the IAP2 spectrum. Although the overall process will be collaborative the sequence of activities and events which make up the process could be located on a different part of the IAP2 spectrum. For example, some steps in the 10-step decision cycle are more suited to an 'inform' approach, while others may suit 'empowerment'.

There are no recipes for good collaborative process because each process should suit the local situation. Instead, six interacting guiding principles for inclusive engagement are outlined in figure 6. More detail on these is in section 3.4 of the guidance.

Engagement activities should:

1. be in line with the guiding principles
2. suit the target group(s)
3. fit the stage of the 10-step decision cycle and achieve the outcomes desired for that step, as well as contribute to the process as a whole.

Information on engagement is also in chapters 7–11 of the guidance.

Understanding and awareness of changing coastal risk

When considering the effects of climate change, uncertainty[5] is unavoidable. Although the fact that sea level is rising, and will continue to rise, is not in question, the future rate is highly uncertain. In short, the impacts of climate change will not be known with precision for the foreseeable future.

Local authorities dealing with those impacts on coastal areas will inevitably have to make decisions in the face of this uncertainty. Despite the uncertainties, the effects of sea-level rise need to be included in coastal planning.

To include this uncertainty in decisions about activities and assets with long lifetimes, a wide set of possible futures need to be considered. This helps ensure responses identified today, for whatever timeframe, are flexible and able to be adapted in future.

Intentionally accounting for uncertainties will help ensure the coastal planning process considers all the evidence and avoids the risk of unexpected consequences arising from our decisions. By not considering a full range of plausible outcomes, decisions could commit the community to increased risk or reliance on a single option, making future adaptation more complex and expensive.

When using hazard assessments in decision-making, four levels of uncertainty exist that lead to different types of decisions and policies (see table 1).

The uncertainty for timeframes beyond 2100 arises mainly because of the unknown rate of future sea-level rise, which locates it in the 'deep uncertainty' category with a wide range of possible consequences (category d in table 1). Likelihoods cannot be assigned to sea-level rise projections, which depend on future global greenhouse gas emissions, nor can a 'best-estimate' be determined for longer-term planning. The range of future scenarios that could eventuate will need to be assessed, along with their likely consequences.

5 When discussing risk, *uncertainty* describes not having enough information to fully understand an event, its *consequences* or *likelihood*. The specific meaning for each of these terms is in the glossary in the guidance.

Figure 6: Principles that encourage effective dialogue

Six principles to encourage a process that:

creates space for dialogue to reconcile contested interests, develops learning and trust, enhances understanding, and considers culture, values, interests and priorities

1. **Be timely and take the time**
   - Initiate adaptation conversations early.
   - Listen to and understand different perspectives before acting.
   - Engage regularly.
   - Respond to existing issues and concerns in a timely manner.
   - Commit to an agreed timeframe.

2. **Be flexible and adaptable**
   - Allow the process to evolve if necessary.
   - Allow the time to understand each perspective.

3. **Be inclusive, empathetic and ensure representative participation (equity)**
   - Enable diverse representation.
   - Balance power.
   - Be sensitive and empathetic.

4. **Run a transparent process**
   - No surprises.
   - Decision-making exposed.
   - Clear expectations.
   - Make limitations of process clear.

5. **Be cognisant of scientific input/knowledge**
   - Explore uncertainty.
   - Include local and cultural knowledge.
   - Jointly seek and explore knowledge (learning).

6. **Secure committed resources and institutional support**
   - Adequate resources.
   - Institutional and cross-organisational support.

Table 1: The four levels of uncertainty and possible policy responses

Future coastal hazards...		response
a. ...are knowable (little uncertainty)	→	predict and act policies
b. ...will behave in much the same way as in the past (statistical uncertainty)	→	'trend-based' policies
c. ...are well described by a few overarching scenarios (scenario uncertainty)	→	'static robust' policies
d. ...are unknown or disagreed upon by experts and/or stakeholders with no consensus on what the future might bring (deep uncertainty)	→	adaptive and iterative policies

Guiding principle

For near-term decisions (eg, with planning horizons up to 2040–2060), uncertainty about sea-level rise should not delay initial decision-making processes. This is because the uncertainty range is smaller – global sea-level rise is projected to lie within a range of about 0.2–0.4 metres above the 1995 level.[6]

Near-term decisions such as these should build in flexibility, to enable changes to actions or pathways that can accommodate higher sea-level rise over longer timeframes. They need to be able to include the impact of sea-level rise increasing the frequency and magnitude of storm-related coastal flooding and erosion.

Flexible adaptive management approaches can also cover the situation where the rate of sea-level rise is slower than anticipated. In this case, planned response options or switching to the next pathway can be delayed.

Waiting until uncertainties are reduced before making decisions, or holding back on changing present plans and strategies under uncertain conditions, is usually not acceptable to those most exposed to the risk, nor to those who have the responsibility to manage such risks or to the wider community who may have to pay for the consequences.

Understanding the consequences of acting and not acting is an essential requirement of local government decision-makers. Making decisions under uncertain conditions will always involve subjective assessments of available knowledge.

Failure to consider uncertainties typically results in risk being transferred from individuals to the wider community and from those alive today to future generations.

The impacts of decisions taken today, for example, on the location of a subdivision on the coast, or to intensify the use of exposed low-lying land, are unlikely to be felt by those making the decisions or current property owners; however, they may have significant consequences in the future for individuals and/or the wider community.

6 This projection is based on IPCC scenarios.

Being aware of potential consequences of today's decisions can help reduce the risk and minimise the transfer of risk to future generations.

Guiding principle

When planning for the future under uncertain conditions, it is important to also consider potential for the transfer of risk in the future, legal liabilities, and the financial consequences of decisions to others, including future generations.

Step 2: Hazard and sea-level rise assessments

The changing climate and future projections for coastal areas

Sea-level rise is highly relevant for long-term decisions made in coastal areas, because its long-term impact on these areas is potentially very large. Past coastal developments were built on the premise that sea level would remain relatively constant, and this has meant that the rise in sea level which has occurred so far (about 0.2 metres since 1900) is already affecting human activities and infrastructure in coastal areas.

Sea-level rise can be considered in two ways (see figure 7):

- *Absolute* sea-level rise, which is measured relative to the centre of Earth by satellites, or using tide gauges corrected for local land movement. It is usually expressed as a global average. It is used in most projections of sea-level rise. Absolute sea-level rise in a given region may not be the same as the global average.
- *Relative* sea-level rise (explained in Part 1), is measured relative to the local landmass (by tide gauges), taking into account regional differences in the absolute sea-level rise as well as local vertical land movement (uplift and subsidence).

Relative sea-level rise is the sea-level rise that has to be adapted to in a given region. If the landmass in question is subsiding, the *relative* sea-level rise will be greater than the *absolute* sea-level rise in that region (see figure 7), while if the landmass is undergoing uplift the opposite is true.

Future climate change and sea-level rise depend on the combined effect on global emissions of a wide range of socio-economic factors and climate-related policies.

It is not possible to assign likelihoods (probabilities) to individual climate change and sea-level rise scenarios. Instead, a set of scenarios is used to span a range of possibilities and provide decision-makers with a range of possible futures to test response options against, rather than adopting a single estimate of future change.

The sea-level rise projections generated for use in the guidance come from:

- the IPCC's Fifth Assessment Report (2013), which provides projections out to 2100
- a recent study by Kopp et al (2014) which produced projections out to 2200.

These have been used to derive four New Zealand scenarios to 2150 (see figure 8), to cover a range of possible future sea levels:

1. a low emissions, effective mitigation scenario (RCP2.6[7])
2. an intermediate-low emissions scenario (RCP4.5)
3. a high emissions, no mitigation scenario (RCP8.5)
4. a higher, more extreme H+ scenario, based on the RCP8.5 (83rd percentile) projections from Kopp et al (2014) – included primarily for the purpose of stress-testing adaptation plans or pathways and major new development at the coast.

More information on how they were derived is in sections 5.5.3 and 5.5.5 of the guidance.

Decision-makers should be aware that future sea-level rise will not exactly follow any one of the sea-level rise scenarios provided in this guidance. Instead, before making decisions within an adaptive planning framework, risk/vulnerability assessments should be conducted to determine how different scenarios would affect risk, levels of service, maintenance, and the viability of the community.

A risk-based approach

As already discussed under step 1, the guidance adopts a risk-based approach, and the range of sea-level rise scenarios should be used for hazard assessments, risk/vulnerability assessments, and comprehensive adaptation plans, as described in chapters 6, 8 and 9 of the guidance. In locations where there is significant ongoing vertical land movement, the New Zealand sea-level rise scenarios will need to be adjusted accordingly, particularly for subsiding regions (see sections 5.3 and 5.6.3 of the guidance).

7 The Representative Concentration Pathways (RCPs) are greenhouse gas concentration scenarios adopted by the IPCC for its Fifth Assessment Report. They describe four alternative futures, in which possible scenarios of human activities result in different concentrations of greenhouse gases in the atmosphere. The numbers refer to the warming effect (radiative forcing) in the year 2100.

Components of New Zealand sea-level rise guidance

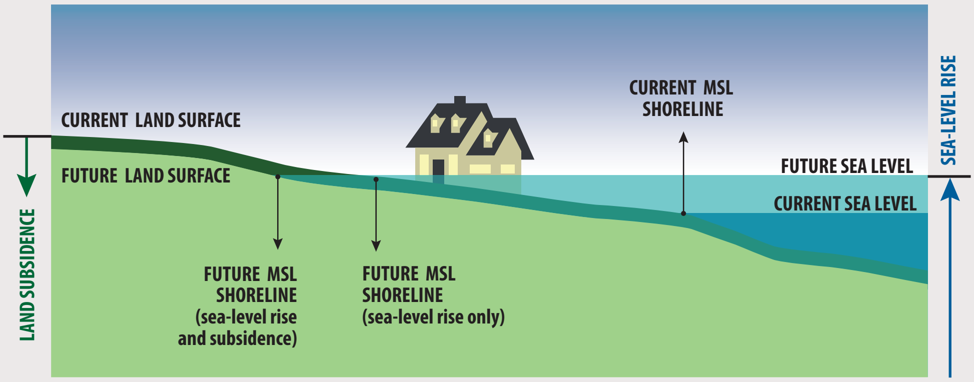
A cornerstone of the sea-level rise guidance is the adoption of **four** New Zealand-wide scenarios for use in hazard, vulnerability/risk assessments, and adaptation planning. This enables the hazard exposure and consequences of a range of possible futures to be considered.

Single values are, however, also provided as transitional minimum values (see figure 9). These were derived using a qualitative risk-based approach in relation to the scale or type of development.

These single values maintain national consistency with sea-level rise values currently being used by local government in New Zealand. However, adopting the dynamic adaptive pathways planning approach, which tests response options against the range of scenarios, is better able to address uncertainty and change for exposed communities at the local scale, and council policy/planning functions and activities at the regional/district scale. Using a range of scenarios enables consideration of the range of potential consequences and their acceptability for the community generally. Such an approach is recommended.

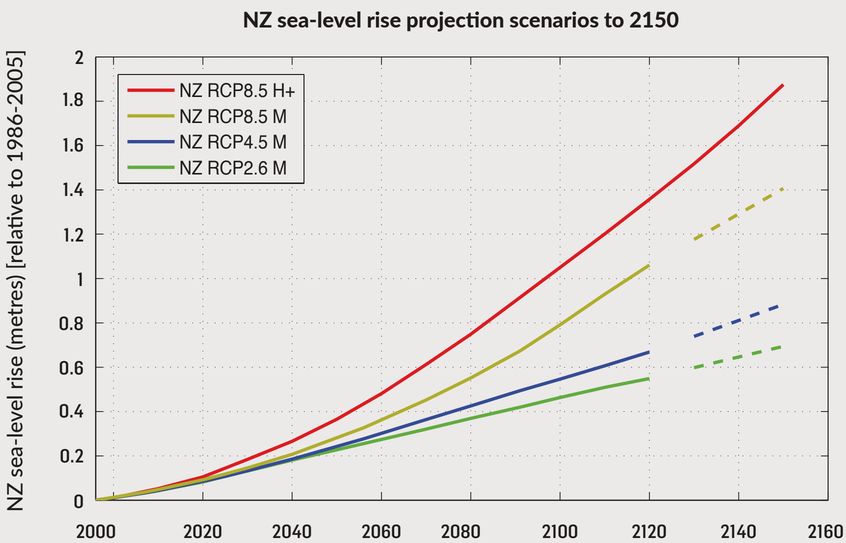
Table 11 in the guidance provides time windows spanning years when different levels of sea-level rise could be reached in New Zealand. It starts from the earliest year (based on the highest sea-level rise scenario) through to the latest year the value could be exceeded (based on the lowest sea-level rise scenario). These bracketed timeframes can be used for possible time windows of triggers (decision points) in adaptation pathways for communities.

Figure 7: The difference in mean sea-level (MSL) shoreline between absolute sea-level rise and local (relative) sea-level rise where land subsidence occurs



Graphics: Adapted from A Wadhwa, NIWA

Figure 8: Four scenarios of New Zealand-wide regional sea-level rise projections for use with this guidance, with extensions to 2150, based on Kopp et al (2014)



Note: New Zealand scenario trajectories are out to 2120 (covering the planning timeframe of at least 100 years), and the NZ H+ scenario trajectory is out to 2150, from Kopp et al (2014). Because no further extrapolation of the IPCC-based scenarios beyond 2120 was possible, the rate of rise for Kopp et al (2014) median projections for RCP2.6, RCP4.5 and RCP8.5 are shown as dashed lines from 2130, to provide extended projections to 2150. All scenarios include a small offset above the global mean sea-level rise for the regional sea around New Zealand.

In planning, four broad categories of development are assigned different sea-level rise allowances to take into account (table 2) until an adaptive pathways planning approach can be undertaken considering the four sea-level rise scenarios in their local or regional context – these are called minimum transitional SLR values. An additional component may need to be applied locally to these transitional sea-level rise values for significant vertical land movement.

The sea-level rise values for Categories C (0.65 m) and D (1.0 m) are similar to sea-level rise values currently being used by local government in New Zealand for the next 100 years. New developments can be in two categories: coastal subdivision, greenfield developments and major new infrastructure (Category A) should avoid hazard risk by using sea level rise over more than 100 years and the H+ scenario; changes in land use and redevelopment (intensification, Category B) should adapt to hazards by conducting a risk assessment using all four scenarios and the pathways planning approach. The H+ scenario is used for stress testing the future climate sensitivity and adaptive capacity of major new development, and testing adaptation pathways for existing development.

More information on the specific sea-level rise guidance is in section 5.7 of the guidance.

Besides sea-level rise, coastal and estuarine environments will also be affected by changes in weather-related coastal hazard drivers such as storm surges, waves, winds, and frequency and intensity of storms. Any changes in impacts from these will have implications for coastal erosion, coastal flooding, and groundwater/drainage levels. However, these other effects of climate change on coastal hazards will be secondary to that of ongoing sea-level rise.

Coastal hazards: impacts and assessments

The guidance primarily addresses the two main coastal hazards:

1. coastal inundation (compounded by flooding from rainfall, rivers and groundwater)
2. coastal erosion (beaches, estuarine shores, cliffs).

There are other impacts of sea-level rise on groundwater, drainage, saltwater intrusion and liquefaction. Tsunami impacts will also be affected by sea-level rise.

Climate change will affect these coastal hazards in two main ways:

- rising sea level
- changes in storm frequency or intensity.

The New Zealand Coastal Policy Statement 2010 directs the identification of areas in the coastal environment that are potentially affected by coastal hazards, and assessment of the associated risks over at least the next 100 years. It also directs a risk-based approach to managing coastal hazards, and prioritises identification of areas at high risk of being affected over at least a 100 year timeframe. This is a key focus of step 2 in the 10-step decision cycle. These hazard assessments then inform community engagement processes, and risk and vulnerability assessments in the following steps of the adaptation process (chapter 8 in the guidance).

The purpose of a coastal hazard assessment is to identify the spatial extent and magnitude of hazards, and to quantify, if possible, the likelihood of hazards occurring. Chapter 6 in the guidance addresses the following common questions when undertaking a coastal hazard assessment. Refer to the relevant sections for more information:

- What are the hazard sources (section 6.2)?
- What will be impacted by the hazard (section 6.4)? What type of hazard assessment should therefore be undertaken?
- What scale of coastal hazard assessment is required (section 6.5.2)?
- Where are the vulnerable areas, and where should we focus our effort (section 6.5.3)?
- What climate change scenarios should be considered? For example, what extreme event probabilities and what sea-level rise scenarios (section 5.7) and future increases in waves and storm surge should be included in a coastal hazard sensitivity assessment (section 5.9)?
- What tools and models should be used and what are the data requirements (section 6.5.5)?

Table 2: Minimum transitional New Zealand-wide sea-level rise allowances and scenarios for use in planning instruments where a single value is required at local/district scale while in transition towards adaptive pathways planning using the New Zealand-wide sea-level rise scenarios

Category	Description	Transitional response
A	Coastal subdividion, greenfield developments and major new infrastructure.	Avoid hazard risk by using sea-level rise over more than 100 years and the H+ scenario.
B	Changes in land use and redevelopment (intensification).	Adapt to hazards by conducting a risk assessment using the range of scenarios and using the pathways approach.
C	Land-use planning controls for existing coastal development and assets planning. Use of single values at local/district scale transitional until dynamic adaptive pathways planning is undertaken.	1.0 m sea-level rise
D	Non-habitable short-lived assets with a functional need to be at the coast, and either low-consequences or readily adaptable (including services).	0.65 m sea-level rise

Note: An adjustment for significant local vertical land movement may also be needed to these values (section 5.3 of the guidance).

Guiding principles for hazard assessments

There is no single way to approach a coastal hazard assessment. Various combinations of data analysis, modelling and mapping techniques can be used, depending on factors such as the locality, data availability, cost and assets at risk.

A coastal hazard assessment should relate the hazard magnitude to its likelihood of occurring, where possible. Sometimes statistical likelihoods cannot be assigned within a planning timeframe, as is the case for sea-level rise. When this happens, an adaptive risk-based approach means including a range of future sea-level rise scenarios in the coastal hazard assessment (chapters 5 and 8 of the guidance), focusing on hazard exposure (eg, using the 1 per cent annual exceedance probability inundation event).

Understanding the uncertainties and effectively communicating how they have been handled is essential for informed, risk-based decisions.

Before any detailed coastal hazard assessment of any scale is undertaken, a region-wide **hazard exposure screening** should guide priorities and more detailed subsequent assessments. A region-wide hazard assessment is useful in its own right to support land-use planning and adaptation planning processes for managing hazard risk across a region or district.

Generally, **more detailed** coastal hazard assessments, using multiple scenarios of sea-level rise and sensitivity to changes in waves and storm surges, will be needed as input to:

- community engagement processes, to provide background information for communities, iwi and hapū and stakeholders about the increasing hazard exposure at local levels
- risk and vulnerability assessments (step 4 of the 10-step decision cycle)
- detailed land-use planning and adaptation planning processes (steps 5–8 of the cycle).

Hazard assessments are required at step 2 of the decision cycle, to inform council staff and affected communities, iwi and hapū, and stakeholders; they provide the necessary information for making decisions during steps 3–10 of the decision cycle.

A checklist of good practice for coastal hazard assessments is in section 6.5.1 of the guidance.

B. What matters most?

Step 3: Values and objectives

Establishing values and objectives

The values and objectives of coastal communities, and also council functions and services, will be affected by coastal hazards and sea-level rise in different ways. These values and objectives need to be identified here in step 3 of the decision cycle. Combined with the hazard assessment completed at step 2, they will support a vulnerability assessment at step 4.

Establishing a collaborative process to explore values and objectives will help develop a joint understanding of the problem, what is important and to whom, so objectives can be developed to guide the adaptive decision-making process. There are three stages:

1. Exploration and capture of values in a way that clearly expresses:
   a. what of value is potentially affected by coastal hazards and sea-level rise
   b. who it is of value to
   c. where it is located geographically.

   This includes consideration by decision makers of the foreseeable needs of future generations, and how communities could be affected in the future by decisions taken today.

   Questions that underpin this activity include: Who should participate? How could they participate? What tools and techniques could be applied to explore community values?

2. Reframe the agreed community values into objectives. This allows them to be included in the vulnerability assessment and future adaptation decisions.

   See sections 7.4–7.6 of the guidance for more detail.

3. Clarify and agree on local government objectives over different jurisdictions, services and functions.

Understanding the community's values and objectives will help the council gauge the feasibility of adaptive plans. Moreover, decision-makers will need to have a clear understanding of their own joint objectives, role and obligations. This information then feeds into step 4 of the decision cycle for assessing vulnerability and risk.

More detail on methods to guide processes in step 3 is in section 7.3 of the guidance.

The outcome should be a summary of community values:

- What values and things of value are likely to be affected by coastal hazards and sea-level rise?
- Where are they and who are they valuable to?
- What is the diversity and (dis)agreement of values and norms?
- To what degree will groups in the community be affected?

Some groups are likely to be more negatively affected than others by coastal hazards and sea-level rise, and the consequences of adaptation decisions taken. For this reason, it is critical to ensure all groups' values are considered when assessing risk and when identifying and evaluating adaptation options.

Step 4: Vulnerability and risk

This step assesses the potential of assets (public and private) and people (including the things they value) to be negatively affected by exposure to coastal hazards and sea-level rise. The capacity of the community to adapt is another key aspect of vulnerability, which is complementary to assessing risk.

Vulnerability assessments

Vulnerability assessments are used worldwide to assess the broader impacts and implications of changes to the coast and communities resulting from climate change. They assess the potential harm and loss to a community or coastal environment caused by sea-level rise and coastal hazards, taking into account the ability of the community or environment to cope and adapt to change. In doing this, it becomes possible to identify and prioritise exposed areas.

Guiding practice: Steps in a vulnerability assessment

There are three main steps to a vulnerability assessment:

1. a sensitivity analysis for the systems associated with the planning area
2. an evaluation of the adaptive capacity of the system
3. an assessment of how vulnerable the system is to the effects of climate change.

Sensitivity is the degree to which a built, natural or human system is directly or indirectly affected by a given hazard exposure, and the changes in climate conditions that result in climate impacts on built and natural systems.

Adaptive capacity is the ability of natural and human systems to accommodate changes in climate impacts with minimum disruption or additional cost.

More information on vulnerability assessments is in section 8.1 of the guidance.

Risk assessments

Risk is typically assessed as a combination of the *likelihood* of an impact occurring, and the *consequences* of that impact. In this case we are assessing the exposure and vulnerability of people and assets to coastal hazards.

When assessing the risk associated with sea-level rise, consequence is the more important component (as likelihood cannot be quantified for future sea-level rise – only for the coastal hazard itself). Calculating the consequences under various sea-level rise scenarios for a particular asset, if sea-level rise is not addressed, can be useful in prioritising assets and exposed populations for adaptation planning.

Guiding practice: Sequence of risk assessments

Different organisations have different goals, data and resource available to them. To accommodate these differences, a three-level risk assessment process (of increasing depth and resource requirement) can be used.

- A ‘first pass’ risk screening can be conducted as a desktop study to screen the climate change-related risk exposure using readily available datasets. This will tell you whether a more detailed second- or third-level assessment is required, or not (if coastal risks are not likely to be an issue for some time at the location in question).
- A ‘second pass’ risk assessment takes a standard risk-based approach using national data, regional/local information and expert knowledge. It enables identification of how climate change may compound existing risks or the emergence of new risks (eg, in areas previously unaffected), and informs whether a more detailed third-level assessment is required.
- A ‘third pass’ (detailed) risk assessment enables further investigation of shortlisted areas of risks, and prioritisation and testing of strategies and actions in conjunction with the vulnerability assessments.

Risk assessments are needed at three steps in the decision cycle:

1. At the end of step 2, to prioritise and inform council stakeholders, iwi and hapū, and coastal communities. Undertaking regional/district risk screening following the hazard assessments will identify areas of greatest risk from sea-level rise and the regional/district extent to align with the approach in the New Zealand Coastal Policy Statement 2010 (Policy 24).
2. At step 4, more detailed risk and vulnerability assessments can be applied to areas with the highest and/or earliest onset of potential risk from the initial hazard- and risk-screening exercises. These should initially focus on areas where significant vulnerabilities and risk emerge at a modest sea-level rise, as well as assessing the regional/district extent of risk.
3. At step 6, detailed risk assessments are an integral part of evaluating the effectiveness of response options in reducing risk, and under what conditions and time periods they remain effective.

More information on risk assessments is in section 8.2 of the guidance. Information on engaging the community around assessing vulnerability and risk can be found in section 8.3.

Vulnerability assessments and risk assessments are essential tools for evaluating and identifying adaptation options and pathways later on, at step 6 of the decision cycle.

C. What can we do about it?

Step 5: Identify options and pathways

Coastal adaptation takes place in a dynamic system, where conditions are changing and risk is increasing. A range of different coastal futures could emerge, and it is important that decisions made now are flexible enough to enable feasible and affordable adjustments to be made over time.

Adaptation options at the coast can be described under the following groupings:

Accommodate: adjust existing assets by using measures that anticipate hazard risk, such as raising floor levels, providing alternative inundation flow paths, or requiring relocatable houses.

Protect: hold the line using natural buffers, like dunes, or hard structures, like seawalls.

Retreat: move existing people and assets away from the coast in a managed way over time, or in response to erosion and inundation damage after climate-related events.

Avoidance strategies: stop putting people and assets in harm's way, primarily using land-use planning measures.

In practice, there will likely be a combination or sequence of these types of measures as coastal areas are increasingly affected.

The ability to adapt relies on decisions that are flexible and can be adjusted, or switched to alternative pathways, whatever future sea-level rise is experienced. Different groups in the community will also have different capacities to adapt, depending on their vulnerability.

Applying an adaptive pathways planning approach

Identifying options and pathways takes place in three steps:

1. Identify and agree on council and community objectives using the outputs from steps 3–4 of the decision cycle.
2. Identify the possible range of adaptation options.
3. Develop pathways that meet the agreed objectives.

At each of these three steps, engagement with the community will take place.

An *adaptive pathways planning* approach is a risk-based approach which avoids the need to have firm 'predictions' or to use only one scenario as a basis for decision-making. It accommodates uncertainty, and can enable active community and stakeholder engagement and community capacity building. This approach is used to identify options and pathways that will be evaluated in step 6. They will be implemented through different strategies and plans depending on the context, at steps 7–8 of the decision cycle.

The *adaptive pathways planning* approach asks:

- What are the first impacts that we will face as a result of climate change (outputs from step 2)?
- Under what conditions will current arrangements be ineffective (outputs from steps 2–4)?
- What are the alternatives (step 5)?
- What are the different pathways that can be taken to achieve the same objectives (step 5)?
- How robust are the options over a range of future climate scenarios (step 6)?
- Are they flexible enough to enable a change of path in the future with minimum disruption and cost (step 6)?

The *dynamic adaptive policy pathways* approach develops a series of actions over time (pathways) to achieve objectives (determined at step 3) under uncertain and changing conditions. It is built on the notion that decisions are made over time as conditions change, and cannot be predicted. Existing policies and decisions will eventually start to fail to meet objectives as the conditions change – for example, as the sea-level rises and the frequency of hazard events exceeds an agreed threshold, expressed as a trigger point. Once this happens, additional or different actions are needed to achieve objectives, and an alternative pathway emerges (figure 9 shows shifts in pathways in response to sea-level rise triggers).

By exploring different pathways and testing the consequences under the different scenarios, an adaptive plan can be designed that includes a mix of short-term actions and long-term options. The plan is monitored for thresholds that signal an approaching decision point to either implement the next step of a pathway, or reassess the objectives or the plan itself, requiring a return to earlier steps of the decision cycle.

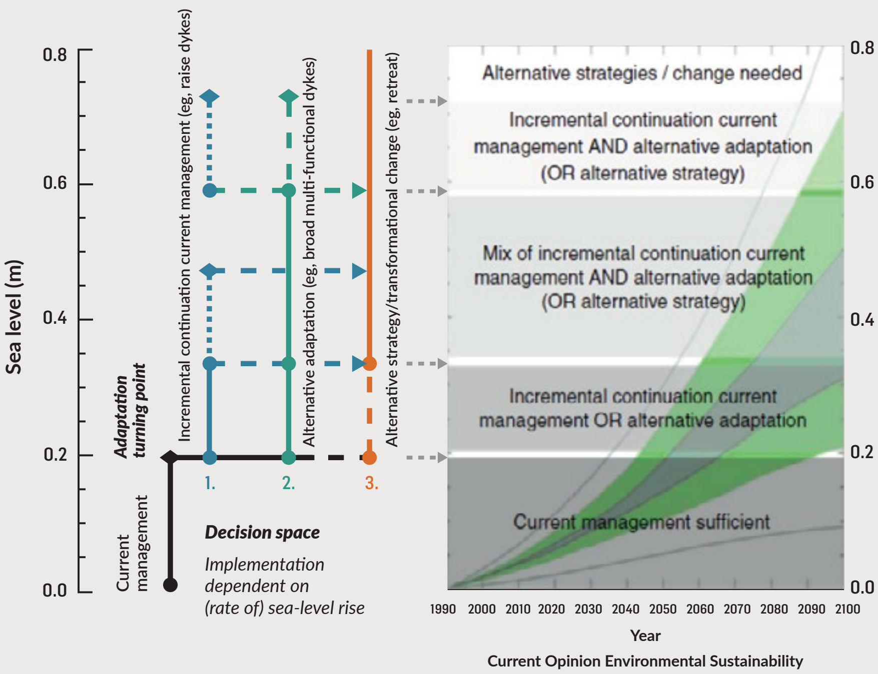
Climate change scenarios allow options to be 'stress tested' for their ability to meet objectives. Stress testing enables us to evaluate whether the response options can still meet the objectives if, for example, a high sea-level rise scenario comes to pass. It also helps to identify future trigger points for transferring to another pathway.

Once options have been identified, they should be described in detail and then tested against the objectives decided at step 3, and other criteria that address uncertainty and robustness over time. Criteria should include:

- flexibility (ability to be adjusted with minimal cost)
- avoiding inflexible commitment to a particular option
- meeting stated objectives over at least 100 years
- performance over a range of possible future climate change and non-climate change scenarios.

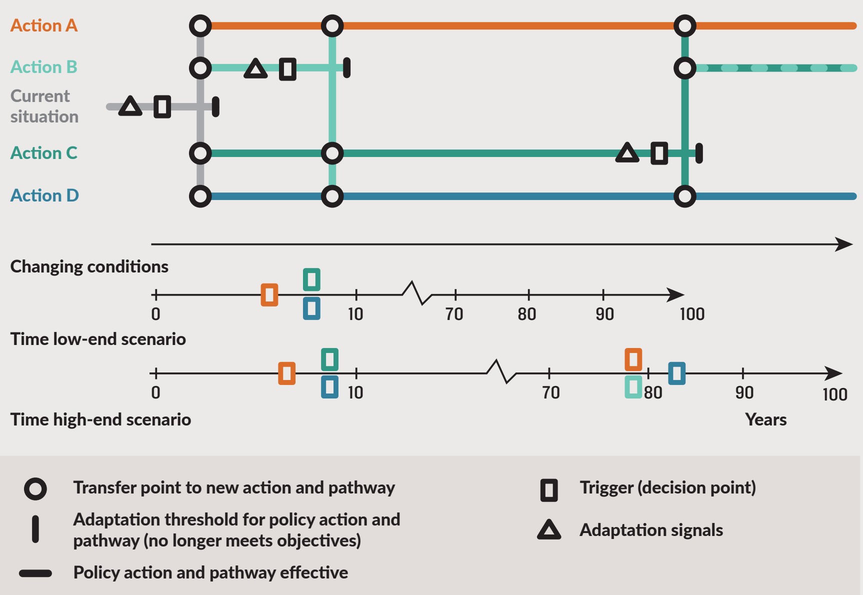
Figure 10 shows an adaptation pathways map. Similar to a 'Metro' map for public transport, it presents alternative routes for getting to the same point (objective) in the future. See section 9.3.3 and appendix G in the guidance for further information and Deltares' video explaining maps: https://publicwiki.deltares.nl/display/AP/Adaptation+Pathways.

Figure 9: Adaptation route map illustrating how different adaptation options combine into adaptation pathways: current management (black): raise dykes or stopbanks (blue), broaden dykes (green) and retreat (red)



Note: Each option is effective for a distinct range of sea-level rise, after which a shift to another option is needed (indicated by arrows). Pathways are implemented depending on improved projections or observed climate change.
Source: Werners et al (2013); with permission

Figure 10: An adaptation pathways map



Source: Adapted from Haasnoot et al (2013); Hermans et al (2017)

Step 6: Option evaluation

Options and pathways may be evaluated using a number of tools (see figure 11), against a range of climate change scenarios.

The applicability of different tools is discussed in section 9.4 of the guidance. The evaluation tools chosen in any situation need to reflect the stage in the decision process, the nature and scale of the issue, the objectives that are to be achieved, and the options that have been identified.

Guiding practice

Dynamic adaptive policy pathways (DAPP) planning is particularly useful for making decisions at the coast, which is a dynamic environment with ever-changing risk profiles, and where there is uncertainty around the rates and magnitude of changes, especially over the long term.

DAPP focuses on:

a. making transparent what the dependencies are between actions

b. whether options will result in lock-in of existing risk or create future exposure to hazard risk, while

c. keeping multiple pathway options open for the future.

This helps to reduce the risk of irreversible decisions that could result in costly future adjustments.

Importantly, DAPP does not prescribe a single solution that is determined at the start. Future options are left for future decisions (when an agreed threshold or advance signal is reached), provided they help achieve the stated objective. This means there is some certainty for the community about what the future possible pathways entail and the consequences of not meeting the objectives. Transparent trade-offs can be made where there are competing options, and different values within communities. Informed debate can then take place on options with an awareness of how these actions might affect future decision-making.

The adaptive planning approach (eg, DAPP) enables:

- an adaptive strategy (step 7) to be built and each pathway to be assessed for its costs over time, including the costs of changing course when options can no longer meet the stated objectives (see appendices G and H of the guidance)
- decisions to be taken in stages over time, by first setting objectives, then deciding thresholds for future actions, and allowing enough time to implement the response options.

See section 9.5 of the guidance for more information on approaches for including community interests in steps 5 and 6 of the decision cycle.

Figure 11: Range of decision support tools

DECISION SUPPORT TOOLS	APPROACH	SUMMARY
Traditional decision support	Multi-criteria analysis	Allows consideration of both quantitative and qualitative data in the scoring and weighting (ranking) of alternative options
Uncertainty decision support	Dynamic adaptive policy pathways planning	Anticipatory, scenario-based to assess options 'use-by' date, robustness, flexibility and monitor trigger/decision point
	Iterative risk-based adaptive planning	Uses iterative framework of monitoring, research, evaluation and learning to improve future strategies
Traditional economic decision support	Cost-benefit analysis	Values all costs and benefits to society of all options, and estimates the net benefits/costs in monetary terms
	Cost-effectiveness analysis	Compares costs against effectiveness (monetary and non-monetary) to rank, then cost-curves for targets/resources
Economic decision-making under uncertainty	Real options analysis	Allows economic analysis of future option value and economic benefit of waiting/information/flexibility
	Robust decision-making	Identifies robust (rather than optimal) decisions under deep uncertainty, by testing large numbers of scenarios
	Portfolio analysis	Economic analysis of optimal portfolio of options by trade-off between return (net present value) and uncertainty (variance)

Note: Tools in light blue colour relate to more traditional approaches and those coloured green to newer approaches to decision-making under uncertainty.

Source: Adapted from Watkiss et al (2015)

D. How can we implement the strategy?

Step 7: Adaptive planning strategy (with triggers)

Step 7 is where the adaptive strategy is developed. This captures the options identified and prioritised in step 5, and the adaptive pathways developed and evaluated in step 6.

This step covers:

1. developing signals and triggers (decision points) for monitoring the plan later at step 9, to allow review and adjustment at step 10
2. identifying which frameworks and measures will be used to implement the plan.

Developing triggers (decision points)

To monitor the strategy as conditions change over time, there needs to be a way to measure when an option or pathway no longer meets its objectives and needs to be adjusted. This requires some kind of advance signal or early warning system. Early signals are preferable to allow enough time for adjustments to be made (eg, resourcing, consenting, implementing).

Examples of specific coastal signals that can be useful early alerts include:

- increasing frequency of clearing stormwater drainage systems
- measurement of saltwater in groundwater systems
- increasing cost and/or complexity of maintaining pumping systems.

Signals and triggers based on measures of sea-level rise or coastal inundation frequency can include a buffer that gives lead time to manage any 'course correction' required (see figure 12).

To enable the adaptive planning strategy to operate over long timeframes, and to address uncertainty about the future, triggers need to define the conditions under which the current option or pathway will not meet the plan objectives.

Step 8: Implementation plan

Step 7 brings together the preferred adaptive planning strategy which councils and communities will be working towards in the long term. The strategy will involve a range of pathways and decision points, parts of which will need to be embedded into statutory planning documents as part of this step.

As the adaptive planning strategy will be longer term than the life of most regional and district plans, it may need to be incorporated in such plans through an appendix or schedule, where it can provide long-term context and guidance for planners and decision-makers. It can then be reviewed at the time of plan reviews or when the triggers in the adaptive plan signal that the pathway no longer meets its objectives. The overall strategy may also involve specific methods (including rules) and other planning techniques in statutory plans.

The choice of method(s) will depend on the situation, the scale of the area and its current development, the objectives and policies, and the community's input. See tables 25-27 in the guidance for more information about types of planning that may be useful, and more detailed methods and techniques that can be used.

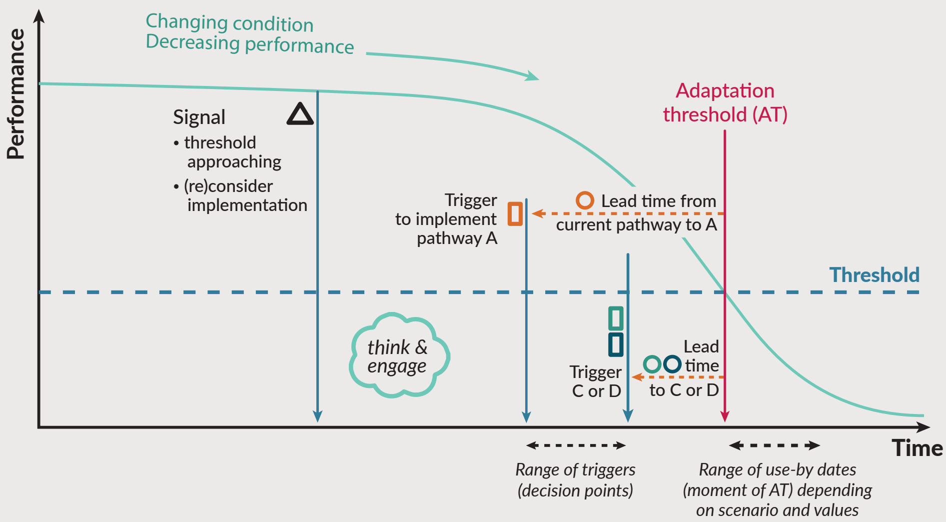
E. How is it working?

Step 9: Monitoring

Regular monitoring contributes to an understanding of changing risks over time, and helps with timely responses to anticipated future levels of risk.

Councils are already engaged in monitoring physical changes and the effectiveness of policies and plans. Because climate change effects will increasingly impact on coastal areas and communities, these monitoring systems will need to be bolstered and re-targeted. For example, councils will need to monitor the achievement of objectives (use-by date of options and pathways) and progression towards signals and triggers (decision points) to enable time to switch between adaptation pathways. Such a trigger could be, for example, the number of damaging or disruptive floods in the central business district over a given time period that is tolerable and acceptable to communities and councils.

Figure 12: Signals and triggers (decision points)



Adapted from graphic by Marjolijn Haasnoot: Deltares 2016

Regular monitoring of the effectiveness of the current pathway against objectives and new information (for example, on climate, sea-level rise, and the effectiveness of global emission reduction) or in light of social, cultural and economic changes, may require adjustments to the decisions or objectives. It may be that some earlier steps in the decision cycle need to be revisited. Regular monitoring, shared with the community and stakeholders, contributes to a shared understanding of changing risks over time, and helps with timely responses to anticipated future levels of risk.

To yield consistent information that reveals trends and changes and is useful for long-term planning, monitoring must:

- be undertaken over time
- follow a consistent framework
- use standardised practice methods
- be done at identified consistent measurement locations.

Some information needs are likely to change over time, so adjustments and additions to the monitoring framework may be needed.

There are three general areas of monitoring that will contribute to an understanding of the changing environment: vulnerability, risk exposure, and effectiveness of responses. See section 11.2 in the guidance for more information.

An adaptation monitoring framework is required as part of the adaptive planning strategy (step 7). This will be linked to plans and actions at the local level as part of the implementation plan (step 8). There are also opportunities to involve the community in monitoring (see section 11.3 of the guidance).

Step 10: Review and adjust

Step 10 reinforces that the 10-step decision cycle is not a linear process. Depending on the nature of the policy, plan or adaptation pathway, regular reviews of the identified adaptation triggers (decision points) may be needed. These triggers will be based on the social and economic effects of physical impacts and the adaptive capacity of communities, and will emerge through monitoring.

Planning along adaptive pathways should also provide for emerging research and findings about hazards and risks, development of new tools for managing hazard risk, and engagement with the community at key decision points.

Part 3: Legislation

In 2014, Local Government New Zealand identified the key responsibilities of regional councils and territorial authorities in relation to natural hazards[8] as:

Regional councils

"Regional councils are charged with:

- controlling the use of land for the purpose of the avoidance or mitigation of natural hazards (section 30 RMA 1991[9]), unless otherwise specified in the RPS;[10]
- setting out (in the RPS) objectives, policies and methods relating to the avoidance and mitigation of natural hazards and specifying responsibilities for functions relating to natural hazards;
- addressing natural hazards risk in carrying out its other RMA planning and consent processing functions;
- coordinating regional CDEM[11] Groups (and participating on such groups); and
- developing and maintaining soil conservation and river control (flood protection) schemes.

Territorial authorities

Territorial authorities are charged with:

- controlling the effects of the use of land for the avoidance or mitigation of natural hazards (section 31 RMA 1991);
- exercising discretion under section 106 to refuse a subdivision consent where the land is subject to certain hazards, or the subsequent use of the land will exacerbate the hazard;
- controlling building under the Building Act by issuing consents for buildings that comply with the Building Code;
- issuing LIMs[12] under the LGOIMA[13] and PIMs[14] under the Building Act; and
- participating in regional CDEM Groups."

Regional policy statements play a central role in determining how local authorities manage natural hazards. They must meet the natural hazard management responsibilities under the Resource Management Act 1991 and national policy statements (including the New Zealand Coastal Policy Statement 2010), and may draw on councils' long-term plans developed under the Local Government Act 2002, Soil Conservation and Rivers Control Act 1941 provisions, and civil defence emergency management group plans.

Key legislation

Key legislation for users of the full guidance is listed in the guidance (chapter 2 and appendix A). It includes:

- Resource Management Act 1991

  Part 2 (Purpose and Principles)

  Section 6 (matters of national importance)

  Section 7 (requires that particular regard must be had to a number of matters including the effects of climate change).

  Figure 13 shows the key RMA policy statements and plans, and their relationships. These have legal force, and their preparation and review are formally required under the RMA. They have specified community and stakeholder process requirements as part of their development, and there are formal opportunities to challenge and test their contents.

  The New Zealand Coastal Policy Statement 2010 (Objective 5 and Policies 3 and 24-27)
- Building Act 2004 (Section 71, Building on land subject to natural hazards)
- Local Government Act 2002
- Civil Defence Emergency Management Act 2002

8 LGNZ 2014, *Managing natural hazard risk in New Zealand – towards more resilient communities.*

9 Resource Management Act 1991.

10 Regional policy statement.

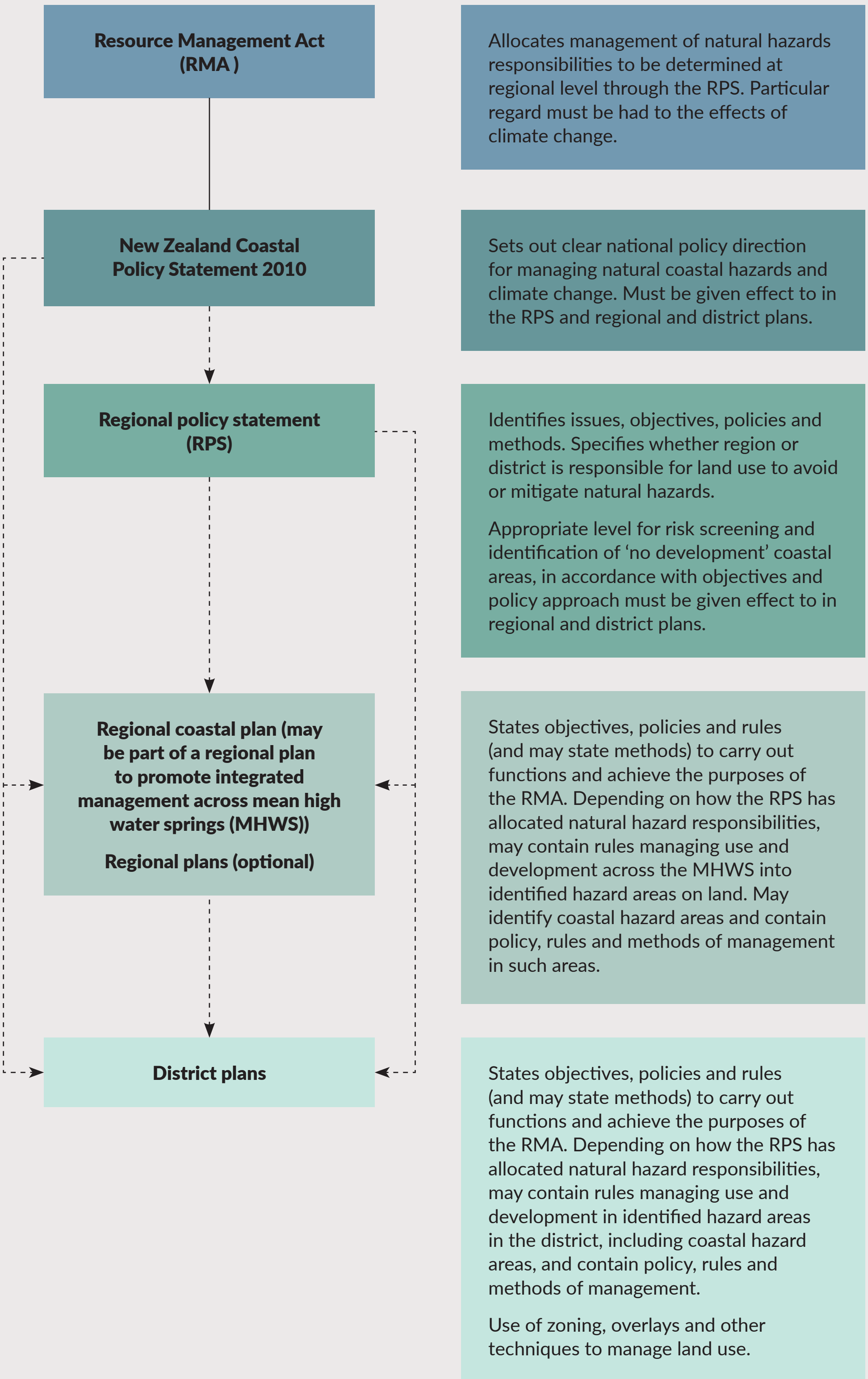
11 Civil defence emergency management.

12 Land information memorandum.

13 Local Government Official Information and Meetings Act 1987.

14 Project information memorandum.

Figure 13: Relationships for coastal hazard management under RMA policy and plans



Part 4: What next?

The third edition of the Ministry for the Environment's Coastal Hazards and Climate Change guidance is a living document. That is, the Ministry intends to review it regularly and provide a statement on whether it remains up to date or whether there have been new developments in science or policy. The Dynamic Adaptive Policy Pathways approach is being implemented globally and now within New Zealand and its practice is being further developed (eg, signal and trigger identification). Reviewing the guidance regularly will ensure the Ministry keeps up with new developments, and provides this information to councils and the wider public.

In developing the guidance, the Ministry has been coordinating with the Department of Conservation (DOC), which is producing guidance on Policies 24–27 and Objective 5 of the New Zealand Coastal Policy Statement 2010. The two guidance documents complement each other, with DOC's guidance covering interpretation of the policies and the Ministry's guidance focusing on implementation.

The Paris Agreement on climate change, concluded in December 2015, has an adaptation goal (that sits alongside a mitigation goal) to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change.

The Agreement obliges Parties to plan for and take action on adaptation, and to report on this. The Agreement does not prescribe how we do this because adaptation to the impacts of climate change is a jurisdictional matter and each country will have its own set of impacts to cope with and adapt to depending on its capacities.

A lot of what is in the Paris Agreement is not completely new, but it does give much more visibility to the importance of each country understanding the likely impacts of climate change, and being prepared through appropriate planning and action.

The previous Minister for Climate Change Issues established a Climate Change Adaptation Technical Working Group comprising technical experts across government and the private sector which will provide advice on options for adapting to the effects of climate change. The group's advice will be based on sound evidence from their first report, a stocktake of existing adaptation work across central and local government and the private sector which was conducted in 2017. The Ministry's climate change adaptation guidance for local government, including the updated *Coastal Hazards and Climate Change* guidance, was included in that stocktake. The work of the Group will also contribute to future updates of the guidance.

Ministry for the Environment
Manatū Mō Te Taiao

New Zealand Government

Appendix A

Adapting to Climate Change in New Zealand - Stocktake Report, Ministry for the Environment, December 2017.

AT A GLANCE

Adapting to Climate Change in New Zealand - Stocktake report

About the Stocktake report

The Stocktake report shows that

- Even if the world stopped all greenhouse gas emissions today, our climate would still change as previous emissions take time to show their impact.
- The extent and pace of change to our future climate (and therefore the level of adaptation we will need) depends on the global mitigation that takes place now.
- We expect to see changes to our air temperatures, our oceans, sea level, rainfall, wind and storms in the medium and long term. These changes will be felt to various extents throughout New Zealand. They will affect where we live, our infrastructure and our economy.
- New Zealand has significant information about what is happening to our climate and the impacts of change such as warmer weather and sea level rise.
- However not all of this information is accessible or in forms that can support decision-making. There are some key gaps in our knowledge, for example potential biosecurity and biodiversity threats.
- Unlike many other countries, New Zealand does not have a coordinated plan for how to adapt to climate change. This includes institutional arrangements for monitoring and implementing a plan.
- Inconsistencies in timeframes across legislation affecting adaptation, and some competing objectives across legislation and policies related to climate change adaptation, resilience and disaster risk reduction means roles can be confused and as a result investment in resources to deliver adaptive action is challenging. Without investment in building capability, capacity to adapt is limited.
- There is limited evidence of proactive adaptation action in New Zealand. In general we react to events after they occur rather than preparing for them. Acting proactively through a risk-based adaptive planning approach is consistent with the latest international best practice.
- The Climate Change Adaptation Technical Working Group is looking at options for how New Zealand can adapt and build resilience to climate change. The group's options report is expected to be completed by March next year.

How will climate change affect our natural environment?

Climate change could have a significant impact on our terrestrial, freshwater, coastal and marine ecosystems, which are already under pressure from land use intensification and other stressors. The range of ecosystems and species will change, as well as the timing of annual and seasonal events like beech masting, and ecosystem functions.

Native species that have highly specialised habitat requirements, such as frogs and lizards, are particularly at risk. Indirectly, climate change will increase the extent and abundance of invasive species, already a key driver of the extinction of native species in New Zealand.

Climate change will also impact on essential ecosystem services we rely on, including the availability of clean fresh water, access to kai moana, soil stability, flood protection, pollination, carbon storage and coastal protection.

What about the impacts on our urban centres and infrastructure?

Most of New Zealand's major urban centres and most of our population are located on the coast or floodplains of major rivers. Our communities, homes, commercial assets and infrastructure are exposed to flooding, sea-level rise, storm surge and inundation from rising ground water levels.

The mid-range projected sea-level rise over the next 50 years is 30cm. Such a rise in sea level would have impacts on all coastal areas to varying extents.

Under this scenario, in Wellington a one in 100-year flood would become an annual event, in Dunedin this would become a one in two-year event, and in Auckland a one in four-year event.

We can also expect to see more damage and disruption to assets and critical infrastructure in parts of these areas. This is significant considering central and local government own over $200 billion in infrastructure assets.

How will climate change affect our communities?

Climate change is increasingly being recognised as a serious emerging risk to public health. Some of the potential impacts will be direct, such as injury and illness from extreme weather events, while others will be indirect, such as increased incidences of existing and new diseases.

For Māori, their reliance on the environment as a cultural, social and economic resource makes them exposed to climate change impacts.

There will be some groups and locations in New Zealand that will be more vulnerable to climate-related risks and have less capacity to adapt. More research is needed to understand who these groups are and where these hotspots are located.

What are the potential impacts on our economy?

Agriculture, fisheries, forestry and tourism are significant contributors to New Zealand's economy, and are all dependent on climate-sensitive natural resources.

These sectors are exposed to the direct impacts of a changing climate for example changes to water availability, as well as indirect impacts that compound and cascade through the economy such as increased biosecurity threats and disruption to supply chains.

In addition, many of our industries are trade-intensive. The Intergovernmental Panel on Climate Change (IPCC 2014) suggest the flow-on effects of climate change impacts and responses outside our region could outweigh some of the direct impacts within New Zealand.

More research is needed on this.

Climate change will also impact on the insurance and finance sectors. More extreme weather events will raise the number and value of claims insurers pay, which will inevitably be reflected in the premiums charged and willingness to provide cover. For banks, this could result in the offer of shorter-term mortgages which may become less affordable. Unavailability or unaffordability of insurance cover will reshape the distribution of vulnerable groups.

While the potential costs of climate change impacts on the New Zealand economy are not known, we do know our exposure to the impacts are high in many areas, for example in coastal floodplains and to our major economic sectors, and as such the costs are likely to be significant. For example, the economic impact of the 2012–13 drought, for which climate change was assessed to have been a factor, is estimated to be a minimum of $1.5 billion.

Who wrote the Stocktake report?

The Climate Change Adaptation Technical Working Group comprises experts from government and the private sector who provide advice on options for adapting to climate change.

Adaptation expert Dr Judy Lawrence co-chairs the group alongside Penny Nelson, Ministry for the Environment's Deputy Secretary, Environmental Performance, Innovation & Climate.

The members of the group have careers in fields that are exposed to or require an active response to the impacts of climate change. They include representatives of central and local government, iwi, banking, insurance, engineering, and science. Expertise from other fields is consulted in the development of the group's advice.

What's next?

The Climate Change Adaptation Technical Working Group is looking at options for how New Zealand can adapt and build resilience to climate change. The group's options report is expected to be completed by March next year.

Review of Otago Regional Council's State of the Environment monitoring programmes

River and lake water quality and ecology

December 2017

Prepared by:
Juliet Milne, Amy Whitehead and Piet Verburg

For any information regarding this report please contact:

Juliet Milne
Resource Management Scientist

+64-4-386 0901
juliet.milne@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

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	Reviewed by:	Dr Scott Larned Dr Neale Hudson
	Formatting checked by:	Pauline Allen
	Approved for release by:	Dr Alison MacDiarmid

Lake Hawea. [Juliet Milne]

Contents

Executive summary

The Otago Regional Council (ORC) monitors water quality and ecological condition in a selection of Otago rivers and lakes through long-term State of the Environment (SoE) monitoring programmes. Information from these programmes is needed to underpin reporting on regional state and trends in river and lake health, performance against the National Policy Statement for Freshwater Management (NPS-FM), and the effectiveness of the Regional Plan: Water for Otago (Water Plan). NIWA was contracted to review the adequacy of the ORC SoE programmes for these purposes, with a specific focus on the site network, monitored variables and monitoring methods.

Rivers

The current monitoring network comprises 65 physico-chemical water quality sites and 29 biological sites. Representativeness analyses based on classification of ORC's Water Plan Receiving Water Groups (RWGs), the River Environment Classification (REC), and Freshwater Environments of New Zealand (FENZ) were used to examine how well the current network of water quality sites represents environmental classes in the Otago region. These analyses indicated similar patterns – a shortage of monitoring sites relative to the abundance of river reaches in unmodified ('natural') catchments, and an overabundance of monitoring sites in catchments dominated by pastoral landcover.

Power analyses were used to estimate the number of monitored sites needed, and the power of the current monitoring network to make comparisons of existing water quality against the ORC Water Plan limits (Schedule 15), compulsory National Objective Framework (NOF) attributes identified in the NPS-FM, and water quality at 'natural state' sites. We found that the current network has sufficient sites to detect statistically-significant differences in water quality between pastoral sites and natural sites, and between NOF attribute states (particularly the C-D band threshold) for most of the water quality variables we assessed. However, the network has insufficient sites to compare current conditions with the Water Plan limits, or to compare urban sites with pastoral and natural sites. Overall, increasing the number of sites in urban areas and in RWG 3 would lead to the greatest gains in power.

The current suite of water quality variables largely aligns with those employed elsewhere in SoE river monitoring programmes, but would be improved with the reinstatement of visual clarity; this is a fundamental variable relating to optical water quality that is of high importance to the public. Adding dissolved copper and zinc (and supporting variables) to the suite of variables monitored at urban sites is also recommended, especially in light of potential future changes to the Water Plan relating to water quality in urban areas. An estimate of flow at the time of sampling ('flow stamping') is required at all water quality monitoring sites as a minimum.

Overall, the existing river monitoring programme has a strong water quality focus, with biological monitoring limited to annual assessments of periphyton and macroinvertebrate community health at 29 sites. The programme would benefit from the inclusion of additional measures of ecosystem health, such as monthly assessments of periphyton cover and annual assessments of stream habitat. The number of sites should also be increased. Implementation of a dedicated periphyton biomass monitoring programme at a selection of sites (for an initial 2-3 year period) should have high priority to ensure that NPS-FM requirements are fulfilled. Monthly monitoring of deposited streambed sediment cover would be useful at some sites; selection of these sites should take into account both current and potential future land use pressures.

Lakes

Water quality monitoring is currently carried out on nine lakes, with most of these lakes listed in RWG 4 or 5 in the Water Plan. The nine lakes represent a range of environmental conditions in terms of depth, lake type (morphometry), trophic state, and upstream catchment landcover.

We recognise that significant resourcing and logistical constraints around lake water quality monitoring have led to the current mix of outlet and on-lake monitoring sites, with the latter only monitored on a rolling basis, monthly for two or three years every ten years. However, in light of their very high regional (and national) values, and potential for change in condition, ongoing monthly sampling of open water sites on Lakes Wakatipu, Wanaka and Hawea is highly recommended. The sampling of these lakes – and Lake Hayes – should be modified to ensure that the full vertical water column is profiled on every sampling occasion for water temperature and dissolved oxygen, with periodic profiling of nutrient concentrations. The addition of a monitoring buoy on each of the three deep lakes would provide high frequency information on stratification and mixing that will help ORC to understand changes in trophic state that are identified through regular monthly sampling. Buoys with fixed sensor strings can record measurements down to the maximum depths of these lakes (maximum depth 384 m).

We recommend establishing an open water monitoring site on each of Lake Onslow and Lake Tuakitoto, with monthly sampling of these sites for a period of at least two years, to verify the monitoring results obtained to date from outlet monitoring. For Lakes Waihola and Waipori, we recommend, as a minimum, increasing the monitoring frequency at open water sites from every 10 to every 5 years to improve the ability for timely detection of changes in lake condition. Overall, across all lakes, ongoing bi-monthly sampling is preferable to continuing rotational monitoring.

In the report we have considered monitoring variables on both lake and site-within-lake basis. The recommended monitoring variables have been grouped into prioritised tiers, with Tier 1 (water temperature, dissolved oxygen, total phosphorus, total nitrogen, chlorophyll *a*, and Secchi depth) and Tier 2 (dissolved reactive phosphorus, ammoniacal nitrogen and nitrite nitrate nitrogen) variables recommended for measurement across all lakes. Tier 3 variables (particulate nitrogen, particulate phosphorus and particulate carbon), as well as phytoplankton, should be monitored in Lakes Wakatipu, Wanaka and Hawea, and total and volatile suspended solids should be monitored in the shallow lowland Lakes Tuakitoto, Waihola and Waipori. Additional Tier 4 and 5 variables are outlined in the report.

Achieving sufficiently low nutrient analytical detection limits is of high importance for the robust tracking of temporal changes in trophic state in Lakes Wakatipu, Wanaka and Hawea. Implementing LakeSPI macrophyte monitoring across the lakes, with initial priority given to establishing a baseline of macrophyte condition in Lakes Wakatipu, Hayes, Dunstan and Wanaka, would provide useful information on lake ecological condition.

Monitoring linkages, out-of-stream pressures and quality assurance (QA)

While river and lake monitoring activities in Otago are managed as separate programmes, it is important to consider linkages between these programmes for effective fresh water management, including monitoring that addresses connections between rivers and lakes with groundwater and downstream estuarine systems. We have provided a brief commentary on linking monitoring between water domains and also the need to track water use, land use and land management activities through time. Finally, the recent release of a draft National Environmental Monitoring

Standard (NEMS) for Discrete Water Quality Sampling and Measurement provides important direction for SoE river and lake monitoring programmes. We recommend that ORC reviews their river and lake monitoring programme documentation and QA practices for field, laboratory and data management procedures against the requirements set out in the draft NEMS.

1 Introduction

Otago Regional Council (ORC) is responsible for promoting the sustainable development and enhancement of Otago's natural resources, including fresh waters. The Otago region's freshwater resources comprise over 55,000 km of rivers and over 60 recognised lakes, including the iconic Clutha/Mata-au and Taieri Rivers, and Lakes Hawea, Wanaka and Wakatipu.

ORC monitors a selection of rivers and lakes through long-term State of the Environment (SoE) monitoring programmes. These programmes date back to the mid-1990s and the information is used to report on:

- Regional state and trends in river and lake health,
- Performance against the National Policy Statement for Freshwater Management (NPS-FM), and
- The effectiveness of particular provisions of the Regional Plan: Water for Otago (Water Plan).

This report documents a review of ORC's SoE river and lake water quality programmes to ensure that they are fit for purpose in terms of the site network, variables monitored and monitoring methods. It provides the first formal review of the programmes in over 10 years. ORC intends to use the review findings to inform its assessment of Long Term Plan resourcing needs.

1.1 Scope

This report assesses current monitoring activities, as well as future monitoring requirements, which include:

- River monitoring site locations and network configuration for water quality, periphyton and macroinvertebrates, and sampling and measurement procedures for monitoring variables, including instream habitat.
- Lake monitoring site locations and network configuration, sampling procedures (e.g., profiles, integrated sampling, LakeSPI) and technology (e.g., monitoring buoys, remote sensing), and sampling and measurement procedures for monitoring variables, including physical-chemical variables, macrophytes, phytoplankton and zooplankton.

The report also briefly:

- Considers linkages between river and lake monitoring, and between other water domains.
- Identifies key out-of-stream pressures that should be monitored to assist with interpretation of SoE data and to guide natural resource management.
- Comments on data quality assurance practices, particularly in light of the recently drafted National Environmental Monitoring Standards for Discrete Water Quality (NEMS 2017).

The following items are out of scope for this review:

- Detailed characterisation or assessment of receiving environment data.
- Consideration of biological monitoring requirements for non-wadeable rivers (e.g., Clutha River/Mata-au).
- Review of hydrological monitoring, other than consideration of the location of hydrological sites in relation to water quality and biomonitoring sites.
- Review of recreational water quality monitoring, other than identifying what ORC would need to measure at SoE sites in order to meet existing NPS-FM requirements in relation to *E. coli* and cyanobacteria.
- Consideration of groundwater inflows and potential effects on surface water quality, or groundwater quality monitoring sites.
- Estuarine and coastal monitoring considerations, other than brief consideration of variables that may need to be measured in freshwater to inform future ORC estuarine SoE monitoring.
- Fish monitoring requirements.
- Cultural health monitoring requirements.
- Health and safety considerations in relation to recommended sites or monitoring methods.
- Monitoring approaches likely to be required for targeted investigations.

1.2 Report outline

This report comprises five sections in addition to this introductory section:

- Section 2 provides a brief overview of ORC’s existing river and lake monitoring programmes.
- Section 3 reviews the existing river SoE monitoring programme, including site representativeness and statistical power associated with the water quality monitoring network, and monitoring variables and monitoring methods.
- Section 4 reviews the existing lake SoE monitoring programme, including representativeness, and monitoring variables and monitoring methods.
- Section 5 provides a brief commentary on linkages between river and lake (and downstream receiving water) monitoring activities, key out-of-stream pressures that should be monitored to assist with interpreting SoE data and guiding management (e.g., land use), and guidance on data quality assurance practices.
- Section 6 presents conclusions and recommendations.

2 Overview of existing monitoring and management

This section briefly overviews monitoring objectives and ORC's existing State of the Environment (SoE) river and lake monitoring programmes. The existing regulatory framework for water quality management is also briefly outlined.

2.1 Monitoring objectives

The primary purpose of most SoE river and lake monitoring programmes is to monitor state (condition) and trends through time. As it is not possible to monitor all rivers or lakes across a region, a small subset of river and lake sites is monitored with the expectation that each site will represent unmonitored sites with similar environmental conditions (Larned et al. 2013). Collectively, these sites comprise a monitoring network and, in terms of river monitoring, the representativeness of the network refers to the degree to which monitoring sites are distributed across the different river environments present in the same proportions as the abundance of river segments or area of habitat in those environments (Unwin et al. 2014).

SoE monitoring at a regional scale is commonly used to satisfy multiple purposes. The ORC has identified (D. Olsen, pers. comm.) that monitoring is used to report on:

- Regional state and trends in river and lake health (with this information also contributing to national environmental reporting),
- Performance against the National Policy Statement for Freshwater Management (NPS-FM), and
- The effectiveness of particular provisions of the Regional Plan: Water for Otago (Water Plan).

It can be difficult to satisfy multiple information needs from a single monitoring network because the questions to be answered are generally different. For example, monitoring the effectiveness of ORC's plans requires assessment of the impacts of different land uses (e.g., pastoral and urban) on water quality – these are not distributed across the region in the same proportion as different river environments. This conflict is well-recognised (e.g., Larned and Unwin 2012), and requires that pragmatism must be exercised in the design and implementation of regional SoE monitoring programmes. Randomised site selection can be one approach for developing representative monitoring networks (e.g., Collier et al. 2005). However, it is important to consider the trade-offs between completely redesigning a monitoring network and modifying an existing network when trying to improve representativeness.

2.2 River monitoring

As at July 2017, ORC monitors 65 river and stream sites across the Otago region as part of its long-term SoE surface water quality monitoring programme (Figure 2-1). A suite of physico-chemical and microbiological water quality variables is measured monthly at each site: water temperature, dissolved oxygen, conductivity, pH, turbidity, total suspended solids (TSS), soluble and total nitrogen and phosphorus, and *E. coli* (as an indicator of faecal pathogens). In addition, macroinvertebrate and periphyton community abundance and diversity are assessed annually during summer/autumn at 29 sites. Water quality monitoring is carried out by ORC's Environmental Services section while biological monitoring is carried out by an external provider, Ryder Consulting Ltd.

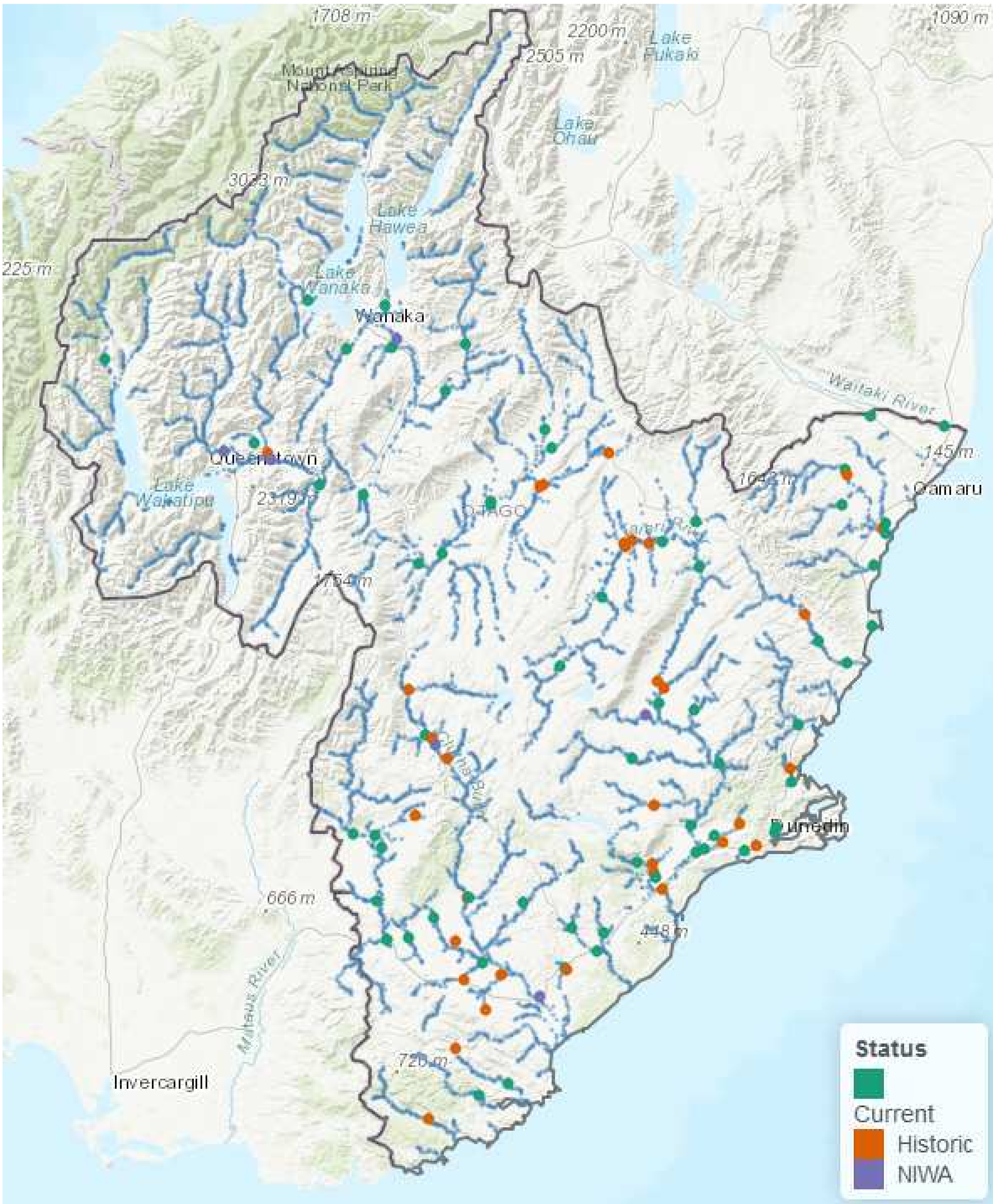

Figure 2-1: Map of existing ORC river and stream water quality monitoring sites as at July 2017. Green and orange circles indicate current and historic sites, respectively. Purple circles indicate NIWA sites. Up until 30 June 2017, when they were transferred to ORC's network, NIWA also monitored Taieri River at Tiroiti and Taieri River at Outram. Fourth order streams and greater are shown in blue.

For 5-yearly SoE reporting purposes, ORC has supplemented its network with data from eight sites monitored monthly by NIWA as part of its National River Water Quality Network (NRWQN). Two of these NIWA sites were transferred to ORC on 1 July 2017, giving ORC a total of 65 water quality monitoring sites. For biomonitoring, data from a total of 36 sites have been available for SoE reporting to date (29 ORC sites and 7 NIWA sites).

2.3 Lakes

ORC currently monitors water quality in nine lakes, at a mix of outlet and on-lake sites (Figure 2-2). Outlet sites are monitored monthly on an on-going basis, while open water sites are monitored on a rolling basis, generally monthly for a two or three-year period every 10 years.

The suite of lake water quality variables is similar to that monitored at river sites, with the addition of Secchi depth visual clarity (some sites) and chlorophyll *a*. Additional forms of nutrients and phytoplankton diversity and abundance have also been monitored on some lakes since September 2016. This is discussed further in Section 4.

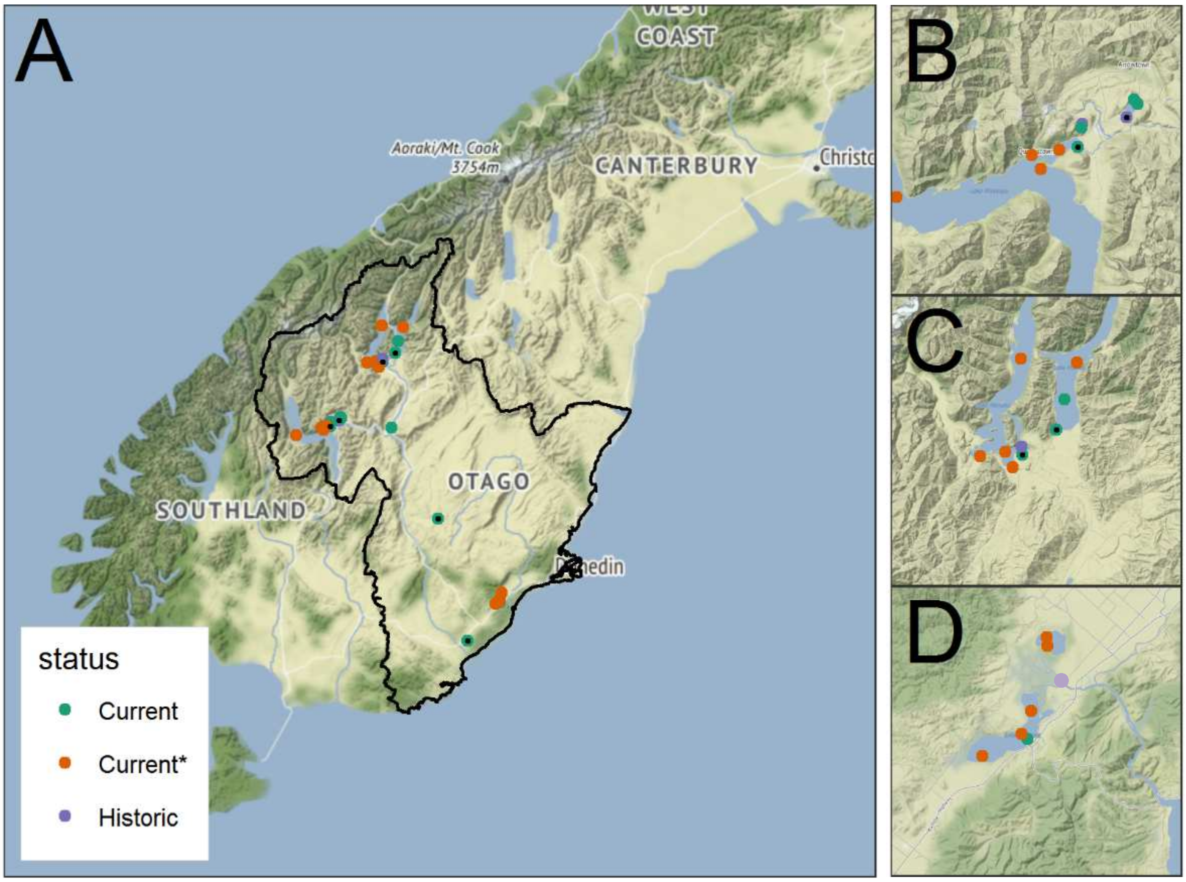

Figure 2-2: Map of existing and historic ORC lake water quality monitoring sites as at July 2017. Green and orange circles indicate current sites, with orange sites currently monitored on a rotational basis (two-three years out of every ten). Purple circles indicate historic sites and black dots indicate lake outlet monitoring sites. The insets provide details for sites on Lake Wakatipu (B), Lakes Wanaka and Hawea (C), and Lakes Waihola and Waipori (D).

2.4 Water management framework

The *Regional Plan: Water Plan for Otago* (Water Plan) provides the regulatory framework for management of river and lake water quality in Otago, including giving effect to the NPS-FM. On 1 May 2014, Plan Change 6A (water quality) became operative, establishing rules to control entry of contaminants from <u>rural land</u> into waterways from runoff, leaching and drains (non-point sources).[1] Schedule 15 sets out receiving water numerical limits for achieving "good water quality" in Otago rivers and lakes, with target dates by which they shall be met. These limits apply to five variables:

[1] In terms of sediment, the rules apply to all activities, not just rural.

nitrate-nitrite nitrogen, dissolved reactive phosphorus, ammoniacal nitrogen, *E. coli* and turbidity, assigned to five Receiving Water Groups (RWGs, Figure 2-3). The five receiving water groups serve as Freshwater Management Units (FMUs) under the NPS-FM (D. Olsen, pers. comm.).

In addition to water quality limits, Schedule 15 contains narrative "characteristics" (essentially variables or attributes) of good water quality. The listed characteristics are: (visual) clarity, colour, (deposited) sediment, smell, algae and bank appearance.

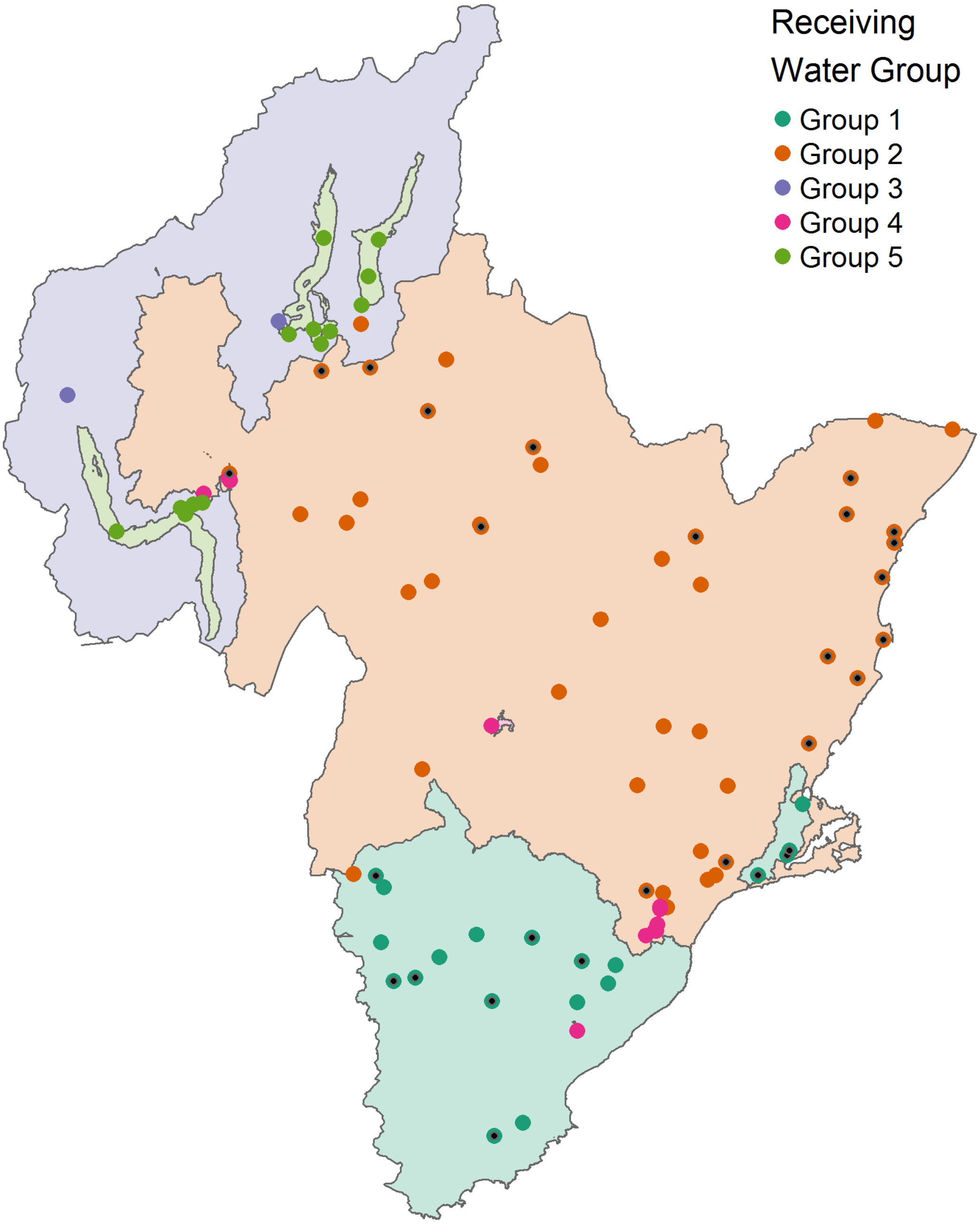

Figure 2-3: ORC's five receiving water groups (RWG) as set out in Schedule 15 of the Water Plan. RWGs 1-3 comprise riverine sites. Lakes Hayes, Johnson, Onslow, Tuakitoto, Waipori and Waihola form RWG 4 and Lakes Wakatipu, Wanaka and Hawea form RWG 5. The coloured circles denote existing ORC river and lake water quality monitoring sites. A black dot within a circle denotes a river site where macroinvertebrates are also monitored.

Around mid-2016, ORC commenced a review of its management of point source discharges, including discharges of stormwater, wastewater, industrial and trade waste to freshwater and coastal water. This review will inform future changes to ORC's Water Plan and Regional Plan: Coast, as well as the implementation of non-regulatory methods to achieve good water quality and ecological health in receiving waters, including rivers and lakes. Such future plan changes may require further modifications to ORC's SoE monitoring programme.

3 Rivers

This section presents the review of current river State of the Environment (SoE) monitoring. The monitoring network is addressed first, starting with an assessment of the representativeness of ORC's existing river water quality monitoring sites. An analysis of statistical power is then used to estimate the number of monitoring sites needed in each river-based Receiving Water Group (RWG) to make robust assessments of water quality against different criteria. Following this, we address monitoring variables and methods relating to physico-chemical and microbial water quality, periphyton, macroinvertebrates and habitat. A brief summary is provided at the end of each major subsection.

3.1 Monitoring sites

The adequacy of the current composition and number of river monitoring sites for ORC's monitoring objectives (Section 2.1) was assessed through:

- Representativeness analyses that examined how well the current monitoring network represents the environmental classes within the Otago region, and
- Power analyses to estimate the number of monitoring sites needed to conclude that observed differences in water quality between different groups (e.g., between landcover classes) are statistically significant.

Regional representativeness was assessed using two nationally-recognised classification schemes, the River Environment Classification (REC, Version 1; Snelder & Biggs 2002) and the Freshwater Environments of New Zealand (FENZ; Leathwick et al. 2010), as well as consideration of the geographic spread of sites across ORC's three river-based RWGs. Power analyses determined the power of the current monitoring network, and the minimum number of monitoring sites needed in each river-based RWG, to determine whether current water quality is different from limits specified in ORC's Water Plan, NOF attributes described in the NPS-FM[2], and estimates of the natural state within Otago. Further details and methods for conducting the representativeness and power analyses are provided in Sections 3.2 and 3.3, respectively.

All analyses were based on ORC's current suite of 65 river water quality monitoring sites, including the two Taieri River sites recently inherited from NIWA (Table 3-1).

Table 3-1: The number of sites currently monitored for each water quality variable in each Receiving Waters Group (RWG) and REC Landcover class. The REC Landcover class 'Natural' is a combination of the Bare, Indigenous Forest, Tussock, Scrub, Wetland and Miscellaneous classes.

RWG			REC Landcover Class		
1	2	3	Natural	Pasture	Urban
20	42	3	14	48	3

[2] The assessment was based on the numeric attribute states contained in Appendix 2 of the NPS-FM as at July 2017.

3.2 Representativeness

The primary purpose of the representativeness assessment was to identify the environmental classes that are most severely under- or over-represented in ORC's existing suite of river water quality monitoring sites.

3.2.1 Introduction

To be highly representative, a river monitoring network in an environmentally heterogeneous region like Otago requires two conditions to be met.

First, data from rivers representing all environmental or geographic classes in the region should be included. If some classes are excluded, the overall estimated state or trend will be over-influenced by classes that are included. For example, a regional water quality analysis including agricultural and urban landcover classes but excluding forested landcover classes in the same region may erroneously indicate that water quality is substantially worse than the true region-wide state.

The second condition is that the number of monitoring sites from each environmental or geographic class, and the abundance of each class in the assessment area, should have the same proportions. This condition can be applied before compiling data (by selecting sites in proportion to the size of their environmental class) or after compiling data (by assigning a weighting factor to the data from each environmental class). For example, if lake-fed rivers comprise 20% of the total number of rivers (or 20% of the total river length) in an assessment area, lake-fed rivers should comprise 20% of the monitoring sites used for assessment. If these conditions are not met, rare environmental classes may have too much influence on estimated water quality and common classes may have too little influence. Proportionality factors available for use include:

- the number of segments in each environmental class as a proportion of total reach number,
- the length of river channel in each class as a proportion of total river length,
- the relative amount of river flow, or
- the catchment area of a river as a proportion of total area (Snelder et al. 2006).

These considerations are particularly important when monitoring data are used for constructing statistical models that predict water quality at unmonitored sites (Unwin & Larned, 2013). While such models can be useful for understanding patterns of water quality in areas with similar environmental characteristics to monitored sites, high uncertainty is often associated with predictions outside of the range of environmental classes that are monitored. This extrapolation issue can be reduced by ensuring that the environmental space is sampled as widely as possible.

Otago Regional Council currently monitors 65 river sites for water quality, with an additional six sites monitored by NIWA (Figure 2-1). These sites span ORC's three river-based RWGs for the Otago region. We assessed the degree to which currently monitored sites are distributed in proportion to the abundance of river length in the three RWGs, 32 REC classes and 19 FENZ classes within the Otago region (Snelder & Biggs 2002; Leathwick et al. 2010).

3.2.2 Methods

Each water quality monitoring site was classified by REC (Version 1)[3] and FENZ classes, in three steps. First, the NZTM location for each site was used to assign an NZReach number for the reach corresponding to the monitoring site. NZReaches are georeferenced river segments defined by upstream and downstream confluences. The assignments of monitoring sites to NZReaches were checked for accuracy on digital topographic maps. Second, the REC classifications for the monitoring sites were extracted using the NZReaches. The classes were based on the REC Climate, Source of Flow and Landcover levels, averaged across all Geology classes present, with network position and valley landform omitted. Third, to make the total number of REC classes in the analysis manageable and to avoid many small REC classes with no sites, the five natural land-cover categories in the REC (Bare, Indigenous Forest, Tussock, Scrub, Wetland and Miscellaneous) were pooled into a single category termed “Natural”. This REC classification was used to produce a relatively large number of classes with sufficient sites in each class to calculate accurate medians for the water quality variables. This generated 32 REC classes.

The REC assigns landcover classes to river segments based on the predominant landcover in the upstream catchment, subject to two exceptions:

- If landcover is > 25% pastoral, the reach is classed as Pastoral, and
- If landcover is > 15% urban, the reach is classed as Urban.

FENZ classifications were extracted from the FENZ database and assigned to monitoring sites based on NZReaches. In addition, all segments in the digital river network in Otago were classified by the ORC’s RWGs.

The "representative number of sites" was calculated as the product of the total number of existing sites and the proportion of river length in each REC, FENZ and major landcover class. Current representativeness was then quantified as the difference between the current number of sites in each river class and the representative number of sites. Positive values indicate that the class is over-represented and negative values indicate that the class is under-represented.

To facilitate interpretation, we distinguished two types of under-representation: “gaps” where there are no monitoring sites in a river class, and “shortages” where there are too few sites to achieve a minimum statistical power for a given variable. Note that gaps are defined in terms of presence or absence of sites, not in terms of the range of variables measured.

To explore the current monitoring network’s ability to sample across environmental space, we ran a Principal Components Analysis (PCA) using 20 continuously distributed environmental variables from the FWENZ ((Freshwater Environments of New Zealand) database, Table 3-2, Leathwick et al. 2005). These variables represent characteristics of the upstream catchment, including landcover, rainfall, temperature and elevation, and are commonly used to construct statistical models of water quality (Unwin & Larned 2013). We made a visual comparison of the environmental space occupied by the current monitoring network and the overall Otago region, as described by the PCA, to identify areas where predictions from a predictive model would have to be extrapolated and, therefore, potentially be associated with higher uncertainty.

[3] To align with the FENZ classification which was developed on REC v1.

Table 3-2: Environmental predictor variables used in a Principal Components Analysis to identify environmental space in the Otago region.

Category	Variable	Description
Topography	usCatElev	Mean elevation of upstream catchment
	segAveElev	Reach elevation
	usAveSlope	Steepness of upstream catchment
	usArea	Area of the upstream catchment
Flow	usFlow	Mean upstream flow
Climate	usRainDays20	Number of rain days greater than 20 mm
	usRainDays100	Number of rain days greater than 100 mm
	usAnRainVar	Variation in upstream annual rainfall
	usAvTCold	Average winter temperature in the upstream catchment
	usAvTWarm	Average summer temperature in the upstream catchment
	segAveTCold	Average winter temperature at the reach
Landcover	usGlacial	% glacier within the upstream catchment
	usIndigForest	% indigenous forest within the upstream catchment
	usWetland	% wetland within the upstream catchment
	usScrub	% scrub within the upstream catchment
	usUrban	% urban within the upstream catchment
	usLake	% lake within the upstream catchment
	usExoticForest	% exotic forest within the upstream catchment
	usPastoral	% pasture within the upstream catchment
	usBare	% bare ground within the upstream catchment

3.2.3 Results

Classification of the Otago region by river-based RWGs showed that RWG 3 is under-represented in the current network of 65 sites (Table 3-3). An additional nine sites would be required in RWG 3 for the network to be representative based on the proportion of the region that falls within this group. One site in RWG 3 is currently monitored by NIWA (Clutha at Luggate Br.) but there are no historic sites within RWG 3 that could be used to fill this shortfall. In comparison, this analysis suggests that RWGs 1 and 2 are over-represented, based on the proportion of the region that these groups cover. Sites that fall within over-represented RWGs are identified in Table A-1.

Table 3-3: Distribution of current ORC river water quality monitoring sites among Receiving Water Groups (RWGs). Blue shading represents classes that are over-represented and purple shading represents classes that are under-represented. Representative numbers of sites are rounded to the nearest whole number. Historic sites represent former ORC monitoring sites in each class that could potentially be used to fill gaps in representativeness.

RWG	Total river length (km)	% total river length	Number of sites	% of sites	Representative number of sites	Site diff.	Number of historic sites
1	8,247	17.3	20	30.8	11	9	11
2	30,063	63.2	42	64.6	41	1	22
3	8,976	18.9	3	4.6	12	-9	0

When the monitoring sites were grouped by REC class at the Climate/Source-of-flow/Landcover level, there were eight gaps and three shortages (Table 3-4). Natural was the predominant landcover class where gaps were identified (Figure 3-1), although gaps were also noted in one exotic forestry and one pastoral class. Five of the REC classes where we identified gaps cover less than 1.5% of the region. In two cases, gaps could be filled by reopening historic monitoring sites (Table 3-4). All shortfalls occurred in REC classes containing Natural landcover, with the potential option of re-instating a historic site (Arrow at Morven Ferry Road; Table 3-6) in the CW/M/N class. Eight REC classes were over-represented, although only two of these (CD/L/P and CD/H/P) cover more than 2% of the region. Sites within over-represented REC classes are identified in Table A-1.

Classifying the monitoring network by FENZ classes identified five classes that are over-represented, one class with a shortfall and two classes with gaps (Table 3-6). The shortfall occurred in class H, which was under-represented by nine sites, while the largest gap was six sites in class N. No historic sites were available in any of the under-represented classes, so shortfalls and gaps would need to be filled by adding new sites to the network. Sites within over-represented FENZ classes are identified in Table A-1.

The environmental space within the Otago region is best explained by predictors describing topography (elevation, slope), climate (rainfall, temperature) and landcover (pasture, indigenous forest, bare ground). Most river reaches within the region occur in *pastoral streams* with relatively flat, low elevation and low rainfall areas that are dominated by pastoral landcover (Figure 3-2). However, a large proportion of the region is dominated by *high country streams* with high elevations, steep slopes, high rainfall, cool temperatures and native vegetation cover. The RWGs showed considerable variation in the environmental space that they represent (Figure 3-3). While RWG 3 only contains 18.9% of reaches within the region (Table 3-4), it has the largest number of small order reaches and represents the greatest variation in environmental space.

Some environments in each RWG are currently unmonitored, particularly in RWGs 2 and 3 (Figure 3-1, Figure 3-3). These unmonitored environments typically represent areas with high elevations and steep slopes associated with small mountain and high country streams. The environmental space corresponding to historic sites and currently monitored sites are similar, indicating that historic sites are unlikely to be useful in filling gaps.

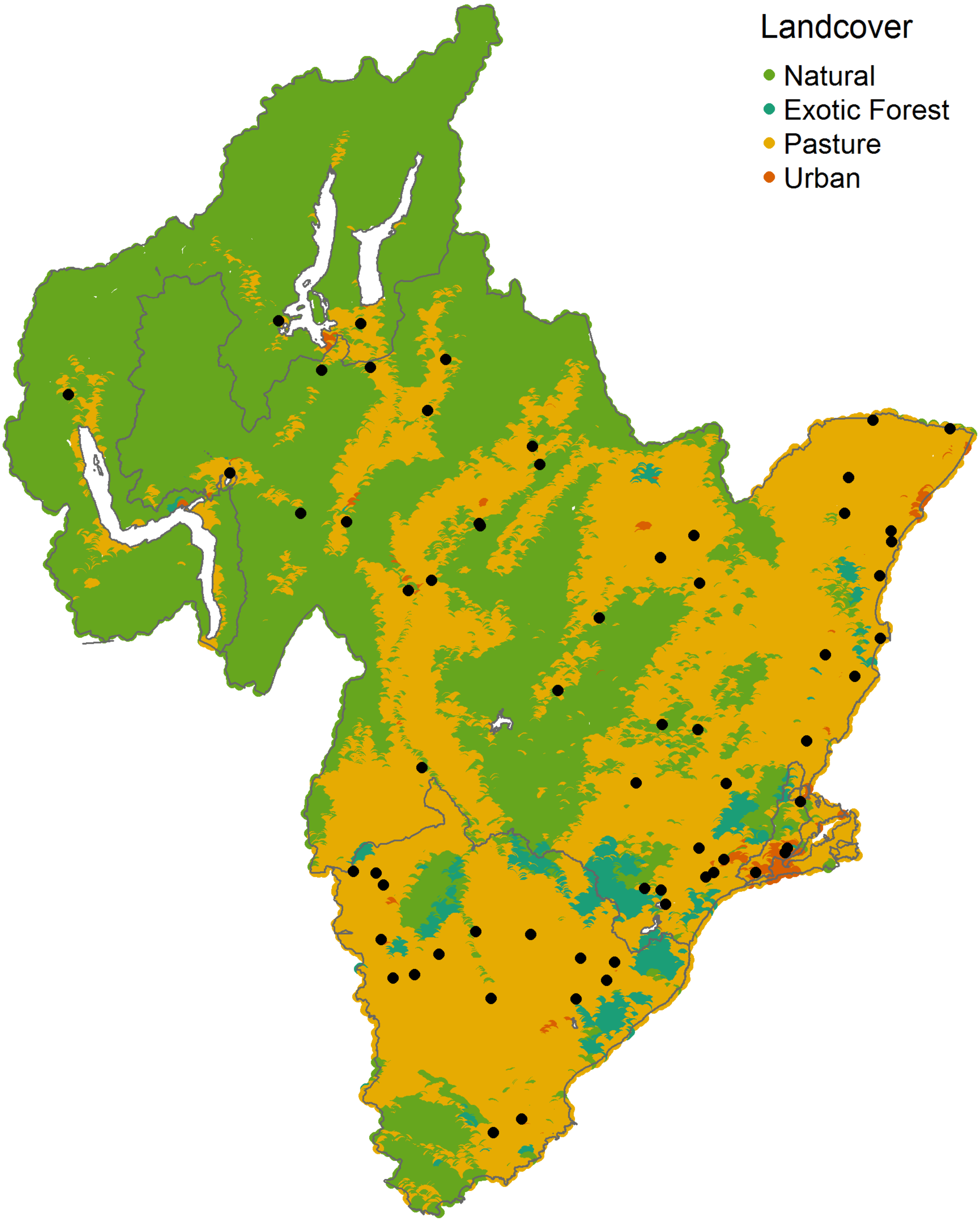

Figure 3-1: Distribution of ORC's existing 65 river water quality monitoring sites across major landcover classes within Otago. The Receiving Water Group boundaries are outlined in grey. Very few sites exist under natural landcover.

Table 3-4: Distribution of current ORC river water quality monitoring sites among REC classes. Blue shading identifies classes that are over-represented by monitoring sites, purple shading identifies classes that are under-represented, and orange shading identifies classes that are not represented. Representative numbers of sites are rounded to the nearest whole number and classes are ordered from the most to least abundant by river length. Historic sites represent former ORC monitoring sites in each class that could potentially be used to fill gaps in representativeness, with green shading representing opportunities to fill gaps or shortfalls by reinstating historic sites.

REC class*	Total river length (km)	% total river length	Number of sites	% of sites	Representative number of sites	Site diff.	Number of historic sites
CD/L/P	10,803	22.7	24	36.9	15	9	11
CD/H/P	10,187	21.4	21	32.3	14	7	15
CW/M/N	6,684	14.1	2	3.1	9	-7	1
CD/H/N	5,847	12.3	7	10.8	8	-1	0
CX/M/N	3,725	7.83	0	0	5	-5	0
CW/H/N	2,099	4.41	0	0	3	-3	0
CX/GM/N	1,449	3.05	2	3.1	2	0	0
CD/M/N	1,419	2.98	1	1.5	2	-1	0
CW/L/P	818	1.72	2	3.1	1	1	1
CD/L/EF	676	1.42	0	0	1	-1	0
CD/L/N	615	1.29	0	0	1	-1	1
CX/H/N	578	1.22	0	0	1	-1	0
CW/H/P	510	1.07	0	0	1	-1	0
CW/L/N	485	1.02	0	0	1	-1	1
CD/H/EF	373	0.78	0	0	1	-1	0
CD/M/P	198	0.42	1	1.5	0	1	0
CD/L/U	194	0.41	2	3.1	0	2	2
CW/Lk/N	159	0.33	0	0	0	0	0
CW/M/P	80	0.17	0	0	0	0	0
CX/Lk/N	72	0.15	1	1.5	0	1	0
CD/Lk/N	65	0.14	1	1.5	0	1	0
CW/Lk/P	63	0.13	0	0	0	0	0
CW/H/EF	51	0.11	0	0	0	0	0
CX/H/P	39	0.08	0	0	0	0	0
CW/L/EF	35	0.07	0	0	0	0	0
CD/Lk/P	19	0.04	0	0	0	0	1
CX/L/P	15	0.03	0	0	0	0	0
CD/H/U	10	0.02	0	0	0	0	0
CW/GM/N	6	0.01	0	0	0	0	0
CW/L/U	4	0.01	1	1.5	0	1	0
CX/L/N	5	0.01	0	0	0	0	0
CX/M/P	3	0.01	0	0	0	0	0

Note: * REC class abbreviations: Climate - CD: cool-dry, CW: cool-wet, CX: cool-extremely wet; Topography - H: hill, L: lowland, Lk: lake-fed, M: mountain, GM: glacial mountain; Landcover - P: pastoral, N: natural, U: urban; EF: exotic forest.

Table 3-5: Distribution of current ORC river water quality monitoring sites among FENZ classes. Blue shading represents classes that are over-represented, purple shading represents classes that are under-represented, and orange shading represents classes that are not represented. Representative numbers of sites are rounded to the nearest whole number and classes are ordered from the most to least abundant by river length. Historic sites represent former ORC monitoring sites that could potentially be used to fill gaps in representativeness.

FENZ class	Total river length (km)	% total river length	Number of sites	% of sites	Representative number of sites	Site diff.	Number of historic sites
G: Mid-elevation streams and rivers in dry inland areas	14,666	30.8	27	41.5	20	7	13
D: South Island low-elevation streams and rivers in dry inland areas	11,049	23.2	15	23.1	15	0	8
H: Steep, mid-elevation streams and rivers in eastern areas	7,027	14.8	1	1.5	10	-9	0
A: Lowland, low-gradient streams and rivers	5,618	11.8	11	16.9	8	3	7
N: Eastern, high-elevation steep headwater streams	4,095	8.61	0	0	6	-6	0
C: Lowland hill country gravel-bed streams	2,928	6.15	9	13.8	4	5	5
P: High-elevation, very cold, steep headwater streams	487	1.02	0	0	1	-1	0
E: South Island low-elevation large rivers in dry, inland areas	281	0.59	2	3.1	0	2	0
O: Western, high-elevation steep headwater streams	249	0.52	0	0	0	0	0
Q: Very high-elevation, very cold, steep headwater streams	238	0.5	0	0	0	0	0
S: Very high-elevation, very cold, steep headwater streams with glacial influence	230	0.48	0	0	0	0	0
J: Mid-elevation headwater streams in wet western areas	175	0.37	0	0	0	0	0
L: Mid-elevation, glacially-influenced streams in the Southern Alps	123	0.26	0	0	0	0	0
T: Very high-elevation, very cold, steep headwater streams with strong glacial influence	71	0.15	0	0	0	0	0
I: Rivers connecting mountains to sea in wet western areas	18	0.04	0	0	0	0	0
K: Mid-elevation, glacially-influenced small rivers in Southern Alps	18	0.04	0	0	0	0	0
F: Small tributaries on braided river floodplains	9	0.02	0	0	0	0	0
B: Lowland, low-gradient streams draining peatlands	3	0.01	0	0	0	0	0

Table 3-6: Historic ORC water quality sites that could be used to fill shortfalls or gaps in representativeness. Green cells indicate the classification for which these gaps or shortfalls occur. See Table 3-6 for FENZ class definitions.

Site	Easting	Northing	Receiving Water Group	REC class*	FENZ class
Arrow R at Morven Ferry Road	1273547	5009605	Group 2	CW/M/N	D
Silver Stream at Three Mile Hill Road	1398204	4919839	Group 2	CD/L/N	G
Tahakopa R at Tahakopa	1323018	4842378	Group 1	CW/L/N	G

Note: * REC class abbreviations: Climate - CD: cool-dry, CW: cool-wet, Topography - L: lowland, M: mountain, Landcover - N: natural

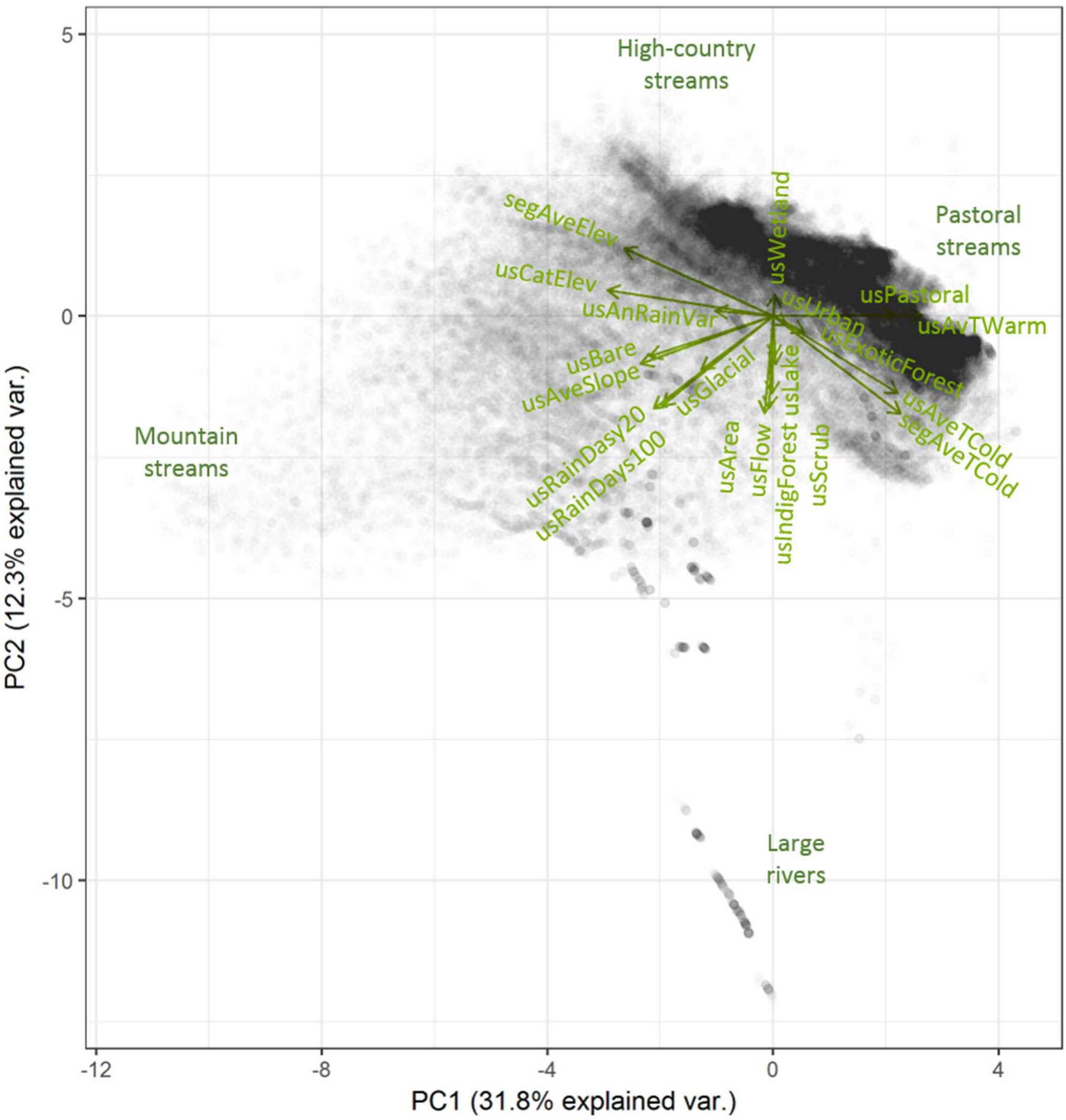

Figure 3-2: Representation of the environmental space within Otago based on a principal components analysis of environmental predictor variables. Arrows represent the direction and strength of each predictor (light green) along the first two axes of the PCA, while dark green labels identify general river types within the environmental space.

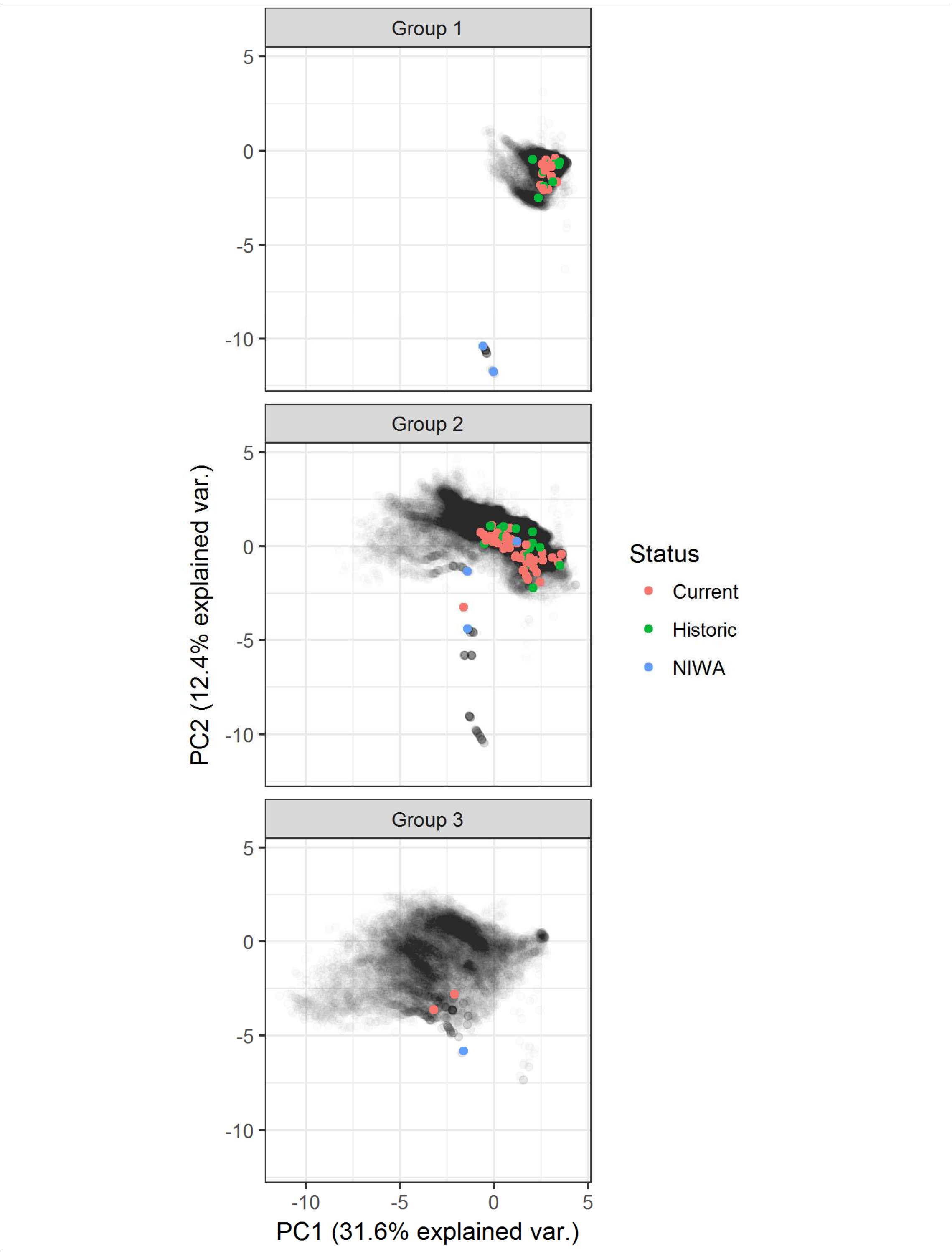

Figure 3-3: Distribution of current ORC river water quality monitoring sites in environmental space plotted by Receiving Water Group. Results are based on a principal components analysis, where black dots represent the regional environmental space and coloured dots represent the environmental space of monitoring sites. The axes represent the first two principal components, which together explain 44% of the variation. The environmental parameters represented on the axes are shown in Figure 3-2.

3.2.4 Discussion

The representativeness analyses based on classification of RWGs, REC and FENZ classes, and the principal components analysis, all indicated similar patterns; there is a scarcity of monitoring sites relative to the abundance of river reaches in undisturbed catchments with natural landcover, and an overabundance of monitoring sites in catchments dominated by pastoral landcover. This shortage of monitoring sites in undisturbed catchments in Otago is consistent with the national-scale shortage of sites in undisturbed catchments (Larned & Unwin 2012).

Most regional council SoE river monitoring programmes have two basic objectives: to make accurate statements about water quality (and biological) conditions at regional scales, and to compare biological and water-quality conditions in agricultural, urban and unmodified (natural) landcover classes. In some cases, these objectives are mutually exclusive; the first requires a highly representative monitoring network with sites in all classes, and the second requires within-class replication of sites that is sufficient to detect between-class differences (Larned & Unwin 2012). Irrespective of the objective, sites are required in unmodified catchments to represent the corresponding landcover class (e.g., natural landcover), and to generate reference-condition data.

While relatively few long-term water quality monitoring sites in New Zealand have been established for the specific purpose of generating reference condition data, a widely-recognised need for reference sites and reference conditions for assessing river health at regional and national scales exists. This is particularly relevant for the ORC given their interest in developing a statistically-based regional scale water quality model to predict reliable instream estimates for turbidity and concentrations of soluble nutrients and *E. coli* across Otago's rivers and streams. As such a model would likely use landcover as the primary explanatory variable, then the distribution of sites, including reference sites, needs to be considered so that the data generated adequately represents water quality across the Otago region.

ORC could use two approaches to select new sites in unmodified catchments to reduce the site shortages described above and generate reference-condition data:

1. Identify candidate reference sites within each RWG. This would likely result in most of those candidate sites being located upstream of existing monitoring sites in pasture or urban-dominated catchments, which creates a risk of confounding land-cover effects with the effects of stream-size and catchment slope. If a large proportion of reference sites are located in the upper reaches of catchments, they will be predominantly small, steep and low-order. These attributes may have effects on water quality and biological condition that are comparable to or greater than the effects of landcover and land use.
2. Use the REC to identify candidate sites that are matched with existing sites in terms of climate, source of flow, gradient, and stream order, but differ in land cover. This approach was applied in the National Environmental Monitoring and Reporting (NEMaR) project to recommend reference site locations at a national scale (Larned & Roulston 2013). For the NEMaR project, several additional criteria were used to filter candidate sites in addition to REC variables. Those criteria included travel time required to operate sites, road access and absence of potential point-sources of contaminants.

In addition to the shortage of sites in unmodified catchments, the representativeness analysis indicated that the Cool-dry/Lowland/Pastoral and Cool-dry/Hill/Pastoral REC classes were over-represented. These classes are common in Otago, and collectively account for 44% of the river length (Table 3-5). However, the 45 monitoring sites in these two classes are 1.6 times the representative number. In view of the general pattern of better water quality and high biological metric scores in natural classes versus pastoral classes (e.g., Larned et al. 2016), the bias towards pastoral sites may lead regional-scale assessments – based on median or average values – to indicate that river conditions are substantially worse than the true region-wide condition. We recommend that ORC looks to reduce the bias through implementation of option 2 above to increase the number of reference sites. It may also be worth examining the 45 pastoral sites and identifying if any data from any of these should be excluded from regional-scale assessments of state.

SUMMARY

The current river water quality monitoring network of 65 sites over-represents pastoral sites and under-represents natural sites, with few sites present in RWG 3. Options to improve representativeness include identifying candidate reference sites within each RWG and/or using the REC to match potential reference sites to existing sites in terms of physical characteristics (e.g., climate, source of flow, gradient, stream order) but differing landcover. ORC may also wish to consider whether all 45 pastoral sites should be included in regional-scale assessments of state.

3.3 Power analyses

3.3.1 Introduction

Power analysis is an important aspect of experimental design. It allows us to determine the sample size required to detect an effect of a given size with a given degree of confidence. Conversely, it can be used to determine the probability of detecting an effect of a given size with a given level of confidence, under sample size constraints. This information can be useful for understanding whether the results of monitoring are likely to be statistically sufficient to answer questions of interest and, if not, how many sites might need to be added to provide the answers required. The following four terms are inter-related in power analyses:

- **sample size:** the number of sites required
- **effect size[4]:** the difference between the group mean and a reference state (e.g. Water Plan limit)
- **significance level:** P(Type I error) or probability of finding an effect that is not there
- **power:** 1 - P(Type II error) or probability of finding an effect that is there.

If any three of these terms are known, we can determine the fourth. In this section, we used power analyses to estimate the number of sites required, and the power of the current monitoring network, to make comparisons of existing water quality against each of the following 'reference values':

- ORC Water Plan limits (Schedule 15),
- NOF attributes identified in the NPS-FM, and
- water quality at 'natural state' sites.

[4] Defined as the dimensionless quantity $(\bar{X} - Y)/\sigma_X$, where $\bar{X}$ is the class mean, Y is the reference value, and σ_X is the class standard deviation.

For the analyses against Water Plan limits and NOF attributes we grouped ORC's water quality sites by RWG. For the comparison with natural state conditions, water quality sites were grouped by dominant landcover class (pastoral, urban or natural).

The power analysis approach is prospective rather than retrospective, seeking to inform future monitoring network design rather than characterise current water quality based on existing data. This type of analysis is often undertaken (or at least recommended) when designing studies to determine the level of sampling effort required to detect differences of a specified magnitude (e.g., 1 standard deviation) between treatments or sites (Cohen 1988, Zar 1999).

Power analysis requires preliminary estimates of group means and standard deviations in order to determine the effect size. We used all available water quality data for the current network of river monitoring sites for these estimates (see Section 3.3.2 for more details), with the exception of data for one site in RWG 2 which lacked accompanying flow information (Nevis River at Wentworth Station). The estimates are likely to vary in accuracy between groups.

Power analyses also require *a priori* specification of the desired statistical significance level (denoted α), and statistical power (denoted $1–\beta$). In the language of statistical hypothesis testing, α is the probability of falsely rejecting the null hypothesis of no difference (i.e., a Type I or false-positive error), and β is the probability of failing to reject the null hypothesis when it is false (i.e., a Type II or false negative error). Therefore, statistical power, or "sensitivity" can be estimated as $1–\beta$. Translated into water quality monitoring objectives, a Type I error occurs if it is concluded that a group mean differs from a reference state when no such difference exists. It commits a Type II error if it fails to conclude that a group mean differs from a reference state when a difference actually exists.

3.3.2 Methods

We consolidated water quality monitoring data from all data sources into a single data structure, with each record representing one measurement of one variable at one site on one date. This dataset comprised 7,112 records across 65 sites, and covered the period from 6 January 2011 to 5 December 2016.

We summarised values for each variable at each site over the last five years (to represent current water quality), after averaging any replicates within sites and sampling dates. Because the water quality criteria (termed 'reference values' in this section) within the NPS-FM NOF and Water Plan are based on different summary statistics (Table 3-7), we calculated two different summary datasets for each site that corresponded to each set of criteria. We then averaged these summary values over each RWG to yield means and associated standard deviations for each group × variable combination. In addition, we used the Water Plan summary dataset to calculate mean values for sites within pastoral, urban and natural (Bare, Indigenous Forest, Tussock, Scrub, Wetland and Miscellaneous) landcover classes of the REC. This third dataset allowed us to assess the power of the current monitoring network to determine whether water quality across pastoral and urban sites is significantly different from water quality at natural sites. It is important to note that in using the Water Plan dataset for the landcover comparison, our power analysis was conservative. This is because the Water Plan limits apply as 80^{th} percentiles to river water quality data collected at less than median flow (i.e., a significant proportion of water quality data from higher flow conditions when differences in water quality are likely more apparent are excluded from the analyses).

All data processing and analyses were performed using R version 3.3.1 (R Development Core Team, 2016), with power analyses implemented as one-sample, two-sided tests using the R *power.t.test()* function. We used two-sided tests in preference to one-sided tests to enable ORC to determine whether the mean value of a particular group (e.g., for pasture sites) is above or below its corresponding water quality reference value (e.g., natural state), regardless of direction. Two-sided tests are more conservative than one-tailed equivalents, which test only whether a group value is above *or* below a particular reference value, but ensure that the network will not miss an effect in the opposite direction to that stated by the reference criteria or guidelines.

Table 3-7: Summary statistics used to compare monitoring data with water quality limits from Schedule 15 of the Water Plan and the band thresholds for NOF attributes within the NPS-FM. Data were restricted to monitoring between January 2011 and December 2016, with all data used to calculate summary statistics for comparing against the NOF attributes, while only data collected when river flows were at or below median were used for comparison against the Water Plan limits. Comparisons of natural sites versus pastoral or urban sites used the same summary statistics as those specified in the Water Plan.

Water quality variable	ORC Water Plan limits	NOF attributes
Ammoniacal nitrogen (mg/L)	80^{th} percentile	Median, Maximum
Dissolved reactive phosphorus (mg/L)	80^{th} percentile	-
E. coli (per 100 mL)	80^{th} percentile	Median, 95th percentile
Nitrite nitrate nitrogen (mg/L)	80^{th} percentile	Median, 95th percentile
Turbidity (NTU)	80^{th} percentile	-

We conducted two sets of power analyses for each group and water quality variable within each dataset, each addressing a separate but related question. First, we estimated the power of the current network to avoid a Type II error, for Type I error levels (α) of 0.1, 0.05, and 0.01. Second, we estimated the number of sites required to avoid a Type II error with powers of 0.8, 0.9, and 0.95, for Type I error levels of 0.1, 0.05, and 0.01.

For all water quality variables, we ran these analyses for effect sizes spanning the full range of potential reference values (Table 3-8 and Table 3-9), where the effect size represents the difference between the current mean state in a RWG and the appropriate reference value for the given analysis (e.g., Water Plan limit, NOF attribute band threshold or natural state). In this assessment, we used $\alpha = 0.1$, equivalent to accepting a 10% probability of false positives, and $\beta = 0.2$, giving an 80% probability of avoiding false negatives. These values are relatively lenient, but are consistent with recommendations for power analyses for water quality testing (Ward et al. 1990, Snelder et al. 2006). We summarise results for all analyses in graphical format, showing the relationship(s) between site numbers, effect size, and power in a format which highlights large-scale patterns at the expense of detail. We provide more detailed results in graphs and tables in the appendices.

Table 3-8: Limits for water quality variables within three Receiving Water Groups (RWG) as specified in Schedule 15 of the ORC's Water Plan. The limits are achieved when 80% of samples collected at a site, when flows are at or below median flow, over a rolling 5-year period, are within the specified limits.

Water quality variable	RWG 1	RWG 2	RWG 3
Ammoniacal nitrogen (mg/L)	0.10	0.10	0.01
Dissolved reactive phosphorus (mg/L)	0.026	0.010	0.005
E. coli (per 100 mL)	260	260	50
Nitrite nitrate nitrogen (mg/L)	0.444	0.075	0.075
Turbidity (NTU)	5	5	3

Table 3-9: Numerical states for selected NOF attributes in the NPS-FM. Sites are allocated to a given band (A to D) based on the summary statistic for the attribute (water quality variable) in question. For the power analyses, the boundary of the attribute bands served as the reference value (i.e., 0.05 mg/L for the A-B band for ammoniacal nitrogen).

Water quality variable	Summary statistic	NOF attribute band			
		A	B	C	D
Ammoniacal nitrogen (mg/L)	Maximum	≤ 0.05	> 0.05 – ≤ 0.4	> 0.4 – ≤ 2.2	> 2.2
	Median	≤ 0.03	> 0.03 – ≤ 0.24	> 0.24 – ≤ 1.3	> 1.3
E. coli (per 100 mL)*	Median	≤ 260	> 260 – ≤ 540	> 540 – ≤ 1,000	> 1,000
	95th percentile	≤ 260	> 260 – ≤ 540	> 540 – ≤ 1,000	> 1,000
Nitrite nitrate nitrogen (mg/L)	Median	≤ 1	> 1 – ≤ 2.4	> 2.4 – ≤ 6.9	> 6.9
	95th percentile	≤ 1.5	> 1.5 – ≤ 3.5	> 3.5 – ≤ 9.8	> 9.8

* Based on the NPS-FM as at July 2017.

3.3.3 Results

Interpreting the results of any power analysis requires us to understand the relationships between the four terms involved: sample size, effect size, significance, and power. These terms are strongly inter-related in the sense that relaxing or tightening any one parameter invariably forces an opposing change in another parameter. For example, if site numbers are fixed by external constraints, statistical power is inversely related to effect size. Conversely, if effect size is fixed (e.g., we wish to compare some group mean to a fixed reference state), and we wish to increase statistical power, we must either increase site numbers or reduce the significance level of our tests.

To illustrate these trade-offs with a specific example, we discuss our results for nitrite nitrate nitrogen (NNN) in some detail, highlighting general trends which are common to all our analyses. Results for the remaining four variables (dissolved reactive phosphorus, *E. coli*, ammoniacal nitrogen and turbidity) are provided in Appendices B to D. We summarise the results for all five variables at the end of this section.

Summary plots for each pair of power analyses (power for given site numbers, (Figure 3-4); site numbers for given power, Figure 3-5) highlight the complementary nature of the two analyses, and the inherent trade-offs within each member of the pair. By way of explanation of Figure 3-4 and

Figure 3-5, the bell-shaped curves (inverted in Figure 3-4) representing the results for each level of significance or power divide the graphic into two regions interior and exterior to each curve. The status of the current network relative to the reference value of interest (i.e., natural state in Figure 3-4 and Figure 3-5) for each group (i.e., pasture and urban landcover in this case) is represented by the intersection of the horizontal dashed line (power = 0.8, or current number of sites) and the vertical purple line representing the reference state. This point lies either inside or outside the bell curve. If it lies outside, the current network is sufficient to establish that the group mean differs from the reference value at the specified significance and power levels. If not, the network has insufficient power. For NNN, it is thus apparent from Figure 3-4 that power is sufficient to determine differences from the natural state for pastoral sites but not for urban sites (despite the larger difference between group means for urban sites compared with pastoral sites).

Power analyses typically show that power for each group is weakest when the reference value equals the group mean, but increases symmetrically as the reference value moves away from the mean in either direction. This is logical in that if the reference value is close to the mean for a given group, then the effect size we are attempting to detect is small, and statistical power will be weak. However, this effect is also influenced by the number of monitoring sites that are available in each group, with power highest when site numbers are large. In the case of NNN, the power of the current network to characterise mean 80th percentile NNN varies between landcover classes, depending on where the group mean lies in relation to the natural state mean (Table 3-10). Power is reasonably high when comparing the pastoral site mean to the natural state mean ($1 - \beta = 0.85$, current sites = 48) but weak when considering urban versus natural site means ($1 - \beta = 0.49$, current sites = 3), based on a significance level of $\alpha = 0.1$.

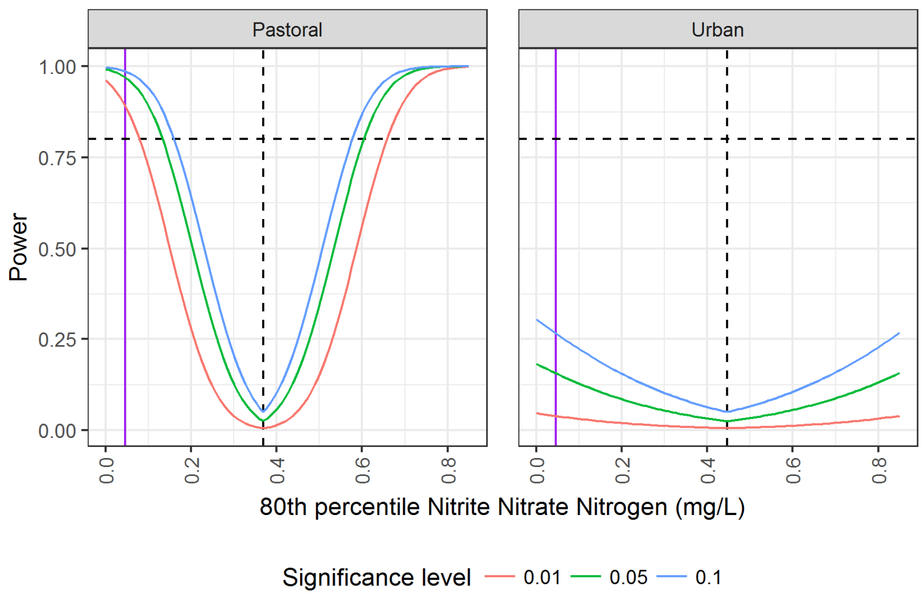

Figure 3-4: Power of ORC's current river water quality monitoring network to determine whether nitrite nitrate nitrogen (NNN) concentrations at pastoral and urban sites are significantly different from those at natural sites. Plots are based on mean 80th percentile values of data collected between January 2011 and December 2016 (at less than median river flows). Each panel shows the power of the current network (1-β) to detect differences between group means and the natural state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Pastoral and urban landcover means are indicated by the vertical dashed line, while the vertical purple lines indicates the mean 80th percentile NNN concentration at natural sites.

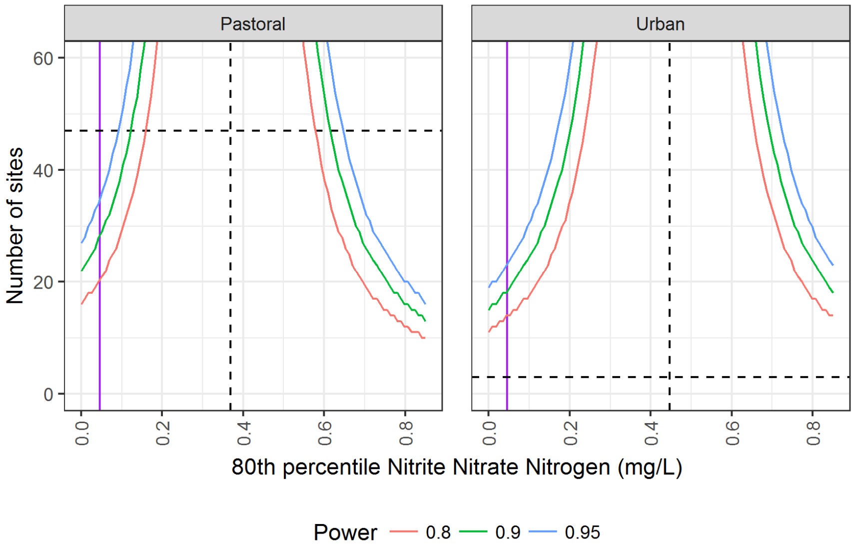

Figure 3-5: Site number requirements for evaluating differences in nitrite nitrate nitrogen (NNN) concentrations at pastoral and urban sites with those at natural sites. Plots are based on mean 80th percentile values of data collected between January 2011 and December 2016. Each panel shows the number of sites required in each landcover class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate class means and current site numbers, respectively; vertical purple lines indicate the mean 80th percentile NNN concentration at natural sites.

Table 3-10: Power of ORC's current river water quality monitoring network to detect whether there are significant differences between pastoral and urban sites and natural state for five water quality variables across the Otago region. Power was assessed for α = 0.1. Orange cells indicate combinations of low power (1-β < 0.45), while blue cells indicate combinations of high power (1-β > 0.8). See Appendix B for more detailed results for each water quality variable.

Water quality variable	Pasture	Urban
Ammoniacal nitrogen (mg/L)	0.82	0.08
Dissolved reactive phosphorus (mg/L)	0.98	0.13
E. coli (per 100 mL)	0.94	0.51
Nitrite nitrate nitrogen (mg/L)	0.99	0.26
Turbidity (NTU)	0.12	0.06

Our second set of analyses, focussing on site numbers needed to achieve a specified level of power (Figure 3-5), is essentially the inverse of the first set. Relatively few sites are needed to detect large effects, i.e., to identify significant differences between group means and widely separated reference values, but site numbers increase rapidly as the natural state mean approaches the pasture or urban landcover group mean. Again, this is intuitive: if a group mean is close to the natural state mean, a very large number of sites will be required to establish a statistically-significant difference with any meaningful level of power. In the most extreme case, as the group mean becomes arbitrarily close to the natural state mean, the number of sites tends to infinity.

Site numbers needed to obtain specific levels of power varied by landcover class (Table 3-11; Figure 3-5). There are sufficient sites for determining if NNN concentrations at pastoral sites are significantly different (α = 0.1) to those at natural sites. However, more sites are required in urban catchments.

The graphics (particularly the number of sites, Figure 3-5) also help to gauge the effect of incrementally adding or removing sites from each class. For example, pastoral sites appear to be well-represented, to the extent that a small reduction in site numbers would have very little impact on network power. However, for urban sites, any increase in the current number of sites (3) would improve network power (although 14 would be needed to obtain the specified level of power).

Table 3-11: Minimum number of sites required to detect significant differences between current state in pastoral or urban sites compared to the natural state across the Otago region. The number of sites was calculated assuming α = 0.1 and 1-β = 0.8. Orange cells indicate that current site numbers are insufficient to establish if the group mean differs from natural state and blue cells indicate the current number of sites is sufficient. See Appendix B for more detailed results for each water quality variable.

Water quality variable	Pasture	Urban
Current sites	48	3
Ammoniacal nitrogen (mg/L)	45	217
Dissolved reactive phosphorus (mg/L)	23	50
E. coli (per 100 mL)	29	6
Nitrite nitrate nitrogen (mg/L)	21	14
Turbidity (NTU)	1,266	1,497

When we consider all water quality variables (see Appendices B – D for individual results), the power to detect whether the means of a particular group of interest differ significantly from the relevant reference values (be they in the Water Plan, natural state or band thresholds for NOF attributes) varies considerably between RWG and landcover class (Table 3-12, Table 3-14 and Table 3-15). The current river water quality monitoring network has sufficient power to detect significant differences between pastoral and natural sites across the entire region for all assessed water quality variables except turbidity, but this does not apply to urban sites, where there is limited power due to the small number of sites (Table 3-10). There is also limited power to detect differences between mean (80th percentile) water quality values within each RWG and most Water Plan limits, with a few exceptions (Table 3-12). Comparison of mean water quality values with the NOF reference values show similar patterns, with noticeably higher power as the RWG means depart further from the attribute band boundaries (Table 3-13).

Table 3-12: Power of ORC's current river monitoring network to detect significant differences between water quality in each Receiving Water Group (RWG) and their corresponding Water Plan limits. Power was assessed for α = 0.1. Orange cells indicate combinations of low power (1-β < 0.45) and blue cells indicate combinations of high power (1-β > 0.8). See Appendix C for more detailed results for each water quality variable.

Water quality variable	RWG 1	RWG 2	RWG 3
Ammoniacal nitrogen	1.00	1.00	0.13
Dissolved reactive phosphorus	0.12	0.48	0.73
E. coli	0.84	0.09	0.09
Nitrite nitrate nitrogen	0.43	0.36	0.16
Turbidity	0.17	0.11	0.12

Table 3-13: Power of ORC's current river monitoring network to detect significant differences between water quality in each Receiving Water Group and different NOF attribute bands. Power was assessed for α = 0.1. Orange cells indicate combinations of low power (1-β < 0.45) and blue cells indicate combinations of high power (1-β > 0.8). See Appendix D for more detailed results for each water quality variable.

Water quality variable	NOF attribute state band	RWG 1	RWG 2	RWG 3
Ammoniacal nitrogen	A – B	0.45	0.30	1.00
	B – C	1.00	1.00	1.00
	C – D	1.00	1.00	1.00
E. coli	A – B	0.34	0.75	0.12
	B – C	0.82	0.44	0.07
	C – D	0.88	0.07	0.09
Nitrite nitrate nitrogen	A – B	0.09	1.00	1.00
	B – C	1.00	1.00	1.00
	C – D	1.00	1.00	1.00

The minimum number of sites needed to detect significant differences in water quality from the various reference values also varied between water quality variables (Table 3-11, Table 3-14 and Table 3-15). Current site numbers are sufficient to detect significant differences (α = 0.1 and 1-β = 0.8) between natural state and pastoral site means for most water quality variables (Table 3-11). However, more urban sites are needed in the monitoring network to ensure significant differences with natural state can be detected. There are also insufficient sites within each RWG to identify if 'mean' values are significantly different from the Water Plan limits. In contrast, there are sufficient sites to identify whether RWG means are significantly different from NOF reference values (bands) for most of the assessed NOF attributes, with the requirement for higher site numbers only present when the mean value is very close to the reference value (i.e., the boundary of the attribute band).

Table 3-14: Minimum number of sites required within each Receiving Water Group (RWG) to detect if group mean (80^{th} percentile) values for five water quality variables are significantly different from their corresponding ORC's Water Plan limits.

The number of sites was calculated assuming α = 0.1 and 1-β = 0.8. Orange cells indicate that current site numbers are insufficient to establish if the group mean differs from the corresponding Water Plan limit and blue cells indicate the current number of sites is sufficient. See Appendix C for more detailed results for each water quality variable.

Water quality variable	RWG 1	RWG 2	RWG 3
Current sites	20	43	2
Ammoniacal nitrogen	2	4	26
Dissolved reactive phosphorus	555	103	3
E. coli	18	3,224	78
Nitrite nitrate nitrogen	57	158	16
Turbidity	266	1,630	28

Table 3-15: Minimum number of sites required within each ORC Receiving Water Group (RWG) to detect if the mean of the relevant summary statistic (Table 3-9) is significantly different from the NOF reference values. The number of sites was calculated assuming α = 0.1 and 1-β = 0.8. Orange cells indicate that current site numbers are insufficient to detect significant differences between the RWG group mean and the corresponding NOF reference value and blue cells indicate the current number of sites is sufficient. Values < 2 occur when the power analysis calculation is unable to estimate the number of sites required and usually occur when power is high or the group mean is very different from the NOF reference value. See Appendix D for more detailed results for each water quality variable.

Water quality variable	NOF attribute state band (reference value)	RWG 1	RWG 2	RWG 3
Current sites		20	43	2
Ammoniacal nitrogen	A – B	7	37	2
	B – C	3	2	< 2
	C – D	< 2	2	< 2
E. coli	A – B	10	8	31
	B – C	12	3	216
	C – D	3	2	71
Nitrite nitrate nitrogen	A – B	27	2	< 2
	B – C	3	2	< 2
	C – D	2	2	< 2

3.3.4 Discussion

The power analyses indicate that the current ORC river water quality monitoring network has sufficient sites to detect statistically-significant differences in water quality between pastoral sites and the natural state, and between RWG group means and the NOF attribute states (particularly the C-D band threshold) for most of the water quality variables we assessed. However, the power analyses also indicate that the network has insufficient sites to assess current water quality against the Water Plan limits. In some cases, the number of monitoring sites required to distinguish between the mean value for a particular group (e.g., a RWG or urban landcover) and relevant reference value (e.g., for turbidity) are extremely high (e.g., over 1,000 sites required to detect some differences). The reasons for these high site number requirements include very small differences between the group mean and the reference value, and high within-group variability. For example, the difference in the mean ammoniacal nitrogen concentration in RWG 3 and the corresponding Water Plan limit is less than 10%, while for many variables the standard deviation was considerably larger than the group mean. Where standard deviations are high, it is unlikely that very large site deficiencies will be addressed by adding many new sites to the monitoring network. However, in many cases where a very large number of sites is required to detect small differences in mean values, there are enough existing sites to produce reasonably accurate and precise means. In these cases, it is reasonable to conclude that the mean states of the groups being compared do not differ in an environmentally meaningful way.

Conversely, there are some situations where the required number of monitoring sites is estimated to be very low (e.g., 2-3 sites). This can happen when the group mean of interest is far from its associated reference value or when there is very little variation in the values measured within a group. For example, very few sites are needed in most RWGs to detect significant differences between the RWG mean (of the relevant summary statistic) and the NOF C-D bands because existing water quality is typically in the B band. In these cases, we recommend using a pragmatic rule-of thumb approach to identify an appropriate number of sites. This is particularly important to ensure that the monitoring network will pick up potential future changes in water quality.

The effect-size used in a power analysis affects the estimated site-number requirements. In our analyses, we used the absolute difference between reference values (natural state means, Water Plan limits or NOF attribute bands) and group means for each variable as the effect-size to detect. If we had used larger effect sizes (e.g., two-times the absolute difference in means), the estimated site-numbers required would have been smaller. In future analyses, a range of effect sizes could be tested, and different effect sizes could be used for each variable.

While power analyses can estimate the number of sites required to detect statistically significant differences between group means and references values, we recognise that it may not be feasible to monitor the suggested number of sites. However, it is important to understand the trade-offs between statistical power and effect size in situations where total sampling effort is constrained by practicalities such as resourcing. For the ORC SoE monitoring network, these trade-offs involve making the best (or at least most informed) compromises when allocating sites to RWGs, particularly if there is limited capacity to increase the overall number of monitoring sites. Considering the power analysis results, it seems that increasing the number of sites in urban areas and in RWG 3 – also a recommendation from a representativeness perspective (refer Section 3.2.4) – would lead to the greatest gains in power but this may not be sufficient for all water quality variables unless a large number of sites are added to the network. Conversely, there may be opportunities to remove current sites in pastoral areas or RWG 2 without reducing the statistical confidence in the results (although confidence varies between water quality variables). Overall, estimating the number of potentially excess sites in this particular comparison (pastoral vs natural) is only one consideration for ORC. The alternative purposes for each site also need to be identified and prioritised before any site is judged to be ‘excess’ (e.g., historical time series, catchment remediation or compliance monitoring).

SUMMARY

The current river water quality monitoring network has sufficient sites to detect statistically-significant differences in water quality between pastoral sites and the natural state, and between RWG group means and the NOF attribute states (particularly the C-D band threshold) for most of the water quality variables assessed. However, the network has insufficient sites to detect statistically significant differences between current water quality and the Water Plan limits, and between natural and urban water quality states. Options to increase power include increasing the number of sites in RWG 3 and urban areas, which provide the greatest gains in statistical power. Conversely, ORC may be able to reduce the number of sites in RWG 2 or pastoral areas without reducing the power to detect significant differences.

3.4 Monitoring variables and methods

This section reviews ORC's existing SoE river water quality and biological monitoring variables and the associated measurement methods. Our approach has been two-fold:

1. We compared the existing suite of monitoring variables alongside the list of river variables recommended for national monitoring in the National Environmental Monitoring and Reporting (NEMaR) programme (Davies-Colley et al. 2012), NPS-FM attributes (including the 2017 amendments), and variables listed in the ORC Water Plan (Table 3-16).

2. We considered the existing measurement methods against currently available national protocols, including the recently drafted National Environmental Monitoring Standard (NEMS) for Discrete Water Quality (NEMS 2017).

We note that from a biological monitoring perspective, only 29 of the 65 river water quality sites in Otago are currently monitored for both macroinvertebrates and periphyton, with the majority (18) of these sites located in RWG 2 (Appendix E), and no sites occur in RWG 3 (refer Figure 2-3). While we have not performed a representativeness assessment on these sites, based on each site's REC assignment (Appendix E), the current network is dominated by pastoral sites (21 sites). When landcover class is assessed as a percentage of total river length using the REC, pasture and natural landcover classes account for around 48 and 49% of the Otago region, respectively. If ORC looks to address the imbalance between water quality and biomonitoring sites, a practical starting point would be to identify existing water quality sites at which biomonitoring could be implemented.

Table 3-16: Water quality and biological variables recommended for river SoE monitoring (NEMaR, Davies-Colley et al. 2012) and/or that appear in the amended NPS-FM and ORC's Water Plan (Schedule 15). Current variables monitored by ORC are listed in the shaded column – all water quality variables are monitored monthly while periphyton and macroinvertebrates are monitored annually, and habitat is monitored 3-yearly. Note that monitoring of periphyton cover and biomass are recent introductions at SoE sites. Flow, an important supporting variable, is discussed in the text.

Variable	NEMaR	NPS-FM	Water Plan	Monitored by ORC
Water temperature	x			x
Dissolved oxygen	x	x		x
Conductivity	(supporting variable)			x
pH	x			x
Visual clarity	x		x*	
Turbidity			x	x
Total suspended solids	x			x
Colour			x*	
Nitrate nitrogen		x		x
Nitrate-nitrite nitrogen	x		x	x
Ammoniacal nitrogen	x	x	x	x
Total nitrogen	x			x
Dissolved reactive phosphorus	x		x	x
Total phosphorus				x
E. coli		x	x	x
Periphyton cover (%)	x		x*	x (2017 only)
Periphyton biomass		x		x (2017 only)
Periphyton diversity				x
Macroinvertebrate community index	x	x		x
Deposited sediment			x*	(with habitat)
Habitat	x		x* (riparian)	x
Odour			x*	

* Narrative rather than numeric limit.

3.4.1 Physico-chemical and microbiological water quality monitoring variables

ORC's current suite of water quality monitoring variables largely aligns with those recommended in the most recent national assessment of river monitoring, the National Environmental Monitoring and Reporting (NEMaR) project (Davies-Colley et al. 2012). The main exception noted in Table 3-16 is visual clarity. This variable was monitored using the horizontal black disc method up until around 2002 before being dropped from routine monitoring, primarily due to health and safety concerns (D. Olsen, pers. comm.).

ORC currently measures two other optically related properties, turbidity and total suspended solids. In terms of the former, obtaining consistent measurements through time using the white light-based method (APHA 2130 B) in Nephelometric Turbidity Units (NTU) is difficult because there is wide variation in sensor configurations; not all sensors use the same light sources, angles of measurement to detect the scattered light, and signal processing strategies (NEMS 2017). As a result, measurements from different makes/models of turbidity sensors may not be comparable to one other. An example of this has been demonstrated in an 18-month parallel SoE sampling exercise between Greater Wellington Regional Council (GWRC) and NIWA; despite joint side-by-side collection of water samples and laboratory measurement following APHA 2130 B using similar (but not identical model) Hach instruments, considerable variation was seen in some paired measurements. Agreement was higher between GWRC and NIWA for measurements of black disc visual clarity (Davies-Colley et al. 2017).

We recommend that ORC reinstate monthly measurements of visual clarity by black disc because it is:

- A variable of high importance to the public (e.g., West et al. 2016) and is an easily understood measure of optical water quality,
- Listed as an important characteristic of water quality in Schedule 15 of ORC's Water Plan,
- Usually well correlated with *E. coli* and can serve as a useful proxy (Davies-Colley et al. in prep), and
- Widely measured in New Zealand.

Health and safety risks in visual clarity measurements can be minimised (large non-wadeable rivers are an obvious exception unless a boat is used for sampling) with the addition of a second field officer, although we note that measurements can be – and are – safely made in many regions by a single field officer (see NEMS 2017). While a possible alternative might be for ORC to collect visual clarity measurements for a minimum of two years to establish site-specific relationships with turbidity, given the high clarity that characterises many of Otago's rivers, it may prove very difficult to establish robust (inverse) relationships. If this option is considered, it will be important to use the ISO 7027 turbidity method. Another option is measurement by a green light beam transmissometer although these instruments have a fixed path length which limits their dynamic range (NEMS 2017).

We recommend that ORC continues with turbidity measurements because there are limits in place for turbidity in the Water Plan and turbidity can provide a useful proxy for other measurements to which it has been correlated, including TSS and *E. coli* (Davies-Colley et al. in prep.). Turbidity is also relatively inexpensive to measure. Some thought will need to be given to methodology; we note that the NEMS (2017) recommends the 'red light' method in Formazin Nephelometric Units (FNU). This is because infra-red light is repeatable and therefore directly comparable from a handheld meter to an ISO 7027 laboratory measurement.[5]

Measurements of TSS in routine monthly monitoring tends to result in many non-detect values (e.g., ORC 2012) and TSS does not appear to feature strongly in ORC SoE reporting. ORC may wish to consider whether TSS measurements are better restricted to specific sites where sediment inputs are of concern or where dedicated wet weather monitoring programmes are needing to be implemented to assess sediment yields. In the latter case, suspended sediment concentration (SSC) would be a more appropriate variable to measure given it is determined on the full sample volume and captures the heavier sediment particles that can be lost when subsamples are taken for TSS analysis (Gray et al. 2010).

Two additional variables ORC should include in routine monitoring of urban SoE sites are copper and zinc. Elevated concentrations of these metals have been regularly reported in the water column and bottom sediments of urban streams across New Zealand (e.g., Gadd 2016, Mills & Williamson 2008), including Otago (e.g., Stewart 2015, Brown 2002). It is possible that both the NPS-FM and Water Plan will be amended to incorporate these variables in some way[6], particularly in light of the significant sources of these contaminants in urban areas, including wear and tear from vehicle brake linings (copper) and tyres (zinc), and runoff from galvanized roofs (zinc) (Kennedy & Sutherland 2008).

We recommend the dissolved form of copper and zinc is measured to represent the biologically available fraction which has the most potential to affect aquatic ecosystem health. In order to meaningfully interpret the metal data, it will be necessary to measure both dissolved organic carbon (DOC) and total hardness (at least monthly for one to two years to characterise their respective variation), as well as water temperature and pH (Gadd et al. 2017).

Table 3-17 sets out our recommended suite of monitoring variables, including laboratory analytical methods and detection limits. Analytical methods and detection limits align with those provided in the current draft NEMS (2017) for Discrete Water Quality and, in some cases (e.g., ammoniacal nitrogen and *E. coli*), differ from those employed by ORC's most recent laboratory provider (Appendix F). We note that ORC recently finalised a contract with a commercial laboratory for water quality analyses, whereby the laboratory will be required to give effect to analytical requirements in the NEMS. This is important because ORC has changed laboratories several times over the last 20 years, resulting in multiple changes to both analytical methods and detection limits. These changes have impacted on the consistency and suitability of long-term data for temporal trend assessment (Figure 3-6).

We support ORC's current laboratory-based measurement of pH. Reliable field measurements of pH in surface waters are difficult to achieve (NEMS 2017). In contrast, conductivity measurements can be performed reliably in the field or laboratory. We note that ORC still uses membrane-based sensors for dissolved oxygen measurement (E. Bruhns, pers. comm.). These sensors rely on mechanical stirrers or other means to ensure that water velocity past the sensor always exceeds 0.3 m/s. In practice this can be difficult to measure. NEMS (2017) recommends the use of optical DO sensors to avoid problems arising from inadequate stirring.

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[5] This might require an amendment to the Water Plan at some point in the future which references NTU measurements.

[6] Initial NOF copper and zinc attribute development work has been investigated by Auckland Council (Williamson et al. 2015) and subsequently led to MfE funding a review of the ANZECC (2000) water column toxicity guidelines for copper and zinc.

Table 3-17: Recommended river water quality monitoring variables and methods. All variables should be measured monthly. An asterisk denotes variables that should be considered for inclusion on on a site by site basis. Methods and (minimum) method detection limits (MDL) are based on the <u>draft</u> NEMS (2017) for Discrete Water Quality.

Variable	Method	MDL
Water temperature (°C)	In-situ measurement	N/A
Dissolved oxygen (DO)	In-situ measurement using an optical DO sensor	N/A
Conductivity	In-situ measurement or laboratory via APHA 2510 B	N/A
pH	Laboratory. APHA 4500-H + B	N/A
Visual clarity (VC)	Black disc, using a 200 mm diameter disc in the 1.5-10 m visibility range, a 60 mm disc in the 0-1.5 m visibility range, and a 20 mm disc or clarity tube between 0.1 and 0.5 m visibility	0.1
Turbidity (FNU)	ISO 7027	0.1
Total suspended solids (TSS)*	APHA 2540 D	1
Nitrate nitrogen	APHA 4500-NO3 I	0.002
Nitrate-nitrite nitrogen (NNN)	APHA 4500-NO3 I (calculation)	0.002
Total ammoniacal nitrogen (TAN)	APHA 4500-NH3 H	0.005
Total nitrogen (TN)	APHA 4500-N C and APHA 4500-NO3 F or I	0.01
Dissolved reactive phosphorus (DRP)	APHA 4500-P G	0.001
Total phosphorus (TP)	APHA 4500-P B and APHA 4500-P E, G or J	0.001
Escherichia coli (E. coli)	APHA 9223 B	1
Dissolved copper*	APHA 3125 B	0.0005
Dissolved zinc*	APHA 3125 B	0.001
Dissolved organic carbon*	APHA 5310 B	0.2
Total hardness*	APHA 2340 B	1

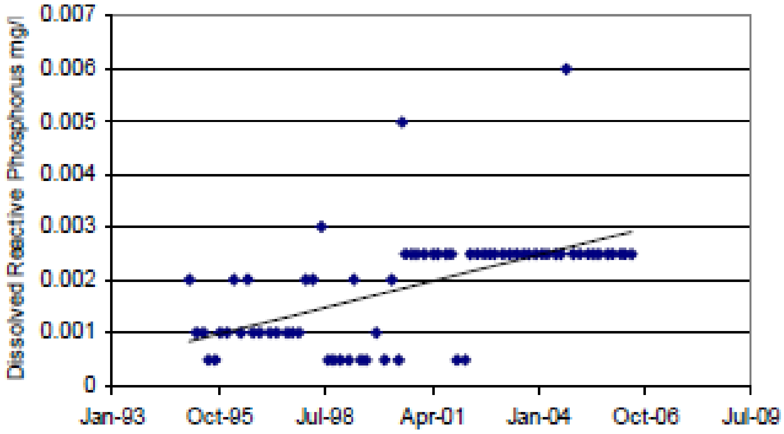

Figure 3-6: Dissolved reactive phosphorus concentrations recorded near the outlet of Lake Wakatipu, 1995 to 2005. The black line shows the misleading trend in the data record, due to changes in analytical detection limits. Figure and caption reproduced from ORC (2007), p145.

Lastly, in terms of monitoring frequency, the existing monthly sampling regime is consistent with that recommended nationally for the timely determination of temporal trends in discrete-based SoE water quality monitoring programmes (Davies-Colley et al. 2012). However, for some variables, high frequency (i.e., <u>continuous</u>) measurement at selected sites would add significant information value to ORC's river monitoring programme. Water temperature and dissolved oxygen are probably the highest priority variables for continuous measurement – at least over summer – because they exhibit wide diurnal variation and can strongly impact aquatic ecosystems. Further, we note that the NPS-FM (MfE 2014) specifically requires continuous DO monitoring below point source discharges.

The ORC is currently trialling the collection of continuous nitrate nitrogen measurements in the Kakanui River catchment in North Otago. While this trial sits outside of the ORC's SoE river programme – and therefore the scope of this review – we note that continuous (nitrate) monitoring will add valuable information to discrete-based SoE river monitoring (e.g., improved estimates of the impacts of land use on water quality through improved source identification, improved accuracy of estimated nutrient loads, and identification periods when nutrient concentrations or loads require additional management (e.g., Pellerin et al. 2016)).

3.4.2 Periphyton

Routine periphyton monitoring to date has focussed on annual assessments of the relative abundance of different periphyton taxa (Biggs & Kilroy 2000) at 29 sites (see Appendix F for method details). Periphyton biomass (measured as chlorophyll *a*) and cover were measured at these sites for the first time in 2017.

We consider that monthly cover assessments, as an indirect measure of periphyton biomass, would be a valuable addition at all water quality monitoring sites. Periphyton growth is often of high interest to the public when reporting river health and we note that a narrative for nuisance cover is included in Schedule 15 of the Water Plan. Periphyton cover is also listed in the core monthly monitoring suite recommended through the NEMaR project (Davies-Colley et al. 2012), although this monitoring could be prioritised to the warmer months of the year when periphyton is actively growing.

In terms of the National Objectives Framework (NOF) of the NPS-FM, periphyton biomass is a core attribute underpinning the mandatory national value of ecosystem health. Although ORC introduced a pilot programme to measure periphyton biomass a few years ago, to date monitoring has been infrequent and patchy. We recommend as a high priority that a new programme is implemented, based around a subset of SoE water quality sites within each of ORC's three main river-based RWGs. We think a practical yet robust approach would be to identify three replicate sites (the minimum needed to generate a measure of variability) in each RWG across each combination of:

- 'Low', 'mid' and 'high' nutrient conditions, and
- Short, moderate and long accrual conditions.

This would give a total of 27 sites for monthly chlorophyll *a* monitoring, although realistically, not all nutrient or flow conditions will likely exist in each RWG so the total number of sites may be more in the order of 15 to 20. It is important to monitor periphyton cover monthly at these same sites (in tandem with water quality sampling which will provide accompanying nutrient data) to enable site-specific cover–biomass relationships to be developed. Assessments of periphyton cover should enable biomass monitoring to cease at most sites after two or three years, with reliance on more cost-effective cover estimates only to inform reporting under the NPS-FM. Monitoring for three years would align with NPS-FM requirements and is preferable to ensure that a range of hydrological conditions are covered and there is a reasonable dataset upon which to assess the relationship between chlorophyll *a* and visual estimates of stream bed cover.

Recent analysis of a comprehensive three-year data set collected across 24 sites by Environment Canterbury (Kilroy et al. 2017) confirmed a strong relationship between measured chlorophyll *a* and chlorophyll *a* derived from visual assessments across all the sites (75% of the variation in chlorophyll *a* explained). It was also found that bankside estimates of periphyton cover can explain a significant amount of the variation in chlorophyll *a* measured at a site. These quick field assessments can therefore provide useful data if resources are limited, especially for reporting high percentage cover (Kilroy et al. 2017).

Periphyton cover and biomass monitoring methods should be consistent with those currently being drafted in a NEMS for periphyton. We anticipate that the periphyton biomass monitoring methods in the NEMS will largely follow those of Biggs and Kilroy (2000), and recommend pooling periphyton scrapings from fixed areas (e.g., 65 mm diameter scraping) on 10 rocks collected along wadeable transects in run habitat. Either two transects of 10 (collecting at every second point) or four transects are considered preferable to a single transect to ensure variability in periphyton biomass within the run is captured. It is important that rocks are selected at random and the area of the rock scraped is representative of the overall periphyton cover on that rock. For *in situ* assessments of periphyton cover, an underwater viewer (e.g., bathyscope) should be used. This viewer can also be used to assess deposited sediment cover at the same time (Section 3.4.5).

3.4.3 Macrophytes

Macrophytes are conspicuous components of some Otago rivers (e.g., East Branch of the Tokomairiro River) but are not currently monitored by ORC. While monitoring methods and guidelines do exist (e.g., Matheson et al. 2012) and an increasing number of regional councils are now monitoring macrophyte growth (Davies-Colley et al. 2012), the need for regular macrophyte monitoring in Otago could be considered on a site by site basis (e.g., to assess negative effects on flow or dissolved oxygen). For a regional SoE perspective on ecosystem health, macrophyte cover could be included in an annual assessment of physical stream habitat (Section 3.4.5).

3.4.4 Macroinvertebrates

Macroinvertebrates are currently monitored annually in riffle habitat at 29 of ORC's 65 river water quality sites. No sites are currently monitored on the Clutha River/Mata-Au because this river is non-wadeable. No sites are currently monitored on the Taieri River for the same reason but there are wadeable segments of river that could be monitored (e.g., Moonlight Bridge in Middlemarch) and we note that macroinvertebrates were monitored annually on the two NIWA Taieri River sites (Tiroiti and Outram) transferred to ORC in July. Similarly, it is likely that there is wadeable riffle habitat in reasonable proximity to other water quality monitoring sites that currently lack macroinvertebrate monitoring. We recommend monitoring macroinvertebrates at as many water quality monitoring sites as possible to maximise the degree to which comprehensive information on stream ecosystem health is collected at each SoE site. We consider this to be consistent with the intent of recent amendments to the NPS-FM (MfE 2017) which include a requirement to measure and report on macroinvertebrate community health.

ORC currently collects and processes macroinvertebrate samples in accordance with Protocols C1 (hard-bottomed, semi-quantitative) and P1 (coded abundance), respectively, of Stark et al. (2001). We understand ORC is contemplating a shift to Protocol P2 (200 fixed count with scan for rare taxa). We support a shift to this sample processing method, which is consistent with the NEMaR recommendations (Davies-Colley et al. 2012), although we note that the final NEMaR recommendations also supported the use of Protocol C3 (hard-bottomed, quantitative) for sample collection, recognising that robust information on invertebrate abundance requires the collection of Surber rather than kicknet samples.[7] We understand that a NEMS for macroinvertebrate sampling is in the early stages of development and recommend ORC be guided by the outcomes of that process in terms of sampling, calculation and reporting methods. In terms of a switch in sample processing protocol from P1 to P2, fixed count data can be 'converted' back to coded abundance data, enabling ORC to combine new and historic SoE data for trend analyses and other assessments (Davies-Colley et al. 2012).

3.4.5 Habitat

Assessments of stream habitat have been undertaken since 2010 (e.g., James 2010, Arthur & Ludgate 2012; 2015; Ryder Consulting 2017), although the methodology has differed and not all sites have been assessed on each occasion. Currently, stream habitat assessments are undertaken once every three years according to the National Rapid Habitat Assessment Protocol (Clapcott 2015) (R. Ozanne pers. comm.).

We consider monitoring of habitat quality to be essential; the health of macroinvertebrate and fish communities is often poorly correlated with water quality, as has been demonstrated for Otago's rivers (e.g., ORC 2012), with habitat factors such as fine-sediment cover, substrate heterogeneity, flow diversity and riparian vegetation cover being more influential (e.g., Jowett & Richardson 2003, Suren and Jowett 2006, Burdon et al. 2013).

We recommend that ORC formalise and standardise habitat monitoring at all SoE biological monitoring sites, with an updated baseline assessment carried out following Protocol 2 of the Stream Habitat Assessment Protocols (Harding et al. 2009). This semi-quantitative protocol, used by James (2010) in February 2010 – but modified in the 2012 and 2015 surveys – is sufficient for SoE monitoring purposes and could be repeated at five-yearly intervals with the rapid habitat assessment

[7] The NEMaR variables report noted that most regional councils employed kick net rather than that Surber sampling but could standardise the area of river-bed kicked to within the range 0.6–0.8 m^2 to maximise precision in macroinvertebrate indices (Davies-Colley et al. 2012).

method outlined in Clapcott (2015) (and applied in 2017) used on an annual basis. The rapid method, while more basic, has the advantage of providing a Health Quality Score (HQS) through assessing the following 10 parameters on a 1 to 10 score:

- deposited sediment
- invertebrate habitat diversity
- invertebrate habitat abundance
- fish cover diversity
- fish cover abundance
- hydraulic heterogeneity
- bank erosion
- bank vegetation
- riparian width
- riparian shade.

As this is a rapid habitat assessment method, it should be possible to carry out this assessment annually, at the same time as macroinvertebrate sampling. As outlined in Section 3.4.1, continuous measurements of water temperature and dissolved oxygen for periods of 1-2 weeks during the warmest months of year would help to quantify the effect that status of these physical variables have on aquatic invertebrates and fish. This monitoring would likely need to be undertaken on a rotational basis – sites that lack riparian shade could be prioritised for monitoring.

Deposited sediment

One aspect of the annual rapid habitat assessment that might warrant more frequent monitoring is deposited sediment, recognised as a stressor of growing concern for stream health, particularly as a result of intensive or changing land use (Clapcott et al. 2011). Either national Sediment Assessment Method (SAM) 1 (bankside visual assessment) or SAM2 (instream visual assessment using an underwater viewer) outlined in Clapcott et al. (2011) would suffice. SAM1 takes very little time to complete and could be a useful addition to the suite of field observations made during monthly water quality sampling at all or a selection of sites where sedimentation impacts are considered likely.

We note that the most recent stream habitat assessments in Otago (Ryder 2017) included sediment cover assessments using SAM2. This method is more robust than SAM1 in that it provides a semi-quantitative assessment of the percent surface area of the streambed covered by sediment. Depree et al. (2017) also recommended the use of SAM2 in a recent report for MfE on developing ecosystem health thresholds for suspended and deposited sediment in New Zealand rivers and streams.

3.4.6 Flow

Flow is a very important aspect of long-term river water quality and biological monitoring programmes. Flow information supports interpretation of water quality data (e.g., for flow adjustment in temporal trend assessment) and for calculation of contaminants loads (Davies-Colley et al. 2012), and is used to determine the timing of biological sampling and interpret periphyton biomass data.

We understand that flow is measured continuously at 25 of ORC's 65 river water quality monitoring sites (Appendix A). Consistent with the NEMaR project (Davies-Colley et al. 2012) recommendations, we recommend that ORC seek to at least estimate flow at the time of sampling ('flow stamping') at all water quality sites. This could be done by installing staff gauges at the sites – or nearby sites – to establish stage-discharge ratings (e.g., from periodic river flow gaugings). In some cases, it may be possible to estimate flow using known correlations with more distant hydrometric sites on the same river, or in a parallel catchment with similar hydrological characteristics.

ORC may need to prioritise the sites at which flow measurements are made/estimated (e.g., those located on the lower reaches of rivers entering lakes or estuaries and those where periphyton cover/biomass are monitored).

SUMMARY

The current suite of water quality monitoring variables largely aligns with those recommended for river SoE monitoring. We recommend that black disc visual clarity is reinstated at all sites because of its critical importance as a measure of optical water quality. Dissolved copper and zinc (together with dissolved organic carbon and total hardness for at least one to two years) would be useful additional variables to monitor at urban SoE sites.

Overall, the existing SoE monitoring network has a strong water quality focus and would benefit from the inclusion of additional measures of ecosystem health across a greater number of (wadeable) sites, including:

- monthly assessments of periphyton cover;
- annual monitoring of macroinvertebrates; and
- annual assessments of stream habitat (including macrophyte cover).

In addition, we recommend:

- monthly assessments of periphyton biomass and deposited sediment cover at a selection of sites, with both current and potential future land use pressures considered when identifying these sites;
- supplementing the existing annual biomonitoring programme with continuous measurements of water temperature and dissolved oxygen for periods of at least 1-2 weeks during the warmest months of year, prioritising monitoring at sites with poor riparian shading; and
- making estimates of flow at the time of sampling ('flow stamping') at all water quality sites that lack regular flow monitoring.

4 Lakes

This section presents the review of ORC's current SoE lake water quality monitoring. The current network is addressed first, followed by monitoring methods, variables, and measurement procedures. Physico-chemical water quality is the primary focus of this section, including the collection of high frequency water quality measurements using profilers and monitoring buoys. Phytoplankton, macrophytes and zooplankton monitoring is a secondary focus.

4.1 Monitoring network

Characteristics of the nine lakes that are currently monitored are presented in Table 4-1. Collectively, the monitored lakes incorporate a range of:

- sizes and depths, from very shallow lakes through to several of the deepest (and largest) lakes in the country,
- lake types and elevations – from high country glacial lakes to reservoirs and lowland coastal lakes,
- natural and pastoral landcover combinations in the upstream catchments, and
- trophic states on the Trophic Lake Index (TLI) scale, from microtrophic to supertrophic.

Table 4-1: Characteristics of lakes currently monitored by ORC. Trophic Lake Index (TLI) scores taken from Verburg et al. (2010). The 'Natural' landcover is a combination of the Bare, Indigenous Forest, Tussock, Scrub, Wetland and Miscellaneous classes of the River Environment Classification (REC).

Lake	Maximum depth (m)	Surface area (ha)	Elevation (m)	TLI	Upstream landcover (%)		Lake type
					Natural	Pasture	
Hawea	384	15,171	334	1.6	97.1	0.2	Glacial
Wanaka	311	19,886	278	2.1	96.0	1.0	Glacial
Wakatipu	380	29,542	317	1.9	94.1	2.0	Glacial
Hayes	33	274	335	4.9	54.3	42.0	Glacial
Johnson	27	26	334	5.0	97.6	0.4	Glacial
Dunstan	30	2,282	149	2.2	95.1	1.0	Reservoir
Onslow	9.5	1,125	678	3.9	93.1	5.0	Reservoir
Tuakitoto	3	130	15	4.9	9.7	80.0	Riverine
Waihola	2.2	604	5	4.5	46.0	29.0	Riverine
Waipori*	1	212	4	5.1	53.6	26.0	Riverine

* Monitoring of Lake Waipori ceased in September 2016 but is included here for completeness.

Given the range of lakes captured in the existing programme, we do not recommend any changes to the lakes monitored. However, we note that Lake Johnson is a very small lake with similar characteristics (other than dominant upstream catchment landcover) to Lake Hayes. This suggests that monitoring Lake Johnson is not essential, other than its inclusion in Schedule 15 of the Water Plan (a small reference lake might warrant consideration as a replacement). Overall, while there are numerous other lakes in Otago that could be monitored, most are small (< 10 ha), with many located within or near conservation areas where pressures are low and access for regular water quality monitoring is difficult (e.g., Diamond Lake, Moke Lake and Lakes Alta, Dispute, Harris, Kirkpatrick, Luna, Lochnagar and Sylvan). The remaining lakes are manmade, including reservoirs of small to moderate size (e.g., Fraser's Dam, Falls Dam, Butcher's Dam, Blue Lake, Poolburn Reservoir, West Eweburn Dam, Manorburn Dam, Greenland Reservoir, Loganburn Reservoir and Lake Mahinerangi) that support water/power supply and/or recreational values.

Despite small and shallow lakes being more common in Otago (Figure 4-1), the townships of Queenstown, Wanaka, Hawea and Cromwell are all located adjacent to large and popular lakes. Therefore, it is appropriate that the proportion of large (and deep) lakes among those that are monitored exceeds their proportion of all lakes in the region. Lake Hawea is the most recent of these large lakes to be included in the monitoring programme; it is an important inclusion that will provide a good baseline or reference dataset because, although this lake is highly modified in terms of water level,[8] it has relatively pristine water quality with (currently) low pressure from land use in the catchment.

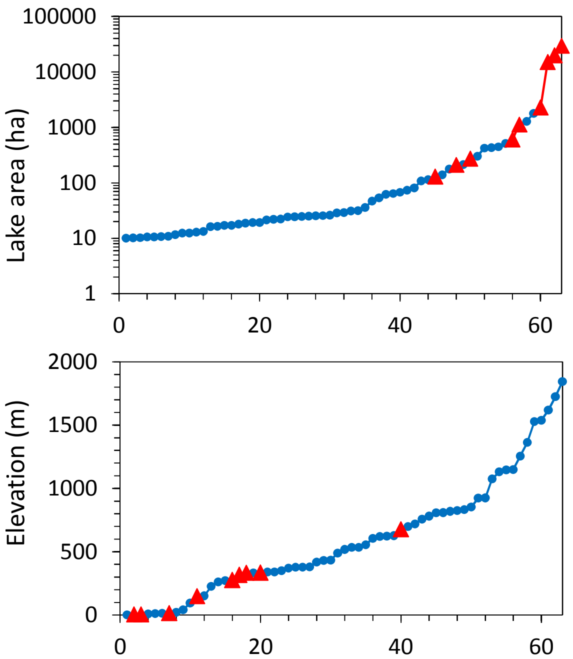

Figure 4-1: Distribution of lake area (top) and elevation (bottom) of 63 lakes that are larger than 10 ha in the Otago region. Monitored lakes (Table 4-1) are indicated by red triangles. Note the logarithmic scale in the top plot.

4.1.1 Monitoring sites

The current sites that are being monitored in each lake are listed in Table 4-2 (also refer Figure 2-2). The largest and deepest lakes – Hawea, Wanaka and Wakatipu – have more sites than the smaller, shallower lakes, apart from Lake Waihola. Each of these three large lakes has a primary open water monitoring site intended to be representative of average conditions, as well as monitoring at their outlet. Lakes Wanaka and Wakatipu are also monitored at nearshore locations that are either close

[8] Lake Hawea's water level was raised ~20 m in the 1950s and the lake has an 8 m operating range (D. Olsen, pers. comm).

to centres of population or in areas that are likely to pick up effects of changes in land use nearby in the catchment. Water quality in Lake Hawea is relatively unaffected by anthropogenic pressure in the catchment and it is reasonable that on-lake monitoring is restricted to one primary open water location.

Table 4-2: Summary of ORC's existing lake water quality monitoring sites. We recommend that all sites are retained, but with the addition of an open water site on each of Lakes Onslow and Tuakitoto and consideration of reinstating monitoring of the Lake Hayes outlet (Hayes Creek at SH 6). Recommended sampling frequencies are outlined in Section 4.2.2.

Lake	Site	Sampling frequency
Hawea	▪ Northern (open water) ▪ Southern (open water) ▪ Outlet	▪ Quarterly, 2016-2019 ▪ Monthly, 2016-2019 ▪ Monthly
Wanaka	▪ Northern (open water) ▪ Southern (open water) ▪ Glendhu Bay[1] ▪ Roy's Bay ▪ Outlet	▪ Quarterly, 2016-2019 ▪ Monthly, 2006-2009, 2016-2019 ▪ Monthly, 2016-2019 ▪ Monthly, 2006-2009, 2016-2019 ▪ Monthly
Wakatipu	▪ Northern (open water) ▪ Southern (open water) ▪ Frankton Arm (bay site) ▪ Queenstown Bay ▪ Outlet	▪ Quarterly, 2016-2019 ▪ Monthly, 2006-2009, 2016-2019 ▪ Monthly, 2006-2009, 2016-2019 ▪ Monthly, 2006-2009, 2016-2019 ▪ Monthly
Hayes	▪ Mid lake (open water) ▪ Bendemeer Bay (shore site)	▪ Monthly over summer 2011 to 2015, then monthly since December 2015 ▪ Monthly
Johnson	▪ South Shore huts (shore site)	▪ Monthly
Tuakitoto	▪ Outlet	▪ Monthly
Waihola	▪ North (open water) ▪ Mid (open water) ▪ South (open water) ▪ Jetty (shore site)	▪ Monthly for 2 years, 2002-2004 & 2014-2016 ▪ Monthly for 2 years, 2002-2004 & 2014-2016 ▪ Monthly for 2 years, 2002-2004 & 2014-2016 ▪ Monthly
Onslow	▪ Boat Ramp (outlet)	▪ Monthly
Waipori	▪ Mid (open water) ▪ South (open water)	▪ Monthly for 2 years, 2002-2004 & 2014-2016 ▪ Monthly for 2 years, 2002-2004 & 2014-2016
Dunstan	▪ Deadman's Point (Clutha Arm)	▪ Monthly

[1] Replaced Stevenson's Arm (2006-2009).

We support ORC's recent inclusion of a second open-water site (sampled quarterly) to the north in each of the three largest lakes. The additional open water site in each lake improves the extent to which monitoring can represent whole-lake conditions and the monitoring results can be compared against those of the primary site to assess within-lake variation. For instance, in Lake Taupo, the main open water site was compared with two other open water sites, monthly for one year. We note that the elongated shape of Lakes Hawea, Wanaka and Wakatipu – compared to the approximately elliptical shape of Lake Taupo – means that within-lake variation in water quality may be more pronounced in the Otago lakes.

Lake Hayes is monitored at the deepest point in the lake ("mid-lake"), and at its shore. Sampling at its outlet (Hayes Creek at SH 6) was carried out until July 2014. Lake Hayes is therefore one of the three lakes presently not monitored at the outlet (Table 4-2). One of the advantages of sampling nutrient concentrations at lake outlets is that the data can inform nutrient budgets. The nutrient export from lakes is estimated as the product of the outflow rate and the outflow nutrient concentration. While nutrient concentrations in the lake are often used (assumed to be representative of outflow concentrations), actual outflow concentrations may be different. Therefore, if a nutrient budget is desired for Lake Hayes, then it would be useful to monitor flow and water quality at the lake outlet.

There are also both open water and near-shore sites for Lake Waihola and open water sites for Lake Waipori, although the open water sites on these lakes are currently only monitored for two years in every ten (i.e., Oct 2002 to Oct 2004 and Sept 2014 to Sept 2016). The remaining four lakes (Dunstan, Johnson, Onslow and Tuakitoto) are monitored only by collecting samples at their shore, and the sites at Lakes Onslow and Tuakitoto are at the outlets.

While monitoring at shore sites in bays or outlets is not recommended as a replacement for monitoring at open water sites, in lakes where ORC considers boat-based sampling is not feasible shore sampling is preferred to no sampling at all. In terms of within-lake representativeness, measuring at the outlet is generally to be preferred over shore sampling further up the lake, as the lake outlet water can be expected to better represent the mixed lake surface water than a shore site. However, outlet samples are not necessarily representative of the lake because by the time lake water reaches the outlet the full nutrient load has entered the lake, including nutrients entering near the outlet which would not be contributing to mid lake nutrient concentrations.

If possible, sampling from the dam wall is preferable to shore-based sampling in dammed lakes (Dunstan, Onslow), because it typically represents the deepest site in a reservoir lake and is less likely to be affected by shore-based processes. Sampling at the outlet in dammed lakes must be done on the lake side of the dam, where possible, and not in the outlet itself. Reservoir lakes may release water from the hypolimnion to the outlet, and in these cases the outlet would be higher in nutrients than the epilimnion during stratified periods, meaning that the outlet would not be representative of the surface layer in the lake, and would result in an unrealistically high trophic level score. Presently sampling in Lake Onslow occurs in a constricted arm very close to both the dam wall and the lake outlet so appears well situated. The present sampling site in Lake Dunstan is well away from the dam wall, upstream from the inflow of the Kawarau River. The Kawarau River contains a lot of glacial flour from the Shotover River and sampling at the dam wall in Lake Dunstan would reflect this. Therefore, in Lake Dunstan the present site at Deadman's Point is better than the dam wall because it is likely to be more representative of average lake conditions.

Shore sites are usually affected by littoral shallow water conditions, including local nutrient run off, and sediment disturbance. Nutrient concentrations are usually higher and phytoplankton and zooplankton species composition and abundance usually differ from mid-lake monitoring sites. Moreover, Secchi depth measurements cannot be made at shore sites. Therefore, we recommend that ORC establish an open water site on Lake Onslow and Lake Tuakitoto that potentially could be monitored on a rotational basis (see Section 4.2.2), allowing comparison to data collected at the lake shore/outlet sites.

Finally, it should be noted that lakes that are not monitored at open water sites may not be used in national water quality reporting. Otago lakes have been excluded from national reporting previously for this reason (e.g., Larned et al. 2015).

SUMMARY

The ORC currently monitors nine lakes, covering a range of depths, types, trophic state, and upstream catchment landcover. While more of the 60+ lakes in Otago could be monitored, a higher priority is to establish representative open water monitoring sites across the monitored lakes, where possible. At the minimum, we recommend:

- ongoing monitoring of open water sites on Lakes Wakatipu, Wanaka and Hawea;
- establishing an open water monitoring site on each of Lake Onslow and Lake Tuakitoto that is monitored (monthly – see Section 4.2.2) for at least two years to verify the monitoring results obtained from outlet monitoring to date; and
- reducing the return interval for monitoring open water sites on Lakes Waihola and Waipori from 10 to 5 years to improve the ability for timely detection of changes in lake condition (see Section 4.2.2 for further commentary).

While monitoring at lake shore sites in bays or outlets is not recommended as a replacement for monitoring at open water sites (and may not qualify for national reporting), shore sampling is preferred to no sampling at all.

4.2 Monitoring methods

General advice on methods to monitor lakes can be found in Sections 5 and 7.4 of Davies-Colley et al. (2012), Section 8 of Davies-Colley et al. (2011) and Part 3 (Lakes) of the draft National Environmental Monitoring Standards (NEMS) for Discrete Water Quality (NEMS 2017). Earlier guidance includes Burns et al. (2000) and Vant (1987).

4.2.1 Monitoring platforms

ORC monitors open water and embayment sites by boat while near shore and outlet monitoring is conducted by wading. Boats are preferred in almost all cases for lake monitoring because they permit vertical measurement of water column stratification, Secchi depth visual clarity and light penetration. Water samples can also be collected at multiple depths from boats.

4.2.2 Sampling frequency

The current sampling frequency for each lake is outlined in Table 4-2. In most cases sampling occurs monthly which concurs with expert panel recommendations from MfE's NEMaR project (Davies-Colley et al. 2012). However, due to resourcing constraints, sampling of open water sites has only occurred for periods of two to three years, once every 10 years, with only lake outlet and shore sites sampled on an ongoing monthly basis. This at least maintains a long-term data time series and may enable a relationship to be established between these outlet sites and open water sites, provided the datasets do not contain many non-detects.

ORC monitors Lakes Hawea, Wanaka, Wakatipu, Hayes and Waihola at three to five sites, more sites than other councils monitor per lake. Monitoring fewer sites per lake would produce some cost savings that might be able to support monthly sampling in these lakes on an ongoing basis, instead of a rotational sampling scheme (although the cost savings are likely to be minor relative to the overall costs associated with travel and boat charter). Consistent monthly sampling facilitates time trend analyses, and is strongly recommended for 'sentinel' lakes for climate change effects, and lakes threatened by catchment land use changes (Davies-Colley et al. 2012). For this reason, we recommend that ORC maintains ongoing monthly sampling at open water sites on at least those lakes considered a high priority. If ongoing monthly sampling is not possible for other lakes in the region, we suggest bi-monthly sampling on an ongoing basis might be a reasonable alternative to reduce costs. Failing that, the next best alternative would be to retain the rotational basis of monitoring open water sites on lakes but reduce the period of no monitoring from the current 10 years to a maximum of five. Significant changes in water quality can occur in a 10-year period and we note that the Water Plan has to be reviewed on at least a 10-year basis.

High frequency sampling, such as using automated lake monitoring buoys, is discussed in Section 4.4.

4.2.3 Sampling depths

All but the shallow coastal lakes of Waipori, Waihola and Tuakitoto are likely to be vertically stratified for a substantial part of each year, resulting in spatial and temporal variation in water quality and biota. This variability needs to be considered in the sampling regime.

In every lake where open water sampling is carried out, sampling should be done at least in the epilimnion to determine the TLI for regional and national reporting purposes. Combining samples from different depths in the epilimnion is fine in principle, but care must be taken to ensure that the deepest sample to be part of the pooled sample is not taken in the metalimnion or hypolimnion. This means that ORC's current sampling strategy for Lakes Hawea, Wanaka, Wakatipu and Hayes (outlined next) should change and we suggest a tube integrated sample as the best solution. Tube integrated sampling is also recommended in the draft NEMS (2017) for Discrete Water Quality.

Lakes Hawea, Wanaka, Wakatipu and Hayes

As described by the Uytendaal and Ozanne (2016) trophic lake monitoring proposal for Lakes Hawea, Wanaka, Wakatipu and Hayes, ORC follows loosely the Burns et al. (2000) methods to collect water samples from the epilimnion. One significant departure is that, instead of checking the water temperature profile to determine first where the bottom of the epilimnion is, followed by sampling at 0.2 m, and at ¼, ½ and ¾ of the depth of the epilimnion (as advised by Burns et al. 2000), ORC samples at fixed depths of 0.5, 15, 30 and 45 m in the three deep lakes, followed by pooling of these four samples to create a single composite sample. This suggests that ORC considers the epilimnion to be typically 60 m deep. However, the temperature profiles of Lakes Wanaka and Wakatipu indicate that the metalimnion, at times, starts at 20 m or even shallower. We agree in general with the problems cited by Uytendaal and Ozanne (2016) regarding estimating appropriate sampling depths following the Burns et al. (2000) protocol. Estimating sampling depths is time-consuming and increases the time spent on the boat. It is often difficult to determine where the thermocline is from the temperature depth profile and the decision is subjective; two field personnel may come to quite different conclusions based on the same temperature data. We therefore agree that there are advantages in deciding on an appropriate sampling depth without first checking the water temperature – depth profile. It is easier to have a predetermined epilimnion sampling depth that is more or less certain to be in the epilimnion, instead of first examining the water temperature profile.

However, it is very important to confirm that none of the sampling depths, intended to be pooled into one surface sample, fall within the range of the metalimnion where nutrient concentrations often increase with depth. As mentioned above, the lower depths of the samples (30 and 45 m), that are presently pooled by ORC to get one surface layer sample, are sometimes at depths below the epilimnion. Therefore, and in view of the water temperature profiles – which show the thermocline sometimes as shallow as 20 m or less – we advise an epilimnion sampling depth of 10 m. We suggest replacing the pooled samples from four depths with a depth-integrated sample between the surface and a maximum depth of 10 m at each of the open water sites.

While the deep chlorophyll maximum is of interest, it typically occurs in the metalimnion and water samples from the metalimnion should not be pooled with surface layer (epilimnion) samples before analysis. This is quite important because nutrient concentrations can increase rapidly below the epilimnion. The TLI is based on data derived from the surface layer. In some cases, the surface layer is not completely mixed in terms of phytoplankton (but note that fluorescence readings are not a good indicator of changes in phytoplankton biomass with depth near the surface in very transparent lakes, as a result of photo quenching) or of nutrient concentrations, in spite of being typically referred to as the surface mixed layer. Therefore, while sampling at a fixed depth such as 10 m would at least supply a standard method comparable over time, it is preferred to collect samples that represent the depth-averaged conditions in the surface layer, as intended by the Burns et al. (2000) protocol. This can be achieved by using a tube sampler (NEMS 2017). In the case of Lakes Hawea, Wanaka, Wakatipu and Hayes, a 10 m-long sampling tube is recommended to provide an integrated sample of the water column between 0 and 10 m. This depth range would provide a sample representative of average conditions in the surface layer, with all depths between 0 and 10 m equally represented. The tube should be weighted at the bottom end so that it fully uncoils and reaches 10 m depth. The upper end is stoppered, the tube hauled up and emptied into a clean bucket, after first rinsing the bucket with sampled water.

The hypolimnion also needs to be sampled in all four lakes. Burns et al. (2000) recommend that a single sample is obtained from the middle depth of the hypolimnion. When part of the hypolimnion is anoxic (i.e., dissolved oxygen at less than 3% saturation, as has occurred in Lake Hayes), Burns et al. (2000) recommend that a water sample should also be taken in the middle of the anoxic zone to obtain information on the strength of sediment nutrient release over the period the lake is stratified.

In order to prevent first having to determine temperature and oxygen profiles – and to base decisions of sampling depths in the hypolimnion on these – we recommend adapting the Burns et al. (2000) protocol to monthly sampling at a selected constant depth, reasonably close to the bottom of the hypolimnion. For Lake Hayes, this sampling would be at a depth of around 28 m (given ORC samples in the middle of the hypolimnion at 22.5 m and the hypolimnion extends for 10-12 m – A. Uytendaal, pers. comm.). In the three deepest lakes, this would mean sampling within 20-30 m or less above the bottom (i.e., less than 10% of the water column depth) which is much deeper than ORC's current sampling practice; nutrients in the hypolimnion are measured monthly at 150 m depth in Lakes Hawea, Wanaka and Wakatipu. This is less than half the maximum lake depth in each case, and not sufficiently informative about the accumulation of nutrients in the hypolimnion. Water samples collected from near the lake bottom will have the highest concentrations of nutrients in the water column, especially towards the end of summer (during stratification), and will provide information on the full range of nutrient concentrations present in the water column.

Other lakes

We understand that water quality at open water sites on Lakes Waipori and Waihola is assessed via a single depth-integrated sample throughout the water column, with sampling standardised to high tide. This approach is sound but care is needed to avoid entrainment of bottom sediment (probably easiest and most safely done by standardising sampling to the top 1 m of the water column given the shallow nature of these lakes).

Should an open water site be established on Lake Tuakitoto in the future, this should be sampled in a similar manner to Lakes Waipori and Waihola. Provided Lake Onslow does not stratify (see Section 4.2.4), then depth integrated sampling should also be carried out.

4.2.4 Profiling

To characterise and track the dynamics of lake mixing, stratification and the availability of nutrients for phytoplankton growth, a depth profile of water temperature and dissolved oxygen (DO) should be measured from the surface to near the bottom of each lake on every sampling occasion, preferably with a Conductivity Temperature Depth (CTD) profiler. Even if shallow lakes are stratified for only short periods of time, oxygen can quickly become depleted near the bottom. This has important implications for nutrient cycling and may reduce the suitability of environmental conditions for most biota. Other variables can be measured as well with a depth profiler, such as light, fluorescence and conductivity. If a depth profiler is not available, then temperature and DO profiles should be measured with simpler and cheaper equipment (NEMS 2017).

Presently ORC's temperature and DO profile measurements in the deep lakes of Hawea, Wanaka and Wakatipu are limited to the upper 200 m of the water column because of limitations with the available equipment. Therefore, more than one third of the water column is missed at most sites. DO is likely to decline in the lower third of the water column so the current 200-m profiles do not generate data that characterise this decline. It is important to know what the minimum DO concentrations are in the bottom water because benthic biota are affected by the availability of oxygen. Moreover, it is only possible to determine that a lake is fully mixed if the near bottom water temperatures are known. Because these alpine lakes are more than 300 m deep (up to 384 m deep for Lake Hawea), this will require monitoring equipment that can withstand pressure at such depths. RBR and Seabird both manufacture profilers that can operate at depths exceeding those in Otago lakes. For instance, RBR models with titanium housings can be used to depths of 6,000 m. Different RBR models are available that have maximum operating depths of 500, 740, 1,000, 2,000, 4,000 and 6,000 m. The Seabird SBE 19plus V2 with a titanium housing can be used up to 7,000 m depth. The sensors on these instruments also have individual maximum operating depths – those provided on RBR and Seabird profilers can typically be used at least down to 600 m. For instance, the RBR XR series multichannel logger can be mounted with a Wetlab transmissometer which has a maximum operating depth of either 600 m or 6,000 m depending on the model. The RBR XR logger range can support a range of sensors (e.g., conductivity, temperature, depth, pH, oxidation-reduction potential (ORP), DO, fluorescence, turbidity, transmittance, and photosynthetically active radiation (PAR)). Newer models may recently have come on the market.

Periodically a full depth profile should be carried out of various nutrients in each of the three largest lakes, as well as Lake Hayes. For instance, biannual profiles can be measured, at the end of the summer when a deep lake has been stratified for a long time and nutrients have been removed from the surface layer, and in midwinter after water column over turn has occurred. This will provide useful information about the effects of stratification and mixing: e.g., to what extent nutrients accumulate during summer (and does this trend between years), which nutrients are returned to the surface during mixing, and in what ratios. Ideally, in a vertical profile nutrient concentrations (refer Section 4.3.6 for details) and pH should be measured at about 10 to 15 depths. Based on 15 depths, we would recommend collection of samples at 0 m (surface), 5 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 80 m, 100 m, 130 m, 160 m, 200 m, 250 m and 300 m, with the depth of the deepest sample adapted depending on the lake to about 10% above the bottom (i.e., at the same depth as the monthly hypolimnion sampling outlined in Section 4.2.3).

4.2.5 Sample collection methods

Sampling water from a specific depth should be carried out using Van Dorn- or Nisken-type water sampling devices. Depth-integrated samples for epilimnion sampling are best collected using a sampling tube (NEMS 2017). Using the latter, it is extremely important that the bottom end of the tube does not include metalimnetic water (the depth range in the thermocline), let alone reach into the hypolimnion where nutrient concentrations will be higher. The thermocline depth can vary substantially and may be quite shallow on calm sunny days. Moreover, in elongated lakes such as Hawea, Wanaka and Wakatipu, internal waves can produce large fluctuations in thermocline depth. These fluctuations are smallest at the centres of lakes and largest at the ends of lakes. In the case of Lakes Hawea and Wanaka, the primary monitoring sites are at one end of the lake. Therefore, the risk of sampling too deep is higher in these lakes, particularly if a tube sampler is always extended down to the same depth (and similarly if samples are collected from fixed depths using a Van Dorn sampler).

Due to the very low nutrient concentrations found in Lakes Hawea, Wanaka and Wakatipu, it is important that extreme care is taken to avoid sample contamination through thorough rinsing of sampling equipment in the water to be sampled and to avoiding touching the inside surfaces of bottle lids. The NEMS (2017) recommends periodic collection of field blanks to confirm the absence of contamination.

SUMMARY

Monthly sampling on an ongoing basis should be implemented where possible and including, as a minimum, at all primary open water monitoring sites on Lakes Wakatipu, Wanaka and Hawea. If monitoring campaigns for periods of two to three years are unavoidable, the return interval should be no more than five years to improve the ability for timely detection of changes in lake condition. Bi-monthly sampling is preferable to continuing rotational monitoring.

Most of the monitored lakes will stratify for a substantial part of the year, requiring a sampling regime for open water sites that targets both the epilimnion and the hypolimnion. We accept the practical advantages of a predetermined, fixed depth for epilimnion and hypolimnion sampling. However, we recommend for the three largest lakes that:

- the current approach of pooling four samples between 0.2 and 45 m is replaced with a single depth-integrated sample to 10 m to avoid contact with the higher nutrient metalimnion waters; and
- hypolimnion samples – currently collected at 150 m depth – are collected closer to the lake bottom to provide improved information on the accumulation of nutrients in the hypolimnion.

We also recommend measuring depth profiles of water temperature and dissolved oxygen (DO) from the water's surface to near the bottom of each lake on every sampling occasion, preferably using a CTD profiler. For Lakes Wakatipu, Wanaka and Hawea, this represents a change in monitoring practice where profiles are currently limited to 200 m. Periodic (e.g., biannual) profiles of nutrients in these lakes – and Lake Hayes – would provide useful information about the effects of stratification and mixing.

4.3 Monitoring variables and measurement methods

4.3.1 Physico-chemical and microbiological water quality monitoring variables

A range of water quality variables can be monitored in lakes. In order of priority, the following variables should be measured: [9]

Tier 1. Water temperature and DO (as profiles – see Section 4.2.4), total phosphorus (TP), total nitrogen (TN), chlorophyll *a*, and Secchi depth

Tier 2. Dissolved inorganic nutrients – dissolved reactive phosphorus (DRP), total ammoniacal nitrogen (TAN, i.e., NH_4-N + NH_3-N) and nitrite nitrate nitrogen (NNN)

Tier 3. Nutrient deficiency indicators – particulate nitrogen (PN) and particulate phosphorus (PP), and particulate carbon (PC) – and, for lowland coastal lakes, total suspended solids (TSS) and volatile suspended solids (VSS)

Tier 4. Dissolved organic phosphorus (DOP) and dissolved organic nitrogen (DON), and photosynthetically active radiation (PAR)

Tier 5. Conductivity, TSS, VSS, coloured dissolved inorganic matter (CDOM), Dissolved Organic Carbon (DOC), Total Organic Carbon (TOC) and other lake-specific variables (e.g., colour for the three large alpine lakes).

We recommend that the Tier 1 and 2 variables above are measured in all lakes that ORC monitors, noting that TP, TN, chlorophyll *a* and TAN are also mandatory NOF lake ecosystem health attributes under the NPS-FM.[9] Water clarity is a particularly important characteristic of lakes and is an attribute highly valued by the public (e.g., West et al. 2016). The best way to characterise water clarity (both aspects) in the deeper lakes is by measuring both Secchi depth (index of visual clarity) and PAR irradiance attenuation with depth (index of light penetration). PAR sensors can be mounted on a CTD used for profiling or by measuring PAR irradiance with a dedicated array at about 10 different depths between the surface and a depth roughly 2 to 3 times the Secchi depth, using LI-COR (or equivalent) equipment. The slope of logPAR against depth gives the attenuation coefficient. Secchi depth and irradiance attenuation are different facets of water clarity, although they typically correlate. While Secchi depth relates to visual clarity, PAR irradiance attenuation relates to the light that phytoplankton receive to allow photosynthesis to occur at certain depths.

The nutrient deficiency indicators in the third tier of variables listed above should also be measured in Lakes Hawea, Wanaka, Wakatipu and Hayes. Particulate nutrients (PN and PP) are very useful as a first indicator of the nutrient that may be limiting algal growth, if any (unless affected by glacial flour inputs, particulates will be almost completely accounted for by algal cells when sampled in an open lake site). These need to be measured together with particulate carbon (PC) because the ratios of PN:PC and PP:PC are used to conclude whether the phytoplankton is phosphorus or nitrogen deficient, or whether there is a trend in the availability in nutrients relative to demand. The ratios of PC:PN and PC:PP increase as nitrogen or phosphorus, respectively, become more limiting for algal growth (Verburg & Albert 2016, Healey & Hendzel 1979, Healey & Hendzel 1980, Guildford et al. 2005). Diagnostic PC:PN and PC:PP molar ratios have been derived from chemostat measurements that can be used to indicate nutrient deficiency status of the algal species assemblage:

- For PC:PN, ratios <8.3 and >14.6 indicate no and extreme N deficiency, respectively (and moderate N deficiency at ratios between 8.3 and 14.6).
- For PC:PP, ratios <129 and >258 indicate no and extreme P deficiency, respectively (and moderate P deficiency at ratios between 129 and 258) (Verburg & Albert 2016, Healey & Hendzel 1979, Healey & Hendzel 1980, Guildford et al. 2005).

All methods for evaluating nutrient limited phytoplankton production have limitations (except whole-lake enrichment, which is not feasible). Therefore, a multiple lines of evidence approach is needed, which may involve bioassays, cellular nutrient ratios and assessment of dissolved nutrient concentrations and ratios. Particulate nutrient analysis has some advantages compared to the bioassays that have been more commonly applied in nutrient limitation studies in New Zealand. They provide an easy, quick, cost-effective method to determine general nutrient deficiency status in a lake. This means that they can be measured on every sampling occasion and therefore will also provide a method to determine long term changes in nutrient deficiency.

PC, PN and PP should be measured directly and to the lowest possible concentrations (around 0.1 µg/L or 0.0001 mg/L), rather than be inferred by difference from other forms of nitrogen and phosphorus (which methods are associated with substantially higher MDLs). As noted above, the point of measuring these variables is not for the concentrations themselves but for their ratios. If the

[9] Monitoring water quality for recreational suitability is not addressed in this report but we note, for completeness, that *E. coli* and cyanobacteria are mandatory NOF attributes for the value of 'human health for recreation' under the NPS-FM. We also note that *E. coli* and turbidity are listed in Schedule 15 of the ORC's Water Plan but have not included these in the recommended suite of variables because neither is commonly measured at open-water sites in lake SoE programmes.

numerator or the denominator (or both) of a ratio are below detection than the result of the ratio is meaningless. Therefore PC, PN and PP must be measured with high accuracy to be useful.

Measurements of total suspended solids (TSS) and volatile suspended solids (VSS) are included as Tier 3 variables for the shallow lowland coastal lakes of Waihola, Waipori and Tuakitoto. Wind-induced sediment resuspension can be significant in these shallow lakes and water quality data may need to be 'deweathered' to remove the effects of wind (see Burns et al. 2000).

Additional variables of interest (Tier 4) in Lakes Hawea, Wanaka, Wakatipu and Hayes are dissolved organic nutrients (DOP and DON); concentrations of these can simply be calculated as total dissolved nutrients minus inorganic dissolved nutrients (or total nutrients minus particulates and inorganic dissolved nutrients). Note that we do not recommend measuring total dissolved phosphorus (TDP) and total dissolved nitrogen (TDN) if concentrations are usually below detection limits.

At present, ORC monitors both dissolved organic carbon (DOC) and total organic carbon (TOC) in Lakes Hawea, Wanaka and Wakatipu. While DOC contributes to reduced water transparency and so it is of interest to know the approximate concentrations in each lake, presently the DOC and TOC concentrations are often below analytical method detection limits (MDLs), reducing the usefulness of these variables. Moreover, we consider DOC and TOC to be of less value compared with PC, PP and PN; without further information, it is not known what proportions of DOC and TOC are derived from production within the lake versus the proportion derived from terrestrial sources. We therefore suggest that DOC and TOC are only included in surveys carried out once every few years, or only as part of periodic depth profiles, and provided detection limits can be improved.

Tier 5 variables will be lake-specific. For example, in Otago's oligotrophic lakes, including the three largest lakes, TSS and VSS concentrations will typically be below the laboratory's MDL. Therefore, we recommend that ORC check their datasets and remove TSS and VSS from the list of measured variables in lakes where non-detects dominate (presently TSS is measured in all nine monitored lakes and is probably most important to monitor in the three lowland coastal lakes). Coloured dissolved organic matter (CDOM) is of interest for its light attenuation in lakes, especially in humic lakes (Davies-Colley et al. 2012). CDOM concentrations can be estimated by the proxy provided by absorbance at various wavelengths (A_{340}, A_{440}, A_{740}; Verburg 2011). CDOM is likely to be very low in the oligotrophic Otago lakes but monthly measurement for one to two years to establish a baseline may supply useful information in the more productive lakes. A baseline assessment of colour (as hue, measured through the use of Munsell standards) could also be worthwhile for Lakes Hawea, Wanaka, Wakatipu.

An additional non-water quality variable that should be routinely measured during every sampling event is lake water level, as an indicator of water inputs and seasonality of the water balance. Presently, we understand lake levels are monitored at the outlets of Lakes Hawea, Wanaka, Wakatipu, Dunstan, Tuakitoto and Waipori. At the very least, a staff level gauge should be installed in each monitored lake, with consideration given to continuous measurements in small lakes with highly varying water levels.

Hypolimnion samples

Currently ORC measures both dissolved and total nutrients in hypolimnion samples from Lakes Hawea, Wanaka, Wakatipu and Hayes. We consider that hypolimnion sample analysis could be restricted to dissolved nutrients only (DRP, TAN and NNN), as the nutrients in bottom water are likely to be mostly in dissolved form, especially towards the end of summer when the hypolimnetic nutrient concentrations are highest.[10] As noted previously, as well as full depth profiles of DO to near the lake bottom, ORC's monthly sampling should also include near bottom hypolimnion measurements of dissolved inorganic nutrients in each of Lakes Hawea, Wanaka, Wakatipu and Hayes. Measurements at a set depth near the bottom will show how these inorganic nutrients are accumulating in the hypolimnion through the summer and are depleted during the winter turnover.

Profile samples

If depth profiling is performed for nutrients (refer Section 4.2.4), water samples should be analysed for DRP, TAN, NNN, TN and TP to provide information about the effects of stratification versus mixing.

Volumetric Hypolimnetic Oxygen Depletion (VHOD)

Uytendaal and Ozanne (2016) discuss volumetric hypolimnetic oxygen depletion (VHOD) monitoring in Lakes Hawea, Wanaka and Wakatipu. VHOD is caused primarily by the decomposition of organic material in the hypolimnion (VHDorg) and is an important indicator of the trophic state of lakes that is used to detect change of trophic state (Burns 1995). However, the determination of VHOD is complicated by factors that may in turn affect the computed result. The apparent oxygen depletion may be affected by changes in oxygen concentration caused by changes in inflowing river water that enters the hypolimnion. VHOD is determined over the summer period when the decrease in total oxygen in the hypolimnion is linear. However, the period over which it is linear can vary between years. Oxygen depletion is determined as the decrease in total oxygen content divided by the number of days of the linear decrease. As a result of differences in the number of days over which it is calculated it is possible to find large differences in VHOD between years without a change in the minimum oxygen concentration that would appear to be consistent with the change in VHOD. Therefore, the results are not always simple to interpret. For instance, in Lake Taupo a several-fold increase in VHOD has occurred in the past 10 years. An increase in VHOD would suggest an increase in the amount of organic matter decomposing in the hypolimnion. However, there was no concomitant increase in the amount of nutrients accumulating in the hypolimnion. In addition, algal biomass in the surface layer showed no significant change over this period, and certainly no change that would explain the large change in VHOD (Verburg & Albert 2016, Verburg & Albert 2017). In Lake Taupo, in spite of the apparent increase in VHOD, there has been no decrease in the annual minimum oxygen concentration in the hypolimnion.

VHOD is calculated from the change in total oxygen content, meaning that the measurements of depth profiles of oxygen at the monitoring site must be extrapolated lake wide. This extrapolation may be appropriate for lakes with a simply bathymetry such as bowl-shaped Lake Taupo, but not for lakes with more complex shapes or multiple basins such as Wakatipu, or the elongated Lake Wanaka, where oxygen profiles are likely to differ along the length of each lake. In these two lakes, it seems likely that more organic matter sinks out and contributes to hypolimnetic oxygen depletion in the part of the lake closest to the outlet than further away from the outlet. In the latter case only HOD, the depletion at a discrete site, should be determined. In addition, HOD (and VHOD) can only be calculated if profiles are done down to near the bottom, which would require CTD equipment that is capable of measuring to more than 300 m depth in the three deepest lakes (see Section 4.2.4).

[10] The accumulated dissolved nutrients in the hypolimnion are derived from decomposition of organic matter that sinks out during the stratified season and are indicative of the productivity during summer and the amount of nutrients that will become available to phytoplankton growth at the onset of the next season after overturn.

However, one may be able to assume that DO does not change between the bottom and the depth of the deepest measurement, as long as the implications of this assumption are understood.

In general, it is more useful to monitor the concentration of oxygen in the hypolimnion and to examine trends between years in the minimum concentration of oxygen, than to determine VHOD. This supplies the information that is most important for the state of the lake ecosystem.

Summary

Tables 4-3 sets out the recommended water quality variables (and phytoplankton – addressed in Section 4.3.2) to be measured by lake and by monitoring site. The full suite of variables, including particulate nutrients and phytoplankton species enumeration, are also recommended at secondary sites such as the near shore sites in Lakes Wakatipu and Wanaka where higher nutrient concentrations may result in changes in nutrient deficiency and in phytoplankton species composition compared with the open lake sites. However, in Lakes Waihola and Waipori, measuring the expanded suite of variables at a single representative site would suffice.

NEMS (2017) recommends laboratory analytical methods and detection limits for lake water quality monitoring. We have not reproduced these here, but we note that in the case of ORC's three largest lakes, it will be necessary to utilise nutrient analysis methods that offer the lowest possible detection limits to ensure that changes in (the currently very low) nutrient concentrations can be tracked through time.[11]

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[11] Presently this will likely require the use of a research-based laboratory, such as NIWA's laboratory, which has specialist expertise for ultra-trace level nutrient analysis, including analysis of components such as PP, PN and PC based on filtered samples (NEMS (2017) does not address these additional variables). While NIWA's laboratory does not currently hold IANZ accreditation for its methods (a reflection of the laboratory being a low throughput facility with a predominantly research focus), the personnel and equipment meet recognised best practice, and rigorous QA/QC practices are in place. Without such accreditation, we note that samples processed by NIWA would not be eligible to receive the highest quality code (QC 600) under NEMS (2017).

Table 4-3: Recommended variables (x) by lake and site. All columns are for variables in surface water (epilimnion where applicable), except the last two columns (hypolimnion and profile). Note that TDP and TDN are only measured to calculate DOP and DON. Includes Lake Waipori should ORC re-establish monitoring on this lake (see Section 4.1). + = optional. Lake water level should also be measured. See the text for discussion.

Lake	Site	Variables											
		TP, TN, chlorophyll *a*	DRP, NNN, TAN	PN, PP, PC	TDP and TDN	Secchi depth	Temp, DO, fluorescence, PAR profile	Phytoplankton	Conductivity (CTD)	TSS & VSS	CDOM (A_{340}, A_{440}, A_{740})	Hypolimnion: DRP, NNN, TAN	Periodic (e.g., biannual) profile: nutrients
Hawea	Northern (open water)	x	x	x	x	x	x	x	x			x	x
	Southern (open water)	x	x	x	x	x	x	x	x			x	x
	Outlet	x	x										
Wanaka	Northern (open water)	x	x	x	x	x	x	x	x			x	x
	Southern (open water)	x	x	x	x	x	x	x	x			x	x
	Glendhu Bay	x	x	x	x	x	x	x	x				
	Roy's Bay	x	x	x	x	x	x	x	x				
	Outlet	x	x										
Wakatipu	Northern (open water)	x	x	x	x	x	x	x	x			x	x
	Southern (open water)	x	x	x	x	x	x	x	x			x	x
	Frankton Arm (bay site)	x	x	x	x	x	x	x	x				
	Queenstown Bay	x	x	x	x	x	x	x	x				
	Outlet	x	x										
Hayes	Mid lake (open water)	x	x	x	x	x	x	x	x	x	x	x	x
	Bendemeer Bay (shore site)	x	x				x		x				
	Outlet (Hayes Ck at SH 6)*	x	x										
Johnson	South Shore huts (shore site)	x	x	x	x			x		x	x		
Tuakitoto	Outlet	x	x	x	x			x					
Waihola	North (open water)	x	x	+	+	x	x	+	x	+	+		
	Mid (open water)	x	x	x	x	x	x	x	x	x	x		
	South (open water)	x	x	+	+	x	x	+	x	+	+		
	Jetty (shore site)	x	x										
Onslow	Boat Ramp (outlet)	x	x	x	x			x		x	x		
Waipori	Mid (open water)	x	x	x	x	x		x		x	x		
	South (open water)	x	x	+	+	x		+		+	+		
Dunstan	Deadman's Point	x	x	x	x			x		x	x		

* We understand that the ORC is reinstating this site.

4.3.2 Phytoplankton

It is useful to monitor phytoplankton species composition and abundance (cell counts and biovolume), especially where seasonal dominance of cyanobacteria, including potentially toxic species, can be a concern (e.g., Lakes Waihola and Hayes). In terms of priority, monthly phytoplankton sampling on all open water lake sites falls under Tier 3 (refer Section 4.3.1 and Table

4-3) and would allow assessment of inter-annual and seasonal changes in community composition within and between lakes. This information may be relevant to understanding such phenomena as lake snow *(Lindavia intermedia)* in Lakes Hawea, Wanaka and Wakatipu.

Presently only cell counts are performed on lake phytoplankton samples collected by ORC and picocyanobacteria have been very abundant in these samples (A Uytendaal, pers. comm. 2017). While picocyanobacteria are small, their contribution to total phytoplankton biomass may be large in the oligotrophic deep and large Otago lakes (e.g., Schallenberg & Burns 2001, Bayer et al. 2015). This is an area that ORC may wish to explore further to improve understanding of shifts in trophic state. Methods are also now available to screen picocyanobacteria (and other phytoplankton) samples for genes involved in toxin production, allowing for cost effective assessment of the presence of potentially toxic species.

4.3.3 Macrophytes

Monitoring lake macrophyte communities provides important information on ecological condition. In New Zealand, macrophyte monitoring for SoE purposes is generally based around Lake Submerged Plant Indicators (LakeSPI) which characterises ecological condition by the composition of native and invasive plants and the depth to which they grow (Davies-Colley et al. 2012). This information is combined into an overall score for lake condition that is easy to understand and well-suited for incorporation into SoE reporting. In general, a five-year frequency is recommended for LakeSPI surveys unless monitoring identifies significant risks or impacts from invasive taxa (e.g., through high boat access).

Native macrophyte values are expected to be high in many of Otago's lakes, reflecting their remote location and the high proportion of natural landcover present in their upstream catchment (refer Table 4-1). However, to date only a handful of lakes have been assessed using the formal LakeSPI methodology – and most of these assessments were performed 10 or more years ago (Figure 4-2). Initial (or, in some cases, updated) baseline surveys would be useful to obtain current information to inform lake management (e.g., on the threats posed by invasive taxa). Lake Wakatipu would be the highest priority lake to assess given that *Lagarosiphon* is already present downstream in the Kawarau River (P. Champion, pers. comm. 2017). All of the other eight lakes currently monitored by ORC would benefit from an initial baseline survey (although Lake Hawea – with manipulated water levels – and Lake Johnson may be of lower priority) which could be performed across two different years as follows:

- Year 1: Lakes Wakatipu, Hayes, Dunstan, Wanaka and Hawea
- Year 2: Lakes Onslow, Waihola, Waipori and Tuakitoto

Lake	Status	Date	LakeSPI %	Native Condition %	Invasive Impact %
Lake Wakatipu	Excellent	1992-01-27	90%	93%	13%
Lake Wanaka	Excellent	2011-02-22	81%	87%	25%
Moke Lake	Excellent	2007-12-02	78%	72%	12%
Diamond Lake	Moderate	2007-12-02	35%	32%	67%
Lake Hayes	Moderate	2001-03-06	26%	14%	69%

Figure 4-2: All available LakeSPI information for Otago lakes as at August 2017.

Aquatic plant surveys of some Otago lakes (e.g., Wanaka and Dunstan) are already carried out for Land Information New Zealand (LINZ) as part of assessing the effectiveness of *Lagarosiphon* control measures. It may be possible to align LakeSPI monitoring with these surveys to reduce costs.

We also recommend that consideration is given to repeating transects assessed during previous assessments (Figure 4-2) which may provide information on changes in ecological condition through time.

4.3.4 Zooplankton

It can be useful to evaluate zooplankton species composition and abundance, either of the full assemblage or a subset such as rotifers. Zooplankton are the link between primary producers (phytoplankton) and higher consumers (such as fish), in the pelagic zone (open water) of a lake. Through their feeding, they recycle the nutrients used by phytoplankton while also enhancing export of nutrients from the epilimnion to the hypolimnion by producing faecal pellets. Different species interact differently within the pelagic ecosystem, resulting in different effects on water quality. Zooplankton species composition is both a result of, and affects, water quality. While the trophic state of a lake is often a good predictor of the zooplankton species composition, changes in zooplankton (and fish) species assemblages can in turn result in marked changes in lake water quality.

In Lake Hayes, there has been a shift in zooplankton composition to an exotic species (*Daphnia pulex*) (Burns 2013). This is likely to explain rapid shifts that have been noticed in water clarity and chlorophyll *a* concentrations in Lake Hayes, through changes in nutrient cycling and grazing rates on phytoplankton. Therefore, changes in zooplankton species composition can affect a lake's TLI. Invasion by *D. pulex* and future invasions by new species are also likely to have implications for water quality in the other Otago lakes. In short, zooplankton monitoring provides useful information in all lakes and may help to explain changes observed in water quality.

At present, ORC collects a 150 m vertical haul (150 µm mesh size) of zooplankton at the open water monitoring sites on Lakes Wanaka, Hawea and Wakatipu, and zooplankton samples are also collected from Lake Hayes. These samples are preserved and provided to University of Otago, in case there is interest in the future in processing of them. We support ORC's current sampling approach but recommend that these samples are analysed. At a minimum, samples should be analysed several times per year, for instance in spring, in mid-summer and during the winter mixing. Samples that are stored lose some of their quality and zooplankton will decompose, especially if the preservatives are not regularly topped up.

4.4 High frequency monitoring

Lake monitoring buoys and remote sensing are additional options that could complement, but not replace, regular on-lake monitoring.

4.4.1 High frequency automated monitoring stations – lake buoys

While monthly discrete sampling and CTD profiles should underpin ORC's lake monitoring programme, high frequency automated measurements – such as those obtained using monitoring buoys – are becoming an increasingly important complementary measure that improves understanding of lake ecosystem function. A monitoring buoy station can supply high-frequency measurements of chlorophyll fluorescence, PAR, water temperature, dissolved oxygen (DO), and other variables. A buoy system can provide continuous measurements at depths throughout the water column, including the full depth of the hypolimnion. In addition, meteorological data (e.g., wind speed and air temperature) can be recorded at the lake surface with sensors on a mast on the buoy, which would otherwise only be available from sites on shore near the lake. Both wind speed and air temperature are drivers of surface heat exchange with the atmosphere and vertical mixing, arguably the most important processes that drive the functioning of lake ecosystems. As these variables differ between lake and land surfaces– especially in large lakes such as Hawea, Wanaka and Wakatipu – monitoring of these on the lake is valuable. Continuous monitoring generates night-time data, which are otherwise rarely collected. At night, marked changes occur in water temperature and DO near the water's surface. The former is driven by cooling and is of interest to improve understanding of vertical stratification and mixing. The change in surface water DO over the day is driven by respiration versus photosynthesis, and is of interest for understanding ecosystem metabolism.

The high-frequency data provided by buoys are essential to guide and facilitate modelling of water movements (hydrodynamics), which control nutrient transport and nutrient cycling. Monitoring buoys also provide a highly visible and continuous demonstration of the effort spent on water quality monitoring programmes and can elicit a strong interest from the public.

We recommend that ORC consider installing a monitoring buoy with a fixed sensor string in each of the three largest lakes – Hawea, Wanaka and Wakatipu – where nutrient dynamics depend strongly on vertical stratification and winter mixing. Information on stratification and mixing will assist ORC to understand changes in trophic state that are identified through regular monthly water quality sampling. A buoy with a fixed string of sensors can provide measurements of selected variables down to the maximum depths of these lakes (maximum depth 384 m).

With monitoring buoys in place in the three deepest lakes there would be less need for a CTD profiler that can exceed 200 m depth (refer Section 4.2.4). However, a CTD profiler has the advantage of much greater depth resolution (>1 measurement per metre). Therefore, if there is a choice between a buoy-based hypolimnion monitoring scheme or the use of a CTD, then the decision will depend on the number of sensors used on the sensor string in the hypolimnion. We recommend using both monitoring buoys and CTDs to measure profiles to the bottom; buoys alone are typically equipped with only a few oxygen sensors in deep water.

It is essential to note that a buoy monitoring station cannot replace ORC's regular monitoring programme, and would not justify a reduced frequency of regular discrete sampling. This is because nutrients cannot presently be measured by automatic sensors (except nitrate-N for which sensors do exist but offer lower accuracy than laboratory analysis), nor can phytoplankton community composition. Secchi depth also cannot be measured by automatic sensors, although a transmissometer could be used to measure light attenuation and establish a relationship with Secchi depth (NEMS 2017). Chlorophyll fluorescence measured by buoy sensors may be affected by photo quenching in near surface water during the day time, especially in clear lakes. Sensor readings also need to be calibrated by regular laboratory measurements of chlorophyll *a* in discrete water samples.

Lake buoy components

Lake buoy systems have three components: 1) the underwater instrumentation, 2) the surface instrumentation and 3) the mooring array and superstructure.

Underwater instrumentation – Temperature sensors are the most important sensors on buoys, especially in deeper lakes, as lake ecosystem functioning is largely tied to lake mixing. Full water column mixing is indicated by the temperature gradients in the water column. Therefore, the choice of depths of the sensors needs attention. More sensors per metre depth should be placed in the upper water layers, compared with the relatively well-mixed hypolimnion. Also, the density of sensors should be higher around the approximate depth of the thermocline. Fewer sensors are needed in the hypolimnion. Buoys should be located at deep sites, and temperature sensors should extend to near the lake bottom. DO should also be measured near the bottom and at several other depths in the hypolimnion. Oxygen and chlorophyll fluorescence sensors at shallow depths need wiping to remove algal growth (deep oxygen sensors don't need wiping because little algal growth is expected in the hypolimnion). Therefore, the top of the sensor string needs to be pulled up every few months to clean optical near-surface sensors.

If PAR sensors at two depths are included in the sensor string, light attenuation can be determined. However, the shallower sensor is likely to develop algal growth faster than the deeper sensor, which can cause errors in calculated attenuation. Cyanobacterial pigment sensors are another option, although these may be more useful in eutrophic lakes. Sensor accuracy must be matched to the conditions expected in the lake. Sensor calibration is also required.

This section has focused on fixed sensor strings attached to buoys. An automatic profiler recently developed by Chris McBride (Limnotrack / University of Waikato) has the advantage that only one instrument of each type is needed to measure the full water column. This means that variables for which instruments are expensive (e.g., DO and chlorophyll), and for which few sensors are included in most buoy systems, can be measured through the entire water column. There is also an advantage for underwater light measurements through avoiding the problem of differential fouling between instruments – as well as inclusion of turbidity and conductivity sensors. The main disadvantage of the profiler is low measurement frequency. In a 100 m water column, only a few full profiles can be done per day because the profiler is slow, mostly because of the time needed for equilibration of the sensors. In other words, the advantage of high frequency data is lost and comparison of diurnal and nocturnal processes are limited, except at the lake surface. It is our understanding that all sensors on the Limnotrack profiler system only record measurements once the profiler has arrived at a measurement depth and after its sensors have equilibrated. Therefore, even stationary sensors at the surface would record at low frequency. Hydrodynamic modelling will be limited by the lack of synoptic measurements at all depths, and the low frequency of measurements at each depth. Moreover, buoy profilers are presently limited to depths less than 100 m. Therefore, much of the advantage of having a buoy would be lost if a profiler instead of a static sensor string is used in Otago's 300+ m deep lakes.

Surface instrumentation – This should include a good quality, high precision weather station that measures air temperature, wind speed, relative humidity and air pressure. These are all measured by the Vaisala instrument which is most often used for this purpose. In addition, we suggest a four-way radiation sensor (up and down solar and long wave radiation). These two instruments supply the data necessary to determine all exchanges of heat between air and the water surface. As noted previously, data from on-lake buoy instruments are preferable to data from a nearby shore station. Air temperature can differ by more than 1°C between mid-lake and shore (Verburg & Albert 2016) and wind speed can be expected to be higher over lake surfaces than on land, because of the absence of obstructions. The fetch across the lake surface increases with lake size.

Mooring array and superstructure – In deep lakes such as Wakatipu (380 m deep), Lake Hawea (384 m deep), and Wanaka (311 m deep) anchoring and the design of the mooring array is more demanding than in shallower lakes, but can be managed. Two or three anchors will be required, with the buoy and the sensor string attached to the mooring system between the anchor positions. The mooring system needs to be designed to avoid entanglement of the sensor string with the anchor lines, as anchor lines can damage the sensors. Other components of buoy include solar-powered data loggers and telemetry equipment. Measuring frequencies for sensors can be set up by a file in the memory card in the logger; the most common frequencies are one record per minute or per 10 minutes.

Monitoring buoys require a high level of support maintenance by technicians, both for the mooring and superstructure (e.g., checking shackles and the sensors (e.g., re-calibration and replacement when malfunctions occur). Skillsets for buoy technicians include electrical engineering and computer programming, to sort problems that invariably arise regularly with the data logging, and especially with the telemetry. Depreciation and costs of equipment replacement may strongly influence the decision to acquire a buoy. Lastly, critical failure of a buoy station can occur. Individual sensors may fail, a complete sensor string may fail through breaking of the internal wiring (this does not necessarily require replacement of the sensors but will mean that the buoy is out of order and no data are received until it is fixed) or, in extreme cases, entire buoy systems can be lost (as happened in Lake Waikaremoana, in Te Urewera National Park).

4.4.2 Remote sensing

In recognition of the limitations of fixed-location monitoring, remote sensing is increasingly of interest as a complementary monitoring tool used to assess the spatial variability of water quality within (and between) lakes. Remote sensing includes both passive imagery and active radar/LIDAR with a range of platforms in use (e.g., satellite and both manned and unmanned aircraft). Remote sensing of ocean colour on the MODIS-AQUA satellite is of sufficient resolution (500 m^2 pixels) to be of value to large lake monitoring of optical water quality and its relevant products (visibility, light attenuation, scattering, TSS, chlorophyll *a*, CDOM). The varying optical properties of lakes in some cases will require regional (lake) calibration/validation – an important step in improving the quality of data. It should be recognised that multi-scaled sampling strategies using surveys, moorings, and remote sensing, are essential tools in their own right, but are more statistically powerful and relevant together.

Remote sensing lake applications do exist in New Zealand (e.g., Allan et al. (2007)), but are still in their infancy. An initial point of interest for ORC may be the analysis of past satellite images to assess potential temporal changes in optical properties of Otago's largest lakes, given the relatively short record of water quality monitoring. Satellite data for Manukau Harbour in Auckland have been successfully analysed to identify decreasing (i.e., improving) trends in TSS, chlorophyll *a* and water column attenuation between 2002 and 2017 (Pinkerton 2017). This same study also identified significant increasing trends in surface water temperature from the satellite data. The 15 years of high resolution (500 m pixels) MODIS-AQUA satellite data provides an unprecedented historical record with sufficient observations to determine inter-annual, annual, seasonal and month scale trends, of particular value in lake water quality monitoring.

SUMMARY

High frequency monitoring technology is of increasing importance in monitoring lake health. The deployment of an automated monitoring buoy in each of Otago's three largest and deepest lakes, Hawea, Wanaka and Wakatipu, would aid in understanding nutrient dynamics in these lakes which depend strongly on vertical stratification and winter mixing. In particular, the high-frequency data the buoys provide would support modelling of water movements (hydrodynamics), which control nutrient transport and cycling.

A buoy with a fixed string is recommended to enable water quality measurements down to the maximum depths of these lakes. Monitoring buoys would complement but not replace ORC's existing monthly water quality monitoring.

Lake monitoring buoys require significant technical expertise to design, deploy, and maintain.

5 Monitoring linkages, out-of-stream pressures and QA

This section provides a brief consideration of linkages between rivers and lakes (and other water domains), key out-of-stream pressures that should be monitored to assist SoE data interpretation and guide natural resource management. Guidance on quality assurance practices is also provided.

5.1 Linking water domains

While we have addressed river and lake monitoring separately in this report, it is important to consider the linkages between these water domains, as well as linkages with groundwater and downstream receiving waters, particularly estuaries.

Although not essential for river and stream ecological health, periodic measurement (e.g., monthly for 12 months once every five years) of the typical suite of anions and cations at river sites would provide useful characterisation of water quality across Otago and, in particular, assist with interpretation of groundwater and surface water interaction (e.g., Guggenmos et al. 2011). This information may also be needed as inputs to water quality models. Isotopic tracers such as radon can also be useful for assessing groundwater and surface water interaction (e.g., Close et al. 2014), while more stable isotopes, including tritium, can be particularly useful for providing indications of the ages of groundwater inputs to surface waters (e.g., Morgenstern 2007).

We understand that the ORC has recently started to monitor ecosystem health in several estuaries, including – to date – the Kakanui, Shag, Catlins and Waikouaiti. Water quality and flow in the lower reaches of the major tributaries entering these estuaries is also currently being monitored, providing good linkages between catchment inputs and what deposits in the estuaries. Where sedimentation and/or nutrient enrichment is identified as an actual or potential threat to estuarine health, it may be useful to consider quantifying suspended sediment and nutrient concentrations in the tributary inputs during specific wet-weather events.

In terms of lakes, we note that the ORC currently already monitors water quality at most outflows, but not at all inflows. This is particularly the case for the three large alpine lakes (Wakatipu, Wanaka and Hawea), with the Dart and Matukituki Rivers the only inflows (to Lakes Wakatipu and Wanaka, respectively) monitored on an ongoing basis. The river catchments surrounding these lakes form Receiving Water Group (RWG) 3 in ORC's Water Plan and drain significant areas of the conservation estate, suggesting that water quality is exceptionally high. While monitoring sites on some of these rivers (e.g., the Makarora and Hunter rivers) is unlikely to be a high priority for ORC, particularly given the added travel to access these rivers, more sites in this RWG are needed to balance the existing network. There are some more easily accessible tributaries that could be considered (e.g., the Fern Burn for Lake Wanaka and the Dingle Burn for Lake Hawea). Moreover, some of the smaller tributaries to these lakes, notably Horne Creek (running through central Queenstown before discharging to Lake Wakatipu) and Bullock Creek (running through Wanaka township before discharging to Lake Wanaka) have the potential to cause localised impacts on lake water quality and might warrant at least some targeted monitoring. Both streams are influenced by urbanisation and establishing a monitoring site on at least one would support better representation of urban catchments within the SoE monitoring network, a need discussed in detail in Section 3.3.

5.2 Out-of-stream pressures

For regional SoE monitoring purposes, the primary out-of-stream pressure that we think should be monitored is land use change because it is a dominant driver of aquatic ecosystem health. Regular updates of aerial photographs and land use/cover databases (e.g., Agribase, LCDB) should be maintained to track land use change and can be combined with other available information, especially census data which provides a range of information on population statistics and land use (e.g., agriculture, horticulture and forestry). Other important information to track – and needed to support water quality accounting under the NPS-FM – includes current and new resource consents (e.g., volumes and types of discharges and water takes) and information on catchment mitigation work (e.g., stream fencing, riparian planting). Encouraging farmers to maintain records of fertiliser and/or effluent application, stock movements and changes in irrigation methods, would also provide valuable farm-scale information that could be scaled up to improve understanding of changes in water quality at the catchment scale that might be observed from SoE monitoring data.

5.3 Quality assurance (QA)

Although quality assurance (QA) is a critical part of monitoring programmes, budgetary constraints or other pressures may constrain these activities in regional SoE freshwater monitoring (Davies-Colley et al. 2012). Consistent with the recommendations from both the NEMaR project (Davies-Colley et al. 2012) and the draft NEMS for Discrete Water Quality (NEMS 2017), we recommend that the ORC's review of its river and lake monitoring programmes considers QA requirements for all aspects of the programmes, from field collection through to laboratory analysis and data archiving.

An important starting point is ORC's existing Water Sampling Procedures Manual. The copy we received during this review is dated August 2014 and should be updated to reflect current practice (e.g., the recent cessation of field filtering of river water samples). The recent release of the draft NEMS (2017) for Discrete Water Quality – as well as ORC's recent change in laboratory provider – make this an opportune time for ORC to revisit its procedures. Data QA, discussed further in Section 5.3.2, is one area that should receive more attention (e.g., Appendix 10 of the ORC procedures manual does not outline any checks made of actual water quality data).

5.3.1 Monitoring QA

The single most useful QA exercise ORC should invest in is an annual field inter-comparison exercise with another experienced monitoring agency (e.g., a neighbouring regional council or NIWA). Councils in several regions (e.g., Wellington, Marlborough) already undertake this type of field verification exercise – or a variation of it – which essentially seeks to:

1. Obtain accurate field measurements (e.g., of dissolved oxygen and visual clarity), and
2. Deliver to the laboratory 'dependable' samples that are representative of the water body at the site and remain unchanged during transit to the laboratory.

The QA field exercise should target specific practices around:

- field meter calibration/validation, deployment and measurements,
- execution and recording of other on-site measurements (e.g., black or Secchi disc, periphyton cover),
- collection and handling of water samples, including bottle labelling, sample pre-treatment or preservation, and sample dispatch, and
- completion of sample records/field sheets, including metadata (NEMS 2017).

The exercise requires two or more staff of different agencies to simultaneously, but independently, complete the tasks above and dispatch a set of duplicate water samples to the same laboratory.

The collection of field blanks on a regular (e.g., quarterly or six-monthly) basis is also recommended when monitoring river – and especially lake – waters with very low nutrient concentrations. This provides a check for background contamination arising from the sample bottle, collection or handling. Field blanks should comprise distilled or pure water submitted to the laboratory for analysis in the same type of bottle as the other water samples (NEMS 2017). The distilled water should be sourced from the laboratory doing the analysis.

For river and lake SoE water quality data to be eligible for the highest quality code under the NEMS (2017) for Discrete Water Quality, water samples should be analysed at a laboratory accredited by International Accreditation New Zealand (IANZ) for each test method. This is to ensure that the laboratory has appropriate quality practices in place to provide accurate and reliable results.

Replicate sampling provides another useful check on laboratory performance. ORC could send replicate samples to their laboratory and/or to another laboratory for comparison. Duplicate or replicate samples should be assigned a false name so that laboratories do not know the location of collection (NEMS 2017).

A QA field exercise can also be designed to verify river biomonitoring methods. As the minimum, annual training should be provided given that most biomonitoring is only conducted annually. We expect the NEMS for periphyton (in development) to outline QA/QC requirements for periphyton cover and biomass measurements. Stark et al. (2001) set out QC procedures to ensure that macroinvertebrate taxa are identified correctly. Around 5 to 10% of macroinvertebrate samples should be referred to a second laboratory for quality checks of the primary laboratory's sorting and identification procedures.

5.3.2 Data QA

All field and laboratory data should be checked prior to archiving for later use. For discrete river and lake water quality data, these checks form an essential part of the quality code assignment process under the draft NEMS (2017).

Field measurement data should be checked by someone other than the officer(s) that made the measurements. For laboratory measurements, the laboratory should have systems in place to check the time, temperature and condition of samples on arrival at the laboratory. The final data from the laboratory should ideally be checked promptly, within two weeks of receipt from the laboratory for water samples, to enable sample re-testing if necessary. To support robust temporal trend assessment, it is very important to also request the 'uncensored' data (i.e., raw unrounded data) and accompanying uncertainty of measurement values from the laboratory (NEMS 2017, Davies-Colley et al. 2012).

To improve the efficiency and effectiveness of data checks, the draft NEMS (2017) for Discrete Water Quality recommends that:

- automated checks are placed on sampling dates (e.g., to limit entry to a week day), times (e.g., to limit entry to between 0700 and 1900 hours), and known measurement ranges (e.g., pH), and
- the 'validity' of water quality measurements are assessed prior to archiving using:

- the historical site measurement range (e.g., 5^{th} and 95^{th} percentile values of the last five years of data or the last 60 data points), and
- relationships with other variables (e.g., turbidity is inversely proportional to visual clarity, *E. coli* and total phosphorus are typically positively correlated with turbidity and suspended sediment).

Recording visit metadata and field measurements electronically in the field can reduce potential for transcription errors. Further, pre-population on the field sheet of the historical measurement ranges for field variables can facilitate detection of potentially anomalous data at the time of collection, thereby providing a flag to revalidate or calibrate an instrument and/or take another measurement NEMS (2017).

6 Summary and recommendations

In the 10 to 15 years since ORC's river and lake SoE monitoring programmes were last reviewed in detail, significant new information demands have arisen. Use of data and information derived from river and lake monitoring extends beyond reporting on regional state and trends in river and lake health, to assisting with reporting on performance against the NPS-FM and the effectiveness of ORC's Water Plan, and contributing to national reporting requirements. This review has identified several areas where ORC's river and lake monitoring programmes could be improved to better meet the requirements of these broader monitoring objectives.

6.1 Rivers

The current monitoring programme has a strong focus on physico-chemical and microbial water quality and is dominated by sites located in pastoral catchments. We recommend that the ORC consider:

1. Increasing the number of sites under natural land cover (principally found in Receiving Water Group 3 of the Water Plan) and reviewing the number of pastoral sites to improve regional representativeness.
2. Identifying additional urban sites that could be included to improve the ability to meaningfully comment on and manage river/stream health in urban catchments and determine statistically significant differences in the health of these catchments versus those under predominantly natural and pastoral landcover.
3. Reinstating monthly visual water clarity measurements at all monitoring sites wherever possible.
4. Introducing monthly measurements of dissolved copper and zinc (plus associated supporting variables of total hardness and dissolved organic carbon) at urban sites.
5. Carrying out monthly estimates of periphyton and deposited sediment cover across at least a selection of water quality monitoring sites, with sites prioritised according to both current and potential future land use pressures.
6. Replacing the existing annual assessment of periphyton community diversity and relative abundance with a dedicated periphyton biomass programme (that also incorporates measures of periphyton cover, nutrients and flow) to meet NPS-FM requirements and improve understanding of river ecosystem health.
7. Extending existing monitoring of macroinvertebrates to as many water quality monitoring sites as possible to maximise the degree to which comprehensive information on stream ecosystem health is collected at each SoE site.
8. Formalising and standardising annual stream habitat assessments at all biomonitoring sites.
9. Supplementing the existing annual biomonitoring programme with continuous measurements of water temperature and dissolved oxygen for periods of at least 1-2 weeks during the warmest months of year, prioritising monitoring at sites with poor riparian shading.

10. Obtaining estimates of flow at the time of sampling ('flow stamping') at all water quality sites that lack regular flow monitoring.

11. Switching to optical-based sensors for *in situ* monitoring of dissolved oxygen.

12. Reviewing its existing monitoring programme documentation – including cross checking existing field and laboratory methods – against the draft NEMS (2017) for Discrete Water Quality and proposed under the NEMS for Periphyton (in prep).

13. Establishing a dedicated field QA programme based around a minimum of an annual field exercise with another monitoring agency.

14. Accessing or collecting robust information on land use change, volumes and types of discharges and water takes, and catchment mitigation work (e.g., stream fencing, riparian planting) to aid interpretation of SoE monitoring data.

6.2 Lakes

A range of lakes are being monitored by ORC in terms of depth, lake type, trophic state, and upstream catchment landcover. Monitoring has evolved in recent years, reflected in more comprehensive monitoring of the large alpine lakes of Hawea, Wanaka and Wakatipu. We recommend that the ORC retains its existing network of 9–10 lakes and additionally consider:

1. Continuing monthly water quality sampling at open water sites on Lakes Hawea, Wanaka and Wakatipu in recognition of the significant regional (and national) values associated with these lakes, with
   - water temperature and dissolved oxygen profiles extending from the lake surface to near the lake bottom,
   - sampling of the hypolimnion at a fixed depth near the lake bottom, and
   - changes to variables as outlined in Section 4.3.

2. Implementing at least bi-monthly water quality sampling on an ongoing basis for all other lakes where possible (the next best alternative being to reduce the return interval from 10 years to 5 years for open water sites monitored on a rotational basis), to facilitate more timely detection of changes in lake condition.

3. Establishing an open water monitoring site on Lake Onslow and Lake Tuakitoto with sampling of these sites monthly for at least two years to verify the monitoring results obtained from outlet monitoring to date.

4. Investing in a monitoring buoy for deployment at a deep site within each of Lakes Hawea, Wanaka and Wakatipu to improve understanding of drivers of lake ecosystem functioning, including the effects of vertical stratification and winter mixing on nutrient dynamics.

5. Implementing LakeSPI macrophyte monitoring across the lakes, with initial priority given to establishing a baseline of macrophyte condition in Lakes Wakatipu, Hayes, Dunstan and Wanaka.

6. Cross checking existing field and laboratory methods against those outlined in the draft NEMS for Discrete Water Quality, including recommendations for submission of periodic field blanks (for determination of nutrient content) when sampling Lakes Hawea, Wanaka and Wakatipu.

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Appendix A River representativeness

Table A-1: Summary of ORC's river monitoring sites. Sites are ordered alphabetically within Status and Receiving Water Group (RWG), with green cells representing the classes for which the site is over-represented. See Table 3-5 for FENZ class definitions. A superscript F in the site column represents a site where flow is measured continuously.

Site	Easting	Northing	RWG	REC class*	FENZ class	Status
Catlins at Houipapa[F]	1335133	4848930	Group 1	CW/L/P	G	Current
Crookston Burn at Kelso Road	1307953	4910331	Group 1	CD/L/P	A	Current
Heriot Burn at Park Hill Road	1306050	4913251	Group 1	CD/L/P	A	Current
Kaikorai Stream at Brighton Road	1400016	4913356	Group 1	CD/L/U	G	Current
Leith at Dundas Street Bridge	1407297	4918263	Group 1	CW/L/U	G	Current
Lindsays Creek at North Road Bridge	1407755	4919444	Group 1	CD/L/U	G	Current
Lovells Creek at Station Road	1355561	4881961	Group 1	CD/L/P	A	Current
Owaka at Katea Road	1342116	4852225	Group 1	CW/L/P	G	Current
Pomahaka at Burkes Ford	1321675	4893104	Group 1	CD/L/P	A	Current
Tokomairiro at Black Bridge	1363155	4886577	Group 1	CD/L/P	G	Current
Tokomairiro at Lisnatunny	1365047	4891081	Group 1	CD/L/P	G	Current
Tokomairiro at West Branch Bridge[F]	1356633	4892027	Group 1	CD/L/P	G	Current
Tuapeka	1330701	4898701	Group 1	CD/L/P	A	Current
Waikoikoi	1307309	4896680	Group 1	CD/L/P	A	Current
Waipahi at Cairns Peak	1310329	4887180	Group 1	CD/L/P	G	Current
Waipahi at Waipahi	1310329	4887179	Group 1	CD/L/P	G	Current
Wairuna at Millar Road	1315641	4887960	Group 1	CD/L/P	G	Current
Waitahuna at Tweeds Bridge[F]	1344378	4897887	Group 1	CD/L/P	G	Current
Waitati at Mt Cargill Rd	1411088	4930857	Group 1	CD/L/P	G	Current
Waiwera at Maws Farm[F]	1334560	4882179	Group 1	CD/L/P	G	Current
Awamoko	1428987	5025175	Group 2	CD/L/P	C	Current
Bannock Burn	1298829	5000070	Group 2	CD/H/N	D	Current
Benger Burn[F]	1317447	4939327	Group 2	CD/H/P	C	Current
Cardrona at Mt Barker[F]	1292623	5037477	Group 2	CD/H/N	D	Current
Contour Channel	1376619	4909005	Group 2	CD/L/P	G	Current
Deep Stream at SH87	1370378	4935501	Group 2	CD/H/P	G	Current
Dunstan Creek at Beattie Road	1344753	5018685	Group 2	CD/M/N	D	Current
Fraser at Marshall Road	1314057	4983106	Group 2	CD/M/P	D	Current
Hawea at Camphill Bridge	1302363	5049023	Group 2	CX/Lk/N	E	Current
Kakanui at Clifton Falls Bridge[F]	1422937	5011061	Group 2	CD/H/P	C	Current
Kakanui at McCones	1433513	4995181	Group 2	CD/H/P	C	Current
Kauru at Ewings	1421935	5002224	Group 2	CD/H/P	C	Current
Kye Burn at SH85 Bridge	1384708	4996734	Group 2	CD/H/P	C	Current

Site	Easting	Northing	RWG	REC class*	FENZ class	Status
Lindis at Ardgour Road[F]	1318851	5027589	Group 2	CD/H/N	D	Current
Lindis at Lindis Peak[F]	1323344	5040201	Group 2	CD/H/N	D	Current
Luggate Creek at SH6 Bridge	1304632	5038216	Group 2	CW/M/N	D	Current
Main Drain	1377725	4905506	Group 2	CD/L/P	G	Current
Manuherikia at Blackstone	1346557	5014304	Group 2	CD/H/N	D	Current
Manuherikia at Galloway	1319791	4985701	Group 2	CD/H/P	D	Current
Manuherikia at Ophir[F]	1331884	4999082	Group 2	CD/H/P	D	Current
Mill Creek at Fish Trap[F]	1269921	5012135	Group 2	CD/H/P	D	Current
Nenthorn at Mt Stoker	1385683	4948654	Group 2	CD/H/P	G	Current
Nevis at Wentworth	1287447	5002191	Group 2	CW/M/N	D	Current
Owhiro Stream Riverside Rd	1389614	4913326	Group 2	CD/L/P	A	Current
Pomahaka at Glenken[F]	1300424	4913602	Group 2	CD/H/P	G	Current
Shag at Craig Road[F]	1417203	4967125	Group 2	CD/H/P	G	Current
Shag at Goodwood Pump	1424509	4961854	Group 2	CD/L/P	G	Current
Silver Stream at Taieri Depot[F]	1392170	4916608	Group 2	CD/L/P	G	Current
Taieri at Allanton Bridge	1387686	4912203	Group 2	CD/H/P	A	Current
Taieri at Linnburn	1351010	4958393	Group 2	CD/H/N	H	Current
Taieri at Outram[F]	1386004	4919321	Group 2	CD/H/P	G	Current
Taieri at Stonehenge	1361323	4976303	Group 2	CD/H/N	D	Current
Taieri at Sutton[F]	1376860	4949914	Group 2	CD/H/P	G	Current
Taieri at Tiroiti[F]	1386020	4984932	Group 2	CD/H/P	C	Current
Taieri at Waipiata[F]	1376401	4991252	Group 2	CD/H/P	D	Current
Thomsons Creek	1331613	4999632	Group 2	CD/H/P	D	Current
Three O'Clock Stream Hindon	1392632	4935302	Group 2	CD/H/P	G	Current
Trotters Creek at Mathesons	1430828	4971210	Group 2	CD/L/P	A	Current
Waianakarua at Browns[F]	1430572	4986738	Group 2	CD/H/P	C	Current
Waiareka Creek at Taipo Road	1433511	4997780	Group 2	CD/L/P	A	Current
Waikouaiti at Confluence[F]	1412608	4945797	Group 2	CD/H/P	G	Current
Waipori at Waipori Falls Reserve	1372538	4909488	Group 2	CD/Lk/N	G	Current
Welcome Creek	1447988	5023090	Group 2	CD/L/P	A	Current
Dart at The Hillocks[F]	1230045	5031514	Group 3	CX/GM/N	C	Current
Matukituki at West Wanaka[F]	1282006	5049681	Group 3	CX/GM/N	E	Current
Careys Creek at SH1	1410783	4934647	Group 1	CD/L/P	G	Historic
Frasers Stream at Station Road	1356061	4881662	Group 1	CD/L/P	A	Historic
Heriot Burn at SH90	1315767	4919090	Group 1	CD/H/P	A	Historic
Kaihiku Stream at Clifton Road	1339409	4879750	Group 1	CD/L/P	G	Historic
Kaihiku Stream at Hillfoot Road Bridge	1336105	4870710	Group 1	CD/L/P	G	Historic
Kaikorai Stream at Townleys Road	1402826	4914689	Group 1	CD/L/U	G	Historic

Site	Easting	Northing	RWG	REC class*	FENZ class	Status
Owaka at Purekireka	1328982	4860600	Group 1	CW/L/P	G	Historic
Tahakopa at Tahakopa	1323018	4842378	Group 1	CW/L/N	G	Historic
Tuapeka at Tuapeka Mouth	1330050	4898602	Group 1	CD/L/P	A	Historic
Waiwera at SH1 Bridge	1330075	4877707	Group 1	CD/L/P	G	Historic
Washpool Stream at Kilhastie Road	1327799	4887432	Group 1	CD/L/P	A	Historic
Arrow at Morven Ferry Road	1273547	5009605	Group 2	CW/M/N	D	Historic
Contour Channel at Henley-Berwick Road	1377088	4907083	Group 2	CD/Lk/P	G	Historic
Contour Channel at No. 4 Bridge	1376658	4909224	Group 2	CD/L/P	G	Historic
Fuchsia Creek at Balruddery	1422981	5009925	Group 2	CD/L/P	C	Historic
Gimmerburn at Wilson Road	1366419	4990313	Group 2	CD/H/P	D	Historic
Ida Burn at Auripo Rd	1344975	5004838	Group 2	CD/H/P	D	Historic
Ida Burn at SH85	1361425	5013607	Group 2	CD/H/P	D	Historic
Kakanui R at Pringles	1432812	4996479	Group 2	CD/H/P	C	Historic
Lee Stream at SH87	1376575	4923967	Group 2	CD/H/P	G	Historic
Minzionburn at Millers Flat Rd u/s 500m	1323329	4933942	Group 2	CD/H/P	C	Historic
Owhiro Stream at Burns Street	1394391	4915143	Group 2	CD/L/U	A	Historic
Pig Burn at ONeill Road d/s	1372794	4990775	Group 2	CD/L/P	D	Historic
Pool Burn at Auripo Road	1343935	5004126	Group 2	CD/H/P	D	Historic
Shag at The Grange	1413235	4974060	Group 2	CD/H/P	G	Historic
Sheepwash Creek at Mt Stoker Road	1377904	4954076	Group 2	CD/H/P	A	Historic
Silverstream at Three Mile Hill Road	1398204	4919839	Group 2	CD/L/N	G	Historic
Sow Burn at Taieri Confluence 300 u/s	1368308	4991315	Group 2	CD/H/P	D	Historic
Taieri at Halls Bridge	1366710	4989613	Group 2	CD/H/P	D	Historic
Taieri at Henley Ferry	1379229	4902907	Group 2	CD/H/P	G	Historic
Taieri R at Middlemarch	1376292	4955504	Group 2	CD/L/P	A	Historic
Teviot at Roxburgh East	1312728	4950718	Group 2	CD/H/P	C	Historic
Tima Burn at Roxburgh Hydro Rd	1319302	4938503	Group 2	CD/H/P	C	Historic
Clutha at Balclutha	1349273	4874447	Group 1	CW/Lk/P	E	NIWA
Clutha at Millers Flat	1320353	4936930	Group 1	CW/Lk/N	E	NIWA
Kawarau at Chards	1274430	5008035	Group 2	CW/Lk/N	E	NIWA
Shotover at Bowens Peak[F]	1262216	5009225	Group 2	CW/M/N	E	NIWA
Sutton at SH87	1373363	4946708	Group 2	CD/H/P	G	NIWA
Clutha at Luggate Br.	1305472	5040410	Group 3	CX/Lk/N	E	NIWA

Appendix B Power analyses to compare pastoral and urban sites to natural sites within Receiving Waters Groups

The following figures and tables represent outputs for power analyses described in Section 3.3.3. Each water quality variable is represented by two figures and a table, summarising

1. the power of the current network to differentiate between natural means and the RWG reference state at α = 0.1, 0.05 and 0.01; and

2. the number of sites required in each RWG, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1.

Ammoniacal nitrogen

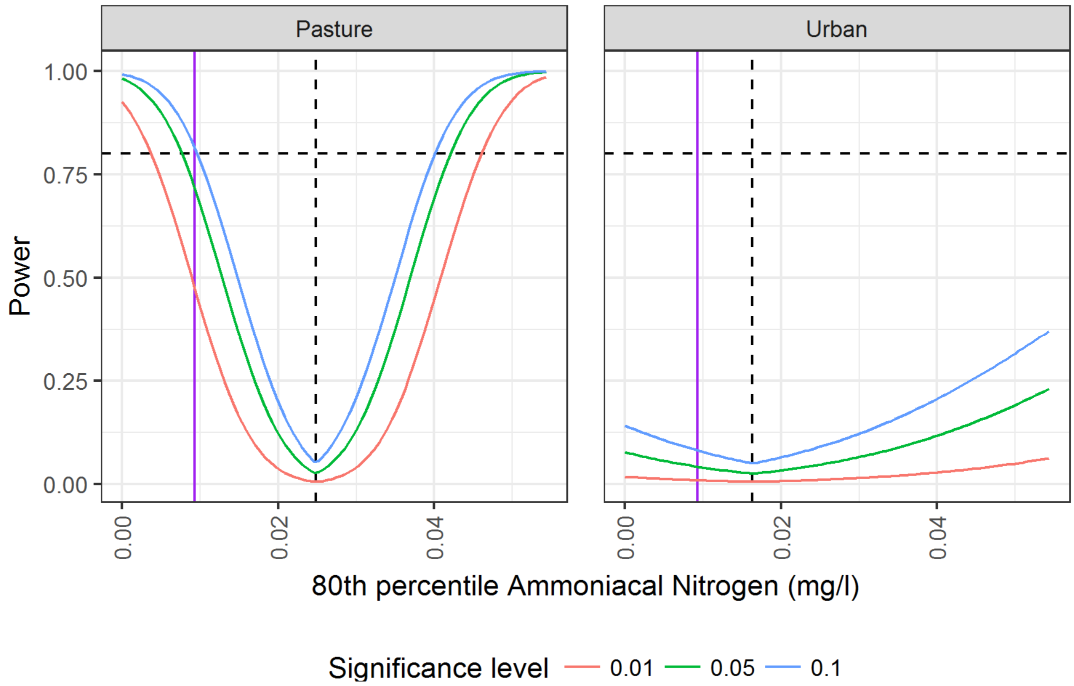


Figure B-1: Power of the current monitoring network to determine whether pastoral and urban sites are different from natural sites in terms of 80th percentile ammoniacal nitrogen (mg/L). Each panel shows the power of the current network (1-β) to detect differences between group means and the natural state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Landcover means are indicated by the vertical dashed line, while the vertical purple line represents the mean level at natural sites.

Table B-1: Required site numbers for detecting differences in 80th percentile ammoniacal nitrogen (mg/L) for pastoral and urban sites relative to natural sites. Results are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all monitoring sites within the Otago region (see Section 3.2.1.).

Natural State	Landcover	Mean	SD	Required sites	Current sites	Current power
0.009	Pasture	0.025	0.029	45	47	0.82
	Urban	0.016	0.029	217	3	0.08

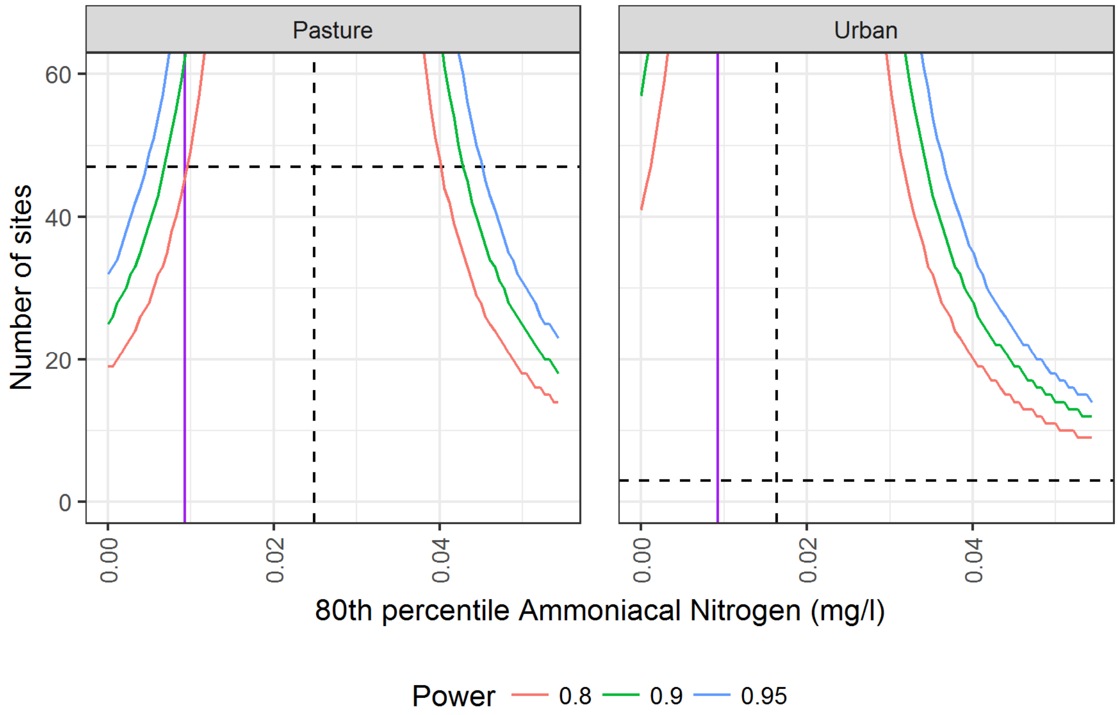


Figure B-2: Site requirements for evaluating 80th percentile ammoniacal nitrogen (mg/L) at pastoral and urban sites relative to natural sites. Each panel shows the number of sites required in each landcover class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate class means and current site numbers, respectively; vertical purple lines indicate the mean at natural sites.

Dissolved Reactive Phosphorus

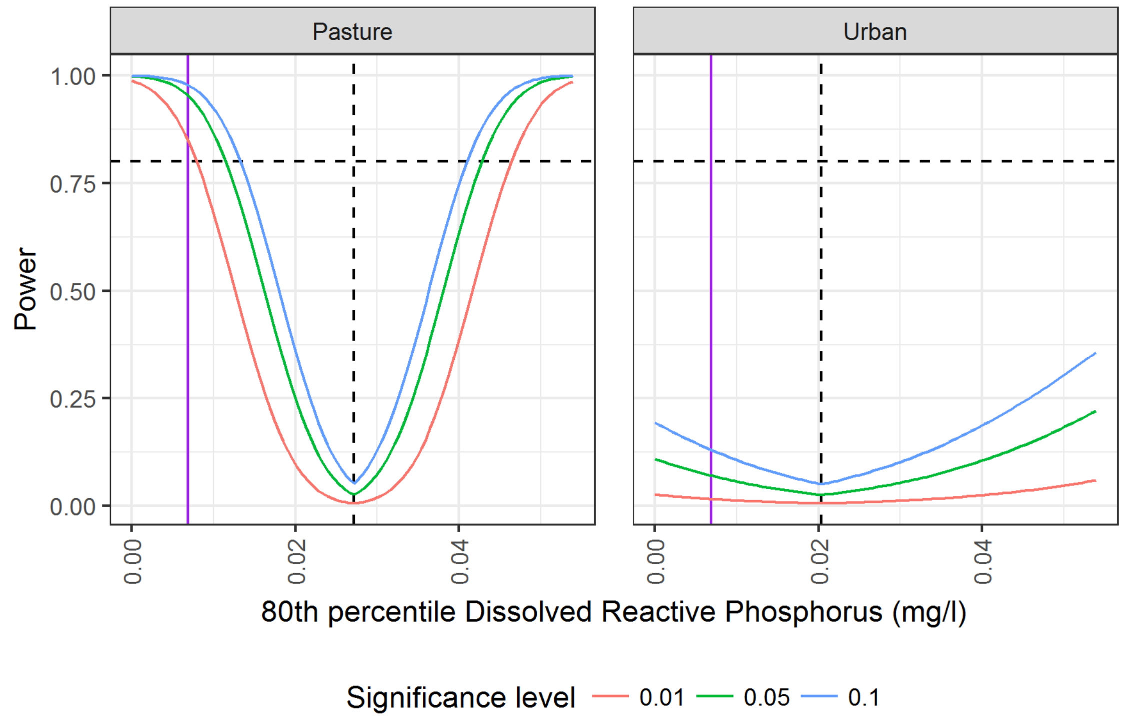


Figure B-3: Power of the current monitoring network to determine whether pastoral and urban sites are different from natural sites in terms of 80th percentile dissolved reactive phosphorus (mg/L). Each panel shows the power of the current network (1-β) to detect differences between group means and the natural state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Landcover means are indicated by the vertical dashed line, while the vertical purple line represents the mean at natural sites.

Table B-2: Required site numbers for detecting differences in 80th percentile dissolved reactive phosphorus (mg/L) for pastoral and urban sites relative to natural sites. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all monitoring sites within the Otago region (see Section 3.2.1.).

Natural State	Landcover	Mean	SD	Required sites	Current sites	Current power
0.009	Pasture	0.027	0.027	23	47	0.98
	Urban	0.020	0.027	50	3	0.13

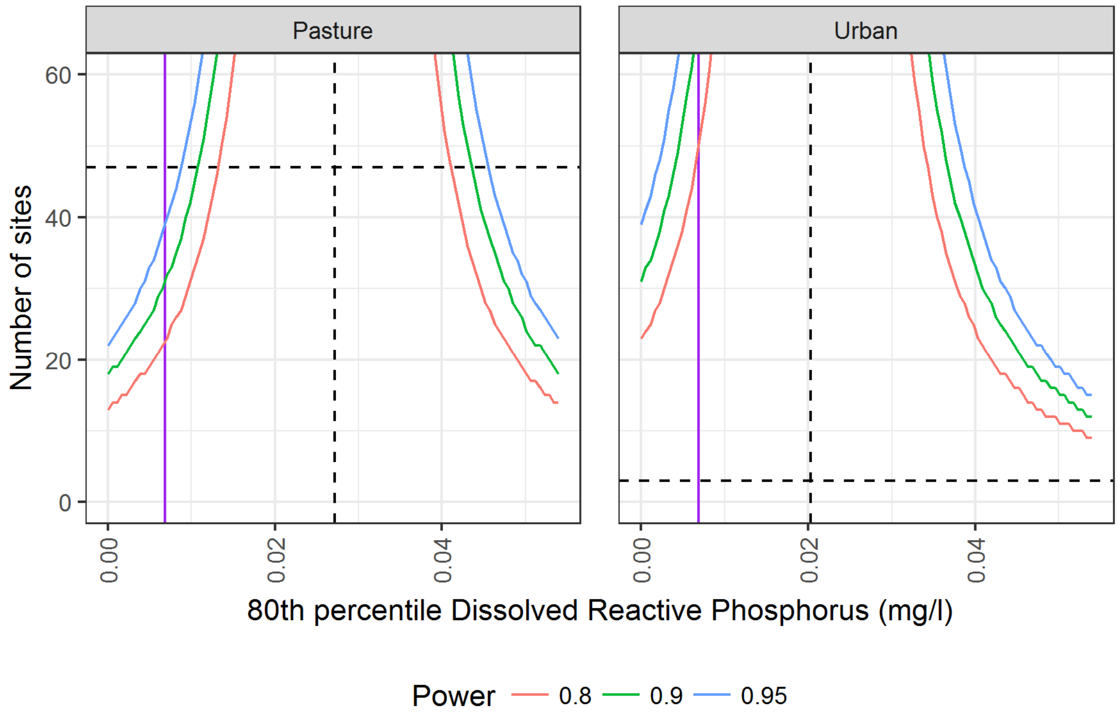


Figure B-4: Site requirements for evaluating 80th percentile dissolved reactive phosphorus (mg/L) at pastoral and urban sites relative to natural sites. Each panel shows the number of sites required in each landcover class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate class means and current site numbers, respectively; vertical purple lines indicate the mean at natural sites.

E. coli

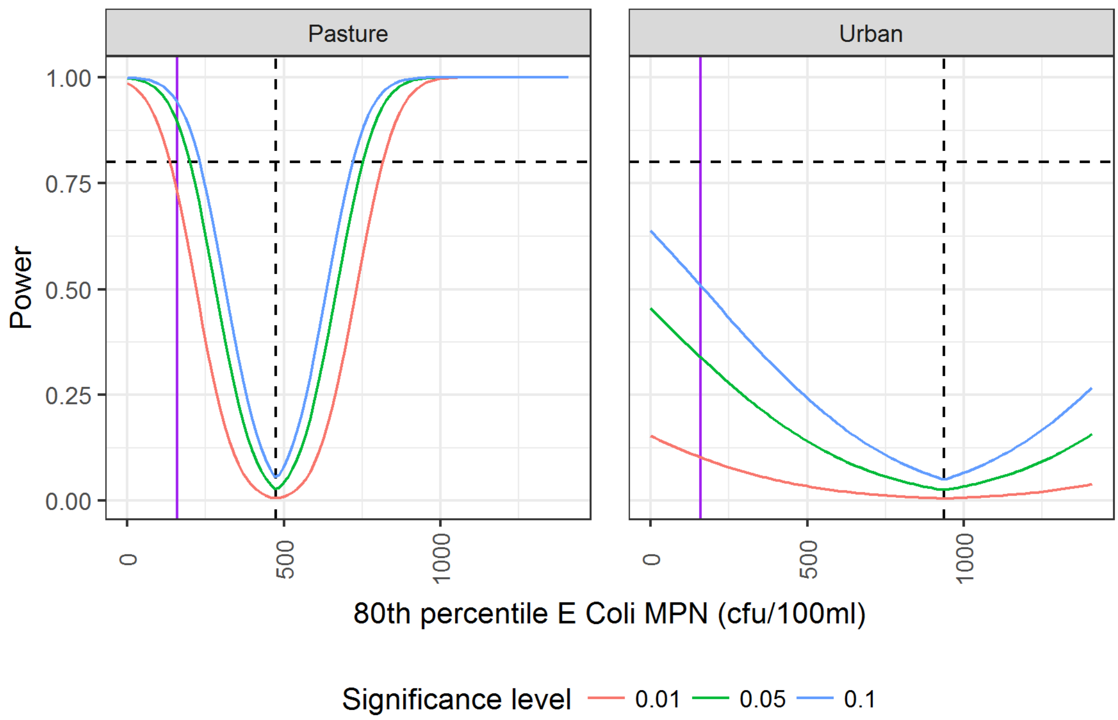


Figure B-5: Power of the current monitoring network to determine whether pastoral and urban sites are different from natural sites in terms of 80th percentile *E. coli* (per 100 mL). Each panel shows the power of the current network (1-β) to detect differences between group means and the natural state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Landcover means are indicated by the vertical dashed line, while the vertical purple line represents the mean at natural sites.

Table B-3: Required site numbers for detecting differences in 80th percentile *E. coli* (per 100 mL) for pastoral and urban sites relative to natural sites. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all monitoring sites within the Otago region (see Section 3.2.1.).

Natural State	Landcover	Mean	SD	Required sites	Current sites	Current power
158.5	Pasture	475.2	473.2	29	47	0.94
	Urban	936.7	473.2	6	3	0.51

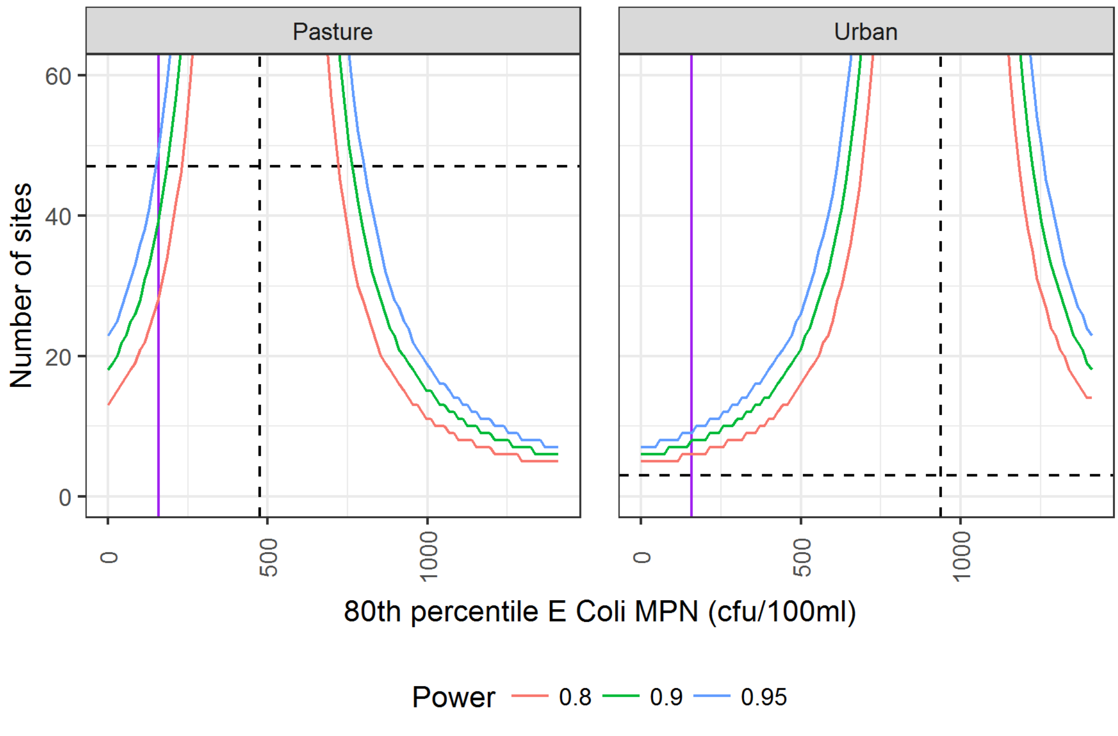


Figure B-6: Site requirements for evaluating 80th percentile *E. coli* (per 100 mL) at pastoral and urban sites relative to natural sites. Each panel shows the number of sites required in each landcover class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate class means and current site numbers, respectively; vertical purple lines indicate the mean at natural sites.

Nitrite Nitrate Nitrogen

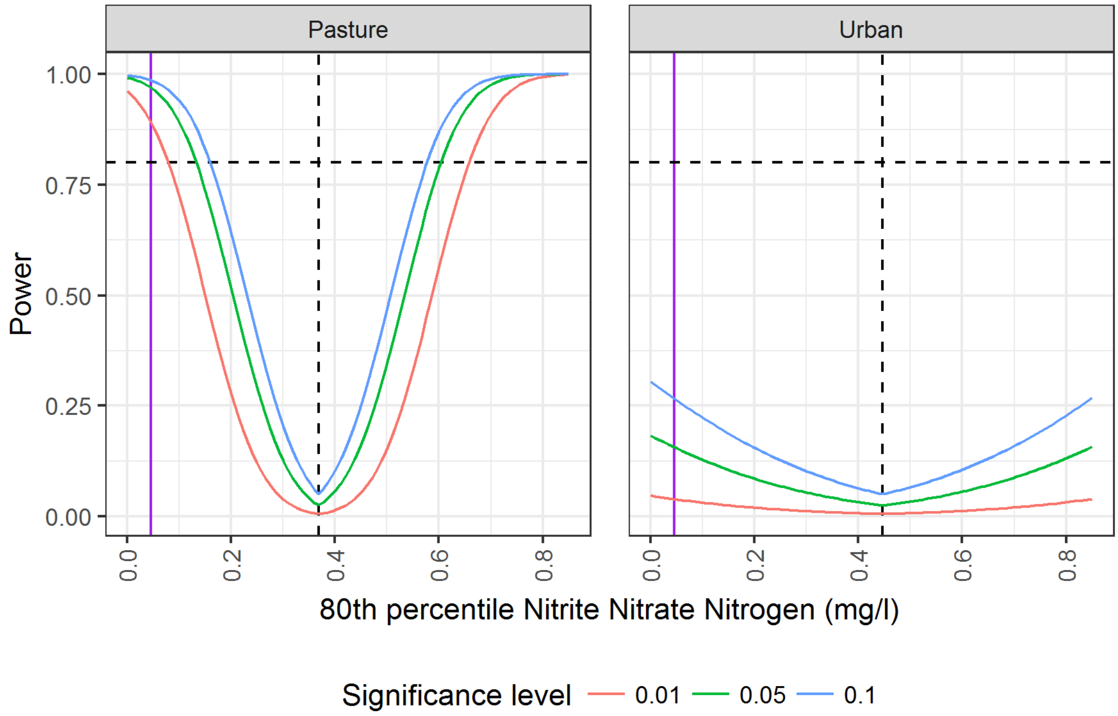


Figure B-7: Power of the current monitoring network to determine whether pastoral and urban sites are different from natural sites in terms of 80th percentile nitrite nitrate nitrogen (mg/L). Each panel shows the power of the current network (1-β) to detect differences between group means and the natural state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Landcover means are indicated by the vertical dashed line, while the vertical purple line represents the mean at natural sites.

Table B-4: Required site numbers for detecting differences 80th percentile nitrite nitrate nitrogen (mg/L) for pastoral and urban sites relative to natural sites. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all monitoring sites within the Otago region (see Section 3.2.1.).

Natural State	Landcover	Mean	SD	Required sites	Current sites	Current power
0.046	Pasture	0.368	0.403	21	47	0.99
	Urban	0.447	0.403	14	3	0.26

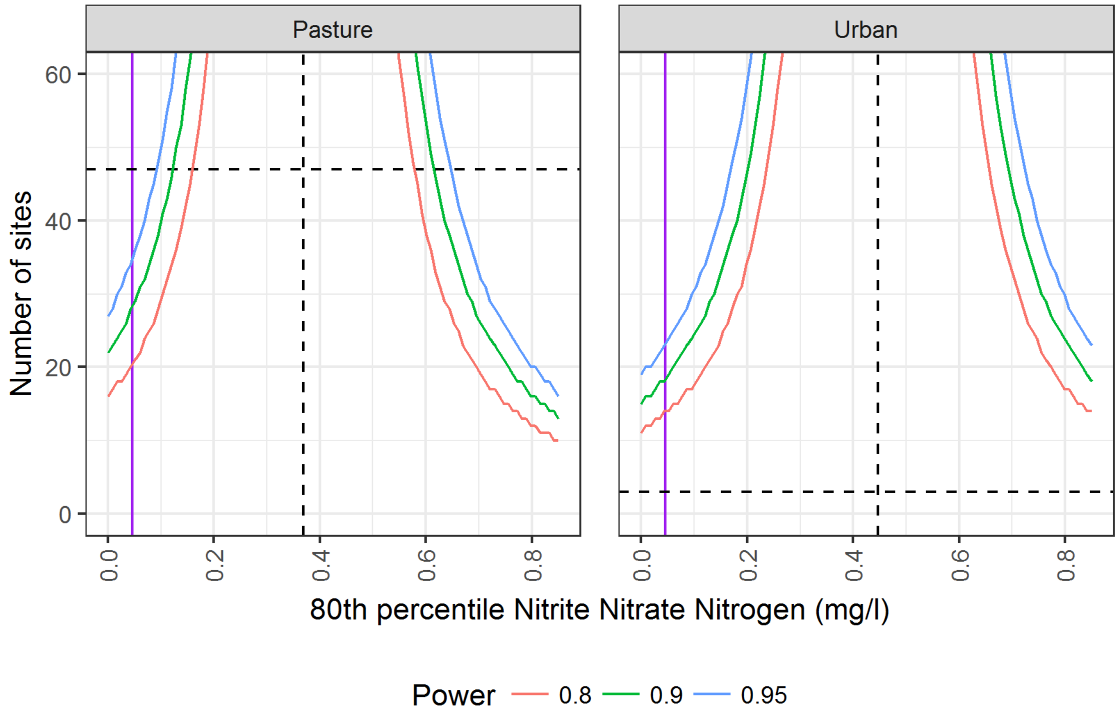


Figure B-8: Site requirements for evaluating 80th percentile nitrite nitrate nitrogen (mg/L) at pastoral and urban sites relative to natural sites. Each panel shows the number of sites required in each landcover class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate class means and current site numbers, respectively; vertical purple lines indicate the mean at natural sites.

Turbidity

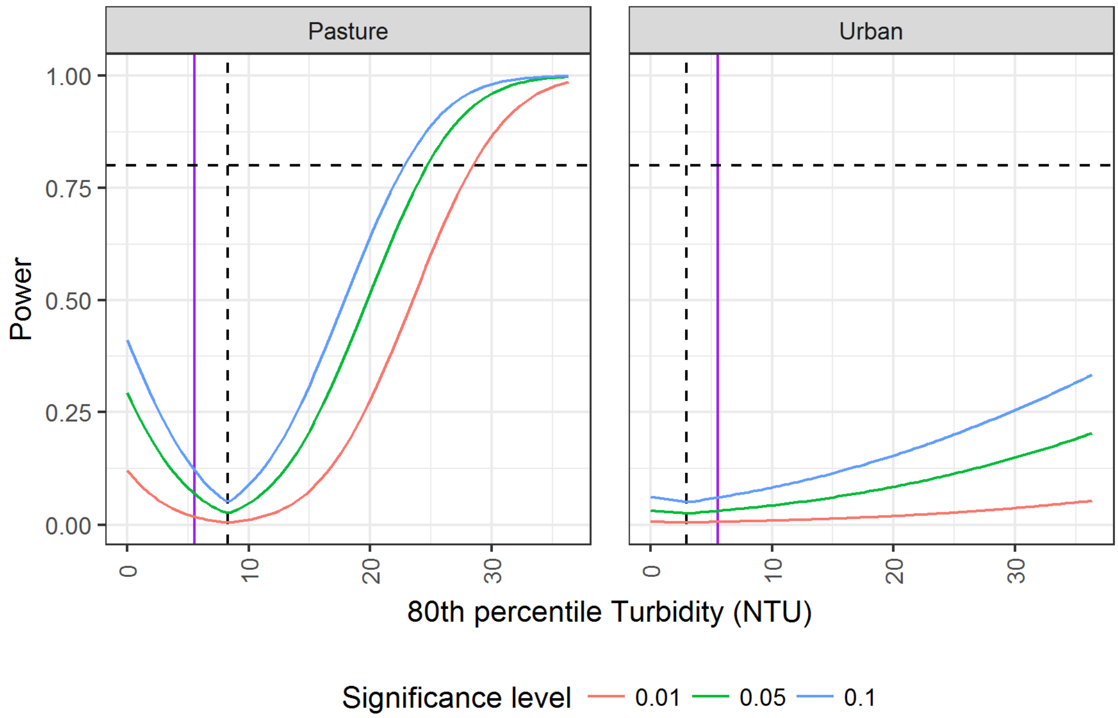


Figure B-9: Power of the current monitoring network to determine whether pastoral and urban sites are different from natural sites in terms of 80th percentile turbidity (NTU). Each panel shows the power of the current network (1-β) to detect differences between group means and the natural state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Landcover means are indicated by the vertical dashed line, while the vertical purple line represents the mean at natural sites.

Table B-5: Required site numbers for detecting differences in 80th percentile turbidity (NTU) at pastoral and urban sites relative to natural sites. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (NTU) are calculated across all monitoring sites within the Otago region (see Section 3.2.1.).

Natural State	Landcover	Mean	SD	Required sites	Current sites	Current power
5.518	Pasture	8.292	28.061	1266	47	0.12
	Urban	2.967	28.061	1497	3	0.06

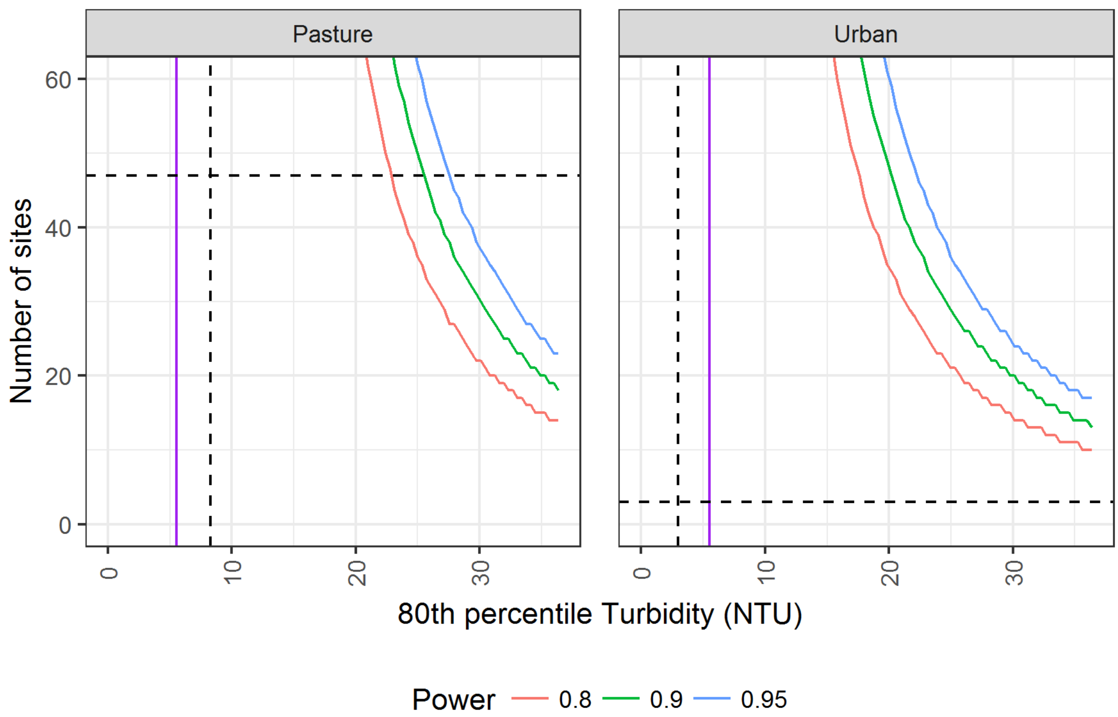


Figure B-10: Site requirements for evaluating 80th percentile turbidity (NTU) at pastoral and urban sites relative to natural sites. Each panel shows the number of sites required in each landcover class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate class means and current site numbers, respectively; vertical purple lines indicate the mean at natural sites.

Appendix C Power analyses to compare water quality metrics to Water Plan limits within Receiving Waters Groups

The following figures and tables represent outputs for power analyses that are described in Section 3.3.3. Each water quality variable is represented by two figures and a table, summarising

3. the power of the current network to differentiate between RWG means and the RWG reference state at α = 0.1, 0.05 and 0.01; and

4. the number of sites required in each RWG, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1.

Ammoniacal nitrogen

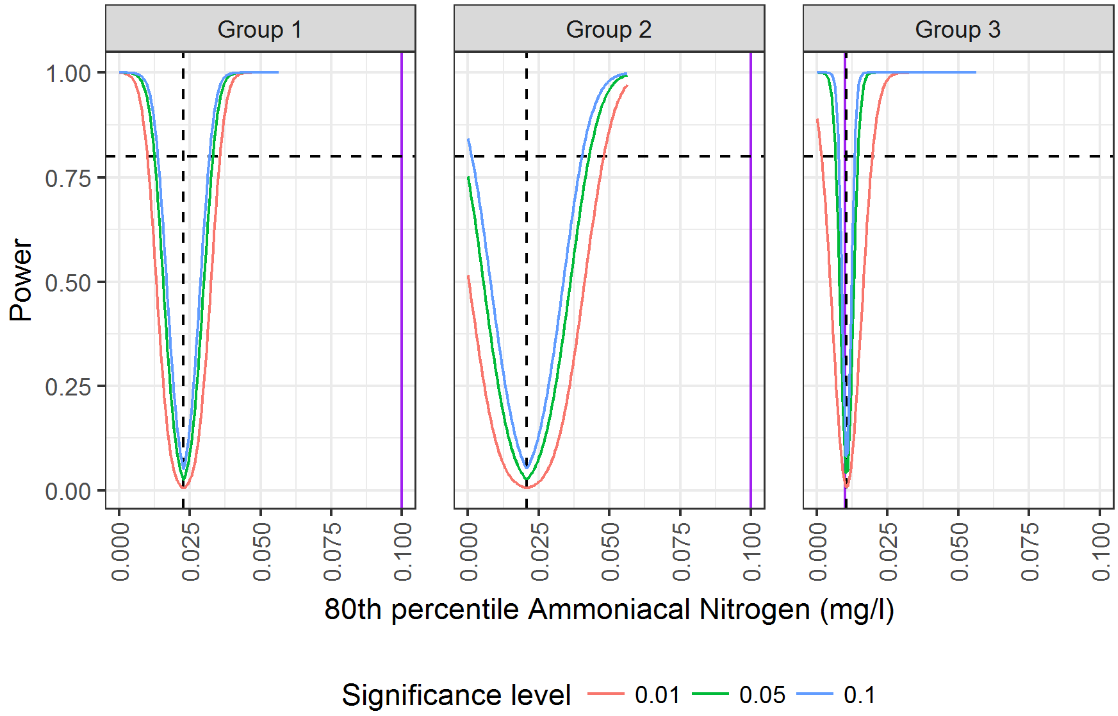


Figure C-1: The statistical power available to evaluate 80th percentile ammoniacal nitrogen (mg/L) relative to the Water Plan limits in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the reference state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple line represents the ORC Regional Water Plan limits for each group.

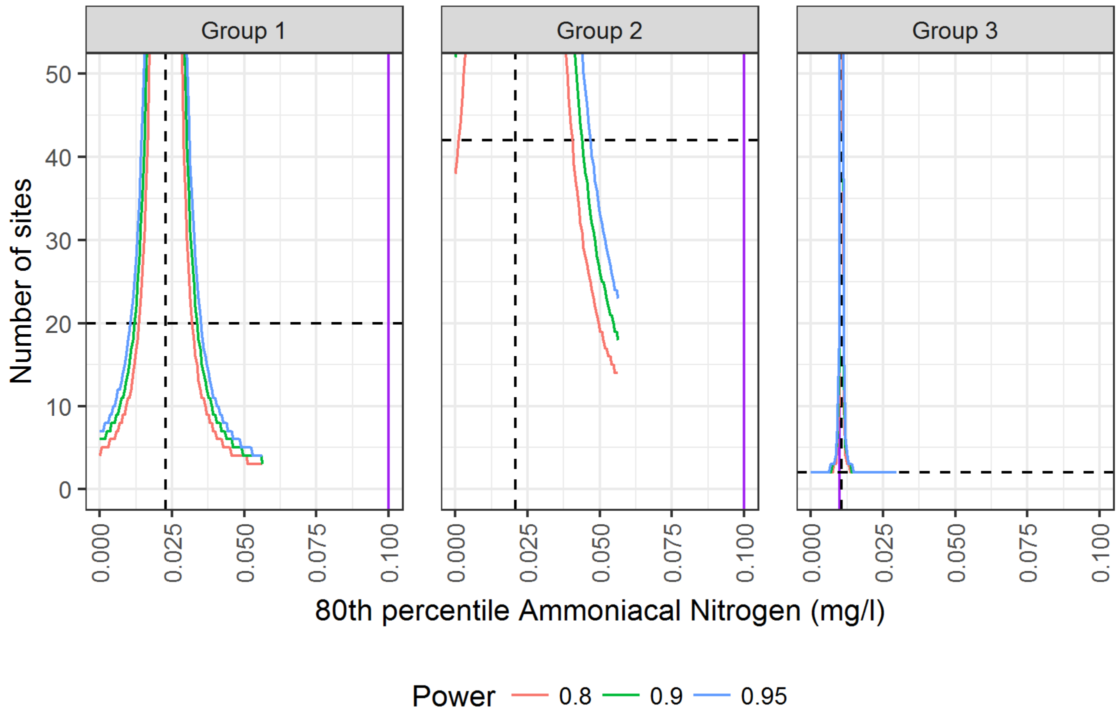


Figure C-2: The number of sites needed to statistically evaluate 80th percentile ammoniacal nitrogen (mg/L) relative to the Water Plan limits in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate Water Plan limits for each group.

Table C-1: Site numbers required to detect differences in 80th percentile ammoniacal nitrogen (mg/L) relative to the limits specified in the Water Plan. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all current monitoring sites (see Section 0.).

RWG	Water Plan limit	Mean	SD	Required sites	Current sites	Current power
Group 1	0.10	0.023	0.011	2	20	1.00
Group 2	0.10	0.021	0.036	4	42	1.00
Group 3	0.01	0.010	0.001	26	2	0.13

Dissolved Reactive Phosphorus

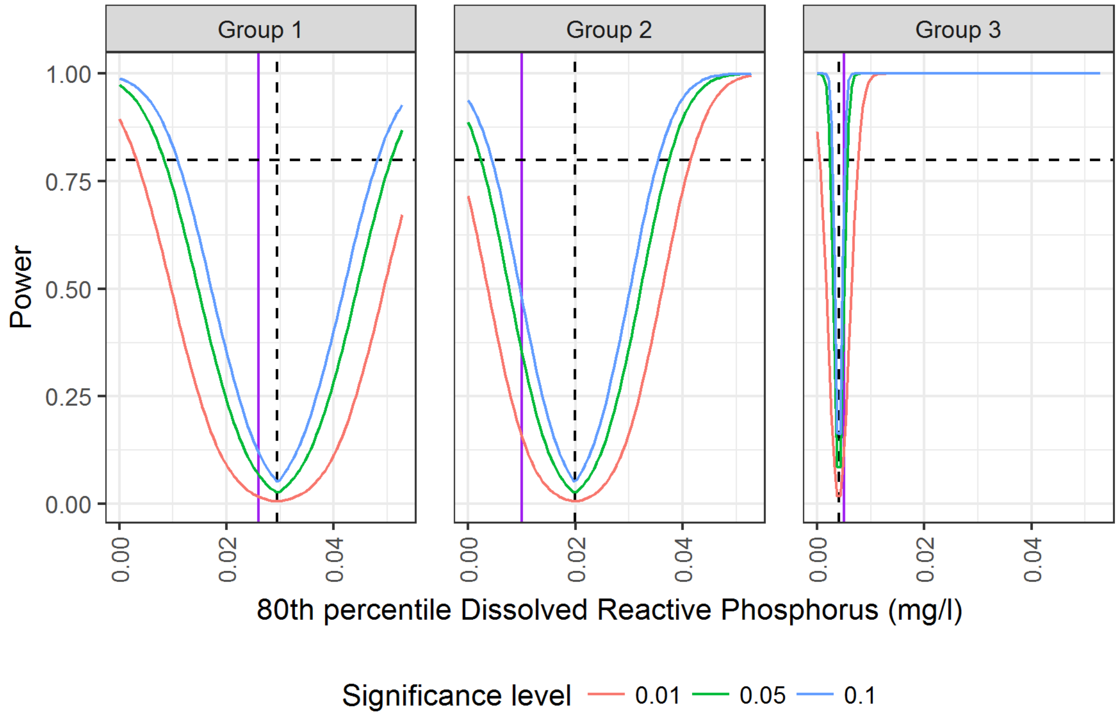


Figure C-3: The statistical power available to evaluate 80th percentile dissolved reactive phosphorus (mg/L) relative to the Water Plan limits in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the reference state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple line represents the ORC Regional Water Plan limits for each group.

Table C-2: Site numbers required to detect differences in 80th percentile dissolved reactive phosphorus (mg/L) relative to the limits specified in the Water Plan. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all current monitoring sites (see Section 0.).

RWG	Water Plan limit	Mean	SD	Required sites	Current sites	Current power
Group 1	0.026	0.029	0.023	555	20	0.12
Group 2	0.010	0.020	0.028	103	42	0.48
Group 3	0.005	0.004	0.000	3	2	0.73

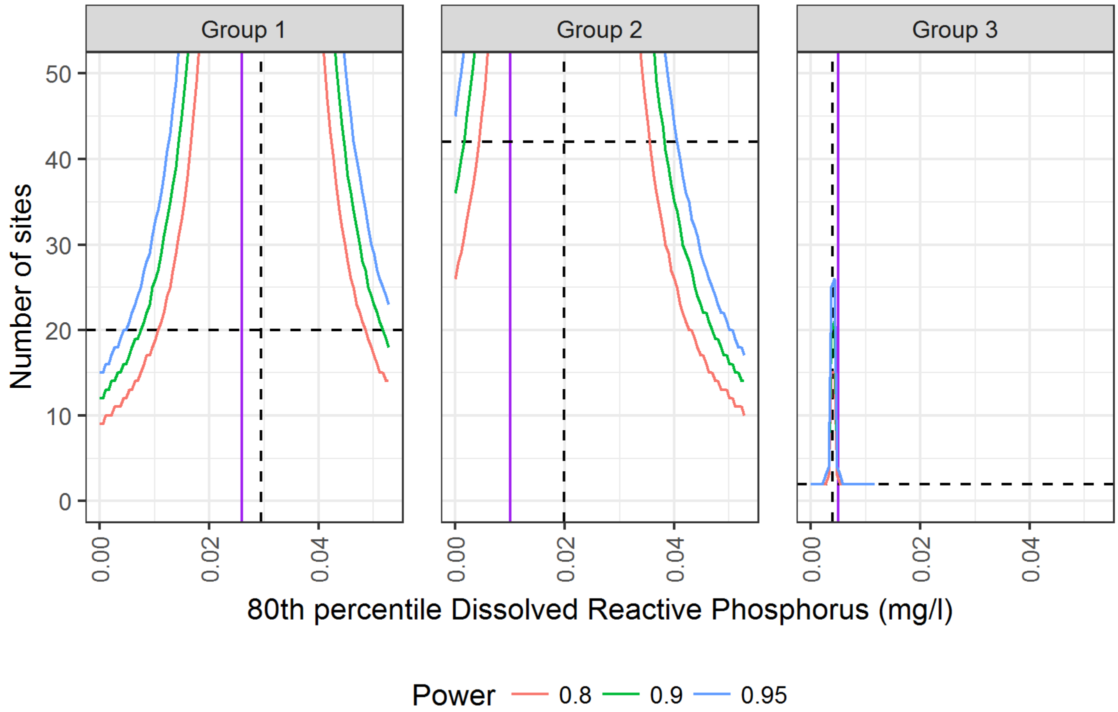


Figure C-4: The number of sites needed to statistically evaluate 80th percentile dissolved reactive phosphorus (mg/L) relative to the Water Plan limits in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate Water Plan limits for each group.

E. coli

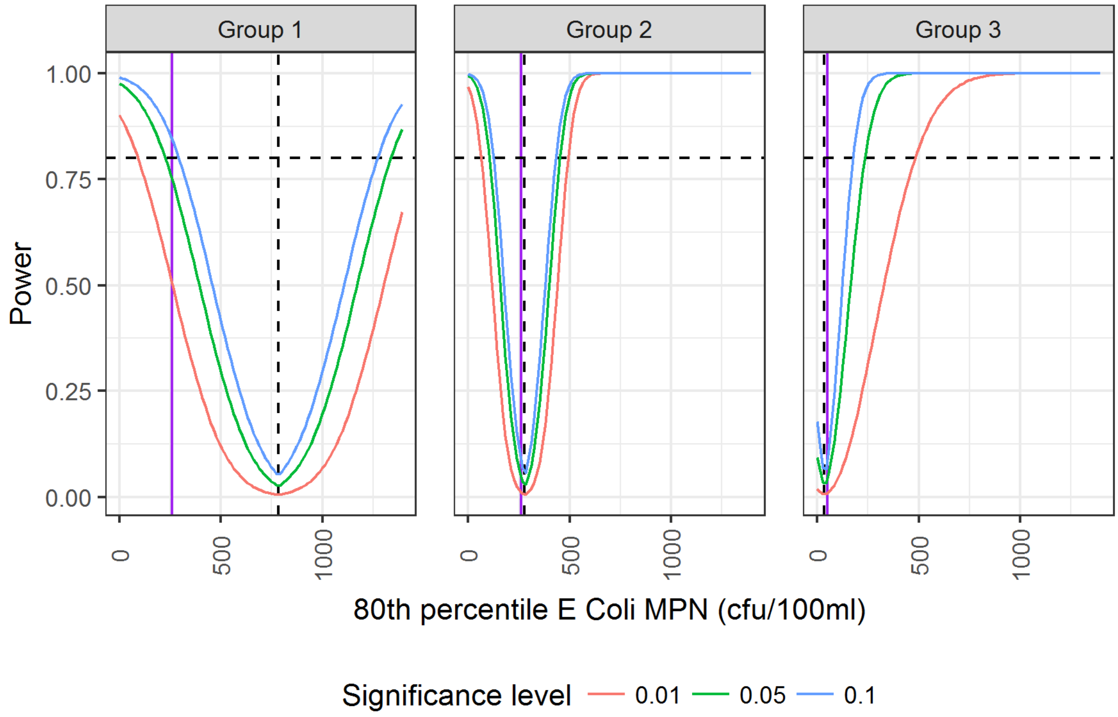


Figure C-5: The statistical power available to evaluate 80th percentile *E. coli* (per 100 mL) relative to the Water Plan limits in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the reference state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple line represents the ORC Regional Water Plan limits for each group.

Table C-3: Site numbers required to detect differences in 80th percentile *E. coli* (per 100 mL) relative to the limits specified in the Water Plan. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all current monitoring sites (see Section 0.).

RWG	Water Plan limit	Mean	SD	Required sites	Current sites	Current power
Group 1	260	782	611	18	20	0.84
Group 2	260	277	281	3224	42	0.09
Group 3	50	36	35	78	2	0.09

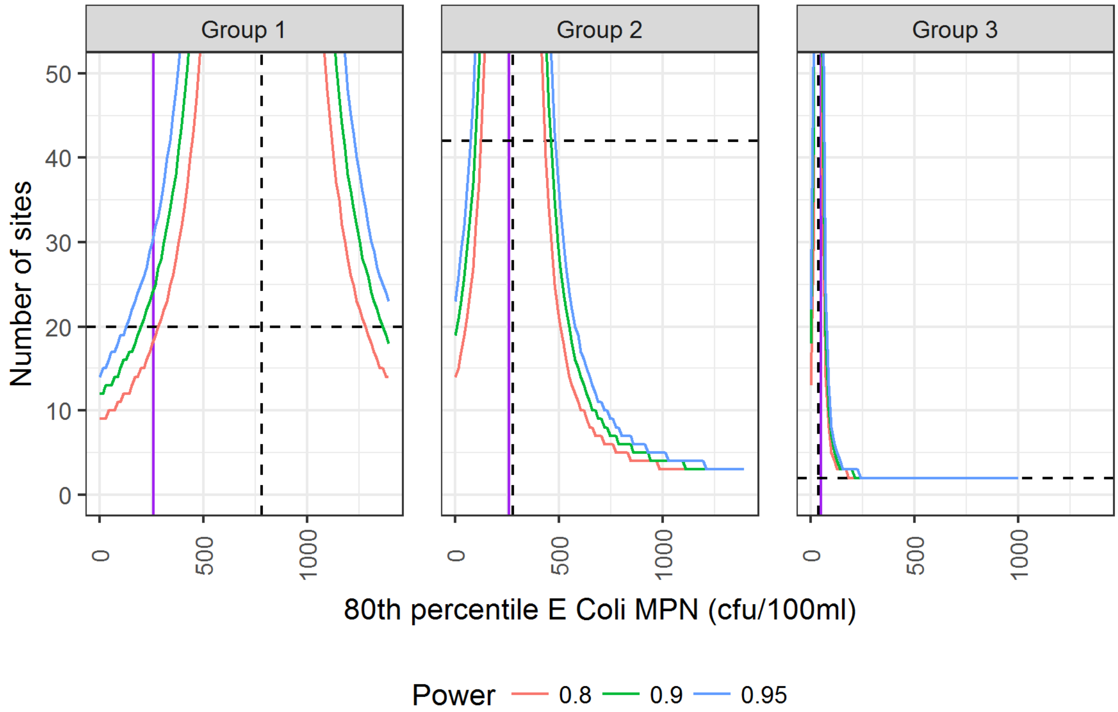


Figure C-6: The number of sites needed to statistically evaluate 80th percentile *E. coli* (per 100 mL) relative to the Water Plan limits in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate Water Plan limits for each group.

Nitrite Nitrate Nitrogen

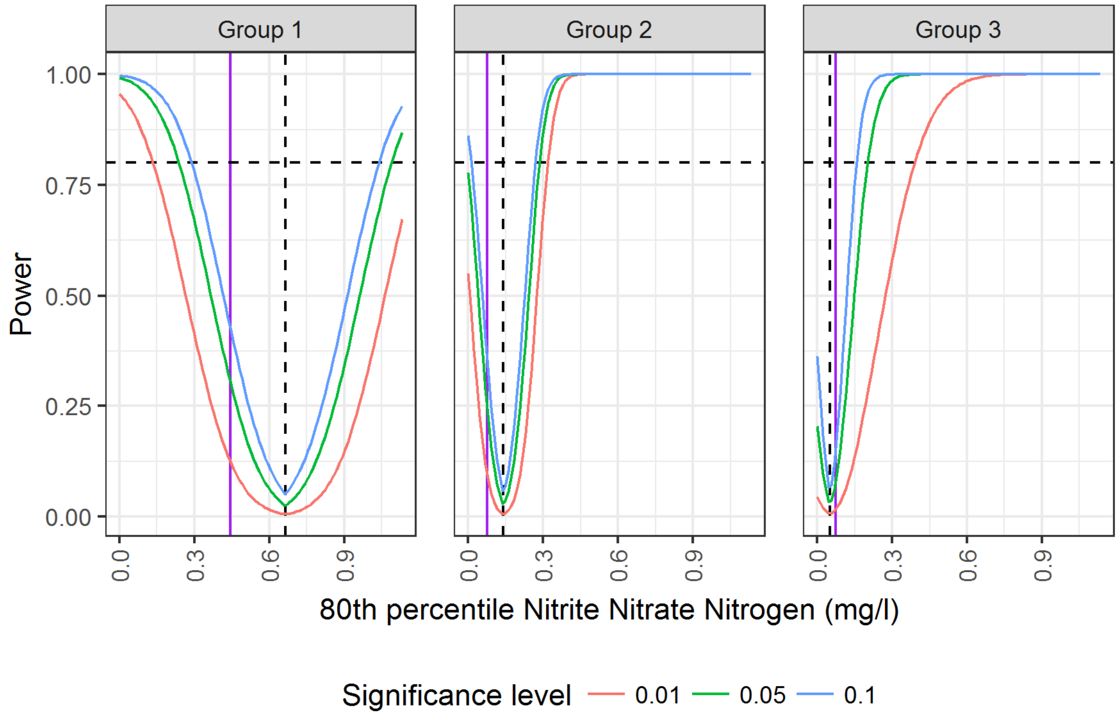


Figure C-7: The statistical power available to evaluate 80th percentile nitrite nitrate nitrogen (mg/L) relative to the Water Plan limits in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the reference state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple line represents the ORC Regional Water Plan limits for each group.

Table C-4: Site numbers required to detect differences in 80th percentile nitrite nitrate nitrogen (mg/L) relative to the limits specified in the Water Plan. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all current monitoring sites (see Section 0.).

RWG	Water Plan limit	Mean	SD	Required sites	Current sites	Current power
Group 1	0.444	0.664	0.468	57	20	0.43
Group 2	0.075	0.141	0.234	158	42	0.36
Group 3	0.075	0.051	0.027	16	2	0.16

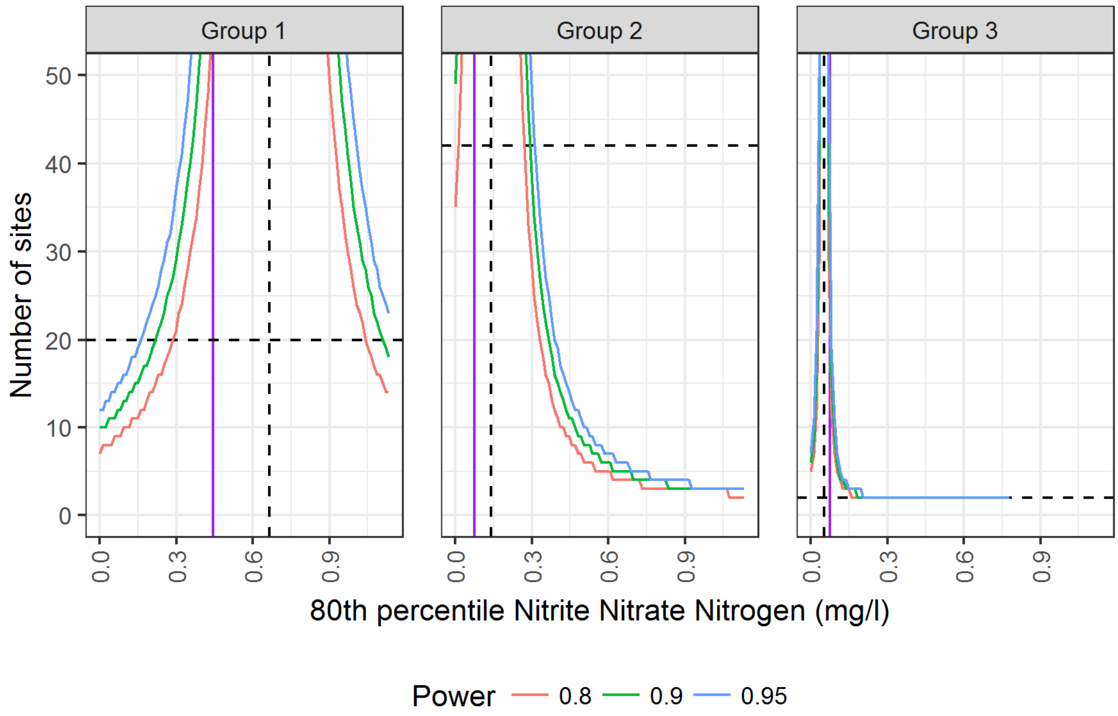


Figure C-8: The number of sites needed to statistically evaluate 80th percentile nitrite nitrate nitrogen (mg/L) relative to the Water Plan limits in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate Water Plan limits for each group.

Turbidity

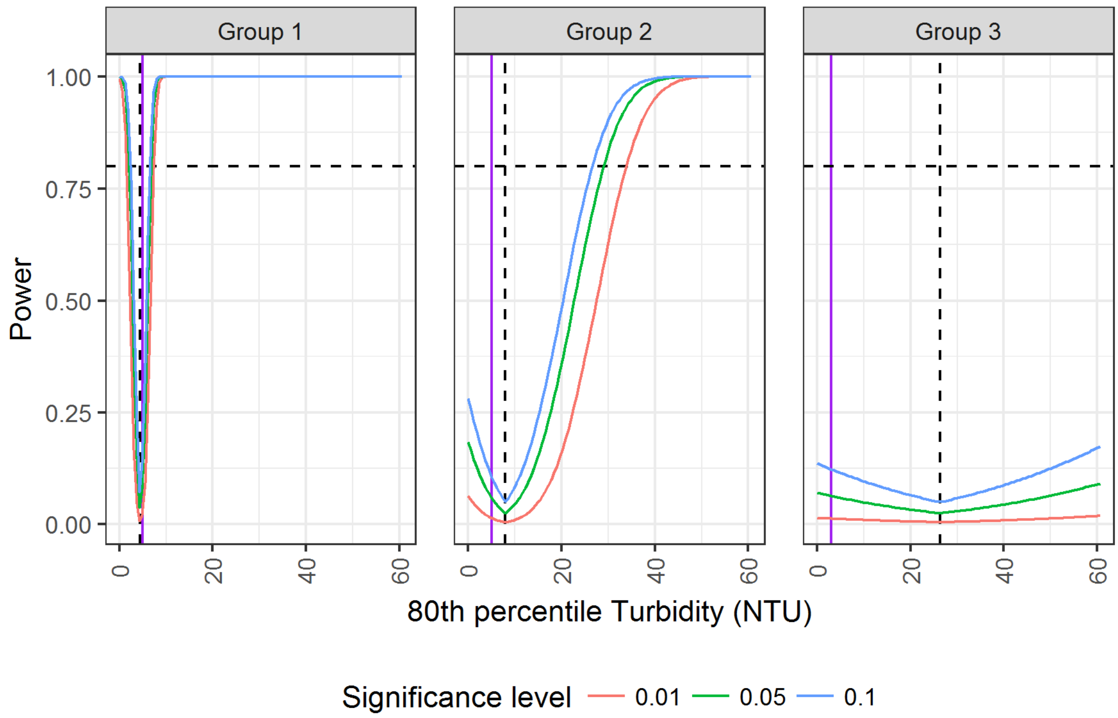


Figure C-9: The statistical power available to evaluate 80th percentile turbidity (NTU) relative to the Water Plan limits in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the reference state for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple line represents the ORC Regional Water Plan limits for each group.

Table C-5: Site numbers required to detect differences in 80th percentile turbidity (NTU) relative to the limits specified in the Water Plan. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all current monitoring sites (see Section 0.).

RWG	Water Plan limit	Mean	SD	Required sites	Current sites	Current power
Group 1	5	4.440	2.592	266	20	0.17
Group 2	5	7.963	34.001	1630	42	0.11
Group 3	3	26.310	34.323	28	2	0.12

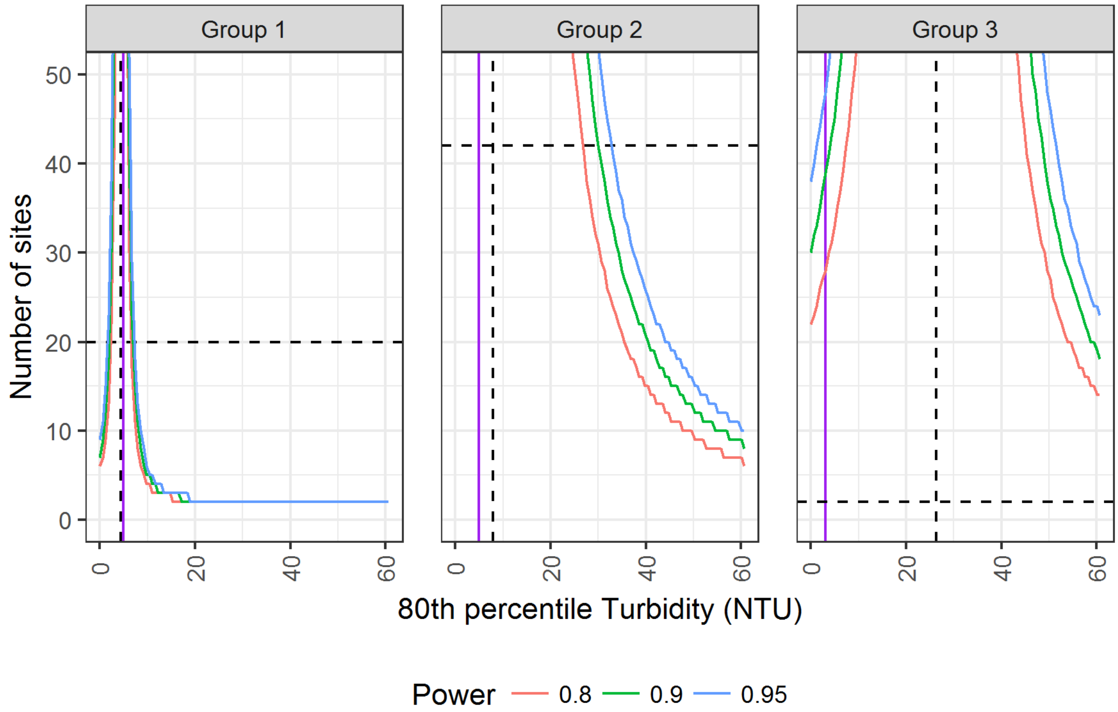


Figure C-10: The number of sites needed to statistically evaluate 80th percentile turbidity (NTU) relative to the Water Plan limits in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate Water Plan limits for each group.

Appendix D Power analyses to compare water quality variables within RWGs to NOF attribute band thresholds

The following figures and tables represent outputs for power analyses that are described in Section 3.3.3. Each water quality variable is represented by two figures and a table, summarising:

- The power of the current network to differentiate between RWG means and band thresholds for NOF attributes at α = 0.1, 0.05 and 0.01; and
- The number of sites required in each RWG, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1.

Ammoniacal Nitrogen

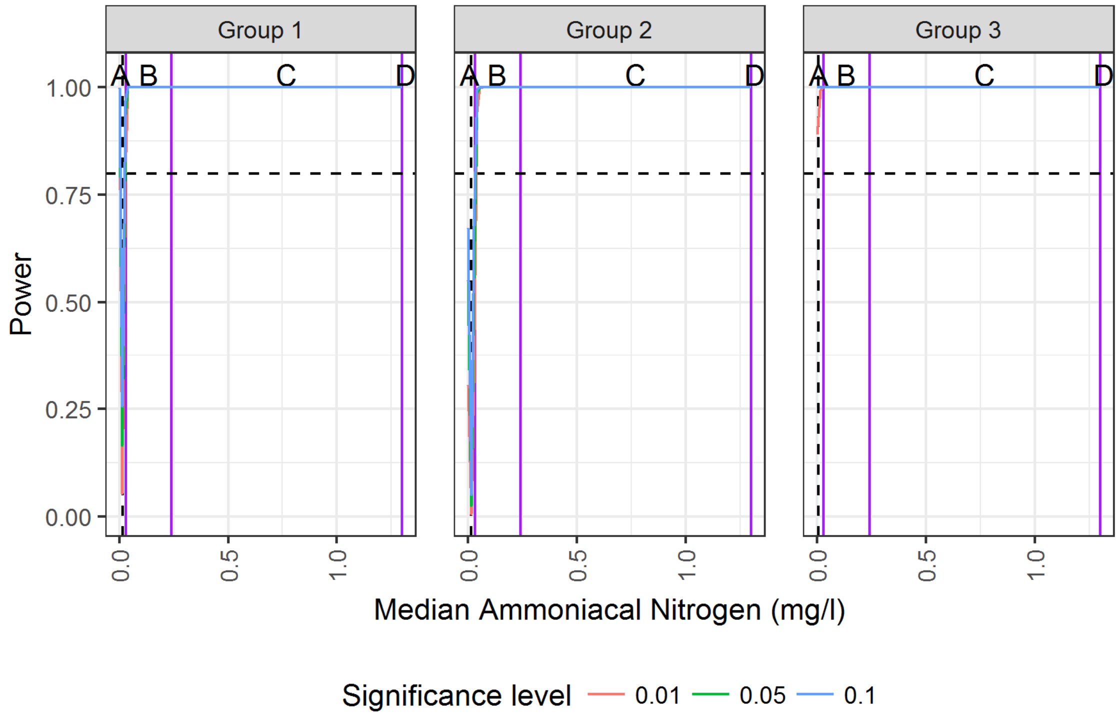


Figure D-1: The statistical power available to evaluate median ammoniacal nitrogen (mg/L) against the NOF attribute bands in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the attribute bands for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

Table D-1: Required site numbers for detecting class level differences in median ammoniacal nitrogen (mg/L) in rivers, relative to the NOF attribute bands. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (mg/l) are calculated across all monitoring sites within each RWG (see Section 3.2.2.).

RWG	Mean	SD	NOF band	NOF band threshold	Required sites	Current sites	Current power
			A-B	0.03	7	20	1.00
Group 1	0.016	0.009	B-C	0.24	< 2	20	1.00
			C-D	1.3	< 2	20	1.00
			A-B	0.03	37	43	0.85
Group 2	0.013	0.029	B-C	0.24	2	43	1.00
			C-D	1.3	< 2	43	1.00
			A-B	0.03	< 2	2	1.00
Group 3	0.005	0.000	B-C	0.24	< 2	2	1.00
			C-D	1.30	< 2	2	1.00

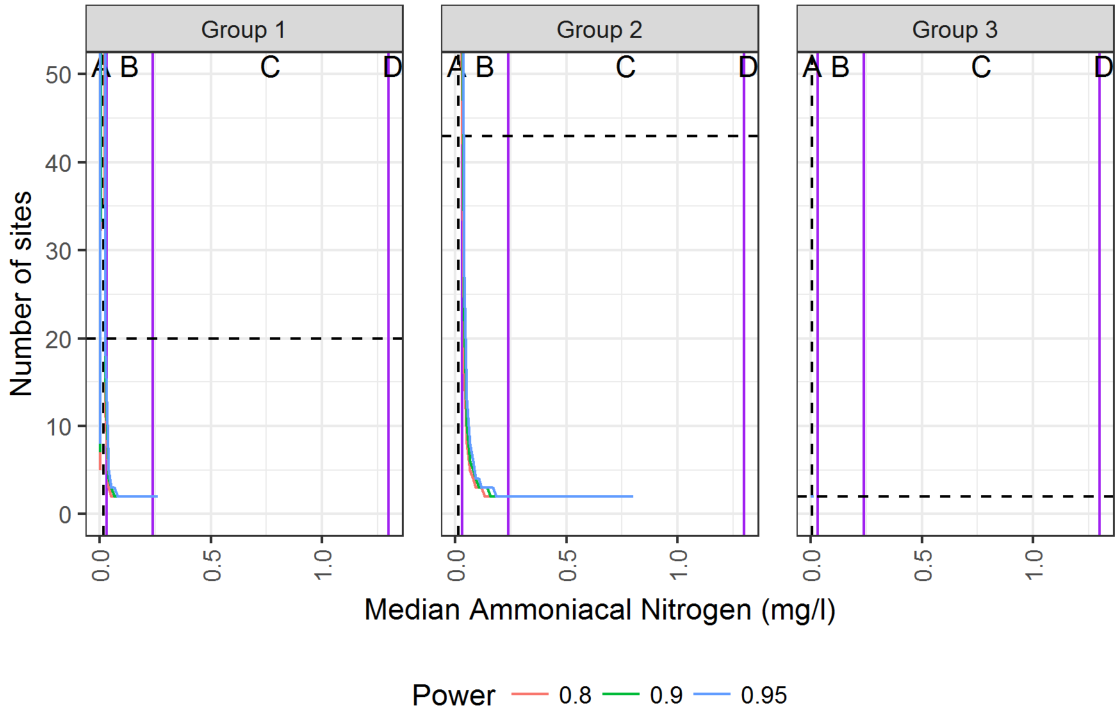


Figure D-2: Site requirements for evaluating median ammoniacal nitrogen (mg/L) relative to NOF attribute bands in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

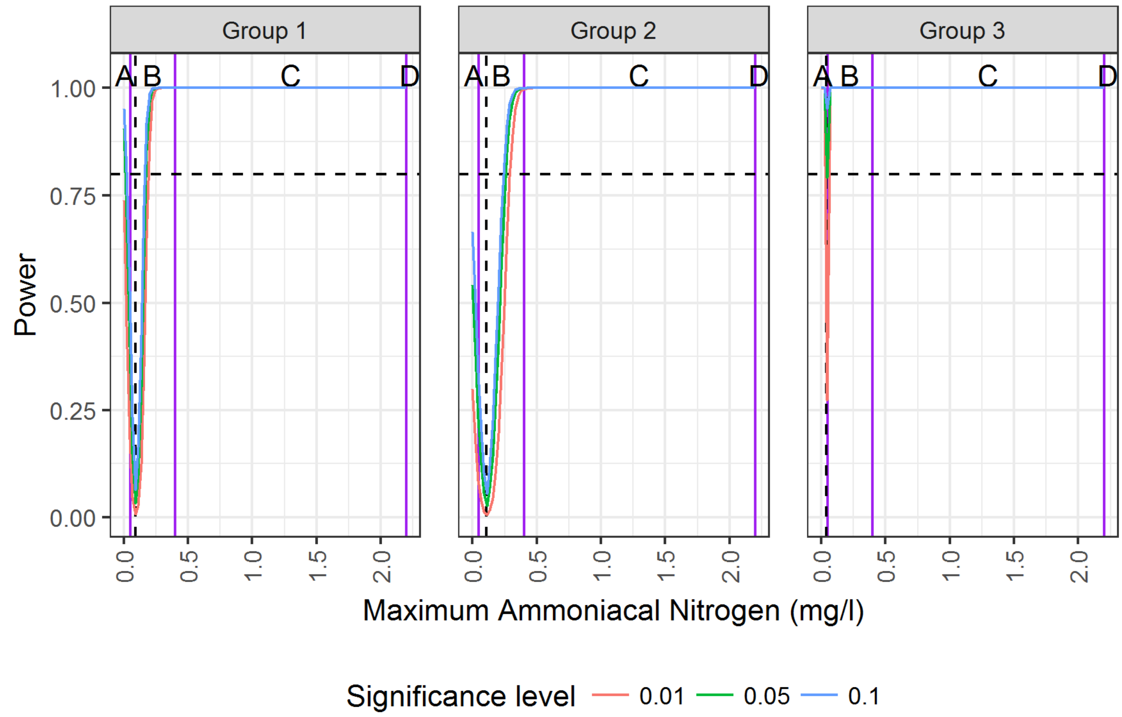


Figure D-3: The statistical power available to evaluate median ammoniacal nitrogen (mg/L) against the NOF attribute bands in three ORC Receiving Waters Groups, based on the current monitoring network. Statistical power versus NOF attribute bands for maximum Each panel shows the power of the current network (1-β) to detect differences between group means and the attribute bands for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

Table D-2: Required site numbers for detecting class level differences in maximum ammoniacal nitrogen (mg/L), relative to the NOF band thresholds. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values are calculated across all monitoring sites within each RWG (see Section 3.2.2).

RWG	Mean	SD	NOF band	NOF band threshold	Required sites	Current sites	Current power
			A-B	0.05	53	20	0.45
Group 1	0.092	0.087	B-C	0.4	3	20	1.00
			C-D	2.2	< 2	20	1.00
			A-B	0.05	210	43	0.30
Group 2	0.109	0.241	B-C	0.4	10	43	1.00
			C-D	2.2	2	43	1.00
			A-B	0.05	2	2	1.00
Group 3	0.04	0.001	B-C	0.4	< 2	2	1.00
			C-D	2.2	< 2	2	1.00

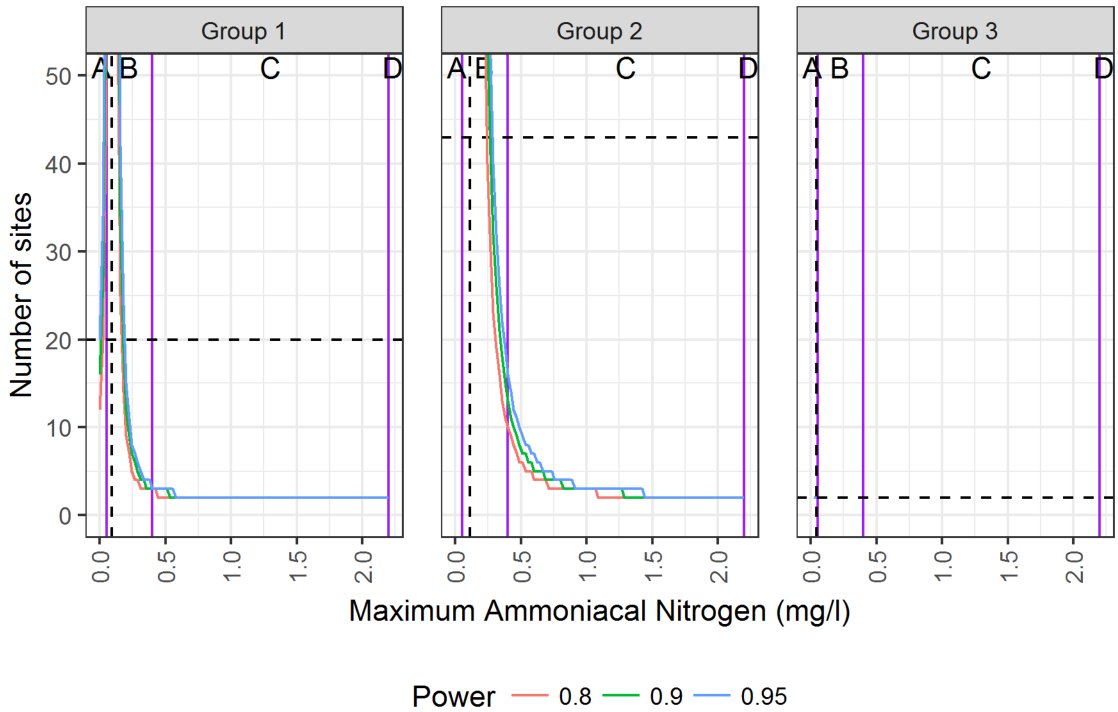


Figure D-4: Site requirements for evaluating maximum ammoniacal nitrogen (mg/L) relative to NOF attribute bands in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

E. coli

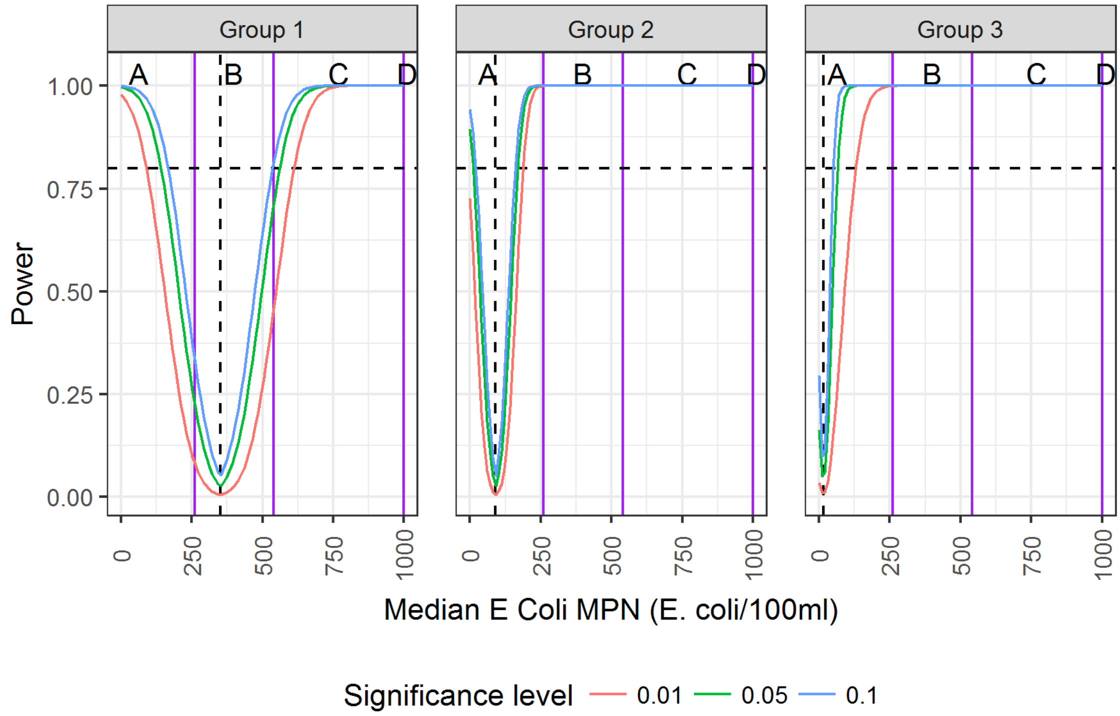


Figure D-5: The statistical power available to evaluate median *E. coli* (per 100 mL) against the NOF attribute bands in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the attribute bands for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

Table D-3: Required site numbers for detecting class level differences in median *E. coli* (per 100 mL), relative to the NOF band thresholds. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values (*E. coli*/100 ml) are calculated across all monitoring sites within each RWG (see Section 3.2.2.).

RWG	Mean	SD	NOF band	NOF band threshold	Required sites	Current sites	Current power
			A-B	260	81	20	0.34
Group 1	350.775	230.705	B-C	540	20	20	0.82
			C-D	1000	3	20	1.00
			A-B	260	8	43	1.00
Group 2	90.317	129.115	B-C	540	3	43	1.00
			C-D	1000	2	43	1.00
			A-B	260	< 2	2	1.00
Group 3	14.6	9.051	B-C	540	< 2	2	1.00
			C-D	1000	< 2	2	1.00

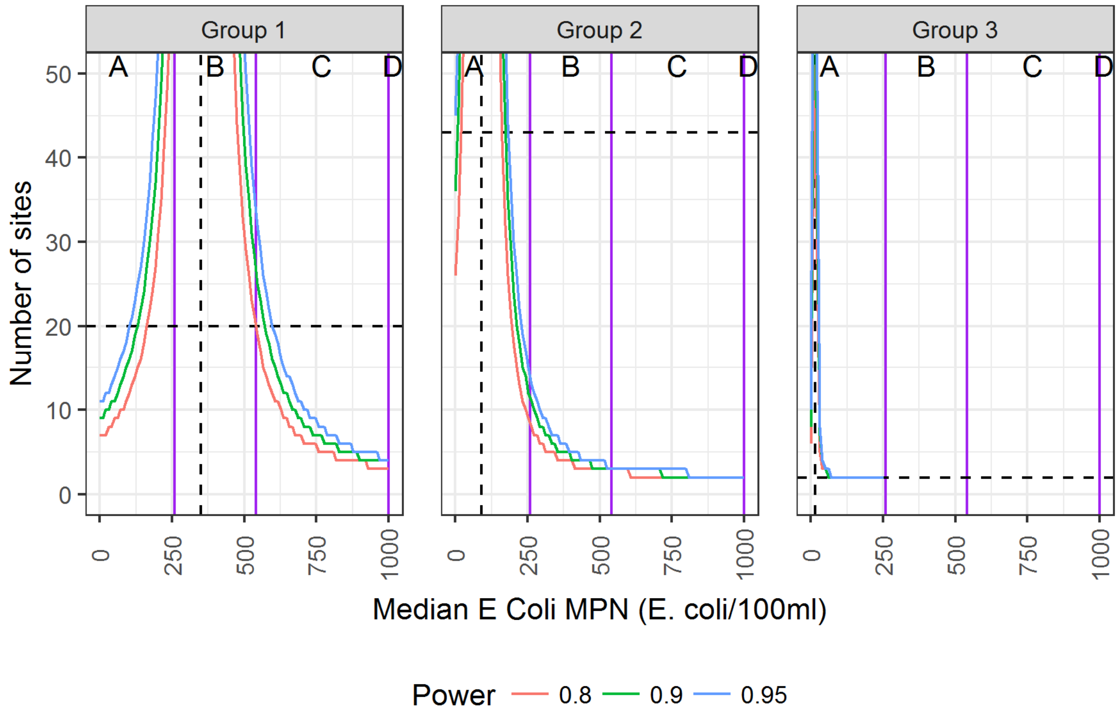


Figure D-6: Site requirements for evaluating median E. coli relative to NOF attribute bands in five ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

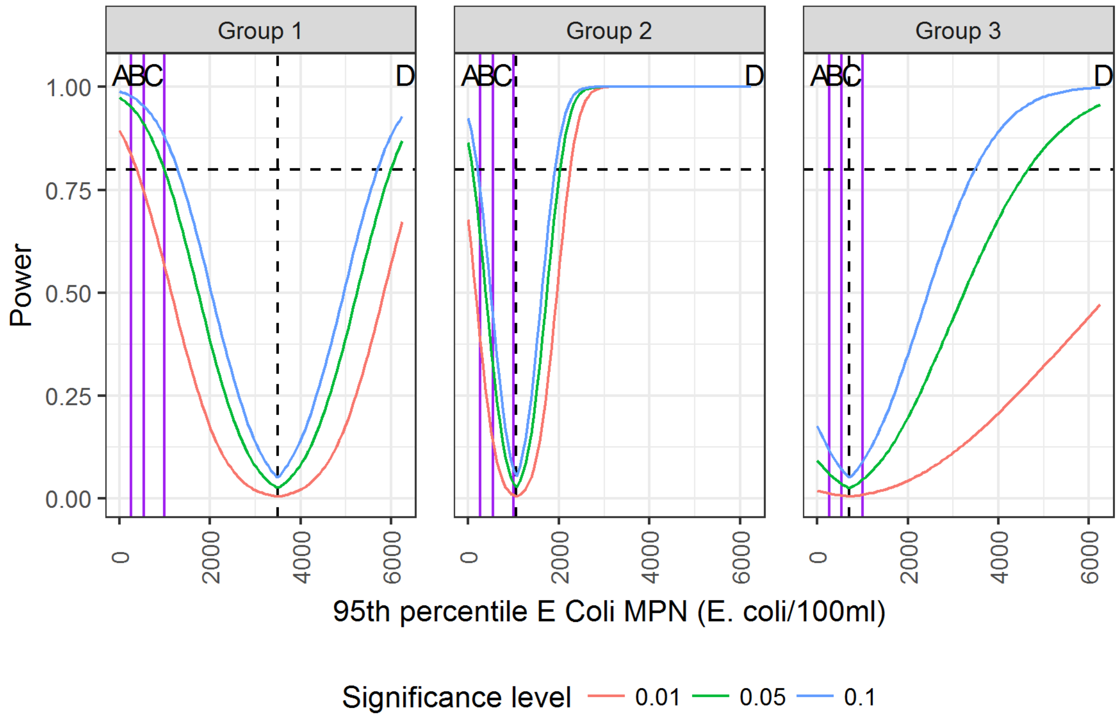


Figure D-7: The statistical power available to evaluate 95th percentile *E. coli* (per 100 mL) against the NOF attribute bands in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the attribute bands for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

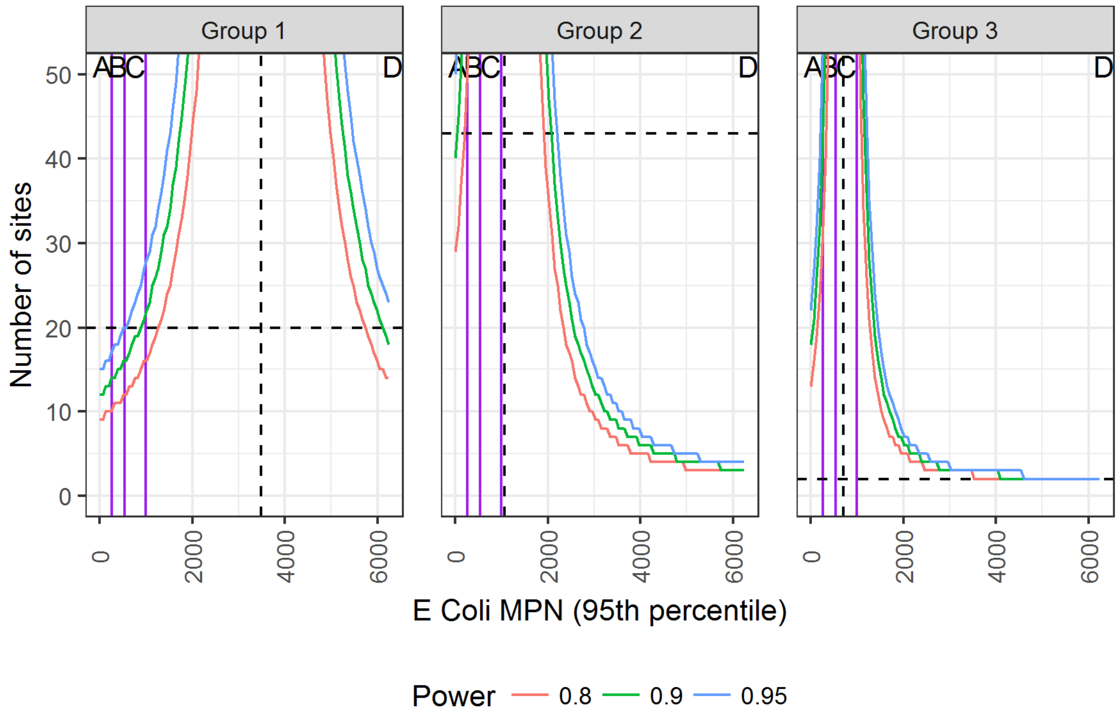


Figure D-8: Site requirements for evaluating 95th percentile *E. coli* (per 100 mL) relative to NOF attribute bands in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

Table D-4: Required site numbers for detecting differences in 95th percentile *E. coli* (per 100 mL), relative to the NOF band thresholds. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values are calculated across all monitoring sites within each RWG (see Section 3.2.2).

RWG	Mean	SD	NOF band	NOF band threshold	Required sites	Current sites	Current power
			A-B	260	10	20	0.98
Group 1	3489.3	2754.1	B-C	540	12	20	0.95
			C-D	1000	16	20	0.88
			A-B	260	50	43	0.75
Group 2	1056.2	1579.9	B-C	540	117	43	0.44
			C-D	1000	9758	43	0.07
			A-B	260	31	2	0.12
Group 3	707.2	697.0.995	B-C	540	216	2	0.07
			C-D	1000	71	2	0.09

Nitrite Nitrate Nitrogen

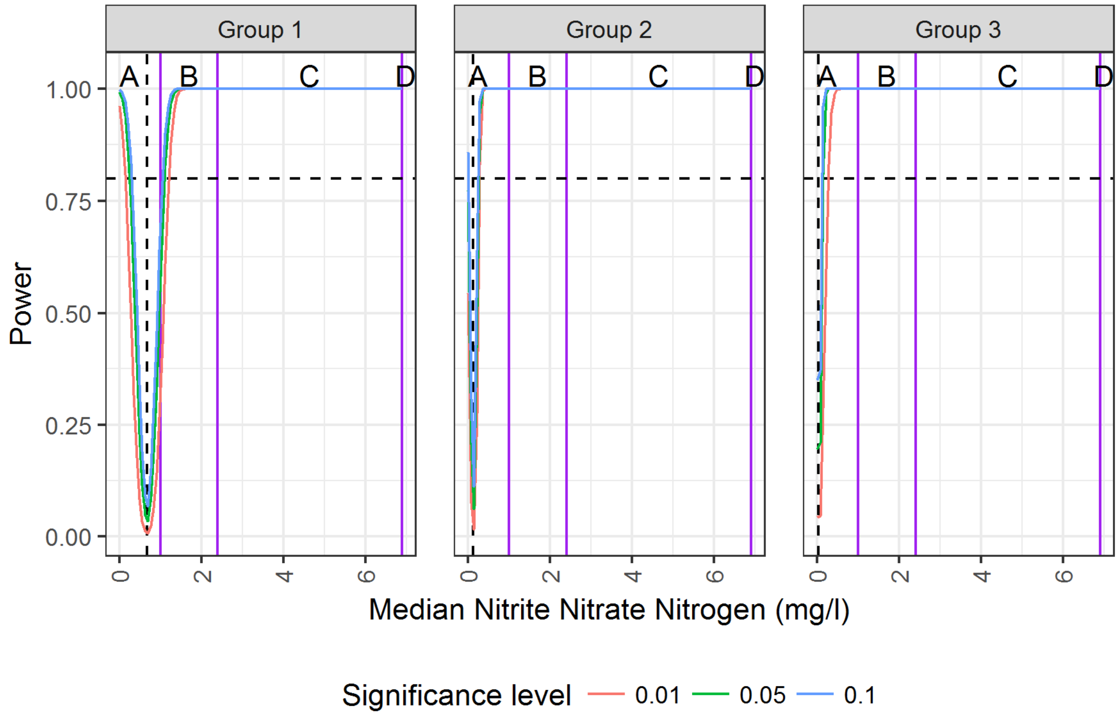


Figure D-9: The statistical power available to evaluate median nitrite nitrate nitrogen (mg/L) against the NOF attribute bands in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the attribute bands for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

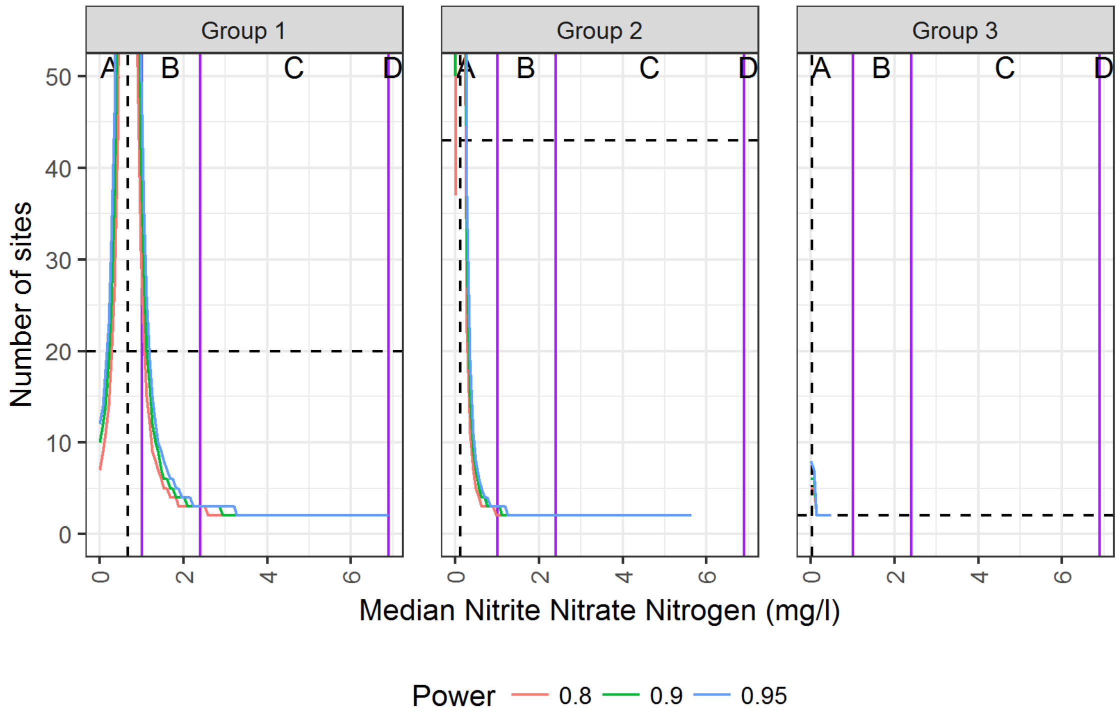


Figure D-10: Site requirements for evaluating median nitrite nitrate nitrogen (mg/L) relative to NOF attribute bands in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

Table D-5: Required site numbers for detecting class level differences in median nitrite nitrate nitrogen (mg/L), relative to the NOF band thresholds. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values are calculated across all monitoring sites within each RWG (see Section 3.2.2).

RWG	Mean	SD	NOF band	NOF band threshold	Required sites	Current sites	Current power
			A-B	1.0	27	20	0.7
Group 1	0.673	0.468	B-C	2.4	3	20	1.00
			C-D	6.9	2	20	1.00
			A-B	1	2	43	1.00
Group 2	0.12	0.204	B-C	2.4	2	43	1.00
			C-D	6.9	< 2	43	1.00
			A-B	1	< 2	2	1.00
Group 3	0.034	0.018	B-C	2.4	< 2	2	1.00
			C-D	6.9	< 2	2	1.00

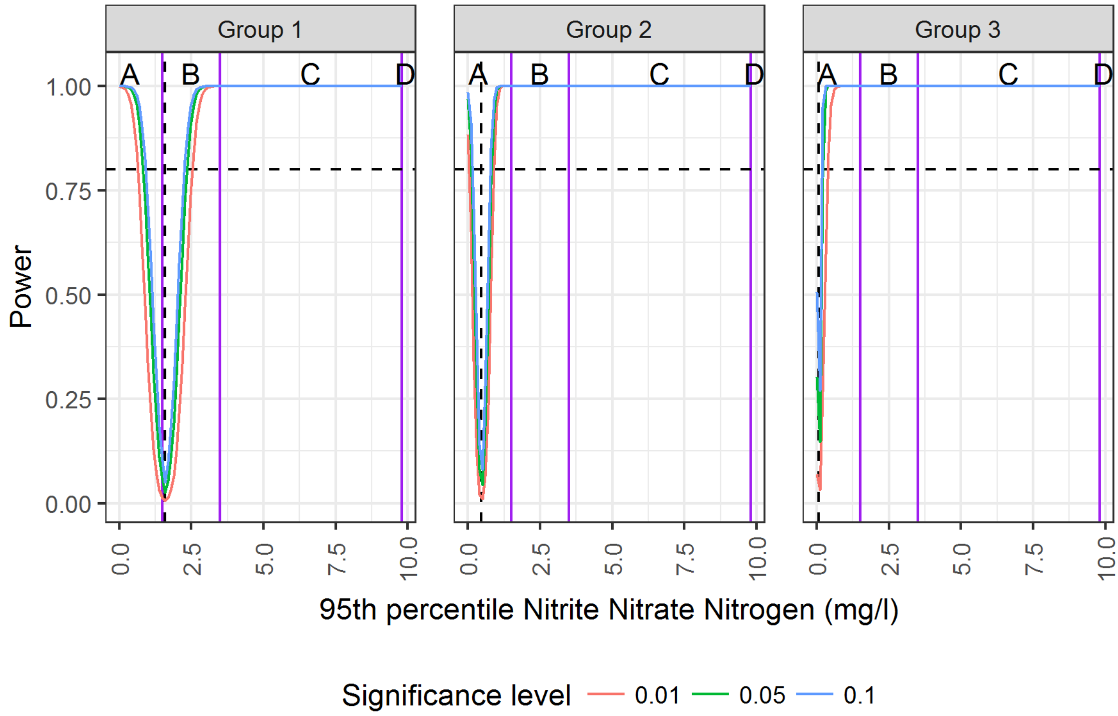


Figure D-11: The statistical power available to evaluate 95th percentile nitrite nitrate nitrogen (mg/L) against the NOF attribute bands in three ORC Receiving Waters Groups, based on the current monitoring network. Each panel shows the power of the current network (1-β) to detect differences between group means and the attribute bands for significance levels (α) of 0.1, 0.05 and 0.01, with the power level of 0.8 indicated by the horizontal dashed line. Group means are indicated by the vertical dashed line, while the vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

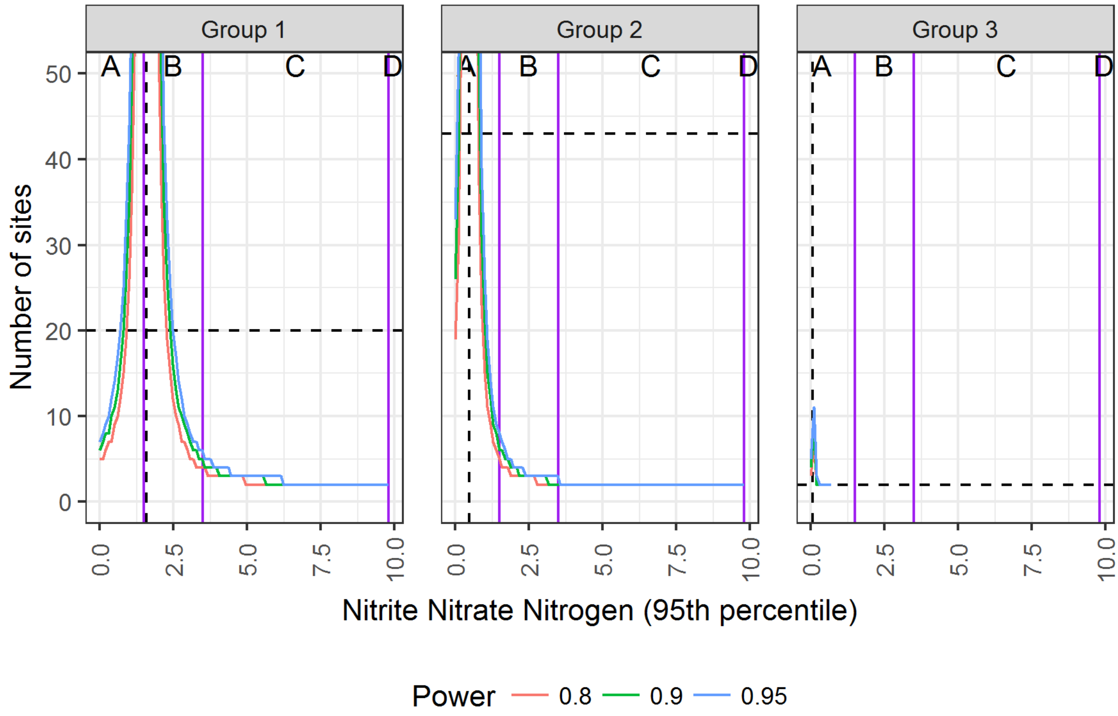


Figure D-12: Site requirements for evaluating 95th percentile nitrite nitrate nitrogen (mg/L) relative to NOF attribute bands in three ORC Receiving Waters Groups. Each panel shows the number of sites required in each class, to achieve statistical powers (1 – β) of 0.20, 0.10 and 0.05, at a significance level of (α) of 0.1. Vertical and horizontal dashed lines indicate group means and current site numbers, respectively; vertical purple lines indicate the thresholds for NOF attribute bands, with the letter bands indicated at the top of each plot.

Table D-6: Required site numbers for detecting differences in 95th percentile nitrite nitrate nitrogen (mg/L) relative to the NOF band thresholds. Analyses are presented for an α-level of 0.1, with the required site estimates based 1-β = 0.8 and the current power estimated using the number of current sites. Mean and standard deviation (SD) values are calculated across all monitoring sites within each RWG (see Section 3.2.2).

RWG	Mean	SD	NOF band	NOF band threshold	Required sites	Current sites	Current power
			A-B	1.5	1188	20	0.09
Group 1	1.585	0.836	B-C	3.5	4	20	1.00
			C-D	9.8	2	20	1.00
			A-B	1.5	5	43	1.00
Group 2	0.465	0.56	B-C	3.5	2	43	1.00
			C-D	9.8	2	43	1.00
			A-B	1.5	< 2	2	1.00
Group 3	0.062	0.025	B-C	3.5	< 2	2	1.00
			C-D	9.8	< 2	2	1.00

Appendix E Current SoE river macroinvertebrate monitoring sites

Site	Receiving Water Group	REC
Kakanui River at Clifton Falls Bridge	2	CD/H/P
Kauru River at Ewings	2	CD/H/P
Kakanui River at McCones	2	CD/H/P
Waiareka Creek at Taipo Road	2	CD/L/P
Waianakarua River at Browns	2	CD/H/P
Trotters Creek at Mathesons	2	CD/L/P
Shag River at Craig Road	2	CD/H/P
Shag River at Goodwood Pump	2	CD/L/P
Waikouaiti River at Confluence D/S	2	CD/H/P
Lindsays Creek at North Road Bridge	1	CD/L/U
Leith Stream at Dundas Street Bridge	1	CW/L/U
Kaikorai Stream at Brighton Road	1	CD/L/U
Tokomairiro River at West Branch Bridge	1	CD/L/P
Catlins River at Houipapa	1	CW/L/P
Kye Burn at SH85 Bridge	2	CD/H/P
Silver Stream at Taieri Depot	2	CD/L/P
Waipori River at Waipori Falls Reserve	2	CD/Lk/N
Mill Creek at Fish Trap	2	CD/H/P
Cardrona River at Mt Barker	2	CD/H/N
Luggate Creek at SH6	2	CW/M/N
Lindis River at Ardgour Road	2	CD/H/N
Dunstan Creek at Beattie Road	2	CD/M/N
Manuherikia River at Ophir	2	CD/H/P
Heriot Burn at Park Hill Road	1	CD/L/P
Waipahi River at Cairns Peak	1	CD/L/P
Waipahi River at Waipahi	1	CD/L/P

Site	Receiving Water Group	REC
Wairuna River at Millar Road	1	CD/L/P
Waiwera River at Maws Farm	1	CD/L/P
Waitahuna River at Tweeds Bridge	1	CD/L/P

Appendix F ORC SoE river monitoring variables and methods

Table F-1: Existing ORC SoE river monitoring variables and methods as at 30 June 2017. MDL = laboratory method detection limit.

Variable and units	Method	MDL
Water temperature (°C)		-
Dissolved oxygen (mg/L and % sat)	In-situ measurement using YSI Pro2030, YSI556, YSI ProPlus Quatro or YSI ProPlus	-
Conductivity (mS/cm)		-
pH (pH units)	Electrode at 20°C, APHA 4500-H B	0.1
Turbidity (NTU)	Nephelometry by APHA 2130 B (modified)	0.05
Total suspended solids (mg/L)	Gravimetry by APHA 2540 D	0.2
Nitrate nitrogen (mg/L)	APHA 4110 B (modified)	0.002
Nitrate nitrogen (mg/L)	APHA 4110 B (modified)	0.002
Nitrate-nitrite nitrogen (mg/L)	Calculation	0.002
Total ammoniacal nitrogen (mg/L)	Colorimetry and discrete analyser by MEWAH, HMSO 1981, ISBN 0117516139	0.005
Total Kjeldahl nitrogen (mg/L)	Calculation	0.02
Total nitrogen (mg/L)	Persulphate digestion and flow analysis by APHA 4500-P B J (modified)	0.010
Dissolved reactive phosphorus (mg/L)	Colorimetry/discrete analysis by APHA 4500-P B F (modified)	0.002
Total phosphorus (mg/L)	Persulphate digestion and colorimetry/discrete analysis, APHA 4500-P B J (modified)	0.004
Escherichia coli (E. coli)	Membrane filtration, USEPA Method 1603 (2002)	2
Periphyton diversity	Collection by pooling scrapings from 20 rocks and assessment via Biggs and Kilroy (2000) scale of relative abundance	-
Macroinvertebrates	Protocols C1 (hard-bottomed semi-quantitative) and P1 (coded abundance) of Stark et al. (2001)	-

8 November 2017

Dr Dean Olsen ID:1647
Manager Resource Science
Otago Regional Council
Private Bag 195
Dunedin 9054

Dear Dean

Peer review of NIWA report on Otago Regional Council's State of the Environment Monitoring programmes

Thank you for the opportunity to review this report. In this letter we summarise our comments on the report. Specific comments on parts of the report have been marked in a tracked changes version supplied. Some of the more general comments on the report are highlighted below.

As discussed on the phone, our lake ecology experts were not able to look at the report in the timeframe available, so this peer review does *not* address the lake monitoring recommendations in the NIWA report. We strongly recommend that an experienced lake ecologist reviews the specific recommendations about lake monitoring contained in the report.

1. Overall, we consider that this review of ORC's State of Environment monitoring programme has been conducted in a robust and thorough manner. We agree with the majority of the recommendations in the report. The representativeness and power analyses presented provide useful information to guide the design of ORC's future monitoring network.

2. A fundamental aspect of SOE monitoring programme design is considering the range of purposes and questions that are ideally addressed by data collected from the SOE network. Unfortunately, a design that will meet the requirements of one purpose may be unsuitable for another purpose. Therefore we agree with the report authors that some pragmatic decisions are required to design a monitoring network that best meets multiple purposes. However, some consideration needs to be given to the priority of these different purposes. As the NIWA report indicates, a sampling network designed solely to representatively cover the range of river types in the region will not have sufficient statistical power to detect differences between some of the rare river types (e.g. urban) because of a lack of sampling sites. There are other approaches to help address representativeness of environmental reporting (e.g. using water quality models for some parameters), but these approaches have their limitations too.

98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042, New Zealand | T (+64) 03 548 2319 | F (+64) 03 546 9464 | www.cawthron.org.nz

3. It was a shame that fish monitoring was considered outside the scope of this report. Fish are important components of freshwater ecosystems and are highly valued by the community. The need for fish monitoring should not be overlooked. Similarly, there was no discussion in the report on riverine macrophyte monitoring. Macrophytes are conspicuous components of many Otago rivers and should be considered for inclusion in ORC's monitoring plans for the future.

4. The representativeness analysis is a useful part of the report, but the focus on just three variables within the River Environment Classification (REC) system (Climate, Source of Flow, Land cover) means that representativeness in terms of stream/river size and geology is not incorporated. We also note that some special types of streams (e.g. spring-fed streams) will not be identified using the REC. Local knowledge on the number and location of important spring-fed streams should be used to address this gap. The FENZ-focussed analysis indicates that there is considerable environmental variability not covered by sites in the existing network (particularly in RWG 2 & 3), but it is not clear what type of streams and river are missing. Presumably the missing streams are small mountainous ones, but it would be good to clarify this.

5. The power analysis was a very interesting and potentially useful part of the report. The results are only relevant to situations where data from groups of sites are compared with other groups or relevant water quality guidelines/limits. Comparisons of the results from single sites against water quality guidelines/limits are likely in SOE reporting, with statistical power of these comparisons affected by the length of the sampling record rather than the number of sites.

6. Turbidity stood out in the power analysis as a variable with high temporal variability and therefore requiring a large number of sites to enable detection of differences. However, the power analysis used all data collected at flows below the median flow. Turbidity is highly responsive to flow, so comparisons of turbidity among site groups at low flows (i.e. much lower than median) might be more relevant/informative. This point again emphasises the authors' recommendation regarding the need for flow to be measured or estimated on all occasions when samples are collected, which we strongly support.

7. We agree that consideration of the purpose of Total Suspended Solids monitoring is required as this parameter may not be relevant at some sites. If TSS is considered important for determining sediment loads or likely effects caused by deposited/suspended sediment then larger sample volumes should be collected for 2-3 years to overcome the non-detect problem with this variable, and enable site-specific relationships between TSS and clarity/turbidity to be developed for on-going monitoring.

8. We endorse the authors' comments about the increasing need for continuous monitoring of parameters like water temperature and dissolved oxygen. The long-term goal should be for continuous monitoring of these parameters year round,

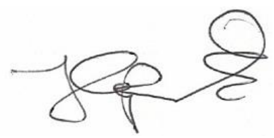
although a good first step is to focus on collecting high quality continuous data for at least a few weeks in summer when high temperatures and low DO are most likely to be a problem.

9. We also support the authors' comments about the need to incorporate monitoring of pressures in regional SOE programmes. However, we were surprised to see no mention of the NZ Landcover Database (LCDB), which provides the most robust information on how land cover (and use) is changing in New Zealand.

We hope these comments are useful as you move forward with your State of the Environment monitoring programme. Let us know if you have any queries.

Yours sincerely

Dr Roger Young
Group Manager Freshwater Science
Cawthron Institute



Dr Joanne Clapcott
Freshwater Ecologist
Cawthron Institute

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Customer Services
P. 03 353 9007 or 0800 324 636
200 Tuam Street
PO Box 345
Christchurch 8140
E. ecinfo@ecan.govt.nz
www.ecan.govt.nz

7th November 2017

Dean Olsen
Otago Regional Council
70 Stafford St
Dunedin 9016

Dear Dean

Request for Review of Lake SoE Monitoring Programme Review

The enclosed review report of Juliet Milne and peers reviews the Otago Regional Council's State of the Environment Monitoring Programme for lakes and rivers. We were asked to provide comments as to whether the review recommendations are reasonable, professional, defensible and correct, and whether there are omissions. Our review of this review only looked at the review report alone, and not at the original reviewed and supporting documents. It also concerns the lakes section of the review only.

In general, the report is a thorough review with mostly well justified recommendations, based on sound science. However, several considerations and recommendations go beyond the scope on what we believe routine State of the Environment Monitoring (SoE) monitoring should encompass, and scope a large share of the scientific methods that could be conducted on lakes. On the other hand, there are some omissions, mostly the lack of small reference lakes that could indicate climate signals. Our comments are made on the assumption that the purpose of State of the Environment Monitoring is to capture the state and trend of a **representative cross section** of lakes of the Otago region **over time**, not to monitor plan effectiveness or investigate specific problems or areas of specific interest.

General comments:

1) **Scope:** There is no mention of coastal lagoons (e.g. Tomahawk Lagoon), but we understand that four estuaries (and hapua) are now included in the ORC's SoE monitoring programme? Despite the logical difficulties, the lake monitoring programme would strongly benefit from the inclusion of one or two small reference lakes, to identify and 'filter out' any strong climate signals. The review also identified a number of unmonitored highly used lakes and reservoirs, but did not recommend whether one or more of those should be monitored, despite their increasing community value and use.
2) **Sampling frequency:** The review report makes a case **for ongoing monthly monitoring of all monitored lakes**, instead of monitoring on a rotational basis. However, this recommendation does not come through strongly in the summary section. The risk of rotational systems is that medium-term (5-20 years) changes may not be picked up, as lakes also respond to short-term variations in climate. If necessary, reducing the number of sampling sites on a particular lake or reducing the number of parameters monitored or considering bi-monthly sampling may be preferable to continuing rotational monitoring.
3) **Sampling parameters:** Nutrients in lake tier 3 and 4 are above and beyond NEMS, NPS-FM, and 'standard' SoE monitoring. However, we agree some may be useful indicators of lake status and may in future become 'standard

parameters' (TDP, TDN, DOC etc.). Nutrient deficiency indicators (PC, PP, PN) are not covered in NEMS 2017 and are not usually part of routine SoE monitoring. This type of nutrient deficiency testing may be more suitable for a short term (e.g. 2 year) investigation than long term routine monitoring. On the other hand, there are several other parameters missing:

   a. Microbiological quality – (NPSFM) swimmability in lakes.
   b. Explicit regular cyanobacteria monitoring - (NPSFM) swimmability in lakes. (Although monthly phytoplankton monitoring is recommended for all open water sites under tier 3).
   c. Explicit "colour and clarity" monitoring (as per RMA) so establishing a baseline and target in Munsell scale colour and colour hue.
   d. Lake water quality is often linked to water level in smaller lakes. In lakes were levels fluctuate seasonally and annually it is recommended to continuously record lake levels, to support spot water quality measurements.

4) **Detection limits**: for parameters, particularly Tier 4 and 5 parameters are an important consideration. It is important to be aware of where parameters may naturally be below laboratory detection limits most of the time, and so monitoring programmes should be realistic on whether monitoring these should routinely be required. This can also include Tier 2 (soluble nutrient parameters) other than those specifically required under NPSFM (ammonium N)).
5) **Organic carbon determinations**: fails to identify that such carbon can be important energy sources for some (mixotrophic) algae. We support targeted measurement of DOC and TOC.
6) **VHOD** discussions fail to identify that these determinations should be categorised only to lake types with a likely risk. Lakes Wanaka and Wakatipu do not represent high VHOD risks.
7) **High frequency monitoring (buoys).** We agree this is a developing field with promise, but is technically challenging particularly in very deep lakes.
8) **Monitoring different taxonomic groups:** (algae, macrophytes, zooplankton) is "useful" but it needs to be clear how that information will be used and reported. Fish communities can also be deterministic but are increasingly labour intensive.

Comments specific to Lakes Wanaka and Wakatipu: I (Tina) spent 3 years working on these lakes, and based on my knowledge of these systems I have made some suggestions about details of proposed monitoring.

Overall, we consider the review to be fair and comprehensive, but can tend to be overly comprehensive on what could be monitored in a regions lakes rather than on what is most effective in an SoE programme.

Yours sincerely,

Tina Bayer
Ecology Scientist

Adrian Meredith
Principal Water Quality & Ecology Scientist

Encl: 1) Annotated Draft - Review of Otago Regional Council's State of the Environment monitoring programmes

Our ref: Size of footer = Arial 10 (not in bold)
Your ref:
Contact:

2) Recommendations for sampling Lakes Wanaka and Wakatipu

PATTLE DELAMORE PARTNERS LTD

Review of Otago Regional Council Groundwater Information

Otago Regional Council

solutions for your environment

Review of Otago Regional Council Groundwater Information

Prepared for

Otago Regional Council

August 2017

PATTLE DELAMORE PARTNERS LTD
295 Blenheim Road
Upper Riccarton, Christchurch 8041
PO Box 389, Christchurch 8140, New Zealand

Tel +64 3 **345 7100**
Website http://www.pdp.co.nz
Auckland Tauranga Wellington **Christchurch**

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DOCUMENT CONTRIBUTORS

Prepared by

SIGNATURE

Neil Thomas

Hilary Lough

Reviewed and approved by

SIGNATURE

Peter Callander

Limitations:

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Otago Regional Council and others (not directly contracted by PDP for the work). PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the report. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

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Executive Summary

The Otago Regional Council (ORC) must manage the aquifers in the region in accordance with the Resource Management Act (RMA), the National Policy Statement for Freshwater Management (2014) (NPS-FM) and the Regional Plan: Water and associated plan changes. To determine whether the objectives within that legislation are being met, ORC collect various data regarding the water quality and quantity of the different aquifers throughout Otago.

In order to ensure that any gaps in understanding or knowledge relating to the management of the region's aquifers are identified, ORC have engaged Pattle Delamore Partners to provide a review of groundwater information available in the region, including models as well as the data collection programmes. The objectives of the review are to:

- summarise the state of knowledge and data collection programmes for each of Otago's aquifers in terms of both water quality and water quantity;
- assess the quality of the available data and collection programmes; and
- comment on whether the data and methods used by ORC to inform the sustainable management of their aquifers are fit for purpose.

Permeable strata where groundwater is easily accessible occur in a number of spatially separate areas within the Otago region. Many of those areas represent alluvial gravel strata that are well connected to neighbouring surface water bodies. Overall, the ORC have delineated 29 different aquifers, each of which has an allocation limit and require some information to manage the aquifer within that limit.

Overall the state of knowledge available for each of Otago's aquifer is very good. The majority of aquifers have detailed reports regarding the patterns of groundwater movement within them, their sources of recharge and locations of discharge. As a result, the conceptual understanding of each of the aquifers is well documented and easily accessible. Many of the aquifers are represented by numerical groundwater models that help to validate those conceptual models, (within the bounds noted in Section 4.3).

Based on this review, there are only two aquifers where further information regarding the state of the aquifers may be required as a priority; the Papakaio Aquifer and the Bendigo-Tarras Aquifer. There are other aquifers where the available information is not strictly consistent with an ideal data collection programme, for example the Earnscleugh Aquifer should ideally have a dedicated continuous water level recorder. However, in each of those aquifers, there is limited consented groundwater use; therefore additional information could be gathered as part of a long term programme for those aquifers, but it is not an immediate priority unless consented groundwater use increases sharply (for example as a result of a deemed permit transferring to an RMA groundwater take consent).

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Appendices

1.0 Introduction

The Otago Regional Council (ORC) must manage the aquifers in the region in accordance with the Resource Management Act, the overall National Policy Statement for Freshwater Management (2014) (NPS-FM) and the Regional Plan: Water and associated plan changes. The NPS-FM (2014) directs regional councils on water management and sets out the requirements for regional plans. These documents define the objectives and policies for freshwater management in the region and the rules by which water is to be managed.

To determine whether the objectives in that legislation are being met, ORC collect various data regarding the water quality and quantity of the different aquifers throughout Otago. Various specific studies have also been undertaken in order to ensure that aquifer characteristics are understood and groundwater models have been developed for some areas in order to aid that understanding and to assist setting allocation limits related to water quality and quantity.

Further changes to the existing Regional Plan: Water will take place over the next few years as set out in the ORC Long Term Plan 2015-2025, including setting volumetric limits or sustainable management levels in aquifers where that has not already been completed. In addition, mining privileges will expire in 2021 and a series of additional resource consents to take water are expected to replace some of these, which could put further pressures on allocation.

In order to ensure that any gaps in understanding or knowledge relating to the management of the region's aquifers are identified, ORC have engaged Pattle Delamore Partners to provide a review of groundwater information available in the region, including models as well as the data collection programmes. The objectives of the review are to:

- summarise the state of knowledge and data collection programmes for each of Otago's aquifers in terms of water quality and quantity;
- assess the quality of the available data and collection programmes; and
- comment on whether the data and methods used by ORC to inform the sustainable management of their aquifers are fit for purpose.

Figure 1 provides a map of the identified aquifers across the ORC region, based on information provided by ORC. An assessment of the appropriateness of the mapped aquifer boundaries is not part of this review.

2.0 Overview of groundwater data collection requirements

2.1 Purpose of groundwater data collection

Groundwater forms an important resource within the Otago region and is used for a number of different purposes, including potable water supply, agriculture (for example irrigation), and industry, (for example water for food processing).

Groundwater also provides baseflow to rivers and streams and is usually a key source of water for wetlands.

Managing groundwater in a sustainable manner in terms of both groundwater quantity and groundwater quality is important to ensure that those uses can continue, and that the ecological, cultural and recreational values of groundwater and connected surface waterways are maintained. Therefore, information regarding the state of the groundwater resource is required. Note that this review excludes level control for land drainage in low lying areas i.e. it focuses on groundwater as a source. Collection of groundwater information can:

- provide a warning system of events such as adverse changes in water quality within an aquifer or water table declines;
- provide information regarding baseline water levels and water quality in an aquifer against which future changes can be judged;
- provide information for modelling, allowing predictions of aquifer behaviour under different scenarios.

That information covers the collected groundwater quantity and groundwater quality data, relevant surface water data for connected surface waterways together with analysis of that data to determine aquifer dynamics and patterns of groundwater movement.

Sustainable management of groundwater needs to ensure that the objectives that are defined to support the agreed values are achieved and the limits required to achieve those objectives are not exceeded. Those limits will vary between areas, depending on the uses of water in each area.

2.2 National Policy Statement for Freshwater Management

The NPS-FM (2014) sets out an overarching framework through which the values of groundwater are to be defined, and how limits can be set to meet the objectives that support those values. In terms of groundwater monitoring, and monitoring in general, the NPS-FM specifies that monitoring plans should provide an approach to monitoring progress towards, and achievement of, freshwater objectives, which include both water quality as well as water quantity accounting:

Policy CB1

By every regional council developing a monitoring plan that:

> *a) establishes methods for monitoring progress towards, and the achievement of, freshwater objectives established under Policies CA1-CA4;*
>
> *b) identifies a site or sites at which monitoring will be undertaken that are representative for each freshwater management unit; and*
>
> *c) recognises the importance of long-term trends in monitoring results.*

The NPS-FM does not specify particular monitoring that should be undertaken, in terms of groundwater quantity or groundwater quality because any monitoring under the NPS-FM should be tailored towards a particular freshwater objective, meaning that it can be variable. However, the NPS-FM does specify national bottom line standards for some attributes for freshwater bodies. Whilst none of those standards are specifically for groundwater, standards for rivers are implicitly relevant where groundwater discharges into rivers, streams or lakes, or where depletion of surface water flow from groundwater pumping may affect surface water quality. The following attributes with relevant standards include:

- Nitrate nitrogen, periphyton and dissolved oxygen (for rivers)
- Ammonia, Cyanobacteria, E.Coli (for lakes and rivers)
- Total phosphorus, total nitrogen and phytoplankton (for lakes)

Note that some amendments to the NPS-FM have been proposed (as of June 2017) as part of the Government's freshwater reform programme, but the above attributes are the same.

The presence of national bottom line standards implies that some baseline monitoring is required to confirm where water bodies sit within those standards. However, the details of monitoring requirements are expected to vary from aquifer to aquifer across the ORC region depending on the specific groundwater system and its interaction with surface waterways.

Box 1: Monitoring groundwater that contributes seepage to nearby surface waterways:

- Monitoring of groundwater that contributes seepage to nearby surface waterways helps to understand the input of groundwater relative to the national bottom line standards for water quality.
  - E.coli;
  - Nitrate nitrogen, Ammonia;
  - Total nitrogen; and
  - Dissolved Reactive Phosphorus

2.3 Resource Management Act

The Resource Management Act (RMA) requires local authorities to monitor the state of the environment (SoE), which typically describes the physical, chemical and biological characteristics of the environment and how those characteristics change over time. That monitoring may overlap with monitoring for the NPS-FM, however it is required for the broader objective of enabling the local authority to effectively carry out its functions under the RMA, in addition to being in accordance with any regulations made under the RMA.

2.4 Otago Regional Plan: Water

The Otago Regional Plan: Water includes a section (Chapter 19.1) covering monitoring and review, which provides a general overview of monitoring requirements. In summary, monitoring under the ORC Regional Plan falls into three categories:

- process monitoring, to monitor the effectiveness or suitability of a policy statement or plan;
- baseline monitoring, to monitor the regional state of the environment (State of the Environment Monitoring); and
- compliance monitoring, to monitor the compliance of resource consents.

This report will focus and review the baseline and process monitoring that ORC currently undertake. Comments on compliance monitoring are outside the scope of this report.

The parts of the Otago regional plan that are relevant to groundwater and groundwater monitoring are included in Chapter 6 (Water Quantity), Chapter 7 (Water Quality) and Chapter 9 (Groundwater). Limits based on those policies are specified in Schedule 4 (Groundwater allocation limits) and Schedule 15 (Water quality limits). However allocation limits or water quality limits are not yet set for all the aquifers in the region; some of the aquifers are moving through the limit setting process, whereas allocation limits and associated trigger levels have been set for other aquifers.

The following sections summarise the key issues and objectives as defined in those chapters of the regional plan, together with a comment around the groundwater monitoring required to measure the suitability or effectiveness of those objectives.

2.4.1 Water Quantity

The key issues and objectives with regard to groundwater quantity are:

6.2.1A - Issues

a) Long term depletion of groundwater levels and water storage volume; and

(b) Loss of artesian conditions; and

(c) Short and long term depletion of surface water; and

(d) Contamination of groundwater or surface water resources; and

(e) Aquifer compaction

6.3.2A – Objectives

To maintain long term groundwater levels and water storage in Otago's aquifers.

Explanation

*The levels and pressures of groundwater in aquifers can be reduced where water is taken at a greater rate than it is being replaced by **aquifer recharge. This objective seeks to avoid any such long term or irreversible reductions in aquifer volume** through appropriate management of groundwater takes.*

*Groundwater often has a dynamic hydrological connection with surface water. **This connection needs to be adequately understood to ensure sustainability of these water resources, which include any river, lake or wetland dependent on groundwater levels**.*

Chapter 6 includes a number of policies (6.4.10A to C) that govern how groundwater take consents are managed in a consistent manner with the issues and objectives. Those policies include allowances for setting maximum allocation limits for each aquifer, as well as restriction levels where required to protect aquifer properties and avoidance of aquifer contamination through sea water intrusion or contaminated sites. In addition, policy 6.4.11 allows for the suspension of groundwater abstraction where a restriction level is reached based on monitoring in a trigger level bore for particular aquifers.

The issues, objective and policies in Chapter 6 provide an overall framework in which individual groundwater quantity limits can be set. Chapter 6 defines the maximum allocation limit for an aquifer as either that set in Schedule 4 or, for aquifers not in Schedule 4A, 50% of the mean annual recharge calculated under Schedule 4D. Note that some values regarding the uses of groundwater are assigned to individual aquifers in Schedule 3. Box 2 summarises the minimum level of monitoring that may be required, however additional monitoring may be required to set groundwater quantity limits in some aquifers.

Box 2: Groundwater monitoring required as a result of overall objectives and policies for groundwater quantity in the Otago Regional Plan (Water):

- Information regarding long term groundwater levels and water storage can only be provided via long term groundwater level monitoring.
- Groundwater monitoring must be reasonably located within the aquifer to represent the overall state of the aquifer and/or located such that changes in groundwater-surface water interaction can be observed or inferred.
- Monitoring to prevent sea water intrusion into an aquifer may require a dedicated coastal monitoring network, depending on the risk identified in different aquifers.
- Restriction of groundwater abstraction based on a trigger level bore will require monitoring in that trigger level bore on a regular basis.

2.4.2 Water Quality

The general water quality objectives specified in the plan include:

> *Objectives*
>
> *7.A.1 To maintain water quality in Otago lakes, rivers, wetlands, and groundwater, but enhance water quality where it is degraded.*
>
> *7.A.2 To enable the discharge of water or contaminants to water or land, in a way that maintains water quality and supports natural and human use values, including Kāi Tahu values.*
>
> *7.A.3 To have individuals and communities manage their discharges to reduce adverse effects, including cumulative effects, on water quality.*

The natural and human use values identified in 7.A.2 for surface water bodies are listed in Schedule 1 of the plan. The values are divided in to five separate schedules which are: natural values; Otago Resident Native Freshwater Fish - Threat Status; water supply values; registered historic places and spiritual and cultural beliefs, values and uses of significance to Kai Tahu. As outlined in section 2.4.1, Schedule 3 sets out values for different aquifers that include water quality objectives relating to drinking water with or without treatment, industrial use, irrigation and stock water quality. Schedule 3 also includes a list of groundwater takes for the purpose of community water supply.

Water quality limits are specified for surface water bodies in Schedule 15 as concentration limits, but no specific limits are listed for groundwater quality at present, although the plan notes that these are to be included following individual aquifer studies. Nonetheless, whilst specific groundwater limits are not listed, some of the surface water limits are relevant. That is because in some circumstances, where groundwater discharge forms a principal part of a surface flow regime, surface water quality will be strongly influenced by groundwater quality (for example around the Kakanui River), allowing for an appropriate dilution factor. In other areas, where groundwater is relatively separate from surface water (for example the Papakaio Aquifer), surface water quality targets are less relevant. The loss of surface water flow due to depletion effects from groundwater pumping can also affect surface water quality.

While there are no specific limits for groundwater quality, there are numerical limits for nitrogen leaching that must be met for land use activities to be classified as permitted under Rule 12.C.1.3. These vary depending on the assessed sensitivity of the receiving environment. It is understood that these limits may be reviewed in some areas, if it is identified that lower limits may be required to meet surface water quality limits.

Chapter 7 includes policies that are relevant to groundwater and groundwater monitoring, in particular policies around items that ORC must have regard to in considering discharges and discharge consents. Policy 7.D.5(e) requires that trends in water quality of the receiving water environment relative to the Schedule 15 characteristics, limits and thresholds are considered.

Chapter 9 identifies issues describing how groundwater resources can become contaminated as a result of point source and non-point source discharges, accidental spills, land excavation removing protective strata in some areas and poor bore construction. It includes objective 9.3.3, which is to maintain the quality of Otago's groundwater. A review of monitoring landuse effects is not part of this report, however, it is important that changes in landuse are tracked as part of groundwater management to help identify areas which may come under pressure.

Groundwater quality monitoring that is required to achieve the water quality objectives are summarised in Box 3:

Box 3: Groundwater quality monitoring required as a result of objectives and policies for groundwater quality:

- Groundwater quality that supports human use values includes drinking water supply for both domestic use and for public supply use. To meet the objective of allowing discharges while maintaining water quality that supports natural and human use values will require groundwater quality monitoring to ensure it remains within at least the drinking water standards.
- Consideration of trends in groundwater quality in the context of discharges to surface water requires regular, long term monitoring for likely groundwater contaminants, such as nitrate from representative sites within an aquifer.
- In aquifers where there is a connection to surface water bodies, monitoring will be required to help determine the impact of groundwater quality on surface water bodies.

2.5 Summary of groundwater data collection requirements

As discussed above, groundwater data collection requirements will vary from aquifer to aquifer, although there is a level of baseline monitoring that will be required in all aquifers. Many aquifers will require additional monitoring beyond that baseline because of particular objectives that have been set for individual areas. Likewise, some aquifers will require additional data to be collected because data is required to set those objectives.

In that respect, the key questions this review aims to answer for each aquifer are:

- Does the existing data collection programme cover the minimum required to meet the objectives of the relevant documents?
- Is the data collection programme that occurs across each aquifer sufficient to assess whether the objectives and any associated limits that have been set are being achieved?
- If no limits have been set, is the information and data collection programme available sufficient to help determine those individual limits?
- Is there sufficient information available in each aquifer to provide information regarding the state of the environment?

3.0 Current limits

The NPS-FM requires groundwater quantity and quality limits to be set to achieve set objectives and their associated values. Data collection is required to monitor progress towards, and achievement of, freshwater objectives. Due to this requirement, relevant groundwater limits in the Otago Region are discussed here.

Table 1 (Appendix A) summarises where groundwater quantity limits have been set for each aquifer and the status of those limits. The source of the information in regarding targets in Table 1 is from the ORC Long Term (2015-2025) and Annual (2017-2018) Plans and the ORC website. Section 3 of this report evaluates the monitoring available for each aquifer individually and comments on whether that data is sufficient.

Processes are also underway to set groundwater quality limits for different Otago aquifers, as aquifer concentration limits in Table 15.3 of the Regional Plan. The surface water quality limits the Regional Plan, which are set as concentrations, in are also relevant to groundwater, where changes in groundwater quality have the potential to affect surface water quality in the water bodies identified.

4.0 Available data and evaluation of current monitoring

The following sections summarise and discuss each individual aquifer, the limits set and the monitoring available for that aquifer. Detailed information sheets for each aquifer are provided in Appendix A.

Note that in some aquifers (listed in Schedule 2C of the Regional Plan for Water), groundwater takes are treated as surface water takes, in terms of allocation. Those aquifers include:

- Kakanui – Kauru Alluvium Aquifer
- Shag Alluvium Aquifer
- Lindis Alluvial Ribbon Aquifer
- Cardrona Alluvial Ribbon Aquifer
- Lowburn Alluvial Ribbon Aquifer
- Pomohaka Alluvial Ribbon Aquifer

In these aquifers, it is generally considered that the surface water quality is of greater relevance than groundwater quality, due to the generally lower concentration thresholds applied to protect instream values. This generally indirectly protects human health. ORC are currently undertaking a separate review of surface water monitoring.

Although groundwater monitoring is therefore considered less important in these locations, individuals will still need to undertake their own monitoring and provide appropriate treatment, for example to ensure their supplies are not affected from microbial contamination, and ORC will still need to ensure land use and discharge effects are appropriately controlled to protect effects on supply bores. Likewise, the surface water quantity (flow) limits are applicable due to the close hydraulic connection with groundwater, so groundwater level monitoring is also considered less important. Comments on the monitoring data available for those aquifers is included in the information sheets in Appendix A, but they are not discussed in the main body of this report.

Based on the available information, groundwater quality monitoring bores are sampled for the typical parameters used as part of a potable water test including:

- Alkalinity (HCO_3)
- Alkalinity Total
- Boron
- Calcium Dissolved
- Chloride
- Conductivity (field)
- Conductivity (lab)
- E.Coli (included as a standard parameter since May 2017)
- Free Carbon Dioxide
- Iron Dissolved
- Magnesium Dissolved
- Manganese Dissolved
- Nitrate Nitrogen
- pH
- pH (field)
- Potassium Dissolved
- Sodium Dissolved
- Sulphate
- Arsenic Dissolved
- Total Hardness

The data show that the following parameters are also included:

- Alkalinity Hydroxide
- Ammoniacal Nitrogen
- Carbonate Alkalinity

- Dissolved Reactive Phosphorus
- Water temperature

That list of parameters is in line with the general requirements in the relevant regulations described in Section 2.0 and is therefore considered appropriate.

4.1 North Otago Volcanic Aquifer

The North Otago Volcanic Aquifer, which is referred to as NOVA, consists of a variety of different sediments, including the Waireka tuff, Totara and McDonald Limestones and Deborah Volcanics. The sediments were deposited at similar times and the stratigraphic divisions between them are seldom precise. The different sediments share similar groundwater flow patterns and are therefore grouped together as the NOVA. The NOVA is underlain by the Kauru formation.

Groundwater within the NOVA is recharged principally via rainfall groundwater flow directions generally follow topography. In the north of the area, groundwater generally flows east towards the coast, but to the south of the area flow direction are shifted to the south where groundwater discharges into the Waireka Creek and Kakanui River. Depth to groundwater in the strata can be variable, but is often in the order of 10 m below ground level. Pumping tests in the aquifer indicate transmissivity values of around 100 m^2/day but also often show dual porosity characteristics.

Groundwater in the aquifer is used for irrigation, domestic supply as well as commercial uses. Groundwater use is concentrated in the area around bore J41/0178 (Deborah at Websters), but use also occurs towards the northwest of the catchment as well as in the area between the Waireka Creek and the Kakanui River.

4.1.1 Existing values, objectives and limits

The current limits for the NOVA were based on recommendations in a 2008 report published by ORC (Rekker, Houlbrooke, & Gyopari, North Otago Volcanic Aquifer Study, 2008). That report describes the objectives of groundwater allocation in the NOVA as:

> *'… groundwater allocation management practices have been to avoid the possibility of seawater intrusion across the coast line, avoid problematic decline in groundwater levels and maintain the beneficial seepage outflows into Waiareka Creek, Awamoa Creek, Oamaru Creek Catchment, plus the Kakanui Alluvium.'*

Schedule 3 of the Plan also notes that groundwater from the NOVA is used for irrigation, which is a use that should '*…be given appropriate protection in managing the taking of water…*'.

Trigger levels

The trigger levels set in the NOVA are based on the results of computer modelling. The bore used (J41/0178, Deborah at Websters) was selected based on its location in the centre of the dominant areas of abstraction and its longer term record (since 1987). The trigger level in the bore is set at 25 m above mean sea level. The trigger level is set to allow exploitation of the resource during periods of low recharge, whilst preventing excessive groundwater level decline. It is not clear from the report what the impact of the trigger level would be on groundwater discharge (i.e. flows in Waiareka Creek, Awamoa Creek, Oamaru Creek and the Kakanui Alluvium).

The 2008 report also suggests that additional continuous monitoring bores should be developed close to the Kakanui mouth and the area north of Weston. It is not clear whether those bores have been added to the monitoring network, although there are additional water quality monitoring bores located close to the Kakanui mouth (J41/0126), where data is available since 2010.

Allocation limit

An allocation limit of 7 x10^6 m^3/year is set for the NOVA, which is based on 35 % of the average annual recharge. The allocation is based partly on relatively small outflows (relative to the mean river flow) to the Kakanui Alluvium and Waiareka Creek, as well as modelled assessments of limited groundwater discharge offshore.

Water quality

No water quality limits are set for the NOVA in Schedule 15 (Table 15.3), although limits around leaching from land use across the aquifer are set to 30 kg nitrate nitrogen per hectare per year (as a permitted activity limit). There are areas of high nitrate nitrogen concentrations within the aquifer, with some areas showing concentrations that are in excess of the drinking water standard (more than 20 mg/L in bores J41/0008, located roughly in the central part of the aquifer and bore J42/0126, located close the Kakanui mouth). That pattern has been reportedly stable for around 30 years.

4.1.2 Current monitoring

- Groundwater levels

Groundwater levels are currently monitored continuously in bore J41/0178 (Deborah at Websters), which represents the aquifer trigger level and groundwater level data is also available for bore J41/0198 (Waireka at Isbisters). Data is available from bore J41/0178 between 1987 and 2017 and the bore is currently telemetered, recording groundwater levels every 15 minutes.

A detailed record is available for bore J41/0198 from 1997 until 2017.

- Groundwater quality

Groundwater quality monitoring is currently undertaken in three bores on a quarterly or six monthly basis and a comprehensive suite of parameters are analysed. The three bores are located south-west of Oamaru and towards the discharge points of the Kakanui Alluvium and the Waiareka Creek. We also note that not all the water quality monitoring bores in this aquifer include analyses for E.Coli, although from May 2017 E.Coli will be part of the standard suite of parameters for water quality monitoring.

4.1.3 Assessment of monitoring

Monitoring in the NOVA is generally consistent with the requirements in both the NPS-FM and the Regional Plan: Water, as well as the objectives defined in the ORC report regarding the aquifer. It is considered that groundwater level monitoring occurs in generally appropriate bores within the aquifer to monitor the effect of groundwater abstraction on long term groundwater levels and on outflow to the coast and seepage to receiving water ways. There are a number of relatively large groundwater take consents in the north of the area, where no groundwater level monitoring occurs. If further resource development occurs in that area, additional monitoring may be warranted to monitor the state of the environment in that area.

There is groundwater quality monitoring in a number of locations located towards the main groundwater discharge points from the aquifer. That groundwater quality monitoring will allow an assessment of the potential effect of groundwater quality on surface water quality where required. However, in a similar way to groundwater level monitoring, if further development occurs in the north of the area, some additional groundwater quality monitoring may be required.

It is considered that the current water level limits set for the aquifer can be achieved with the existing monitoring. In terms of water quality, monitoring directed specifically towards saline intrusion around the mouth of the Kakanui River may be prudent. However, we understand that monitoring is being investigated as part of a separate project looking at groundwater surface water interaction along the Kakanui River.

The water quantity limits for the aquifer are based on the results from a groundwater model, which was calibrated to groundwater level measurements. In general, groundwater models calibrated to groundwater heads are suitable for predicting groundwater heads, so the groundwater model is considered fit for purpose and the groundwater trigger levels are therefore likely to be reasonably robust. The overall allocation limit was set based on the modelled outputs indicating that saline intrusion was a lower risk apart from the area around the Kakanui River mouth and likewise, that conclusion is based on groundwater levels which appear reasonably robust.

No limits are set in terms of surface water- groundwater interaction and the default position based on the plan is to ensure that the interaction is adequately understood. The interaction between the main surface water courses in the NOVA area appears to be reasonably understood and represented in the computer model of the area. However, we note that the model is not calibrated to surface flows; therefore, if limits are set on groundwater-surface water interaction in future the model should be updated to include groundwater-surface water interaction in its calibration.

4.2 Lower Waitaki Plains aquifer

The Lower Waitaki Plains aquifer represents alluvial deposits that occur on the south side of the Waitaki River. The aquifer is bounded to the north by the Waitaki River and to the south by the low permeability basement strata. The coast forms the eastern boundary of the aquifer. The Lower Waitaki Plains generally consist of a relatively thin veneer (around 10 m thick) of Quaternary deposits, although the plains are underlain by a significant tectonic controlled trench, which is infilled with older, Pleistocene aged, gravels. That trench is underlain by low permeability basement strata.

Groundwater flow is generally towards the coast, sub parallel to the line of the Waitaki River, which reportedly forms a key discharge point for shallow groundwater. According to SKM (2004) groundwater discharge is roughly evenly split between discharge to the Pacific Ocean and discharge into the Waitaki River. Some groundwater also discharges into Welcome Creek.

Groundwater in the area is reportedly shallow and the piezometric surface generally follows surface contours. Groundwater is generally used for irrigation, although domestic supplies are also sourced from shallow groundwater.

4.2.1 Existing values, objectives and limits

Individual limits have not been set in the RPW for the lower Waitaki plains aquifer however a maximum annual limit has been proposed based on the total of rainfall recharge, irrigation losses and recharges from streams and rivers. The proposed MAL is 115.85 $x10^6$ m^3/year. Rainfall recharge is around 23.17 x 10^6 m^3/year and the total recharge is therefore strongly dependent on additional irrigation losses.

Trigger level limits are in the process of being developed for the aquifer.

Schedule 3 of the Plan also notes that groundwater from the Lower Waitaki Plains aquifer is used for irrigation and also human consumption without treatment. As a result, maintaining groundwater within the limits for drinking water will be important.

4.2.2 Current monitoring

- Groundwater levels

Groundwater levels are monitored in bore J41/0377 (Dennisons) located towards the coastal edge of the aquifer. Data is available for that bore since 1997 until the present and is monitored via telemetry at 15 minute intervals. The available data suggests generally stable groundwater levels with 1 to 2 m seasonal variations.

- Groundwater quality

Groundwater quality data is available from a number of bores across the aquifer, but regular (approximately quarterly) monitoring occurs in J41/0317 (data from 1993 to 2017) located 1.5 km south-west- of the township of Waitaki Bridge. Monthly monitoring data is available from bores J41/0442, J41/0586, J41/0571 and J41/0576 and since August 2016.

4.2.3 Assessment of monitoring

The monitoring that is undertaken across the Lower Waitaki Aquifer is consistent with the minimum monitoring that is required for all aquifers. The groundwater level monitoring bore is considered to provide a reasonable representation of groundwater levels in the alluvial deposits. Due to the stable record in this bore and permeable nature of the groundwater resource, and limited groundwater allocated relative to the estimate maximum annual limit, it is considered that continuing with one groundwater level monitoring bore is sufficient at this stage.

Relatively little consented abstraction occurs from the aquifer, although there are a number of domestic supply bores and the aquifer is used as a source of drinking water supply. Therefore, monitoring groundwater quality is important, particularly as there is extensive irrigation across the area, and landuse effects on water quality may be important. The existing groundwater quality monitoring is considered sufficient and consistent with the RPW and NPS requirements.

4.3 Papakaio Aquifer

The Papakaio Aquifer is hosted within the Taratu Formation, which unconformably overlies the Rakaia Terrane basement strata and is up to 120 m thick, but typically less than 50 m thick. The Taratu Formation is overlain by the Kauru Formation, particularly in the south of the area, where the Kauru Formation can be up to 70 m thick and heavily confines the aquifer, which can be more than 400 m deep towards the coast. The Kauru Formation is overlain by the North Otago Volcanics towards the eastern part of the area, towards the coast. The aquifer is split into a number of fault controlled blocks which may separate and restrict groundwater movement between the different aquifer zones.

As a result of faulting, there is no single groundwater flow direction within the aquifer. The aquifer system in the southern zone, abutting the coast, may be blind and no groundwater movement occurs under a natural setting. However groundwater movement and active recharge may occur in the northern zones, where some active interaction (i.e. groundwater discharge) occurs with the Maerewhenua River. Strongly above surface artesian groundwater pressures are present in the southern zone and Enfield Zones, particularly towards the middle of the area, and above surface artesian pressures are also present in parts of the Enfield Basin. Those high pressures, coupled with very evolved groundwater has resulted in a characteristic and corrosive groundwater chemistry, which has contributed to the deterioration of a number of deeper bores in the aquifer, resulting in leakage to the surface.

Groundwater abstraction from the aquifer occurs, with the greatest use for irrigation.

4.3.1 Existing values, objectives and limits

Specific limits have not yet been set in the Regional Plan: Water for the Papakaio Aquifer and as a result the default allocation limit is 50 % of the average annual recharge. Trigger level limits have not been set for any of the different aquifer blocks.

Groundwater in the Papakaio Aquifer is listed as being used for irrigation in Schedule 3 in the Regional Plan: Water, implying that value should be protected in managing the allocation of water from the strata.

4.3.2 Current monitoring

- Groundwater levels

Groundwater monitoring across the Papakaio Aquifer is limited, which largely reflects the significant depth of the aquifer in some areas as well as difficulties in installing adequate monitoring bores. No continuous groundwater level recorders are located within the aquifer blocks and manual monitoring data is only available up to 2008. We understand from ORC that further monitoring is planned for the aquifer, particularly in the Enfield and Southern blocks.

- Groundwater quality

Very limited groundwater quality data is available for the Papakaio Aquifer.

4.3.3 Assessment of monitoring

Existing monitoring in the Papakaio Aquifer is not sufficient and does not meet the minimum requirements under the RPW or the NPS-FM. Insufficient information is available to determine limits or to provide information regarding the state of the environment.

4.4 Kakanui-Kauru Alluvium

The Kakanui Kauru Alluvial Aquifer is hosted within shallow, thin alluvial strata around the Kakanui River, which are underlain by low permeability mudstone of the Kauru Formation, and, in some areas, the North Otago Volcanics and the Taratu Formation (which includes the Papakaio aquifer), both of which are likely to discharge some water into the Kakanui River (particularly around the estuary) and tributaries to the Kakanui River such as the Waireka River. Typical thicknesses of gravels are around 5 m to 6 m. Groundwater is shallow, and the saturated thickness of the alluvial gravels is typically around 4 m to 5 m.

Broadly, the conceptual model of the Kakanui River is that it is subdivided into a series of basins, defined based on the pattern of losing and gaining reaches in the river. Streamflow is lost to the alluvial aquifer at the upstream end of each of the basins before returning to the river at the downstream end of each basin. Groundwater levels in the alluvial strata that make up the aquifer in each basin respond rapidly to increases in river flow, with a recharge front moving through the groundwater systems from the top of each basin towards the downstream end. At times of river flow recession, the system drains progressively from the lower end of the basin towards the top.

The movement of groundwater through the system means that nutrients that accumulate in the unsaturated zone during river flow recession can be mobilised during high flow events. Nutrients can then be transported through the aquifer towards the river during subsequent river flow recession, potentially resulting in relatively high concentrations of nutrients in groundwater discharging to the river, when less river water is available to dilute the effects.

There are a number of consented groundwater takes in the alluvium, the majority of which are used for irrigation, however other domestic takes are also present. Groundwater abstractions are restricted based on river flows at various points along the river due to the close connection between the river and groundwater in the alluvium.

4.4.1 Existing values, objective and limits

Limits, in terms of water quality, are in the process of development for the Kakanui – Kaurau Alluvium and the main driver for limit setting in the Kakanui-Kauru Alluvium is water quality in the river, which is strongly influenced by the water quality in the adjacent alluvial aquifer.

Groundwater allocation is tied to surface water limits, because all groundwater takes are managed as surface water abstractions. However, it is useful to note that, as a result, any groundwater allocation limits may also be influenced by concentration limits in groundwater and the river once those limits are defined.

4.4.2 Current monitoring

Intensive monitoring for both groundwater levels and groundwater quality in the aquifer has been carried out between May 2014 and May 2017. Groundwater levels and groundwater quality have been monitored in 15 different bores, five of which will include continuous water level recorders. Surface water sampling and flow rates are also recorded at a number of different locations.

4.4.3 Assessment of monitoring

The extent and frequency of monitoring in the aquifer meets the minimum requirements is expected to be sufficient to develop quality and quantity limits for the aquifer and to provide information regarding the state of the environment.

4.5 Hawea Basin Aquifer

The Hawea Basin aquifer consists of a sequence of unconsolidated gravels, moraine and glacial tills. The unconsolidated strata overlie low permeability basement strata and can be more than 100 m thick, although based on structure contours in Heller (2003), are more often around 50 m thick.

The Hawea Basin aquifer has been subdivided for management purposes into a series of separate domains, based on topographic and surface water boundaries. Movement of groundwater in the overall aquifer is partly driven by seepage from Lake Hawea, as well as runoff and land surface recharge across other parts of the area. Groundwater in the aquifer eventually discharges into the Clutha River and the overall flow direction is to the south-west. Groundwater depths vary; groundwater is typically shallower around the northern Hawea Flats (around 5 to 10 m deep), but can be much deeper around the southern part of the aquifer, where the topography rises into the Hawea Terrace (more than 20 m deep). The aquifer is well connected to the Clutha River.

Groundwater use is greatest across the Hawea Flats area, with relatively limited use across the rest of the aquifer to the south. The majority of bores are used for domestic supply, although in terms of volume, the greatest use is for irrigation. The consented use is around 9.25 x 10^6 m^3/year (2014 data) across the whole aquifer, although the majority of that use is in the Hawea Flats, Hillside Domain Existing values, objectives and limits

An ORC report describing the Hawea Aquifer defined a number of groundwater values, including:

- Campbells Reserve Wetland and
- Butterfield Wetland, which are two of a number of regionally significant wetlands identified in the Otago Regional Plan: Water; and
- shallow bores in the Hawea Flat area, a number of which are used for irrigation and/or domestic supply purposes.

Whilst values have been identified for the aquifer, specific objectives and allocation limits have not yet been set in the plan to protect those values. However, proposed allocation limits have been developed, which were specifically targeted to protect levels at Campbells Wetland and groundwater levels in the Hawea Flat area, although there is some uncertainty around the connection between Campbells Wetland and groundwater.

4.5.1 Current monitoring

- Groundwater levels

Groundwater levels are currently monitored at two locations, both within the Hawea Flats Domain. The groundwater level records from both are relatively short (less than three years) and extend from July 2014 to the present day and are continuously telemetered to ORC. Some further groundwater level monitoring occurs around the Campbells Wetland as part of a consent condition, which will continue until 2018.

- Groundwater quality

Groundwater quality in the basin is monitored at three locations at quarterly intervals, all of which are in the Hawea Flats Domain.

4.5.2 Assessment of monitoring

The existing monitoring covers the minimum requirements to meet the objectives of the RPW and NPS-FM, with some exceptions.

The existing groundwater level monitoring will be used as part of a calibration dataset for a transient groundwater model, which will subsequently be used to determine allocation limits to protect users in the Hawea Flats Domain (note that the original limits were based on a steady state groundwater model).

The groundwater level monitoring available is considered appropriate to determine an allocation limit for the Hawea Flats area and the area around the Campbells wetland while monitoring continues.

Likewise, groundwater quality monitoring is considered appropriate to identify any effects on groundwater quality around the Hawea Flats Domain (where most abstraction for domestic supply occurs), however, some groundwater quality monitoring may be required to determine effects across the Hawea Terrace and around the wetland.

Monitoring is sufficient to provide information regarding the state of the environment.

The Hawea basin was included in the list of High Priority area for risk due to groundwater contamination as a result of septic tank leachate, although part of the township is reticulated to a wastewater treatment plant.

4.6 Wanaka Basin and Cardrona Gravel Aquifer

The Wanaka Basin and Cardona Gravel Aquifer covers a sedimentary basin consisting of gravel dominated strata downstream of the Larches flow recorder on the Cardrona River. The aquifer is bounded the Clutha River to the north-east and Lake Wanaka to the north-west. Lower permeability basement strata form the boundary to the basin to the south-east. The gravels have been reworked and various depositional phases have occurred as a result of glacial retreats and advances, as well as deposition by the Clutha River and the resulting gravels are, in detail, relatively complex. However at a broader scale they behave as a relatively consistent unit. Two outliers of basement strata also occur within the basin.

Groundwater in the aquifer is dominantly recharged by seepage losses from the Cardrona River where it enters the basin, together with additional land surface recharge. Groundwater discharges from the aquifer directly into Lake Wanaka and via Bullock Creek into Lake Wanaka, and into the downstream reach of the Cardrona River and into the Clutha River. The detailed flow direction is therefore relatively complex, but generally groundwater flows in a northerly direction from the low permeability bounding hills towards the aquifer discharge points in the north. Groundwater depths vary, and around the Larches flow recorder where the Cardrona River enters the basin groundwater levels can be 20 to 30 m deep. However, towards the aquifer discharge points, around the Clutha and Lake Wanaka, groundwater levels are shallow and close to the surface.

Groundwater in the basin is used for a variety of purposes, including irrigation and domestic supply. Note that Wanaka township is supplied with water from Lake Wanaka. Groundwater across the aquifer is well connected to surface water bodies.

4.6.1 Existing values, objectives and limits

The proposed groundwater allocation limit for the Wanaka Basin-Cardona Gravel Aquifer is 5 x 10^6 m^3/year, which is based on in stream flow requirements for juvenile brown trout in the downstream reach of the Cardrona River. In effect the groundwater allocation limit is based on protecting ecological values in surface water receptors that are hydraulically connected to groundwater.

The allocation limit is based on the modelled results of a number of different groundwater abstraction scenarios and the effect of pumping on groundwater outflows to the Cardrona River. A detailed review of the groundwater model is outside the scope of this report, but we note that the groundwater model was calibrated to groundwater heads rather than surface water outflows, and that the groundwater level calibration dataset for the transient model was only based on one bore and four years of data. Some uncertainties may therefore be inherent in the model and it is not clear how those uncertainties are accounted for in the model predictions. We note that Bullock Creek is a surface waterway that rises due to spring discharge close to Wanaka township. Maintaining flow and water quality in Bullock Creek is recognised to be of high importance and some more detailed modelling may be required to better understand its sensitivity to land use changes and changes in recharge.

4.6.2 Current monitoring

- Groundwater levels

Groundwater levels are currently monitored at one location in the aquifer, at bore F40/0014 (Envirowaste Tip bore), which is approximately adjacent to the

Cardrona River. Water level records are available from that bore between 2001 and 2017.

- Groundwater quality

Groundwater quality data has been collected from three bores on a quarterly basis since 2010 and 2016. The three bores are located: close to Wanaka township, adjacent to the losing reach of the Cardrona River and around 1 km from the Cardrona River, just upstream of SH6.

4.6.3 Assessment of monitoring

The groundwater level monitoring available is considered to meet the minimum requirements, however some additional groundwater level monitoring around the downgradient reach of the Cardrona River (downstream of SH6) would be beneficial, because that may provide a better indicator of groundwater abstraction effects on the sensitive reach of the river that the proposed limit intends to protect.

Groundwater quality monitoring appears to be appropriate to meet the objectives and covers a reasonable spatial area of the aquifer. However some of the bores are relatively deep (e.g. bore F40/0206, 45 m deep) and may not represent groundwater quality that discharges into the Cardrona River. We note that nitrate nitrogen in that bore is low (<2 mg/L) so an additional bore may not yet be necessary provided the aquifer is not heavily stratified.

There are a number of abstractions and, potentially, domestic supply bores towards the eastern extent of the aquifer. No groundwater quality or level monitoring is available in that area and the effects of landuse on groundwater quality or abstraction on water level in that area may need some consideration if further development occurs.

4.7 Bendigo Tarras and Ardgour Aquifer

The Bendigo Tarras Aquifer is hosted with alluvial strata located close to the Clutha River. The strata includes highly permeable gravels located close to the Clutha River as well as less permeable silts and sands located further away from the river. Similarly, the Ardgour Valley Aquifer is characterised by alluvial deposits, but is not directly connected to the Lindis River.

Based on computer modelling, groundwater within the Lower Tarras aquifer is predominantly recharged by seepage from the Clutha River together with some land surface recharge. Groundwater flow directions are generally sub-parallel to the river and groundwater discharges back into the Clutha River in the downstream Bendigo Allocation Zone.

The aquifer thickness is variable, but relatively well defined based on geophysical and electrical resistivity assessments. The base of the aquifer is defined by silts and schists and can be more than 100 m thick, with the greatest thickness at the southern edge of the Lower Tarras Aquifer. Lesser thicknesses occur away from that area. Groundwater levels are typically around 25 m below ground level in the Lower Tarras Aquifer in bore G41/0211.

The confluence of the Lindis River and the Clutha River occurs at the downstream end of the Tarras Allocation Zone and the extent of surface flow within the Lindis River close to its confluence depends on local groundwater levels i.e. the Lindis River is well connected to local groundwater. Based on computer modelling, the Clutha River is also considered well connected to groundwater, although there are no pumping tests in the Lower Tarras Aquifer to confirm that.

Groundwater use is concentrated in the Bendigo Aquifer, with relatively limited consented abstraction from the Lower Tarras Aquifer. There is no consented abstraction from the Ardgour Valley Aquifer. The majority of groundwater use is reportedly for irrigation.

4.7.1 Existing values, objectives and limits

Allocation limits have been proposed for the Bendigo Tarras Aquifer, based on a reportedly acceptable modelled steady state groundwater level decline due to pumping of up to 1 m across the whole aquifer. It is not clear why a 1 m decline is appropriate, other than ensuring that abstraction from bores can continue, or how the decline is related to values defined for the aquifer or surface water receptors that may depend on groundwater discharge from the aquifer, for example the Bendigo wetland at the head of Lake Dunstan. Based on the modelling carried out to determine that groundwater allocation limit, the majority of abstraction would represent increased stream depletion effects from the Clutha River. Whilst no allocation limit is defined for the Clutha River, an allocation limit may also need to consider effects on the operation of hydropower stations along the river.

Given that some groundwater is used for drinking water supply, some values are therefore implied around maintenance of groundwater quality for drinking water.

4.7.2 Current monitoring

- Groundwater levels

No long term groundwater level monitoring is available for the Bendigo Tarras Aquifer.

- Groundwater quality

One bore, located within the Lower Tarras aquifer is monitored for groundwater quality. The bore (G41/0211) is monitored on a quarterly basis.

4.7.3 Assessment of monitoring

The absence of long term groundwater level monitoring information for the Bendigo, Lower Tarras and Ardgour aquifers means that monitoring is not consistent with the requirements of the NPS-FM and the Regional Plan: Water.

We understand that ORC have investigated the possibility of installed a dedicated monitoring bore but there have been difficulties in securing an appropriate site. However, given the absence of long term monitoring of groundwater levels, the effect of the proposed allocation limit cannot be observed and is entirely reliant on the accuracy of the groundwater model.

The absence of long term monitoring data also means that the groundwater model used to define allocation limits for the aquifer is subject to potentially wide uncertainties, which have not been quantified.

Groundwater quality information is restricted to a single bore located in the Lower Tarras Aquifer and groundwater quality monitoring may be suitable for the Lower Tarras aquifer, but the majority of groundwater use is in the Bendigo Aquifer and monitoring is needed in that aquifer. Whilst the majority of consented use is for irrigation, they are likely to be a number of domestic supply bores, and effects on groundwater quality around those takes are not monitored. Groundwater monitoring in the Bendigo Aquifer is not sufficient to meet the minimum requirements, nor is the monitoring available sufficient to determine limits for the aquifer or provide state of the environment trend data. Continued work to secure a suitable site to install a dedicated monitoring bore is recommended.

4.8 Pisa – Luggate – Queensbury Groundwater Management Zone

The Pisa – Luggate – Queensbury Groundwater Management Zone extends from the southern edge of the Wanaka Basin (around Luggate) and covers the western bank of the Clutha River to mid-way along Lake Dunstan.

The aquifer consists of Quaternary gravels overlying basement schist strata. Where the Clutha River has eroded down into the basement strata, the Quaternary Gravel Aquifers are effectively perched above the river. Whilst the strata may drain into the Clutha River, it does not gain water from the river. Recharge to the aquifer is from land surface recharge, as well as from stream losses where surface water runoff emerges from the lower permeability hills to the west. Groundwater within the strata is expected to generally flow towards the Clutha River, although the relationship between groundwater and the Clutha River is variable, with some areas of surface water loss from the river to groundwater and some areas of surface water gain from groundwater. Depths to groundwater vary, but in the water quality monitoring bore G41/0103, groundwater levels are around 17 m below ground level.

There are a number of consented groundwater abstractions in the zones and groundwater is used for a variety of purposes including irrigation and industry (quarrying) as well as domestic supply. The Bendigo Wetland is a regionally significant wetland at the head of Lake Dunstan.

4.8.1 Existing values, objectives and limits

Specific values are under development, the groundwater is taken from the aquifer for irrigation, domestic supply as well as commercial uses and some values are therefore implied around maintenance of groundwater quality for drinking water. The Bendigo Wetland at the head of Lake Dunstan is a regionally significant wetland that may be supported by groundwater discharge and ecosystem values for the creeks that cross the aquifers may also be important.

Likewise, specific allocation limits have not yet been set in the plan for these groundwater management zones. The estimated consented allocation is around 12.2 x 10^6 m^3/year and the holding Maximum Annual Limit is:

- *6.5 Mm^3/year for the Pisa zone,*
- *2.2 Mm^3/year for the Queensbury Zone and*
- *5.8 Mm^3/year for the Luggate Zone* .

Based on those limits ORC indicate that the Pisa zone is considered under allocated, the Queensbury Zone is considered over allocated and the Luggate Zone is considered under allocated.

4.8.2 Current monitoring

- Groundwater level monitoring

There are two current, dedicated groundwater level monitoring bores in the Pisa – Luggate – Queensbury Groundwater Management zone, which were installed in June 2017. Some groundwater level information is available from quarterly monitoring of groundwater quality in the Pisa Zone between 1996 and 2013 (bore G41/0103).

- Groundwater quality monitoring

There are two current, dedicated groundwater quality monitoring bores in the Pisa – Luggate – Queensbury Groundwater Management zone, which were installed in June 2017. These are the same as the groundwater level monitoring bores. One groundwater quality monitoring bore (G41/0103) was sampled on a quarterly basis between 1996 and 2013 in the Pisa Zone.

4.8.3 Assessment of monitoring

Based on the available data, there is insufficient information available to reasonably define limits for the aquifer. No long term water level monitoring data is available for any of the Zones, and only one (currently discontinued) groundwater quality monitoring site is available. However further data collection is underway in these aquifers and aquifer studies are expected to be released in June 2018.

4.9 Cromwell Terrace Aquifer

The Cromwell Terrace aquifer is made up of glacial outwash deposits located between the Kawarau Arm of Lake Dunstan and immediately upstream of the Kawarau- Clutha confluence. The edges of the aquifer are defined by the low permeability hill strata to the north and surface water bodies to the west, south and east. The overall Cromwell basin is asymmetric, with the greatest depth towards the hill strata (over 350 m) and thinning towards the Clutha River and Lake Dunstan. Groundwater within the basin is relatively deep, around 20 m below ground level, which reflects the close connection with the topographically lower Lake Dunstan.

Groundwater in the aquifer drains generally south-east towards Lake Dunstan and is recharged via a combination of land surface recharge, inflow from the Kawarau Arm and infiltration of irrigation applied at the surface of the aquifer. However, some seepage of water from Lake Dunstan into the aquifer also occurs because the aquifer is strongly connected to the lake and groundwater abstraction can induce recharge from the lake into the aquifer.

Groundwater abstraction from the aquifer is predominantly used for irrigation and public supply and the total consented allocation was around 1.7×10^6 m^3/year in 2012. Groundwater abstraction occurs across the aquifer and the strata can be highly permeable with pumping tests showing transmissivity values of up to 14,000 m^2/day.

4.9.1 Existing values, objectives and limits

Limits for the Cromwell Terrace aquifer are set within the Regional Plan: Water, where the maximum annual volume is 4×10^6 m^3/year and restrictions may also be imposed on takes based on levels in Lake Dunstan. The value of the maximum annual volume is based on a computer model scenario where abstraction was increased to three times the fully allocated rate (3.9×10^6 m^3/year), which resulted in around 0.15 m of groundwater level decline at the groundwater level monitoring bore F41/0171 on average.

Based on the ORC Technical Report for the Cromwell Terrace Aquifer (Rekker, 2012), a decline of 0.15 m was not expected to restrict the ability of bores to take water from the aquifer, and therefore was acceptable. No other values were defined for the aquifer in the report.

4.9.2 Current monitoring

- Groundwater level monitoring

No long term groundwater level monitoring is currently available for the aquifer.

- Groundwater quality monitoring

Groundwater quality is monitored in bore F41/0300 at quarterly intervals.

4.9.3 Assessment of monitoring

No dedicated groundwater level monitoring is currently available for the Cromwell Terrace Aquifer. However, groundwater level data is collected from the groundwater quality monitoring bore, which provides a general indication of longer term trends and may be sufficient until allocation from the aquifer increases, particularly as groundwater levels in the aquifer are strongly connected with levels in Lake Dunstan.

Groundwater quality information is available from a single bore and groundwater across the aquifer is used for domestic supplies as well as irrigation (although the town of Cromwell is supplied via a dedicated bore field and a networked rural supply scheme is also reportedly present (Rekker, 2012). Given the depth to water in the aquifer and the location of the monitoring bore in the centre of the aquifer, that is considered to be sufficient to meet the minimum requirements and also ensure that values associated with maintaining groundwater quality for drinking water supply are protected.

4.10 Earnscleugh Terrace Aquifer

The Earnscleugh Terrace Aquifer originates from a glacial outwash following the Albert Town glacial advance and primarily consists of sandy gravels. The base of the aquifer consists of very low permeability silt and mudstone of the Manuherikia Group which is underlain by basement schist of the Torlesse supergroup. The aquifer is raised above the Clutha River and is considered not to have a direct connection with that surface waterway.

Recharge to the aquifer is predominantly from the Fraser River which loses a substantial proportion of its flow to the aquifer as it crosses the permeable surface of Eurnscleugh Flat. Irrigation losses, leakage from water races and a small amount of excess rainfall also contribute to aquifer recharge. Groundwater generally flows from the north-west to the south-east and discharges into the Clutha River via seepage and springs as well as via upward seepage of aquifer water into the Lower Fraser River immediately upstream of the confluence with the Clutha River. The depth to water across the aquifer varies from around 20 m in bore G42/0119 (in the north of the aquifer) to around 10 m below ground in bore G42/0190 (closer to the Fraser River, towards the south of the aquifer).

Groundwater use across the aquifer is generally for irrigation and domestic supplies and around 0.5 x 10^6 m^3/year is allocated across the Earnscleugh Aquifer. The aquifer is highly permeable but groundwater use is limited due to the extensive network of water races derived from surface water.

4.10.1 Existing values, objectives and limits

Allocation limits have been proposed for the Earnscleugh Terrace Aquifer, based on 50% of Mean Annual Recharge. The estimated mean annual recharge for the aquifer is 25.49 Mm^3 of which 24.60 Mm^3 is associated with downward infiltration of Fraser River water. This results in an allocation limit of

12.75 Mm^3/year for the aquifer which compares to a consented allocation of 0.514 Mm^3/year (Otago Regional Council, 2012).

Trigger level limits have not been set for the aquifer.

The discharge of groundwater into the Fraser River close to its confluence with the Clutha River means that values and objectives and limits for that reach of the Fraser River are relevant, in particular the volume of discharge at low flows. In addition, groundwater quality is important for drinking water supplies, as well as in terms of groundwater quality discharging into the Fraser River.

4.10.2 Current Monitoring

- Groundwater level monitoring

Groundwater level monitoring was undertaken in one bore between February 1993 and October 1999. There is no current groundwater level monitoring in the Earnscleugh Terrace Aquifer.

- Groundwater quality monitoring

There are two monitoring bores with historical groundwater quality information in the Earnscleugh Terrace Aquifer. Bore G42/0119 (37.8 m deep) and bore G42/0190 (21.3 m deep) were sampled for a comprehensive suite of parameters at quarterly intervals between 1996 and 2013. There is no current groundwater quality monitoring in the Earnscleugh Terrace Aquifer.

4.10.3 Assessment of monitoring

The historical groundwater level and water quality monitoring in the Earnscleugh Terrace Aquifer was appropriate. Whilst groundwater level information is currently not collected from the main aquifer the groundwater allocation is very small compared to the allocation limit. It may be prudent to re-instate groundwater level monitoring if increased abstraction from the aquifer is expected.

Given that water in the aquifer is used for drinking water supply, it is considered that there may be some incentive to re-instate the groundwater quality monitoring. Considering the main recharge source for the aquifer is the Fraser River a limited groundwater quality sampling regime may be appropriate in combination with regular water quality monitoring of the Fraser River to ensure that the limits for the Fraser River are not adversely affected by groundwater discharge.

4.11 Dunstan Flats Aquifer

The Dunstan Flats Aquifer primarily consists of sandy gravels which, as for the Earnscleugh Terrace Aquifer, originate from glacial outwash following the Albert Town glacial advance. In contrast to the Earnscleugh Terrace Aquifer the outwash gravels are underlain by older gravels from the early quaternary period.

The aquifer is strongly connected to the Clutha River and groundwater contours imply that groundwater flows from northeast to the south-west directly into the river. High river levels temporarily boost the water table along riparian strips of the aquifer and sustained low river levels can lower the water table over the whole aquifer.

Groundwater levels in the aquifer are typically relatively deep, around 20 to 25 m below ground level. Groundwater use is concentrated towards the centre of the aquifer, close to the river. Consented abstraction is around 1.43 x 10^6 m^3/year, of which around 0.43 x 10^6 m^3/year is used. Groundwater use is mostly for irrigation, with some domestic use. The strata are permeable based on aquifer tests indicating transmissivities of 1,250 to 7,000 m^2/day.

Recharge to the aquifer is predominantly from water race losses and subsurface flow from the adjoining Manuherikia Claybound Aquifer. A small amount of recharge is also received from rainfall excess and irrigation as well as downward infiltration of Waikerikeri Creek water into the Dunstan Flat Aquifer.

Groundwater in the Dunstan Flats Aquifer is discharged into the Clutha River via seepage.

4.11.1 Existing values, objectives and limits

Based on a water balance assessment carried out by Otago Regional Council (2012) a default allocation limit based on 50 % of mean annual recharge was calculated. The mean annual recharge for the aquifer is estimated to be 3.68 Mm^3/year resulting in an allocation limit of 1.84 Mm^3. The current consented allocation is 1.45 Mm^3. It is noted that the current main source of recharge (leaky water race systems was not included in calculating the mean annual recharge as these are likely to be replaced by pipelines in the future.

Trigger level limits have not been set for the aquifer.

Groundwater use in the Dunstan Flats Aquifer is predominantly for irrigation and drinking supply with a smaller number of takes for frost fighting, commercial/industrial use, recreation and stockwater supply. The Dunstan Flat Aquifer is the most intensively utilised aquifer in the Alexandra basin.

Considering the use of water for drinking water adequate groundwater quality and drinking water standards are relevant.

4.11.2 Current Monitoring

- Groundwater level monitoring

Regular groundwater level monitoring is undertaken in bore G42/0695 (Dunstan Flat at Muttontown, 17.85 m deep).

- Groundwater quality monitoring

There are two monitoring bores with groundwater quality information in the Dunstan Flat Aquifer. Bore G42/0150 (located towards the northern edge of the aquifer, 35.0 m deep) and bore G42/0160 (located towards the centre of the aquifer, 32.3 m deep) are currently sampled at quarterly intervals for a comprehensive suite of parameters.

4.11.3 Assessment of monitoring

The monitoring that is undertaken in the Dunstan Flats Aquifer is consistent with the minimum water quality monitoring required for groundwater and is also sufficient to achieve the limit set for the aquifer.

4.12 Manuherikia Claybound Aquifer

The Manuherikia Claybound Aquifer consists of Quaternary aged alluvial deposits, which fall into two distinct groups. The northern area covers the Waikerikeri alluvial fan is made up of older outwash fans, which have been weathered and geochemically altered resulting in a lower permeability claybound structure. In contrast, the same weathering does not appear to have occurred in the formations to the south which represent the Lindis outwash that makes up the 'Airport Terrace' and the Letts Gully Road area. The Lindis outwash parts of the Manuherikia Claybound Aquifer are more permeable.

The depth to groundwater in the northern part of the aquifer is generally shallow, but much greater (up to 60 m deep) across the Lindis outwash gravels which may reflect the greater permeability of those deposits. The overall groundwater flow direction is to the south-west and there is considerable throughflow from the Manuherikia Claybound aquifer to the adjacent Dunstan Flats aquifer. However, some seepage also occurs into the Manukerikia River to the southeast.

Groundwater use is limited across the aquifer with the total consented groundwater allocation at around 0.5 x 10^6 m^3/year which is used for drinking water supply and some irrigation.

4.12.1 Existing values, objectives limits

The mean annual recharge for the Manuherikia Claybound Aquifer was estimated to be 1.56 Mm^3 (excluding water race losses) by the Otago Regional Council (2012). The current consented allocation is 0.68 Mm^3/year.

Trigger level limits have not been set for the aquifer.

Groundwater use in the Manuherikia Claybound Aquifer is predominantly for drinking water supply, irrigation, commercial/industrial and stockwater supply.

4.12.2 Current Monitoring

- Groundwater level monitoring

There are no current groundwater level monitoring bores in the Manuherikia Claybound Aquifer.

- Groundwater quality monitoring

There are two monitoring bores that are currently monitored for groundwater quality in the Manuherikia Claybound Aquifer. Bore G42/0123 (32.4 m deep) and bore G42/0290 (16.1 m deep) are monitored quarterly for a wide range of parameters.

4.12.3 Assessment of monitoring

The Manuherikia Claybound Aquifer discharges in the Dunstan Flats aquifer and the Manuherikia River. That discharge/throughflow into the Dunstan Flats aquifer forms an important part of the Dunstan Flats Aquifer water balance, and the groundwater allocation volume for the Dunstan Flats Aquifer. That throughflow will depend on groundwater levels, and whilst the Manuherikia Claybound Aquifer is stratified, which makes representative groundwater monitoring difficult, some groundwater monitoring is required to ensure that groundwater level remain stable and the throughflow is maintained. One option may be to use groundwater level monitoring in the Dunstan Flats Aquifer as a proxy for representative groundwater levels in the Manuherikia Claybound Aquifer.

Groundwater quality monitoring is considered to be appropriate for this aquifer. The two monitoring bores are located within the more permeable strata and will provide a useful indication of potential effects on the groundwater in the parts of the aquifer that are more often utilised for drinking water supplies, and on the quality of groundwater that discharges to the Manuherikia River.

4.13 Manuherikia Alluvial Aquifer

The Manuherikia Alluvium Aquifer is a small, thin, alluvial aquifer system located north of Alexandra township and covers the area adjacent to the Manuherikia River. The aquifer is closely connected to the Manuherikia River and is comprised of shallow quaternary alluvial sediments.

The aquifer receives a high proportion of recharge from waterway and irrigation losses from the Galloway Irrigation Scheme and ultimately discharges into the Manuherikia River. Storage in the aquifer is limited as a result of the shallow extent of the deposits, and groundwater levels are typically close to the surface around the river. Groundwater flow directions are not defined, but are expected to be towards the south –east, subparallel to the river.

Groundwater level and quality monitoring in the aquifer is sufficient, with a small amount of consented abstraction currently occurring in the area. However, the aquifer is used for domestic and stock supplies.

4.13.1 Existing values, objectives and limits

Whilst the aquifer is not specified in Schedule 3A listing human uses of aquifers, the aquifer is used for domestic and stockwater supplies. Therefore water quality in the aquifer is an important value and maintaining the water quality is an objective for the aquifer.

The Manuherikia Alluvial Aquifer has an allocation limit of 0.7 x 10^6 m^3/year, which accounts for irrigation excess recharge as well as rainfall recharge across the aquifer. Current consented abstraction is below that limit and the aquifer is under-allocated. However, new abstractions will need to consider stream depletion effects on the Manuherikia River.

4.13.2 Current monitoring

- Groundwater levels monitoring

Groundwater levels are monitored in one bore (G41/0152, Galloway bore, 10 m deep) located in the centre of the aquifer.

- Groundwater quality monitoring

Groundwater quality is currently monitored at quarterly intervals in two locations (G42/0283 and G46/0152, Galloway Bore) and groundwater quality has been previously monitored in G42/0282. All three bores are around 10 m deep and represent shallow groundwater quality.

4.13.3 Assessment of monitoring

Sufficient groundwater level and quality monitoring occurs in the Manuherikia Alluvial Aquifer to manage the aquifer. Groundwater in the aquifer is closely connected to the river, and therefore changes in river water quality and levels may also reflect changes in the aquifer.

4.14 Roxburgh Basin Aquifer

The Roxburgh Basin Aquifer is an alluvial aquifer located either side of the Clutha River, upstream of Roxburgh township. The Roxbugh Aquifer is split into two parts; the Roxbugh East aquifer represents the alluvial strata on the eastern (true right) bank of the Clutha River, and the Roxburgh West Aquifer represents the alluvial strata on the west (true left) bank of the Clutha River.

Groundwater in the Roxburgh East aquifer is largely derived from rainfall recharge, with few other sources of water seeping into the aquifer. That is partly due to the network of irrigation races that intercept runoff from the high ground to the east. Groundwater within the aquifer discharges into the Clutha River and there is no consented groundwater abstraction.

In contrast, groundwater in the Roxburgh West Aquifer is derived from a variety of sources, including rainfall recharge, recharge from the foothill streams and artificial recharge sumps that originate as part of the water race system. Groundwater discharge is via some consented groundwater abstraction as well as discharge into the Clutha River.

Note that both the Roxburgh East and West aquifers may be perched above the Clutha River in some areas, restricting the groundwater resource by excluding interaction with the river.

4.14.1 Existing values, objectives and limits

Human use values identified for the Roxburgh Basin Aquifers in Schedule 3 include drinking water supply without treatment, stock supply, irrigation and industrial uses. Further values related to ecological protection have not yet been defined for this aquifer.

Groundwater allocation limits have been proposed for both the Roxburgh East and West Aquifers based on 50 % of the mean annual recharge. Current consented abstraction for the Roxburgh East aquifer is zero and current consented abstraction across the Roxburgh West aquifer is less than 20 % of the allocation limit.

A trigger level bore is set within the Roxburgh West aquifer, where groundwater abstraction is progressively restricted based on progressive declines in groundwater levels. It is not clear how the trigger levels were defined or the values they intend to protect, however, they have not been breached since monitoring in the trigger level bore (G43/0072, White Hall Bore) began in 1995.

4.14.2 Current monitoring

- Groundwater level monitoring

Only one groundwater level monitoring bore is available in the Roxburgh Basin aquifer, which is located in the Roxburgh West Aquifer. No groundwater level monitoring takes place in the Roxburgh East Aquifer.

- Groundwater quality monitoring

Groundwater quality monitoring takes place in the Roxburgh West Aquifer (bore G43/0065, changed lately to the White Hall Bore) but no current monitoring data is available for the Roxburgh East Aquifer.

4.14.3 Assessment of monitoring

Sufficient groundwater level and quality monitoring takes place in the Roxburgh West Aquifer, however very limited monitoring occurs in the Roxburgh East Aquifer. There is no consented abstraction from the Roxburgh East Aquifer although permitted takes occur on the flats close to the Clutha River. Therefore, some groundwater level monitoring around the flats would be useful to establish background information given the possibility of future consented takes. However, groundwater is reportedly limited across the upper terrace and a number of dry bores have been drilled in that area. Therefore, groundwater monitoring in that area may not be necessary as groundwater use is likely to be limited.

Groundwater quality monitoring should also be undertaken in the Roxburgh East aquifer because the aquifer discharges into the Clutha River and groundwater is used for domestic drinking water supplies.

4.15 Ettrick Basin Aquifer

The Ettrick basin aquifer consists of largely unconfined Quaternary alluvial strata located to the north of Ettrick township. The strata vary in thickness and bores show up to 30 m of gravels towards the western part of the aquifer, thinning to around 5 m closer to the boundary with the Clutha River. Note that the mapped aquifer extent is bisected by, and extends across, the Clutha River.

Recharge to the aquifer is generally expected to be from land surface recharge, runoff recharge from surface waterways exit the hills and flow across the aquifer and surface water seepage from the Benger Burn at the southern end of the aquifer. The Clutha River is does not expected to provide significant recharge to the aquifer, except at occasional times of higher river flows. Groundwater in the aquifer ultimately discharges to the Clutha River, although some groundwater discharge also occurs to the Benger Burn, which subsequently flows into the Clutha River. The overall groundwater flow direction is towards the east. The depth to groundwater varies across the aquifer, with the greatest depths closer to the western edge of the aquifer (around 20 m) and groundwater levels approaching the surface towards the Clutha River.

Groundwater abstraction is concentrated in the south- western part of the aquifer. Total consented groundwater abstraction is estimated to be around 2.85 $x10^6$ m^3/year, of which around 30% is actually used. Groundwater use is dominated by irrigation use, together with stock and domestic supply.

4.15.1 Existing values, objectives and limits

The key groundwater values for the Ettrick Basin aquifer, based on Schedule 3 in the plan include drinking water without treatment, stock supply water and irrigation. However, groundwater in the Ettrick Basin aquifer also discharges into the Benger Burn, and values have been defined for the Benger Burn based on its flows. Therefore, there is a link between groundwater values and surface water values and those surface water values may be relevant for groundwater monitoring.

The groundwater allocation limit for Ettrick Basin Aquifer is set to 50% of the mean annual recharge and a trigger level is also set in bore G43/0032. It is not clear what the trigger levels represent or how they have been set.

4.15.2 Current monitoring

- Groundwater level monitoring

Water level information indicates that bore G43/0032 is no longer monitored (the last level was recorded in 2009), but monitoring does take place in bore G43/0209 (Cemetery bore), which is nearby. Both these water level bores are located on the west bank of the Clutha River. There is no groundwater level monitoring in the part of the Ettrick basin that is on the east bank of the river.

- Groundwater quality monitoring

There are four bores where groundwater quality has been monitored, including bores on both the east and west banks of the Clutha River. The monitoring record is relatively short with a maximum of four samples from any one bore. There is also an ongoing nutrient monitoring programme taking place across the aquifer.

4.15.3 Assessment of monitoring

Overall, groundwater quality monitoring in the Ettrick Basin is consistent with the monitoring required in the Regional Plan: Water and the NPS-FM. However, the length of groundwater quality monitoring record is short and continued monitoring is required to provide information regarding longer term trends and the state of the environment. In particular groundwater quality monitoring is important around the Benger Burn where that waterway gains water from groundwater. Groundwater quality samples from the bore located closest to the Benger Burn (G43/0220) indicated nitrate nitrogen concentrations of 11 mg/L which are close to the drinking water standards (11.3 mg/L) for nitrate nitrogen in the most recent data (January 2017).

The Ettrick Basin is currently split into two parts by the Clutha River, however it is proposed that the eastern portion of the aquifer will be removed from the aquifer boundary during the next plan change process. Monitoring for groundwater levels across the western portion of the aquifer is considered to be sufficient and complies with the minimum requirements. Sufficient groundwater level monitoring takes place to assess whether the limits set for the aquifer are complied with.

4.16 Inch Clutha Gravel Aquifer

The Inch Clutha gravel aquifer consists of recent (Holocene) gravel deposits close to the sea outfall of the Clutha River. It is bounded to the west and north by lower permeability basement strata and to the east by conglomerates from the Taratu Formation, which are not considered permeable. The Holocene gravels are expected to vary in thickness, but are at least 38 m deep based on drillers' logs.

Groundwater flow directions are not defined but are expected to be towards the coast and some interaction with the Clutha River may also occur. Based on available information, there is limited groundwater use in the aquifer

4.16.1 Existing values, objectives and limits

Given the absence of consented groundwater use in the Inch Clutha Aquifer, there are few groundwater values associated with the aquifer. However, there may be some domestic supplies sourced from areas of more permeable gravel strata. Therefore, there may be some groundwater quality values associated with the aquifer, as well as maintenance of storage in the aquifer.

4.16.2 Current monitoring

- Groundwater levels

No dedicated groundwater level monitoring occurs in the aquifer.

- Groundwater quality

Two bores are currently monitored on a quarterly basis, one on each bank of the Clutha River.

4.16.3 Assessment of monitoring

Given the very limited consented groundwater abstraction in the aquifer, the lack of a dedicated groundwater level recorder is not expected to presently limit management of the aquifer. The presence of groundwater quality monitoring allows some groundwater level information to be collected, albeit at less frequent intervals.

Groundwater quality monitoring is available and the data from two bores is considered sufficient for this aquifer unless further information is required due to increased groundwater consenting.

4.17 Wakatipu Basin Aquifers

The Wakatipu Basin aquifers are split into six subzones on the basis of geology, where the different zones are separated by basement rock ridges or hills. The aquifers consist of glacial outwash material including variable sands, gravels and some silts. Recharge to the aquifers is varied with some depending entirely on land surface recharge and others including a proportion of surface water seepage (for example the Frankton Flats Aquifer, Shotover Alluvial Ribbon Aquifer and Kawarau Alluvial Ribbon Aquifer).

Groundwater in the aquifers that are not in direct connection with a river, stream or lake discharges into springs.

Depths to groundwater in the aquifer are variable; the greatest depths appear to be around the Lake Hayes subzone, where groundwater levels can be 40 m to 50 m deep. However, in other zones, groundwater levels are shallower, around 5- 10 m deep. Groundwater use is predominantly for public supply and domestic stockwater. Relatively limited abstraction for irrigation use occurs due to the Arrow River irrigation race.

4.17.1 Existing values, objectives and limits

Allocation limits have been proposed for the Wakatipu Basin Aquifers, based on 50% of mean annual recharge, with the exception of the Frankton Flats Aquifer, the Shotover Alluvial Ribbon Aquifer and the Kawarau Alluvial Ribbon Aquifer, which are managed as surface water due to their high degree of connection with adjacent surface water bodies.

Note that these groundwater allocation limits have not been specifically included in the Regional Plan: Water.

Groundwater use in the Wakatipu Basin aquifers is predominantly for public supplies and domestic / stockwater use; irrigation water is typically supplied via the Arrow River irrigation race. As a result of that use, a key value of the groundwater supply is adequate quality for drinking water and drinking water standards are therefore relevant.

4.17.2 Current Monitoring

- Groundwater level monitoring

Current monitoring across the Wakatipu Basin includes two bores with continuous monitoring (at 15 minute intervals). One continuously monitored bore is located in the Mid Mill Creek Aquifer and the other is located in the Speargrass-Hawthorn Aquifer. An additional bore is located in the Morven Aquifer.

- Groundwater quality monitoring

There are four monitoring bores that are currently monitored for groundwater quality in the Wakatipu Basin Aquifers. One is located in the Windemeer Aquifer, a second is in the Morven aquifer, a third is located in the Speargrass-Hawthorn Aquifer and the final bore is located in the Mid Mill Creek Aquifer.

Samples from all four bores are taken at quarterly intervals.

4.17.3 Assessment of monitoring

Generally, the monitoring in the Wakatipu Basin Aquifers is appropriate. Whilst groundwater quality and groundwater level information is not collected for all the aquifer zones, it is generally collected from the main aquifers where groundwater is abstracted. The only exception to that appears to be the Bush Creek Aquifer, which is reportedly the source of water for the Arrowtown public supply. Given that water in that aquifer is used for public supply, it would be prudent to monitor water quality in that area, although the supply is likely to be monitored to comply with the drinking water standards and regulations. The Wakatipu Basin was also identified as a High Priority area for risks to groundwater contamination as a result of septic tank leachate.

4.18 Glenorchy Groundwater Management Zone

The Glenorchy Groundwater Management Zone covers a relatively small area of Holocene river gravels. The strata to the east and south consist of low permeability basement strata, which are likely to underlie the gravel deposits at a shallow depth. There is little information around groundwater depths or groundwater flow directions, although the likely flow direction is towards Lake Wakatipu.

Groundwater use in the zone is currently low, with one abstraction for the settlement water supply and another for the operation of a commercial lodge operation. The abstraction for community supply purposes is located on the north bank of Buckler Burn, just south of the township. Groundwater is taken from a shallow bore adjacent to the stream and is defined as a having a high stream depletion effect.

Shallow groundwater is expected to be closely connected to surface water bodies with alluvial fans covering the majority of the zone. Groundwater is expected to discharge to the west into Lake Wakatipu.

4.18.1 Existing values, objectives and limits

Although specific groundwater values have not been defined for the Glenorchy Groundwater Management Zone, given the use of groundwater for community supply and some private supplies there are values associated with those uses, particularly in terms of maintaining groundwater quality. Quality changes could also affect the lake, which it discharges into.

Specific allocation limits have not been set for the aquifer, and the default limit is expected to be equivalent to 50% of recharge.

4.18.2 Current monitoring

There is no current monitoring for either groundwater levels or groundwater quality in the Glenorchy Groundwater Management Zone.

4.18.3 Assessment of monitoring

Given the absence of any monitoring in the aquifer, and the use of groundwater for community supply as well as domestic and private supply, together with an expected increase in residential development, it would seem appropriate for some groundwater monitoring should occur. Whilst a dedicated groundwater level monitoring bore may not be required given the connection to the lake, it would be useful to commence some groundwater quality monitoring which would also provide some information around groundwater levels, albeit at less frequent intervals.

4.19 Kingston Groundwater Management Zone

Groundwater information around the Kingston Groundwater Management Zone is relatively limited. A historic report indicates that there are bores in the area that have previously been used for domestic water supply. However, there are currently no consented groundwater takes within the aquifer.

Groundwater is expected to be closely connected to surface water bodies, receiving flow from the creeks on the surrounding hillsides and ultimately flowing into Lake Wakatipu.

Although the aquifer is not currently utilised for consented groundwater takes, given the rapid growth of Queenstown there may be a demand for groundwater in the area in the future.

4.19.1 Existing values, objectives and limits

Whilst no groundwater values and objectives have been defined for the Kingston Aquifer, groundwater has value in the area as a source of private, domestic water supplies, and quality changes could affect the lake, which it discharges into. An estimate of rainfall recharge across the aquifer has not yet been defined, and therefore no allocation limit has been defined for the area.

4.19.2 Current monitoring

- Groundwater level monitoring

There are no dedicated groundwater level monitoring bores within the Kingston Groundwater Management Zone.

- Groundwater quality monitoring

Two monitoring bores are present near Kingston. Bore F42/0104 (9.3 m deep) only has two samples from September 2010 and March 2011 respectively. Bore F42/0113 (4.4 m deep) has been monitored for a range of parameters, generally at quarterly intervals, between September 2010 and December 2016.

4.19.3 Assessment of monitoring

Although no dedicated groundwater level monitoring occurs in the Kingston Groundwater Management Zone, there is limited groundwater use and groundwater levels are likely to be controlled by levels in Lake Wakatipu. Some groundwater level data is collected as part of the groundwater quality monitoring and although that data is less frequently collected, it is sufficient given the current pressures on groundwater in the area. However if further development occurs, or if larger scale groundwater abstraction is consented, then a dedicated groundwater level monitoring bore may be required.

Likewise, groundwater quality monitoring is considered appropriate given the current use of groundwater in the area, however some further monitoring may be necessary, particularly towards the south-western part of the area if further development occurs.

4.20 Lower Taieri Aquifer

The Lower Taieri Aquifer covers the Taieri Basin south-west of Dunedin. The Taieri Basin is a fault controlled tectonic depression and there is a substantial thickness of sands and gravels, as well as silts, clay and peat deposit up to 200 m thick overlying lower permeability basement strata. The strata in the east of the basin consist of relatively permeable sands and gravels and are largely unconfined. Towards the west of the basin, the more permeable sands and gravels are interbedded with silts and are more consistently layered. A fine grained marine deposit is present at the surface across the western part of the basin, which acts to confine the more permeable gravel and sand strata beneath.

Groundwater in the basin is generally shallow and occurs within a few metres of the surface. Recharge is predominantly from land surface recharge, together with a smaller component of seepage from the streams and rivers the flow across the basin, including Silver Stream. Generally, groundwater flows from the north-east of the area, around Mosgiel, towards the south-west. Groundwater discharge occurs via seepage to wetlands and the Lake Waipori Wetlands complex towards the south-west end of the basin. The basin is split into east and west zones, where the Taieri River forms the dividing line.

Strata in the basin are relatively permeable, with transmissivities of up to 14,000 m^2/day recorded in both the east and west zones. Groundwater use is greatest around Mosgiel, where groundwater is used extensively for public supply but some use for irrigation occurs elsewhere within the basin. Some domestic and stock use also occurs, generally away from the major towns.

4.20.1 Existing values, objectives and limits

Allocation limits have been proposed for the Lower Taieri Aquifer and groundwater level triggers are in place to restrict abstractions at times of lower groundwater levels. Trigger levels are set in one bore in the western part of the basin (the Momona bore) and one bore in the eastern part of the basin (Harleys - Caledonia Drive well). The justification for the trigger levels in the Momona bore are to prevent groundwater levels falling below 1 m below sea level, while the justification for the trigger level in the Harleys bore is reportedly arbitrary.

Allocation limits have been proposed for the in the East Taieri zone but are not yet implemented in the Regional Plan: Water. The proposed allocation limits are much less than 50% of recharge. For the Taieri East Zone, the allocation limit is based on effects in Silver Stream, where effects were limited to an additional seepage loss from the stream of 25 L/s. Flow in the Silver stream is therefore a value for the groundwater system in that area and an objective is maintaining that flow. The groundwater allocation limit in the East Zone is proposed as 2.9×10^6 m^3/year. However, based on a groundwater model, abstraction effects on shallow groundwater levels in the west zone were smaller, partly due to the presence of confining strata and therefore a larger limit of 3×10^6 m^3/year was proposed. Combined, the proposed limit for the overall Lower Taieri Basin is 5×10^6 m^3/day, which is reportedly around 12 % of the mean annual recharge.

The use of water for public supply around Mosgiel and for domestic supply in other parts of the aquifer means that a key value for the aquifer is maintenance of water quality for drinking water, as well as maintaining aquifer storage levels.

4.20.2 Current monitoring

- Groundwater levels

Groundwater levels are currently monitored in four bores across the basin, two of which represent a multilevel piezometer close to Mosgiel. The other two bores are located: close to the Taieri River where it enters the basin, and in the centre of the West Taieri zone. All the bores are monitored continuously.

- Groundwater quality

Groundwater quality is monitored quarterly in five bores distributed throughout the basin for a range of parameters.

4.20.3 Assessment of monitoring

Groundwater monitoring on the Lower Taieri Basin is consistent with the requirements under the Regional Plan: Water and with the requirements in the NPS-FM. Monitoring targets the areas of greatest groundwater demand and there is a reasonable geographic spread of groundwater level bores and groundwater quality bores. The available monitoring should also help to achieve the proposed limits in the basin, including restricting drawdown around the Silver Stream to prevent excessive seepage from the river in the groundwater system and reducing the risk of saline intrusion if groundwater levels fall below sea level.

Groundwater quality monitoring is also consistent with the minimum requirements and provides a good coverage of the basin, both in terms of spatial location and depths. Generally the depths of the monitoring bores are consistent with the depths of abstraction bores and therefore represent the strata from which water is drawn. However where groundwater is connected to surface water (for example around Silver Stream) shallower bores may be more useful if groundwater quality effects on the stream need to be assessed in more detail.

4.21 Maniototo Tertiary Aquifer

The Maniototo Tertiary Aquifer is formed within the Maniototo Basin, which consists of low permeability schistose basement strata, overlain by Tertiary sediments and Quaternary strata. The Tertiary sediments generally consist of silty marine and lacustrine sediments, together with some volcanic rocks. The Quaternary strata generally occur on terraces and consist of poorly consolidated sands and gravels.

Whilst the Tertiary sediments generally consist of less permeable strata, water bearing units do occur, which are relatively deep, commonly confined and flowing artesian. The Quaternary sediments form unconfined, often highly permeable aquifers with shallow water tables. The overall groundwater flow direction in the Quaternary strata is from the surrounding hill country and generally to the south-east, and groundwater appears to discharge into the Taieri River where it exits the basin. The ORC (1997) report describing the

Maniototo Aquifer notes that many of the water bearing strata in the Tertiary sediments occur as discontinuous lenses of more permeable material, meaning that groundwater in one lens may be in poor hydraulic connection with others. It is not clear where groundwater in the Tertiary sediment discharges and some of the aquifers in the Tertiary sediments may be blind.

There are currently six consented groundwater takes in the basin, totalling 1.4 x 10^6 m^3/year, which are generally used for irrigation. However, there are a number of other bores within the basin, and groundwater is also used for smaller scale domestic and stock water supplies.

4.21.1 Existing values, objectives and limits

Preliminary allocation limits have been estimated for the Maniototo Tertiary Aquifer by ORC (2014) based on 50 % of mean annual recharge. Mean annual recharge was estimated to be 31.6 Mm^3/year resulting in an allocation limit of 15.8 Mm^3/year.

The estimate for mean annual recharge is based on rainfall recharge only as inflow volumes from other sources are unknown. .

Groundwater use in the Maniototo Basin aquifers is predominantly used for drinking water supply and for irrigation. As of 2014 there are eight consented groundwater takes with a total consented volume of 1.4 Mm^3/year.

4.21.2 Current Monitoring

- Groundwater level monitoring

A detailed groundwater level record is available for bore H42/0155 (unknown depth) between July 1998 and March 2008. There is no current water level monitoring across the Maniototo Tertiary Aquifer, although a piezometric survey took place in September 2015 as part of the investigations to improve the knowledge of the aquifer which may lead to a revision of the allocation limits.

- Groundwater quality monitoring

There are two monitoring bores that are currently monitored for groundwater quality in the Maniototo Tertiary Aquifer. Bore H42/0213 (10 m deep) and bore H42/0214 (10 m deep) have been sampled since September 2015 for a reasonable range of parameters at quarterly intervals.

4.21.3 Assessment of monitoring

Generally, the monitoring in the Moniototo Tertiary Aquifer is appropriate. Whilst groundwater level information is not collected for the aquifer, it is noted that water level monitoring is planned as part of the investigations to improve the knowledge of the aquifer and to update the preliminary allocation limits for the aquifer. In addition it is noted that the current consented groundwater allocation (1.4 x10^6 m^3/year) is relatively small compared to the (preliminary) maximum groundwater allocation limit for the aquifer (15.8 x10^6 m^3/year).

4.22 Manuherikia and Ida Valley Groundwater Management Zones

The geological settings for both the Manuherikia and Ida Valley Groundwater Management Zones is similar. Both areas represent thin, shallow Quaternary deposits overlying Tertiary deposits which can be relatively thick (up to 600 m in the southern part of the Ida Valley). The Tertiary deposits overlying low permeability schist basement strata.

Groundwater levels are typically shallow across both areas, which is thought to reflect the presence of a shallow clay pan that underlies the youngest Pleistocene strata. Limited groundwater exploration has occurred in either the Ida Valley or the Manuherikia GWMZ, which also reflects the low yield from the bores that have been drilled. The deeper Tertiary sediments tend to have a lower permeability compared to the overlying Quaternary strata.

Groundwater flow patterns are not well defined, but given the structure of the areas, surrounded on all sides by low permeability basement strata, flow directions are likely to be generally towards the Ida Burn and Pool Burn (in the Ida Valley) and the Manuherikia River.

Very little groundwater use occurs in either area, although there is some groundwater use for domestic and stock supplies. However there are few examples of bores accessing sufficient yield for larger supplies. A recent ORC report (Wilson & Rekker, 2012) delineated some areas of Tertiary sediments where coarser material was more prevalent and some groundwater supplies could be achieved. However yields were in the order of 1 L/s.

4.22.1 Existing values, objectives and limits

Currently an allocation limit of 9.4 Mm^3/year has been adopted for the Ida Valley and 22.55 Mm^3/year for the Manuherikia Groundwater Management Zone which are based on half the mean annual rainfall recharge.

4.22.2 Current Monitoring

- Groundwater Level Monitoring

There is no dedicated groundwater level monitoring in the either the Manuherikia or Ida Valley Groundwater Management Zones.

- Groundwater Quality Monitoring

There are 2 bores for groundwater quality monitoring within the Manuherikia Groundwater Management Zone.

- Bore G41/0280 (5.4 m deep) was sampled once during December 2012.
- Bore G41/0254 (6.5 m deep) was sampled for a range of parameters at quarterly intervals between March 2011 and December 2012.

No monitoring for groundwater quality occurs in the Ida Valley Groundwater Management Zone.

4.22.3 Assessment of monitoring

There is very little groundwater use from either of the Manuherikia or Ida Valley Groundwater Management Zones. Therefore, the requirement for detailed groundwater monitoring is considered low at present. In general, given that groundwater in both basins is likely to discharge into the Ida Burn, Pool Burn and the Manuherikia River, monitoring those surface waterways will provide some information on the effect of groundwater abstraction and land use on those surface waterways.

If land use intensification is anticipated in these valleys it would be appropriate to monitor/increase monitoring of groundwater quality so that any effects can be observed and managed before surface water quality changes occur, given the potentially long travel times through the groundwater system.

Similarly, given that some areas of the Ida Valley and the Manukerikia Valleys have been identified as potentially useful sources of stock and domestic water supplies, particularly from within the deeper Tertiary sediments, some groundwater monitoring may become necessary if and/or when groundwater use increases from those areas.

4.23 Strath Taieri Groundwater Management Zone

The Strath Taieri Aquifer covers the Strath Taieri Basin approximately 50 km north-west of Dunedin. The Strath-Taieri Basin is a fault controlled tectonic depression and there is a relatively shallow thickness of alluvial deposits recorded up to 28 m thick overlying lower permeability basement schist. The strata in the west of the basin is dominated by late quaternary fan deposits extending out from the base of the Rock and Pilar Range. These fans grade into fluvial deposits towards the east of the basin towards the Taieri River.

Groundwater recharge originates from land surface recharge, runoff from the adjacent Rock and Pillar Range and from river losses. Generally, groundwater flows from the north-west of the area, at the base of the range front, towards the south-east where discharge to the Taieri River is expected to occur.

Groundwater is closely connected to surface waterways across the basin and generally groundwater levels are shallow, within 5 m of the surface. There are three consents to take groundwater which are used for irrigation and stockwater supply and all three are for takes of less than 300 m^3/day, although groundwater may also be used for domestic and stockwater supplies. There have been no aquifer tests in shallow bores screened within the alluvium. Aquifer testing on a deeper bore within the underlying schist indicates that the basement rock is poor yielding.

4.23.1 Existing values, objectives and limits

Detailed values and objectives have not yet been defined for the Strath Taieri Groundwater Management Zone, and a default groundwater allocation limit is set to 50% of mean annual recharge, or around 4.15 x 10^6 m^3/year.

4.23.2 Current monitoring

- Groundwater level monitoring

There is no dedicated groundwater level monitoring bore within the Strath Taieri Basin.

- Groundwater quality monitoring

There is one bore within the aquifer with available water quality data. Bore H43/0132 is currently sampled for a typical range of parameters generally at quarterly intervals with data available between September 2010 and December 2016.

4.23.3 Assessment of monitoring

Given the limited use of groundwater within the Strath Taieri Groundwater Management Zone, detailed monitoring of groundwater levels and groundwater quality may not be necessary at this stage. The presence of groundwater quality monitoring allows some groundwater level information to be collected, albeit at less frequent intervals.

Groundwater quality monitoring is available and the data from one bores is considered sufficient for this aquifer unless further information is required due to increased groundwater consenting or land use intensification.

5.0 Summary

5.1 Summary of monitoring review

Overall, monitoring in the region is appropriate and is generally consistent with the requirements under the NPS-FM and the Regional Plan: Water relative to the scale of groundwater use in a particular catchment. In some areas, additional monitoring may be required if and/or when groundwater utilisation increases in those areas. However, there are two areas where, based on our review, conceptual understanding, and the extent of groundwater use in the area, additional monitoring should be implemented as a higher priority. Those areas are the Papakaio Aquifer and the Bendigo Tarras aquifer.

Table 2 lists each of the aquifers where additional information or monitoring may be required, in order of priority.

Table 1: Additional monitoring required

Aquifer	Monitoring required	Reasoning
Papakaio Aquifer (High priority)	Groundwater level /quality monitoring	Groundwater level and quality monitoring required to determine limits particularly as groundwater allocation is approaching the allocation limit. Groundwater level monitoring is planned. Further groundwater quality information is required to determine limits.
Bendigo Tarras Aquifer (High priority)	Groundwater level monitoring	Bendigo Tarras aquifer maximum annual volume is based on a groundwater model which is uncertain and a drawdown limit that may not protect the values that may be assigned to surface water bodies that depend on the aquifer discharge, for example the Lindis River, and the Bendigo Wetland. Whilst the consented allocation is relatively small compared to the MAL (around 10% to 15%) the uncertainty around the limit means that additional monitoring for both water levels and water quality should be installed in the aquifer.
Hawea Basin Aquifer (Medium Priority)	Groundwater level / quality monitoring	Groundwater level monitoring / information required regarding groundwater interaction with Campbells Wetland and effect of proposed allocation limit. Additional groundwater quality monitoring may be required to determine any effect on the wetland from surrounding landuse. We also note that not all the water quality monitoring bores in this aquifer include analyses for E.Coli (although from June 2017 E.Coli will be part of the standard set of parameter analysed for each bore).
Pisa – Luggate – Queensbury Groundwater Management Zone (Low priority)	Groundwater level and quality monitoring	Further investigation is taking place in this aquifer, Two groundwater level and quality monitoring bores have been installed in June 2017 for the Pisa and Luggate GWMZ.
Cromwell Terrace Aquifer (Low priority)	Groundwater level monitoring	No dedicated groundwater level monitoring is available although quarterly groundwater level monitoring may be sufficient until aquifer consented allocation increases. Limits are already set for this aquifer.
Earnscleugh Terrace Aquifer	Groundwater level and quality	No groundwater level or current monitoring is available, however, the consented allocation is very small compared to the maximum annual volume and

(Low priority)	monitoring	dedicated groundwater level monitoring may not be required unless groundwater allocation increases. Groundwater discharges into the Fraser River and some groundwater quality monitoring may be required in order that any effects due to groundwater seepage on that water body can be identified. We also note that not all the water quality monitoring bores in this aquifer include analyses for E.Coli.
Manuherikia Claybound Aquifer (Low priority)	Groundwater level monitoring	Groundwater allocation in the downgradient Dunstan Flats aquifer depends on throughflow from the Manuherikia Claybound aquifer. Groundwater level monitoring is required to allow some early warning if that throughflow may be declining as a result of reduced losses from irrigation races. However, representative groundwater levels may be difficult to define due to the stratified nature of the strata. Groundwater level monitoring in the Dunstan Flats aquifer may therefore be suitable as a proxy.
Maniototo Tertiary Aquifer (Low priority)	Groundwater level monitoring	No groundwater level monitoring data is available although further data collection is planned and ongoing.
Kingston and Glenorchy Aquifers	Groundwater levels and groundwater quality	No dedicated groundwater level monitoring is available for either aquifer, and only groundwater quality monitoring is available for the Kingston Aquifer. Given potential development, some monitoring would be appropriate.

In general, the data reviewed as part of this report indicates that groundwater quality monitoring occurs at an adequate frequency in many areas. Groundwater quality monitoring is typically completed on a quarterly basis and involves collection of water level information as well as a water quality sample. In some aquifers, that information may be sufficient to provide groundwater level information in terms of the State of the Environment monitoring, because it can provide some information on long term trends, however that is too infrequent for groundwater level monitoring to be suitable for setting limits, although where limits are set, it may be sufficient.

There are a number of aquifers that occur along the Clutha River and we note that groundwater abstraction from most of those aquifers will ultimately result in some reduction in the Clutha River flow. No allocation limit is set for the Clutha River (although we understand that a limit is under development) and therefore that effect cannot be set into the context of the river allocation. Likewise, any contaminants in groundwater from those aquifers will ultimately discharge into the river, and may be of concern if they contributed to excessive periphyton growth.

Figure 2 shows the location of public supply bores listed in the Schedules for the Regional Plan: Water. Almost all the bores are located within 100 m of a surface water body, and are therefore allocated as surface water takes. As a result, increased abstraction from those bores will have no effect on the groundwater allocation status of an aquifer. The listed takes are also generally located adjacent to very large water bodies (for example lakes or the Clutha River).

Public supply bores that are not within 100 m of a surface water body are the Mosgiel Water Supply, located within the Lower Taieri Aquifer and the Owaka Water Supply, which is not located within a mapped aquifer. In that respect, there are a number of consented takes that do not fall within any of the mapped aquifers in the region (Figure 3). Therefore, there is no allocation limit associated with those takes and some consideration of the management of those takes may be required.

There are a number of deemed mining permits in the region, which are historic water rights with no specified limits on the rate of take. The deemed permits are all surface water takes and will expire in 2021. Transfers from deemed permits to RMA consents will be treated as new takes. It is not possible to predict whether the permits will be transferred to surface water takes or groundwater takes (unless the surface water allocation in an area is already fully utilised), but some additional groundwater allocation could occur, which may place pressures on the groundwater resource in some areas.

5.2 Landuse and groundwater quality

Groundwater quality is influenced via a number of different factors including the geochemistry of the host strata, rates of groundwater movement as well as effects from overlying landuse and point-source discharges to groundwater. Groundwater quality limits will vary depending on the requirements at the point of discharge, for example where groundwater is discharged via abstraction for drinking water supplies, the New Zealand Drinking Water Standards are relevant and applicable. An example of that situation is in the Lower Taieri East Aquifer, where Dunedin City Council abstract groundwater for public supply. However, where groundwater discharges via seepage into a river for example, other standards may be applicable to maintain the ecology of that river reach. An example of that situation may be where the Earnscleugh Aquifer discharges into the Fraser River. In either case, it is important that groundwater monitoring provides a reasonable reflection of the general water quality in the area.

Groundwater quality monitoring is generally more widespread in Otago’s aquifers relative to the greater frequency required for some groundwater level monitoring. Based on this review, it is considered that groundwater quality monitoring generally includes appropriate parameters to meet the objectives of the Regional Plan: Water and the NPS-FM. The majority of aquifers include some groundwater quality monitoring that is appropriate for State of the Environment monitoring for general trends. It is considered likely to be suitable in terms of providing information on the general groundwater quality in an area and its suitability for drinking water, although all drinking water supplies should undertake their own monitoring and specific effects from land use and discharges need to be considered at the consenting stage. However, it appears that there is relatively little monitoring that is specifically targeted towards assessing the quality of groundwater that discharges into surface waterways. This is likely to be required in order to measure the effectiveness of controls on land use and discharges to groundwater on surface waterways that receive groundwater inflows.

It will also be important to maintain a general review of landuse practices and discharge effects across aquifers, both to protect groundwater quality and, where surface water – groundwater interaction occurs, as part of ensuring surface water quality limits are met and values achieved. A review of ORC's current monitoring of discharges to groundwater and land use activities is outside the scope of this review of specific groundwater information, but it is acknowledged that this monitoring is a very important aspect of managing water quality effects. The Regional Plan: Water identifies the importance of this monitoring in Chapter 9.

5.3 Comments on groundwater models

A number of groundwater models, set-up using numerical computer programmes, have been developed for aquifers in the region, which have been used to develop allocation limits. Some of these limits have been included in the Regional Plan: Water. In general, groundwater models can be an effective tool for developing groundwater allocation limits because they can represent the water balance for an aquifer in three dimensions and simulate the changes to that balance over time. Therefore they can be used to separate the effects of abstraction from natural, seasonal or longer term climatic changes to a groundwater system. Allocation limits can be established by determining what scale of effects from abstraction can occur without adversely affecting agreed values in groundwater and surface waterways.

A disadvantage of groundwater models is that the parameters used to define particular parts of the groundwater system, for example hydraulic conductivity or river bed conductance are calibrated to observed groundwater levels or surface water flows. Those parameters may not be unique, and an alternative set of parameters can provide an equally good fit to the observed data. The resulting parameter uncertainty will translate to uncertain predictions of water levels or surface water flow depletion based on the model. It is important that those uncertainties are accurately characterised and accounted for in any model predictions.

Transient groundwater models that represent groundwater level changes through time are generally better than a steady state model, partly because the calibration dataset and range of model stresses (principally in terms of different recharge values) is much greater. However groundwater models that are calibrated to groundwater levels only may not be particularly accurate in estimating changes in stream discharges because that information is not included in the calibration dataset.

It is also useful to note that groundwater models should not be viewed as a single 'one off' piece of work. Groundwater models can be a valuable means by which conceptual ideas can be tested, and also a means of identifying areas of limited data. It is also possible to use groundwater models to determine 'data worth', or where the location of additional monitoring would reduce the uncertainty of a model prediction by the greatest amount. Therefore, models are most effectively used where they are regularly updated and improved based on new data as it become available. We therefore recommend that ORC should obtain and retain the various groundwater models that have been developed over the years and ensure that staff are familiar with their use.

Table 5 lists the aquifers where groundwater models have been used to develop allocation limits and includes a brief comment on the adequacy of the model used. Note that we have not completed a detailed review of each model. In general, all the groundwater models appear to provide a good representation of the conceptual understanding of the groundwater system in the area, with the main shortcoming being a limited calibration dataset and limited calibration to surface water flows.

As part of Plan Change 6A, where nitrate nitrogen leaching limits were developed across the region, some of the groundwater models were used to evaluate the effect of different leaching rates on groundwater quality, including;

- Ettrick Basin groundwater model
- The Lower Taieri Groundwater model
- Bendigo Tarras groundwater model; and
- Hawea Basin groundwater model

That modelling included use of MODFLOW as a flow model and MT3D as a contaminant transport model. The modelling of potential groundwater quality changes could be considered for other aquifers, particularly as many of the aquifers in the region have defined values as untreated drinking water sources and concentration limits have been set in connected surface waterways.

Table 2: Groundwater models

Aquifer	Comment on model
North Otago Volcanic Aquifer	Model reasonably calibrated to groundwater levels and used to predict groundwater level change under different scenarios. Allocation limit is based on the proposed NES limit of 35% of maximum annual recharge. Allocation limit is not based on surface water receptors. Model sensitivities are defined, but uncertainties in predictions are not estimated. However, generally the model appears fit for purpose.
Hawea Basin Aquifer	Further data is being collected to convert this model to a transient model from an initial steady state model. The steady state model included some assumptions around abstraction rates which have been updated. Uncertainty assessments should be included to define the range of potential effects on Campbell's Wetland for different allocation limits.
Wanaka Basin/Cardona Alluvial Aquifer	Transient model calibrated primarily to a single four year groundwater level record. Limited calibration to surface water- groundwater interaction, which is the subject of the integrated allocation limit. Uncertainties in the predicted allocation limit should be quantified and additional data to reduce those uncertainties should be collected. Further work is required for this model to ensure that it is calibrated to surface water flows as well as groundwater levels.
Bendigo Tarras Aquifer	Steady state model calibrated to a single set of groundwater level measurements. Limited pumping test data used to inform model parameters. Model appears to represent conceptual understanding, but steady state model means that predictions are uncertain and that uncertainty should be quantified. Updating this model based on transient data would be beneficial, as well as including pumping test data to define interactions with the Clutha River. Based on this review, further data should be collected (i.e. long term groundwater levels) to help calibrate the model to a transient timeseries, together with further pumping test data.

Table 2: Groundwater models

Aquifer	Comment on model
Cromwell Terrace Aquifer	Transient model calibrated to a single groundwater level timeseries. Calibration does not represent seasonal water level variations particularly closely and allocation is based on model declines from seasonal groundwater level abstraction. Quantification of the uncertainty in model predictions has not been completed. However given the close relationship between groundwater levels in the aquifer and the level of Lake Dunstan, the model is suitable for estimating the effect of groundwater abstraction on groundwater levels and is fit for that purpose.
Ettrick Basin Aquifer	A report on the groundwater model for the Ettrick Basin aquifer was included as part of the Assessment of the Nitrogen Sensitive Zone loading limits. The model is steady state and calibrated to groundwater levels. The reported calibration shows a good match between modelled and averaged observed groundwater levels, achieved using PEST. No uncertainty analysis is reported, although in this case, where the model was primarily used to estimate the effect of different nitrogen loading rates, that may not significantly change the result (which is driven by the concentration of nitrate applied to the model). Although estimating discharges into surface waterways was not the intent of the model, discharges into Benger Burn may be important to support the ecological habitat of that waterway. If the model is used to develop an allocation limit or used for more detail groundwater contamination studies some uncertainty analysis may be required. The report is fit the purpose it was designed for.
Lower Taieri Aquifer	Some analysis of uncertainty is provided in the report for the model, but further assessment of that uncertainty and how it feeds through to model predictions of, for example flows in Silver Stream should be included. However, generally the model appears fit for purpose.

6.0 Conclusion

The intent of this report was to:

- summarise the state of knowledge of each of Otago's aquifers;

- assess the quality of the data collected to monitor the state of those aquifers; and
- comment on whether the models and/or methods used to collect that data are appropriate.

Overall the state of knowledge available for each of Otago's aquifer is very good. The majority of aquifers have detailed reports regarding the patterns of groundwater movement within them, their sources of recharge and locations of discharge. As a result, the conceptual understanding of each of the aquifers is well documented and easily accessible. Many of the aquifers are represented by numerical groundwater models that help to validate those conceptual models, (within the bounds noted in Section 4.3).

Integrated modelling for some of the aquifers has also been undertaken to relate limits to surface water values where groundwater and surface water interaction is important. However, specific values, objectives and limits are not yet assigned to all the aquifers, although that is an ongoing process that is taking place in many of the aquifers, as set out in the ORC Long Term Plan 2015-2025.

Based on this review, there are only two aquifers where further monitoring may be required as a priority; the Papakaio Aquifer and the Bendigo-Tarras Aquifer. There are other aquifers where monitoring is not strictly consistent with an ideal monitoring programme, for example the Earnscleugh Aquifer should ideally have a dedicated continuous monitoring bore. However, in each of those aquifers, there is limited consented groundwater use; therefore additional monitoring should be part of a long term programme for those aquifers, but it is not an immediate priority unless consented groundwater use increases sharply.

For the dedicated groundwater monitoring bores the frequency of monitoring is generally at appropriate intervals for groundwater levels and also for water quality. In addition, the parameters analysed from water quality samples are appropriate and consistent.

Generally, the groundwater models used to represent groundwater in the region's aquifers focus on modelling water quantity rather than water quality. The models are generally good and considered fit for purpose, but in some cases need additional uncertainty analyses, or calibration to surface water flows to ensure that the predictions are within reasonable bounds and appropriate to the water quality and quantity objectives for the models.

7.0 References

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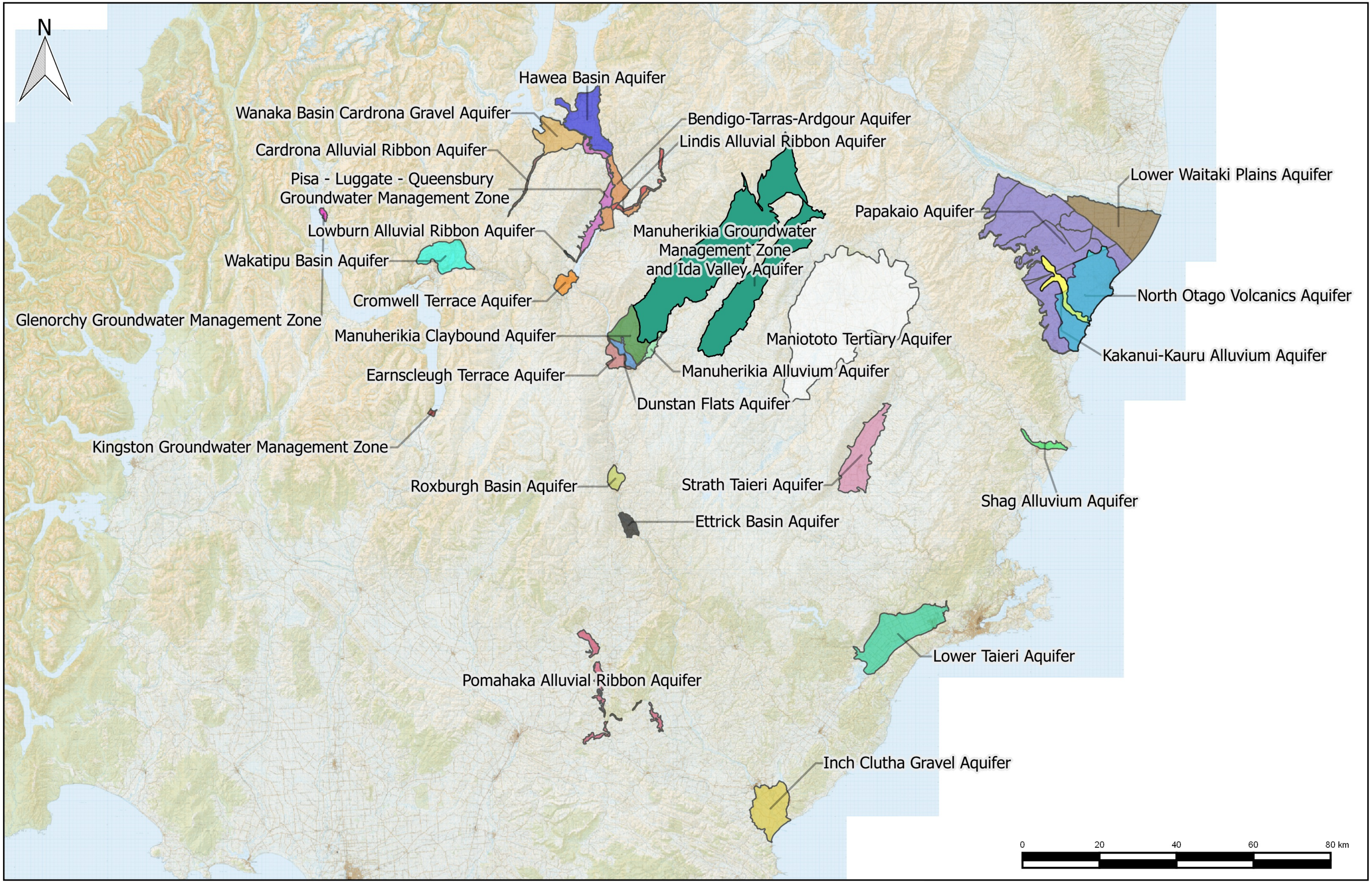
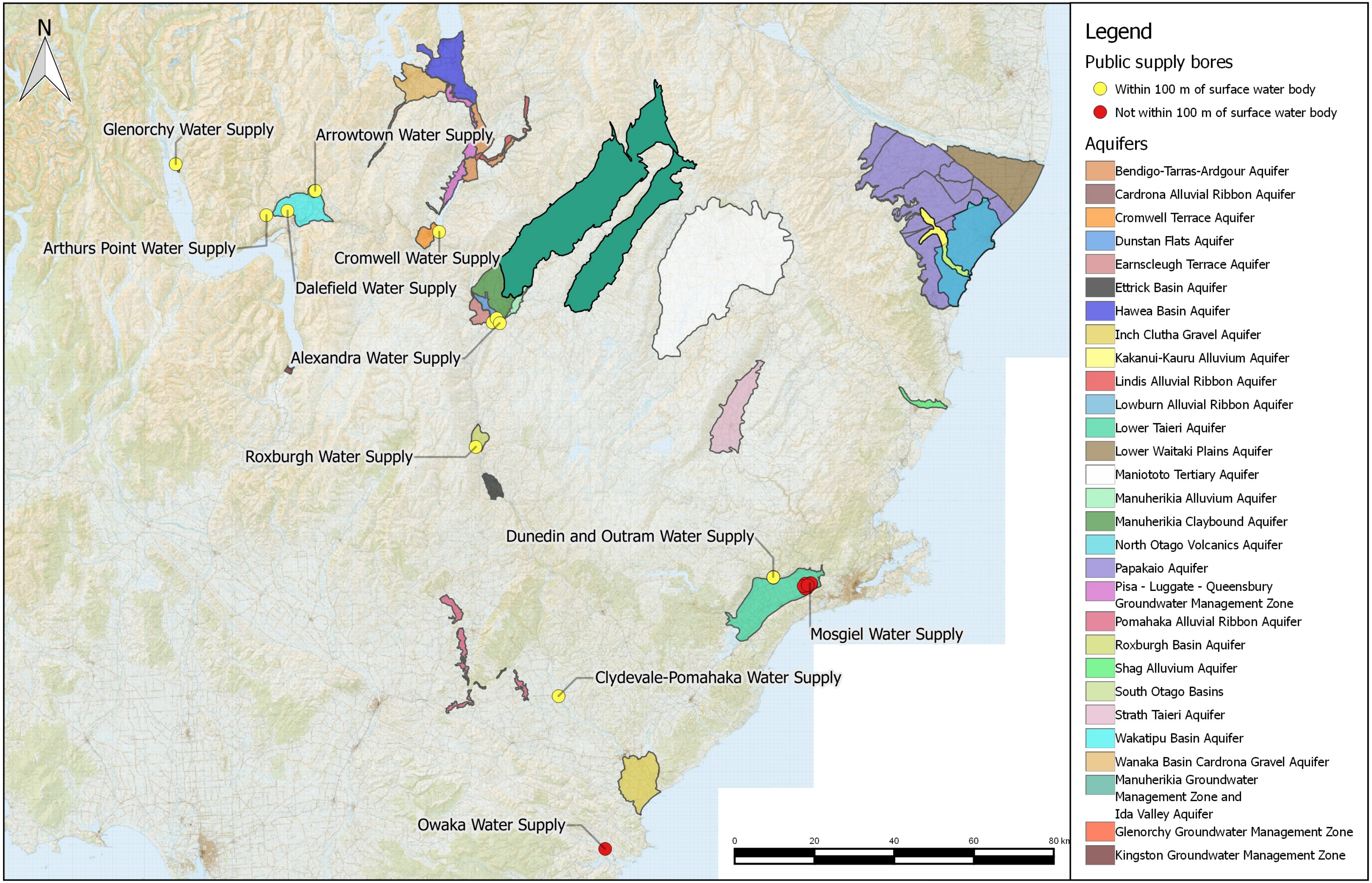


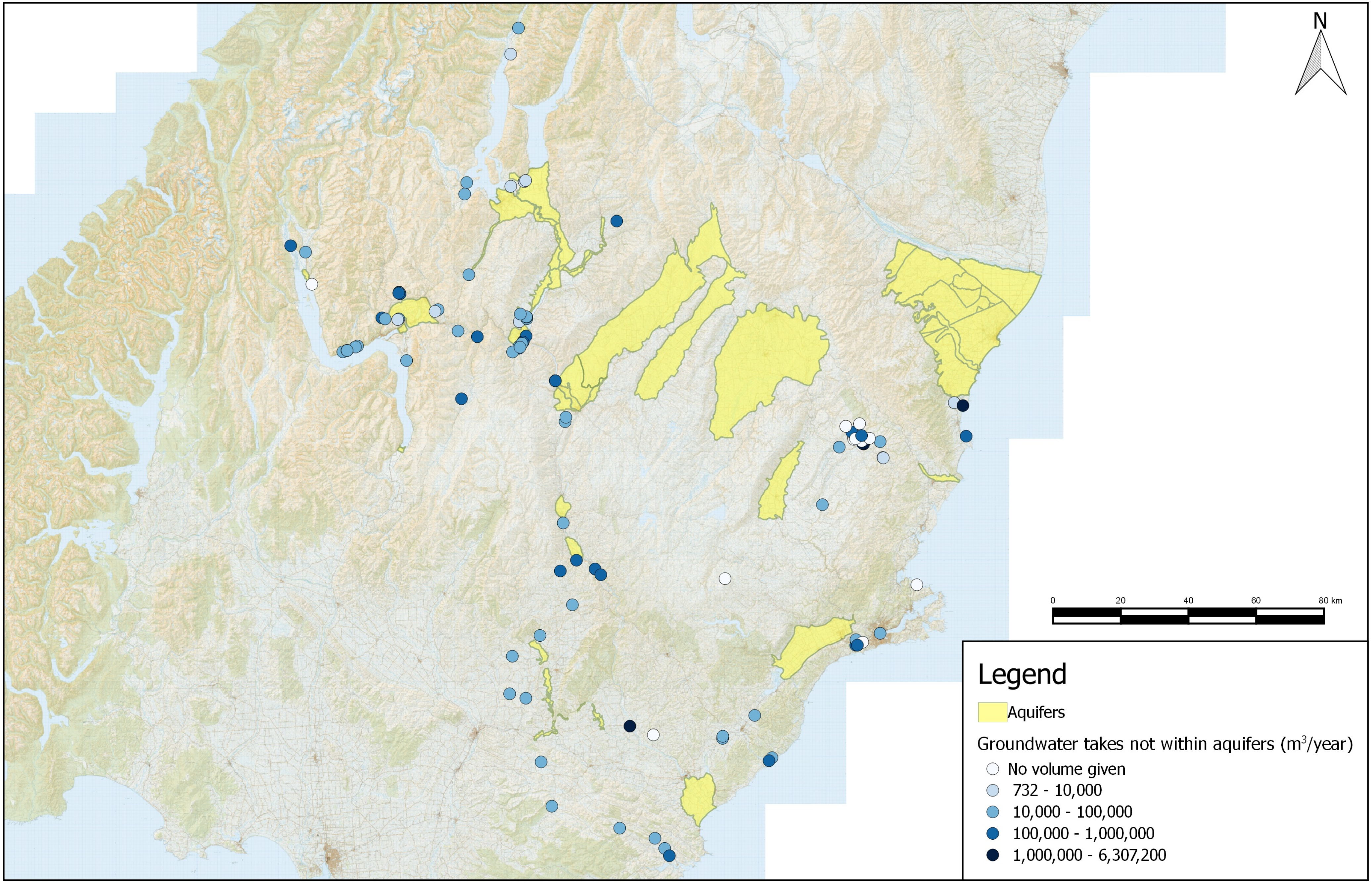
Note: Locations of features shown above are approximate.Aquifer information supplied by Otago Regional Council

FIGURE 1: OTAGO AQUIFERS



Note: Locations of features shown above are approximate.Aquifer information supplied by Otago Regional Council

FIGURE 2: OTAGO REGIONAL COUNCIL PUBLIC SUPPLY BORES



Note: Locations of features shown above are approximate.Aquifer information supplied by Otago Regional Council

FIGURE 3: GROUNDWATER TAKES NOT WITHIN MAIN OTAGO AQUIFERS

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Appendix A
Aquifer Summary Sheets and Aquifer Plans

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit ($x\ 10^6\ m^3$/year)	Limit status	Target
North Otago Volcanic Aquifer	The Council made its decisions on Proposed Plan Change 4A (Groundwater and North Otago Volcanic Aquifer) on Wednesday 14 September 2011. **A trigger level and an allocation limit of 7 Mm^3/year was set in this aquifer in Plan Change 4A.**	7 (operative)	Under allocated	Monitor compliance with set minimum flows/environmental levels.
Ettrick Basin Aquifer	Due to the connection between the Ettrick Basin Aquifer and the Benger Burn, a maximum allocation limit is being developed in conjunction with a minimum flow regime for the Benger Burn. **A trigger level for the Ettrick Basin was set in Plan Change 4C.**	2.75 (retired)	Over allocated	Monitor compliance with set minimum flows/environmental levels. An allocation limit will be set during the next plan change process, scheduled for 2017-2018
Lower Taieri Aquifer	Work on developing a maximum allocation limit for this aquifer commenced mid 2012. **Trigger levels were set for the Lower Taieri Aquifer in Plan Change 4C.**	5 (recommended) (2.9 for eastern portion and 3 for western portion has been proposed but not yet in Schedule 4A)	Under allocated	Monitor compliance with set minimum flows/environmental levels.
Cardrona-Wanaka Basin Aquifer	Due to the connection between the Cardrona-Wanaka Basin Aquifer and the Cardrona River, a maximum allocation limit is being developed in conjunction with a minimum flow regime for the Cardrona River.	5 (recommended)	Under allocated	An allocation limit will be set during the next plan change process, scheduled for 2017-2018

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Bendigo-Tarras and Ardgour Valley Aquifers	Due to the connection between the Bendigo-Tarras Aquifer, and the Lindis River, a maximum allocation limit is being developed in conjunction with a minimum flow regime for the Lindis River.	Ardgour Valley – 0.19 (proposed) Bendigo – 29 (recommended) Lower Tarras – 18.8 (proposed)	Under allocated	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.
Cromwell Terrace Aquifer	Work on developing a maximum allocation limit for this aquifer commenced mid-2012. A workshop was held in Cromwell on 18 March 2014. During this workshop local community members and interest groups debated a technical recommendation for managing the groundwater resources of the Cromwell Terrace Aquifer. **An allocation limit of 4 Mm^3/year was set for this aquifer in Plan Change 4C.** Restrictions for Cromwell Terrace Aquifer There shall be no takes from the Cromwell Terrace Aquifer for irrigation purposes between 1 May and 31 August inclusive in each year. Because the Cromwell Terrace Aquifer is hydraulically connected to Lake Dunstan, other restrictions may be imposed on resource consents to take water, to help maintain lake levels.	4 (operative)	Under allocated	Monitor compliance with set minimum flows/environmental levels.

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Earnscleugh Terrace Aquifer	Work on developing a maximum allocation limit for this aquifer commenced mid-2012. The first workshop was held in Alexandra on 18 March 2014. During this workshop ORC staff presented local community members and interest groups with an update on the current state of scientific knowledge on the Earnscleugh Terrace Aquifer and potential implications for the future management of this resource.	12.75 (recommended)	Under allocated	An allocation limit for the Fraser River will be set during the next plan change process, scheduled for 2017-2018.
Maniototo Basin Aquifer	ORC held a public workshop in Ranfurly on 21 August 2014. During the workshop local community members were invited to get involved in a study of the Maniototo Basin Aquifer.	15.8 (draft)	Under allocated	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.
Roxburgh Aquifer	ORC held a public workshop in Roxburgh on 27 August 2014. During the workshop local community members were invited to get involved in a study of the Roxburgh Aquifer. A technical report has been completed for this aquifer and is awaiting review by the Council Committee.	2.38 (as 0.75 for East Roxburgh and 1.63 for West Roxburgh)	Under allocated	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Pisa Groundwater Management Zone / Queensbury Groundwater Management Zone / Luggate Groundwater Management Zone	ORC held a public workshop in Lowburn on 28 August 2014. During the workshop local community members were invited to get involved in a study of these groundwater management zones. Allocation limits have been estimated for each different zone and will be refined after aquifer studies have been completed (June 2018).	Pisa - 6.5 Queensbury - 2.2 Luggate - 5.8 (recommended)	Pisa – under allocated Queensbury – over allocated Luggate – under allocated	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Hawea Basin Aquifers	Work on developing maximum allocation limits for the aquifers in the Hawea Basin commenced mid 2012. A workshop to discuss the aquifer technical report and identifying community values for groundwater was held on 27 August 2014. During the workshop domestic water supply (drinking water), irrigation and the Regionally Significant Wetlands in the Hawea Basin were identified as important values that are currently supported by groundwater. In light of concerns raised during the workshop regarding the recommendation to set maximum allocation limits and restriction levels for the Hawea Basin aquifers, ORC staff will review the groundwater modelling upon which these recommendations were based. ORC staff will also look at other issues that were raised (e.g. making monitoring available, consent review processes, alternative water supply options) and will report back to the community as soon as there is sufficient new information to discuss.	13.59 Hawea Flat, Lakeside Domain: 4.6 Hawea Flat, Hillside Domain: 4.08 High Terrace, Riverside Domain: 1.56 High Terrace, Hillside Domain: 0.41 Sandy Aquifer: 0.86 Te Awa Aquifer: 0.29 Maungawera Flat Aquifer: 0.57 Maungawera Valley Aquifer: 1.21	The aquifer is split into eight domains. The Hawea Flat Aquifer, Hillside Domain is over allocated. The High Terrace Aquifer (both domains) and the Maungawera Valley Aquifer are approaching full allocation.	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Manuherikia Alluvial and Manuherikia Claybound Aquifer	Work to determine an allocation limit for these aquifers was carried out in 2011/2012. The maximum allocation limit is being developed in conjunction with a minimum flow regime for the Manuherikia River.	Manuherikia Alluvium – 0.7 (recommended) Manuherikia Claybound Aquifer – 0.68 (recommended)	Under allocated (Manuherikia Alluvium) Approaching full allocation (Manuherikia Claybound Aquifer)	An allocation limit for the Manuherikia River will be set during the next plan change process, scheduled for 2017-2018.
Dunstan Flats Aquifer		1.84 (Recommended)	Approaching full allocation	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.
Manuherikia and Ida Valley Groundwater Management Zones		9.4 – Ida Valley (Draft)		An allocation limit for the Manuherikia River will be set during the next plan change process, scheduled for 2017-2018.

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Wakatipu Basin Aquifers : Bushy Creek Aquifer Frankton Flats Aquifer Kawarau Alluvial Ribbon Aquifer Mid Mill Creek Aquifer Morven Aquifer Shotover Alluvial Ribbon Aquifer Speargrass-Hawthorn Aquifer Upper Mill Creek Aquifer Windermere Aquifer	Initial work to determine an allocation limit for these aquifers was carried out in 2014. Further work to define the limit in conjunction with a minimum flow regime in the Arrow River is ongoing.	19.25 (recommended) excluding Bush Creek, Kawarau and Shotover Alluvial Ribbons.	This aquifer is split into 11 zones. The Mid Mill Creek Aquifer is over allocated.	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits. Allocation limits will be put into Schedule 4A upon completion of the Arrow River minimum flow and Wakatipu Aquifers plan change in 2017/2018,

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Glenorchy and Kingston GWMZ	Aquifer Quality Study in 2006. Further work needed to assess allocation limits.	N/A	The Glenorchy and Kingston Groundwater Management Zones have not been assessed.	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.
Lower Waitaki Plains Aquifer		115.85 (Recommended)	Under allocated	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.

Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Papakaio Aquifer: Big Hill Zone Waikoura Zone Camerons Zone Enfield Basin Maerewhenua Zone Waipati Zone Southern Zone		0.67 - Big Hill Zone (Recommended) 0.63 - Waikoura Zone (Recommended) 0.28 - Camerons Zone (Recommended) 2.6 - Enfield Basin (Recommended) 0.54 - Maerewhenua Zone (Recommended) 0.54 - Waipati Zone (Recommended) 0.69 - Southern Zone (Recommended)	Under allocated (Waikoura, Camerons and Waipati Zones) Over allocated (Big Hill and Maerewhenua Zones and Enfield Basin)	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.
Kakanui-Kauru Alluvium	(Managed as surface water)	Managed as surface water	N/A	Work to establish a water quality limit for groundwater is ongoing in this aquifer and scheduled for completion in 2018

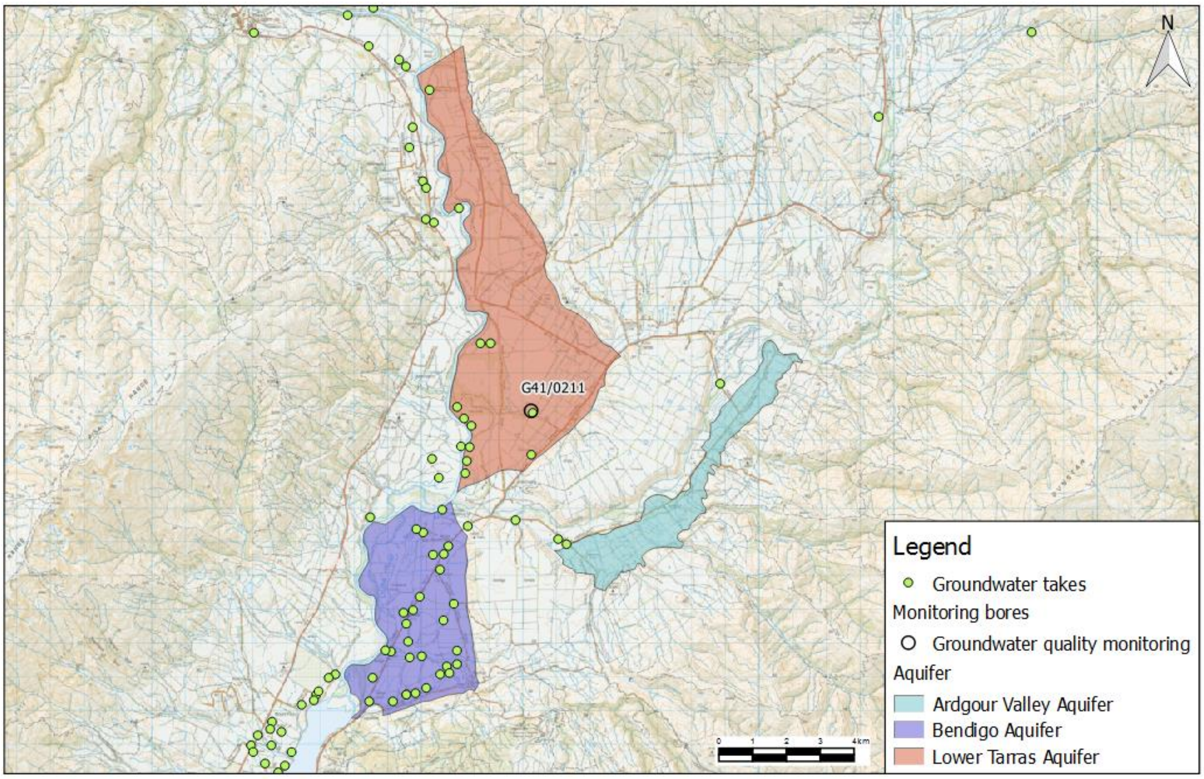
Table A1: Groundwater management plans

Aquifer	Groundwater Management Programme Status	Allocation Limit (x 10^6 m^3/year)	Limit status	Target
Inch Clutha Gravel Aquifer		5.2 (Draft)	Under allocated	Set sustainable environmental flows and allocation limits. Monitoring to ensure water quality meets limits.
Strath Taieri Groundwater Management Zone		4.15 (Draft)		Science work for setting minimum flows and environmental levels is scheduled for 2017/2018

Appendix B

Aquifer Summary Sheets

Bendigo-Tarras and Ardgour Valley Aquifers:



The Bendigo Tarras Aquifer is hosted with alluvial strata located close to the Clutha River. The strata includes highly permeable gravels located close to the Clutha River as well as less permeable silts and sands located further away from the river. Similarly, the Ardgour Valley Aquifer is characterised by alluvial deposits, but is not directly connected to the Lindis River.

Based on computer modelling, groundwater within the Lower Tarras aquifer is predominantly recharged by seepage from the Clutha River together with some land surface recharge. Groundwater flow directions are generally sub-parallel to the river and groundwater discharges back into the Clutha River in the downstream Bendigo Allocation Zone.

The aquifer thickness is variable, but relatively well defined based on geophysical and electrical resistivity assessments. The base of the aquifer is defined by silts and schists and can be more than 100 m thick, with the greatest thickness at the southern edge of the Lower Tarras Aquifer. Lesser thicknesses occur away from that area. Groundwater levels are typically around 25 m below ground level in the Lower Tarras Aquifer in bore G41/0211.

The confluence of the Lindis River and the Clutha River occurs at the downstream end of the Tarras Allocation Zone and the extent of surface flow within the Lindis River close to its confluence depends on local groundwater levels i.e. the Lindis River is well connected to local groundwater. Based on computer modelling, the Clutha River is also considered well connected to groundwater, although there are no pumping tests in the Lower Tarras Aquifer to confirm that.

Groundwater use is concentrated in the Benidgo Aquifer, with relatively limited abstraction from the Lower Tarras Aquifer. There is no abstraction from the Ardgour Valley Aquifer. The majority of groundwater use is reportedly for irrigation.

Information available

Groundwater level monitoring: *There are currently no groundwater level monitoring bores within the aquifers. However, the southern and western portions of the aquifers are closely connected to levels in the Clutha and Lindis Rivers.*

Groundwater quality information: *There is one groundwater quality monitoring bore within the Lower Tarras Aquifer, G41/0211 (41.5 m deep). This bore has been sampled for a range of parameters, generally at quarterly intervals, between March 2011 and December 2016. However, note that groundwater levels in the bore are around 25 m below ground, and samples from the bore may not reflect shallow groundwater quality used for drinking water.*

Stream/aquifer interaction: *Higher permeability deposits closer to the Clutha and Lindis Rivers are in close connection with flows in these waterbodies in some areas.*

Recharge volume: *The aquifers are recharged by rainfall recharge, irrigation recharge and from river losses.*

Discharge locations: *The current allocation for the Lower Tarras Aquifer is 2.3 Mm^3/year and 3.62 Mm^3/year for the Bendigo Aquifer (Houlbrooke, 2010). There are 41 consents to take groundwater within the Bendigo-Tarras aquifers. These are mainly used for irrigation, especially in the Bendigo Aquifer. The Lower Tarras Aquifer has a higher proportion of drinking water, stockwater, frost fighting and commercial industrial consents. There are currently no groundwater takes within the Ardgour Valley Aquifer.*

Allocation status: *The most recent report indicates that 18.8 Mm^3/year could be allocated from the Tarras Aquifer, 29 Mm^3/year from the Bendigo Aquifer and 0.19 Mm^3/year from the Ardgour Valley Aquifer outside of the Lindis Alluvial Ribbon (Houlbrooke, 2010).*

Typical landuse: *Landuse in the area is generally agricultural.*

Aquifer parameters: *There are six bores within the aquifers that have been subjected to pumping tests. The reported transmissivity values range from 900 to 31,200 m^2/day.*

Groundwater movement

Groundwater flow is constrained by the valley, and flows in a general southerly direction down-valley, sub parallel to the river.

Information required

To meet the objective of maintaining storage in the aquifer, some long term continuous groundwater level monitoring is required. Groundwater quality monitoring is expected to be sufficient to meet to relevant objectives for the Lower Tarras aquifer, but not for the Bendigo or Ardgour Aquifers, where no monitoring occurs. Additional monitoring is required in the aquifers to meet the minimum requirements.

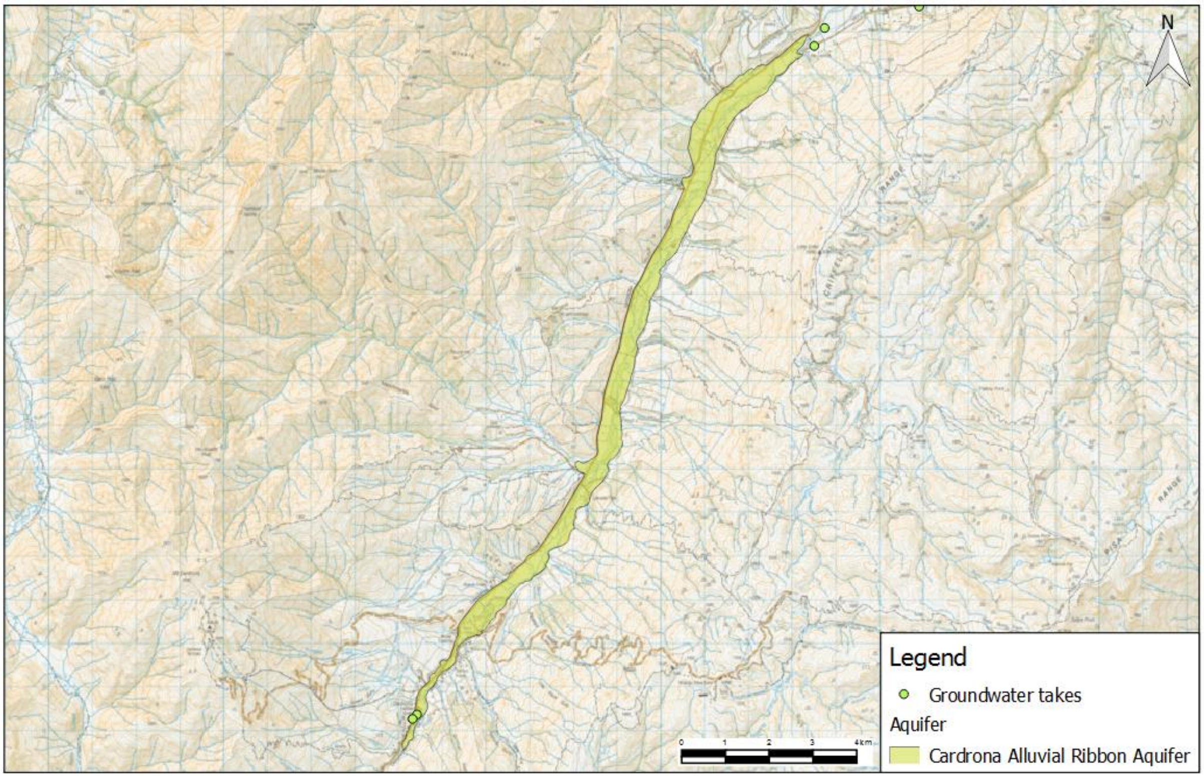
Summary

The allocation status is currently under development in conjunction with a minimum flow regime for the Lindis River.

Reference list

Houlbrooke, C. (2010). Bendigo and Tarras Groundwater Allocation Study. Dunedin: Otago Regional Council.

Cardrona Alluvial Ribbon Aquifer:



Information available

Groundwater level monitoring: *There are currently no groundwater level monitoring bores within the Cardrona Alluvial Ribbon Aquifer. However, groundwater is in close connection with the Cardrona River which has four flow stage sites along the reach of the aquifer.*

Groundwater quality information: *There are currently no groundwater quality monitoring bores in the aquifer. However, groundwater quality in the area is considered likely to generally be good due to a lack of populated areas and point source and diffuse discharge sources.*

Stream/aquifer interaction: *The Cardrona Alluvial Ribbon Aquifer and the Cardrona River are in close hydraulic connection.*

Discharge locations: *The Cardrona Alluvial Ribbon Aquifer is constrained to the Cardrona Valley. Hence, it is assumed that the aquifer discharges to the termination of the valley towards the north-east. There are two consented groundwater takes at the south-western end of the aquifer which are for drinking water supply purposes for commercial properties. At the north-eastern extent of the valley, the Cardrona River is split into four water races authorised by mining rights to take 1.278 m^3/s. Additionally, there are 27 consumptive surface water takes within the catchment.*

Recharge volume: *Recharge volumes of various sources are currently under development, with the majority of recharge originating from and relative to flows in the Cardrona River.*

Allocation status: *The allocation status of the aquifer is currently being developed in conjunction with a minimum flow regime for the Cardrona River.*

Typical landuse: *The dominant landuse in the Cardrona Valley is agricultural.*

Groundwater movement

Groundwater flow is in close connection with the Cardrona River and flows in a similar direction towards the north-east.

Information required

Aquifer parameters: *There are no bores within the aquifer with aquifer parameter information. However, groundwater takes are effectively considered as surface water takes so knowledge of aquifer parameters is considered to be less relevant.*

Summary

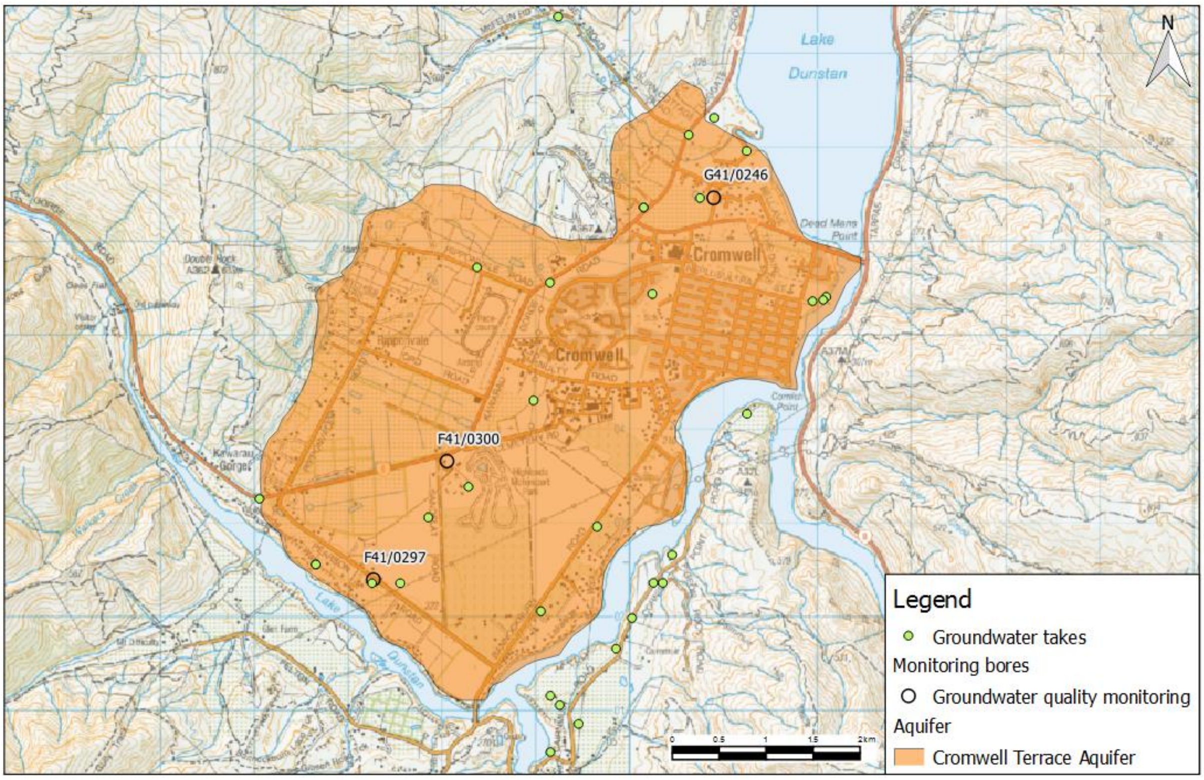
Currently, the allocation volumes and limits for the Cardrona Alluvial Ribbon Aquifer are under development in conjunction with a minimum flow regime for the Cardrona River. The aquifer is closely connected to the Cardrona River and as such, it is considered that groundwater takes can effectively be allocated to surface water limits so specific information on groundwater levels/quantity is unlikely to be required.

Given this hydraulic connection, it is considered that surface water quality will be of more relevance than groundwater quality and that land use/discharges in the zone will primarily be controlled based on surface water quality. In this instance, groundwater quality for human health is likely to be indirectly protected and specific groundwater quality monitoring is not considered crucial. However ORC will need to ensure that land use and discharge consents are appropriately controlled and monitored such that effects on individual groundwater supplies are well managed. Groundwater users should also undertake their own monitoring to ensure the supply is suitable for their needs.

Reference list

Dale, M., & Rekker, J. (2011). Integrated Water Resource Management for the Cardrona River. Dunedin: Otago Regional Council.

Cromwell Terrace Aquifer:



The Cromwell Terrace aquifer is made up of glacial outwash deposits located between the Kawarau Arm of Lake Dunstan and immediately upstream of the Kawarau- Clutha confluence. The edges of the aquifer are defined by the low permeability hill strata to the north and surface water bodies to the west, south and east. The overall Cromwell basin is asymmetric, with the greatest depth towards the hill strata (over 350 m) and thinning towards the Clutha River and Lake Dunstan. Groundwater within the basin is relatively deep, around 20 m below ground level, which reflects the close connection with the topographically lower Lake Dunstan.

Groundwater in the aquifer drains generally south-east towards Lake Dunstan and is recharged via a combination of land surface recharge, inflow from the Kawarau Arm and infiltration of irrigation applied at the surface of the aquifer. However, note that some seepage of water from Lake Dunstan into the aquifer also occurs because the aquifer is strongly connected to the lake and groundwater abstraction can induce seepage from the lake into the aquifer.

Groundwater abstraction from the aquifer is predominantly used for irrigation and public supply and the total consented allocation was around 1.7 $x10^6$ m^3/year in 2012. Groundwater abstraction occurs across the aquifer and the strata can be highly permeable with pumping tests showing transmissivity values of up to 14,000 m^2/day.

Information available

Groundwater level monitoring: *There are currently no groundwater level monitoring bores within the aquifer. However, general depths to groundwater are known from previous investigations with a mean depth to water of 20 m.*

Groundwater quality information: *Groundwater quality is generally high and has been monitored in three bores.*

1. *Bores F41/0297 (44.85 m deep) and G41/0246 (37.22 m deep) have only been monitored once each in March 2011.*
2. *Bore F41/0300 (48.71 m deep) has been monitored for a wide range of parameters at quarterly intervals between March 2011 and December 2016.*

Stream/aquifer interaction: *There is a high degree of connectivity between the aquifer and Lake Dunstan and the lake contributes significant inflows into the aquifer.*

Recharge volume: *Recharge volumes are well constrained and originate from rainfall and irrigation recharge and infiltration from Lake Dunstan with a total inflow of 2.4 Mm^3/day (Rekker, 2012).*

Discharge locations: *Aquifer outflows are estimated to be 0.4 Mm^3/year to bore abstraction and 2 Mm^3/year to seepage into Lake Dunstan (Rekker, 2012). There are currently 20 consents to take water from the aquifer, which are mainly used for irrigation and frost fighting with a smaller amount of drinking water supplies, a commercial supply and a school water supply.*

Allocation status: *A detailed allocation model has been carried out for this aquifer which showed that inflows are 2.4 Mm^3/year with a similar volume of outflows. However, due to the significant of inflows from Lake Dunstan an allocation limit of 4 Mm^3/year has been set (Rekker, 2012).*

Typical landuse: *The landuse in the basin mainly consists of fruit orchards, farming and populated areas.*

Aquifer parameters: *There are three bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 800 to 14,000 m^2/day.*

Groundwater movement

The aquifer receives inflow from the Kawarau Arm of Lake Dunstan and outflows to Lake Dunstan further to the east.

Information required

Additional groundwater level monitoring is required to comply with the minimum requirements to maintain aquifer storage. Groundwater quality monitoring is expected to be suitable.

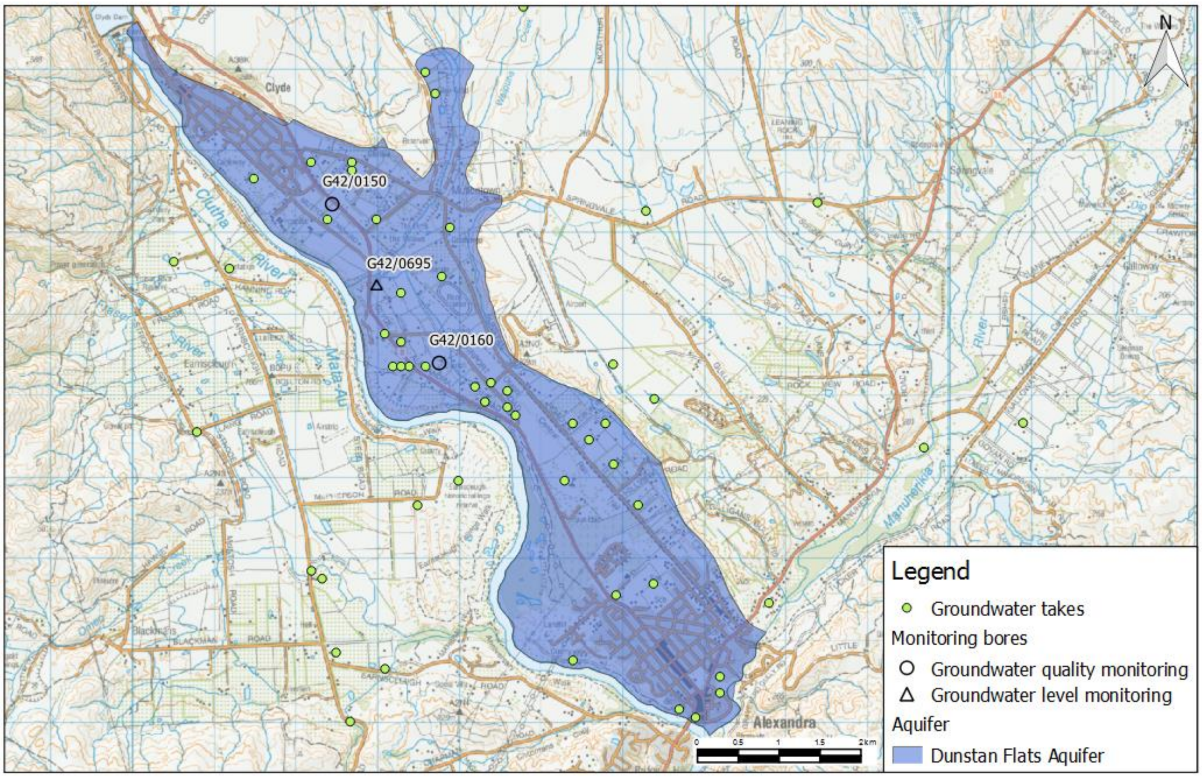
Summary

Groundwater movement is well understood in this aquifer and a model has been constructed that allows assessment of scenarios of development.

Reference List

Rekker, J. (2012). Cromwell Terrace Aquifer Study. Dunedin: Otago Regional Council.

Dunstan Flats Aquifer:



The Dunstan Flats Aquifer primarily consists of sandy gravels which, as for the Earnscleugh Terrace Aquifer, originate from glacial outwash following the Albert Town glacial advance. In contrast to the Earnscleugh Terrace Aquifer the outwash gravels are underlain by older gravels from the early quaternary period.

The aquifer is strongly connected to the Clutha River and groundwater contours imply that groundwater flows from northeast to the south-west directly into the river.   High river levels temporarily boost the water table along riparian strips of the aquifer and sustained low river levels can lower the water table over the whole aquifer.

Groundwater levels in the aquifer are typically relatively deep, around 20 to 25 m below ground level. Groundwater use is concentrated towards the centre of the aquifer, close to the river. Consented abstraction is around 1.43 x 10^6 m^3/year, of which around 0.43 x 10^6 m^3/year is used. Groundwater use is mostly for irrigation, with some domestic use. The strata are permeable based on aquifer tests indicating transmissivities of 1,250 to 7,000 m^2/day.

Recharge to the aquifer is predominantly from water race losses and subsurface flow from the adjoining Manuherikia Claybound Aquifer. A small amount of recharge is also received from rainfall excess and irrigation as well as downward infiltration of Waikerikeri Creek water into the Dunstan Flat Aquifer.

Groundwater in the Dunstan Flats Aquifer is discharged into the Clutha River via seepage.

Information available

Groundwater level monitoring: *There is one groundwater level monitoring bore within this aquifer (G42/0695, 17.85 m deep) which has a continuous monitoring record from April 1986 to May 2017.*

Groundwater quality information: *Bores G42/0150 (35 m deep) and G42/0160 (32.3 m deep) have been monitored quarterly for a wide range of parameters between March 2011 and December 2016.*

Stream/aquifer interaction: *The aquifer receives infiltration from Waikerikeri Creek and the water table in the aquifer is potentially influenced by Clutha River levels.*

Recharge volume: *Recharge volumes are well constrained and originate predominantly from water race losses and subsurface flow from the adjoining Manuherikia Claybound Aquifer. Smaller components of recharge are sourced from rainfall and irrigation recharge and infiltration from Waikerikeri Creek. The mean annual recharge for the aquifer is estimated to be 3.68 Mm^3/year (Otago Regional Council, 2012).*

Discharge locations: *The majority of the aquifer is discharged via seepage to the Clutha River. There are currently 36 consented takes with the aquifer mainly used for irrigation and drinking water supply, with a smaller number of takes for frost fighting, commercial/industrial use, aquaculture, recreation and stockwater supply.*

Allocation status: *A detailed water balance assessment has been carried out for this aquifer. A default allocation limit of 50% mean annual recharge results in total allocation volume of 1.84 Mm^3/year. The current consented allocation is 1.45 Mm^3/year (Otago Regional Council, 2012).*

Typical landuse: *Landuse in the area consists mainly of agricultural land, lifestyle blocks and urban areas.*

Aquifer parameters: *There are seven bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 2.5 to 13,900 m^2/day.*

Groundwater movement

Groundwater flows in a generally south-west direction and discharges to the Clutha River.

Information required

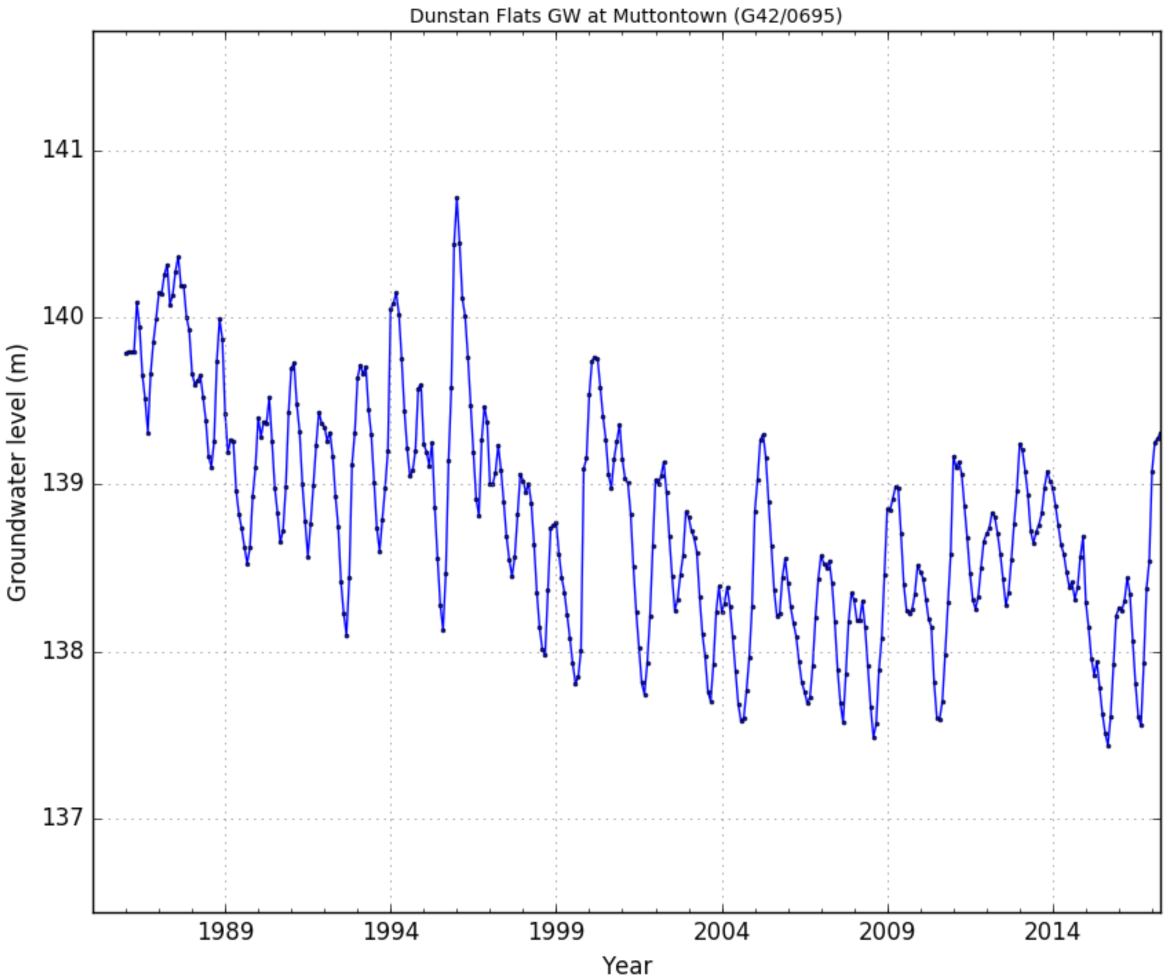
Monitoring in the Dunstan Flats Aquifer is considered to be consistent with the requirements for this aquifer

Summary

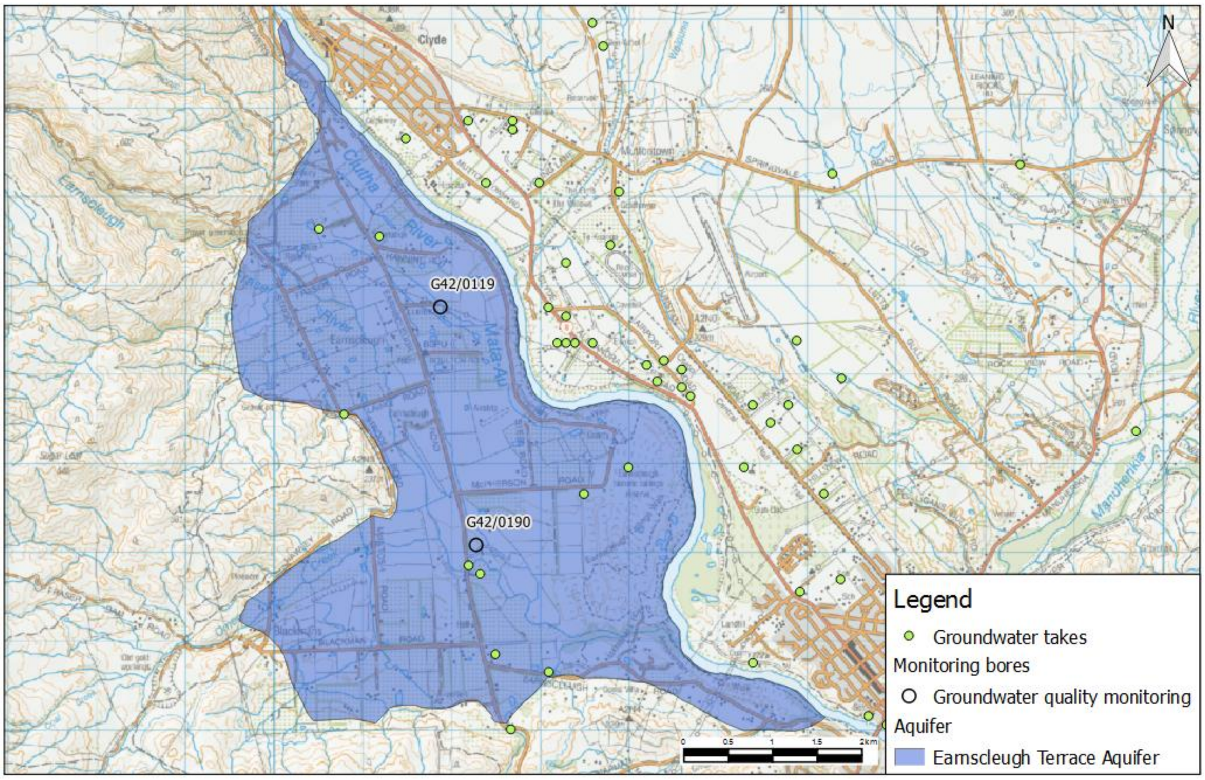
Groundwater movement is well understood in this aquifer and the allocation status is well constrained. There is sufficient groundwater quality monitoring..

Reference list

Otago Regional Council. (2012). Alexandra Groundwater Basin Allocation Study. Dunedin: Otago Regional Council.


Dunstan Flats GW at Muttontown (G42/0695)
141
140
139
138
137
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year

Earnscleugh Terrace Aquifer:



The Earnscleugh Terrace Aquifer originates from a glacial outwash following the Albert Town glacial advance and primarily consists of sandy gravels. The base of the aquifer consists of very low permeability silt and mudstone of the Manuherikia Group which is underlain by basement schist of the Torlesse supergroup. The aquifer is raised above the Clutha River and is considered therefore to not have a direct connection with that surface waterway.

Recharge to the aquifer is predominantly from the Fraser River which loses a substantial proportion of its flow to the aquifer as it crosses the permeable surface of Eurnscleugh Flat. Irrigation losses, leakage from water races and a small amount of excess rainfall also contribute to aquifer recharge. Groundwater generally flows from the north-west to the south-east and discharges into the Clutha River via seepage and springs as well as via upward seepage of aquifer water into the Lower Fraser River immediately upstream of the confluence with the Clutha River. The depth to water across the aquifer varies from around 20 m in bore G42/0119 to around 10 m below ground in bore G42/0190.

Groundwater use across the aquifer is generally for irrigation and domestic supplies and around 0.5×10^6 m^3/year is allocated across the Earnscleugh Aquifer. The aquifer is highly permeable but groundwater use is limited due to the extensive network of water races derived from surface water.

Information available

Groundwater level monitoring: *There is one groundwater level monitoring bore within this aquifer which was monitored between February 1993 and October 1999. This bore is listed as 'P82 Earnscleugh Bore' and is of unknown depth and location.*

Groundwater quality information: *Bores G42/0119 (37.8 m deep) and G42/0190 (21.3 m deep) have been sampled for a range of parameters at quarterly intervals between September 1996 and June 2013.*

Stream/aquifer interaction: *The aquifer is well connected to the Fraser River with both gaining and losing reaches of river present above the aquifer. The aquifer also provides seepage into the Clutha River.*

Recharge volume: *Recharge volumes are well constrained and originate predominantly from water losses from the Fraser River. A smaller component of recharge is sourced from rainfall, water race losses and excess irrigation drainage. The mean annual recharge for the aquifer is estimated to be 25.5 Mm^3/year (Otago Regional Council, 2012).*

Discharge locations: *The aquifer is discharged to the Clutha River via seepage or into springs that enter the Clutha River. A significant component is also discharged via upward seepage into the Lower Fraser River. There are a total of eight consents to take groundwater. Various uses include irrigation, drinking water supply, commercial/industrial and frost fighting.*

Allocation status: *A detailed water balance assessment has been carried out for this aquifer. The default allocation limit of 50% mean annual recharge results in total allocation volume of 12.75 Mm^3/year. The current consented allocation is 0.514 Mm^3/year indicating that there is room for further allocation (Otago Regional Council, 2012)*, although no specific limit has been developed.

Typical landuse: *Landuse in the area consists mainly of horticultural activities such as vineyards and orchards and also mining activities.*

Aquifer parameters: *There are six bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 1,100 to 9,000 m^2/day.*

Groundwater movement

Groundwater flows in an eastern direction with water entering the aquifer along the upper Fraser River and discharging to the Clutha River.

Information required

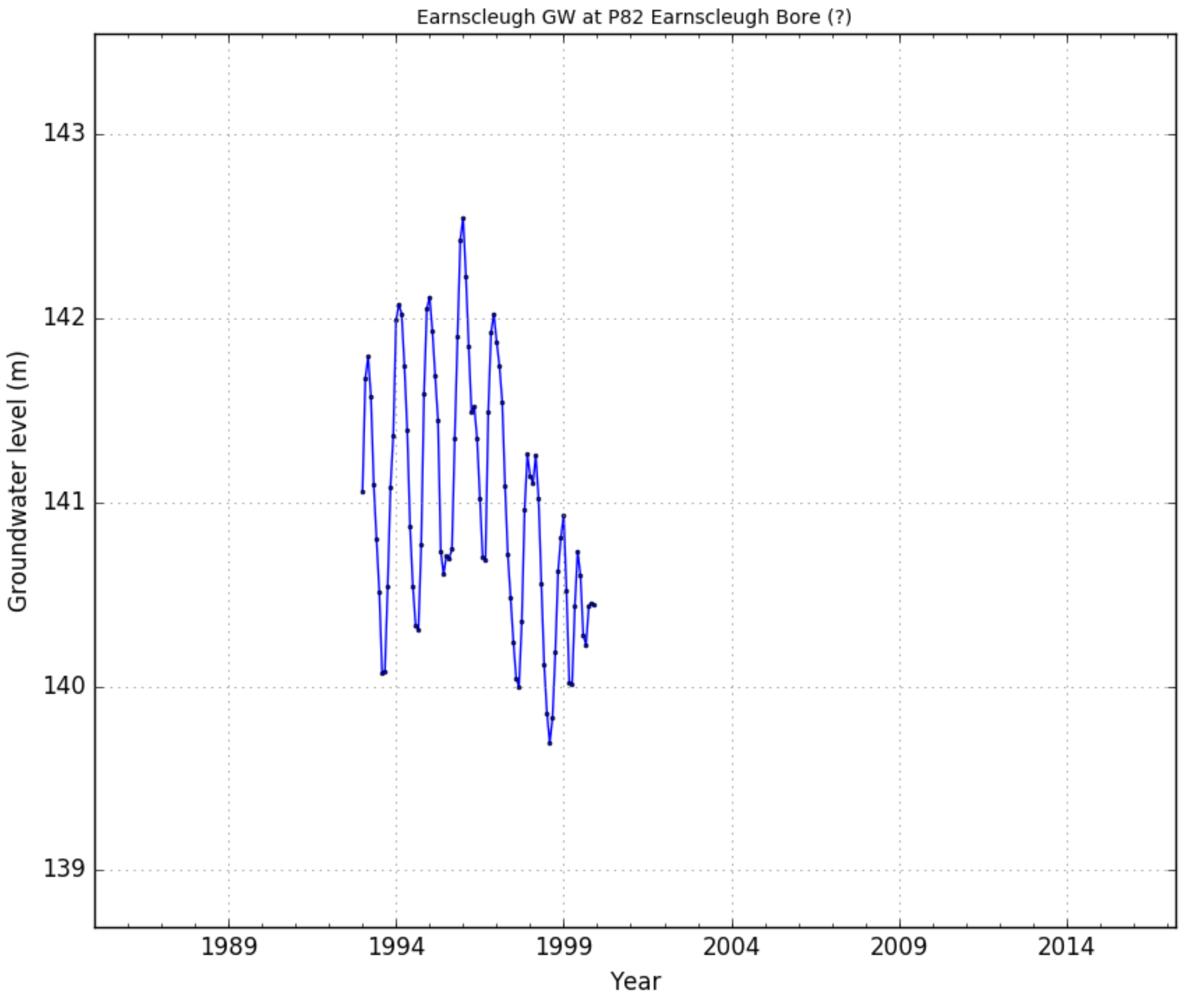
Water quality monitoring and groundwater level monitoring to inform groundwater allocation.

Summary

Groundwater movement is generally well understood in this aquifer.

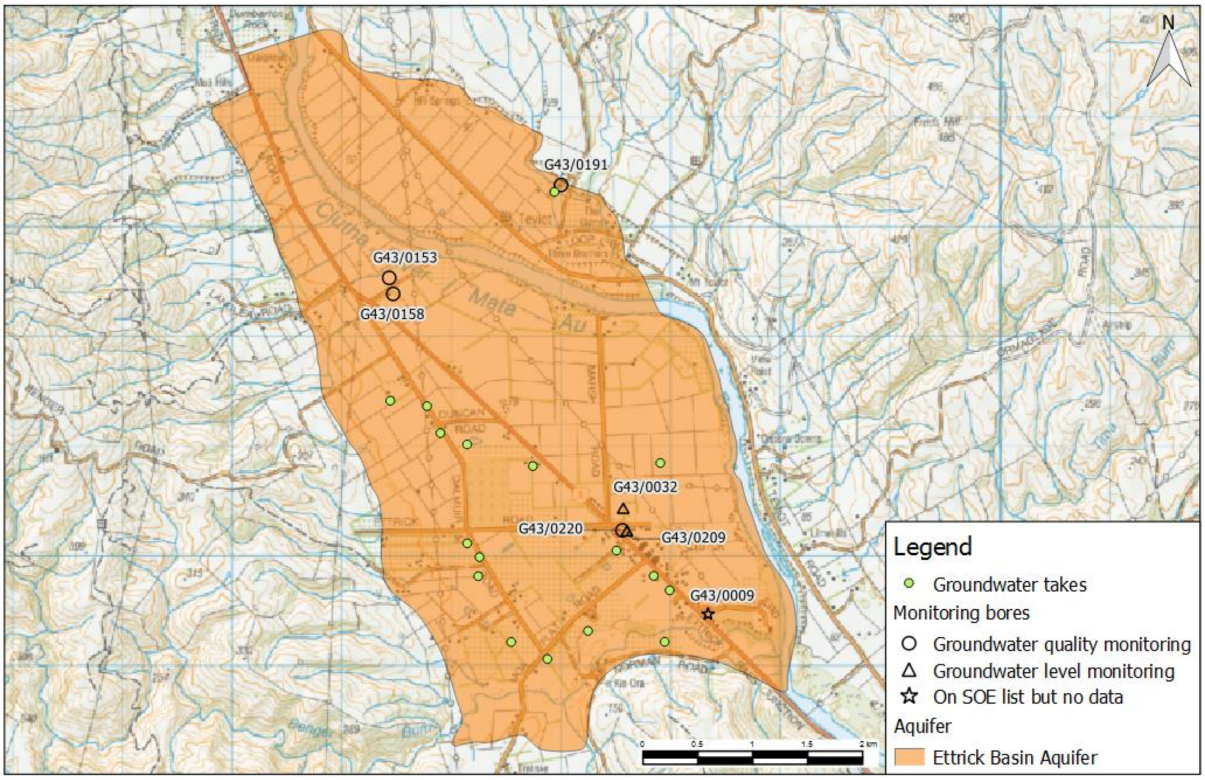
Reference list

Otago Regional Council. (2012). Alexandra Groundwater Basin Allocation Study. Dunedin: Otago Regional Council.



Earnscleugh GW at P82 Earnscleugh Bore (?)
Groundwater level (m)
143
142
141
140
139
1989
1994
1999
2004
2009
2014
Year

Ettrick Basin Aquifer:



The Ettrick basin aquifer consists of largely unconfined Quaternary alluvial strata located to the north of Ettrick township. The strata vary in thickness and bores show up to 30 m of gravels towards the western part of the aquifer, thinning to around 5 m closer to the boundary with the Clutha River. Note that the mapped aquifer extent is bisected by, and extends across, the Clutha River.

Recharge to the aquifer is generally expected to be from land surface recharge, runoff recharge from surface waterways exit the hills and flow across the aquifer and surface water seepage from the Benger Burn at the southern end of the aquifer. The Clutha River is not expected to provide significant recharge to the aquifer, except at occasional times of higher river flows. Groundwater in the aquifer ultimately discharges to the Clutha River, although some groundwater discharge also occurs to the Benger Burn, which subsequently flows into the Clutha River. The overall groundwater flow direction is towards the east. The depth to groundwater varies across the aquifer, with the greatest depths closer to the western edge of the aquifer (around 20 m) and groundwater levels approaching the surface towards the Clutha River.

Groundwater abstraction is concentrated in the south- western part of the aquifer. Total consented groundwater abstraction is estimated to be around 2.85 x10^6 m^3/year, of which around 30% is actually used. Groundwater use is dominated by irrigation use, together with stock and domestic supply.

Information available

Groundwater level monitoring: *There are two groundwater level monitoring bores within the aquifer.*

1. *Bore G43/0032 (18.8 m deep) has a continuous monitoring record between July 1995 and October 2009.*
2. *Bore G43/0209 (23 m deep) has a continuous monitoring record between July 2009 and May 2017.*

Groundwater quality information: *There are four bores within the basin with available groundwater quality information.*

1. *Bores G43/0158 (unknown depth) and G43/0191 (unknown depth) have been sampled for a range of parameters once during June 2016.*
2. *Bore G43/0220 (unknown depth) has been sampled for a range of parameters twice, once during November 2016 and once during January 2017.*
3. *Bore G43/0153 has the longest groundwater quality record (4 samples) with samples analysed for a range of parameters in September 2010, March 2011, November 2016 and January 2017.*

Stream/aquifer interaction: *There is a high degree of connectivity between the aquifer and the Benger Burn. The Benger Burn loses flow to the aquifer between the base of the surrounding hills and State Highway 8, and receives flow from the aquifer between State Highway 8 and the Clutha River.*

Recharge volume: *Rainfall recharge to the aquifer is estimated to be 1.3 Mm^3/year. Range front recharge from stream and hill side seepage is estimated to be 1.4 Mm^3/year. The Benger Burn is also estimated to contribute 2.8 Mm^3/year of river losses to the aquifer. The Clutha River is not thought to provide any recharge to the aquifer, except in occasional flood events where there may be a reversal in the piezometric gradient (Dale & Morris, 2014).*

Discharge locations: *Groundwater discharge mainly occurs as seepage into the Clutha River (4.65 Mm^3/year). The current consented volume of groundwater takes in the aquifer is 2.85 Mm^3/year. However, water meter data suggests that only 0.85 Mm^3/year is actually used (Dale & Morris, 2014).*

Allocation status: *The total allocation for the aquifer (2.85 Mm^3/year) has exceeded half of the mean annual recharge (2.75 Mm^3/year) indicating that the aquifer has reached and exceeded its maximum allocation limit (Dale & Morris, 2014).*

Typical landuse: *The basin mainly consists of orchards and agricultural land.*

Aquifer parameters: *There are four bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 6.5 to 12,000 m^2/day.*

Groundwater movement

Groundwater is recharged via surface water infiltration and drainage off the surrounding hills and flows towards the Clutha River on either side of the basin, together with discharge to the lower reaches of the Benger Burn.

Information required

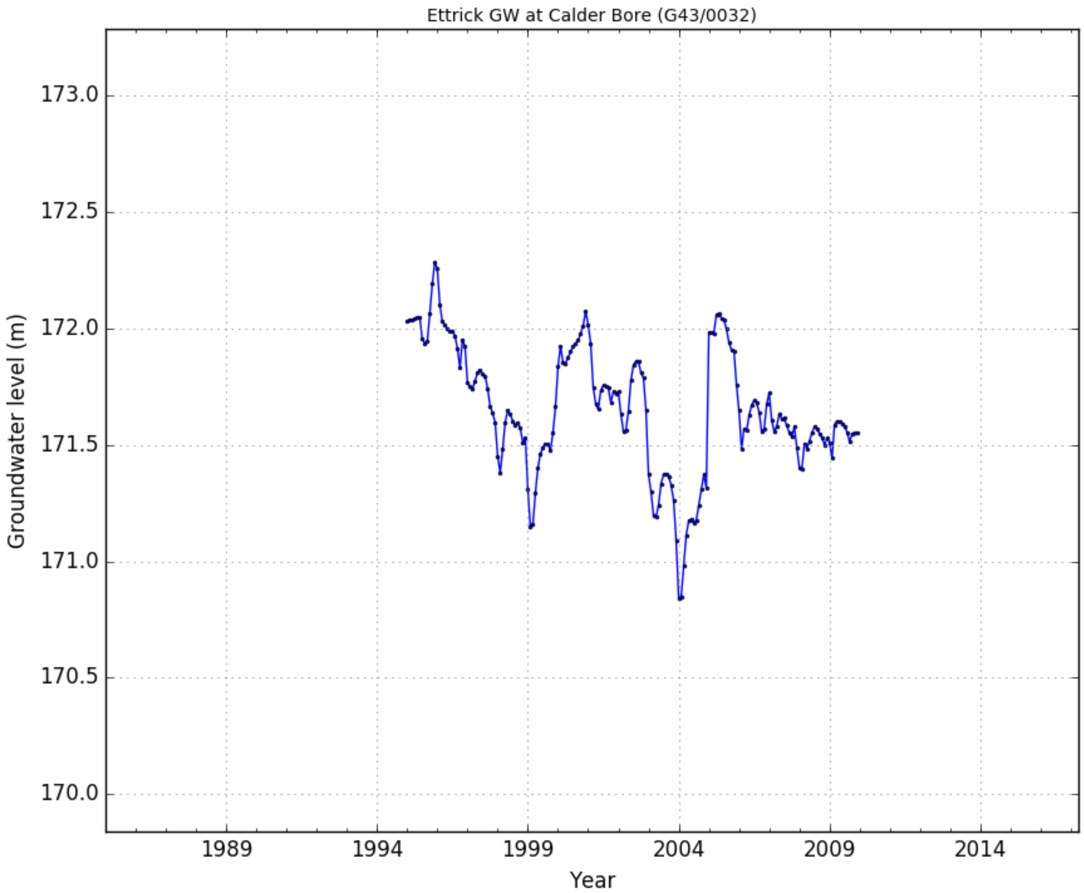
None.

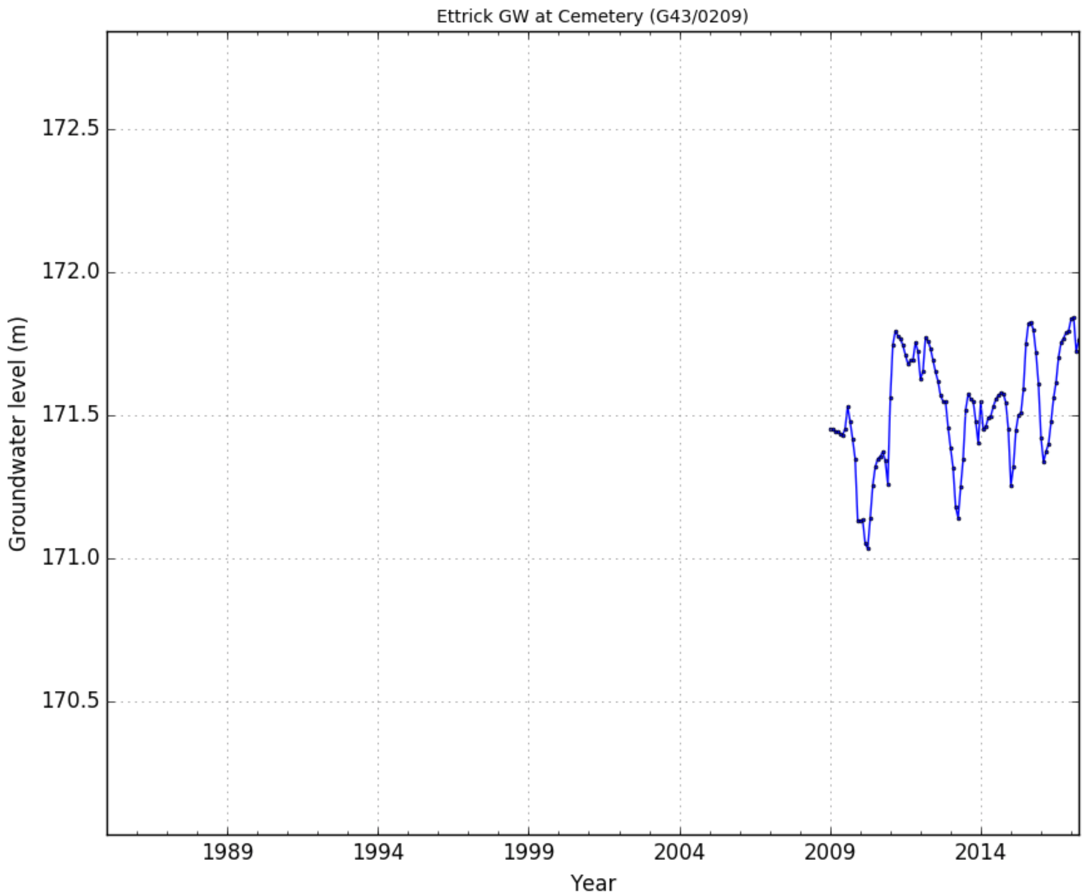
Summary

Groundwater movement is relatively well understood in this aquifer.

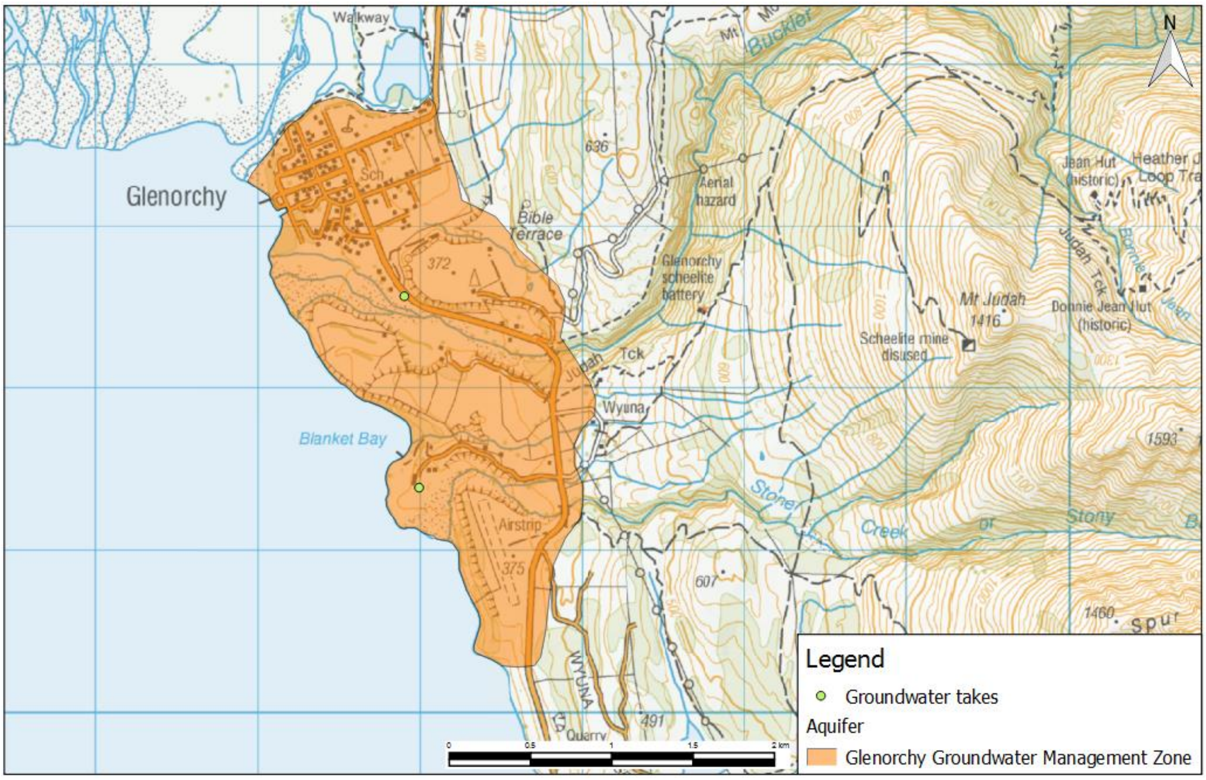
Reference list

Dale, M., & Morris, R. (2014). Integrated Water Resource Management for the Benger Burn and Ettrick Basin Aquifer. Dunedin: Otago Regional Council.


Ettrick GW at Calder Bore (G43/0032)
Groundwater level (m)
173.0
172.5
172.0
171.5
171.0
170.5
170.0
1989
1994
1999
2004
2009
2014
Year


Ettrick GW at Cemetery (G43/0209)
Groundwater level (m)
172.5
172.0
171.5
171.0
170.5
1989
1994
1999
2004
2009
2014
Year

Glenorchy Groundwater Management Zone:



The Glenorchy Groundwater Management Zone covers a relatively small area of Holocene river gravels. The strata to the east and south consist of low permeability basement strata, which are likely to underlie the gravel deposits at a shallow depth. There is little information around groundwater depths or groundwater flow directions, although the likely flow direction is towards Lake Wakatipu.

Groundwater use in the zone is currently low, with one abstraction for the settlement water supply and another for the operation of a commercial lodge operation. The abstraction for community supply purposes is located on the north bank of Buckler Burn, just south of the township. Groundwater is taken from a shallow bore adjacent to the stream and is defined as a having a high stream depletion effect.

Shallow groundwater is expected to be closely connected to surface water bodies with alluvial fans covering the majority of the zone. Groundwater is expected to discharge to the west into Lake Wakatipu.

Information available

Groundwater level monitoring: *There are no groundwater level monitoring bores within the Glenorchy Groundwater Management Zone. However, groundwater levels are expected to be in close connection with Lake Wakatipu and surface waterways in the area.*

Groundwater quality information: *There are currently no groundwater quality monitoring bores within the aquifer. However, a historical report by Lindqvist (1997) indicates that background concentrations of arsenic of around 0.003 mg/L are present in the groundwater, likely a result of arsenopyrite in the local schist bedrock. The report also contains other groundwater quality information including faecal coliforms and nitrate however this data is now likely obsolete.*

Stream/aquifer interaction: *The Glenorchy Groundwater Management Zone is expected to be in close connection with the Buckler Burn and Stone Creek which flow across the area as alluvial fans. Lake Wakatipu is also expected to have an influence on groundwater in the area, receiving the majority of groundwater outflow.*

Recharge volume*: Recharge in the Glenorchy Groundwater Management Zone is expected to be mainly sourced from surface waterway losses and range front recharge.*

Discharge locations: *There are two consents to take groundwater near Glenorchy, one for domestic supply for the settlement, and another for a commercial lodge that includes drinking water supply, firefighting, irrigation and stockwater supply. The majority of the groundwater in the Glenorchy Groundwater Management Zone is expected to discharge to Lake Wakatipu.*

Typical landuse: *landuse consists of agriculture, low-density residential areas, resorts, a golf course and an airfield.*

Aquifer parameters: *There is one bore with the results of a pumping test within the Glenorchy area with a reported transmissivity of 3,100* m^2*/day.*

Groundwater movement

Groundwater in the Glenorchy Groundwater Management Zone is expected to generally flow west towards Lake Wakatipu.

Information required

Allocation status: *The allocation status of the Glenorchy Groundwater Management Zone is currently unknown.*

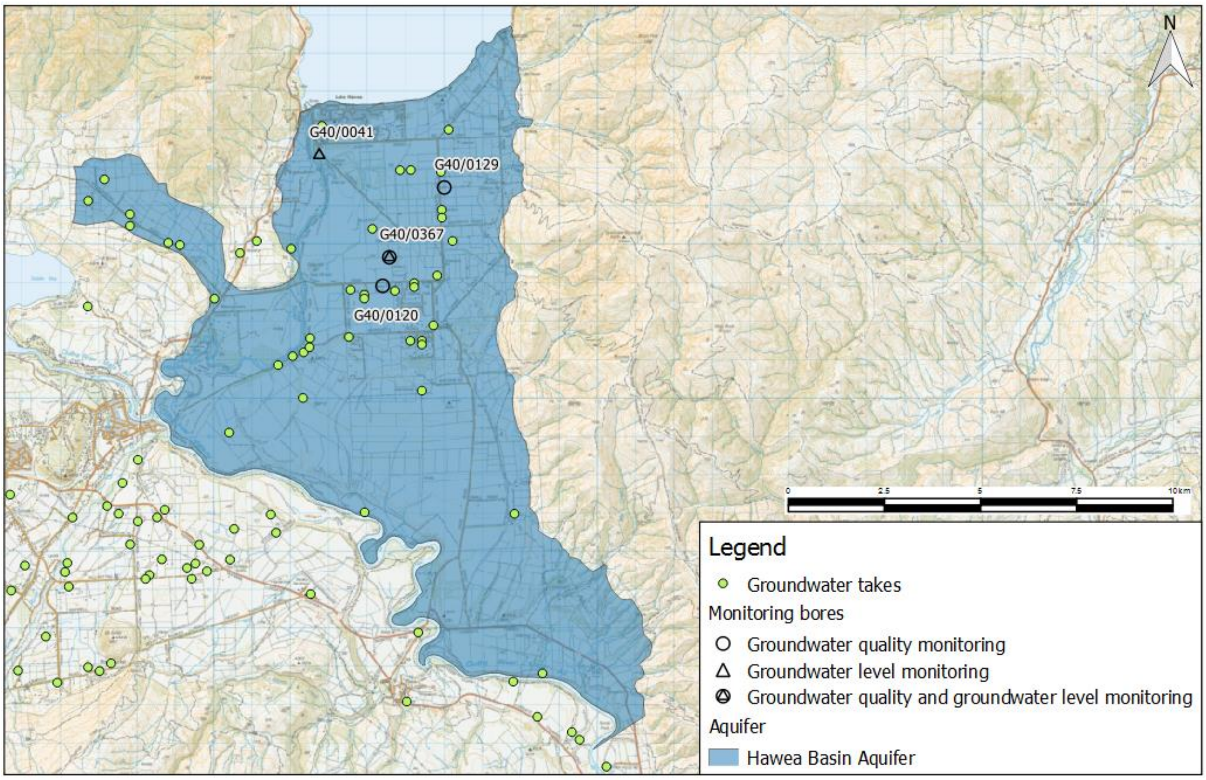
Summary

There is limited information on groundwater levels and quality in the Glenorchy Groundwater Management Zone. However, there is currently only limited groundwater abstraction in the zone. If greater groundwater use occurs in the future, some further monitoring may be required.

Reference List

Lindqvist, J. (1997). Otago Regional Council Ground Water Investigations 1996/97 - Glenorchy. Dunedin: JK Lindqvist Research.

Hawea Basin Aquifer:



The Hawea Basin aquifer consists of a sequence of unconsolidated gravels, moraine and glacial tills. The unconsolidated strata overlie low permeability basement strata and can be more than 100 m thick, although based on structure contours in ORC (2006) are more often around 50 m thick.

The Hawea Basin aquifer has been subdivided for management purposes into a series of separate domains, based on topographic and surface water boundaries. Movement of groundwater in the overall aquifer is partly driven by seepage from Lake Hawea, as well as runoff and land surface recharge across other parts of the area. Groundwater in the aquifer eventually discharges into the Clutha River and the overall flow direction is to the south-east. Groundwater depths vary; groundwater is typically shallower around the northern Hawea Flats (around 5 to 10 m deep), but can be much deeper around the southern part of the aquifer, where the topography rises into the Hawea Terrace (more than 20 m deep). The aquifer is well connected to the Clutha River.

Groundwater use is greatest across the Hawea Flats area, with relatively limited use across the rest of the aquifer to the south. The majority of bores are used for domestic supply, although in terms of volume, the greatest use is for irrigation. The consented use is around 9.25 x 10^6 m^3/year (2014 data) across the whole aquifer, although the majority of that use is in the Hawea Flats, close to the Lake Hawea.

Information available

Groundwater level monitoring: *Groundwater levels have been monitored in two bores.*

1. *Bore G40/0041 (unknown depth) has a continuous water level record between July 2014 and January 2017.*
2. *Bore G40/0367 (15 m deep) has a continuous record from to July 2014 to February 2017.*

Groundwater quality information: *There are three groundwater quality monitoring bores within the Hawea Basin.*

1. *Bore G40/0120 (15.9 m deep) has a reasonable spread of parameters monitored for between 1993 and 2013, and generally the bore has been sampled every 3 to 6 months.*
2. *Bore G40/0129 (26.4 m deep) also has a reasonable spread of parameters monitored for between 1996 and 2013 generally at 3 monthly intervals.*
3. *Bore G40/0367 (15 m deep) has a slightly more comprehensive suite of parameters and water quality samples have been taken at 3 monthly intervals between March 2015 and December 2016.*

Stream/aquifer interaction: *Rivers, streams and wetlands are considered to be well connected to groundwater in the basin. Seepage inflow from Lake Hawea occurs in the north of the basin and aquifer outflow is mainly discharged to the Hawea and Clutha Rivers in the south-west.*

Recharge volume: *A comprehensive summary of aquifer recharge sources and volumes has been provided for various aquifers within the Hawea Basin. The total average recharge volume for the Hawea Basin Aquifers has been estimated as approximately 70.22 Mm^3/year (East, 2014).*

Discharge locations: *There are 41 consented groundwater takes within the Hawea Basin Aquifer which are mainly used for irrigation. Well use is estimated to be 18.5 % of the aquifer outflow, with 81.5 % of aquifer outflow discharging to rivers (Heller, 2003).*

Allocation status: *The Hawea Basin is well utilised for irrigation and there is relatively little to no remaining allocation considered available in the basin (Morris, 2014). The maximum allocation limit for the aquifer is 13.59 Mm^3/year as provided by ORC.*

Typical landuse: *The basin mainly consists of irrigated agricultural land.*

Aquifer parameters: *There are 8 bores within the Hawea Basin listed as having aquifer parameters with transmissivity values ranging from 1,250 to 31,600 m^2/day. Additionally, the ORC (2003) science report lists 20 bores with aquifer parameters ranging from 25 to 993 m^2/day with an average transmissivity of 281.3 m^2/day.*

Groundwater movement

The main source of recharge to this aquifer is considered to be via seepage from Lake Hawea and infiltration runoff from adjacent topography, but also to include rainfall and irrigation infiltration and seepage from streams. Groundwater flows from the north-east to the south-west and the main source of discharge is to the Hawea and Clutha Rivers.

Information required

None.

Summary

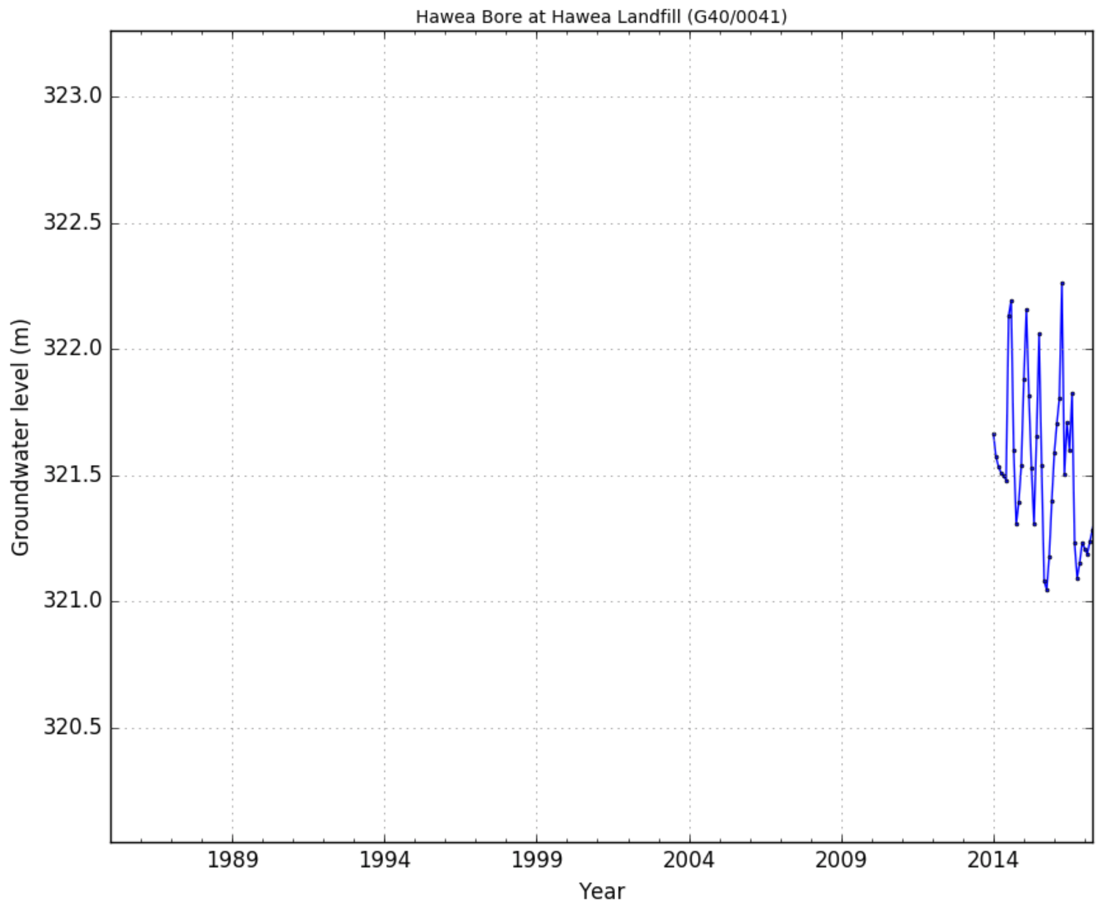
Groundwater movement is well understood in this aquifer and a model has been constructed that allows assessment of scenarios of development. The allocation status is well constrained and overall there is sufficient information to ensure that groundwater is sustainably managed.

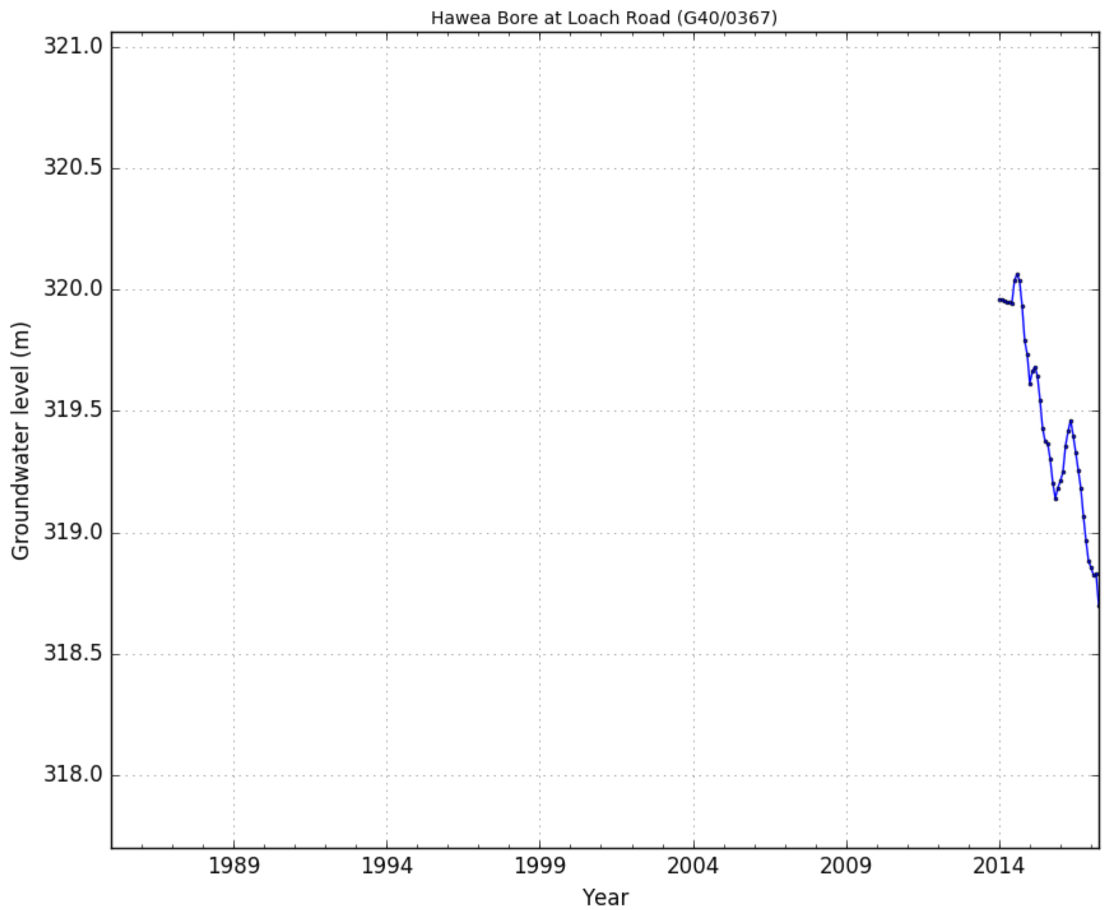
Reference list

East, S. (2014). Memorandum: Hawea Basin Allocation Groundwater Modelling. Otago Regional Council.

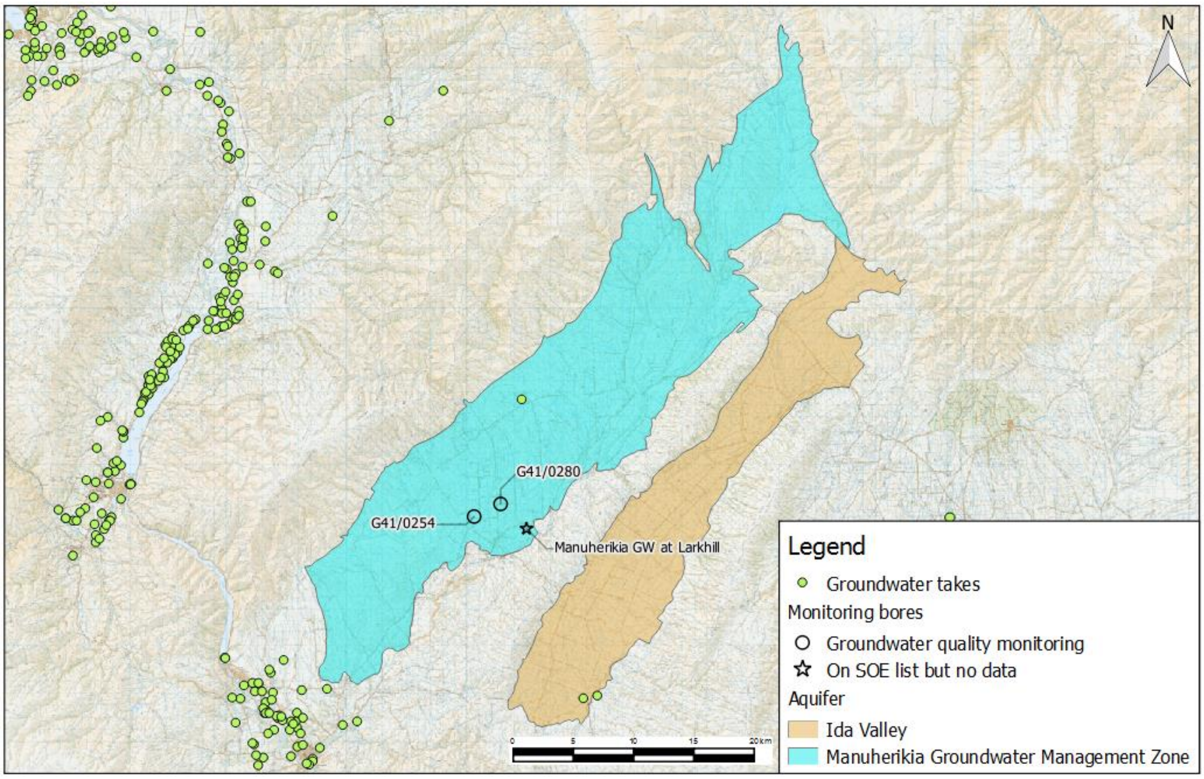
Heller, T. B. (2003). Hawea Basin Aquifer: Groundwater Balance and Allocation. Dunedin: Otago Regional Council.

Morris, R. (2014). Memorandum: Steady State Maximum Allocation Limit Options. Otago Regional Council.


Hawea Bore at Hawea Landfill (G40/0041)
323.0
322.5
322.0
321.5
321.0
320.5
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year


Hawea Bore at Loach Road (G40/0367)
321.0
320.5
320.0
319.5
319.0
318.5
318.0
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year

Manuherikia Groundwater Management Zone and Ida Valley Aquifer:



Information available

Groundwater quality information: *There are 2 bores within the Manuherikia Groundwater Management Zone.*

1. *Bore G41/0280 (5.4 m deep) has been sampled once during December 2012.*
2. *Bore G41/0254 (6.5 m deep) has been sampled for a range of parameters at quarterly intervals between March 2011 and December 2012.*

Stream/aquifer interaction: *The water table is shallow and connected to ponds, wetlands and surface waterways.*

Recharge volume: *The Ida Valley is dry, with only 12% of rainfall estimated to infiltrate below the soil profile (Wilson & Rekker, 2012). The mean annual recharge volume is estimated to be 18.8 Mm^3/year, however the use of groundwater in the valley is minimal. The mean annual rainfall recharge volume for the Manuherikia Groundwater Management Zone is estimated to be 45.1 Mm^3/year (Wilson & Lu, 2011).*

The estimated mean annual rainfall recharge for the Manuherikia Groundwater Management Zone is 45.1 Mm^3/year (Wilson & Lu, 2011).

Discharge locations: *A detailed investigation of groundwater inflows and outflows has not been undertaken in the Ida Valley. Groundwater is poorly utilised with only two consents to take water within the Ida Valley.*

The Manuherikia Groundwater Management Zone is expected to drain into the Manuherikia River. There is one groundwater take within the Manuherikia Groundwater Management Zone which is used for mining purposes.

Allocation status: *The Ida Valley and Manuherikia Groundwater Management Zone are barely utilised for groundwater abstraction, therefore an allocation status does not appear to be a high priority for these catchments. Currently an allocation limit of 9.4 Mm^3/year has been adopted for the Ida Valley and 22.55 Mm^3/year for the Manuherikia Groundwater Management Zone which are based on half the mean annual rainfall recharge.*

Typical landuse: *The dominant landuse in the valleys is agriculture.*

Aquifer parameters: *Groundwater in the valleys is generally poor yielding. There are 4 bores in the south-west portion of the Ida Valley that have been subjected to pumping tests. The reported transmissivity values range from 15 to 325 m^2/day.*

There is one bore within the Manuherikia Groundwater Management Zone with a transmissivity estimate of 5,857 to 6,638 m^2/day.

Groundwater movement

No piezometric survey has been carried out in the valley. However, shallow groundwater is expected to flow in conjunction with the local topography down-valley towards the south-west.

Information required

Groundwater quality information: *There are no groundwater quality monitoring bores within the Ida Valley. There are no recent groundwater quality records within the Manuherikia Groundwater Management Zone.*

Groundwater level monitoring: *There are no groundwater level monitoring bores within either of the valleys.*

Summary

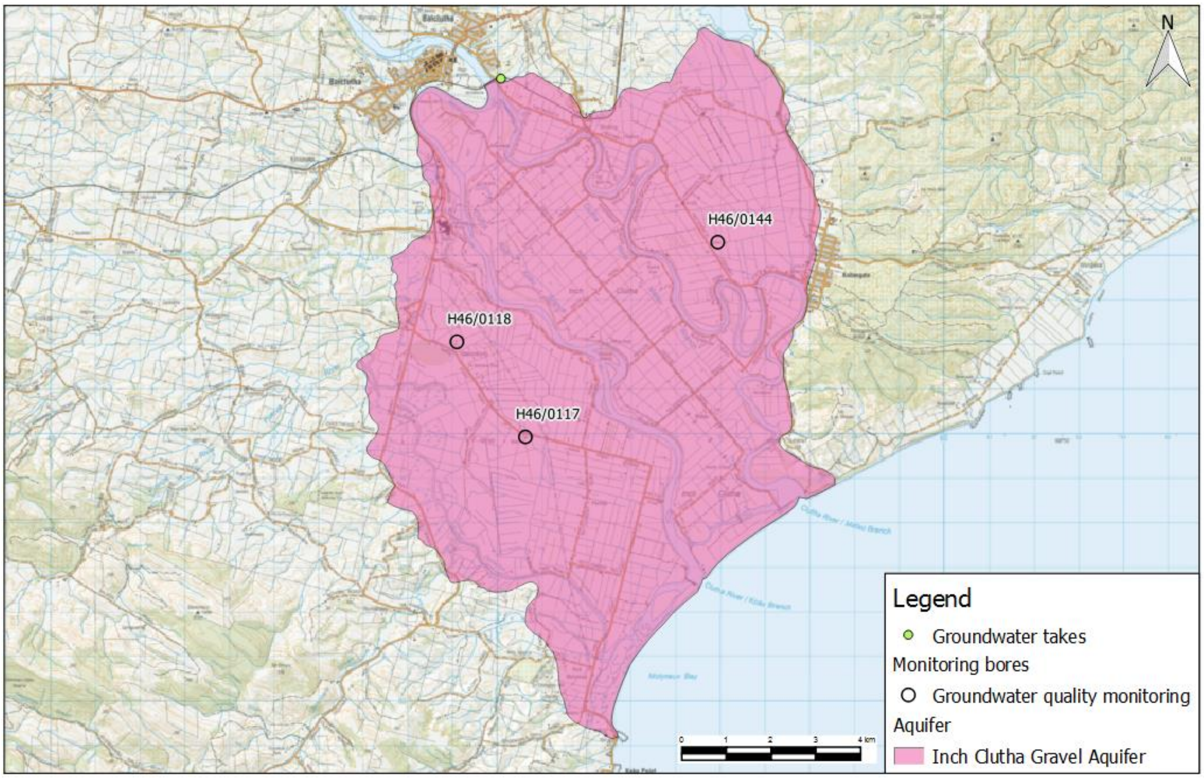
The Ida Valley is poor yielding and barely used for groundwater abstraction. There is minimal groundwater information available for the Manuherikia Groundwater Management Zone. It is expected that groundwater in the two zones is closely connected to surface waterways and can as such, be allocated as surface water. There have not been any investigations relating to the allocation status of either zones.

Reference list

Wilson, S., & Lu, X. (2011). Rainfall Recharge Assessment for Otago Groundwater Basins. Dunedin: Otago Regional Council.

Wilson, S., & Rekker, J. (2012). Groundwater Exploration in the Ida Valley. Dunedin: Otago Regional Council.

Inch Clutha Gravel Aquifer:



The Inchclutha gravel aquifer consists of recent (Holocene) gravel deposits close to the sea outfall of the Clutha River. It is bounded to the west and north by lower permeability basement strata and to the east by conglomerates from the Taratu Formation, which are not considered permeable. The Holocene gravels are expected to vary in thickness, but are at least 38 m deep based on drillers logs.

Groundwater flow directions are not defined but are expected to be towards the coast and some interaction with the Clutha River may also occur. Based on available information, there is only one groundwater use in the aquifer which is at the northern margin of the aquifer and is close to the Clutha River.

Information available

Groundwater level monitoring: *There are no groundwater level monitoring bores within the aquifer. However, groundwater levels are expected to be in close connection with the Clutha River.*

Groundwater quality information: *There are 3 bores within the aquifer that have available water quality data.*

1. *Bore H46/0117 (6 m deep) has been sampled 13 times for a range of parameters between March 2011 and January 2015.*
2. *Bores H46/0118 (12 m deep) and H46/0144 (38 m deep) have been sampled generally 3 to 4 times a year for a range of parameters between March 2011 and December 2016.*

Stream/aquifer interaction: *It is assumed that the aquifer is closely connected to the Clutha River. However, this has not yet been investigated.*

Recharge volume: *It is assumed that the aquifer is primarily recharged by rainfall recharge and the Clutha River. The estimated mean annual rainfall recharge to the aquifer is 10.4 Mm^3/year (Wilson & Lu, 2011). Other sources of recharge have not been quantified.*

Discharge locations: *It is assumed that groundwater within the aquifer is discharged via offshore seepage to the east. There is one groundwater take within the aquifer which is used by Clutha District Council for their wastewater treatment plant.*

Allocation status: *The aquifer is currently lightly used due to the abundancy of surface water in the area. The allocation limit is currently set at half of the mean annual rainfall recharge (5.2 Mm^3/year).*

Typical landuse: *Landuse overlying the aquifer is mainly agricultural.*

Aquifer parameters: *There is one bore within the aquifer that has been subjected to a pumping test. The reported transmissivity value ranges from 1,300 to 1,800 m^2/day.*

Groundwater movement

As of yet, no piezometric survey has been undertaken for this aquifer. However, considering the local topography, groundwater likely flows towards the south-east to the coast in the general direction of the Clutha River.

Information required

None.

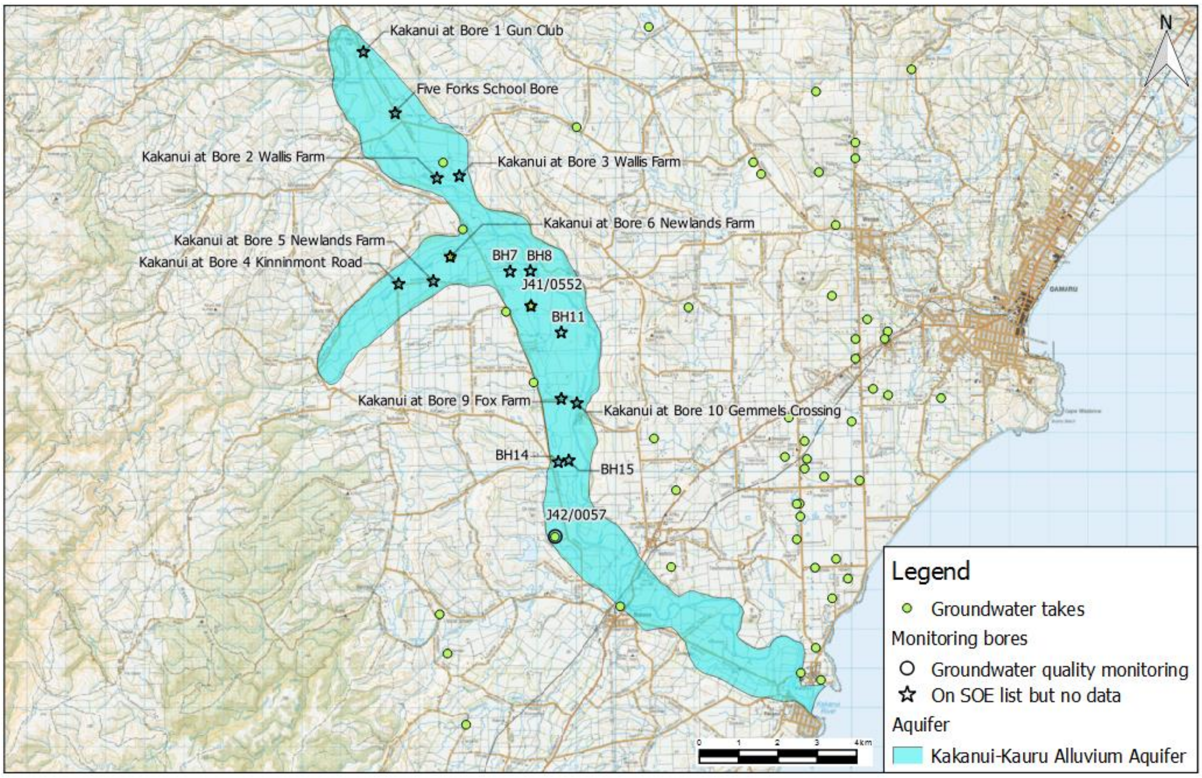
Summary

This aquifer has not been studied in detail. Due to the lack of groundwater takes and abundance of surface water, the aquifer is expected to be suitably managed at present. The presence of groundwater quality bores will allow any land use effects to be monitored and give a general indication of longer term groundwater level trends.

Reference list

Wilson, S., & Lu, X. (2011). Rainfall Recharge Assessment for Otago Groundwater Basins. Dunedin: Otago Regional Council.

Kakanui-Kauru Alluvium Aquifer:



The Kakanui Kauru Alluvial Aquifer is hosted within shallow, thin alluvial strata around the Kakanui River, which are underlain by low permeability mudstones of the Kauru Formation, and, in some areas, the North Otago Volcanics and the Taratu Formation (which includes the Papakaio aquifer), both of which are likely to discharge some water into the Kakanui River (particularly around the estuary) and tributaries to the Kakanui River such as the Waireka River. Typical thicknesses of gravels are around 5 m to 6 m. Groundwater is shallow, and the saturated thickness of the alluvial gravels is typically around 4 m to 5 m.

Broadly, the conceptual model of the Kakanui River is that it is subdivided into a series of basins, defined based on the pattern of losing and gaining reaches in the river. Streamflow is lost to the alluvial aquifer at the upstream end of each of the basins before returning to the river at the downstream end of each basin. Groundwater levels in the alluvial strata that make up the aquifer in each basin respond rapidly to increases in river flow, with a recharge front moving through the groundwater systems from the top of each basin towards the downstream end. At times of river flow recession, the system drains progressively from the lower end of the basin towards the top.

The movement of groundwater through the system means that nutrients that accumulate in the unsaturated zone during river flow recession can be mobilised during high flow events. Nutrients can then be transported through the aquifer towards the river during subsequent river flow recession, potentially resulting in relatively high concentrations of nutrients in groundwater discharging to the river, when less river water is available to dilute the effects.

There are a number of consented groundwater takes in the alluvium, the majority of which are used for irrigation, however other domestic takes are also present. Groundwater abstractions are restricted based on river flows at various points along the river due to the close connection between the river and groundwater in the alluvium.

Information available

Groundwater level monitoring: *There are currently no long term groundwater level monitoring bores within the aquifer. However, 14 monitoring bores have recently been installed as part of the Kakanui Project.*

Groundwater quality information: *There is one groundwater quality bore within the aquifer. Twice monthly monitoring has been undertaken in bore J42/0057 (unknown depth) between May 2014 and January 2017. Additionally, the newly installed Kakanui Project bores are expected to be sampled for groundwater quality.*

Stream/aquifer interaction: *The aquifer is closely connected to the Kakanui and Kauru Rivers.*

Recharge volume: *The aquifer is expected to be dominantly recharged by flows in surface water bodies. Currently, there is no information on aquifer recharge volumes.*

Discharge locations: *The aquifer is expected to discharge offshore and also into the Kakanui River. There are four consents to abstract water from the aquifer for irrigation purposes.*

Allocation status: *Groundwater within the aquifer is closely connected to surface waterways and abstractions can effectively be managed as surface water takes. The Kakanui Project is currently underway which will aid in determining a suitable allocation and management method for the Kakanui-Kauru Alluvium Aquifer.*

Typical landuse: *Landuse overlying the aquifer is dominantly agricultural.*

Groundwater movement

Groundwater movement is currently under investigation as part of the Kakanui Project. However, due to the close connection with surface water bodies, groundwater flow patterns reflect that link.

Information required

The extent of current monitoring covers the requirements under the RPW and the NPS-FM. However some of the monitoring represents data for a defined project and it is not clear whether that monitoring will continue into the future. Some care will be required in order to ensure that monitoring going forwards is relevant.

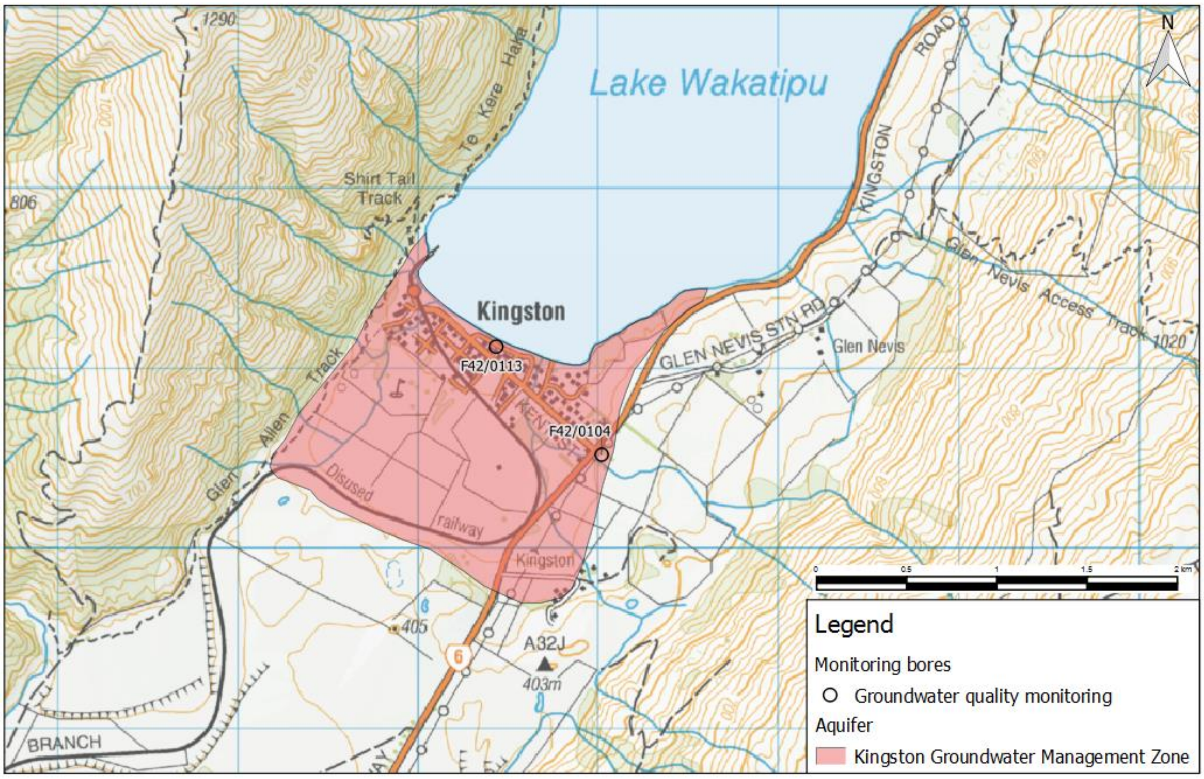
Summary

Groundwater quantity in the Kakanui Kauru Alluvium is managed as surface water. Limits around groundwater quality are currently under development following a detailed monitoring project.

Reference list

Ozanne, R., & Wilson, S. (2013). Kakanui River Water Quality Report. Dunedin: Otago Regional Council.

Kingston Groundwater Management Zone:



Information around the Kingston Groundwater Management Zone is relatively limited. A historic report indicates that there are bores in the area that have previously been used for water supply. However, there are currently no consented groundwater takes within the aquifer.

Groundwater is expected to be closely connected to surface water bodies, receiving flow from the creeks on the surrounding hillsides and ultimately flowing into Lake Wakatipu.

Although the aquifer is not currently utilised for consented groundwater takes, given the rapid growth of Queenstown there may be a demand for groundwater in the area in the future. In this instance, further research and monitoring of the groundwater zone would be beneficial.

Information available

Groundwater level monitoring: *There are no dedicated groundwater level monitoring bores within the Kingston Groundwater Management Zone. However, it is likely that groundwater levels will be closely connected to levels in Lake Wakatipu. A report by Lindqvist, (1997) indicates that the deepest groundwater level observed in bores in the area was 4.3 m bgl. A slight artesian flow was observed in a bore at the holiday camp. However, it should be noted that this information is 20 years old and the current state of groundwater levels are unknown.*

Groundwater quality information:

Two monitoring bores are present near Kingston.

1. *Bore F42/0104 (9.3 m deep) only has two samples from September 2010 and March 2011 respectively.*
2. *Bore F42/0113 (4.4 m deep) has been monitored for a range of parameters, generally at quarterly intervals, between September 2010 and December 2016.*

Stream/aquifer interaction: *The Kingston Groundwater Management Zone is expected to be closely connected to surface waterways and Lake Wakatipu. There are several small streams which flow off the adjacent hillsides and go dry at the base of the valley, which could indicate seepage into groundwater.*

Recharge volume*: The quantity of recharge in the Kingston Groundwater Management Zone is expected to be mainly sourced from surface waterway losses and range front recharge, and potentially from Lake Wakatipu during periods of high lake level.*

Discharge locations: *There are currently no consents to take groundwater within the Kingston Groundwater Management Zone. It is expected that the majority of groundwater is discharged down-gradient into Lake Wakatipu.*

Typical landuse: *Landuse consists of non-irrigated agriculture, low-density residential areas and a golf course.*

Aquifer parameters: *There is one bore within the Kingston area with a reported transmissivity ranging from 80 to 110* m^2*/day.*

Groundwater movement

Groundwater in the Kingston Groundwater Management Zone is expected to generally flow towards the north-east towards Lake Wakatipu.

Information required

Allocation status: *The allocation status of the Kingston Groundwater Management Zone is currently unknown.*

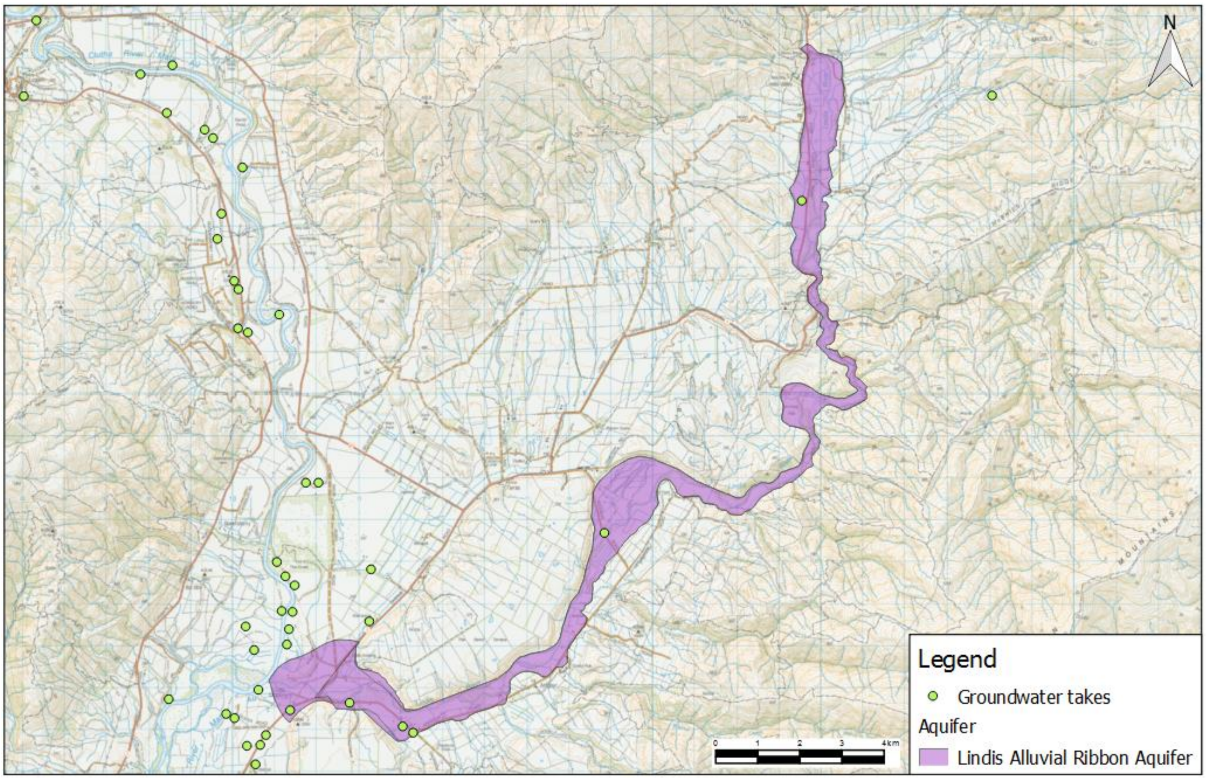
Summary

There is limited information on groundwater movement in the Kingston Groundwater Management Zone. However, the zone is currently not utilised for consented groundwater abstraction. If greater groundwater exploitation occurs in the Kingston Groundwater Management Zone, some further monitoring may be required.

Reference List

Lindqvist, J. (1997). Otago Regional Council Ground Water Investigations 1996/97 - Kingston. Dunedin: JK Lindqvist.

Lindis Alluvial Ribbon Aquifer:



Information available

Groundwater level monitoring: *There are currently no groundwater level monitoring bores within the aquifer. However, groundwater is in close connection with the Lindis River and flow data is available for three sites along the reach of the river.*

Stream/aquifer interaction: *The Lindis Alluvial Ribbon Aquifer and the Lindis River are in close hydraulic connection.*

Discharge locations: *The Lindis Alluvial Ribbon Aquifer is constrained to the Lindis Valley. Hence, the aquifer discharges to the end of the valley towards the south-west and into the Clutha Valley above Lake Dunstan. There are six consented groundwater takes in the aquifer which are used for irrigation or domestic water supply.*

Recharge volume: *Recharge volumes of various sources are currently under development, with the majority of recharge originating from flows in the Lindis River.*

Allocation status: *The allocation status of the aquifer is currently being developed in conjunction with a minimum flow regime for the Lindis River.*

Typical landuse: *The dominant landuse in the Lindis Valley is irrigated agricultural land.*

Aquifer parameters: *There are three bores within the aquifer that have aquifer test data available. The reported transmissivity values range from 3,900 to 4,000 m^2/day.*

Groundwater movement

Groundwater flow is in close connection with the Lindis River and flows in a similar direction down-valley towards the south-west.

Information required

Groundwater quality information: *There are currently no groundwater quality monitoring bores in the aquifer.*

Summary

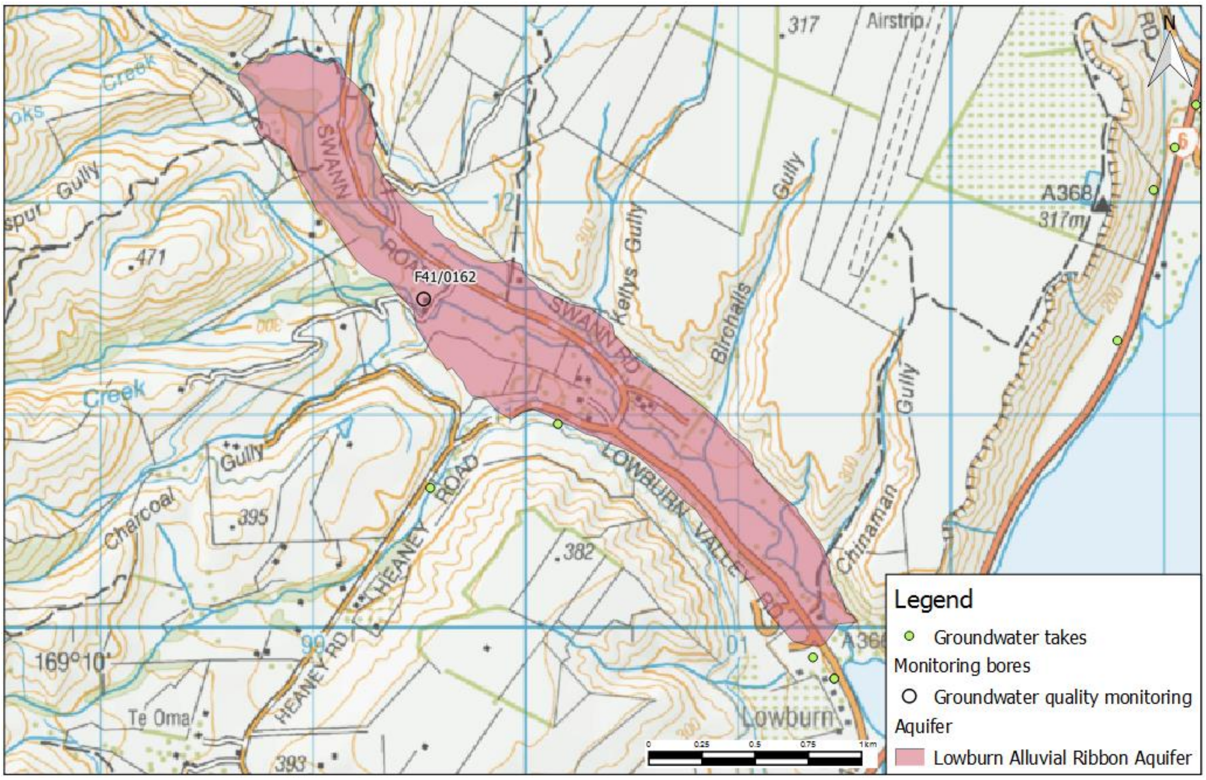
Currently, the allocation volumes and limits for the Lindis Alluvial Ribbon Aquifer are under development in conjunction with a minimum flow regime for the Lindis River. The aquifer is closely connected to the Lindis River and as such, groundwater takes can effectively be allocated to surface water limits.

Given this hydraulic connection, it is considered that surface water quality will be of more relevance than groundwater quality and that land use/discharges in the zone will primarily be controlled based on surface water quality. In this instance, groundwater quality for human health is likely to be indirectly protected and specific groundwater quality monitoring is not considered crucial. However ORC will need to ensure that land use and discharge consents are appropriately controlled and monitored such that effects on individual groundwater supplies are well managed. Groundwater users should also undertake their own monitoring to ensure the supply is suitable for their needs.

Reference list

Houlbrooke, C. (2010). Bendigo and Tarras Groundwater Allocation Study. Dunedin: Otago Regional Council.

Lowburn Alluvial Ribbon Aquifer:



Information available

Groundwater level monitoring: *There are currently no groundwater level monitoring bores within the aquifer. However, groundwater is assumed to be in close connection with the Low Burn which flows through the valley and flow statistics are available for this river (Dale, 2012).*

Groundwater quality information: *There is one groundwater quality monitoring bore within the aquifer, F41/0162 (16.53 m deep), which has been sampled quarterly between March 2011 and December 2016 for a relatively wide range of parameters.*

Stream/aquifer interaction: *The Lowburn Alluvial Ribbon Aquifer and the Low Burn are in close hydraulic connection.*

Recharge volume: *Recharge volumes for this aquifer are currently unknown. However, it is expected that the Low Burn contributes to the majority of groundwater in the aquifer, and groundwater takes can, in effect, be allocated as surface water takes.*

Discharge locations: *The Lowburn Alluvial Ribbon Aquifer is constrained to the Lowburn Valley. Hence, the aquifer discharges to the end of the valley towards the south-east and into Lake Dunstan. There is one consented take within the aquifer for irrigation purposes. A further 3 takes for irrigation and drinking water supply exist between the south-eastern extent of the aquifer and Lake Dunstan and it is assumed that these abstract water outflowing from the aquifer.*

Typical landuse: *The dominant landuse in the Lowburn Valley is agricultural.*

Groundwater movement

Groundwater flow is in close connection with the Low Burn and flows in a similar direction down-valley towards the south-east.

Information required

Allocation status: *The allocation status of the aquifer is currently unknown.*

Aquifer parameters: *There are no bores within the aquifer with available pumping test information.*

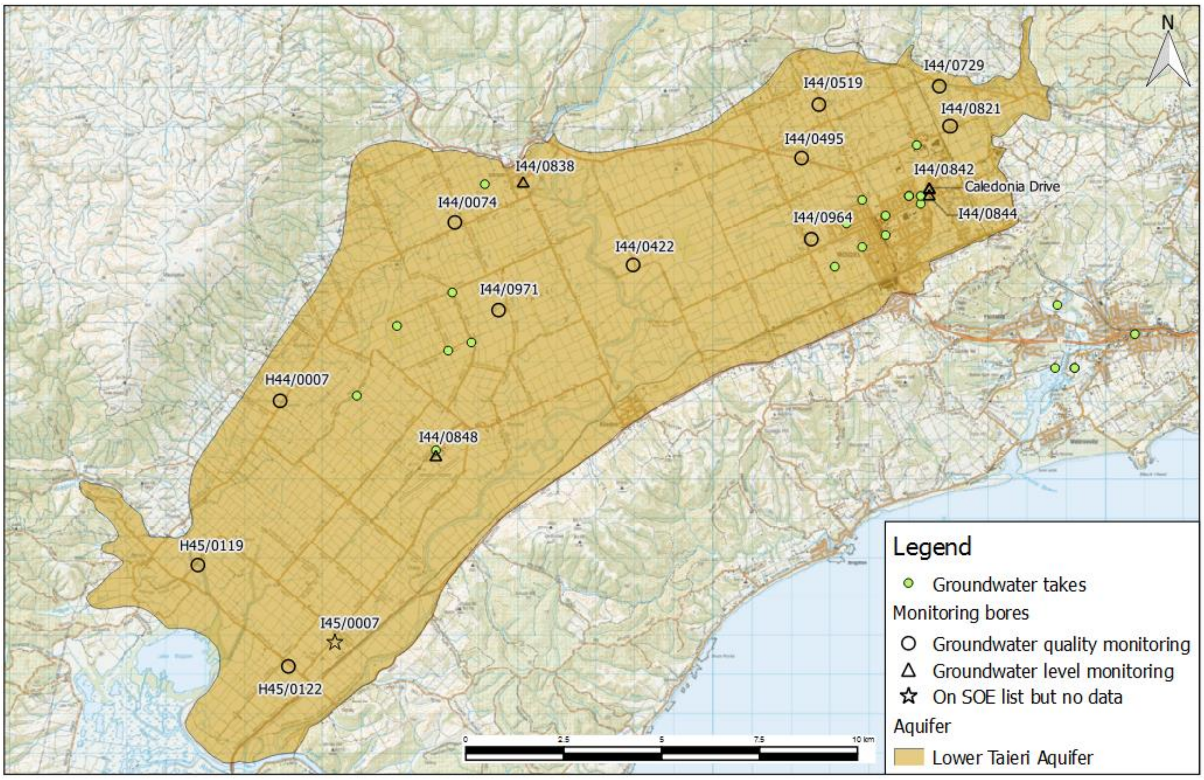
Summary

Currently, there are no allocation volumes and limits for the Lowburn Alluvial Ribbon. It is assumed that the aquifer is closely connected to the Low Burn and as such, groundwater takes can effectively be allocated to surface water limits.

Reference list

Dale, M. (2012). Management Flows for Aquatic Ecosystems in the Low Burn. Dunedin: Otago Regional Council.

Lower Taieri Aquifer:



The Lower Taieri Aquifer covers the Taieri Basin south-west of Dunedin. The Taieri Basin is a fault controlled tectonic depression and there is a substantial thickness of sands and gravels, as well as silts, clay and peat deposit up to 200 m thick overlying lower permeability basement strata. The strata in the east of the basin consist of relatively permeable sands and gravels and are largely unconfined. Towards the west of the basin, the more permeable sands and gravels are interbedded with silts and are more consistently layered. A fine grained marine deposit is present at the surface across the western part of the basin, which acts to confine the more permeable gravel and sand strata beneath.

Groundwater in the basin is generally shallow and occurs within a few metres of the surface. Recharge is predominantly from land surface recharge, together with a smaller component of seepage from the streams and rivers the flow across the basin, including Silver Stream. Generally, groundwater flows from the north-east of the area, around Mosgiel, towards the south-west. Groundwater discharge occurs via seepage to wetlands and the Lake Waipori Wetlands complex towards the south-west end of the basin. The basin is split into east and west zones, where the Taieri River forms the dividing line.

Strata in the basin are relatively permeable, with transmissivities of up to 14,000 m^2/day recorded in both the east and west zones. Groundwater use is greatest around Mosgiel, where groundwater is used extensively for public supply but some use for irrigation occurs elsewhere within the basin. Some domestic and stock use also occurs, generally away from the major towns.

Information available

Groundwater level monitoring: *Groundwater levels have been monitored in four bores within the aquifer.*

1. *Bore I44/0848 (19 m deep) has a detailed monitoring record from April 1995 to May 2017.*
2. *Bore I44/0838 (6 m deep) has a detailed monitoring record from April 1997 to May 2017.*
3. *Bore I44/0842 (40 m deep) had two piezometers installed in order to measure both shallow and deep groundwater levels. The second piezometer I44/0844 is 10 m deep. This bore was monitored between December 1995 and July 2015.*
4. *Bores I44/0842 and I44/0844 were replaced with the Caledonia Drive bore with groundwater levels recorded between May 2015 and May 2017. The depth is unknown but there are two piezometers installed in this bore, presumably at different depths.*

Groundwater quality information: *There are a total of eleven bores within the aquifer with available water quality data. However, six of these bores only have one sample.*

1. *Bores H44/0007 (24.4 m deep), I44/0495 (22.9 m deep), I44/0519 (17.5 m deep), I44/0821 (27.4 m deep) and I44/0964 (40.5 m deep) have generally been sampled at quarterly intervals for a range of parameters between March 2011 and January 2017.*
2. *In addition to groundwater monitoring, numerical modelling indicates that the basin is resilient to sea water intrusion accounting for 1.5 m of sea level rise (Rekker & Houlbrooke, 2010).*

Stream/aquifer interaction: *The aquifer is connected to surface water bodies and wetlands within the basin. Surface waterways contribute to aquifer recharge and the School Swamp functions as a discharge zone for groundwater. The Lake Waipori Wetlands Complex is also closely connected to groundwater.*

Recharge volume: *The aquifer is recharged by rainfall, river infiltration and range-front recharge from the adjacent slopes. The total mean annual recharge for the aquifer is estimated to be 43 Mm^3/year (Rekker & Houlbrooke, 2010).*

Discharge locations: *The aquifer discharges a component of water to surface waterbodies via seepage. Additionally, there are 18 consents to abstract groundwater from the aquifer mainly for community water supply. There are also several takes for irrigation, commercial/industrial use, waste/sewage treatment, frost fighting, dairy shed use and stockwater use.*

Allocation status: *The total consented allocation volume for the aquifer is estimated to be 2.4 Mm^3/year. Trigger levels have been set for this aquifer and an allocation limit is currently under development.*

The latest allocation study suggests an allocation limit of 5 Mm^3/year which is approximately 12% of the mean annual recharge to the aquifer from all sources including rainfall recharge and river infiltration. Additionally, an allocation limit of 2.9 Mm^3/year has been set for the eastern portion of the aquifer (Rekker & Houlbrooke, 2010).

Typical landuse: *Landuse in the basin is dominantly agricultural with smaller extents of orchards and built up areas.*

Aquifer parameters: *There are ten bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 300 to 14,000 m^2/day.*

Groundwater movement

Groundwater in the basin flows from the north-east margin of the basin, down towards the south-west and generally follows the level of topography in the basin.

Information required

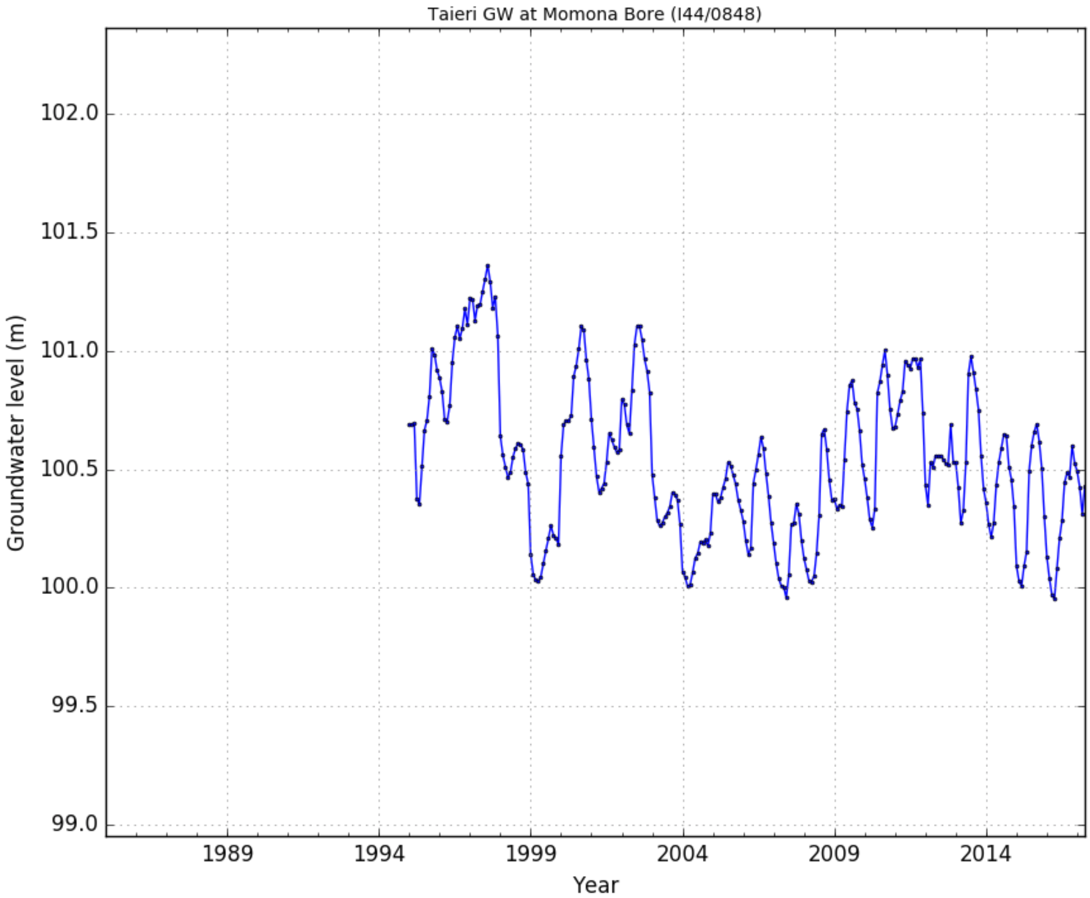
None.

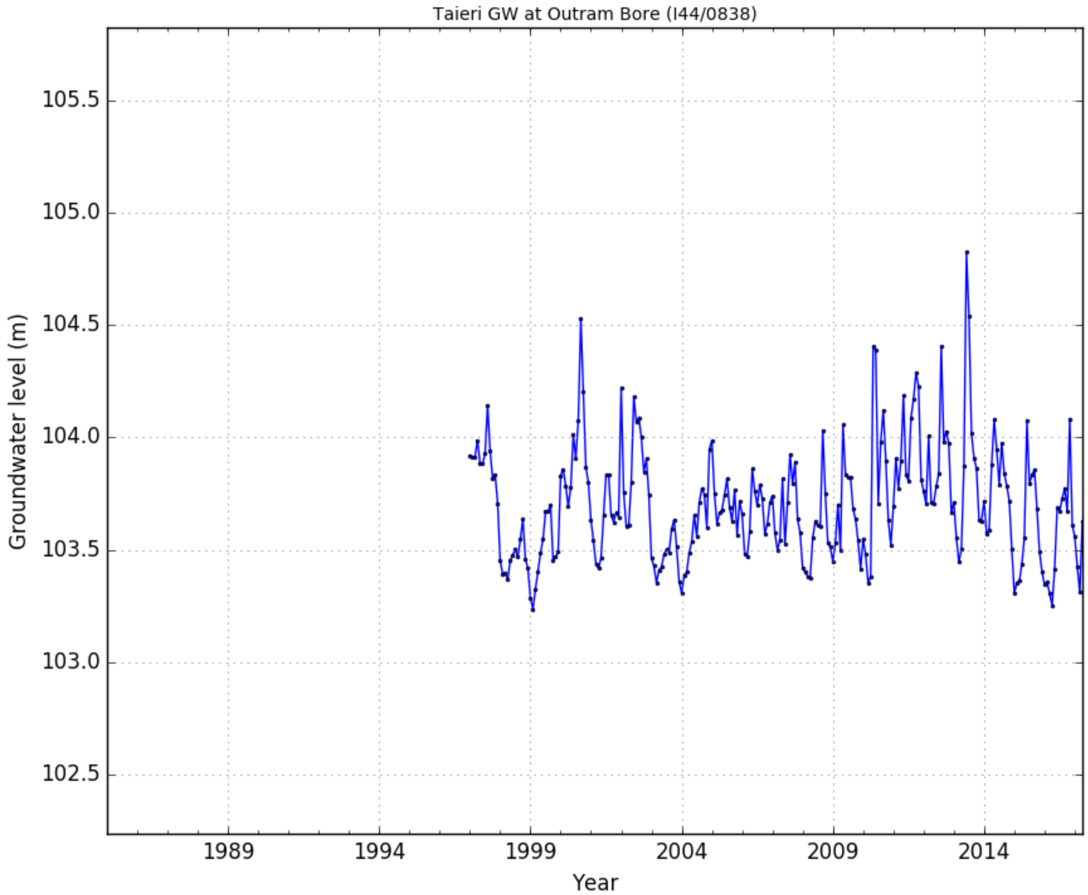
Summary

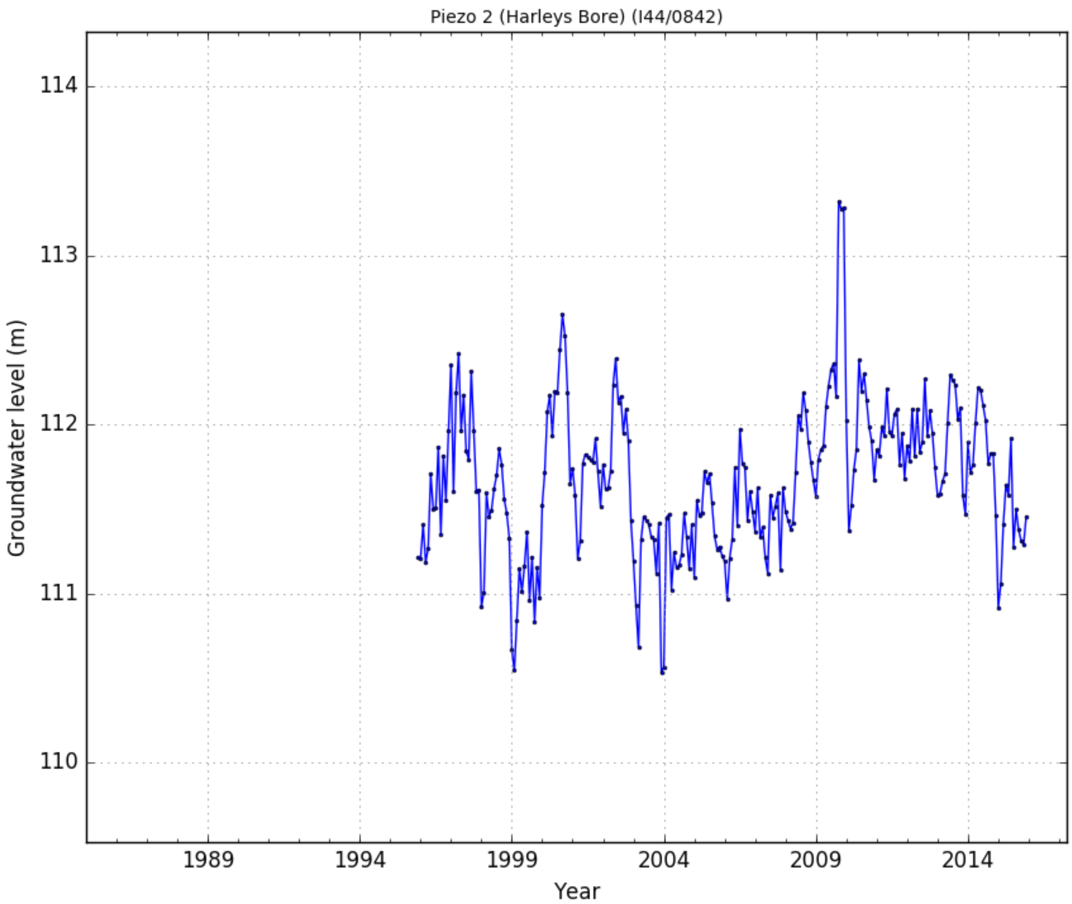
Groundwater movement is well understood in this aquifer and a model has been constructed that allows assessment of scenarios of development. The allocation status is currently under development, with the latest allocation study indicating that the aquifer is not yet fully allocated.

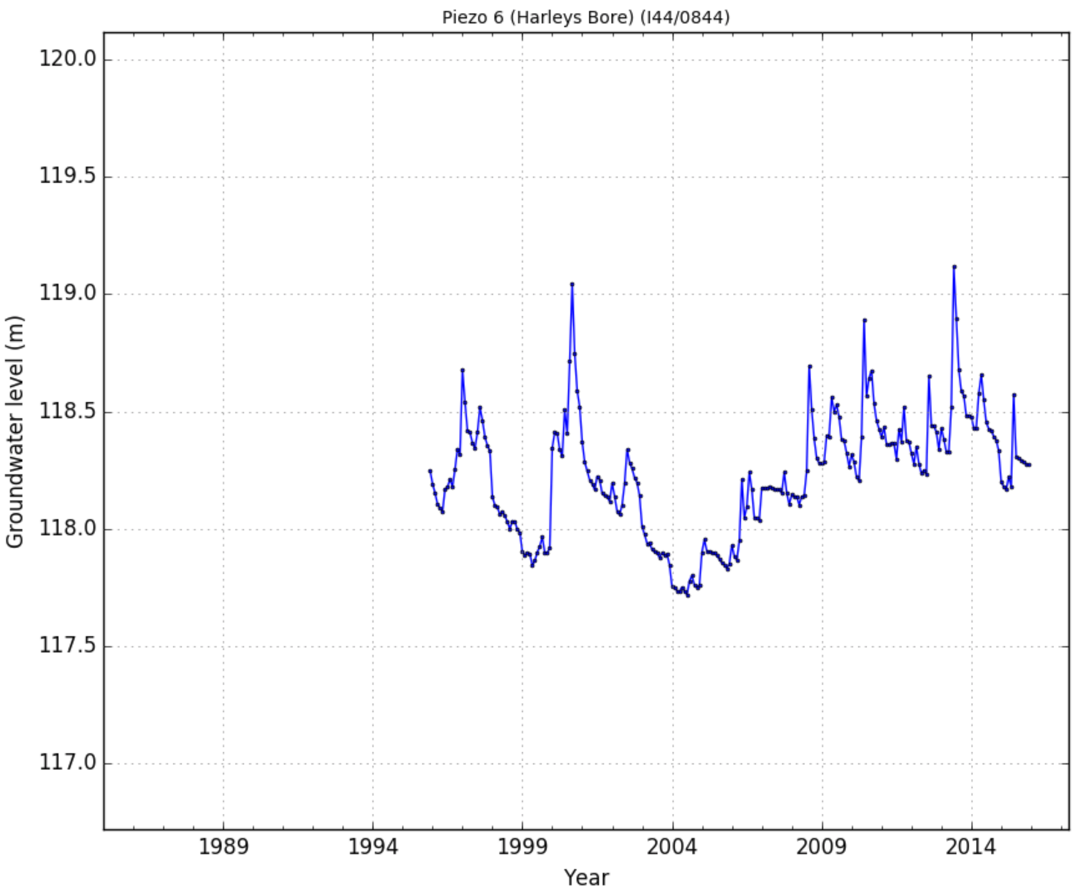
Reference list

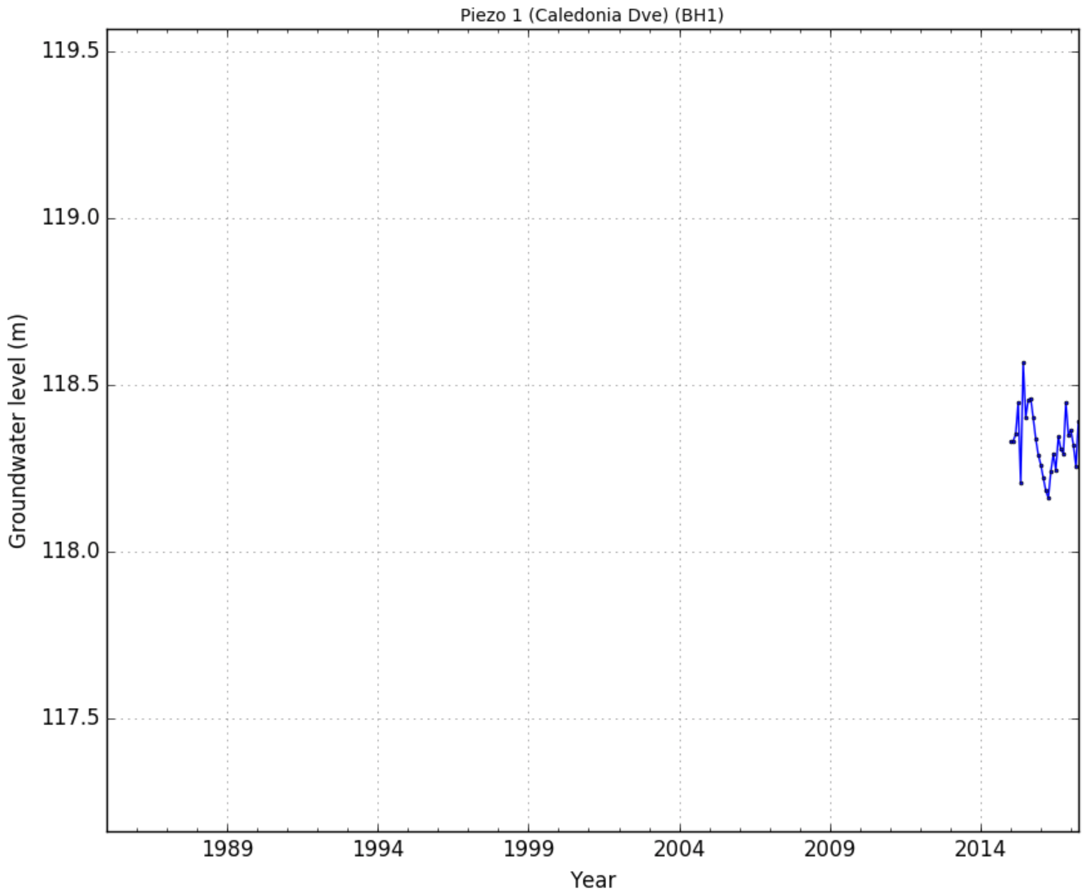
Rekker, J., & Houlbrooke, C. (2010). Lower Taieri Groundwater Allocation Study. Dunedin: Otago Regional Council.

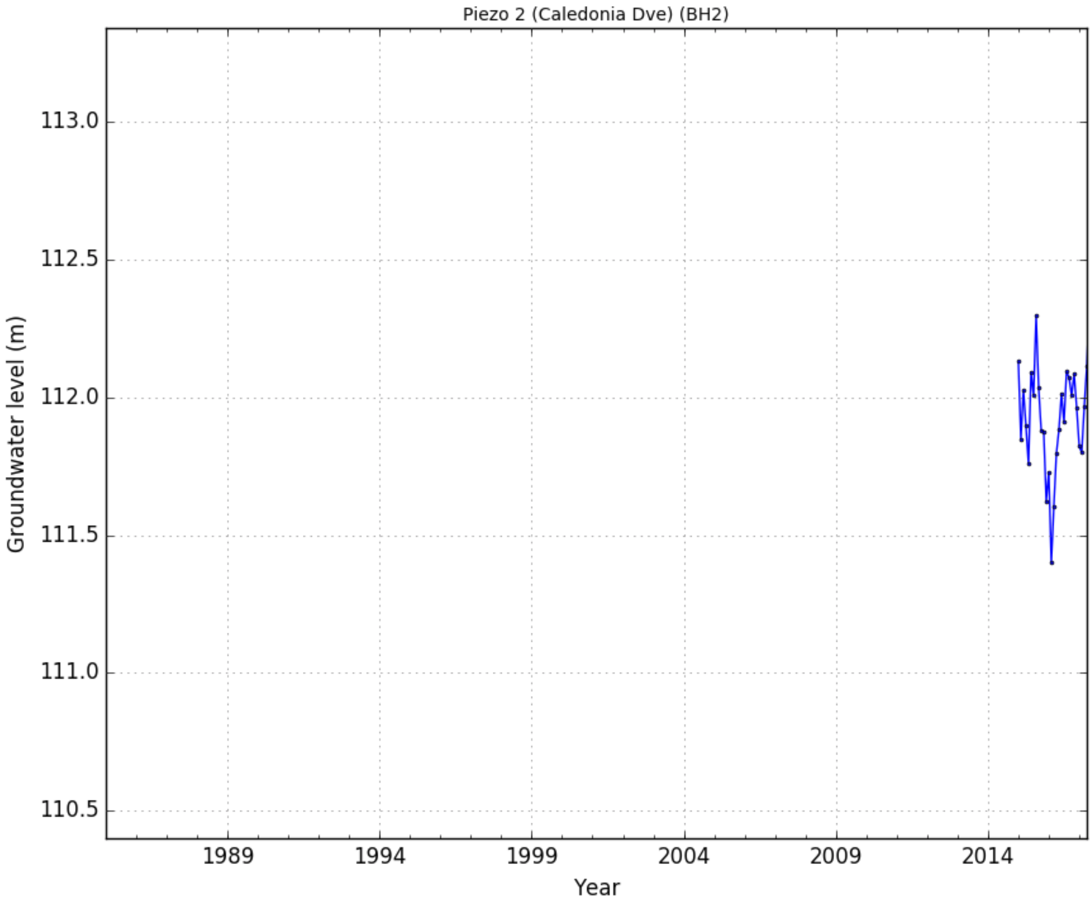

Taieri GW at Momona Bore (I44/0848)
102.0
101.5
101.0
100.5
100.0
99.5
99.0
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year


Taieri GW at Outram Bore (I44/0838)
105.5
105.0
104.5
104.0
103.5
103.0
102.5
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year

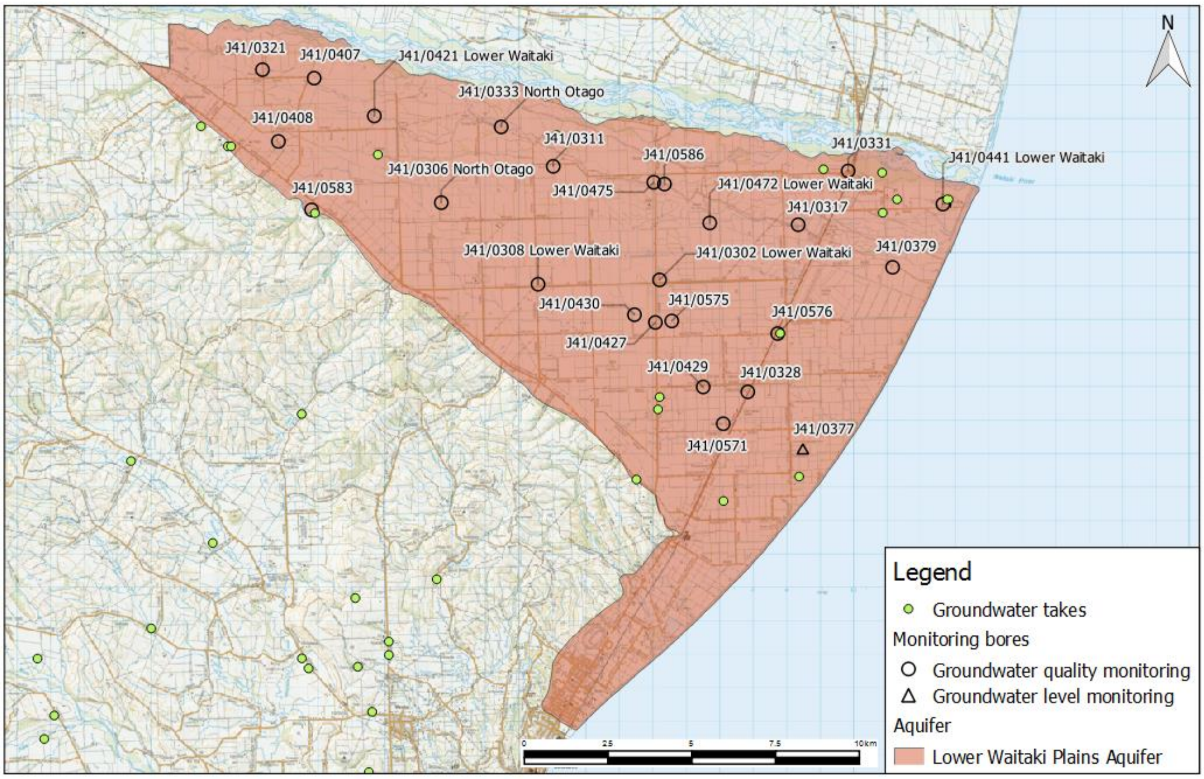

Piezo 2 (Harleys Bore) (I44/0842)
Groundwater level (m)
114
113
112
111
110
1989
1994
1999
2004
2009
2014
Year


Piezo 6 (Harleys Bore) (I44/0844)
Groundwater level (m)
120.0
119.5
119.0
118.5
118.0
117.5
117.0
1989
1994
1999
2004
2009
2014
Year


Piezo 1 (Caledonia Dve) (BH1)
119.5
119.0
118.5
118.0
117.5
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year


Piezo 2 (Caledonia Dve) (BH2)
113.0
112.5
112.0
111.5
111.0
110.5
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year

Lower Waitaki Plains Aquifer:



The Lower Waitaki Plains aquifer represents alluvial deposits that occur on the south side of the Waitaki River. The aquifer is bounded to the north by the Waitaki River and to the south by the low permeability basement strata. The coast forms the eastern boundary of the aquifer. The Lower Waitaki Plains generally consist of a relatively thin veneer (around 10 m thick) of Quaternary deposits, although the plains are underlain by a significant tectonic controlled trench, which is infilled with older, Pleistocene aged, gravels. That trench is underlain by low permeability basement strata.

Groundwater flow is generally towards the coast, sub parallel to the line of thee Waitaki River, which reportedly forms a key discharge point for shallow groundwater. According to SKM (2004) groundwater discharge is roughly evenly split between discharge to the Pacific Ocean and discharge into the Waitaki River. Some groundwater also discharges into Welcome Creek.

Groundwater in the area is reportedly shallow and the piezometric surface generally follows surface contours. Groundwater is generally used for irrigation, although domestic supplies are also sourced from shallow groundwater.

Information available

Groundwater level monitoring: *Groundwater levels have been monitored in one bore, J41/0377 (30 m deep) between April 1997 and April 2017 at intervals of 15 minutes.*

Groundwater quality information: *There are a total of 24 bores within the Waitaki Plains with available water quality data. Five of these bores have more than two samples.*

1. *Bore J41/0317 (16.5 m deep) has the most comprehensive record, with a range of parameters sampled for between June 1993 and January 2017 with 66 samples taken during this period.*
2. *Bores J41/0571 (unknown depth), J41/0576 (unknown depth) and J41/0586 (unknown depth) have been sampled six times between June 2016 and January 2017.*
3. *Bore J41/0583 (17.4 m deep) has been sampled at six-monthly intervals between March 2008 and March 2011.*

Stream/aquifer interaction: *SKM (2004) indicate that the Waitaki River gains from groundwater in the Lower Waitaki area.*

Recharge volume*: An assessment of rainfall recharge has been undertaken for the Lower Waitaki Plain which indicates that the mean annual rainfall recharge is 18.5 Mm^3/year* (Wilson & Lu, 2011). *Recharge including irrigation losses, which, based on information from SKM (2004), may be much greater than rainfall recharge and form the dominant form of recharge into the aquifer. Water for irrigation is largely sourced from the Waitaki River Irrigation Scheme.*

Discharge locations*: Groundwater discharges predominantly into the Pacific Ocean and into the Waitaki River. There are 17 consented groundwater abstractions within the aquifer which are mainly used for irrigation. There are a smaller number of takes for drinking water supply, stockwater and dairy shed use.*

Allocation status: Information supplied by ORC indicates that a maximum allocation volume of 115.85 Mm^3/year has been set for this aquifer which accounts for recharge originating from the Waitaki River.

Typical landuse*: Landuse in the area consists mainly of irrigated agricultural land.*

Aquifer parameters: *There are four bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 1,200 to 20,000 m^2/day.*

Groundwater movement

Due to the likely connectivity with the Waitaki River and the local topography, it is likely that groundwater flows in a general easterly direction towards the coast.

Information required

It is considered that there is sufficient monitoring information to meet the relevant objectives,

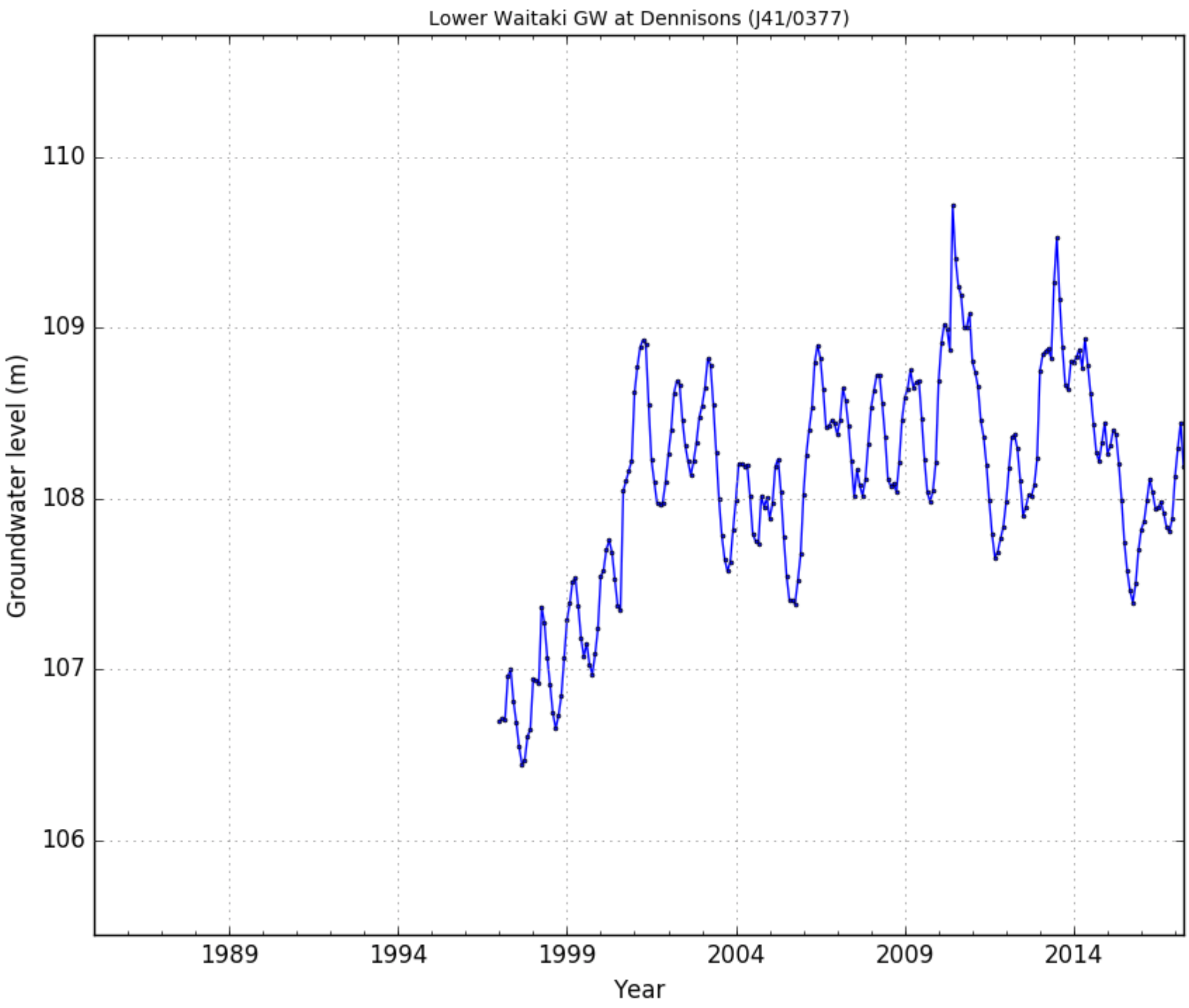
Summary

The Lower Waitaki Plains Aquifer is used extensively for irrigation and there is a good range of groundwater quality data available.

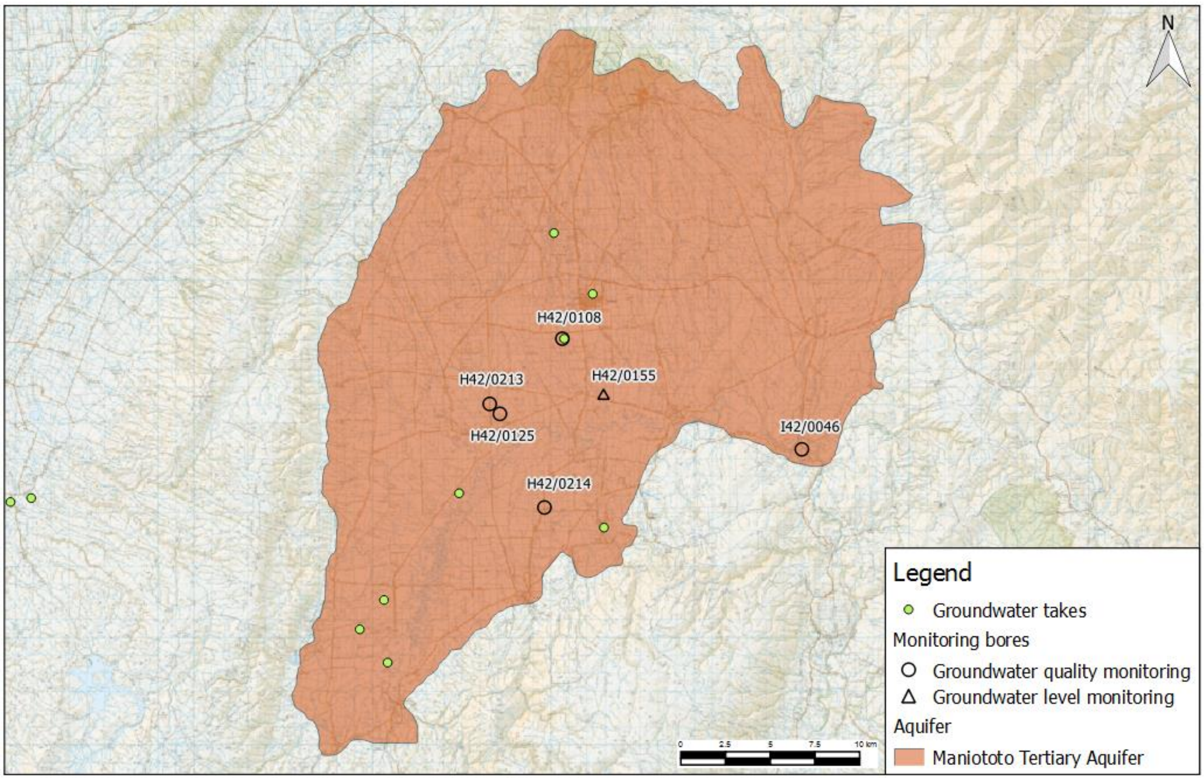
Reference list

SKM. (2004). Waitaki Catchment Groundwater Information. SKM.

Wilson, S., & Lu, X. (2011). Rainfall Recharge Assessment for Otago Groundwater Basins. Dunedin: Otago Regional Council.


Lower Waitaki GW at Dennisons (J41/0377)
Groundwater level (m)
110
109
108
107
106
1989
1994
1999
2004
2009
2014
Year

Maniototo Tertiary Aquifer:



The Maniototo Tertiary Aquifer is formed within the Maniototo Basin, which consists of low permeability schistose basement strata, overlain by Tertiary sediments and Quaternary strata. The Tertiary sediments generally consist of silty marine and lacustrine sediments, together with some volcanic rocks. The Quaternary strata generally occur on terraces and consist of poorly consolidated sands and gravels.

Whilst the Tertiary sediments generally consist of less permeable strata, water bearing units do occur, which are relatively deep, commonly confined and flowing artesian. The Quaternary sediments form unconfined, often highly permeable aquifers with shallow water tables. The overall groundwater flow direction in the Quaternary strata is from the surrounding hill country and generally to the south-east , and groundwater appears to discharge into the Taieri River where it exits the basin. The 1997 report describing the Maniototo Aquifer notes that many of the water bearing strata in the Tertiary sediments occur as discontinuous lenses of more permeable material, meaning that groundwater in one lens may be in poor hydraulic connection with others. It is not clear where groundwater in the Tertiary sediment discharges and some of the aquifers in the Tertiary sediments may be blind.

There are currently six consented groundwater takes in the basin, totalling 1.4 x 10^6 m^3/year, which are generally used for irrigation. However, there are a number of other bores within the basin, and groundwater is also used for smaller scale domestic and stock water supplies.

Information available

Groundwater level monitoring: *A detailed groundwater level monitoring record is available for bore H42/0155 (unknown depth) between July 1998 and March 2008.*

Groundwater quality information: *There are five bores within the Maniototo Basin with available water quality data.*

1. *Three bores, H42/0108 (4 m deep), H42/0125 (unknown depth) and I42/0046 (unknown depth) have been sampled once during June 2015.*
2. *Two additional bores, H42/0213 (10 m deep) and H42/0214 (10 m deep) have been sampled for a reasonable range of parameters at quarterly intervals since September 2015.*

Stream/aquifer interaction: *Groundwater within the basin is thought to both receive and discharge water to surface water bodies. Further investigations are planned to better understand the groundwater-surface water interaction in the basin.*

Recharge volume: *Mean annual recharge from rainfall is estimated to be 31.6 Mm^3/year in the basin (Wilson & Lu, 2011). Inflow volumes from other sources are currently unknown.*

Discharge locations: *Groundwater is thought to discharge a proportion of water to the Taieri River before leaving the basin. There are currently eight consents to take groundwater within the basin which are mainly used for irrigation and drinking water supply. There are a smaller number of consents for dairy shed and stockwater use and one non-consumptive mining consent.*

Allocation status: *Currently, half of the mean annual rainfall recharge is used for the allocation limit (15.8 Mm^3/year) and in 2014 the total consented volume was 1.4 Mm^3/year indicating that further allocation is available (Otago Regional Council, 2014). However, a more detailed allocation model is currently under development.*

Typical landuse: *Landuse in the area consists mainly of irrigated agricultural land.*

Aquifer parameters: *There are two bores within the basin that have been subjected to pumping tests and the reported transmissivity values range from 200 to 500 m^2/day.*

Groundwater movement

Groundwater movement has been defined from a piezometric survey in 1997 and generally flows in a south-easterly direction.

Information required

Groundwater level monitoring.

Summary

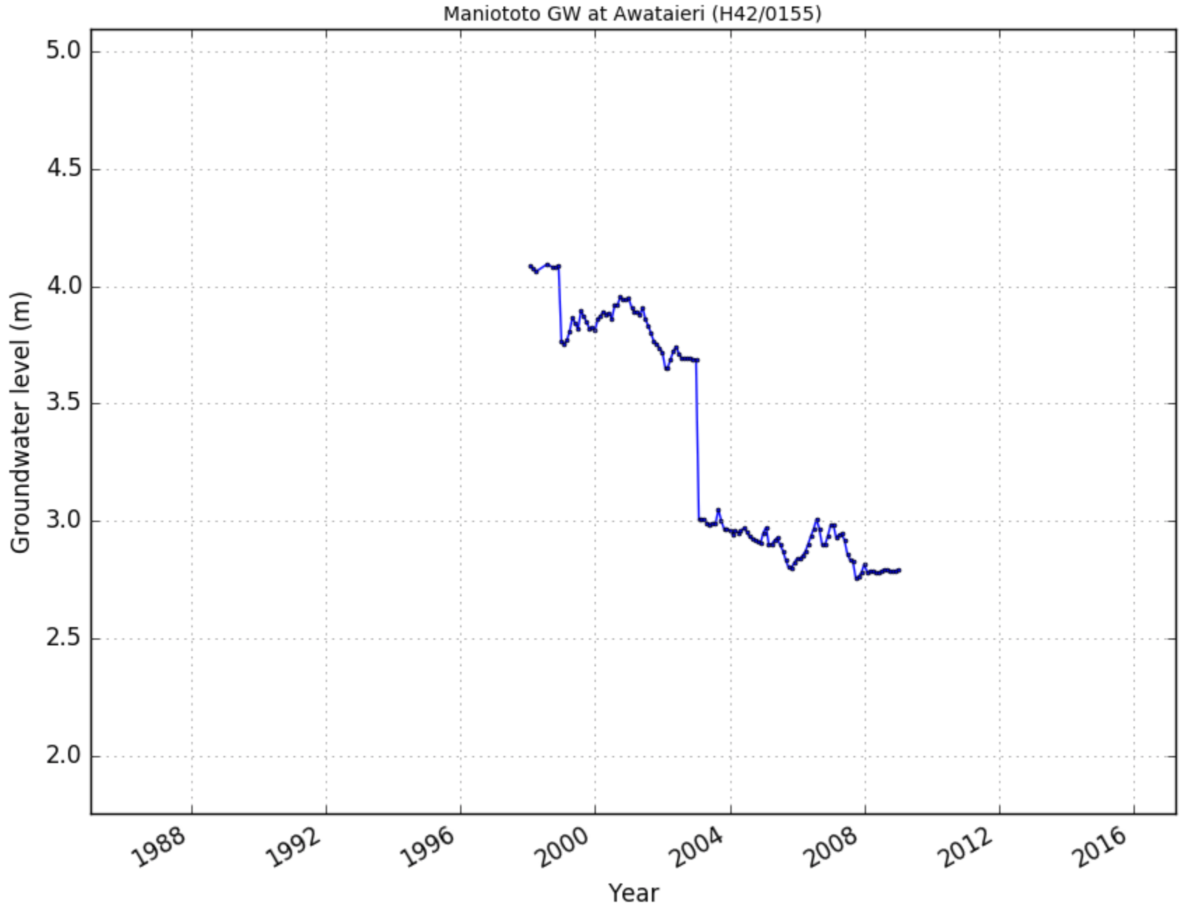
A more detailed allocation model is currently under review for the aquifer. However, the current model indicates further allocation is available. Shallow groundwater within the basin appears to be closely connected to surface waterways, but there is less information available regarding the Tertiary aquifers.

Reference list

Otago Regional Council. (2014). Groundwater Resources of the Maniototo Aquifer - ORC Workshop. Dunedin: Otago Regional Council.

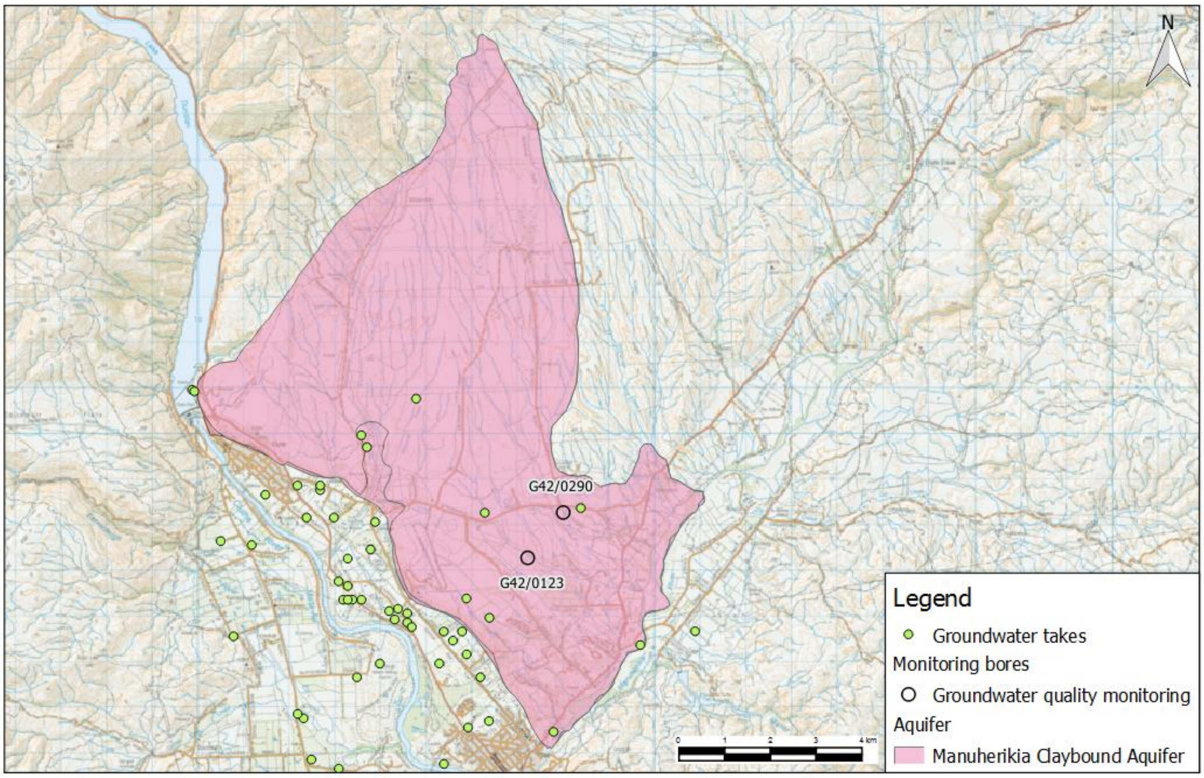
Wilson, S., & Lu, X. (2011). Rainfall Recharge Assessment for Otago Groundwater Basins. Dunedin: Otago Regional Council.

ORC, 1997. Groundwater study of the Maniototo Basin



Maniototo GW at Awataieri (H42/0155)
Groundwater level (m)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1988
1992
1996
2000
2004
2008
2012
2016
Year

Manuherikia Claybound Aquifer:



The Manuherikia Claybound Aquifer consists of Quaternary aged alluvial deposits, which fall into two distinct groups. The northern area covers the Waikerikeri alluvial fan is made up of older outwash fans, which have been weathered and geochemically altered resulting in a lower permeability claybound structure. In contrast, the same weathering does not appear to have occurred in the formations to the south which represent the Lindis outwash that makes up the 'Airport Terrace' and the Letts Gully Road area. The Lindis outwash parts of the Manuherikia Claybound Aquifer are more permeable.

The depth to groundwater in the northern part of the aquifer is generally shallow, but much greater (up to 60 m deep) across the Lindis outwash gravels which may reflect the greater permeability of those deposits. The overall groundwater flow direction is to the south-west and there is considerable throughflow from the Manuherikia Claybound aquifer to the adjacent Dunstan Flats aquifer. However, some seepage also occurs into the Manukerikia River to the southeast.

Groundwater use is limited across the aquifer with the total consented groundwater allocation at around 0.5 x 10^6 m^3/year, is used for drinking water supply and some irrigation.

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Information available

Groundwater quality information: *There are 2 bores within the Manuherikia Claybound Aquifer. Bores G42/0123 (32.4 m deep) and G42/0290 (16.1 m deep) have been monitored quarterly for a wide range of parameters between March 2011 and December 2016.*

Stream/aquifer interaction: *There are no perennial surface waterbodies above the Manuherikia Claybound Aquifer, some groundwater discharges into the Waikerikeri Creek, although the volume is limited. Groundwater also discharges into the Manuherikia River at the south-east edge of the aquifer boundary..*

Recharge volume: *Recharge volumes for the claybound aquifer are well constrained and originate from rainfall and irrigation recharge from the Manuherikia Irrigation Scheme. There is a lack of permanent surface waterways overlying this aquifer. The mean annual recharge for the claybound aquifer is estimated to be 3.6 Mm^3/year and 1.56 Mm^3/year excluding water race losses (Otago Regional Council, 2012).*

Discharge locations: *Water is discharged via subsurface outflow to the Dunstan Flats Aquifer and also via seepage in the Manuherikia River. There are currently seven consented takes with the Manuherikia Claybound Aquifer mainly used for drinking water supply, with a smaller number of takes for irrigation, commercial/industrial and stockwater supply.*

Allocation status: *A detailed water balance assessment has been carried out for the claybound aquifer. A default allocation limit of 50% mean annual recharge results in total allocation volume of 0.68 Mm^3/year. The current consented allocation is 0.61 Mm^3/year indicating that the available unallocated volume of groundwater is small (Otago Regional Council, 2012).*

Typical landuse: *The dominant landuse in the area is agricultural.*

Aquifer parameters: *There are two bores within the claybound aquifer that have been subjected to pumping tests. The reported transmissivity values are 1.5 and 4.8 m^2/day indicating poor yields are available from this aquifer.*

Groundwater movement

Groundwater flows in a generally south-east direction and discharges to the Dunstan Flats Aquifer and the Manuherikia River.

Information required

Groundwater level monitoring: *There are currently no groundwater level monitoring bores within the aquifer.*

Summary

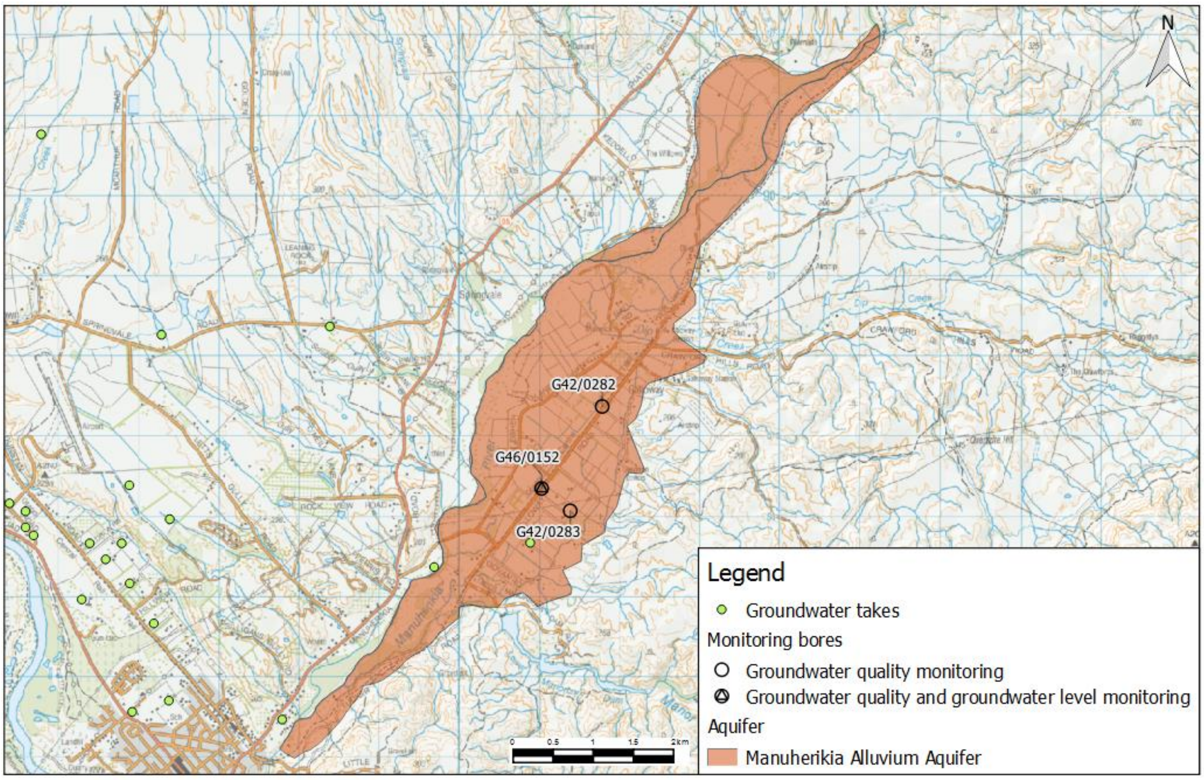
Groundwater movement is well understood in the Manuherikia Claybound Aquifer and the allocation status is well constrained. There is sufficient groundwater quality monitoring but insufficient groundwater level monitoring to ensure sustainable groundwater management.

Reference list

Otago Regional Council. (2012). Alexandra Groundwater Basin Allocation Study. Dunedin: Otago Regional Council.

Wilson, S., & Lu, X. (2011). Rainfall Recharge Assessment for Otago Groundwater Basins. Dunedin: Otago Regional Council.

Manuherikia Alluvium Aquifer:



The Manuherikia Alluvium Aquifer is located north of Alexandra township and covers the area adjacent to the Manuherikia River. The aquifer is highly connected to the Manuherikia River and is comprised of quaternary alluvial sediments.

The aquifer receives a high proportion of recharge form waterway and irrigation losses from the Galloway Irrigation Scheme and ultimately discharges into the Manuherikia River.

Groundwater level and quality monitoring in the aquifer is sufficient, with a low amount of abstraction currently occurring in the area.

Information available

Groundwater level monitoring: *There is one groundwater level monitoring bore within this aquifer (G46/0152, 10 m deep) which has a 15 minute interval monitoring record from June 2015 to May 2017.*

Groundwater quality information: *There are 3 groundwater quality monitoring bores within the aquifer.*

1. *Bore G42/0282 (9 m deep) has been monitored quarterly for a wide range of parameters between March 2011 and September 2014.*
2. *Bore G42/0283 (10 m deep) has been monitored quarterly between March 2011 and December 2016 for a wide range of parameters.*
3. *Bore G46/0152 (10 m deep) has also been monitored for a range of parameters at quarterly intervals between March 2015 and December 2016.*

Stream/aquifer interaction: *The aquifer is well connected to the Manuherikia River.*

Recharge volume: *Recharge volumes are well constrained and originate predominantly from water race losses and irrigation losses from the Galloway Irrigation Scheme. A smaller component of recharge is sourced from rainfall. The mean annual recharge for the aquifer is estimated to be 1.41 Mm^3/year (Otago Regional Council, 2012).*

Discharge locations: *The aquifer is discharged either via seepage directly to the Manuherikia River or via spring discharge to the Manuherikia River. There is currently one consent to take water within the aquifer for drinking water supply.*

Allocation status: *A detailed water balance assessment has been carried out for this aquifer. The default allocation limit of 50% mean annual recharge results in total allocation volume of 0.7 Mm^3/year. The current consented allocation is 0.014 Mm^3/year indicating that there is room for further allocation (Otago Regional Council, 2012), although further consideration of the linkage with the river may be required*

Typical landuse: *Landuse in the area consists mainly of irrigated agricultural land.*

Groundwater movement

Groundwater is relatively shallow and expected to flow in the same direction as the river towards the south of the Manuherikia Valley.

Information required

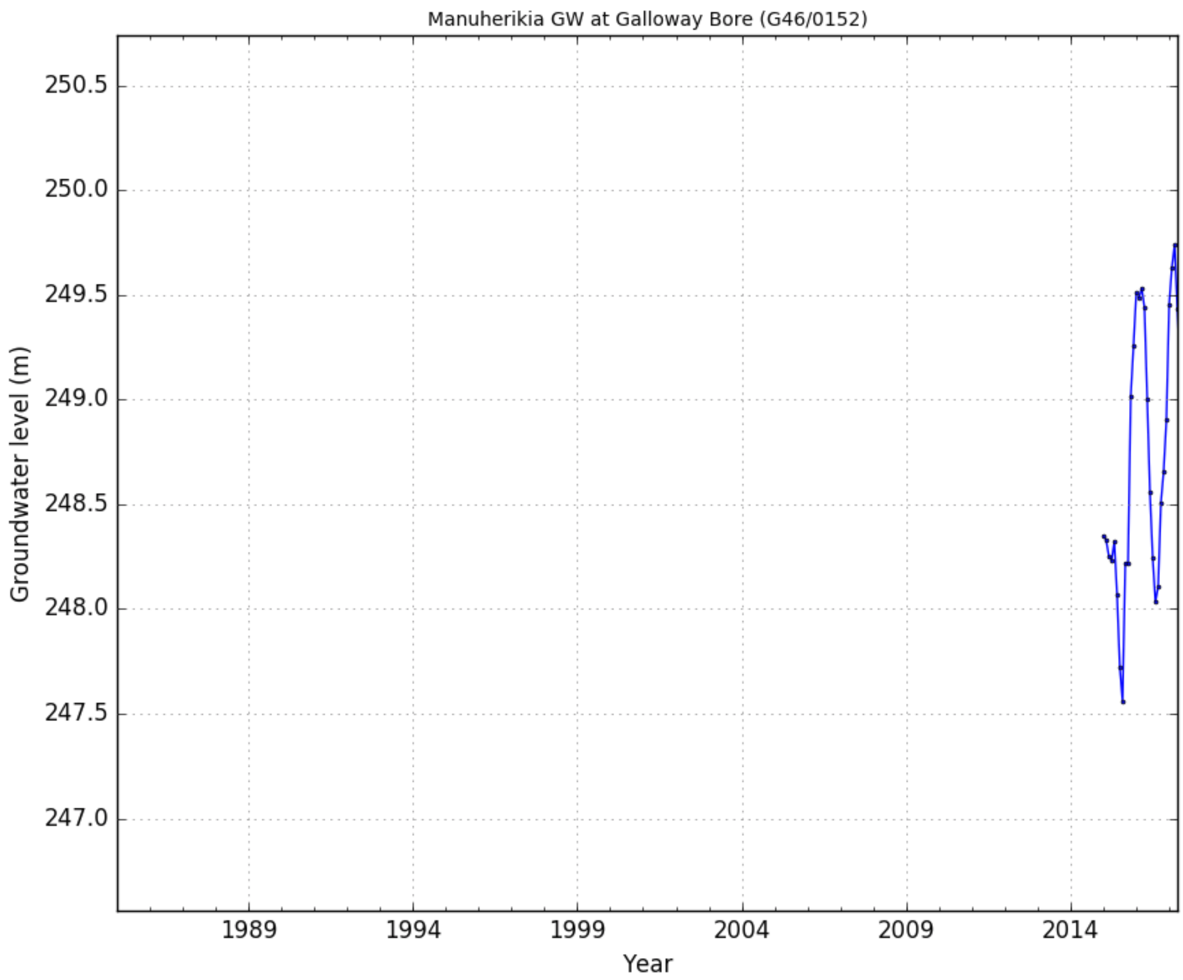
Aquifer parameters: *There are currently no bores within the aquifer that have aquifer test information.*

Summary

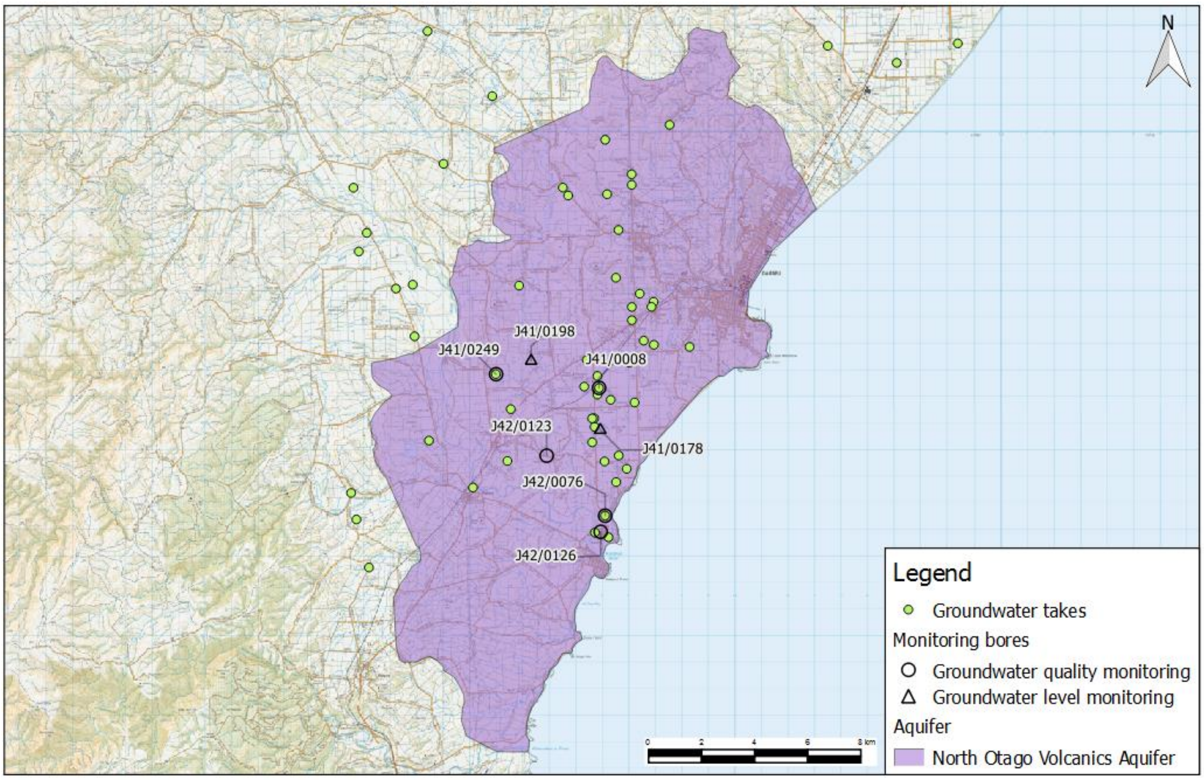
Groundwater movement appears to be well understood in this aquifer and the allocation status is well constrained. Overall there is sufficient information to ensure that groundwater is sustainably managed.

Reference list

Otago Regional Council. (2012). Alexandra Groundwater Basin Allocation Study. Dunedin: Otago Regional Council.


Manuherikia GW at Galloway Bore (G46/0152)
250.5
250.0
249.5
249.0
248.5
248.0
247.5
247.0
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year

North Otago Volcanic Aquifer:



The North Otago Volcanic Aquifer, which is referred to as NOVA, consists of a variety of different sediments, including the Waireka tuff, Totara and McDonald Limestones and Deborah Volcanics. The sediments were deposited at similar times and the stratigraphic divisions between them are seldom precise. The different sediments share similar groundwater flow patterns and are therefore grouped together as the NOVA. The NOVA are underlain by the Kauru formation.

Groundwater within the NOVA is recharged principally via rainfall groundwater flow directions generally follow topography. In the north of the area, groundwater generally flows east towards the coast, but to the south of the area flow direction are shifted to the south where groundwater discharges into the Waireka Creek and Kakanui River. Depth to groundwater in the strata can be variable, but is often in the order of 10 m below ground level. Pumping tests in the aquifer indicate transmissivity values of around 100 m^2/day but also often show dual porosity characteristics.

Groundwater in the aquifer is used for irrigation, domestic supply as well as commercial uses. Groundwater use is concentrated in the area around bore J41/0178, but use also occurs towards the northwest of the catchment as well as in the area between the Waireka Creek and the Kakanui River.

Information available

Groundwater level monitoring: *There are two long term groundwater level monitoring bores within the aquifer.*

1. *Bore J41/0178 (7.6 m deep) has a continuous monitoring record from August 1986 to April 2017.*
2. *Bore J41/0198 (21.5 m deep) has been monitored between December 1997 to April 2017,*

Groundwater quality information: *There are five groundwater quality monitoring bores within the aquifer.*

1. *Bores J41/0008 (20 m deep), J41/0249 (90 m deep) and J42/0126 (18.8 m deep) have been monitored one to four times a year between September 2010 and January 2017.*
2. *Historical monitoring generally at 3 monthly intervals occurred in bore J42/0076 (70.1 m deep) between September 2010 and December 2013 and in bore J42/0123 (66.5 m deep) between September 2010 and June 2012.*
3. *The aquifer has elevated concentrations of sodium which is a natural product of the volcanic minerals within the aquifer. High nitrate concentrations are also present which are thought to be from overlying cropping and market gardening landuse.*

Stream/aquifer interaction: *The aquifer has been assessed as contributing to the base flow in several waterways including the Waiareka, Awamoa and Oamaru Creeks and the Kakanui River.*

Recharge volume: *The dominant recharge mechanism for the aquifer has been identified as rainfall recharge with an estimated inflow of 20.5 Mm^3/year (Rekker, Houlbrooke, & Gyopari, 2008).*

Discharge locations: *The aquifer discharges to surface waterways (estimated at 5.8 Mm^3/year) such as the Waiareka, Awamoa and Oamaru Creeks and the Kakanui River and also loses water to evaporation in the process (estimated at 5.4 Mm^3/year). A proportion (estimated as 8 Mm^3/year) of outflow also discharges offshore via seepage through the sea bed (Rekker, Houlbrooke, & Gyopari, 2008).*

Allocation status: *The latest aquifer report indicates that a maximum of 7 Mm^3/year can be allocated from the aquifer. Trigger levels have also been set for this aquifer.*

Typical landuse: *The main landuse in the area is agricultural, with a smaller component of built up areas.*

Aquifer parameters: *There are nine bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 6 to 330 m^2/day.*

Seawater intrusion: *The latest aquifer report indicates that there is minimal risk for seawater intrusion along the coastline. However, the estuarine zone near Kakanui has potential for future risk of seawater intrusion.*

Groundwater movement

Groundwater flow is influenced by local topography and is complex. However, flow is generally in a southern or eastern direction and ultimately flows towards the coast.

Information required

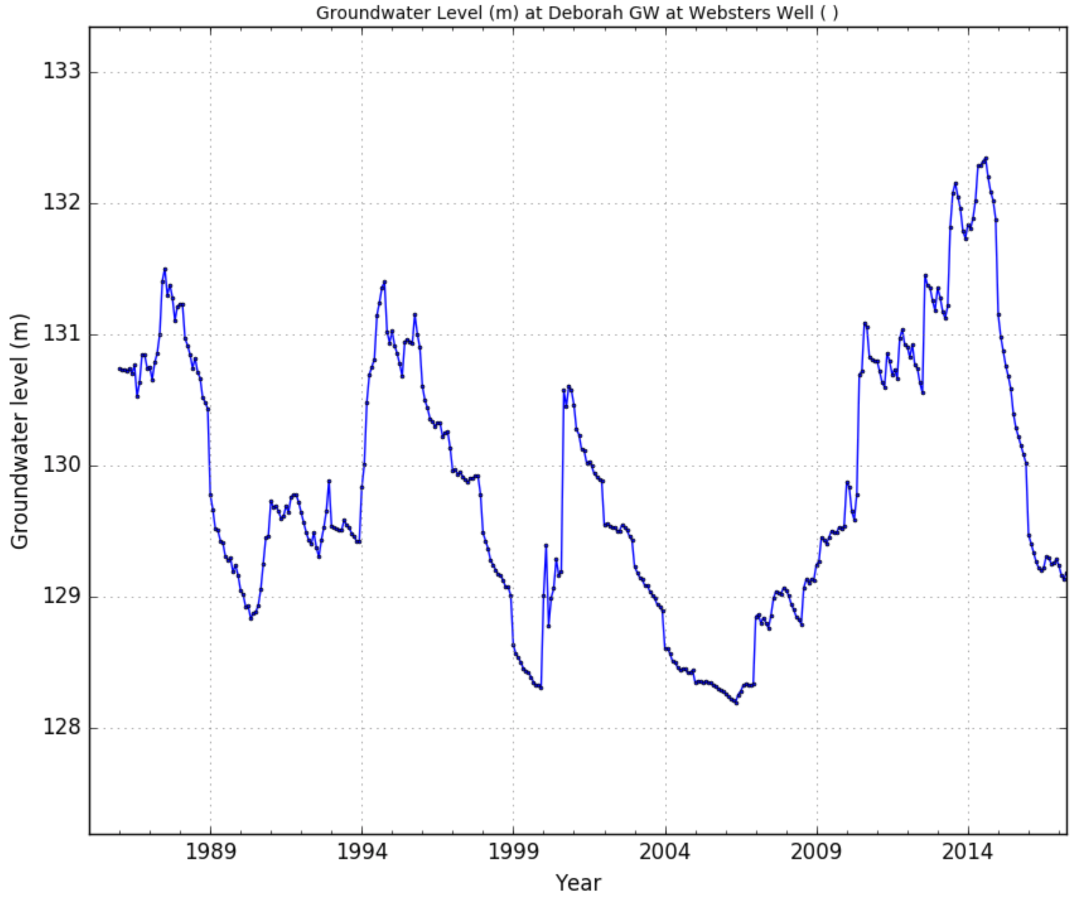
It is considered that there is sufficient monitoring information to meet the relevant objectives.

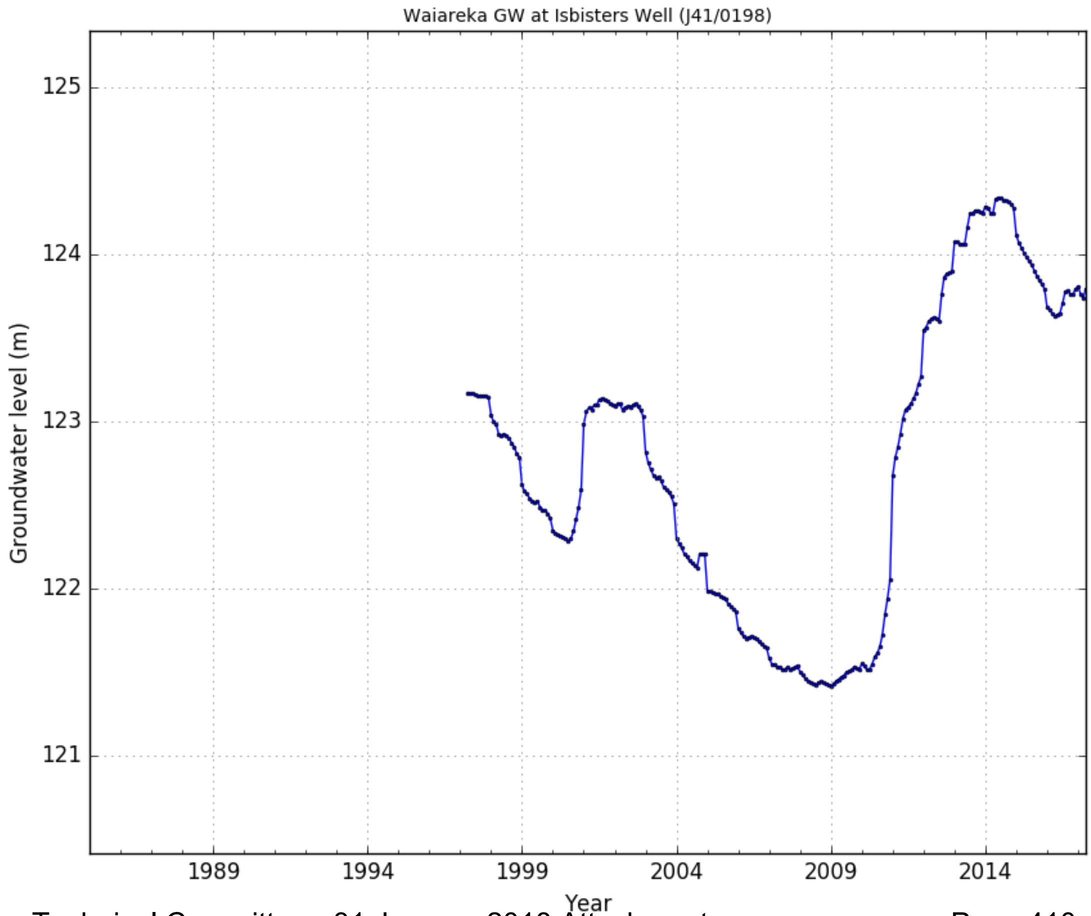
Summary

Groundwater movement appears to be well understood in this aquifer and a model has been constructed that allows assessment of scenarios of development. The allocation status appears well constrained and overall there appears to be sufficient information to ensure that groundwater can be sustainably managed, based on the current state of development across the aquifer..

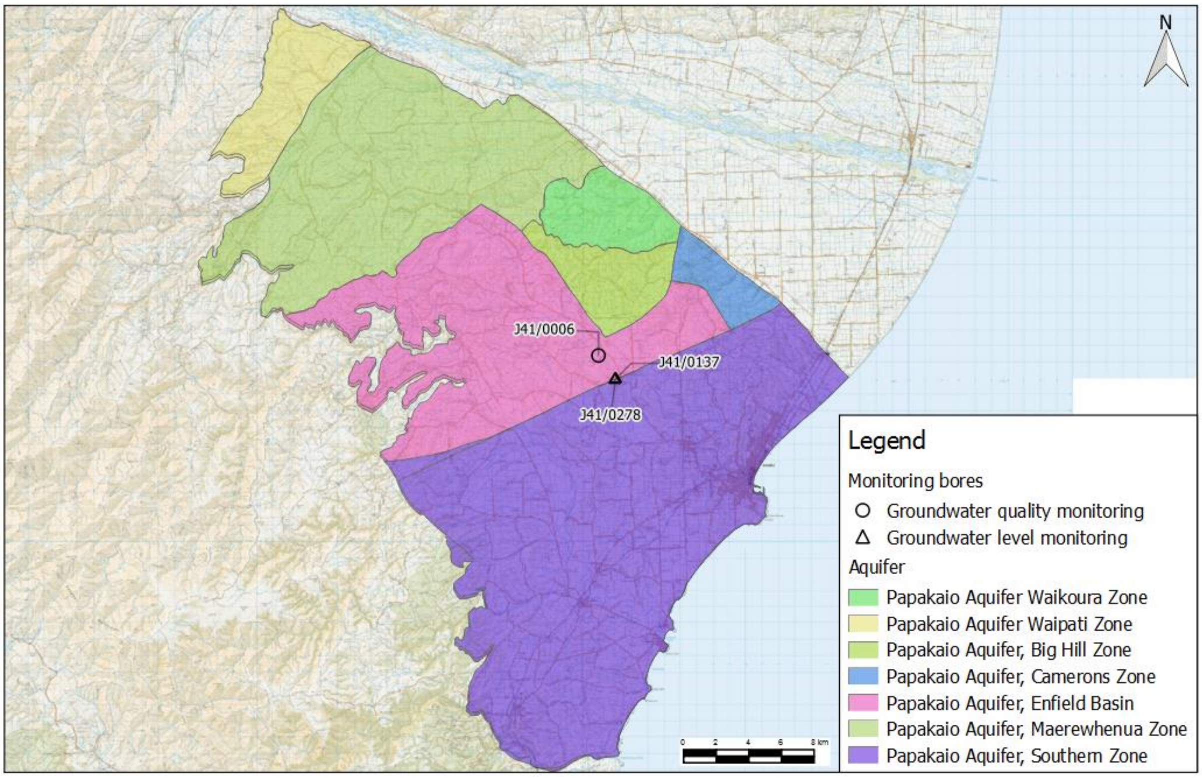
Reference list

Rekker, J., Houlbrooke, C., & Gyopari, M. (2008). North Otago Volcanic Aquifer Study. Dunedin: Otago Regional Council.


Groundwater Level (m) at Deborah GW at Websters Well ( )
Groundwater level (m)
Year
133
132
131
130
129
128
1989
1994
1999
2004
2009
2014


Waiareka GW at Isbisters Well (J41/0198)
Groundwater level (m)
Year
125
124
123
122
121
1989
1994
1999
2004
2009
2014

Papakaio Aquifer:



The Papakaio Aquifer is hosted within the Taratu Formation, which unconformably overlies the Rakaia Terrane basement strata and is up to 120 m thick, but typically less than 50 m thick. The Taratu Formation is overlain by the Kauru Formation, particularly in the south of the area, where the Kauru Formation can be up to 70 m thick and heavily confines the aquifer, which can be >400 m deep towards the coast. The Kauru Formation is overlain by the North Otago Volcanics towards the eastern part of the area, towards the coast. The aquifer is split into a number of fault controlled block which may separate and restrict groundwater movement between the different aquifer zones.

As a result of faulting, there is no single groundwater flow direction within the aquifer. The aquifer system in the southern zone, abutting the coast, may be blind and no groundwater movement occurs under a natural setting. However groundwater movement and active recharge may occur in the northern zones, where some active interaction (i.e. groundwater discharge) occurs with the Maerewhenua River. Strongly above surface arteisan groundwater pressures are present in the southern zone and Enfield Zones, particularly towards the middle of the area, and above surface artesian pressures are also present in parts of the Enfield Basin. Those high pressures, coupled with very evolved groundwater has resulted in a characteristic and corrosive groundwater chemistry, which has contributed to the deterioration of a number of deeper bores in the aquifer, resulting in leakage to the surface.

Groundwater abstraction from the aquifer occurs, with the greatest use for irrigation.

Information available

Groundwater level monitoring: *Groundwater levels have been monitored in three bores.*

1. *Bore J41/0137 (160 m deep) has a continuous monitoring record from January 1986 to August 2004. A further two days of measurements are available during January 2008.*
2. *Bore J41/0278 (unknown depth) has a continuous monitoring record from January 1986 to November 2001.*
3. *Water levels in bore I41/0039 (unknown depth and location) were recorded at 15 minute intervals between February 1988 and June 1989.*

Groundwater quality information: *Groundwater quality monitoring is limited in this aquifer. Bore J41/0006 (155.4 m deep) only has two samples from September 2010 and March 2011.*

Stream/aquifer interaction: *There appears to be some seepage loss to the Marawhenua River in the northern section of the aquifer.*

Recharge volume: *An assessment of aquifer recharge is currently being developed. Current information indicates that there are minimal inflows and outflows to this aquifer, with old groundwater present.*

Discharge locations: *It is currently unknown if groundwater is discharged to the east offshore, but it appears as though groundwater movement is very minimal in the eastern section of the aquifer. There are currently 13 consents to take groundwater from the Papakaio Aquifer which are mostly used for irrigation.*

Allocation status: *A suitable aquifer allocation assessment is currently under development. (Otago Regional Council, 2004).*

Typical landuse: *Landuse over the aquifer consists mainly of agricultural land with some populated areas.*

Aquifer parameters: *There are 7 bores within the aquifer that have been subjected to pumping tests. The reported transmissivity values range from 14 to 450* m^2*/day.*

Groundwater movement

Groundwater generally flows towards the coast in a south-east direction with some variances due to topography and faulting in the area.

Information required

Further monitoring is required for this aquifer to comply with the requirements in the RPW and NPS-FM.

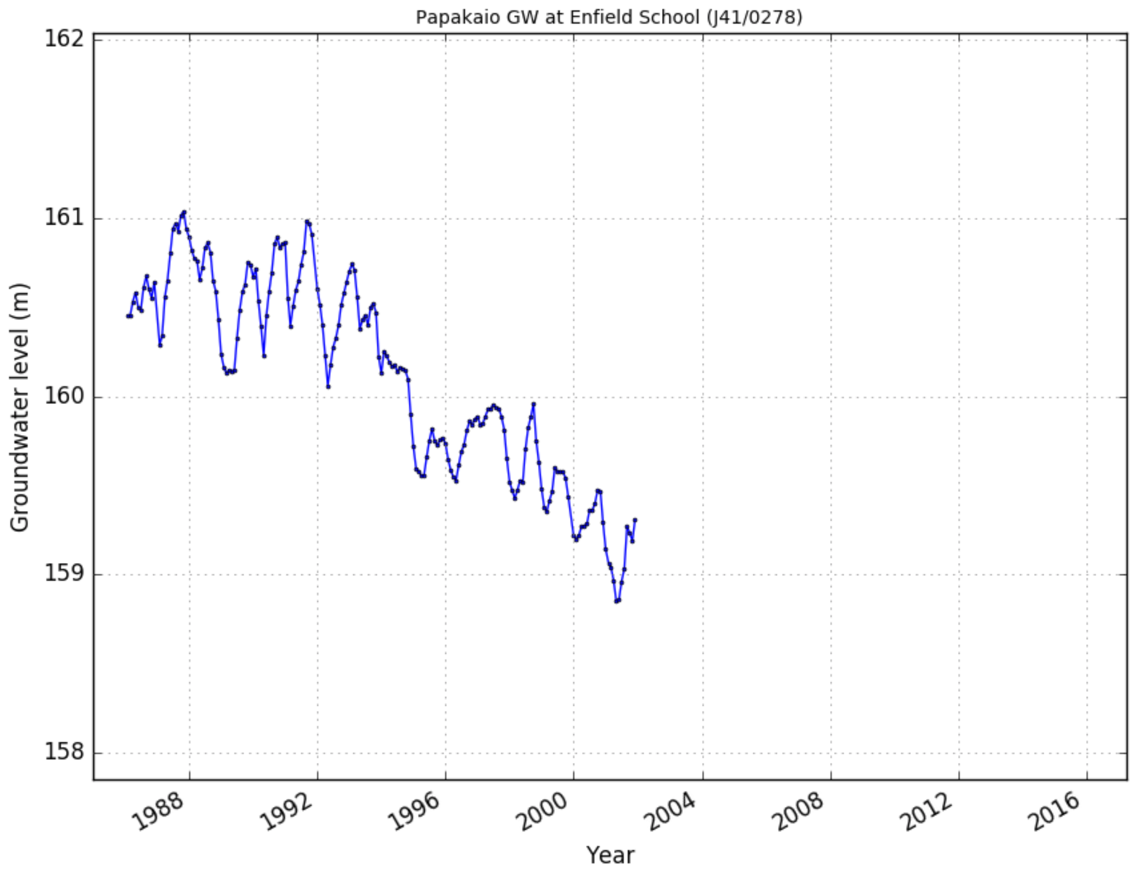
Summary

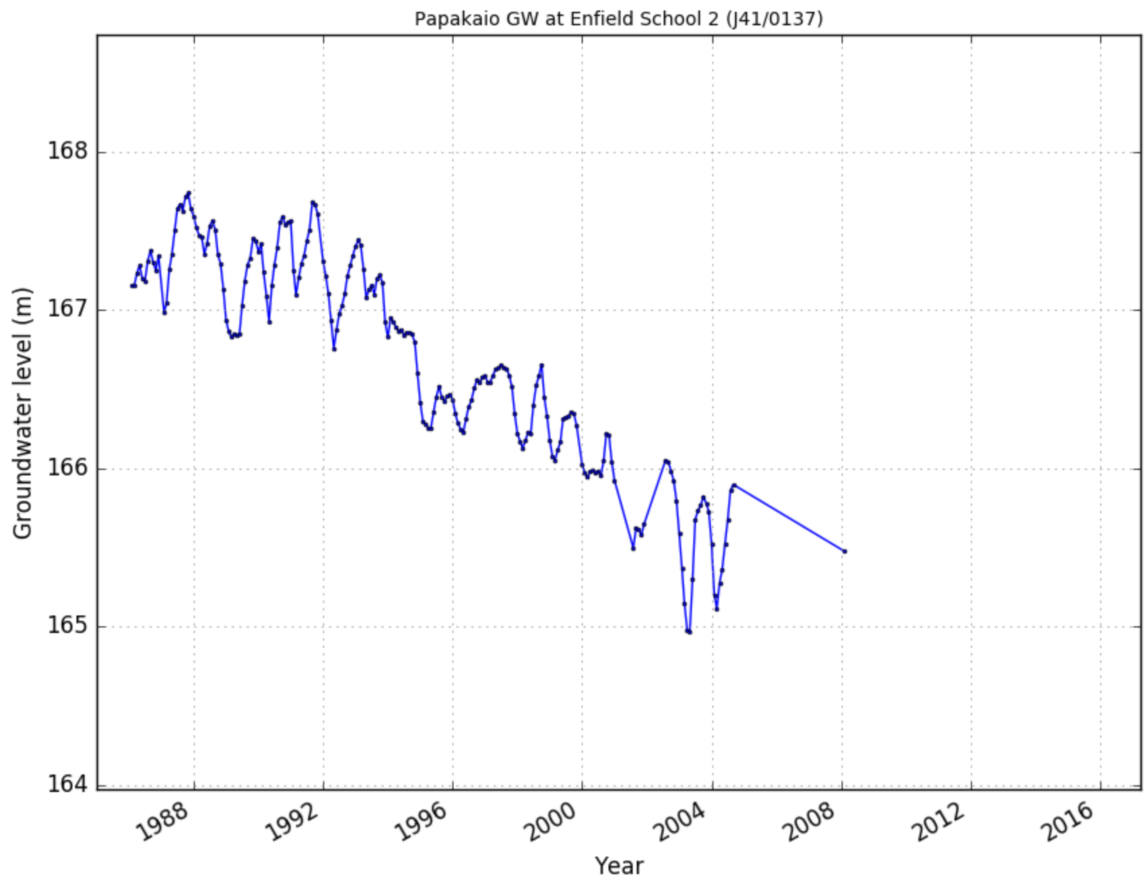
A more detailed allocation model is currently under review for the aquifer. Groundwater within the aquifer is old and movement in the eastern portion of the aquifer is limited.

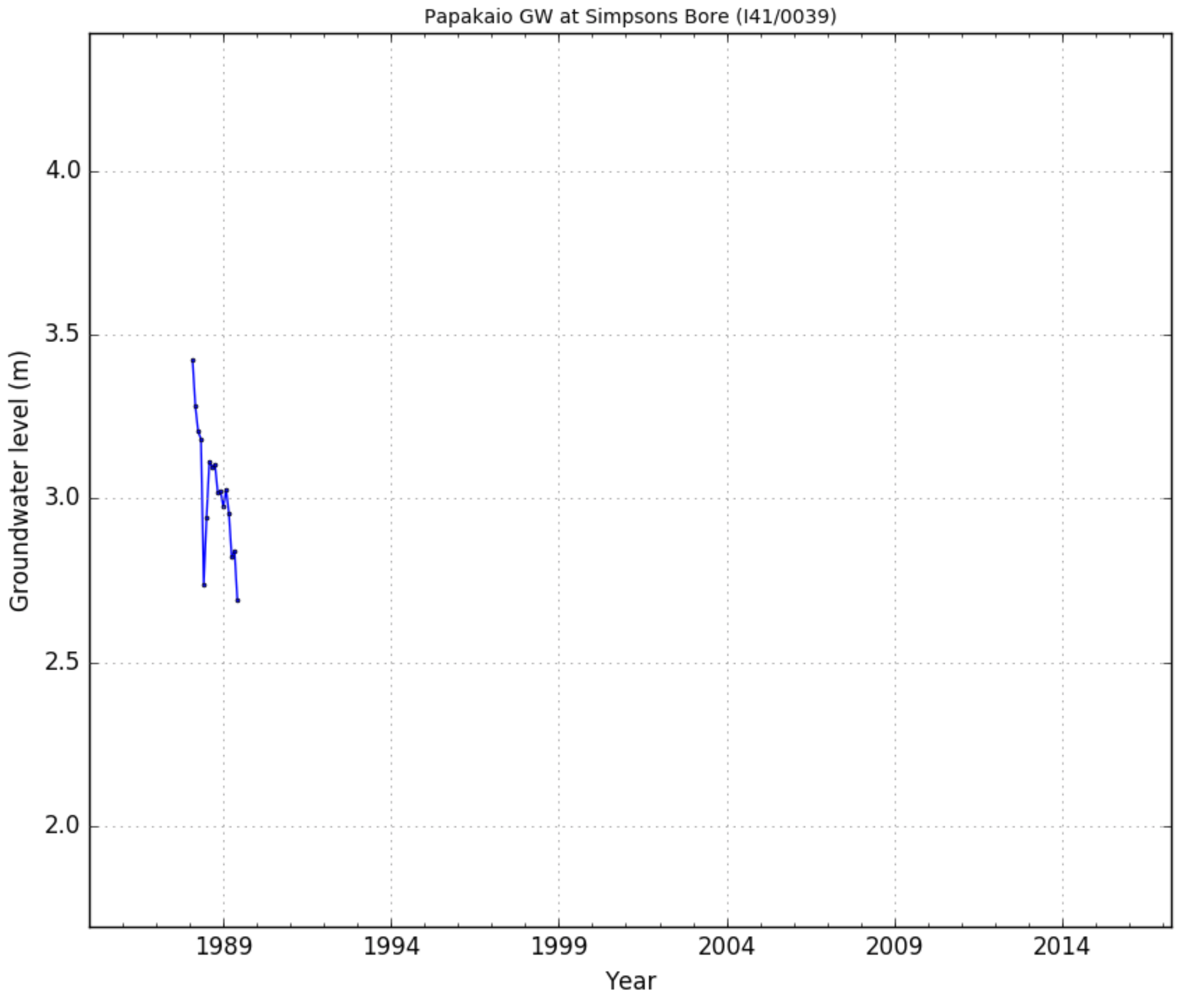
Reference list

Otago Regional Council. (2004). Papakaio Aquifer Report: Outside of the Enfield Basin North Otago. Dunedin.

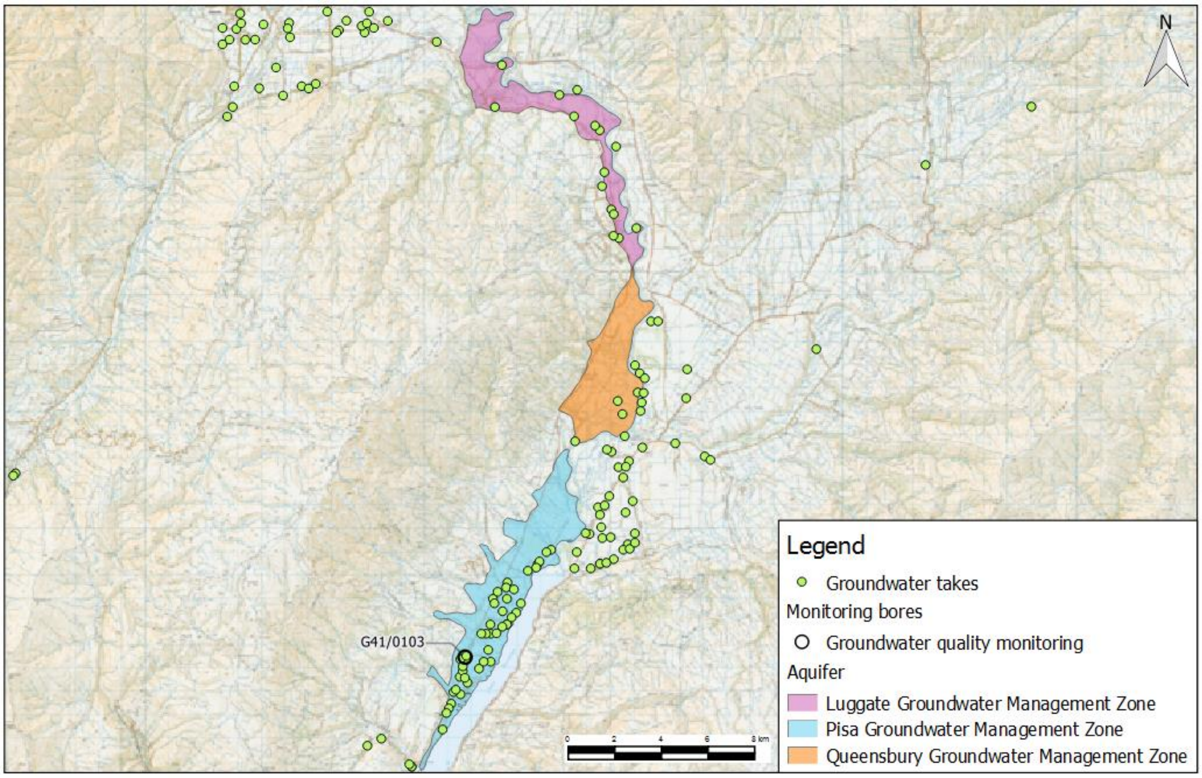
Otago Regional Council (2012) Papakaio Aquifer Allocation Review (Unpublished technical report).


Papakaio GW at Enfield School (J41/0278)
162
161
160
159
158
Groundwater level (m)
1988
1992
1996
2000
2004
2008
2012
2016
Year


Papakaio GW at Enfield School 2 (J41/0137)
168
167
166
165
164
Groundwater level (m)
1988
1992
1996
2000
2004
2008
2012
2016
Year


Papakaio GW at Simpsons Bore (I41/0039)
Groundwater level (m)
4.0
3.5
3.0
2.5
2.0
1989
1994
1999
2004
2009
2014
Year

Pisa - Luggate – Queensbury Groundwater Management Zones:



The Pisa – Luggate – Queensbury Groundwater Management Zone extends from the southern edge of the Wanaka Basin (around Luggate) and covers the western bank of the Clutha River to mid way along Lake Dunstan.

The aquifer consists of Quaternary gravels overlying basement schist strata. Where the Clutha River has eroded down into the basement strata, the Quaternary Gravel Aquifers are effectively perched above the river. Whilst the strata may drain into the Clutha River, it does not gain water from the river. Recharge to the aquifer is from land surface recharge, as well as from stream losses where surface water runoff emerges from the lower permeability hills to the west. Groundwater within the strata is expected to generally flow towards the Clutha River, although the relationship between groundwater and the Clutha River is variable, with some areas of surface water loss from the river to groundwater and some areas of surface water gain from groundwater. Depths to groundwater vary, but in the water quality monitoring bore G41/0103, groundwater levels are around 17 m below ground level.

There are a number of consented groundwater abstractions in the zones and groundwater is used for a variety of purposes including irrigation and industry (quarrying) as well as domestic supply. The Bendigo Wetland is a regionally significant wetland at the head of Lake Dunstan.

Information available

Groundwater level monitoring: *There are currently no dedicated groundwater level monitoring bores within the aquifer zones (although groundwater levels are recorded quarterly in the groundwater quality monitoring bore). However, the aquifers are expected to be closely connected to flows in the Clutha River and Lake Dunstan.*

Groundwater quality information: *There is one groundwater quality monitoring bore, G41/0103 (29 m deep), that has been monitored for a range of parameters, generally at quarterly intervals, between September 1996 and June 2013.*

Stream/aquifer interaction: *All three zones cover areas of quaternary deposits and are expected to be closely connected with the Clutha River and Lake Dunstan.*

Recharge volume: *The aquifers are recharged by rainfall recharge, irrigation recharge, range front infiltration and from waterway losses. The mean annual rainfall recharge is estimated to be 4.5 Mm^3/year and the mean annual stream recharge is estimated to be 24.6 Mm^3/year* (Weaver, 2014).

Discharge locations: *Water is thought to be discharged to the Clutha River and Lake Dunstan along sections of the aquifer zones, where other areas receive recharge from surface waterways. There are 55 consents to take groundwater within the three zones. These consents are mainly used for irrigation and drinking water supply, with a smaller number of consents for stockwater, commercial/industrial use and frost fighting. There is one mining take in the area.*

Allocation status: *The allocation status of the aquifers is currently under development. The current consented volumes for all three zones are estimated to be 12.2 Mm^3/year which is considerably higher than the estimated rainfall recharge* (Otago Regional Council, 2014). *The suggested allocation limit for these aquifers is 14.5 Mm^3/year* (Weaver, 2014).

Typical landuse: *Landuse in the area is generally agricultural.*

Aquifer parameters: *There are 10 bores within the aquifer zones that have been subjected to pumping tests. The reported transmissivity values range from 300 to 14,720 m^2/day.*

Groundwater movement

Groundwater flow is expected to be constrained by topography, and flow from the base of the Pisa Range towards the Clutha River and Lake Dunstan.

Information required

To meet the objective of maintaining storage in the aquifer, some long term continuous groundwater level monitoring is required. Some groundwater quality monitoring is also required to meet the minimum requirements and maintain groundwater quality.

Summary

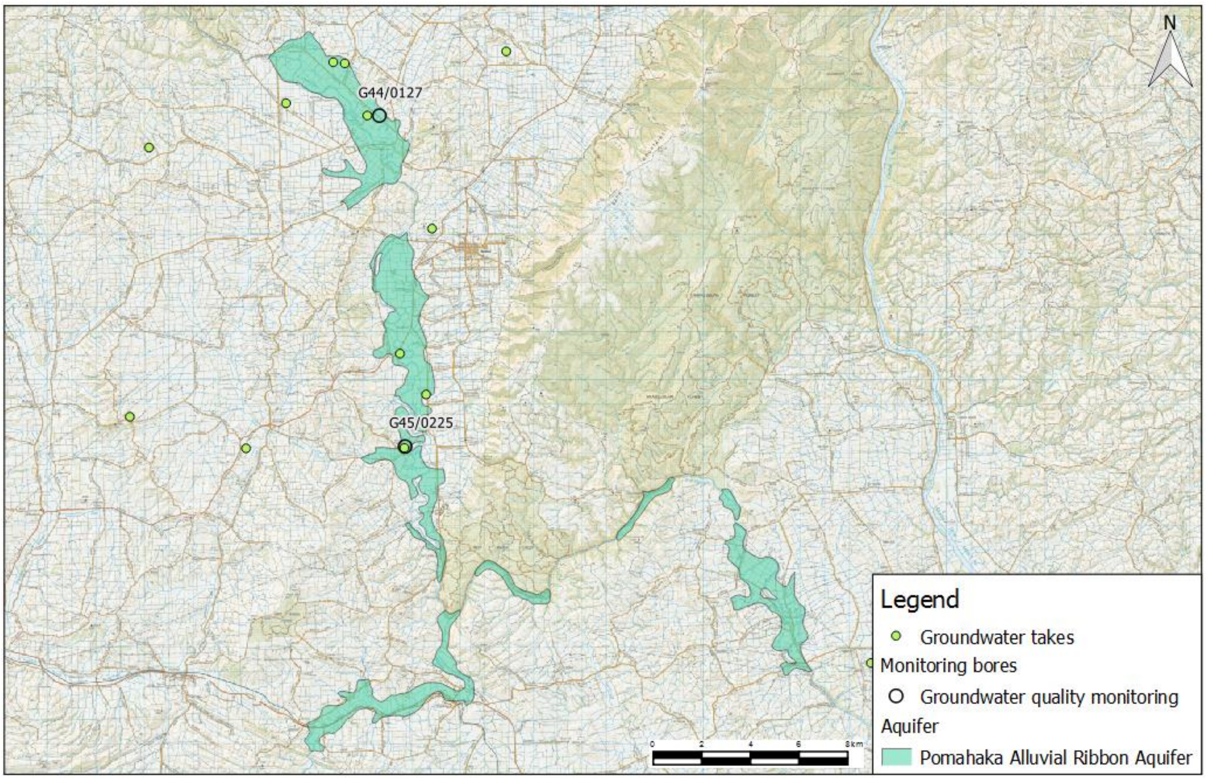
These groundwater zones are extensively used for groundwater abstraction. The allocation status of these zones are currently under development in conjunction with public workshops.

Reference list

Otago Regional Council. (2014). Groundwater Resources of Pisa Terraces, Luggate and Queensberry - ORC Workshop. Otago Regional Council.

Weaver, M. (2014). West Bank of Clutha Groundwater Management Zone. Otago Regional Council.

Pomahaka Alluvial Ribbon Aquifer:



Information available

Groundwater level monitoring: *There are currently no groundwater level monitoring bores within the aquifer. However, groundwater is in close connection with the Pomahaka and Waipahi Rivers and flow data is available for two sites along the reach of the Pomahaka River.*

Groundwater quality information: *There are two groundwater quality monitoring bores within the alluvial ribbon.*

1. *Bore G44/0127 (5.2 m deep) has a quarterly sampling record for a range of parameters between March 2011 and December 2016.*
2. *Bore G45/0255 (unknown depth) has been sampled generally at quarterly intervals between October 2011 and December 2016.*

Stream/aquifer interaction: *The Pomahaka Alluvial Ribbon Aquifer and the Pomahaka and Waipahi Rivers are in close hydraulic connection.*

Discharge locations: *The Pomahaka Alluvial Ribbon Aquifer flows in close connection with the Pomahaka and Waipahi Rivers and hence flows in a general south-east direction towards the coast. There are six consented groundwater takes in the aquifer which are used for drinking water supply, dairy shed water, stockwater and irrigation.*

Recharge volume: *Recharge originates from rainfall as well as the Pomahaka and Waipahi Rivers and is dependent on flows in these waterways.*

Allocation status: *Due to the close connectivity with surface waterways, groundwater takes are effectively managed as surface water takes. The allocation status is currently unknown but expected to be based on surface water allocation.*

Typical landuse: *The dominant landuse overlying the aquifer is agriculture.*

Aquifer parameters: *There is one bore within the aquifer that has aquifer test data available. The reported transmissivity value is 3,100 m^2/day.*

Groundwater movement

Groundwater flow is in close connection with the Pomahaka and Waipahi Rivers and flows in a similar direction towards the south and east in the direction of the coast.

Information required

None.

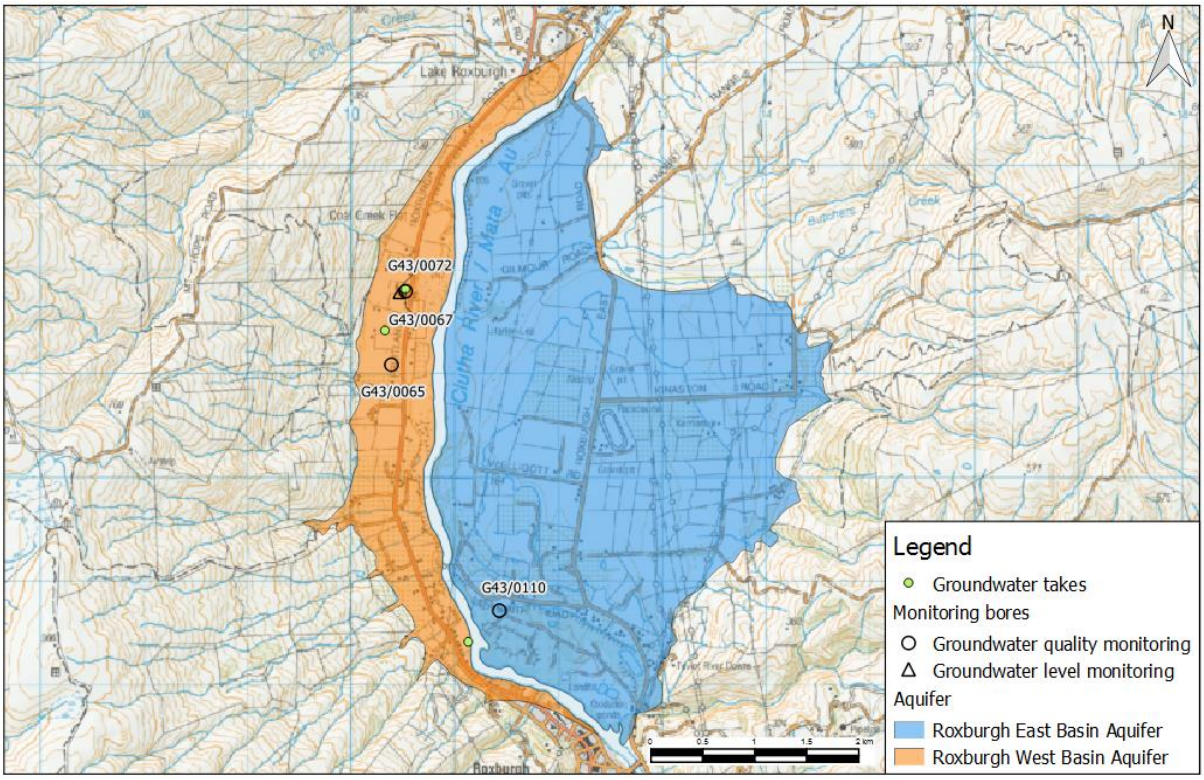
Summary

The groundwater takes in the Pomahaka Alluvial Ribbon Aquifer are effectively managed as surface water takes and hence the allocation limits for the relevant surface water bodies apply.

Reference list

Morris, R. (2014). Groundwater Resource Management Review of the South Otago Basins. Dunedin: Otago Regional Council.

Roxburgh Basin Aquifer:



The Roxburgh Basin Aquifer is an alluvial aquifer located either side of the Clutha River, upstream of Roxburgh township. The Roxbugh Aquifer is split into two parts; the Roxbugh East aquifer represents the alluvial strata on the eastern (true right) bank of the Clutha River, and the Roxburgh West Aquifer represents the alluvial strata on the west (true left) bank of the Clutha River.

Groundwater in the Roxburgh East aquifer is largely derived from rainfall recharge, with few other sources of water seeping into the aquifer. That is partly due to the network of irrigation races that intercept runoff from the high ground to the east. Groundwater within the aquifer discharges into the Clutha River and there is no consented groundwater abstraction.

In contrast, groundwater in the Roxburgh West Aquifer is derived from a variety of sources, including rainfall recharge, recharge from the foothill streams and artificial recharge sumps that originate as part of the water race system. Groundwater flow directions are perpendicular to the line of the Clutha river, although ORC (2015) note that Slaughterhouse Creek may form a divide across the aquifer. Groundwater discharge is via some consented groundwater abstraction for irrigation as well as discharge into the Clutha River.

Note that both the Roxburgh East and West aquifers may be perched above the Clutha River in some areas, restricting the groundwater resource by excluding interaction with the river.

Information available

Groundwater level monitoring: *There is one groundwater level monitoring bore screened within this aquifer. Bore G43/0072 (16.8 m deep) has a detailed monitoring record from July 1995 to Febraury 2017. However, we are aware that the construction of a mine is planned in the area and subsequently, this bore will be removed.*

Groundwater quality information: *There are three bores within the Roxburgh Basin with available groundwater quality data.*

1. *Bores G43/0067 (18.9 m deep) and G43/0110 (unknown depth) have one-off samples taken in May 2015.*
2. *Bore G43/0065 (19.5 m deep) has been monitored for a range of parameters, generally at quarterly intervals between September 2010 and July 2016.*

Stream/aquifer interaction: *The aquifer is thought to be well connected to the Clutha River, with the majority of the aquifer discharge entering the river via seepage.*

Recharge volume: *The aquifer receives rainfall recharge, drainage recharge off the surrounding hills and from artificial recharge sumps. The estimated recharge volumes are 3.26 Mm^3/year for Roxburgh West and 1.49 Mm^3/year for Roxburgh East (Morris, 2015).*

Discharge locations: *The aquifer is thought to discharge to the Clutha River via seepage, although the volume is currently unknown. There are three consented groundwater takes within the Roxburgh Basin Aquifer which are used for irrigation, drinking water supply, frost fighting and stockwater supply.*

Allocation status: *A detailed investigation into the allocation status of the aquifer is currently under development. The Roxburgh Basin Aquifer is split into two smaller aquifers east and west divided by the Clutha River. The latest draft report indicates that the allocation limit as 50 percent of mean annual recharge is 0.75 Mm^3/year for Roxburgh East and 1.63 Mm^3/year for Roxburgh West and that the aquifers are currently under-allocated (Morris, 2015).*

Typical landuse: *The basin mainly consists of orchards and agricultural land.*

Groundwater movement

Groundwater is recharged via rainfall infiltration and drainage off the surrounding hills and flows towards the Clutha River on either side of the basin.

Information required

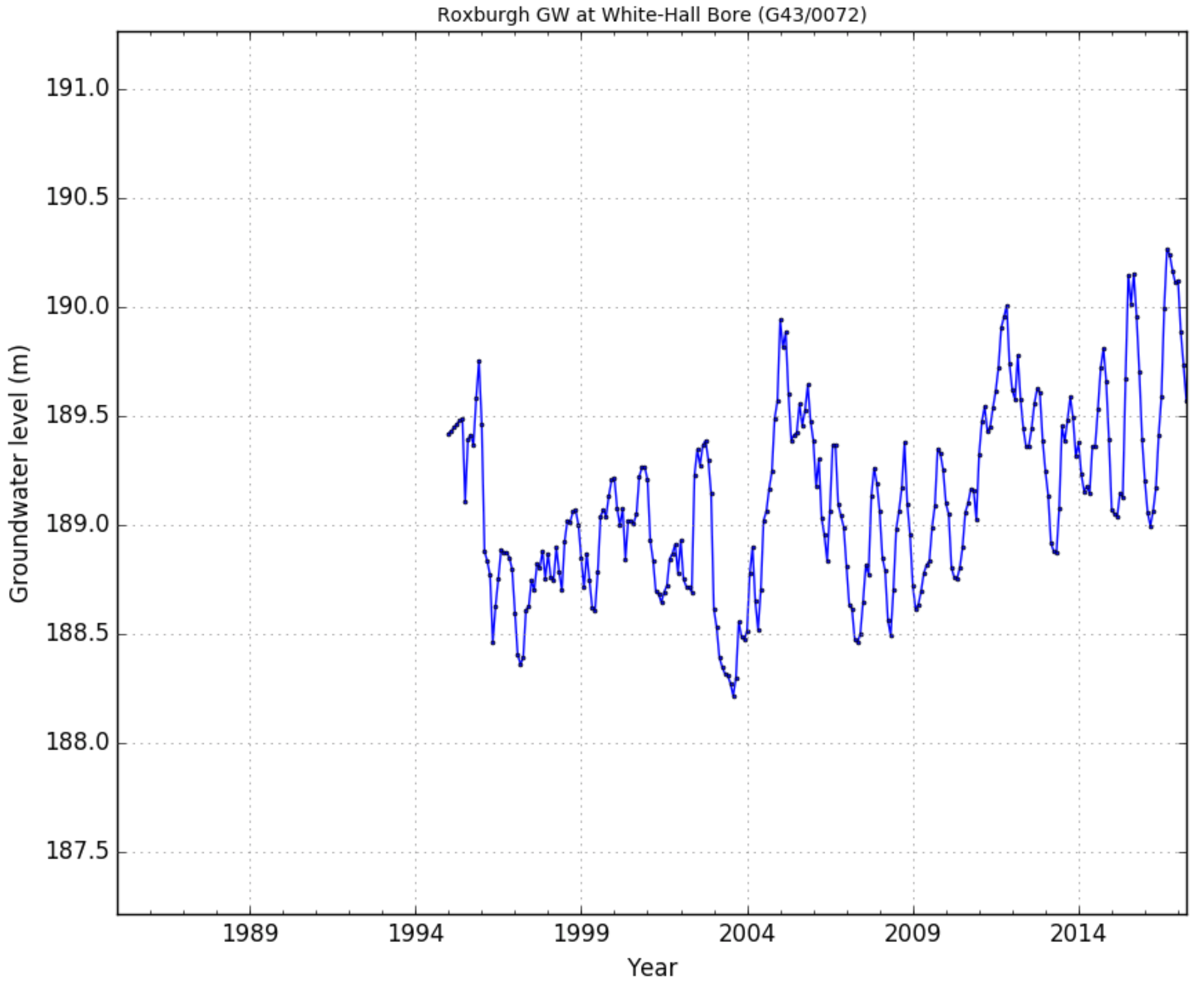
Groundwater monitoring for both levels and flows is required to comply with the minimum requirements in the Roxburgh East Aquifer.

Summary

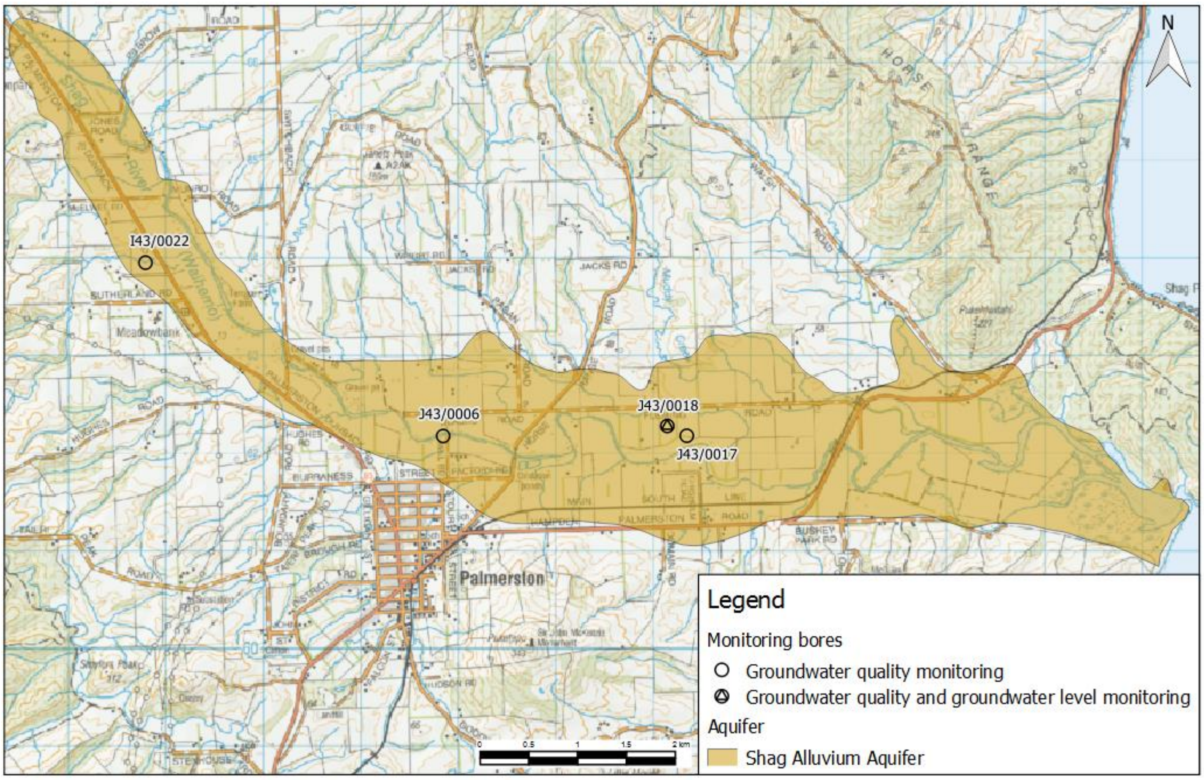
Groundwater movement is relatively well understood in this aquifer. A detailed investigation into the inflow and outflow volumes and subsequent allocation status of the aquifer is currently under development which will aid in better management of the aquifer resource.

Reference list

Morris, R. (2015). Roxburgh Basin Aquifer Study. Dunedin: Otago Regional Council.


Roxburgh GW at White-Hall Bore (G43/0072)
191.0
190.5
190.0
189.5
189.0
188.5
188.0
187.5
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year

Shag Alluvium Aquifer:



Information available

Groundwater level monitoring: *There is one bore within the Shag Alluvium Aquifer with water level records. Bore J43/0018 (4.5 m deep) has been monitored between April 1996 and March 2010. Shallow groundwater is expected to be closely related to the river height in the Shag River.*

Groundwater quality information:

Groundwater quality has been monitored in 4 bores.

1. *Two samples have been taken from bore I43/0006 (37 m deep) in October 2010 and March 2011. However, given the depth of this bore, it is likely screened within the deeper confined aquifer.*
2. *Three samples were taken from bore J43/0017 (unknown depth) in the 1990's but these were limited in terms of parameters sampled for.*
3. *Bore J43/0018 (4.5 m deep) has been sampled for a limited range of parameters, typically at yearly intervals between August 1995 and November 2008.*
4. *Bore J43/0006 (9.1 m deep) has been sampled for a wide range of parameters generally at quarterly intervals between September 2010 and January 2017.*

Stream/aquifer interaction: *The aquifer is thought to be in close connection with the Shag River, with the main source of aquifer recharge originating from river loses.*

Recharge volume: *The potential sources of groundwater recharge for this aquifer are losses from the Shag River and tributaries, rainfall infiltration and groundwater outflow from surrounding hill country.*

Discharge locations: *It is assumed that the majority of the aquifer outflow discharges to the Shag River or flows offshore. There are no consented takes in the aquifer.*

Allocation status: *Aquifer storage volume has been estimated at 3.9 Mm^3 (Turnbull & Fraser, 2005). However, a detailed allocation model has not yet been developed. Therefore, the allocation status is currently unknown. This aquifer is considered to have low potential for water abstraction.*

Typical landuse: *Landuse overlying the aquifer consists mainly of agricultural land.*

Groundwater movement

Groundwater flow is expected to be constrained by the local topography and influenced by the Shag River, flowing in a general easterly direction towards the ocean. However, a piezometric survey has not been completed for this aquifer.

Information required

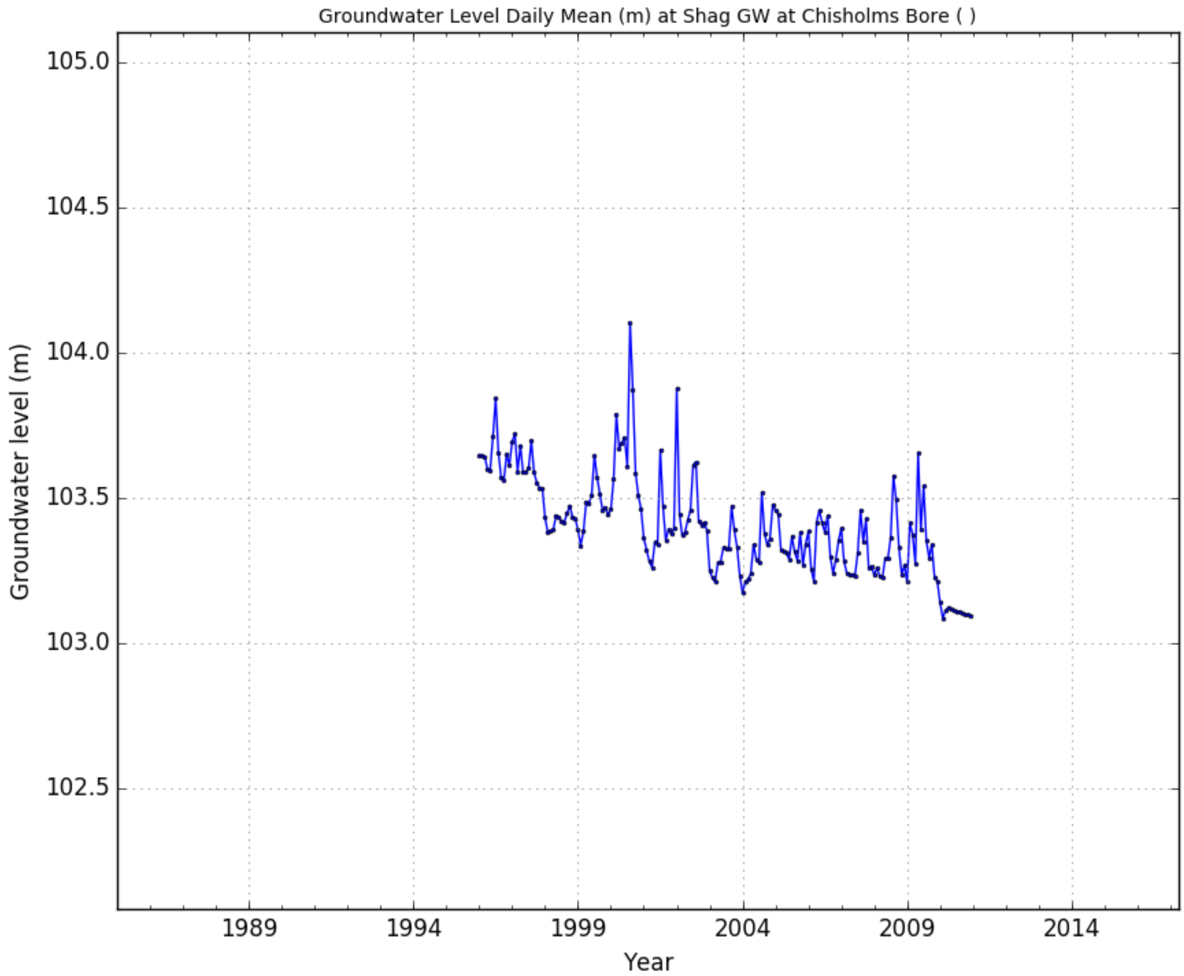
Aquifer parameters: *There are no bores within the aquifer that have been subjected to pumping tests.*

Summary

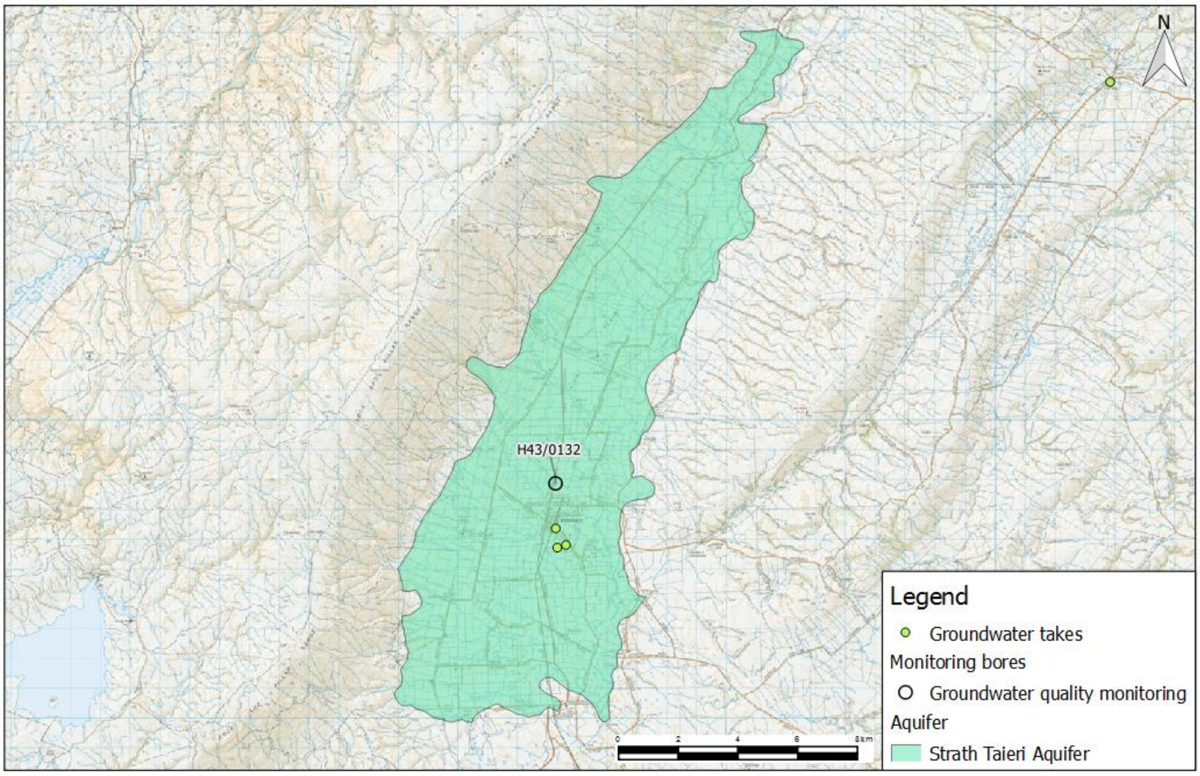
There is currently limited information available for the Shag Alluvium Aquifer. However, there are no consented takes within the aquifer indicating that the groundwater resource is not likely to be under pressure at the present time.

Reference list

Turnbull, I. M., & Fraser, H. L. (2005). Groundwater of the Lower Shag Valley, North Otago: Phase 2 Investigations. GNS Science.


Groundwater Level Daily Mean (m) at Shag GW at Chisholms Bore ( )
Groundwater level (m)
105.0
104.5
104.0
103.5
103.0
102.5
1989
1994
1999
2004
2009
2014
Year

Strath Taieri Aquifer:



The Strath Taieri Aquifer covers the Strath Taieri Basin approximately 50 km north-west of Dunedin. The Strath-Taieri Basin is a fault controlled tectonic depression and there is a relatively shallow thickness of alluvial deposits recorded up to 28 m thick overlying lower permeability basement schist. The strata in the west of the basin is dominated by late quaternary fan deposits extending out from the base of the Rock and Pilar Range. These fans grade into fluvial deposits towards the east of the basin towards the Taieri River.

Groundwater recharge originates from land surface recharge, runoff from the adjacent Rock and Pillar Range and from river losses. Generally, groundwater flows from the north-west of the area, at the base of the range front, towards the south-east where discharge to the Taieri River is expected to occur.

Groundwater is closely connected to surface waterways and as such, groundwater takes can effectively be managed as surface water takes. There are three consents to take groundwater which are used for irrigation and stockwater supply. There have been no aquifer tests in shallow bores screened within the alluvium. Aquifer testing on a deeper bore within the underlying schist indicates that the basement rock is poor yielding.

Information available

Groundwater quality information: *There is one bore within the aquifer with available water quality data. Bore H43/0132 has been sampled for a typical range of parameters generally at quarterly intervals between September 2010 and December 2016.*

Stream/aquifer interaction: *The aquifer is connected to surface water bodies and is expected to receive some recharge from surface water as well as discharging to the Taieri River in the southern extent of the basin. As such that groundwater takes can effectively be managed as surface water takes.*

Recharge volume: *The aquifer is recharged by rainfall, river infiltration and range-front recharge from the adjacent slopes. The total mean annual rainfall recharge for the aquifer is estimated to be 8.3 Mm^3/year (Wilson & Lu, 2011).*

Discharge locations: *The aquifer discharges a component of water to surface waterbodies via seepage. Additionally, there are three consents to take groundwater from the aquifer which are used for irrigation and stockwater supply.*

Allocation status: *The current allocation status of the aquifer is unknown however an allocation limit of 4.15 Mm^3/year has been adopted which is based on half the mean annual rainfall recharge.*

Typical landuse: *Landuse in the basin is dominantly agricultural.*

Groundwater movement

Groundwater in the basin flows from the north-west base of the Rock and Pillar Range towards the south-east in the general direction of topographical relief.

Information required

Groundwater level monitoring: *There are no groundwater level monitoring bores within the aquifer.*

Aquifer parameters: *There are no bores within the aquifer that have been subjected to pumping tests. One bore with aquifer test information exists in the deeper basement schist (H43/0188, 96.65 m deep) and has a reported transmissivity value of 7 m^2/day.*

Summary

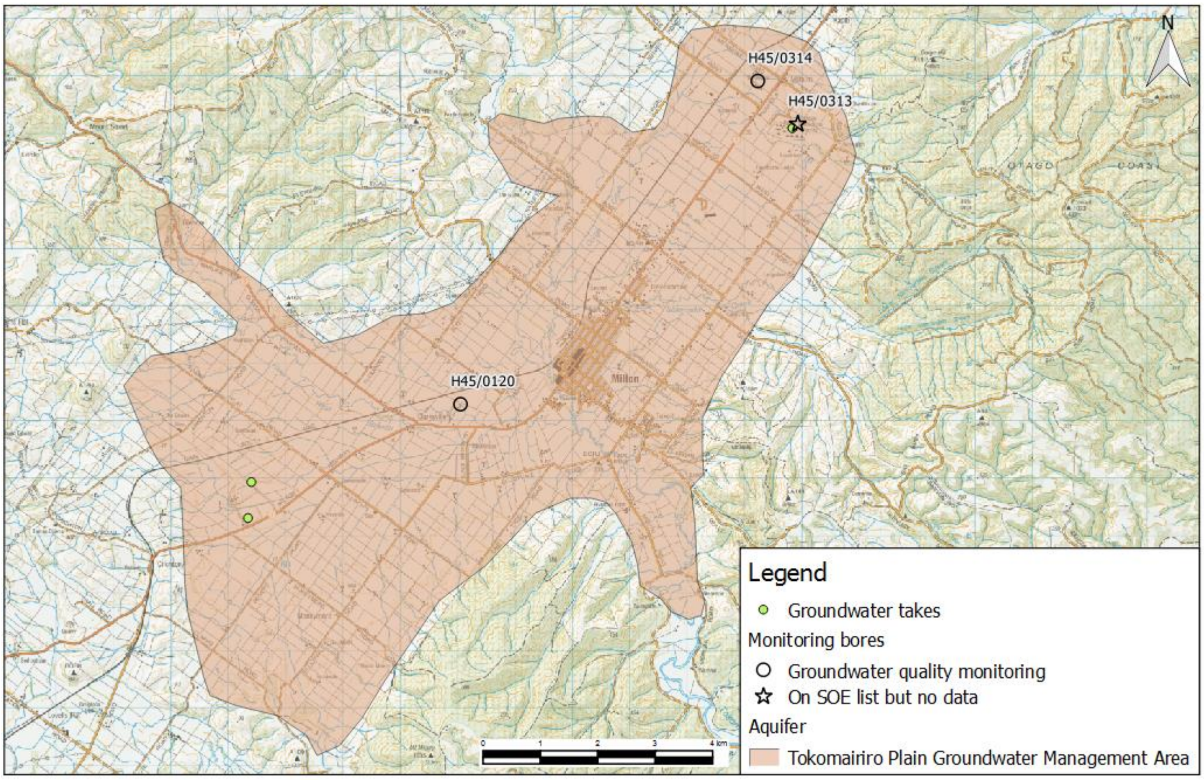
Groundwater within the basin is closely connected to surface water bodies and as such, groundwater takes can be effectively managed as surface water takes. The allocation limit of the aquifer is currently set at half of the mean annual rainfall recharge volume.

Reference list

Rekker, J., Durie, M., & MacTavish, D. (2004). Strath Taieri Groundwater Resources Study: Preliminary Report. Palmerston: Irricon Consulting.

Wilson, S., & Lu, X. (2011). Rainfall Recharge Assessment for Otago Groundwater Basins. Dunedin: Otago Regional Council.

Tokomairiro Plan Groundwater Management Area:



Information available

Groundwater quality information: *There are two bores in the area that have water quality data available.*

1. *Bore H45/0120 (15 m deep) has been sampled for a range of parameters 3 to 4 times a year between March 2011 and March 2014.*
2. *Bore H45/0314 (unknown depth) has been sampled 3 times per year between October 2014 and December 2016.*

Stream/aquifer interaction: *The relationship between groundwater and surface water has not been defined. However, the basin is filled with quaternary deposits and therefore it is likely that shallow groundwater is connected to surface waterways.*

Recharge volume: *An assessment of rainfall recharge has been undertaken for this area, with an estimated mean annual rainfall recharge of 10.3 Mm^3/year (Wilson & Lu, 2011).Quantitative estimates on other recharge sources have not been investigated.*

Discharge locations: *Natural discharge sources have not been defined. However, there are 3 groundwater consents in the area for construction/repairs, dairy shed, single household and stockwater supply.*

Allocation status: *Information supplied by ORC indicates that an allocation limit of 2.35 Mm^3/year has been set for this aquifer.*

Typical landuse: *Landuse in the area is mainly agricultural, with some populated zones.*

Groundwater movement

No piezometric survey has been undertaken for this area. Shallow groundwater is expected to flow in conjunction with the local topography, down-valley towards the south-west.

Information required

Groundwater level monitoring: *There are no groundwater level monitoring bores within the basin.*

Aquifer parameters: *There are no bores in the area with aquifer parameter information.*

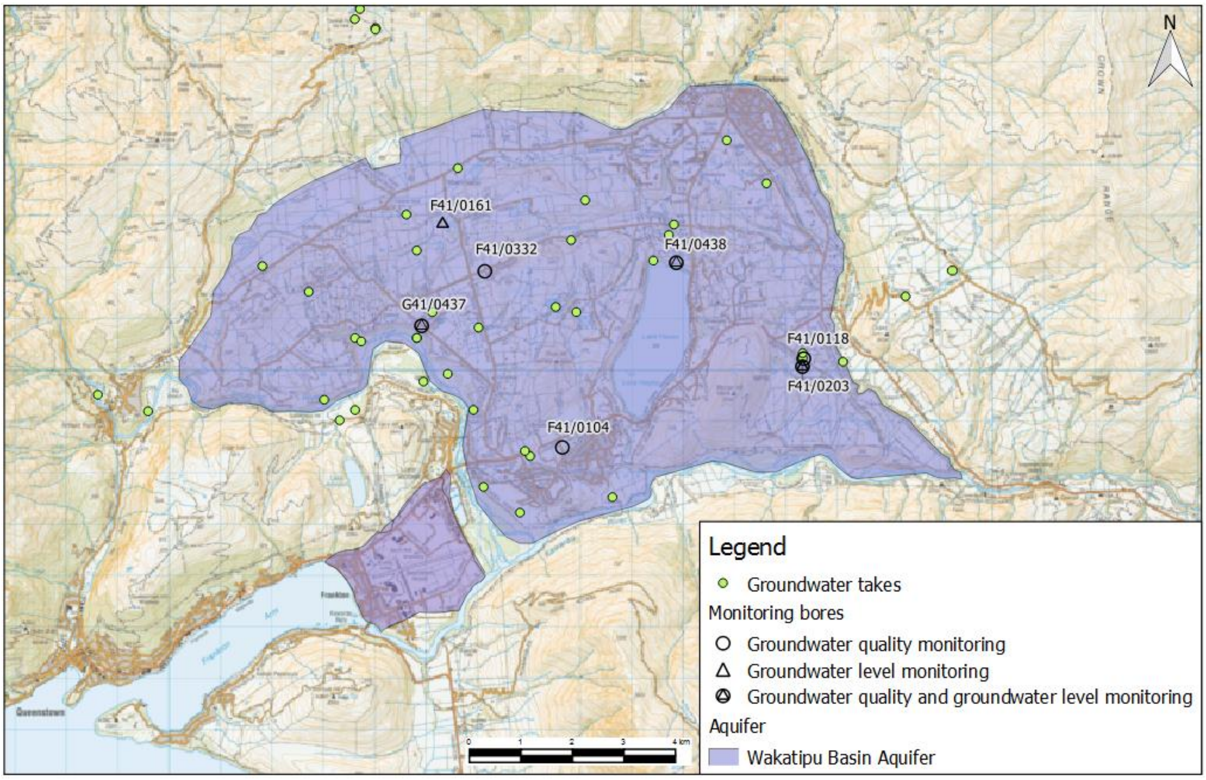
Summary

The aquifer is currently poorly utilised and there has been minimal research around recharge and discharge sources and allocation limits to date.

Reference list

Wilson, S., & Lu, X. (2011). Rainfall Recharge Assessment for Otago Groundwater Basins. Dunedin: Otago Regional Council.

Wakatipu Basin Aquifer:



The Wakatipu Basin aquifers are split into six subzones on the basis of geology, where the different zones are separated by basement rock ridges or hills. The aquifers consist of glacial outwash material including variable sands, gravels and some silts. Recharge to the aquifers is varied with some depending entirely on land surface recharge and others including a proportion of surface water seepage (for example the Frankton Flats Aquifer, Shotover Alluvial Ribbon Aquifer and Kawarau Alluvial Ribbon Aquifer).

Groundwater in the aquifers that are not in direct connection with a river, stream or lake discharges into springs.

Depths to groundwater in the aquifer are variable; the greatest depths appear to be around the Lake Hayes subzone, where groundwater levels can be 40 m to 50 m deep. However, in other zones, groundwater levels are shallower, around 5- 10 m deep. Groundwater use is predominantly for public supply and domestic stockwater. Relatively limited abstraction for irrigation use occurs due to the Arrow River irrigation race.

Information available

Groundwater level monitoring: *There are four groundwater level monitoring bores within the Wakatipu Basin Aquifer.*

1. *Bores F41/0438 (10 m deep) and G41/0437 (30 m deep) have monitoring records between June 2015 and January 2017 at 15 minute intervals.*
2. *Bore F41/0161 (unknown depth) has a detailed monitoring record from November 1995 to April 2012, with an additional two days of measurements during September 2015. Levels began to be recorded at 15 minute intervals during 2007.*
3. *The fourth bore, F41/0203 (4.1 m deep), has a detailed monitoring record from June 1997 to June 2009 with 15 minute logging commencing during 2007.*

Groundwater quality information: *A total of 6 monitoring bores within the Wakatipu Bain have been sampled for a range of parameters.*

1. *Bore F41/0104 (60 m deep) has been sampled generally at quarterly intervals between September 2010 and December 2016.*
2. *Bore F41/0203 (4.1 m deep) has been sampled quarterly between December 2013 and December 2016.*
3. *Bores F41/0437 (30 m deep) and F41/0438 (10 m deep) have been sampled quarterly between April 2015 and December 2016.*
4. *Bore F41/0118 (10.2 m deep) has been sampled generally at quarterly intervals between September 2010 and October 2013, with one additional sample taken during May 2015.*
5. *Bore F41/0332 (25.2 m deep) has only been sampled twice, during October 2010 and March 2011 respectively.*

Groundwater quality monitoring has shown a dominant concentration of calcium and bicarbonate ions (Rekker, Investigation into the Wakatipu Basin Aquifers, 2014).

Stream/aquifer interaction: *The Arrow and Shotover Rivers and Lake Hayes provide input to the Wakatipu Basin Aquifer. During times of high lake levels, the groundwater gradient is thought to reverse in the southern margin of the aquifer, providing input from Lake Wakatipu into the southern margin of the basin.*

Recharge volume*: Rainfall-recharge modelling is available for the Wakatipu Basin* (Otago Regional Council, Investigation into the Wakatipu Basin Aquifers, 2014). *River and lake recharge have also been estimated to provide an overall water balance for the basin.*

Discharge locations: *In the Wakatipu Basin, generally, groundwater discharges to the main rivers (Kawarau and Shotover Rivers) in southerly and westerly directions. The Arrow River Irrigation Scheme allows for the diversion of around 700 L/s taken under an existing mining right . There are also 31 consents to abstract groundwater within the Wakatipu Basin which are mainly for drinking water supply, with a smaller amount of irrigation takes.*

Allocation status: *The allocation status of the Wakatipu Basin aquifer is currently based on 50% of the mean annual recharge* (Rekker, 2014). *The aquifer is split into six different sub-aquifers.*

Typical landuse: *landuse consists of agriculture, low-density residential areas, resorts and golf courses.*

Aquifer parameters: *There are five bores within the Wakatipu Basin listed as having aquifer parameters with transmissivity values ranging from 700 to 11,600 m^2/day.*

Groundwater movement

Groundwater movement in the Wakatipu Basin is quite complex due to the varying topography. Generally, groundwater flows towards the areas of lowest topography (the Shotover and Kawarau Rivers) towards the south and west of the basin. The piezometric gradient flattens towards the south of the basin and is influenced by the levels in Lake Wakatipu, which can sometimes cause reversals in the piezometric gradient towards the southern extent of the aquifer.

Information required

None.

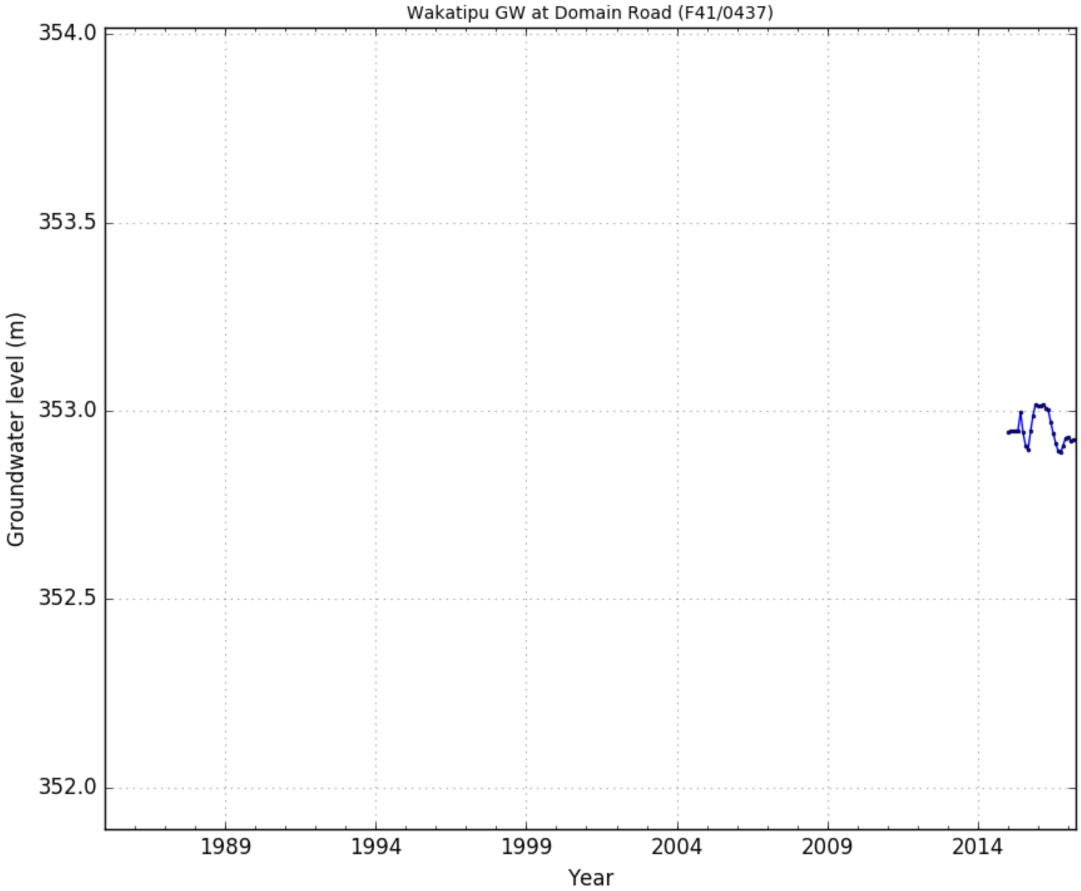
Summary

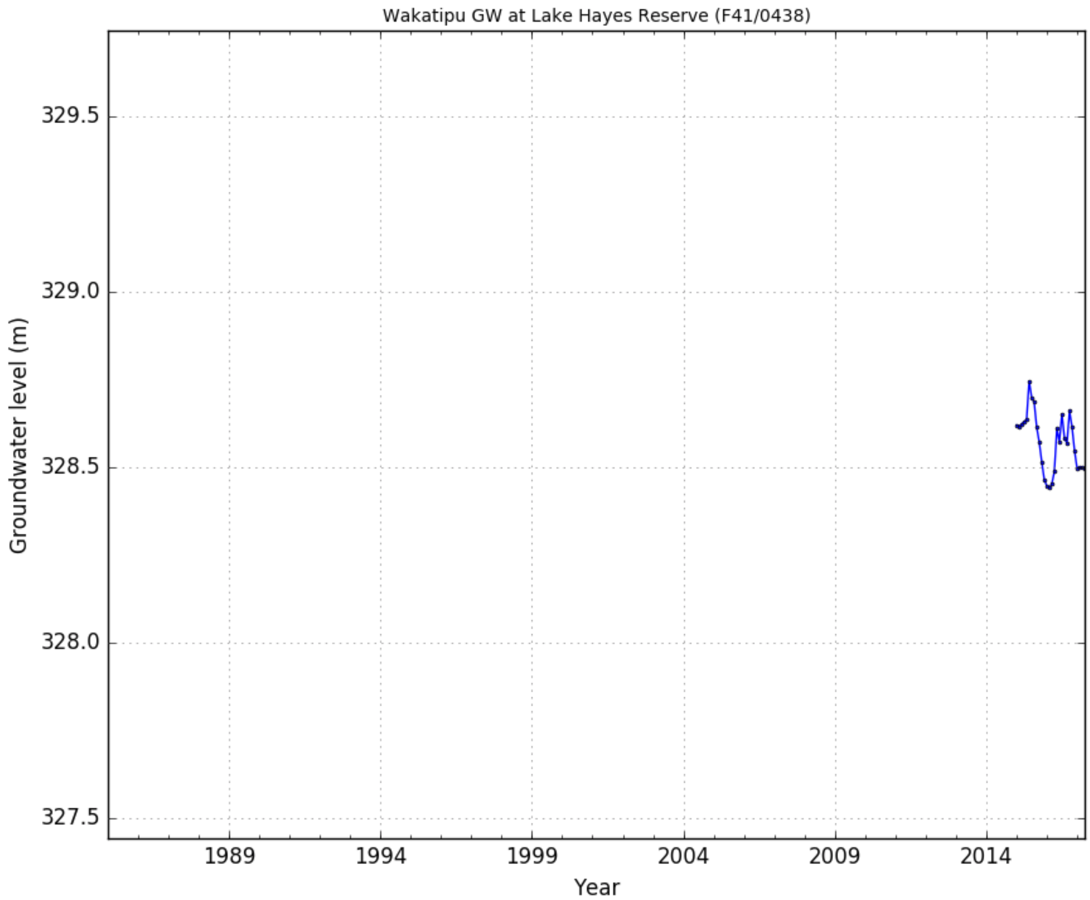
Groundwater movement is well understood in this aquifer. A detailed aquifer water balance assessment has been undertaken for the Wakatipu Basin and the resulting allocation status is reasonable. There is sufficient information to ensure that groundwater is suitably managed in this aquifer to meet the values and objectives in the aquifer. Sufficient groundwater level monitoring occurs to ensure that aquifer storage levels are maintained and generally sufficient groundwater quality information is collected to ensure that groundwater quality trends are identified and can be managed.

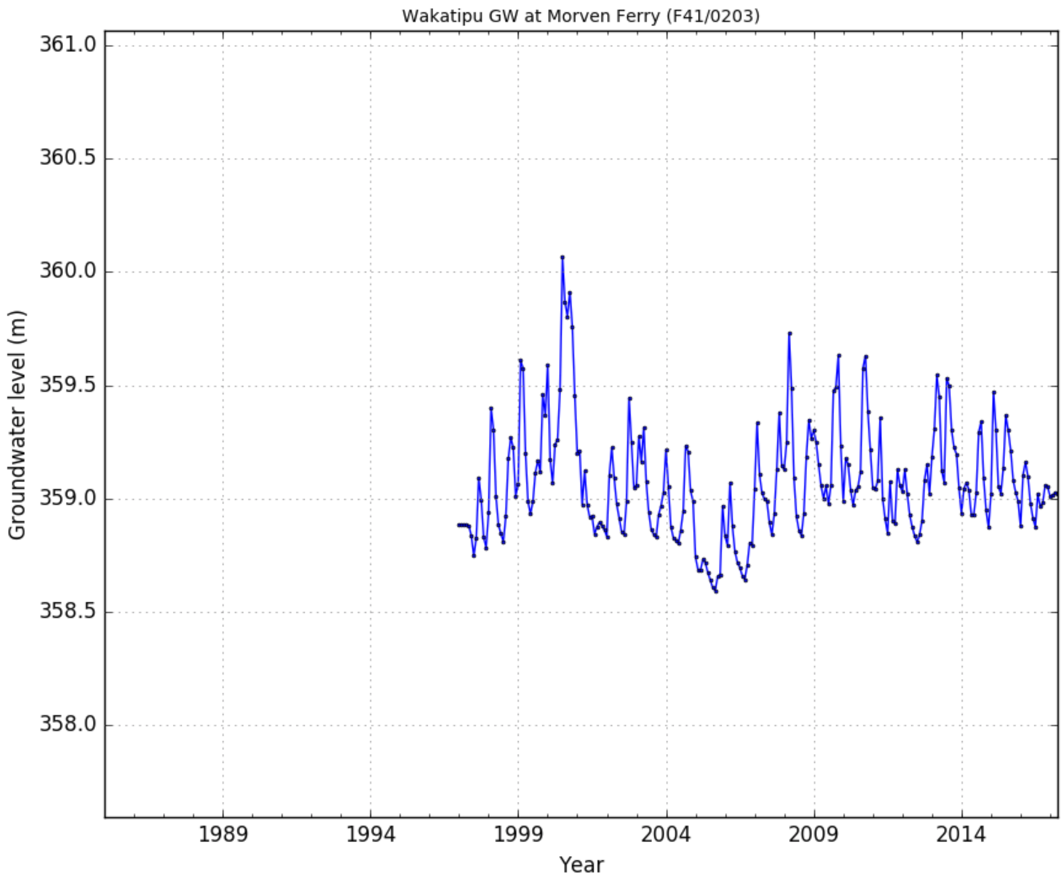
Reference List

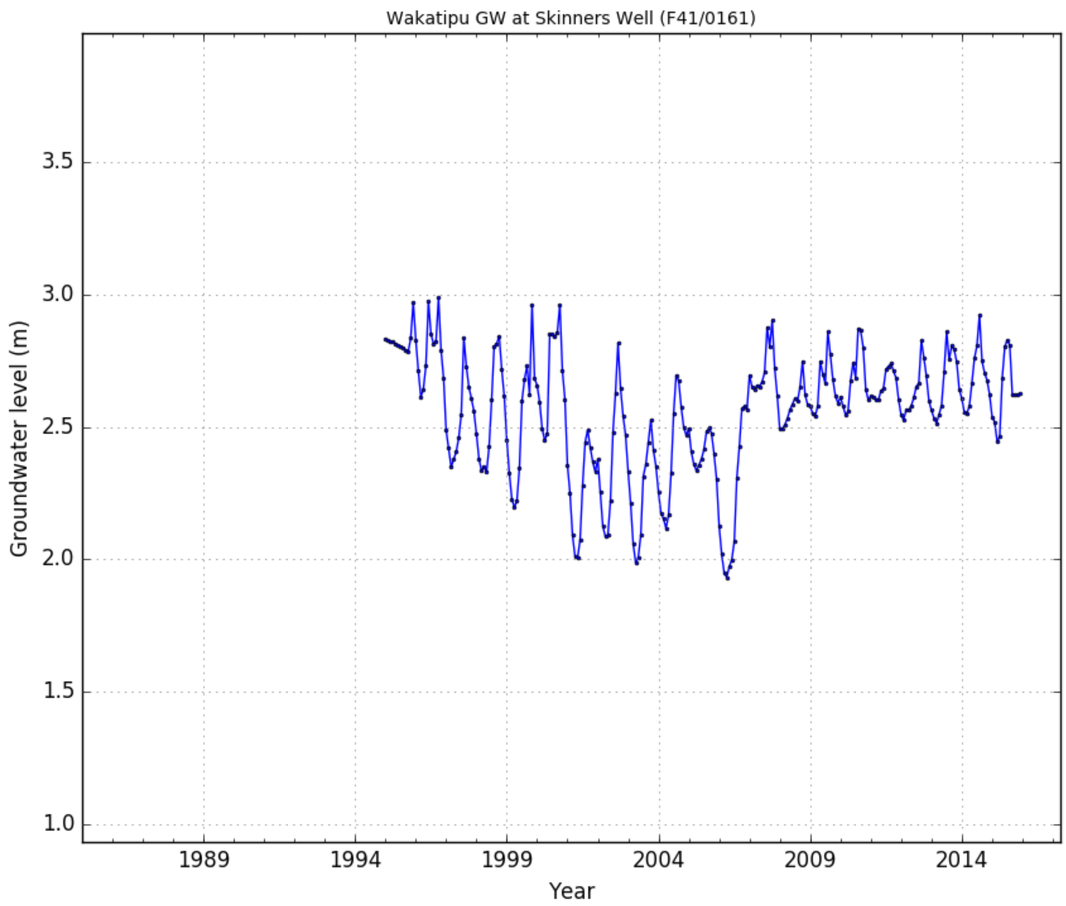
Otago Regional Council. (2014). Investigation into the Wakatipu Basin Aquifers. Dunedin: Otago Regional Council.

Rekker, J. (2014). Investigation into the Wakatipu Basin Aquifers. Dunedin: Otago Regional Council.

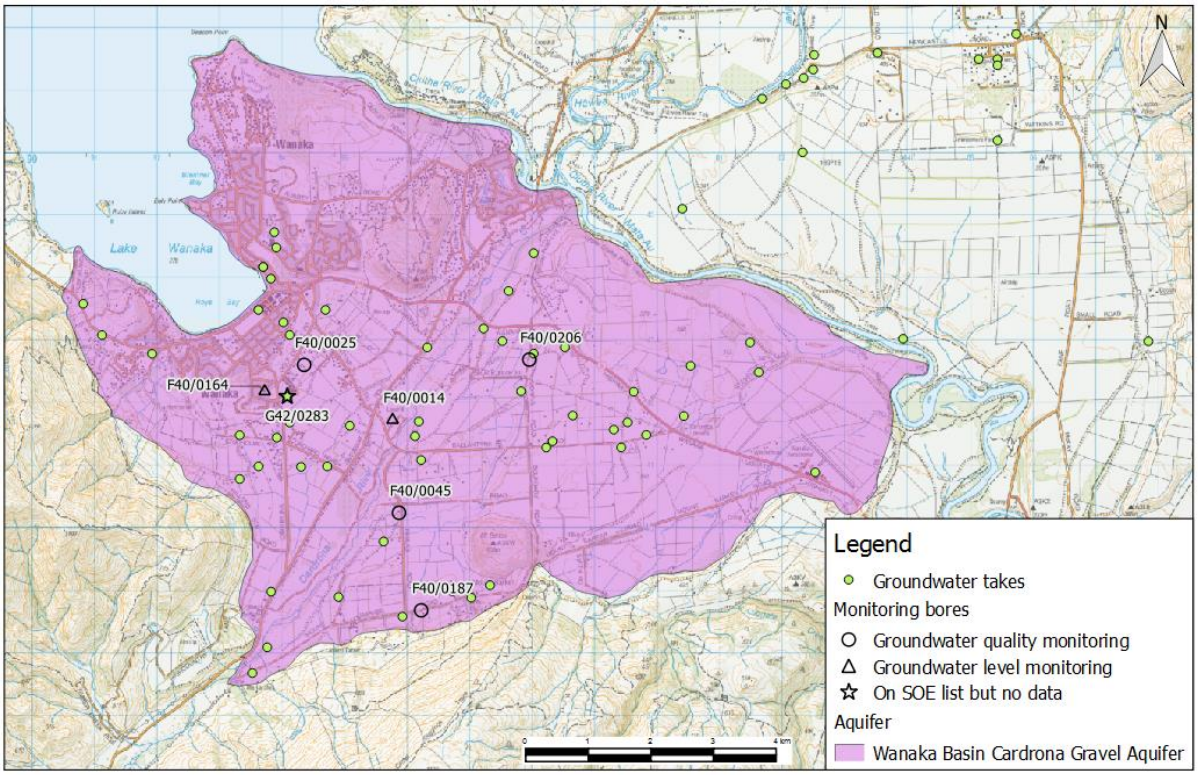

Wakatipu GW at Domain Road (F41/0437)
354.0
353.5
353.0
352.5
352.0
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year


Wakatipu GW at Lake Hayes Reserve (F41/0438)
329.5
329.0
328.5
328.0
327.5
Groundwater level (m)
1989
1994
1999
2004
2009
2014
Year


Wakatipu GW at Morven Ferry (F41/0203)
Groundwater level (m)
361.0
360.5
360.0
359.5
359.0
358.5
358.0
1989
1994
1999
2004
2009
2014
Year


Wakatipu GW at Skinners Well (F41/0161)
Groundwater level (m)
3.5
3.0
2.5
2.0
1.5
1.0
1989
1994
1999
2004
2009
2014
Year

Wanaka Basin - Cardrona Gravel Aquifer:



The Wanaka Basin and Cardona Gravel Aquifer covers a sedimentary basin consisting of gravel dominated strata downstream of the Larches flow recorder on the Cardrona River. The aquifer is bounded the Clutha River to the north-east and Lake Wanaka to the north-west. Lower permeability basement strata form the boundary to the basin to the south-east. The gravels have been reworked and various depositional phases have occurred as a result of glacial retreats and advances, as well as deposition by the Clutha River and the result gravels are, in detail relatively complex. However at a broader scale they behave as a relatively consistent unit. Two outliers of basement strata also occur within the basin.

Groundwater in the aquifer is dominantly recharged by seepage losses from the Cardrona River where it enters the basin, together with additional land surface recharge. Groundwater discharges from the aquifer into Lake Wanaka, the downstream reach of the Cardrona River and into the Clutha River. The detailed flow direction is therefore relatively complex, but generally groundwater flows in a northerly direction from the low permeability bounding hills towards the aquifer discharge points in the north. Groundwater depths vary, and around the Larches flow recorder where the Cardrona River enters the basin groundwater levels can be 20 to 30 m deep. However, towards the aquifer discharge points, around the Clutha and Lake Wanaka, groundwater levels are shallow and close to the surface.

Groundwater in the basin is used for a variety of purposes, including irrigation and domestic supply. Note that Wanaka township is supplied with water from Lake Wanaka. Groundwater across the aquifer is well connected to surface water bodies.

Information available

Groundwater level monitoring: *There are two groundwater level monitoring bores within the aquifer.*

1. *A detailed record of historical groundwater measurements is available for bore F40/0164 (unknown depth) between November 1995 and September 2000.*
2. *Groundwater levels in bore F40/0014 (unknown depth) are available between May 2001 February 2017.*

Groundwater quality information: *There are four groundwater quality monitoring bores within the Wanaka Basin Cardrona Gravel Aquifer.*

1. *Quarterly sampling has been undertaken between September 2010 and December 2016 in bores F40/0025 (40 m deep), F40/0045 (60 m deep) and F40/0206 (45 m deep). All bores were sampled for a wide range of parameters.*
2. *Additionally, there are two groundwater quality samples (September 2010 and March 2011) for F40/0187 (27.65 m deep) covering a basic range of parameters.*

Stream/aquifer interaction: *The Cardrona River is the primary source of recharge to the aquifer. However, input volumes are currently under development.*

Recharge volume: *Recharge volumes are currently under consideration and will take into account flow input from the Cardrona River.*

Discharge locations: *Groundwater discharges both to the north-west of the basin, discharging to springs around Wanaka Township, and also likely discharges to the Clutha River to the north-east. There are 55 consented groundwater takes within the basin primarily used for irrigation, domestic and community water supply.*

Allocation status: *The allocation status of the aquifer is currently under development and will be in conjunction with a minimum flow regime for the Cardrona River. A maximum allocation limit of 5 Mm^3/year has been proposed(Otago Regional Council).*

Typical landuse: *Landuse in the area consists of agricultural, lifestyle properties and residential areas.*

Aquifer parameters: *There are 12 bores within the Wanaka Basin Cardrona Gravel Aquifer with reported transmissivity values ranging from 25 to 6,246 m^2/day.*

Groundwater movement

Groundwater flows from the Cardrona River in the south-west and diverges towards both Lake Wanaka and the Clutha River.

Information required

The groundwater level monitoring available is considered to meet the minimum requirements,, however, some additional groundwater level monitoring around the downgradient reach of the Cardrona River (downstream of SH6) would be beneficial, because that may provide a better indicator of groundwater abstraction effects on the sensitive reach of the river that the proposed limit intends to protect.

Groundwater quality monitoring appears to be appropriate to meet the objectives and covers a reasonable spatial area of the aquifer. However some of the bores are relatively deep (e.g. bore F40/0206, 45m deep) and may not represent groundwater quality that discharges into the Cardrona River.

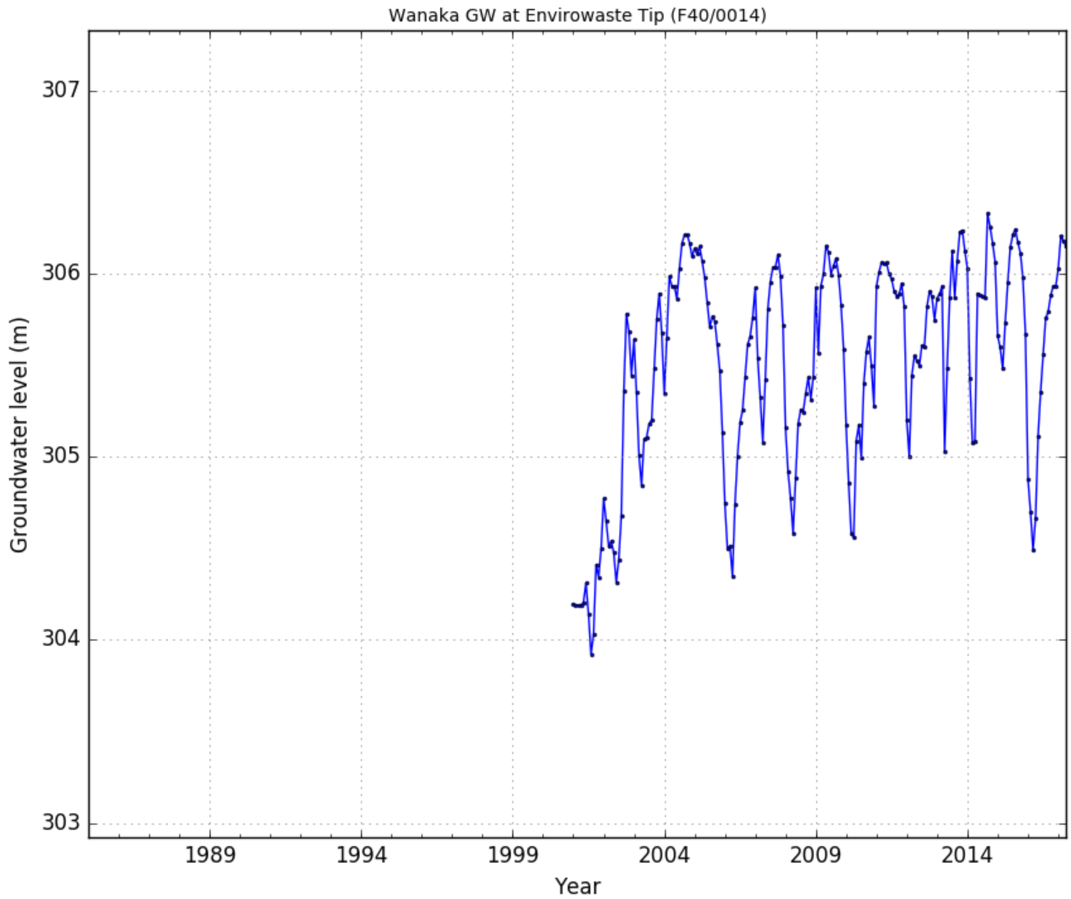
Summary

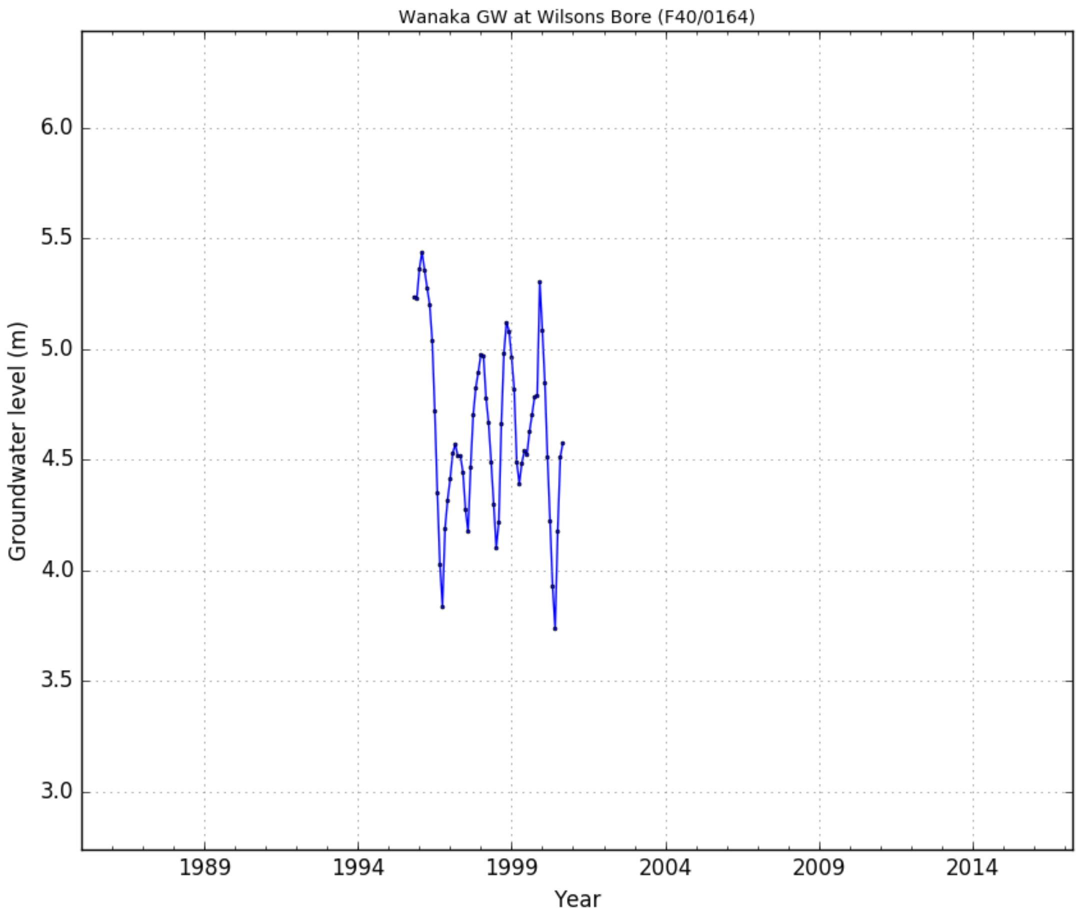
Groundwater movement is relatively well understood in this aquifer. Groundwater allocation statistics for this aquifer are currently under development in conjunction with a minimum flow regime for the Cardrona River.

Reference list

Dale, M., & Rekker, J. (2011). Integrated Water Resource Management for the Cardrona River. Dunedin: Otago Regional Council.

Otago Regional Council. (n.d.). Groundwater Update and Resource Management Options - ORC presentation.


Wanaka GW at Envirowaste Tip (F40/0014)
Groundwater level (m)
307
306
305
304
303
1989
1994
1999
2004
2009
2014
Year


Wanaka GW at Wilsons Bore (F40/0164)
Groundwater level (m)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
1989
1994
1999
2004
2009
2014
Year

Appendix A

Excerpt from “Otago Alluvial Fans: High Hazard Fan Investigation”, Otago Regional Council, June 2011

12. Reservoir Creek, Roxburgh

Located on the eastern flanks of the Old Man Range, the Reservoir Creek catchment (Figure 12.1) is a geologically old landscape, as discussed in Section 1.2. The catchment ranges in elevation from 1023m at its crest to around 140m at the head of the alluvial fan. Reservoir Creek has built an alluvial fan onto old river terraces previously deposited by the Clutha River. The fan has been modified extensively by urban development and is bisected by SH 8 across the mid-fan.

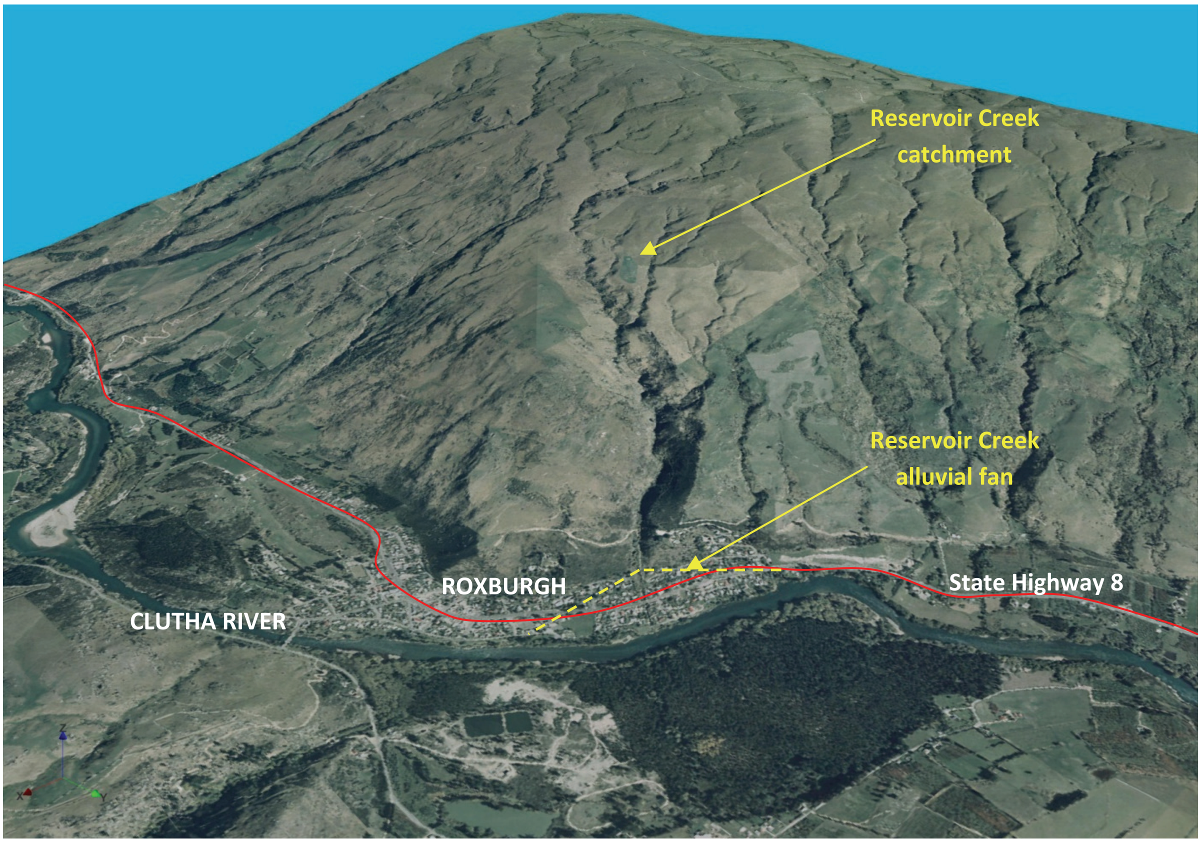


Figure 12.1 Image showing the Reservoir Creek alluvial fan with respect to the surrounding environment

12.1 Catchment characteristics

The Reservoir Creek catchment is approximately 10.4km^2 in size (Figure 12.2) and is steep. The upper catchment is dominated by small bushes and alpine tussocks, with no large areas of forest present.

Catchment observations, undertaken by ORC in March 2011, found that Reservoir Creek is well incised into basement schist, having been subject to progressive erosion and valley uplift in the past. Catchment slopes are mantled by large-scale mass-movement features overlain by highly weathered colluvial deposits that are being actively eroded by the creek (Figure 12.3-P1). The bed of the creek is comprised of unconsolidated debris deposits sourced from the adjacent slopes, and deposited during debris-flow events (Figure 12.3). Following the recession of debris-flow events, the channel has incised into these deposits. For much of its length, the catchment channel is well defined and confined between the adjacent slopes. These conditions are favourable for the efficient transfer of debris and flood flows down to the alluvial-fan surface.

Active slope instability in the catchment is generally the direct result of over-saturation during storm events. Slides and rock falls are common occurrences during high-intensity events, as observed in October 1978 (Figure 12.4).

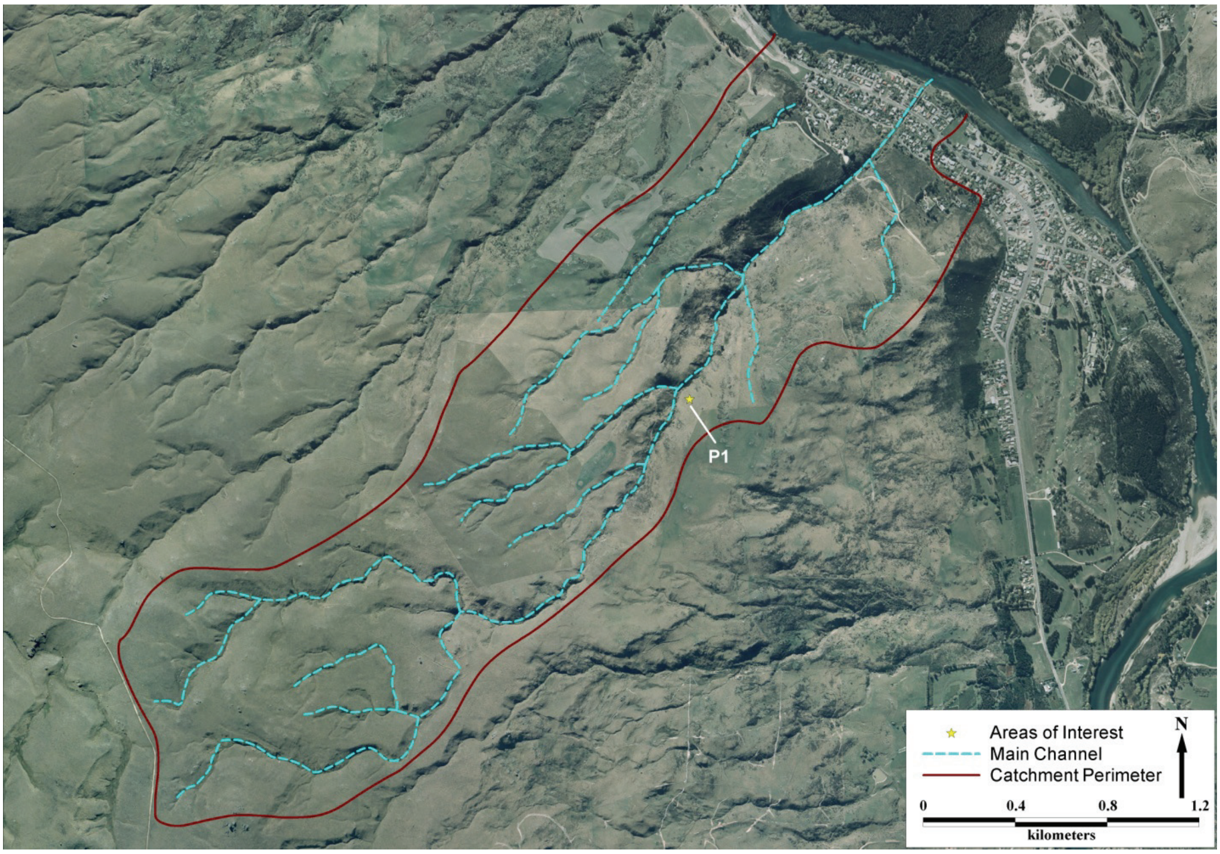


Figure 12.2 The Reservoir Creek catchment and surrounding environment; aerial photo dated March 2006

Figure 12.3 The Reservoir Creek catchment. Left: Incision into the base of the adjacent slopes contributes sediment and debris to the channel. Centre: Lower catchment on 17 October 1978, looking downstream; fresh debris deposits are evident along the length of the channel. Right: The same stretch of lower catchment as centre image, taken in March 2011, looking upstream. Debris deposits are now vegetated in this reach and have been subsequently incised by the active channel.

Figure 12.4 Left: Upper catchment debris slide almost impounding the Reservoir Creek channel, 17 October 1978. Right: Channel incision and erosion directly supply debris to the channel, 17 October 1978.

12.2 Fan characteristics

Reservoir Creek has formed a semicircular alluvial fan onto old river terraces, previously deposited by the Clutha River (Figure 12.5). At the toe of the alluvial fan, the Clutha River actively removes sediment and debris. Near the topographic apex of the fan, the channel flows in a U-shaped scoured valley, indicating historic-debris flows have passed through this location. As the channel leaves the confines of the valley, it has been extensively modified by excavation and the construction of concrete-lined channels on the fan surface (Figure 12.6). The intention of this structure is to enable the efficient transfer of debris flows down the fan surface to the Clutha River to prevent flows from spreading into residential areas.

Channel contouring and the construction of the concrete-lined channel were undertaken by the Otago Catchment Board (OCB) in 1980 and 1981 (Figure 12.6). In 1983, a storm event in the Reservoir Creek catchment caused damage to the lined channel, and further improvements were undertaken by the OCB in 1984. Upstream of the concrete-lined channel, large willows and dense vegetation has grown in the channel, following the 1984 works (Figure 12.6).

12.3 Reservoir Creek alluvial-fan hazard

The Reservoir Creek alluvial fan has been subject to recurrent debris-flow events in the past (Figure 12.7). In October 1978, debris flows overwhelmed the channel and impacted residential properties on the fan surface above and below the state highway. In response, authorities excavated the channel and constructed a concrete-lined channel to convey debris flows efficiently to the lower fan. This structure was in place by the early 1980s (Figure 12.6).

The alluvial-fan hazards associated with Reservoir Creek generally consist of high-velocity-debris and debris-flood flows, channel avulsion, bank erosion and floodwater ‘sheet-flow’ inundation. Upper parts of the fan are subject to high-velocity debris flow where the channel is currently confined and steep. As the fan and channel gradients change downstream, debris-flood deposits are more common (Figure 12.7), with considerable channel aggradation occurring during and in the immediate recession of the debris-flow event.

Depending on the nature and characteristics of each storm event, any part of the hazard area may be impacted by debris or debris-flood flows or floodwater inundation in the future. It is likely that the fans upper slopes will be impacted by debris flow, as these processes have occurred here in the past, forming the underlying landforms. On the fan’s lower margins, it is more likely that debris-flood or floodwater sheet-flows will occur; however, debris flows may impact these areas during high-magnitude events. Catchment conditions indicate that a large volume of unconsolidated debris is stored in the active channel margin that may be transported to the fan surface in future events.

It is noted that alluvial fans to the north of the Reservoir Creek catchment, located on the northern fringe of the Roxburgh urban area, including the Quail Haven subdivision, have not been assessed as part of this investigation. These catchments are smaller than Reservoir Creek, but still have the potential to create debris and debris-flood flows and floodwater inundation on the alluvial-fan surfaces. The hazard area defined in Figure 12.5 resembles the active alluvial fan areas mapped by Barrell *et al*. (2009).

Figure 12.5 Reservoir Creek alluvial fan noting key features; aerial photo dated March 2006

Figure 12.6 Reservoir Creek concrete-lined channel, upstream of SH 8 in March 1983 (top left), and in March 2011 (top right), looking upstream. Bottom left: Reservoir Creek channel upstream of concrete-lined channel. Bottom right: Reservoir Creek concrete-lined channel below SH 8

Figure 12.7 Top: Reservoir Creek at SH 8 after the October 1978 storm event, compared to March 2011. Large volumes of debris blocked the state highway in 1978 and impacted residential property. Bottom: Reservoir Creek, looking upstream (left) and downstream (right) of SH 8 in October 1978. Large volumes of debris are evident in both images.

Glossary

Relevant definitions extracted from Barrell D.J.A..; Cox, S.C.; Greene, S.; Townsend, D.B. 2009: Otago Alluvial Fans Project: Supplementary maps and information on fans in selected areas of Otago. *GNS Science Consultancy Report* 2009/052. Prepared for Otago Regional Council. 19 pages, 3 tables and 3 appendices.

Aggradation	The accumulation, or build-up, of sediment on a surface, leading to a rise in the ground level.
Alluvial	Of, or pertaining to, rivers or streams. ‘Fluvial’ is another word that means the same thing.
Avulsion or break-out	Break-out is the switching of a stream channel to a new course. Breakout may involve re-occupation of a previously abandoned channel, or the formation of a new channel. Channel break-out or switching is also known as avulsion.
Catchment	The area from which a surface or subsurface water system derives its water.
Debris	Loose unconsolidated material, can include silt, sand gravel, boulders, and vegetation.
Debris flood	A debris flood is a very rapid (up to ~5 m/s), surging flow of water, heavily charged with sediment. Debris floods are more fluid than debris flows. Debris floods and debris flows may occur during the same flood.
Debris flow	A flow comprising a slurry of water and debris. Debris flows typically form within steep, narrow stream channels during high-intensity rainstorms, and travel downstream rapidly (e.g. between 15 and 30 km/h). A small to medium-size landslide into a flooded stream may commonly result in a debris flow. A debris flow is generally classified as a type of landslide. Debris flows are highly charged with sediment and have a consistency like wet concrete. Debris flows can pick up and carry all manner of material, including trees and huge boulders. Because of their high velocity, high density and ability to carry large volumes of material, debris flows are the most dangerous and destructive process associated with fans.
Erosion	The wearing away of land surface materials, especially rocks, sediments, and soils, by the action of water, wind, or a glacier. Usually erosion also involves the transport of eroded material from one place to another.
Fan	A gently to steeply sloping landform, shaped like an open fan or a segment of a cone, associated with river or stream deposits. An alluvial fan is constructed from deposits laid down by flowing water. A debris-flow fan is a special type of alluvial fan, where the deposits have been laid down by debris-flow events. Fans form where a valley, channel or gully meets an area that is unconfined, or less confined. A typical location is where mountain or hill terrain meets a valley floor. In technical terms, a fan is formed where the sediment transport capacity of a stream decreases because of factors such as increase in channel width, or reduction in channel gradient.
Hyperconcentrated flow – From: https://en.wikipedia.org/wiki/Hyperconcentrated_flow	A hyperconcentrated flow is a two-phase flowing mixture of water and sediment in a channel which has properties intermediate between fluvial flow and debris flow.
Landform	A recognizable feature of the Earth's surface. Landforms have characteristic shapes and may include large features such as plains, plateaus, mountains, and valleys, as well as smaller features such as terraces, alluvial fans and gullies.
Precipitation	Any form of water, such as rain, snow, sleet, or hail, which falls to the Earth's surface.
Sediment	Fragmented material, typically derived from rock or soil, that is transported and deposited by water, ice, or wind, or which is derived from biologic sources (e.g. peat or guano). Fragmental sediment is commonly classified according to the size of fragments (grain-size, or ‘texture’); gravel grains are larger than 2 mm, sand grains are between 2 mm and 0.06 mm, silt grains

	are between 0.06 and 0.004 mm, and clay is finer than 0.004 mm. “Mud” consists mostly of silt, but also commonly includes some sand or clay. Sedimentary rocks consist of consolidated sediment (e.g. sandstone).
Sedimentation	The deposition of sediment.

DAMWATCH
ENGINEERING BEYOND THE SURFACE

22 December 2017

Jean-Luc Payan
Manager Natural Hazards
Otago Regional Council
Private Bag 1954
Dunedin 9054

Dear Jean-Luc

Roxburgh – Preliminary Assessment of Flood and Erosion Hazards in Clutha River

Introduction

The area around Roxburgh Township experienced an intense thunderstorm on 26 November 2017. Local watercourses draining the steep hillsides mobilised substantial volumes of sediment as debris flows and deposited this material into the Clutha River[1]. The sediment lobes which have formed locally constrict the river flow and, in one case, have caused the formation of a new set of rapids.

In response to this sediment deposition into the Clutha River, the Otago Regional Council (ORC) requested that a preliminary assessment of flood and bank erosion hazards arising from the sediment lobes be undertaken. This letter report presents the results of the preliminary assessment.

The assessment involved a site visit and computational hydraulic modelling of river flows past the sediment deposition sites to estimate changes in backwater profiles for floods of different magnitudes and increases in flood flow velocities. The computational hydraulic modelling calculations utilised the results of a bathymetric survey of the sediment deposits[2].

Site Inspection

The sediment deposition into the Clutha River was inspected by Grant Webby on 13 December 2017. The most significant deposition areas on Reservoir Creek at the north end of Roxburgh Township and on the fan of Black Jacks Creek, 3 km south of the town, were inspected. Other affected areas on unnamed creeks north of the town and near the golf course at the south end of the town were also viewed but these were much less significant.

Figure 1 shows an aerial photo of the sediment deposition at the confluence of Reservoir Creek with the Clutha River taken the day after the rainstorm event which caused it. This is the site where a new set of rapids have formed. Figures 2 and 3 show a view of these rapids taken at separate times on 13 September (about 1130 hours and 1400 hours respectively). The flow dropped 90 m^3/s from about 490 m^3/s to 400 m^3/s between these times which enabled the extent of the underwater sediment lobe to become much more visible (see Figure 3). The average size of the deposited sediment material was estimated to be in the order of 200-400 mm.

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[1] Otago Regional Council File Note "2017-11-27 – Roxburgh Debris Flow Inspection". Document ID A1069263, dated 28 November 2017.
[2] Geomatics NZ Ltd (2017). "Report of Survey of the Clutha River and points Below – 2017". Dated 13 December 2017.

Figure 1 – Sediment deposition at confluence of Reservoir Creek with Clutha River (photo provided by Otago Regional Council, taken 28 November 2017) – flow right to left

Figure 2 – Rapids formed by sediment deposit at confluence of Reservoir Creek with Clutha River (photo taken about 1130 hours NZST on 13 December 2017 - river flow ≈ 490 m^3/s) – flow left to right

Figure 3 – Rapids formed by sediment deposit at confluence of Reservoir Creek with Clutha River (photo taken about 1400 hours NZST on 13 December 2017 - river flow ≈ 400 m^3/s) – flow left to right

Figure 4 shows an aerial photo of the sediment deposition at the confluence of Black Jacks Creek with the Clutha River taken the day after the initiating rainstorm event (28 November 2017). The wake induced by the underwater sediment lobe projecting out into the river is clearly marked by the edge of the downstream sediment plume hugging the right bank of the river. The line of the wake remains visible in the photo taken during the site inspection on 13 December 2017 (Figure 5) after the sediment blockage at the creek outlet had been removed. The sediment size along the water's edge is quite fine and contrasts with the much coarser cobble material heaped up on either side of the creek where it meets the Clutha River. The coarse nature of the deposited sediment material is evident from the aerial photo in Figure 4.

Figure 6 shows an aerial photo of the sediment deposition at the confluence of an unnamed creek with the Clutha River at the north end of Roxburgh Township taken the day after the initiating rainstorm event (28 November 2017). The minor sediment plume being emitted from the underwater sediment indicates that, unlike the Reservoir Creek and Black Jacks Creek sediment deposits, it does not project out very far into the Clutha River. In fact it projects less distance than the left bank delta seen in the bottom of the photo. Figure 7 provides another perspective of the degree of projection into the main river channel of both sediment features. This view looking upstream from the right bank just downstream of both features confirms that the amount of projection into the river is very small.

The presence of sediment deltas at the confluence of tributary streams and rivers is a common geomorphic feature. Figure 8 shows a further view looking upstream from the Roxburgh Bridge over the Clutha River where the Teviot River enters the main river. The delta at the confluence of the Teviot River with the Clutha River is located in the middle of the photo and is marked by the area of willow trees extending away from the river along the true left bank (the right bank in the photo). Deltas such as this one are exposed to a continuous cycle of sediment deposition, from tributary flood events, and sediment erosion by flood events in the main river.

Figure 4 – Sediment deposition at confluence of Black Jacks Creek with Clutha River (photo provided by Otago Regional Council, taken 28 November 2017) – flow right to left

Figure 5 – Wake formed by sediment deposition in Clutha River from Black Jacks Creek (photo taken about 1220 hours NZST on 13 December 2017 - river flow ≈ 490 m^3/s) – flow left to right

Figure 6 - Sediment deposition at confluence of unnamed creek with Clutha River at north end of Roxburgh (photo provided by Otago Regional Council, taken 28 November 2017 – flow right to left

Figure 7 – View looking upstream towards sediment deposition at confluence of unnamed creek with Clutha River at north end of Roxburgh (photo taken about 1330 hours NZST on 13 December 2017 - river flow ≈ 400 m^3/s)

Figure 8 – View looking upstream from Roxburgh Bridge towards confluence of Teviot River with Clutha River on left bank (in right of photo)

Effect of 26 November 2017 Rainstorm Event on Clutha River Flows

From an inspection of Clutha River flow records on the ORC website, the 26 November 2017 rainstorm event did not appear to have any appreciable effect of flows in the Clutha River.

Reference River Flows

For the purposes of this assessment, several reference river flows were used as set out in Table 1.

Table 1 – Reference river flows used for assessment purposes

Flow (m^3/s)	Description	Comments
450	Low flow	Measured water level profile available
620	Moderate flow	Flow at time of bathymetric survey on 8 Dec 2017
1,280	Fresh with return period of ≈ 1.8 years*	Measured water level profile available
2,200	Flood with return period of ≈ 10 years*	
3,350	Approximate magnitude of Dec 1995 flood	Measured water level profile available
3,600	Approximate magnitude of Nov 1999 flood	

* Frequency analysis data provided by Magdy Mohssen from ORC's Hydrological Monitoring Team

River Cross-Sections

ORC maintain a network of river cross-sections along the Clutha River for geomorphologic monitoring purposes. Many of these cross-sections utilise the same locations as cross-sections from an old Ministry of Works and Development (MWD) network[3].

Figure 9 shows the location of Clutha River cross-sections downstream of Roxburgh Dam which cover the area of interest for this preliminary assessment.

Table 2 summarises the distances of selected river cross-sections downstream of Roxburgh Dam which were used to develop a MIKE11 computational hydraulic model of the Clutha River as discussed in the next section.

Table 2 – Distances downstream of Roxburgh Dam for selected Clutha River cross-sections used to set up MIKE11 computational hydraulic model

MWD Cross-sec Reference	ORC Cross-sec Reference	Distance d/s of Roxburgh Dam (m)	Location
BM533	C43	4900	
BM534		6180	
BM535	C42	7880	Tweed St, Roxburgh
BM536	C41	9090	At old Roxburgh Bridge
BM537	C40	9910	
	C39	10450	At shingle beach at end of Grovers Hill Rd
BM538	C38	11160	
BM539	C37	13050	
BM540		15220	Dumbarton Rock
BM541	C36	17830	End of Frames Lane, Ettrick

3 Opus (2010). "Lower Clutha River Investigations River Cross-sections – Ministry of Works and Development Benchmark Finder Diagrams, LINZ Benchmark Finder Diagrams". Report prepared by Opus International Consultants for Otago Regional Council, Ref. 350492.00.

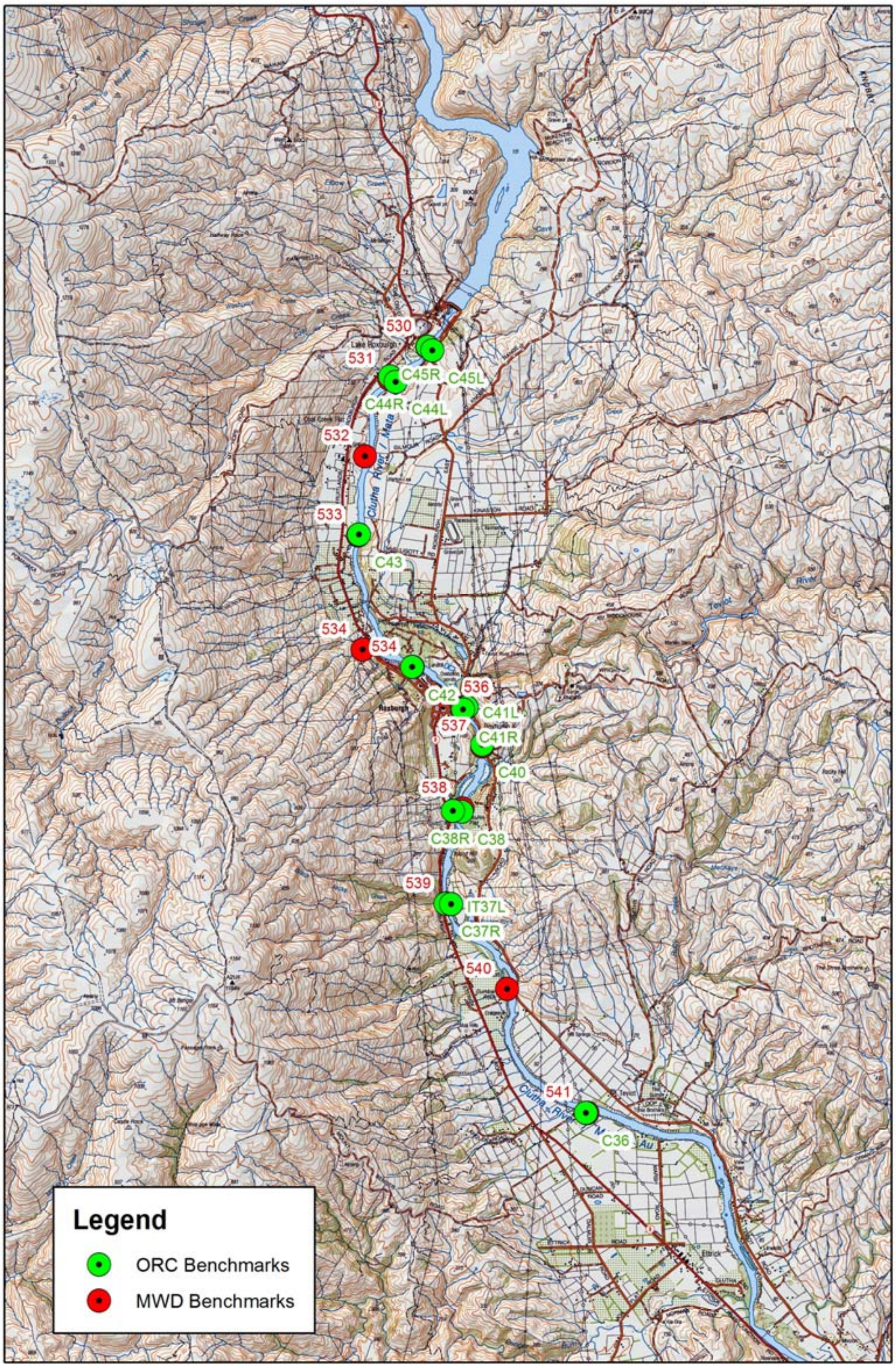

Figure 9 – Location of Clutha River cross-sections downstream of Roxburgh Dam covering the area of interest for this preliminary assessment

Results of Bathymetric Survey

A bathymetric survey of the main sediment deposition areas (Geomatics Ltd, 2017 – see footnote 2 on page 1) was commissioned by the Otago Regional Council to provide input to this preliminary assessment. This was carried out on 8 December 2017.

Appendix A includes topographic plans produced from the bathymetric survey data for each of the main sediment deposition areas in the Clutha River, with an aerial photo background. These topographic plans cover:

(a) The area around Reservoir Creek (see the commentary in the paragraphs below on this area);
(b) The sediment deposition area for the unnamed creek passing through the golf course at the south end of town; and
(c) The sediment deposition area for Black Jacks Creek, 3 km to the south of the town.

Unfortunately the current in the river past the Reservoir Creek sediment deposition area was too strong for the survey boat to be able to survey the modified river bathymetry at that location. However, upstream and downstream river cross-sections were surveyed along with a longitudinal water surface profile past the sediment deposition area when the river flow was about 620 m^3/s.

Figure 10 shows the surveyed long-section water surface profile along the centreline of the river past the Reservoir Creek sediment deposition area. This shows a head drop of about 0.5 m with the most severely constricted section of the river located about 140 m downstream of the ORC reference location C42 (refer Figure 9). Cross-section C42 was last surveyed in December 2015 and comparison of the surveyed cross-section from this survey with the newly surveyed cross-section showed no change (this is not surprising as cross-section C42 is 70 m upstream of the confluence of Reservoir Creek with the Clutha River).

Figure 11 shows a long-section water surface profile along the centreline of the river past the area where the unnamed creek through the Roxburgh Golf Course enters the Clutha River close to ORC reference location C38 (refer Figure 9). The water surface profile shows no discernible head drop which suggests that any sediment deposition from the creek at this location would have been very minor. Observations suggest that most of the sediment transported by the creek in the 26 November 2017 rainstorm event was trapped by the culvert under State Highway 8 and the pine tree plantation between the SH8 culvert and the Clutha River.

Figure 12 shows a long-section water surface profile along the centreline of the river past the confluence of Black Jacks Creek with the Clutha River. The water surface profile shows a head drop of about 0.3 m past the sediment deposition. The cross-section at ORC reference location C37 is located right at the confluence (refer Figure 9). Figure 13 compares the December 2015 and December 2017 cross-sections at location C37. The underwater sediment lobe from the 26 November 2017 rainstorm event projects a lateral distance of about 10-12 m out beyond the original river cross-section and substantially constricts the main river flow. The front face of the lobe has a slope of about 3.25: 1 (horizontal to vertical).

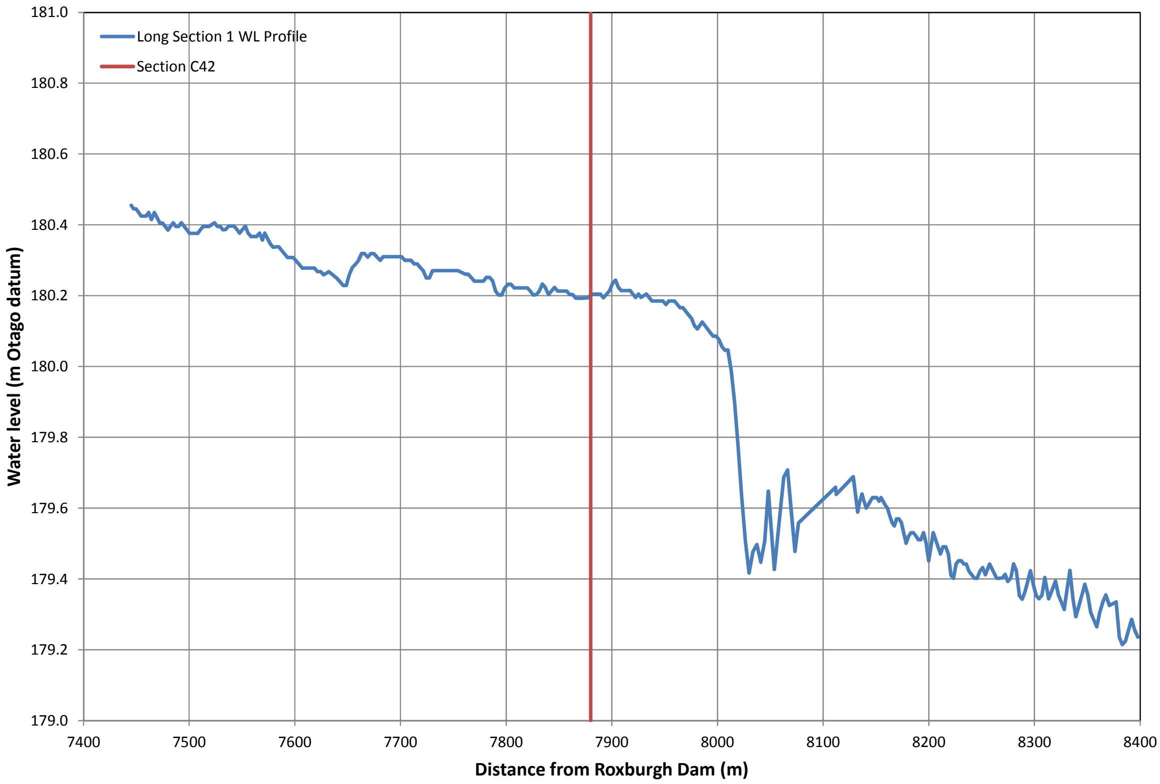

Figure 10 – Long-section water surface profile past sediment deposition area at confluence of Reservoir Creek with Clutha River (river flow ≈ 620 m^3/s)

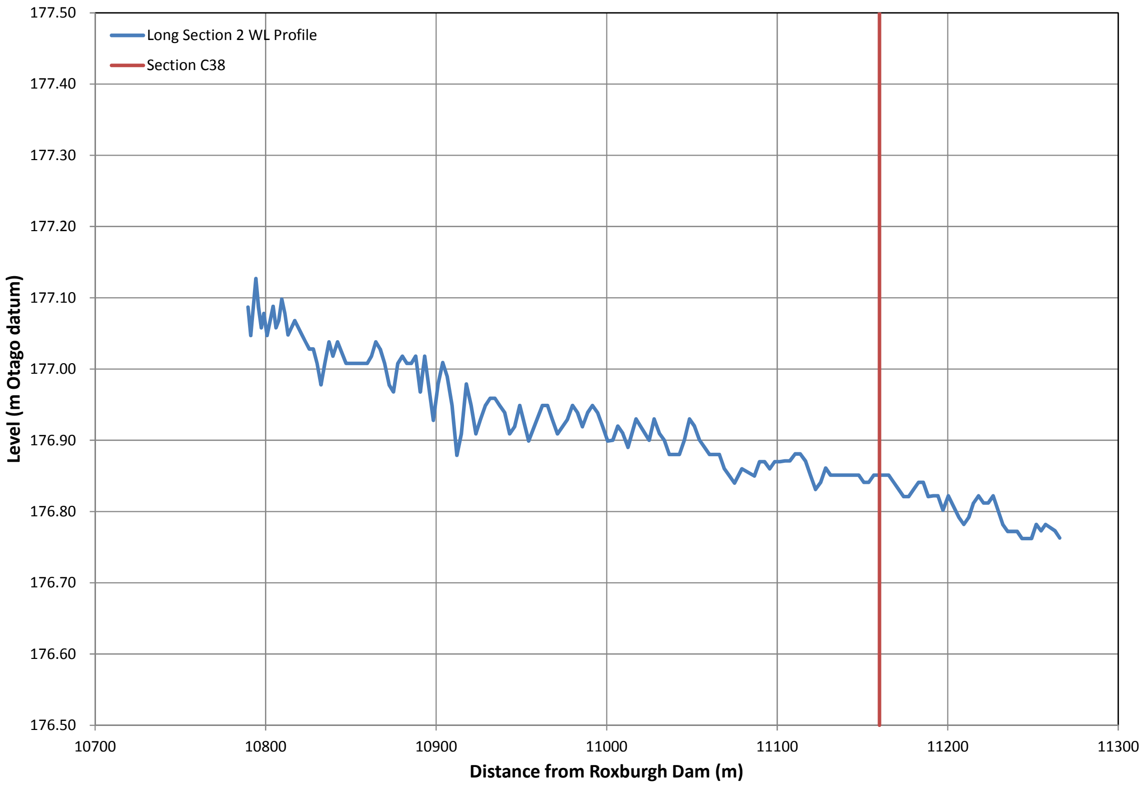

Figure 11 - Long-section water surface profile past sediment deposition area at confluence of unnamed creek through golf course with Clutha River (river flow ≈ 620 m^3/s)

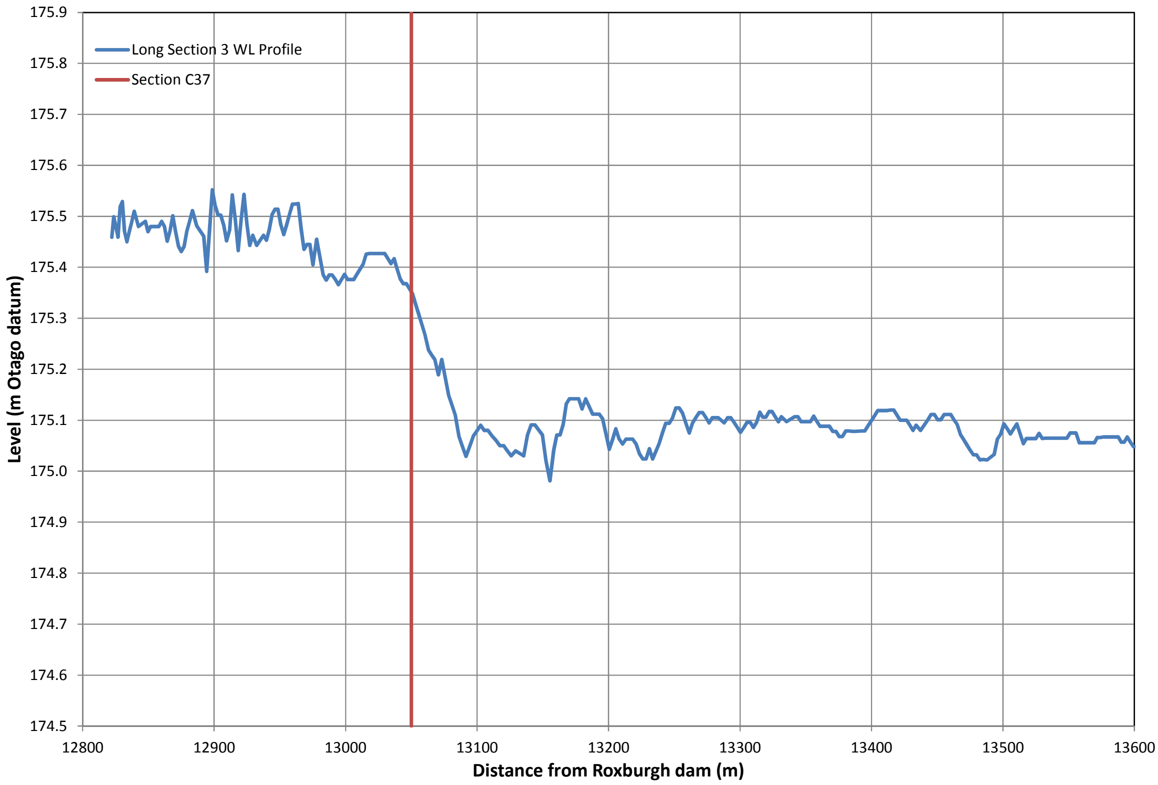

Figure 12 - Long-section water surface profile past sediment deposition area at confluence of Black Jacks Creek with Clutha River (river flow ≈ 620 m³/s)

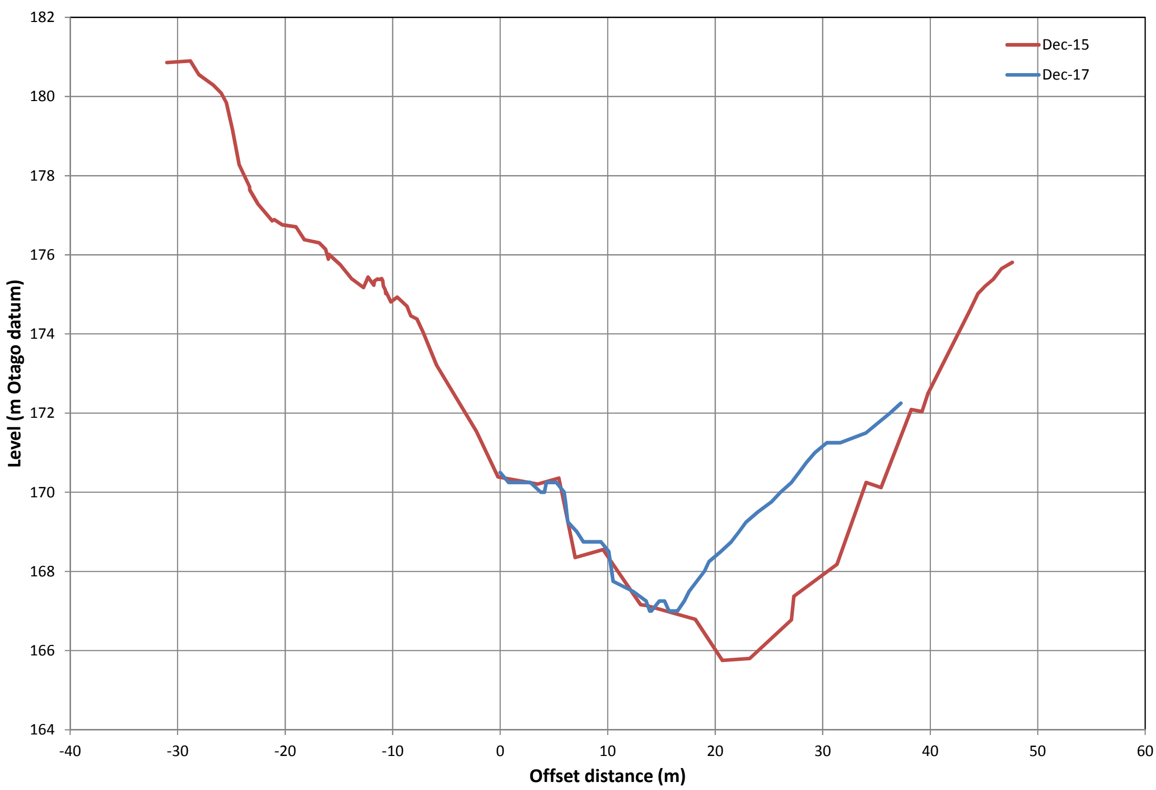

Figure 13 Comparison of surveyed cross-sections at ORC reference location C37 (Black Jacks Creek)

Computational Hydraulic Modelling Investigations

The December 2015 surveyed river cross-sections for locations C36 to C43 were used to set up a simple MIKE11 computational hydraulic model of the Clutha River covering this reach. Unfortunately the original cross-sections for MWD locations BM534 and BM540 were not able to be located so cross-sections from locations C43 and C36 respectively were copied (with their zero datum adjusted for the riverbed slope) to fill this information gap.

A water level / discharge rating curve was derived from a mix of historic measured water level data and predicted water levels for the flows in Table 1 for ORC cross-section C36. This was applied as a downstream boundary condition for the MIKE11 model.

The MIKE11 model for the river channel prior to 26 November 2017 was recalibrated against the historic measured water level data for flows of 450, 1,280 and 3,350 m^3/s (Table 1). The model was used to establish water level / discharge downstream boundary conditions for localised HEC-RAS models of the Clutha River past the Reservoir Creek and Black Jacks Creek sediment deposition areas.

The US Army Corps of Engineers HEC-RAS software was used in preference to the MIKE11 software for these localised models as it was found to better reproduce the effects of a narrow channel constriction. The effect of the channel constricting sediment lobes on Clutha River flows of 400-600 m^3/s is quite marked as can be seen from the photos in Figures 1, 2 and 3 for the Reservoir Creek sediment deposition area and in Figures 4 and 5 for the Black Jacks Creek sediment deposition area.

From trial runs with the localised HEC-RAS model of the Clutha River past the Black Jacks Creek sediment deposition area, it was found to be necessary to exaggerate the geometric extent of the sediment lobe in the model to satisfactorily reproduce the observed head loss past the lobe at a river flow of 620 m^3/s (see Figure 12). This is not surprising given the extent of the wake seen in the photo in Figure 4 and observed during the site visit. The extent of the wake indicates that the effective conveyance width of the river channel past the sediment lobe is smaller than indicated by the actual geometric extent of the lobe determined from the bathymetric survey, probably due to the shallowness of the flow out from the waters edge.

In the case of the Reservoir Creek sediment deposition area, the cross-section at the most constricted section of the Clutha River was inferred from the measured water level profile data to be located at about distance 8020 m on Figure 10. The absence of any bathymetric data for the sediment deposition area meant that the profile of the sediment lobe had to be crudely estimated for the HEC-RAS model so that the predicted water surface profile for a river flow of 620 m^3/s approximately matched the measured water surface profile from the date of the bathymetric survey.

The localised HEC-RAS models of the Clutha River past the Reservoir Creek and Black Jacks Creek sediment deposition areas were 'calibrated' to reproduce the observed head drop at each site at a river flow of 620 m^3/s (see Figures 10 and 12).

Computational Hydraulic Modelling Results for Blacks Jacks Creek Sediment Deposition Area in Clutha River

Figure 14 shows the predicted and measured water level profiles past the Black Jacks Creek sediment deposition area for a Clutha River flow of 620 m^3/s.

Figure 15 shows the predicted water level profiles past the Black Jacks Creek sediment deposition area for Clutha River flows of 450, 620, 1280, 2200, 3350 and 3600 m^3/s.

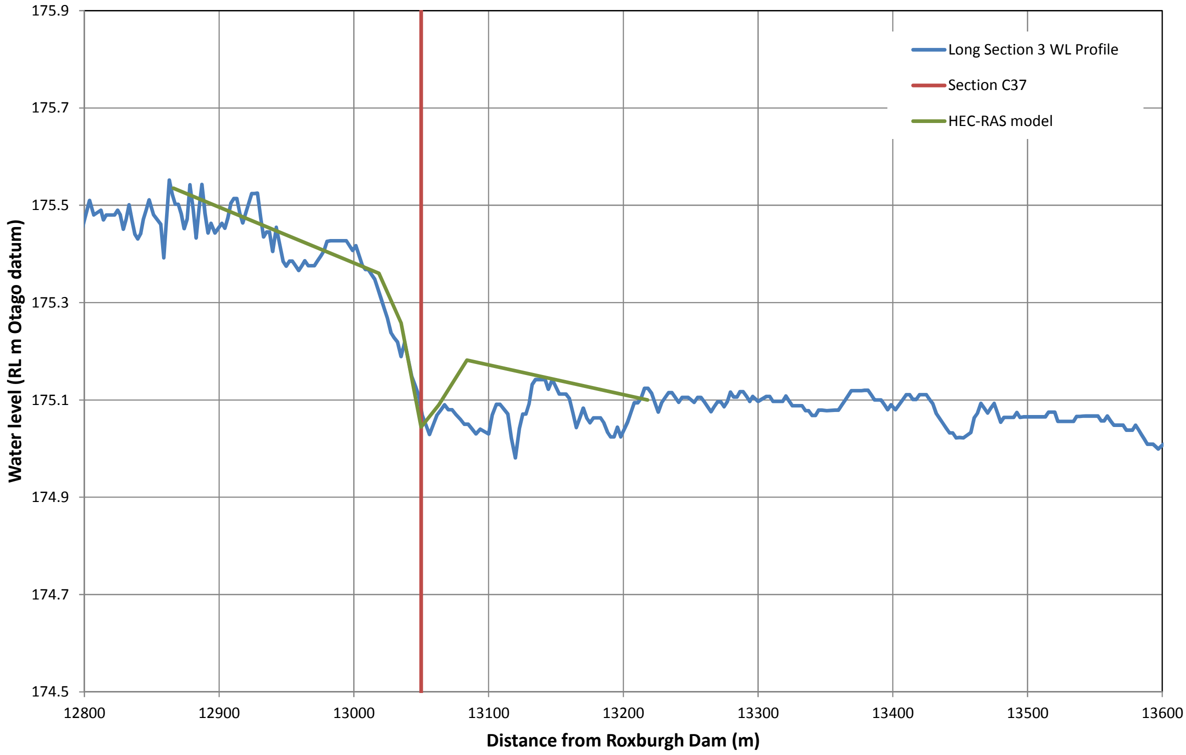

Figure 14 – Predicted and measured water level profiles past the Black Jacks Creek sediment deposition area for a Clutha River flow of 620 m^3/s

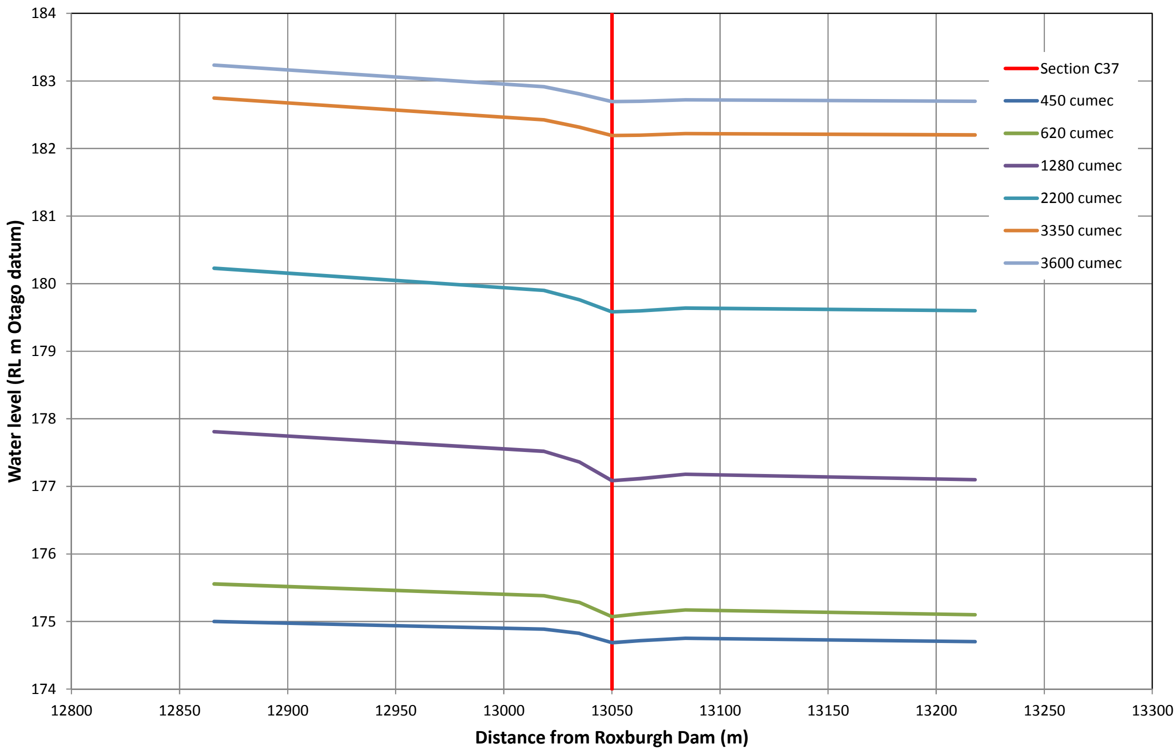

Figure 15 – Predicted water level profiles past the Black Jacks Creek sediment deposition area for Clutha River flows of 450, 620, 1280, 2200, 3350 and 3600 m^3/s

Table 3 summarises the HEC-RAS model-predicted upstream and downstream water levels past the Black Jacks Creek sediment deposition area, and the head drop across the sediment lobe.

Table 3 – Predicted upstream and downstream water levels and head drop across Black Jacks Creek sediment deposition area in Clutha River

Clutha River Flow (m^3/s)	Upstream Water Level (RL m Otago datum)	Downstream Water Level (RL m Otago datum)	Head Drop (m)
3600	182.91	182.70	0.21
3350	182.42	182.20	0.22
2200	179.90	179.60	0.30
1280	177.52	177.10	0.42
620	175.38	175.10	0.28
450	174.89	174.70	0.19

The head drop past the Black Jacks Creek sediment deposition area reaches a maximum value of 0.42 m at a flow of 1280 m^3/s. It gradually reduces as the river flow increases further. The head drop has a value of about 0.2 m at a flow of the magnitude of the November 1999 flood (3600 m^3/s).

Due to the steepness of the water surface slope in the Clutha River, the effects of the slightly elevated flood levels upstream of the sediment deposition area due to this head drop will rapidly dissipate within a few hundred metres upstream.

This analysis assumes that the profile of the sediment deposition area is fixed. However, due to the nature of the deposit, the sediment material will gradually be eroded away over a long period of time with continual flood activity. These head drop values will therefore diminish over time.

Figure 16 shows predicted flow velocities at the maximum constricted channel cross-section past the Black Jacks Creek sediment deposition area compared to flow velocities at the downstream model boundary where the channel is unrestricted. Not surprisingly, average flow velocities at the maximum channel constriction are exacerbated compared to those at the unrestricted downstream channel cross-section. However, they reach a maximum value of about 3.6 m/s which is not excessive for a hydraulically steep river. The increased flow velocities at the maximum constricted channel cross-section will contribute to the erosion over time of the sediment material forming the channel constriction.

The other trend to note from Figure 16 is that the difference between the average flow velocities at the two channel cross-sections reduces as the river flow increases above 1280 m^3/s.

The Black Jacks Creek sediment deposition area is located more than 5 km downstream of the Reservoir Creek sediment deposition area. This distance is much too great and river slope too steep for the backwater effect from the Black Jacks Creek sediment deposition area to affect water levels at the Reservoir Creek sediment deposition area.

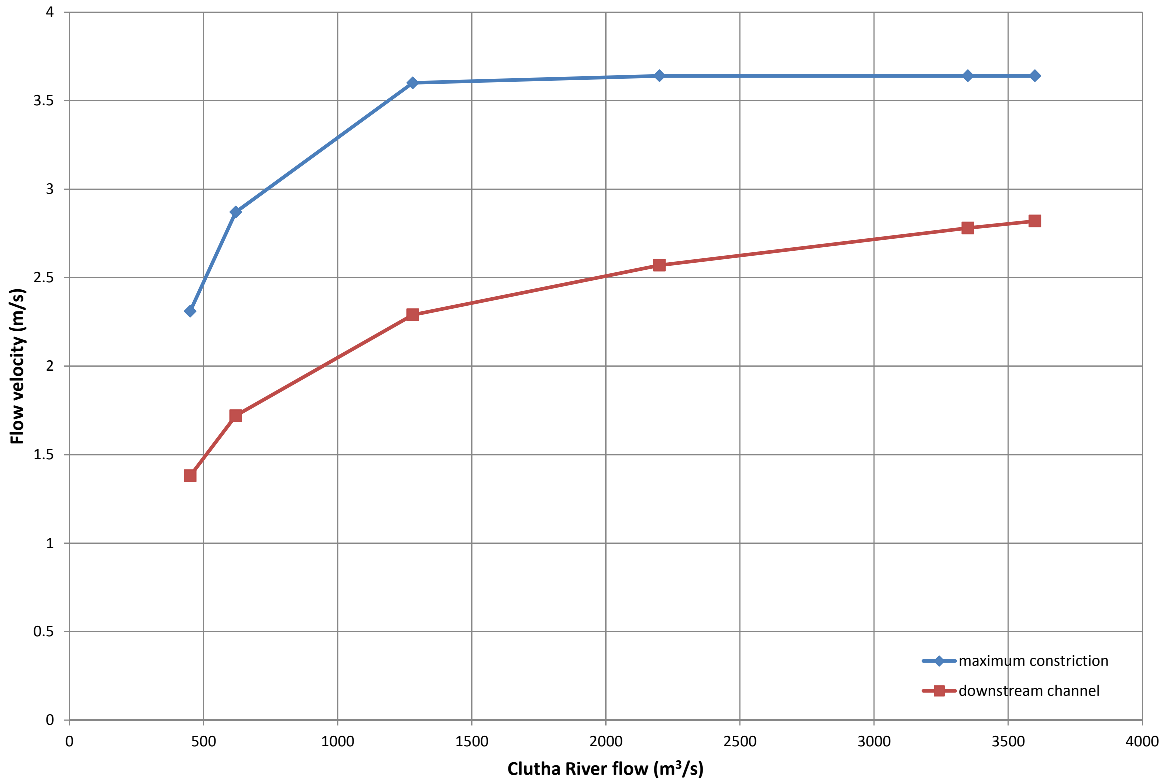

Figure 16 – Predicted flow velocities at maximum channel constriction past Black Jacks Creek sediment deposition area for various flows in Clutha River

Computational Hydraulic Modelling Results for Reservoir Creek Sediment Deposition Area in Clutha River

Figure 17 shows the predicted and measured water level profiles past the Reservoir Creek sediment deposition area for a Clutha River flow of 620 m^3/s.

Figure 18 shows the predicted water level profiles past the Reservoir Creek sediment deposition area for Clutha River flows of 450, 620, 1280, 2200, 3350 and 3600 m^3/s.

Table 4 summarises the HEC-RAS model-predicted upstream and downstream water levels past the Reservoir Creek sediment deposition area, and the head drop across the sediment lobe.

Table 4 – Predicted upstream and downstream water levels and head drop across Reservoir Creek sediment deposition area in Clutha River

Clutha River Flow (m^3/s)	Upstream Water Level (RL m Otago datum)	Downstream Water Level (RL m Otago datum)	Head Drop (m)
3600	188.36	187.93	0.43
3350	187.80	187.34	0.46
2200	184.88	184.27	0.61
1280	182.39	181.74	0.65
620	180.35	179.81	0.54
450	179.74	179.29	0.45

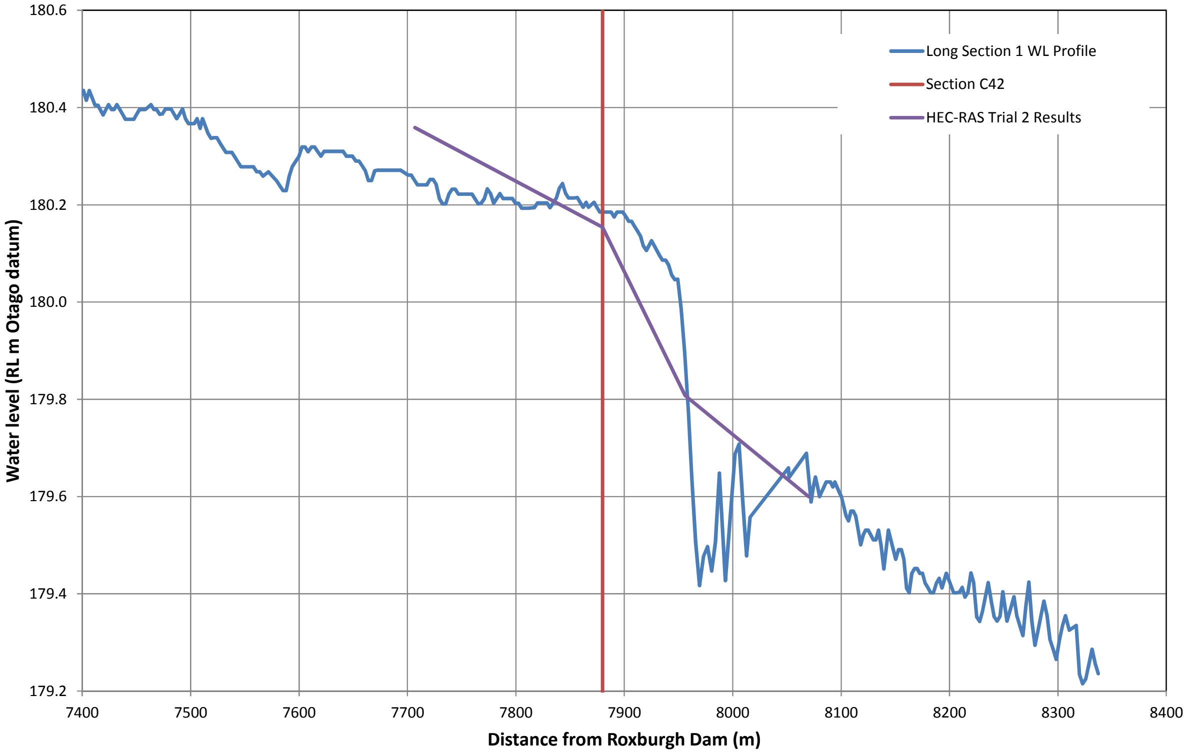

Figure 17 - Predicted and measured water level profiles past the Reservoir Creek sediment deposition area for a Clutha River flow of 620 m^3/s

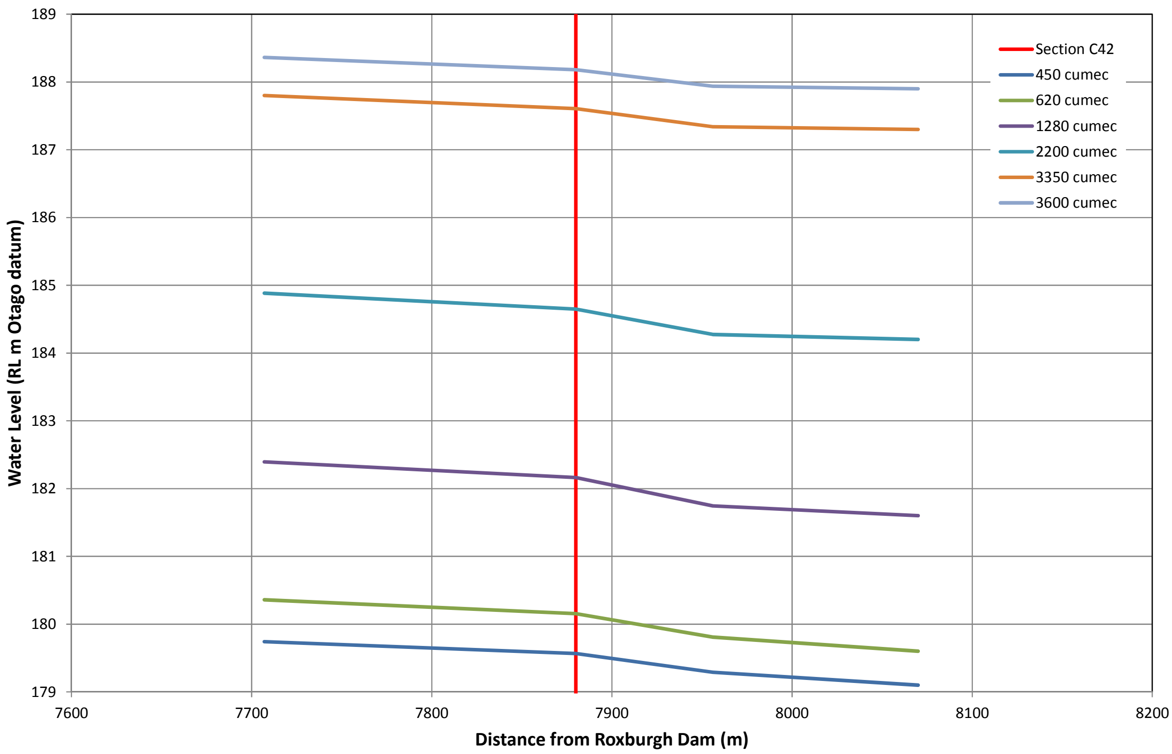

Figure 18 – Predicted water level profiles past the Reservoir Creek sediment deposition area for Clutha River flows of 450, 620, 1280, 2200, 3350 and 3600 m^3/

From Table 4, the head drop past the Reservoir Creek sediment deposition area shows a similar trend to the head drop past the Black Jacks Creek sediment deposition area. The head drop reaches a maximum value of 0.65 m at a flow of 1280 m^3/s. It gradually reduces as the river flow increases further. The head drop has a value of about 0.4 m at a flow of the magnitude of the November 1999 flood (3600 m^3/s).

As with the Black Jacks Creek sediment deposition area, the steepness of the water surface slope in the Clutha River means that the effects of the slightly elevated flood levels upstream of the Reservoir Creek sediment deposition area caused by the head drop will rapidly dissipate within several hundred metres upstream. However, water levels at flows in excess of about 3350 m^3/s (the magnitude of the December 1995 flood) will be starting to overtop the right bank of the Clutha River where houses are located at the bottom of Tweed Street (see Figure 1).

Figure 19 shows predicted flow velocities at the maximum (inferred) constricted channel cross-section past the Reservoir Creek sediment deposition area compared to flow velocities at the downstream model boundary where the channel is unrestricted.

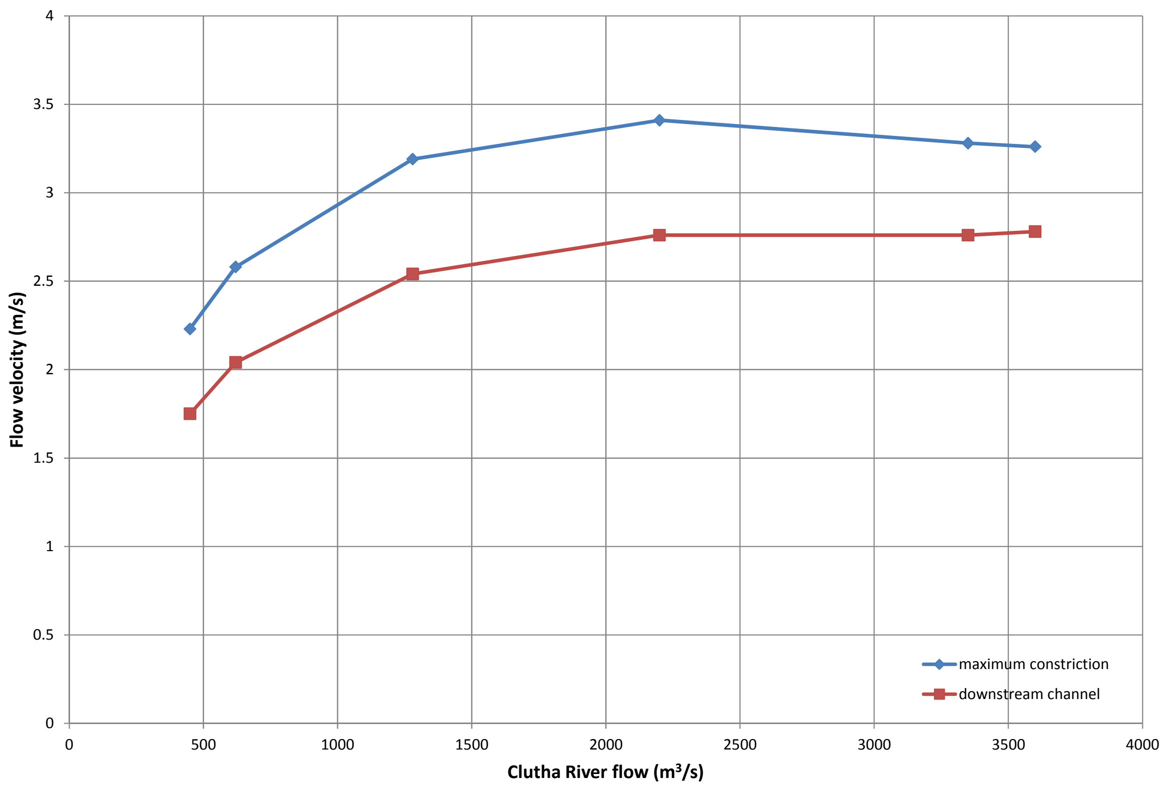

Figure 19 – Predicted flow velocities at maximum channel constriction past Reservoir Creek sediment deposition area for various flows in Clutha River

Again the average flow velocities at the maximum constricted channel cross-section are increased compared to those at the unrestricted downstream channel cross-section. They reach a maximum value of about 3.4 m/s (which is not excessive for a hydraulically steep river) and remain roughly constant for river flows above 2200 m^3/s. The flow velocities at the maximum constricted channel cross-section will contribute to the erosion of the sediment material forming the channel constriction over time.

The gradual erosion of the channel constriction will also lead to a gradual reduction in the head drop along the sediment deposition area over time.

Assessment

The flood hazard in the Clutha River past the two most significant sediment deposition areas in the Clutha River at Reservoir Creek and Blacks Jacks Creek confluences has increased slightly. The sediment deposits at these two locations cause slightly elevated flood levels although the amount of flood level elevation relative to that for the pre 26 November 2017 river channel reduces as the river flow increases above 1280 m^3/s. The extent of these elevated flood levels will diminish within several hundred metres upstream of each sediment deposition area due to the steep slope of the Clutha River channel.

Flood levels upstream of the Reservoir Creek sediment deposition area will start to overtop the right bank at the bottom end of Tweed Street in Roxburgh Township at river flows above 3350 m^3/s (the magnitude of the December 1995 flood with an Annual Exceedance Probability of about 1 in 75 years). There are a number houses located along the section of Tweed Street which runs parallel with the Clutha River. These are the only houses which are exposed to a slightly increased flood hazard. The extent of the slightly increased flood hazard has not been able to be determined with the available information.

No buildings are located within the area likely to be affected by the slightly increased flood levels caused by the Blacks Jacks Creek sediment deposition area.

The sediment deposition areas in the Clutha River at Reservoir Creek and Blacks Jacks Creek confluences also cause increased flood flow velocities past the most constricted channel cross-section. These increased flow velocities will slightly increase the erosion hazard along the opposite left bank of the river. However, the increased flood flow velocities are not excessive and tend to approach an upper limit of 3.4-3.6 m/s. The river banks are protected by willow trees at both locations.

The sediment deposits appear to be comprised of a mix of sediment sizes from coarse gravel material up to large boulders in the order of 500 mm in diameter. The material has been deposited on a lateral slope relative to the direction of river flow. Over time flood flows will gradually erode the smaller gravel material and cobbles (aided by the material lying on a lateral slope). While the flood flow velocities may be insufficient to transport the largest boulders, they will be undermined by the erosion of smaller sized material around them and will then tend to roll down the slope to the bottom of the river channel.

The gradual erosion of the sediment deposits by flood flows over time will cause the slightly increased flood and bank erosion hazards to slowly trend back to the pre 26 November 2017 levels.

Conclusions

1. The sediment lobes deposited in the Clutha River by Reservoir Creek and Black Jacks Creek due to the 26 November 2017 rainstorm event are the only ones that have significantly affected the water level profile along the river at these locations. At a river flow of 620 m^3/s, the head drop past these two lobes is about 0.5 m and 0.3 m respectively.

2. The water surface profile past the confluence of the unnamed creek (which passes through the Roxburgh Golf Course) and the Clutha River shows no head drop at a river flow of 620 m^3/s. It can be inferred from this observation that minimal sediment deposition has occurred in the Clutha River sourced from this unnamed creek due to the 26 November rainstorm.

3. Other minor sediment lobes deposited in the Clutha River upstream of Reservoir Creek do not visually appear to project out very far into the main river, and in fact project less than the

sediment deltas of other tributary creeks that were not affected to the same extent by the 26 November 2017 rainstorm event.

4. The two most significant sediment deposition areas in the Clutha River at the Reservoir Creek and Blacks Jacks Creek confluences has caused the existing flood hazard to be increased slightly due to slightly elevated flood levels. The amount of the increased flood levels reduces above a flood flow of 1280 m^3/s. The extent of these elevated flood levels will rapidly diminish within several hundred metres upstream of each sediment deposition area due to the steep slope of the Clutha River.

5. Flood levels upstream of the Reservoir Creek sediment deposition area will start to overtop the right bank at the bottom end of Tweed Street in Roxburgh Township at river flows above about 3350 m^3/s. There are a number houses located along the section of Tweed Street which runs parallel with the Clutha River which will be exposed to a slightly increased flood hazard at such flows.

6. The sediment deposition areas in the Clutha River at the Reservoir Creek and Blacks Jacks Creek confluences has also caused the existing bank erosion hazard along the opposite left bank to be increased slightly due to increased flow velocities. However, the increased flood flow velocities are not excessive and tend to approach an upper limit of 3.4-3.6 m/s. The river banks are protected by willow trees at both locations.

7. The lateral slope of the sediment deposits will enhance erosion of the sediment material by flood flows. While the largest boulders may not be moved by flood flows, erosion of sediment material around them will tend to undermine them and cause them to roll down the slope and deposit on the river bed.

8. The gradual erosion of the sediment deposits by flood flows over time will cause the slightly increased flood and bank erosion hazards to slowly trend back to the pre 26 November 2017 levels.

Recommendations

1. The lack of any bathymetric data covering the primary sediment deposition area at Reservoir Creek has hindered this preliminary assessment. It is recommended that bathymetric data for this area is obtained to confirm the inferences from this assessment about the extent and effects of the sediment deposition.

2. It is further recommended that the use of ADCP equipment (normally utilised for river flow gauging purposes) in conjunction with a GPS tracker be explored as a suitable means of acquiring bathymetric data along a small number of fixed transects across the river past the Reservoir Creek sediment deposition area.

3. These bathymetric transects would be useful for monitoring the gradual attrition of the Reservoir Creek sediment deposition area due to erosion by continual flood events. They should be resurveyed at 5 year intervals, or after any significant flood event exceeding about 1800 m^3/s (which corresponds to about a 1 in 5 Annual Exceedance Probability flood).

Yours sincerely,

Grant Webby
Principal Hydraulic Engineer

Appendix A – Bathymetric maps of sediment deposition areas in Clutha River at Reservoir Creek, Black Jacks Creek and an unnamed creek through Roxburgh Golf Course

Notes Keys and References

Rev	Drawn	Comments	Appr'd	Date

Title
Otago Regional Council
Clutha River – Bathymetric Survey at confluence with Reservoir Creek

Scale 1:2000
Project E1836
Drawing Number
Revision

Graphic Scales
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Original Sheet Size A3 (420x297)

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Damwatch Engineering, Wellington Club Building Level 3, 88 The Terrace, PO Box 1549, Wellington 6140, New Zealand
E info@damwatch.co.nz
P +64 4 381 1300
F +64 4 3811301

Notes Keys and References

Rev	Drawn	Comments	Appr'd	Date

Title
Otago Regional Council
Clutha River – Bathymetric Survey of confluence with unnamed creek

Scale 1:2000
Project E1836
Drawing Number
Revision

Graphic Scales
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Original Sheet Size A3 (420x297)

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E info@damwatch.co.nz
P +64 4 381 1300
F +64 4 3811301

Notes Keys and References

Rev	Drawn	Comments	Appr'd	Date

Title
Otago Regional Council
Clutha River – Bathymetric Survey of confluence with Black Jacks Creek

Scale 1:2000
Project E1836
Drawing Number
Revision

Technical Committee - 31 January 2018 Attachments

Graphic Scales 1:2000 0 10 20 30 40 50 60 70 80 90 100 m

Original Sheet Size A3 (420x297)

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