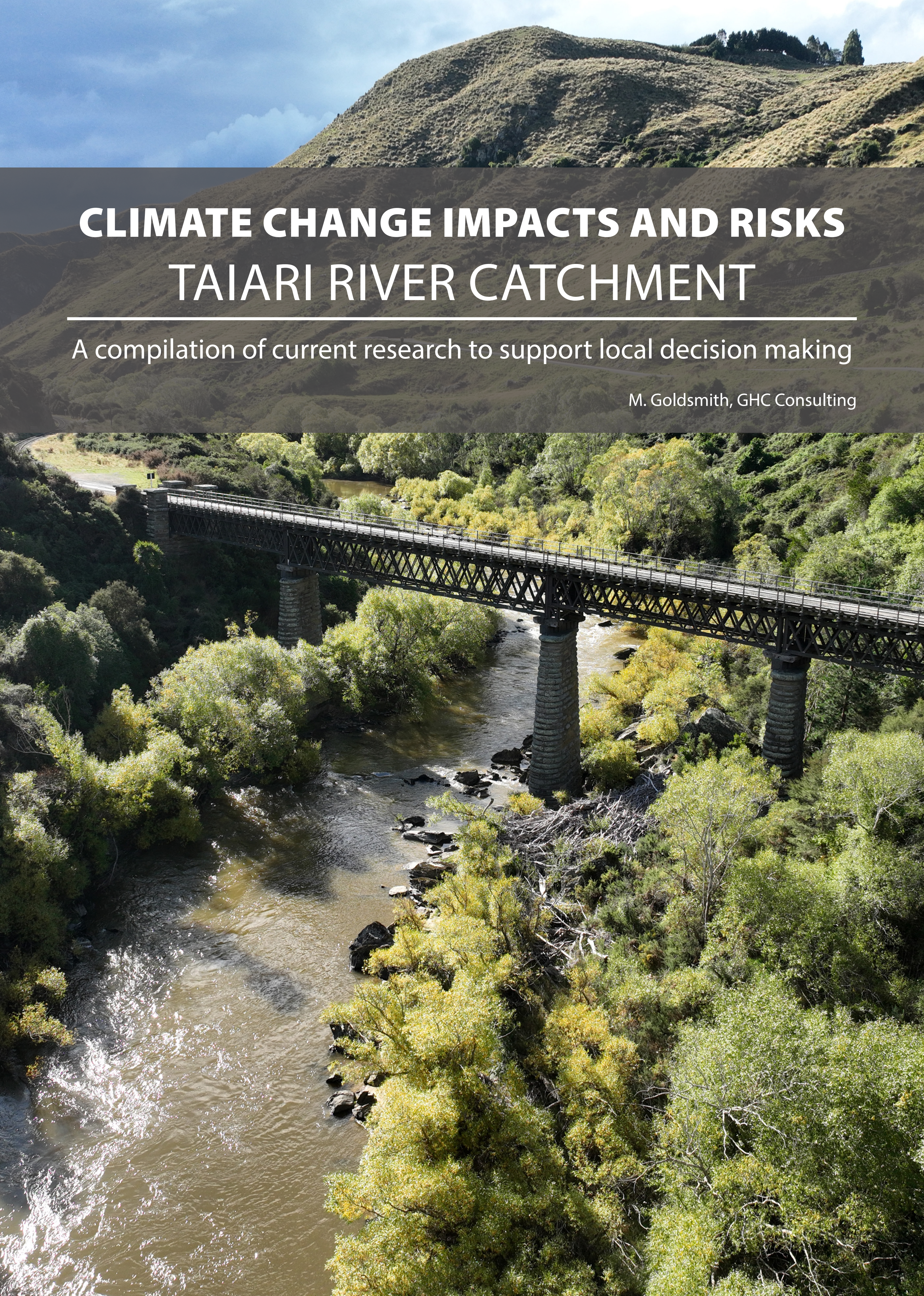
CLIMATE CHANGE IMPACTS AND RISKS
TAIARI RIVER CATCHMENT

A compilation of current research to support local decision making

M. Goldsmith, GHC Consulting



Climate change impacts and risks for the Taiari River catchment – a compilation of current research to support local decision-making.

M. J. Goldsmith

GHC Consulting Report
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EXECUTIVE SUMMARY

The Taiari River is the second-largest river in Otago and flows for more than 280 km from the eastern Otago uplands, in an almost circular path, from its source to the sea. The awa (river), as well as the wider catchment is predicted to face a range of new challenges and opportunities in a future of changing climate.

Drawing on the best available data,[4] the first part of this report summarises the impacts associated with climate change for the Taiari. Although the report looks at potential impacts across the whole catchment, its focus is primarily on the waterways which contribute to the well-being of our ecosystems and communities. The second part discusses risks associated with these changes – particularly for freshwater and wetland ecosystems [22]. The final section of this report provides a selected list of practical options for managing the risks associated with climate change. These have been included as a starting point, to prompt discussion and inform future work.

Climate change impacts:

We have sourced historic rainfall and temperature records, and future climate and hydrological projections produced by the National Institute of Water and Atmospheric Research (NIWA), to describe the local impacts of climate change. Overall, the catchment will become warmer and wetter in the future, although there will be significant local and seasonal variations within these trends. For example:

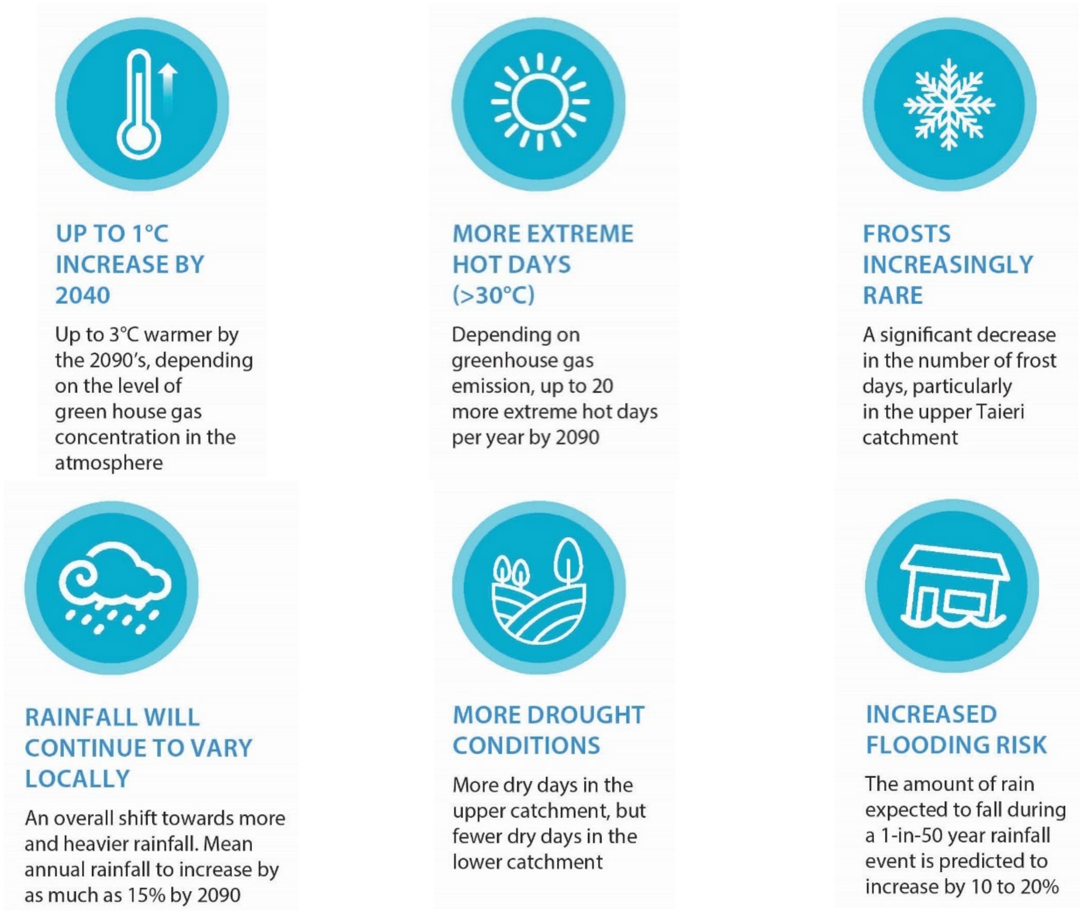
- *Basin areas in the upper catchment may experience an extra 20 extremely hot days (>30°C) by 2090 with most of these occurring in the summer. Other parts of the catchment may only experience an additional one or two such days.*
- *Droughts may become more severe around Ranfurly, Naseby, Waipiata and Paerau with more days with no rain predicted. Closer to the coast, fewer dry days are expected.*

View towards the Strath Taiari from the Old Dunstan Road (Source: GHC)

Although the average flow in the Taiari River and its tributaries will generally remain about the same, the upper and lower limits (floods and droughts) will become more pronounced. In particular:

- *Streams in the mid and upper catchment already experience periods of very low flow, and these conditions are predicted to become even more pronounced by the end of the century.*
- *When it does rain, storm events are predicted to deliver more and heavier rainfall, which in turn is likely to produce larger floods in streams across the whole catchment, as well as the main stem of the Taiari River itself.*

The key changes in climate predicted across the Taiari catchment are illustrated below.



Climate change risks:

This report also describes the risks associated with changes in climate. Key findings are that:

- By the end of the century, freshwater ecosystems in many lakes & rivers will have suffered significant losses, with extreme weather events (floods) having a major impact, for example:
    - Removal of fish and invertebrates from waterways due to extreme flood flows.
    - Riverbank erosion resulting in the loss of spawning habitats for native fish and invertebrates.
- The risk rating for alpine, inland and coastal wetlands will increase over this century, with high to extreme ratings by 2090. Changes in climate will result in different types of risk for different types of wetland environments. For example, reduced snow and ice will result in higher risks for alpine wetlands, while coastal wetlands will be more impacted by sea level rise and coastal flooding.
- River water quality and quantity is likely to deteriorate quickly due to changes in climate-related hazards.
- Losses are most likely to occur following large event-type disturbances such as severe floods, rather than in response to gradual changes.

The following tables summarise climate change risks for native ecosystems, wetlands, and water quantity/quality in the Taiari catchment.

Risk to *native ecosystems and species*, due to:	Risk rating[a]		
	Present	2040	2090
Change in rainfall	L	L	M
Drought	L	L	M
Higher temperature	M	M	E
Extreme weather events (floods)	M	H	E

Risk to *alpine wetland ecosystems,* due to:	Risk rating		
	Present	2040	2090
Higher temperature	M	H	E
Drought & rainfall changes	M	E	E
Reduced snow and ice	H	E	E

Risk to *inland wetland ecosystems,* due to:	Risk rating		
	Present	2040	2090
Higher temperature	L	M	E
Drought	M	M	E
Change in rainfall	M	H	E

Risk to *coastal wetland ecosystems*, due to:	Risk rating		
	Present	2040	2090

[a] Risk ratings incorporate assessments of hazard exposure, sensitivity and adaptive capacity. The four ratings used are Low (L), Moderate (M), High (H) and Extreme (E). See Appendix A1.2 for more detail.

Drought	L	L	H
Change in rainfall	L	M	E
Salinity stress, coastal flooding and sea level rise	L	H	E

Risk to *river water quantity & quality*, due to:	Risk rating		
	Present	2040	2090
Change in rainfall	L	H	E
Drought	L	H	E
Higher temperature	L	H	E
Inland flooding	M	E	E
Reduced snow and ice	M	E	E

Risk to *coastal lakes water quality,* due to:	Risk rating		
	Present	2040	2090
Salinity stress	L	M	E
Higher temperature	L	H	H

Climate change management responses

A selection of management options are listed in Section 8 to prompt discussion and future work. Focusing on the highest risk issues in the Taiari catchment, a number of possible management responses are described, including:

- *Wetland protection and restoration (particularly in alpine and inland areas).*
- *Restoration of headwaters and riparian margins, designed to intercept and buffer high flows via multiple 'micro interventions' across the landscape.*
- *Shading smaller streams via canopy closure to create habitat diversity.*
- *Proactive management of invasive species such as wildling pine that can increase fire risk (especially during drought).*

These, and other appropriate management options should be considered by landowners and decision-makers looking to proactively address the complex challenges posed by climate change in the Taiari.

1.0 INTRODUCTION

This report has been prepared for the Department of Conservation (DOC) Te Mana o Taiari Ngā Awa river restoration programme by GHC Consulting. It uses pre-existing information, relying heavily on 'Climate Change Projections for the Otago Region' [4] and 'Otago Climate Change Risk Assessment' [22], prepared by NIWA and Tonkin & Taylor respectively. Information relevant to the Taiari has been extracted and compiled for consideration by those involved in restoration in the catchment, particularly mana whenua.

The report provides down-scaled climate change predictions for the Taiari/Taieri catchment (to the extent they are available),[b] and places these within the context of historical changes in climate observed over the last 100+ years. The report also broadly describes the risks associated with climate change for freshwater ecosystems, wetland ecosystems, and water quality/quantity. Climate change predictions and risks, described at the local scale and with local context, can more easily be incorporated into river restoration and resilience planning than information presented at the national or regional scale.

The report is aimed at mana whenua to assist them to understand climate change impacts[c] on freshwater values from a western science perspective only but may be useful for other entities undertaking restoration work. It is a first step at collating current climate change information from a river restoration perspective. Ideally in upcoming work, we will further tailor this information to address iwi priorities (e.g., by examining relevant case studies of mahika kai species or notable sites).

The report relates to the Taiari catchment, which is one of 14 river catchments in Ngā Awa – DOC's River Restoration Programme [19]. Ngā Awa began in 2019 and is an extension of DOC's work to slow the decline in New Zealand's biodiversity. The programme focuses on a diverse range of priority river catchments across the country, with the outcome objectives of:

- *river ecosystems and species which are thriving from mountain to sea, and*
- *restored rivers that enrich people's lives.*

Ngā Awa also has the process objectives of:

- *co-design and co-led with iwi/hapū/whānau,*
- *collaborating with others,*
- *becoming resilient to climate change.*

More information about DOC's work in the Taiari River, and important values within the catchment (including scroll plains, threatened species and wetland complexes) is provided on the Ngā Awa website [19].

1.1 THE TAIARI CATCHMENT

The Taiari River is the second-largest river in Otago, and flows for more than 280 km. It drains the eastern Otago uplands and follows an almost circular path from its source to the sea. The Taiari River discharges to the Pacific Ocean at Taiari Mouth, only 60 km from its source area in the Lammermoor (Te Papanui) and Lammerlaw ranges (see Figure 1-1). From its source, the Taiari River flows north towards Ranfurly before turning south at Waipiata, almost encircling Pātearoa (the Rock & Pillar Range) as it passes through the Strath Taiari region,[d] before

[b] This report takes the same approach used within DOC's Ngā Awa programme in regard to the naming of place names and features. Wherever possible, the correct spelling for traditional Kāi Tahu names like Taiari and Māniatoto are used, in accordance with the Kā Huru Manu atlas [20].

[c] See [40] *'We all understand the impacts of climate change on the natural environment and are contributing to minimising those impacts'*. Page 17.

[d] the Strath Taiari and the middle reaches of the river are only 30 km from the source.

flowing out towards the Taiari Plain and its confluence with the Pacific Ocean at Taiari Mouth [15].

The total catchment area of the Taiari River is about 5,700 km^2, with a varied topography that comprises low mountain ranges, areas of steep hill country, large areas of gently rolling hill country, and three major plains [13]. Farming is the major land-use in the catchment, with sheep and beef farming occurring in the steeper areas of the catchment and more intensive sheep and cattle farming, as well as dairying, occurring in the flatter plains areas [14].

The major tributaries are the Loganburn (which drains from the Loganburn Reservoir), the Kyeburn, Sutton Stream, Nenthorn Stream, Deep Stream, Three O'Clock Stream, Lee Stream, and the Silver Stream and Waipōuri River, which merge with the Taiari River on the Taiari Plain. The Waipōuri River and Deep Stream both rise in the Lammermoor/Lammerlaw Ranges, in close proximity to the headwaters of the Taiari (Figure 1-1). Lakes within the catchment include the Loganburn Reservoir, and lakes Mahinerangi, Waipōuri (Waipori) and Waihora (Waihola) (Figure 1-1).

1.2 GEOGRAPHICAL SCOPE

In general, New Zealand is expected to experience warmer and (for some areas) wetter conditions in the future. However, rates of change will vary across the country. Similarly, at the catchment scale, there will be local variations in the amount of change experienced - some areas will warm more, while others will experience higher increases in precipitation. For this reason, we have divided the Taiari catchment into three distinct areas to summarise localised climate change impacts. These are areas which experience similar climatic conditions or contain similar geographic features.

- **Māniatoto:** The Māniatoto is an elevated inland basin which forms the upper reaches of the Taiari River (Figure 1-2). It is bounded by the Kakanui Mountains to the north and Pātearoa (Rock and Pillar Range) to the southeast. It has a harsh, dry climate, ranging from over 30 °C in mid-summer to -15 °C in mid-winter. The region has a small population, with the largest centres being Ranfurly and Naseby. The land surrounding the plain is hilly, with many outcrops of rock which also break up the plain in places. Significant wetlands within the Māniatoto include the Styx (Paerau) Basin Scroll Plain and the Māniatoto Basin Scroll Plain.
- **Strath Taiari:** The Strath Taiari basin slopes from about 300 m above sea level in the north to about 150 m in the south. The study area selected for this report is the reach of the Taiari River between the gorge downstream of Hyde to Sutton (Figure 1-3). Numerous short watercourses join the Taiari River in this reach, mainly from Pātearoa (Rock and Pillar Range) to the west. Middlemarch (with a population of about 150) and Hyde are the two main settlements in this area.
- **Lower Taiari:** This is the largest expanse of flat land close to Dunedin city and is mainly used for agricultural purposes. Mosgiel is the largest settlement, with smaller communities including Outram (Maka Kahikātoa), Allanton and North Taiari (Figure 1-4). The area is gently sloping, from an elevation of about 40 m above sea level in the east, to below sea level in the west. As well as the Taiari River, the Silver Stream and Waip*ōu*ri River also cross the plain. Lakes Waip*ōu*ri and Waihora mark the plain's western boundary (Figure 1-1). This area has a significant flood hazard, although this varies across the plain. The Lower Taieri Flood Protection and Drainage Scheme provides flood protection to an area of approximately 180 km^2.

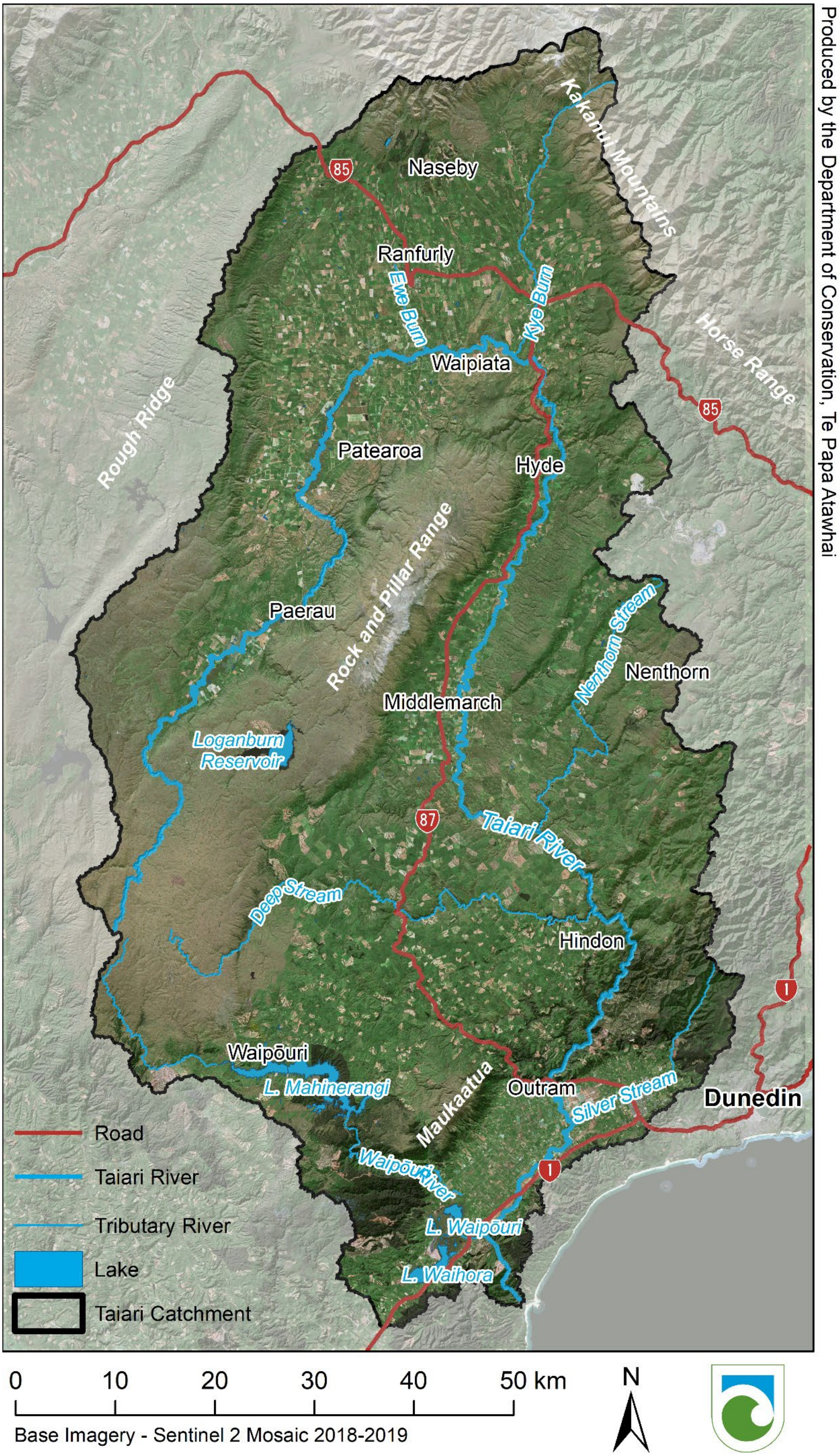


Figure 1-1 The Taiari catchment, showing the course of the Taiari River and its main tributaries

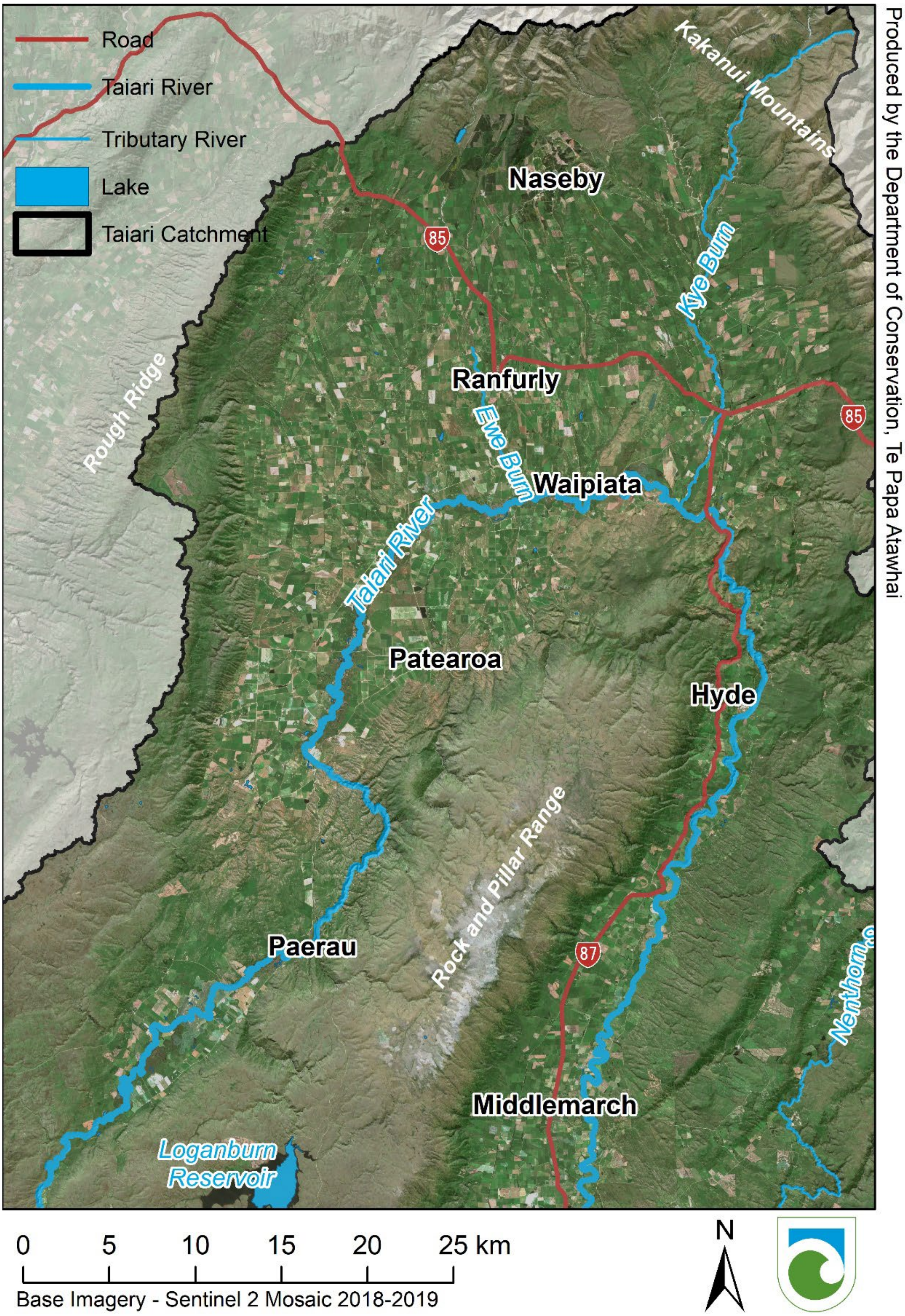


Figure 1-2 The Māniatoto Basin

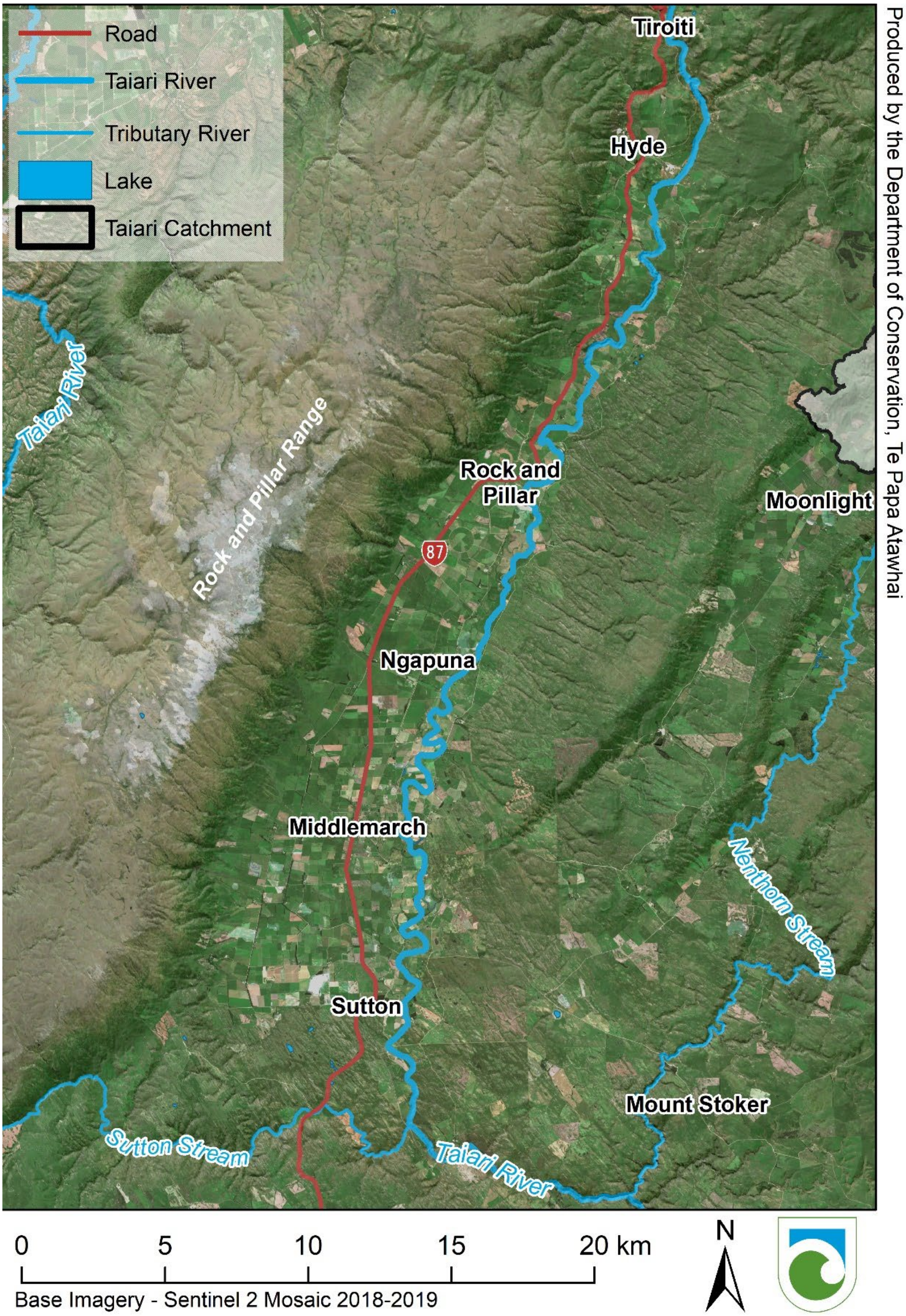


Figure 1-3 The Strath Taiari Basin

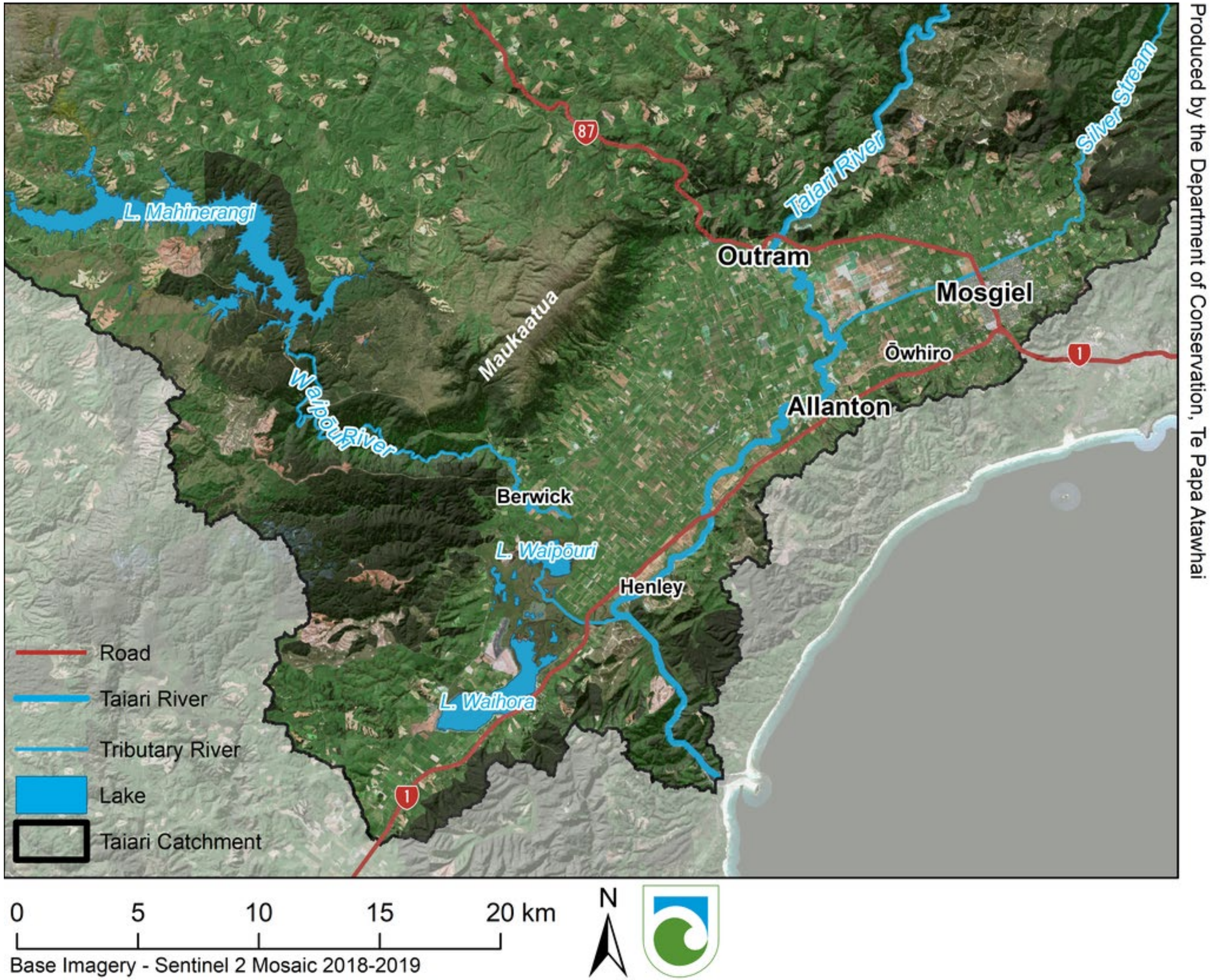


Figure 1-4 The Lower Taiari Plain

1.3 HUMAN SETTLEMENT AND DEVELOPMENT

The following sections bring together information from previous publications to briefly describe the social and physical environment of the three main parts of the Taiari catchment, as defined in this report. We recommend that more authoritative sources of information are used to properly characterise mana whenua use of the catchment as this is not our area of expertise.

1.3.1 Māniatoto[e]

For early Māori, the major valley systems that lead into the interior were natural pathways enabling exploration and discovery. Many trails were established that followed these systems, including the Taiari River, to the plains and valleys of Central Otago. Māori established permanent habitations and semi-permanent seasonal campsites (nohoaka) and hunted and fished for food (mahika kai) that they often transported back to coastal settlements. The plains were particularly important for weka and tuna harvesting.

There was a large Māori moa hunters' campsite at Puketoi with several well-used ovens (umu). Māori also obtained stone tools from silcrete at Oliverburn, Waipiata and Oturehua. In the 1860's, Kai Tahu were slowly edged out of the high country by the establishment of pastoral farming. With access to trails and land becoming difficult or impossible, coupled with population decline due to introduced diseases, travel to and occupation of, Central Otago declined and eventually stopped altogether.

The name Pātearoa is said to mean 'fortification with a clear view'. However, it is also believed to be a personal name of Ngāti Māmoe origins. The first European owner of Patearoa Station, William Henry Valpy Jnr, was told that Pātearoa was the Māori name for the Rock and Pillar range.

European settlers first came to the area, known then as Sowburn, in search of gold. There was a significant but short-lived gold strike in 1863 at nearby Hamilton's, then another at Sowburn a year later. By the mid-1870s, Sowburn had become a substantial settlement with at most around 500 miners. After the initial rush, numbers soon dwindled as the workings were very deep.

Earlier than 1860, William Henry Valpy had taken up a pastoral run near the site of the present Patearoa township, which became known as Patearoa Station. Sowburn (or Hamilton's) Station was on the east of the Sowburn, and owned by J.C. Rowley, Captain James Hamilton and Frederick Wayne. Alnwick Cottage, reputed to be the second oldest building in the Māniatoto, is believed to be the original homestead for both stations.

When the larger farming runs were broken up in the 1880's, some of the miners took up farming and other settlers also moved to the area. To service the growing community a settlement emerged with a church, post office, store, blacksmith, baker and butcher all operating in the village in the 1890's. The population of Patearoa is said to have peaked around 1904 and farming expanded in the area as larger runs continued to be broken up and sold as smaller land holdings.

Tunaheketaka (Taiari Lake) is an important location for iwi found approximately 2.5km northeast of Waipiata and just south of the Waipiata Kyeburn Road.[f] The lake, like the river, was impacted in the late 1800's by significant sediment inputs from gold sluicing in the Hamilton and Naseby diggings. The lake was then actively drained in the late 1940's to support agricultural development. Although some of the lake remains permanent wetland, it is

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[e] Much of this section is adapted from a community plan developed in 2019 [21]. Although it focuses on the Pātearoa area, the plan also has relevance to the broader Māniatoto Basin.

[f] see also Box 8 in section 7.4.1

considered a significant loss by Kāi Tahu. Tunaheketaka[g] is the most downstream of three sub-areas in the Upper Taiari Wetland complex which is currently the subject of an ORC mapping and management prioritisation project.

Figure 1-5 Taiari River at Linnburn Runs Road in the upper Māniatoto (Source: GHC).

1.3.2 Strath Taiari

Previous publications which describe the physical and cultural environment include reports for Otago Regional Council [13],[14], DOC [24] and Kai Tahu's Natural Resource Management Plan [41].

Numerous nohoaka and mahika kai sites in the Strath Taiari and Māniototo were accessed by iwi following the Waikouaiti and Waihemo (Shag) River systems inland. Areas further downstream could be accessed from Blueskin Bay through the Silver Peaks range. Many of these mahika kai sites have been lost as a result of resource use and development [41].

European settlement commenced in the early 1850's, with much of the land in and around the Strath Taiari being taken up by pastoralists on lease from the Crown. From 1861, the Otago gold rushes saw the development of the Dunstan Trail stagecoach route, which crossed the southern part of the basin before crossing the Rock and Pillar Range to the Maniototo. In 1864, gold-bearing ground was reported at Hyde and briefly there were two thousand people living there.

At present the area is dominated by dry stock agriculture – sheep, beef and lamb, with some (generally small) areas being planted in pine trees. Irrigation plays an important role in

[g] Included in the 187ha Taiari Lake Recreation Reserve (ORC website, accessed May 2023, https://www.orc.govt.nz/managing-our-environment/water/wetlands-and-estuaries/central-otago-district/upper-taieri-wetlands-complex).

supporting rural land use, with water taken from the main stem of the Taiari and also from tributary streams.

Remaining conservation values generally occur away from the main stem of the river, amongst the surrounding hill country and tributaries. Sutton Salt Lake is located at the southern end of the plain and is New Zealand's only inland Salt Lake. The Strath Taieri sub-catchment also has many ephemeral wetlands with associated specialised rare and threatened plant species [14].

Channel morphology

While the main stem of the Taiari River follows a sinuous course in places, aerial imagery shows that in some places, the river channel has been straightened, simplified and narrowed. Figure 1-6 shows a typical scene, with farmland, an irrigation dam, small forestry blocks and the Taiari River winding its way across the plain. Old river meanders and braids can be seen in the paddock contours, giving an idea of the 'corridor' the river would naturally occupy in the landscape over long time frames. Riparian planting, intended to help stabilise the river channel can be seen towards the lower right of the image.

The ORC prepared a strategy for managing river morphology and riparian margins in the Strath Taiari in 2016 [14], which describes the morphology of the river as "*a dynamic system where flood events and sediment transport movement regularly cause changes in riverbed morphology… Human activities, such as gravel extraction and physical works, can also result in significant morphological change…across the wider river system."*

Gravel extraction has previously been used as a method to secure arable land and mitigate bank erosion/scouring and excessive gravel accumulation [24]. The ORC strategy [14] promotes riparian plantings to lessen the need to conduct gravel extraction, as this has been shown to have an overall negative effect on instream ecology.

Figure 1-6 View of the Strath Taiari looking downstream from near Middlemarch. Inset: close-up view of riparian planting on the true left bank (Source: GHC).

1.3.3 Lower Taiari Plain

Prior to European settlement, the Lower Taiari Plain was occupied by Kāi Tahu [34]. The Taiari River provided an important access route to inland lakes and wetlands, which were rich in essential food and the raw materials for cultural practices [35]. The area was rich in eels and was used for duck and weka hunting [36]. The river and inland lakes were abundant in fish life, notably patiki (flounder) and inaka (whitebait). The wetlands on the Lower Taiari Plain also produced harakeke (flax) and raupo (bulrush), which were used to make kete (baskets), clothing, rope, mats and fishing nets [37]. These elements meant that the Lower Taiari wetland area was absolutely central to the identity of the hapu and whanau that lived there, and they were fundamental to providing sustenance to those people.

As settlers started to arrive in Dunedin during the mid-1800s, the search began for expanses of flat land to develop into farms and market gardens [16]. Despite being one of the largest areas of flat land near Dunedin city, the Taiari Plains were not considered suitable at first. During a visit in 1844, with Frederick Tuckett, official surveyor to the New Zealand Company, Dr David Munro, a politician and speaker of the House of Representatives, noted that:

> *'About the upper third of the basin is, in my opinion, available but the two lower thirds can hardly be called 'terra firma', being, in fact, an immense grass – tree swamp, through which canals of black sluggish water wind in various direction and interspersed with stagnant lagoons. And I very much fear that this swamp is not susceptible of being drained, for its level is not above that of the sea'* [17].

Dr Munro's observations show that the plain, in its natural state, was subject to flooding from even a modest variation in flows of the Taiari River [17]. Overland flow from Maukaatua (Maungatua Range), variations in the level of Lake Waipōuri and tidal influences contributed to the lower part of the plains being in a permanent state of swampiness.

Figure 1-7 Examples of current land use on the Lower Taiari Plain – intensive farming, wetlands and forestry. The S.I. Main Trunk Line and SH1 also cross the Waipōuri River at this point (Source: GHC).

It was Frederick Tuckett who later realised the agricultural and economic value of such an expanse of alluvial lowland so close to a large centre of population for pākehā settlers [17]. The plain was subdivided into 20-25 ha sections of land, with wheat, oats, grass and potatoes grown on the upper third. The lower part needed extensive drainage and increased flood protection to bring it up to a suitable standard for production. However, the development of refrigerated shipping and the construction of the Burnside Freezing Works saw a movement towards intensification of farming, making the drainage of this land viable. This marked the beginning of the modification of the plain's natural-drainage systems, and the ongoing reliance on these changes for land-drainage and flood protection.[h]

Drainage and flood protection development was and still is highly contentious. From the 1800's, mana whenua have consistently advocated for their ongoing rights, including the access to key, valued locations for mahika kai [34]. For example, in 1901 Lake Tatawai (located just north of Lake Waipōuri) was set aside as a reserve to support Māori fishing rights but in 1920, under the Taieri River Improvement Act,[44] it was drained to make way for agriculture [43]. This issue has been recognised by the Waitangi Tribunal and in the Kāi Tahu Claim Settlement Act – resulting in return of the nearby Te Nohoaka o Tukiauau/Sinclair Wetlands to Kāi Tahu [43]. Two other lakes, Potaka and Marama Te Taha (Loch Ascog) were also part of the complex north of Waipōuri and were drained. For Kāi Tahu, the cumulative impact of engineered works across the lower part of the plain eventually resulted in the loss of local wetlands, which significantly impacted food gathering and cultural practices [34].

1.4 AN OVERVIEW OF THE CLIMATE DATA SOURCED FOR THIS REPORT

This report draws on a range of data sources to describe the past, present and future climate of the Taiari catchment. These data sources are described below.

1.4.1 Historic records

To better understand the local climate, and how it may change under different climate scenarios, we obtained historic temperature, precipitation and wind data for various weather stations within the Taiari catchment (available through NIWA's Cliflo database [3]). Where possible, we used climate stations with records that cover several decades, or those which date back over one hundred years – for example, there are records from Ranfurly and Middlemarch which date back to 1897. Some shorter records from more modern climate stations were also used. The stations used to show historical climate trends in this report are listed in Table 1-1.

Table 1-1 Climate stations used in this report to show historical changes in climate

	Start year - end year	Parameters used in this report		
		Precipitation	Temperature	Wind
Naseby Forest 1	1923 - 1983		✓	
Naseby Forest 2	1983 - 2017			✓
Ranfurly Eweburn	1897 – 1922	✓	✓	
Ranfurly	1944 - 2000	✓		
Ranfurly EWS	2000 - 2022	✓	✓	✓
Middlemarch Garthmyl	1897 - 2014	✓		
Middlemarch EWS	2001 - 2022		✓	✓
Outram Balmoral	1948 - 2020	✓		
Mosgiel Town	1952 – 2022	✓		
Dunedin Aero	1962 - 1991		✓	
Dunedin Aero AWS	1991 - 2022		✓	✓

[h] The hydrology of the Lower Taieri Plain continues to be affected by the Lake Mahinerangi dam, which regulates the flow in the Waipori River, particularly during the summer when flows can be artificially reduced.[42]

The following climatic variables were extracted from the climate stations listed in Table 1-1:

- *Mean annual air temperature,*
- *Extreme maximum and extreme minimum temperature (in any given year),*
- *Mean annual rainfall (total precipitation in any given year),*
- *Maximum 1-day rainfall (in any given year),*
- *Mean annual wind speed, and*
- *Highest daily wind run.*

While all attempts were made to select the most comprehensive records, there are some limitations to this historic data. Some years are missing from the records, and it is likely that historic data recorded by hand was rounded to the nearest decimal point, while newer records have maintained greater detail due to modern recording practices.

1.4.2 Future temperature and precipitation models

To understand what the Taiari catchment's future climate may look like, a series of computational models developed by NIWA have been used to inform this report. These models make predictions about future temperature and precipitation patterns by the years 2040 and 2090, relative to present day conditions. They are based on dynamical downscaling[i] of global climate models produced by the Intergovernmental Panel on Climate Change (IPCC) and are presented as a 5 by 5 km grid over all of New Zealand [2]. The climate projections are produced as two 20-year averages relative to a baseline period of 1986 to 2005. This means that predictions for 2040 represent the modelled average for the period between 2031 and 2050. Likewise, 2090 represents the modelled average for the period 2081 to 2100 [1]. A full discussion of the methodology employed by NIWA and the IPCC can be found elsewhere [1][2][4].

Within this report, we rely on climate projection data from NIWA's work for the Otago Regional Council titled, 'Climate change projections for the Otago region' [4]. For simplicity, but also to demonstrate that there is uncertainty around future greenhouse gas emissions at the global scale, we have reported on just two emissions scenarios. These include the 'low-mid range' emissions scenario (RCP 4.5), and the high-range emissions scenario (RCP 8.5).[j]

GIS raster files were obtained from NIWA, and DOC GIS staff clipped these outputs to the Taiari catchment boundary and produced maps for the two RCP scenarios and two timeframes (2040 for RCP 4.5 and 8.5, and 2090 for RCP 4.5 and 8.5). We have restricted our analysis to annual rates of change in order to communicate future changes simply and clearly; however, seasonal changes have also been modelled by NIWA (and are available at the Otago scale [4]).

There are of course some limitations to NIWA's climate models that are presented in this report. Firstly, it is difficult to absolutely predict future rates of global greenhouse emissions. To overcome this, the IPCC have developed a range of likely future emissions scenarios; however, it is possible that actual emissions may be more or less than these scenarios indicate. Secondly, natural variability in future climate trends related to large-scale climate oscillations (the El Nino Southern Oscillation, the Interdecadal Pacific Oscillation and the Southern Annual Mode) introduces some uncertainty into the models [4]. While at times these climatic oscillations may offset or contribute to projected climate trends, by the end of the century the anthropogenic influence is predicted to become the dominant factor determining climatic conditions (for a full discussion see [4]).

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[i] the process of applying large global climate models, to a regional scale.

[j] section 1.5 provides more detail on representative concentration pathways.

1.4.3 Hydrological projections

To understand the impacts of climate change on water resources, this report summarises the results of previous hydrological modelling undertaken by NIWA for the Otago Regional Council [4]. NIWA's TopNet model (Box 1) is used routinely for surface water hydrological modelling in New Zealand and can simulate soil moisture and river flows continuously and under a range of different climatic conditions, both historical and future.

Box 1: Technical details of NIWA's TopNet model [4]

The TopNet model is a spatially semi-distributed, time-stepping model of water balance. It is driven by time-series of precipitation and temperature, and of additional weather elements where available. TopNet simulates water storage in the snowpack, plant canopy, rooting zone, shallow subsurface, lakes and rivers. It produces a time-series of modelled river flow (without consideration of water abstraction, impoundments, or discharges) throughout the modelled river network. TopNet has two major components: a basin module and a flow routing module.

Other modelling notes:

- TopNet was run continuously from 1971 to 2100, with the spin-up period 1971 excluded from the analysis. The climate inputs were stochastically disaggregated from daily to hourly time steps.
- The simulation results comprise time-series of modelled river flow for each computational sub-catchment, and for the four RCPs considered (see section 1.5).
- Hydrological projections are presented as the average for two future periods: 2036-2056 (termed 'mid-century') and 2086-2099 (termed 'late-century'). Modelled changes are relative to the baseline climate (1986-2005 average).

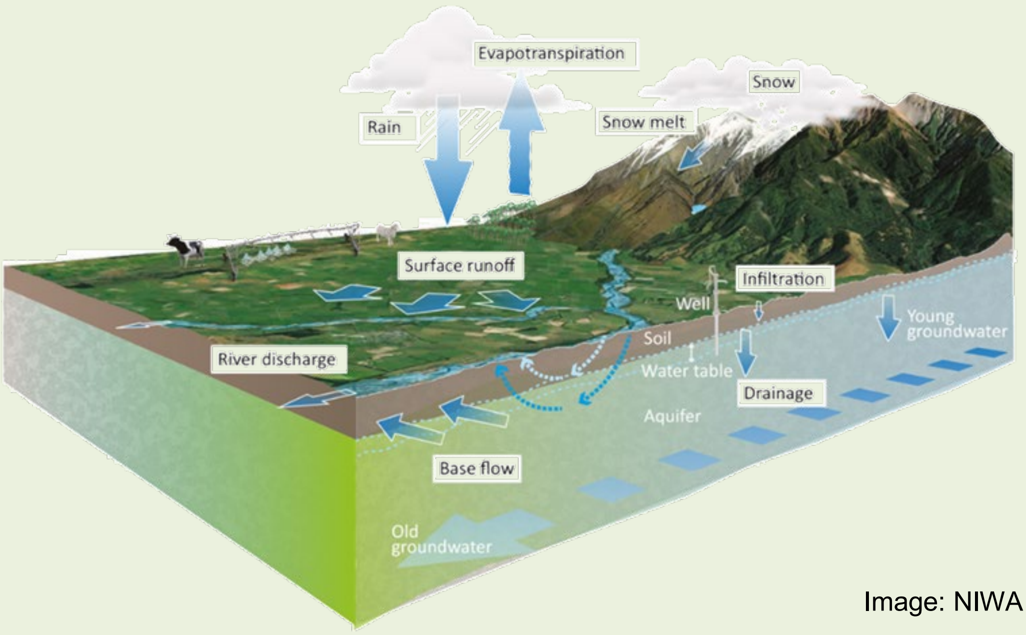


Image: NIWA (link)

1.5 UNDERSTANDING EMISSIONS SCENARIOS

The information presented in this report draws on greenhouse gas emission scenarios agreed on by the IPCC. Generally, climate models are produced for a range of different emission scenarios, termed 'representative concentration pathways' (RCP). Representative concentration pathways are used to make projections on what the future climate will look like. The IPCC have agreed on four predictive emissions pathways that consider factors such as future population size, economic activity, lifestyle, energy use, land use patterns, technology and the implementation of climate policy [1]. Within this document we report on results from the ‘low-mid’ stabilisation pathway (RCP 4.5) and the ‘business as usual’ or high range scenario (RCP 8.5). While actual changes in climate or precipitation may in fact be higher or lower than either of these scenarios, they provide a reasonable indication of the range of possible climate ‘outcomes’ for the Taiari catchment. The four representative concentration pathways are outlined below, and while we focus our discussion on the RCP 4.5 and RCP 8.5 scenarios, an analysis of each pathway at the New Zealand scale can be found elsewhere [2].

- ***Best case scenario (RCP 2.6):*** *This is a mitigation scenario and assumes that changes in energy use and climate policy will lead to considerable removal of current levels of CO_2 from the atmosphere.*
- ***Low-mid stabilisation pathway (RCP 4.5):*** *This scenario assumes that greenhouse gas concentrations will continue to rise until approximately 2040 after which time concentrations will begin to decline.*
- ***Mid-high stabilisation pathway (RCP 6.0):*** *This scenario assumes that greenhouse gas concentrations will continue to rise until approximately 2080 after which time concentrations will begin to decline.*
- ***High range scenario (RCP 8.5):*** *This is a business-as-usual scenario and assumes that greenhouse gas concentrations will continue to grow at the current rate, assuming an uninhibited supply of fossil fuels. Under this scenario, the concentration of greenhouse gases in the atmosphere will continue to increase beyond 2100 [10].*

The following chapter describes the patterns and rates of temperature, precipitation and wind changes that can be expected with climate change in the Taiari catchment (assuming a low-mid range RCP 4.5, and high range RCP 8.5 scenario). These predictions are compared against historical data from climate stations in the catchment.

2.0 OVERVIEW – PAST, PRESENT AND FUTURE CLIMATE

Previous climate trends and predicted changes in the climate and hydrology of the Taiari catchment are discussed in some detail in sections 3.0 to 6.0. These changes can be summarised as follows:

1. *Air temperature has increased since records began in the late 19th century and is predicted to increase further over the coming century. More extreme hot days and fewer frosts are predicted.*
2. *Average annual rainfall has increased at sites on the Lower Taiari, and the intensity of storm events has also increased. These historical trends are not evident at sites in the Māniatoto and Strath Taiari. An overall shift towards more and heavier rainfall is predicted over the coming century, especially in the lower catchment.*
3. *Records from Ranfurly, Middlemarch and the Taiari Plain show that it has generally become less windy in these places over the last 2-3 decades. An increase in extreme wind speed may occur by the end of the century, particularly around Ranfurly and Naseby.*
4. *There will generally be less water in the Taiari River and its tributaries during extended dry periods, particularly in the mid and upper catchment.*
5. *High flow (flood) events will generally be larger across much of the catchment.*

The key changes in climate predicted across the Taiari catchment are illustrated in Figure 2-1.

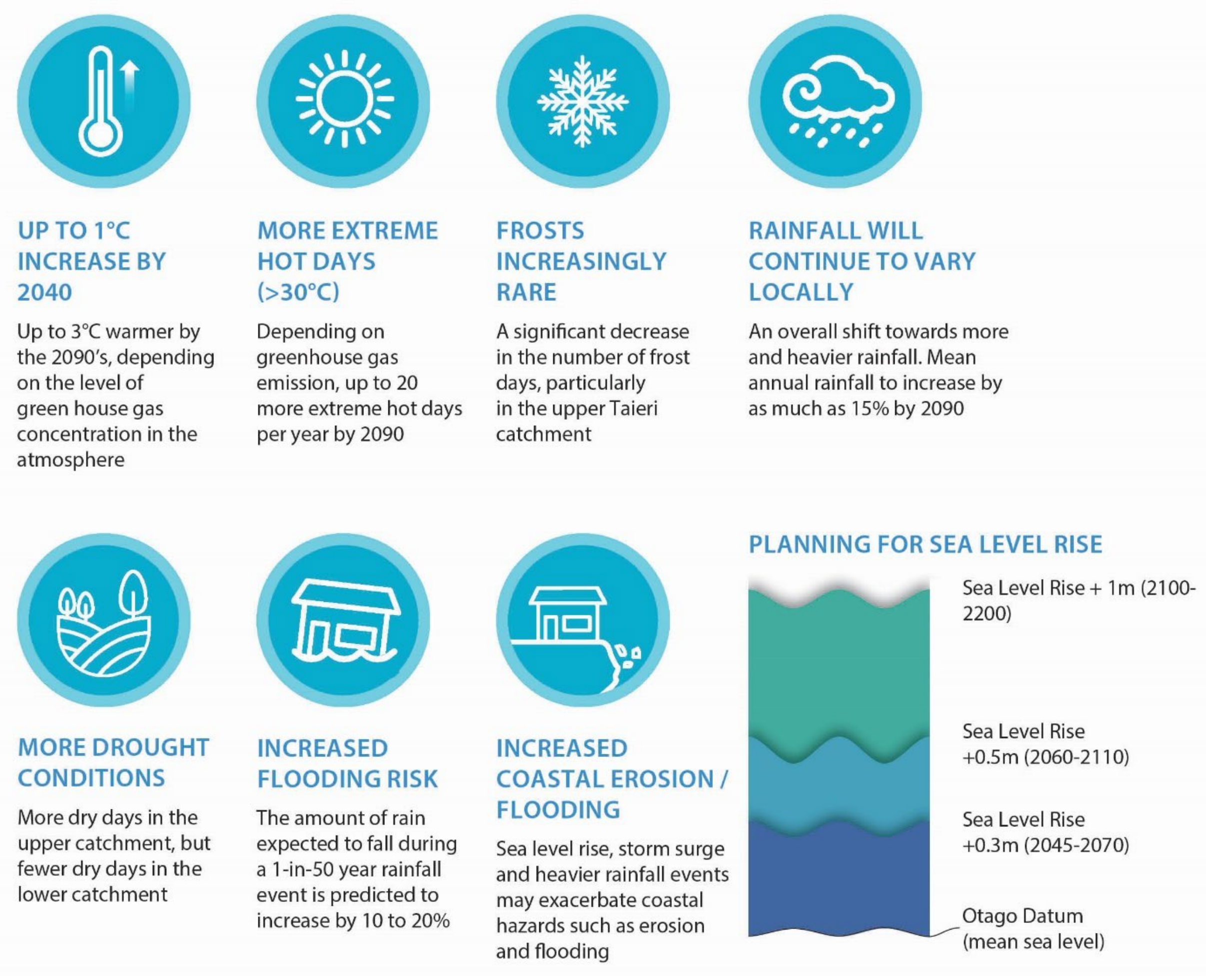


Figure 2-1 Summary of predicted climate change impacts for the Taiari catchment

3.0 TEMPERATURE

At present, the average temperature on the Lower Taiari Plain is between 10-12°C, while further up the catchment, the average temperature is 8-10°C in the Strath Taiari and Māniatoto areas. Seasonal temperatures are influenced by proximity to the sea, so that the Lower Taiari is typically cooler in summer and warmer in winter compared to inland parts of the catchment. Mean temperatures at higher elevation remain several degrees Celsius colder than the remainder of the catchment throughout the year.

3.1 UNDERSTANDING THE PAST – HISTORICAL CHANGES IN TEMPERATURE

Observed changes in mean annual air temperature are discussed below, along with records of extreme minimum and extreme maximum temperature.

3.1.1 Mean annual air temperature

Past records tell us that New Zealand's air temperatures have increased by about 1°C over the past century [3], a trend that is also supported by local weather observations within the Taiari catchment. The climate station with the oldest temperature records is Ranfurly at Eweburn, which operated from 1897 to 1922. This was a state forest nursery, located half a mile north of the Ranfurly Post Office [3]. The mean annual temperature record from this site shows a gradual increase from 1897 through to 1916 (Figure 3-1). The data for the last six years show a marked change in 1916 to higher temperatures, suggesting that something changed at the site prior to it closing – for example, nearby trees may have been cut down, providing more sunlight.

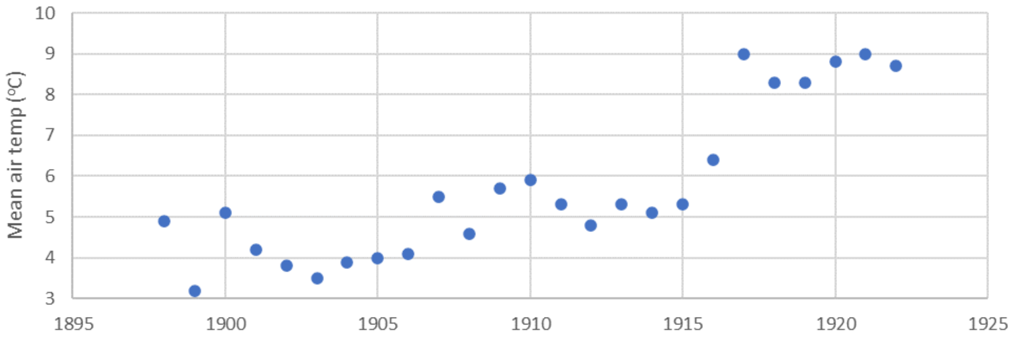


Figure 3-1 Historic mean annual air temperature data from the Ranfurly at Eweburn climate station

A longer-term (and perhaps more reliable) temperature record from two climate stations in the Naseby area is shown in Figure 3-2, with a 5-year moving average also shown for each dataset. Although the records from these two stations are independent, as they are from different locations,[k] they do provide a good record of changes over time in Naseby. Between 1923 and 1982, mean air temperature at the Naseby 1 site increased from about 7.6°C to 8.2°C, while at Naseby 2, an increase of about 0.4°C was observed between 1992 and 2016.

[k] Naseby 1 and Naseby 2 are located about 4 km apart, but at a similar altitude (610 and 607m above sea level) [3]

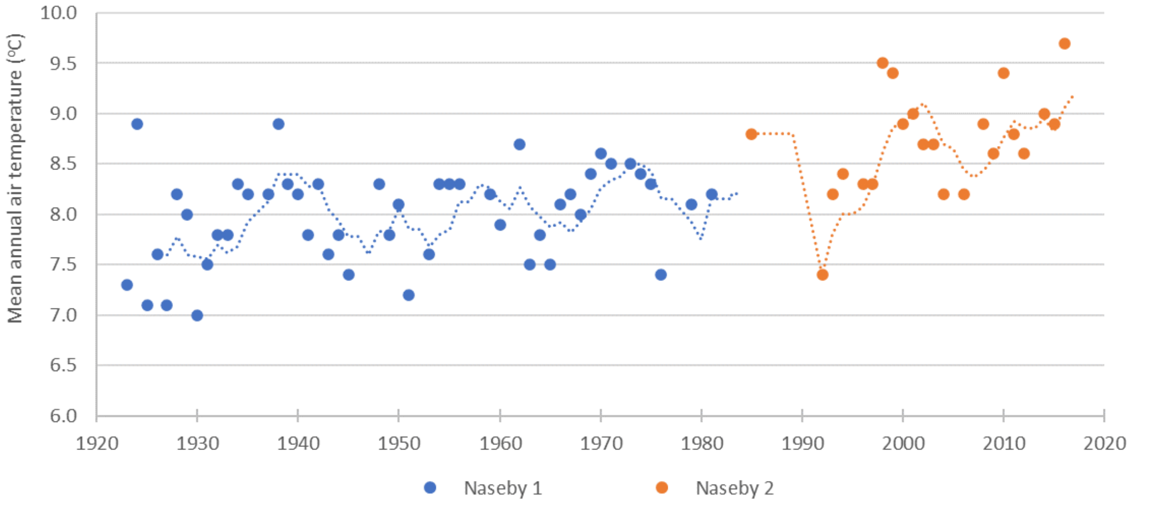


Figure 3-2 Historic changes in mean annual air temperature at two stations in Naseby, between 1923 and 2016. A 5-year moving average is also shown for each dataset.

Mean annual temperature records from other climate stations within the catchment are shown in Figure 3-3. The Ranfurly EWS station (which is located near the historic Eweburn site described above) shows an increase in mean annual temperature of at least 1°C between 2002 and 2021. Increases in mean annual temperature over time are also shown at the two Dunedin Aero climate stations (both located at Dunedin Airport).

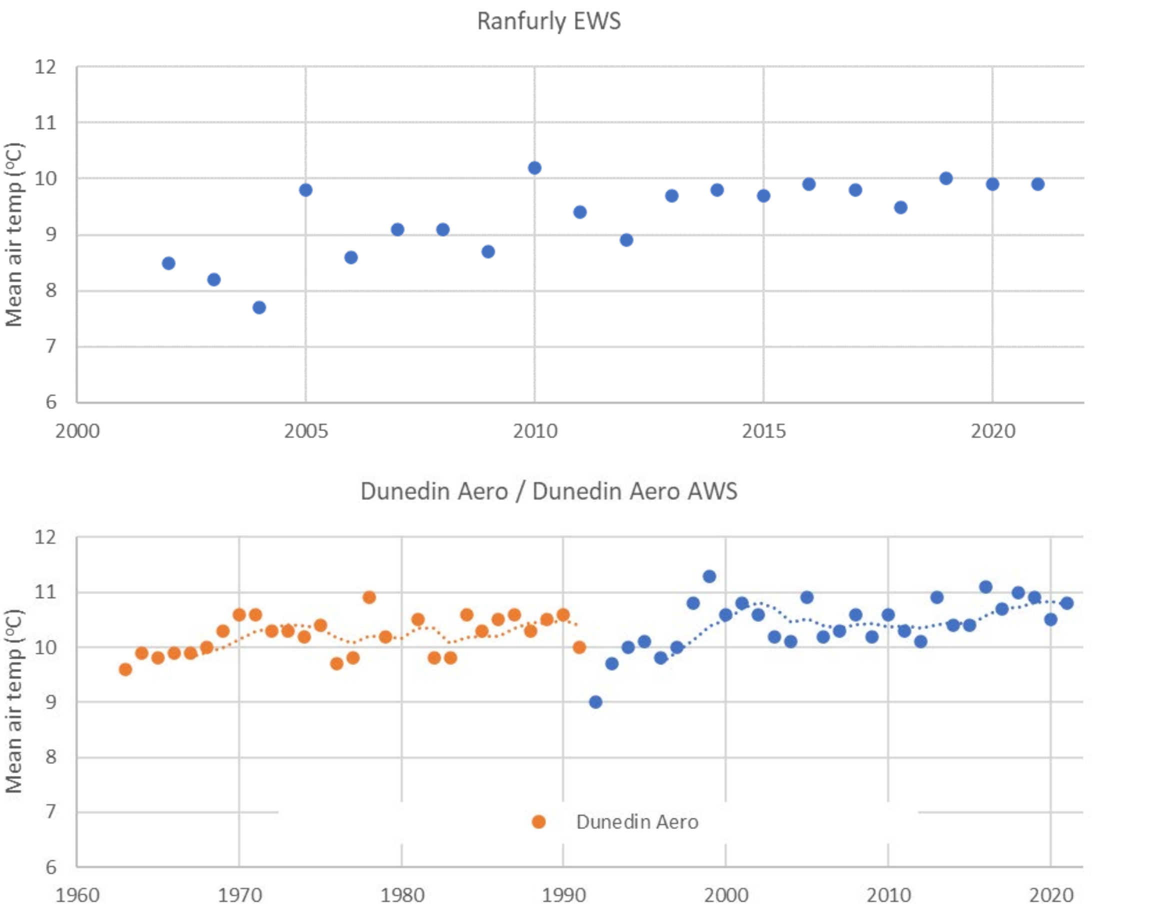


Figure 3-3 Historic mean annual air temperature data from the Ranfurly EWS (top) and Dunedin Aero/Dunedin Aero AWS climate stations (bottom). A 5-year moving average is shown for the Dunedin Aero data.

3.1.2 Extreme hot and extreme cold days

Data from the two Naseby stations has been used to show changes in temperature extremes in the Māniatoto Basin. Both the extreme maximum temperature (i.e., the hottest day each year) and the extreme minimum temperature (coldest day each year) show an increasing trend over time (Figure 3-4).

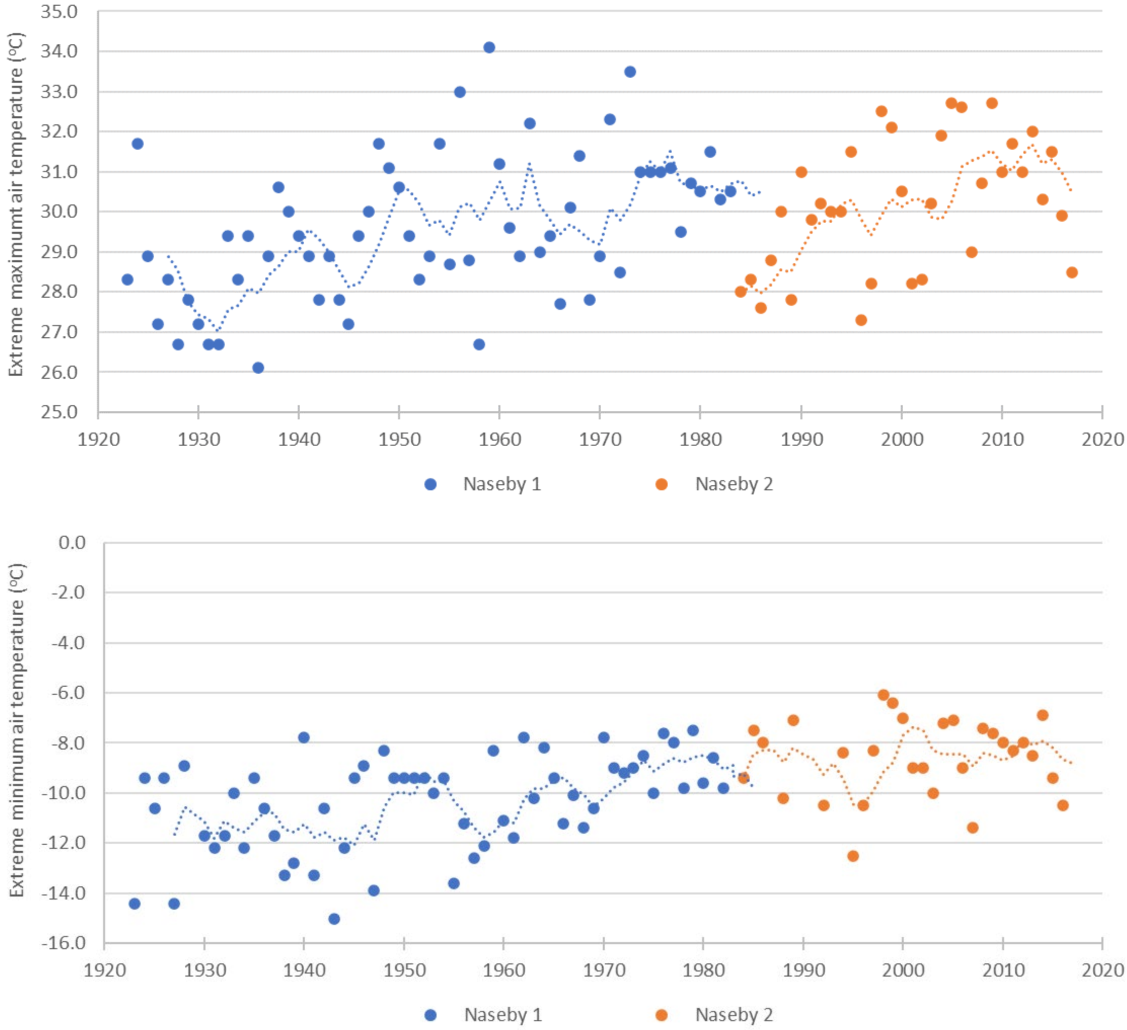
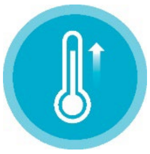


Figure 3-4 Historic changes in extreme maximum (top) and extreme minimum (bottom) temperature at two stations in Naseby, between 1923 and 2016. A 5-year moving average is also shown for each dataset.

Figure 3-5 Cooling off on a hot day at Te Kirikiri (Outram Glen), November 2019 (Source: Otago Daily Times)

3.2 LOOKING TO THE FUTURE – PREDICTED CHANGES IN TEMPERATURE



The Taiari catchment is predicted to experience overall warmer conditions in the future [4]. This will be experienced as an overall increase in mean annual temperature, increase in the number of hot days (those greater than 30°C), and a decrease in frost days. These parameters are discussed below.

3.2.1 Mean annual air temperature

At present, mean annual air temperature at climate stations in the Taiari catchment range from about 9°C to 11°C (Figure 3-2 and Figure 3-3). Modelling undertaken by NIWA shows that temperatures are likely to continue to increase. An example is shown in Figure 3-6, where modelled changes in mean annual temperature are shown for Middlemarch in the Strath Taiari. There are large temperature variations throughout the year in parts of the Taiari catchment, and modelled changes in mean summer and mean winter temperature are also shown in Figure 3-6 to help illustrate this seasonality.[4]

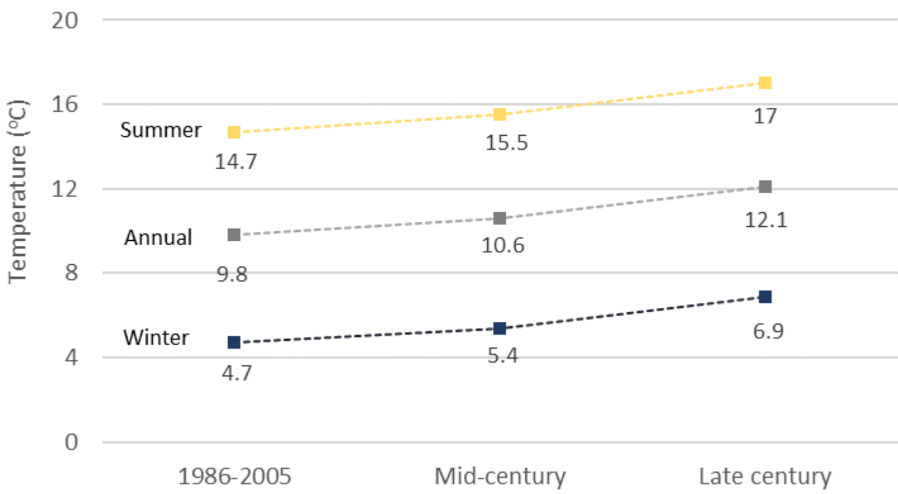


Figure 3-6 Modelled summer, winter and mean annual temperature for present and climate change scenario RCP8.5 in Middlemarch. Time periods: present (1986-2005), mid-century (2031-2050) and late-century (2081-2100;); based on the average of six global climate models [4].

Temperature increases will vary across the catchment. Figure 3-7 shows that the largest increases in mean annual air temperature are expected over the Māniatoto Basin and upper catchment, particularly under a high range emission scenario by the end of the century. The lowest increases are predicted in the south-eastern part of the district, between Hindon in the Taiari Gorge, and Mosgiel on the Lower Taiari Plain.

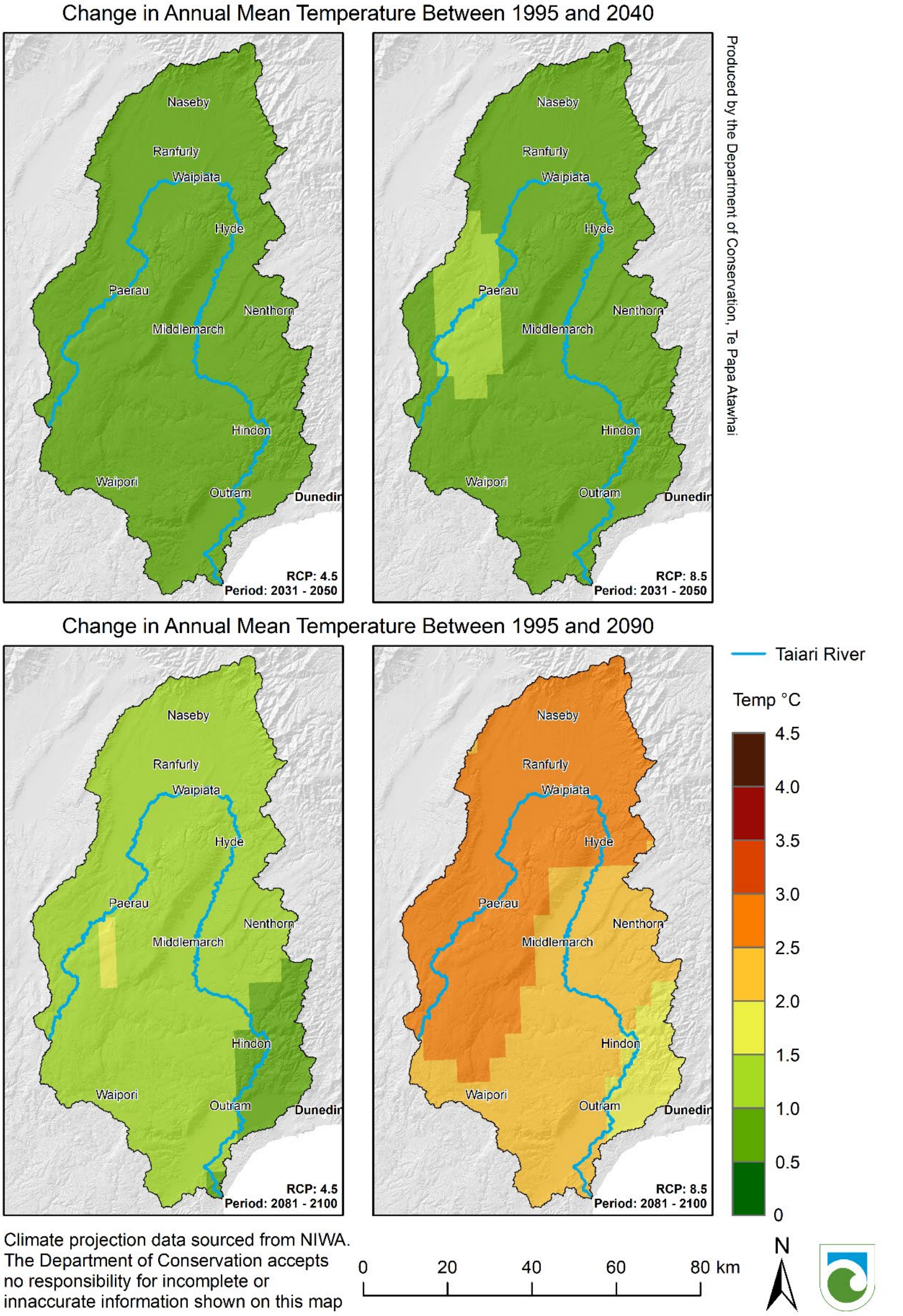


Figure 3-7 Change in mean annual temperature predicted in the Taiari catchment under two climate change scenarios. The top two images show the expected increase in mean annual temperature (in °C) by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show the expected increase by 2090, under a low-mid (left) and high range (right) emission scenario.

3.2.2 Extreme hot days

Climatic changes are often most noticeable when we look at temperature extremes, such as very hot or very cold days. In this report, an extreme hot day is considered to occur when the maximum temperature is above 30°C. At present, the more elevated parts of the catchment (e.g., the Rock and Pillar Range and the Kakanui Mountains) experience very few extreme hot days (up to one per year), while the Lower Taiari Plain, Strath Taiari and parts of the Māniatoto can experience as many as four per year [3].

The number of extreme hot days in the Taiari catchment is predicted to increase by between zero and four days per year by 2040, with larger increases possible in the upper catchment (Figure 3-8). More significant change is predicted by 2090, when the catchment may experience up to eight additional extreme hot days under a low-mid range emissions scenario (RCP 4.5), or up to 20 days assuming a high range scenario (RCP 8.5).

The upper catchment is expected to experience the largest increases, particularly around Ranfurly and Pātearoa. The predicted changes are likely to have a seasonal trend and the majority of these additional extreme hot days will occur in summer.

3.2.3 Frost days

The climate projection modelling supplied by NIWA [4] defines a frost day as when the modelled daily minimum temperature falls below 0°C. Historical records suggest that there has already been a reduction in the frequency of frosts in parts of the Taiari catchment, and Figure 3-9 shows that further decreases are predicted into the future. By 2040, the catchment may expect between five and 20 fewer frost days each year. By 2090 this increases to between five and 50 fewer frost days each year, depending on the emission scenario (Figure 3-9).

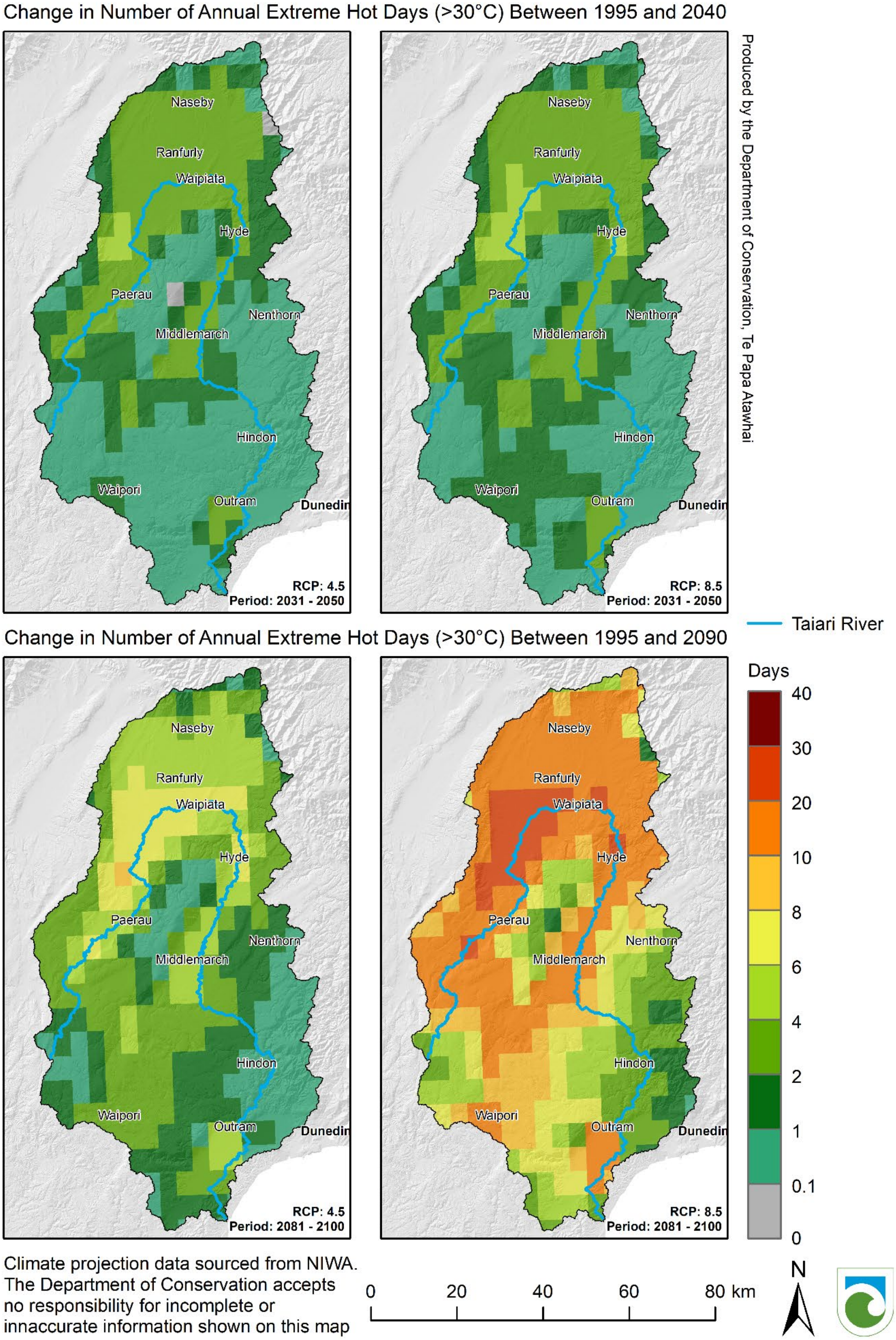


Figure 3-8 The change in number of extreme hot days predicted for the Taiari catchment under two climate change scenarios. The top two images show the increase in number of hot days by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show the expected increase by 2090 under a low-mid (left) and high range (right) emission scenario.

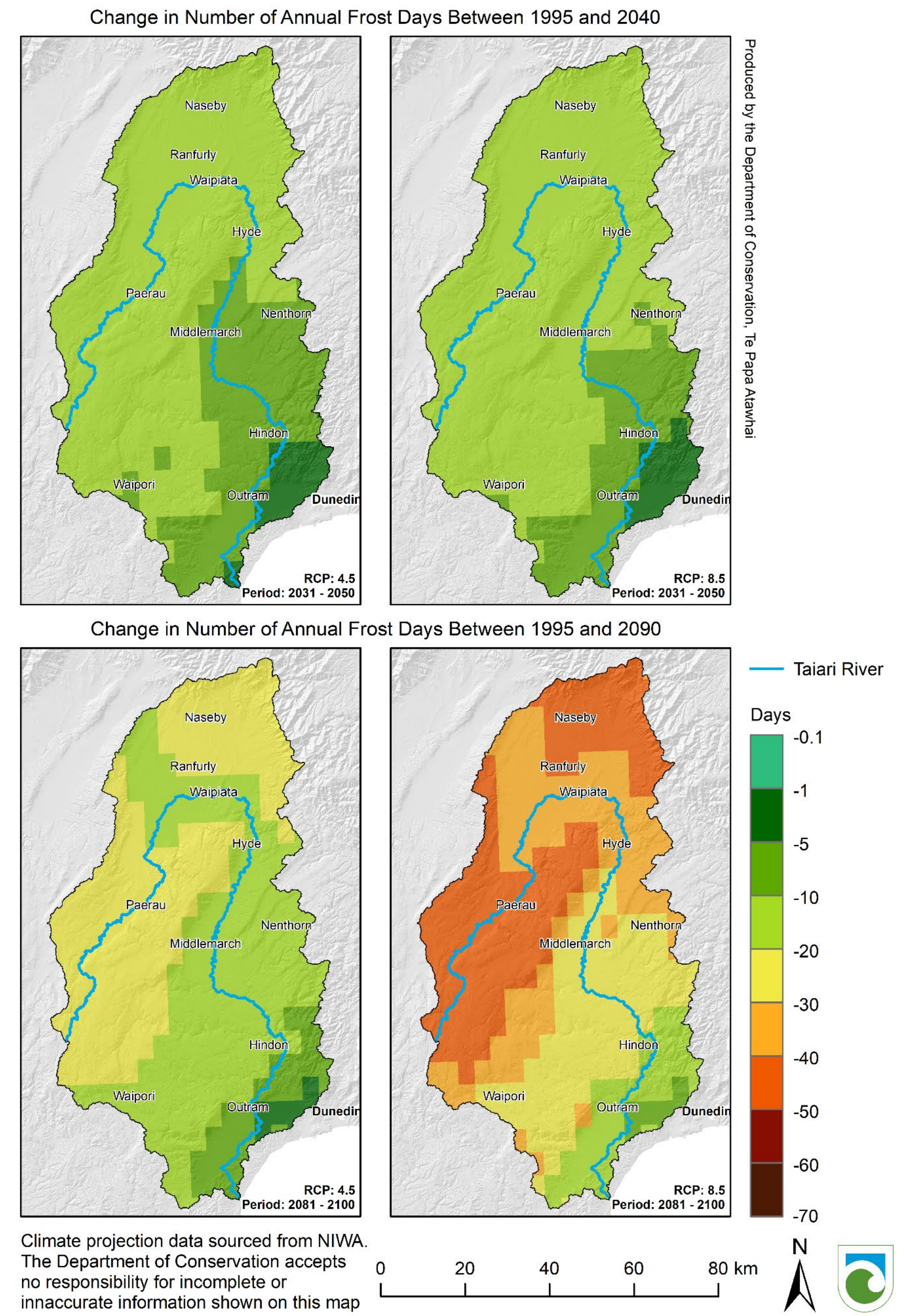


Figure 3-9 Changes in the number of frost days predicted for the Taiari catchment under two climate change scenarios. The top two images show the decrease in the number of frost days by 2040 under a low-mid (left), and high range (right) emission scenario. The bottom two images show the expected decrease by 2090, under a low-mid (left) and high range (right) emission scenario.

4.0 PRECIPITATION

Annual rainfall across the Taiari catchment ranges from 400-600mm in the Māniatoto and Strath Taiari basins, to 600-800mm on the Lower Taieri Plain. The driest area is Waipiata (<400mm/year), with the wettest area in the headwaters of the Silver Stream (>1,000mm/year).

As a warmer atmosphere can hold more moisture [4], rainfall patterns are likely to change in the future. While future precipitation patterns are variable, an overall shift towards more and heavier rainfall is expected for the Taiari catchment. These changes are reflected in models of mean annual precipitation, heavy rain days, high intensity rainfall events, and dry days, as outlined below.

4.1 ANNUAL PRECIPITATION

4.1.1 Understanding the past – historical changes in annual precipitation

Historical records of annual precipitation are shown in Figure 4-1 for rain gauges in Ranfurly on the Māniatoto, and Middlemarch in the Strath Taiari. A 5-year moving average has been added to each dataset. Although their records stretch back well over 100 years, the moving average trend lines do not show any long term trend at these stations. It is noted that the records from these towns are somewhat disjointed, with the different stations located at different places in each town – although the sites are close to each other, each set of data is a discrete record from a particular location with its own physical characteristics (elevation, exposure etc.).

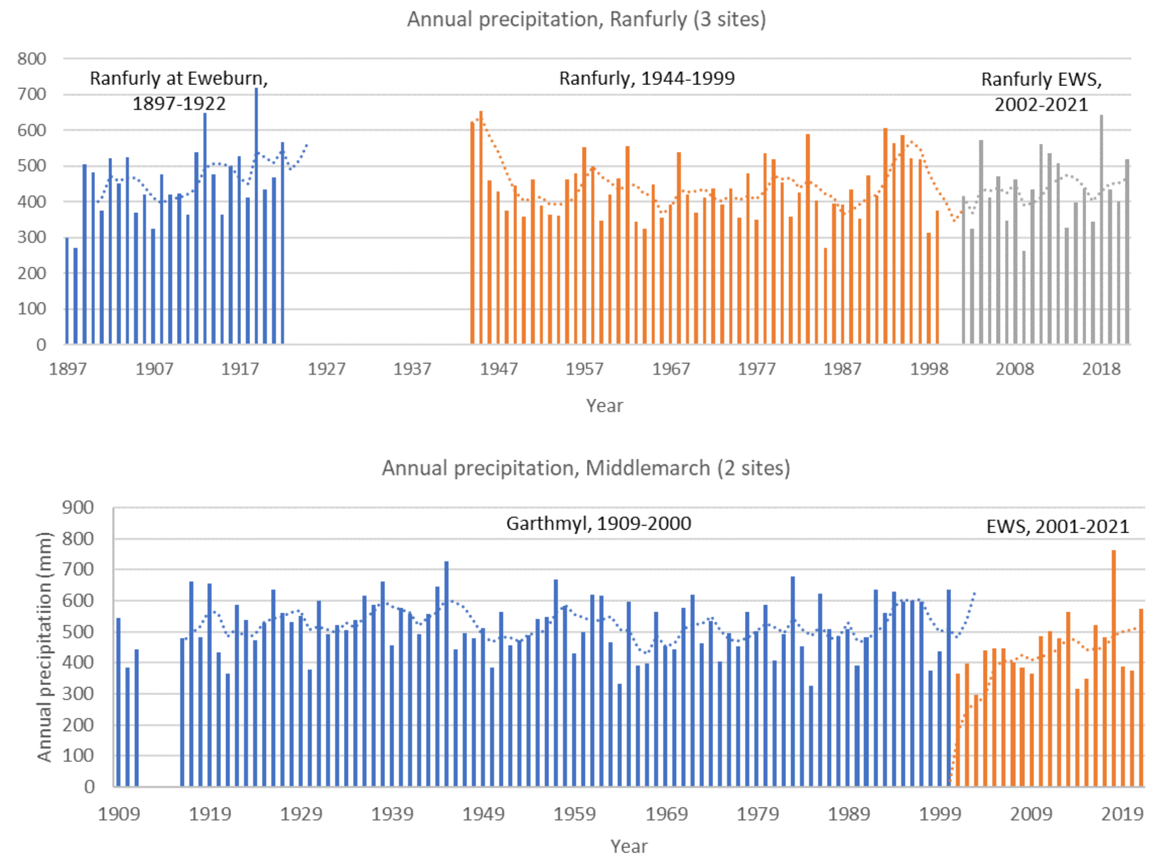
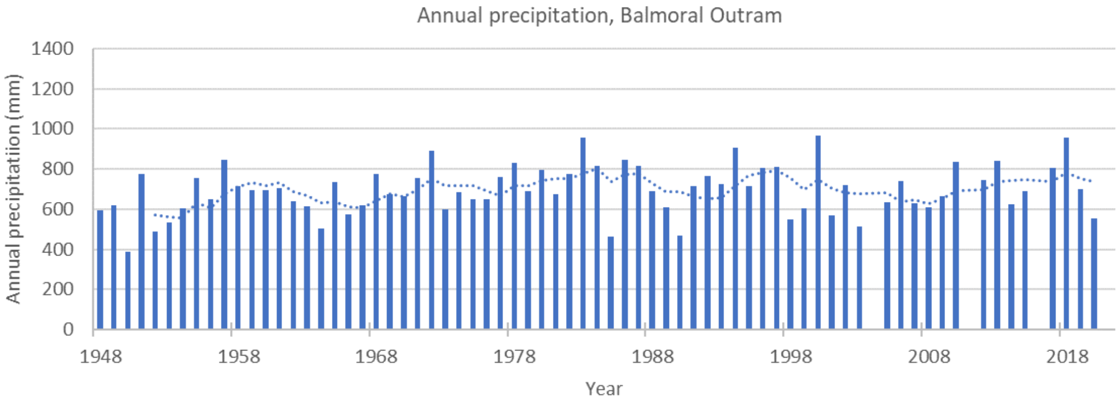


Figure 4-1 Historic annual precipitation data from the Māniatoto Basin (Ranfurly) and Strath Taiari Basin (Middlemarch). Data from neighbouring, or replacement/upgraded climate stations has been overlaid on the same graph.

On the Taiari Plain at the Maka Kahikātoa (Outram) and Mosgiel rain gauges, the trend lines show a gradual increase in annual precipitation since records began. At the Balmoral Outram station, annual precipitation has increased by approximately 170mm, from 570mm/year in the early 1950's to about 740mm/year in recent years. There is a shorter length of record from Mosgiel, but this also shows an increase of about 170mm, from 580mm/year in the late 1960's to 750mm/year in 2021.



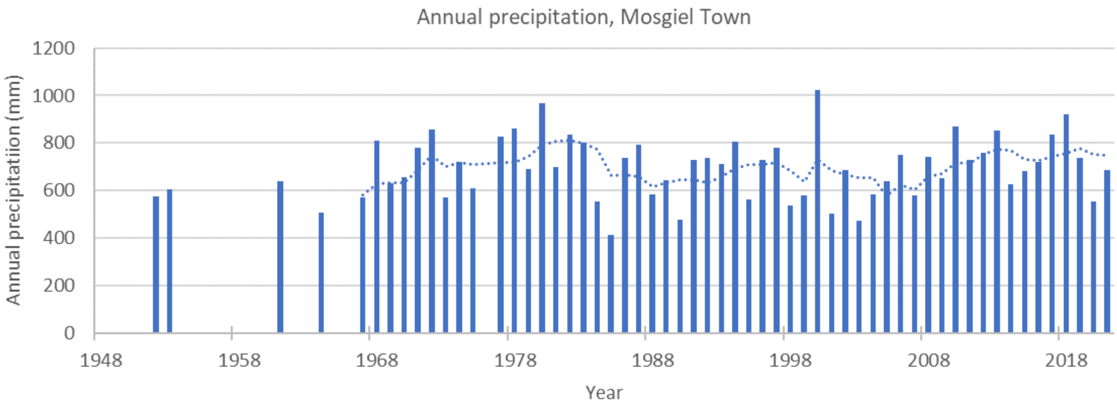


Figure 4-2 Historic annual precipitation data from the Taiari Plain at Balmoral Outram and Mosgiel Town.

Figure 4-3 People peruse the stalls at the 2015 Mosgiel Community Market Day after the rain clears (Source: Otago Daily Times)

4.1.2 Looking to the future – predicted changes in annual precipitation

Mean annual rainfall across the Taiari catchment is generally predicted to increase (Figure 4-4). By 2040 a relatively small change is predicted, between -5% and +5%). However, by 2090, larger increases in annual rainfall are predicted, especially in the lower catchment (including the Taiari Gorge downstream of Sutton, the Lower Taiari Plain and Mauka Atua/ Maungatua Range) which may experience up to 15% more rainfall.

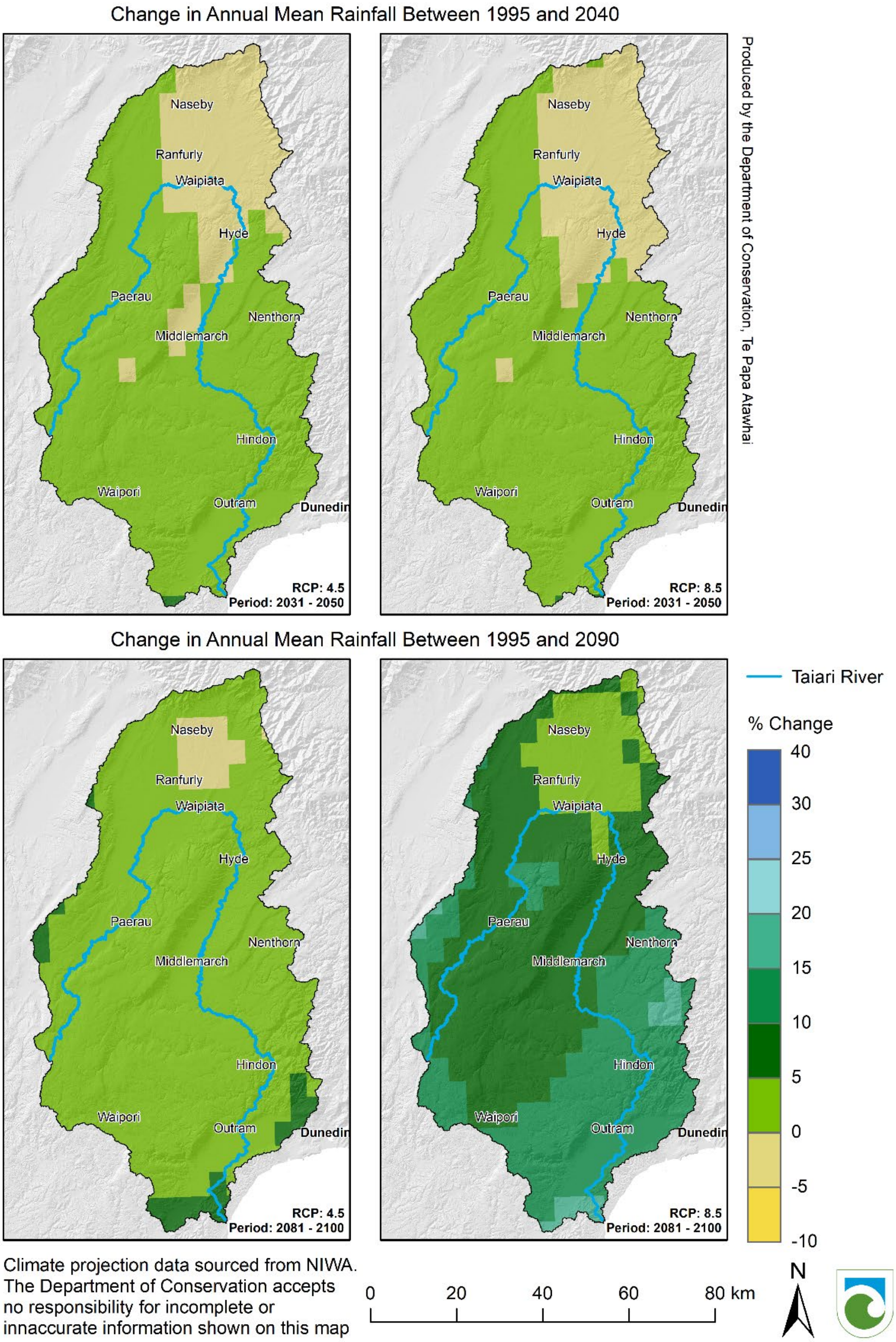


Figure 4-4 Percentage change in mean annual precipitation, as predicted for the Taiari catchment under two climate change scenarios. The top images show percentage increase in mean annual precipitation by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom images show the percentage increase by 2090, under a low-mid (left) and high range (right) emission scenario.

4.2 HEAVY RAINFALL EVENTS

4.2.1 Understanding the past – historical changes in maximum 1-day rainfall

Historical records of the maximum 1-day rainfall recorded each year are shown in Figure 4-5 for climate stations in in the Māniatoto and Strath Taiari basins.[l] A 5-year moving average trend line has been added to each dataset. The data does not show any significant trend at these two stations, although as noted above, the records are somewhat disjointed, are taken from different locations, and there are several periods of missing data.

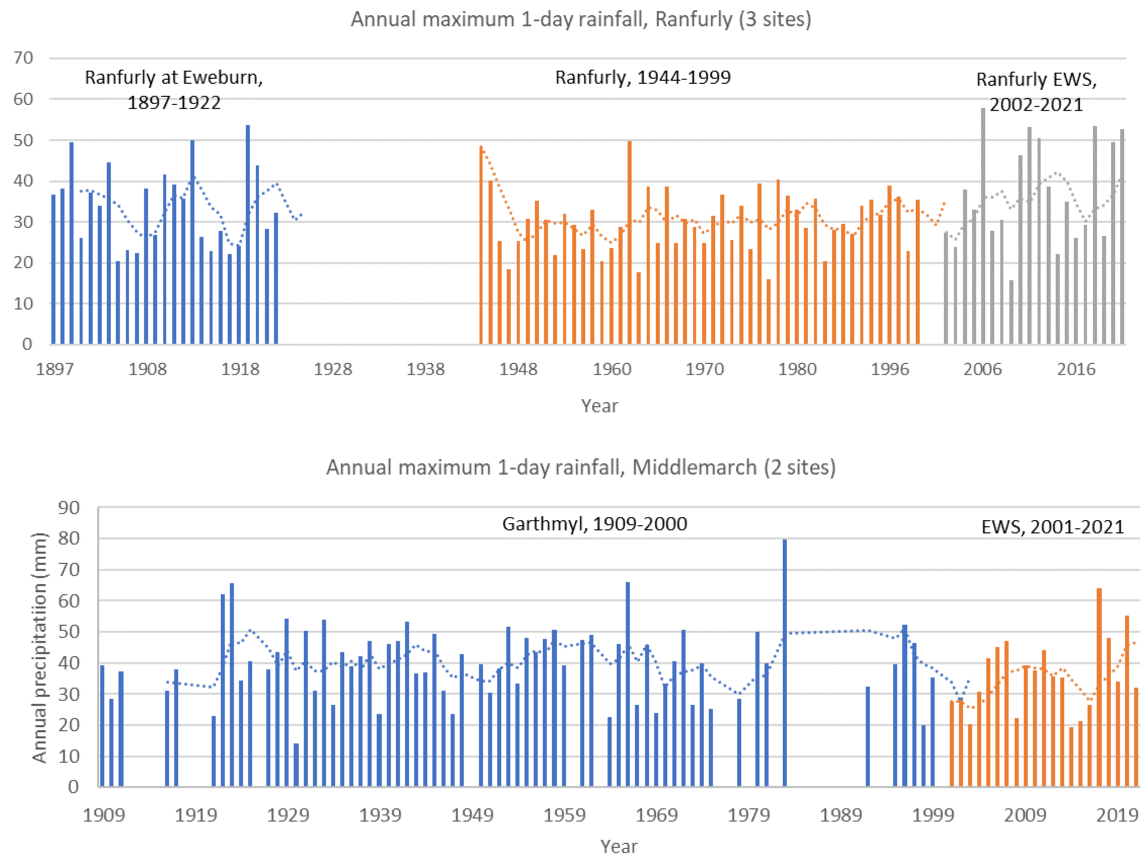
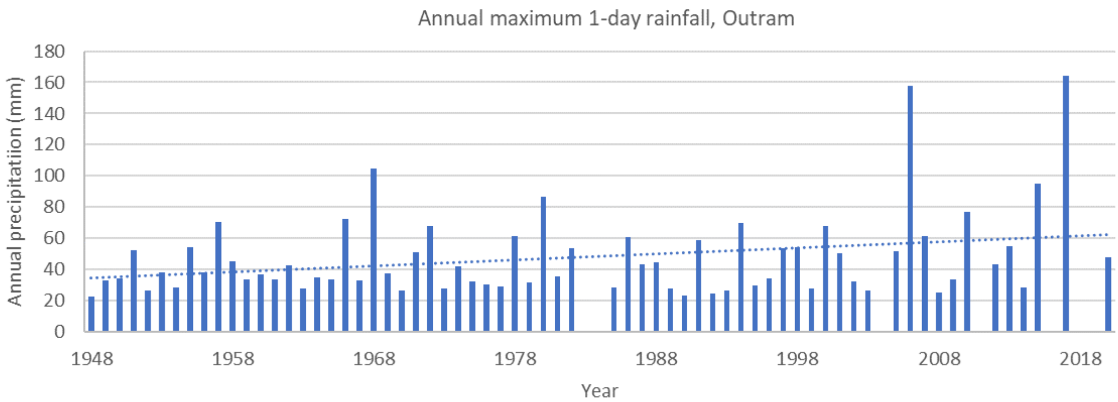


Figure 4-5 Historic maximum 1-day rainfall data from the Māniatoto Basin (Ranfurly) and the Strath Taiari Basin (Middlemarch). Data from neighbouring, or replacement climate stations is overlaid on the same graph.

[l] This analysis uses manual 9am rainfall readings. Rainfall totals over any 24-hour period can be much higher.

Figure 4-6 Floodwaters in Middlemarch, January 2021. Source: RNZ, https://www.rnz.co.nz/news/national/433989/severe-weather-eases-over-otago

A more definite trend is shown at the two long-term stations on the Lower Taiari Plain (Figure 4-7). The linear trend line for Maka Kahikātoa (Outram) shows that, on average, the maximum 1-day rainfall increased from about 34mm in 1948 to about 62mm in 2020. The most significant events on record at this site were in 2006 (158mm over 1 day) and 2017 (164mm). In Mosgiel, the linear trend is similar, increasing from 40mm in 1952, to 65mm in 2021. Heavy rainfall events of about 145mm were experienced in Mosgiel in 2006, 2015 and 2017.



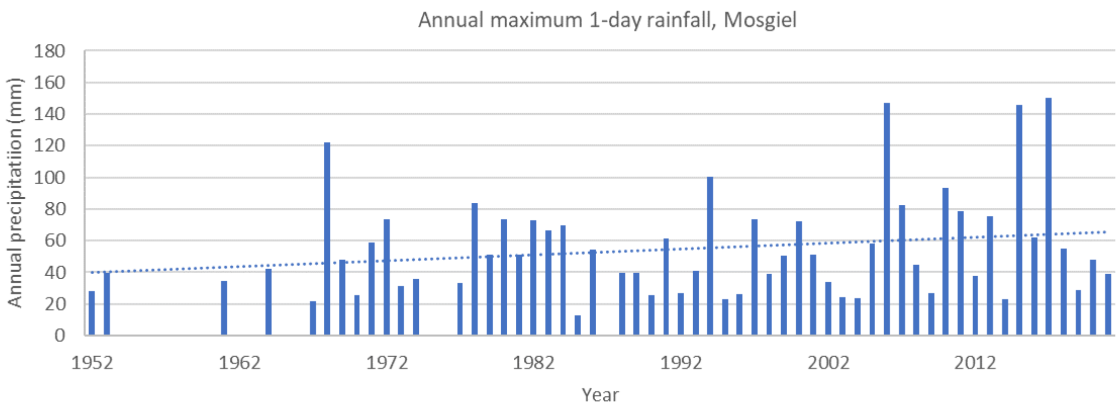


Figure 4-7 Historic maximum 1-day rainfall data from the Taiari Plain at Outram and Mosgiel.

4.2.2 Looking to the future – predicted changes in heavy rainfall events

The magnitude of heavy rainfall events is predicted to increase over this century and predicted changes at three locations with long-term historical rainfall records (see Table 1-1) are shown in Table 4-1.

Table 4-1 Rainfall totals (mm) during a 1 in 50-year rainfall event lasting 24 hours at Ranfurly, Middlemarch and Mosgiel. Data obtained from HIRDS [3].

	Ranfurly	Middlemarch	Mosgiel
Current estimate	79.4	95.7	127
2090 (low-mid scenario, RCP 4.5)	87.4 (+8)	105 (+9.3)	140 (+13)
2090 (high scenario, RCP 8.5)	96.6 (+17.2)	116 (+20.3)	155 (+28)

The scenario chosen is a 24-hour rainfall event, with an estimated return period of 1 in 50-years (Box 2). A range of other scenarios could have been modelled, using different duration events, and different return periods. These would likely show the same general trend: that when heavy rainfall events occur in the future (across a range of different scenarios), they will be more intense. The other reason this scenario was used is that storms lasting approximately one day are reasonably common in coastal Otago and the Taiari catchment and have previously resulted in significant flooding (see for example [6] and [7]).

Compared to the current situation, the scenario shown in Table 4-1 will bring an additional 8-28 mm of rain by 2090, depending on location and emission scenario.

Figure 4-8 North Taiari resident Harley Quinn walks in floodwater outside the North Taiari Tavern, September 2017 (Source: Otago Daily Times)

Box 2: Return Periods

A return period is an estimate of the average time between events such as heavy rainfall, floods, landslides, or river flows to occur. It is a statistical measurement typically based on historic data over an extended period.

Estimated return periods can change significantly when one or more large events are added to the record, particularly when the length of record is relatively short (<20 years) [7].

As well as increases in the magnitude of heavy rainfall events, parts of the Taiari catchment will also experience an increase in the number of heavy rain days.[m] At present, between zero and six heavy rain days can be expected across the Taiari catchment each year, with the highest number occurring in the upper Silver Stream catchment (to the north of the Taiari Plain), and the fewest in the Strath Taiari and Māniatoto basins [2]. By 2090, the southern part of the catchment (from Waipōuri to Henley) and the headwaters of the Silver Stream are predicted to experience an increase of up to two extra heavy rain days per year under the high range emission scenario (Figure 4-10).

Figure 4-9 Patearoa township bridge being cleared of debris after flooding in the Māniatoto in January 2021 (Source: Central Otago District Council/Fulton Hogan/Otago Daily Times)

[m] defined by NIWA as those with greater than 25 mm of rain [4]

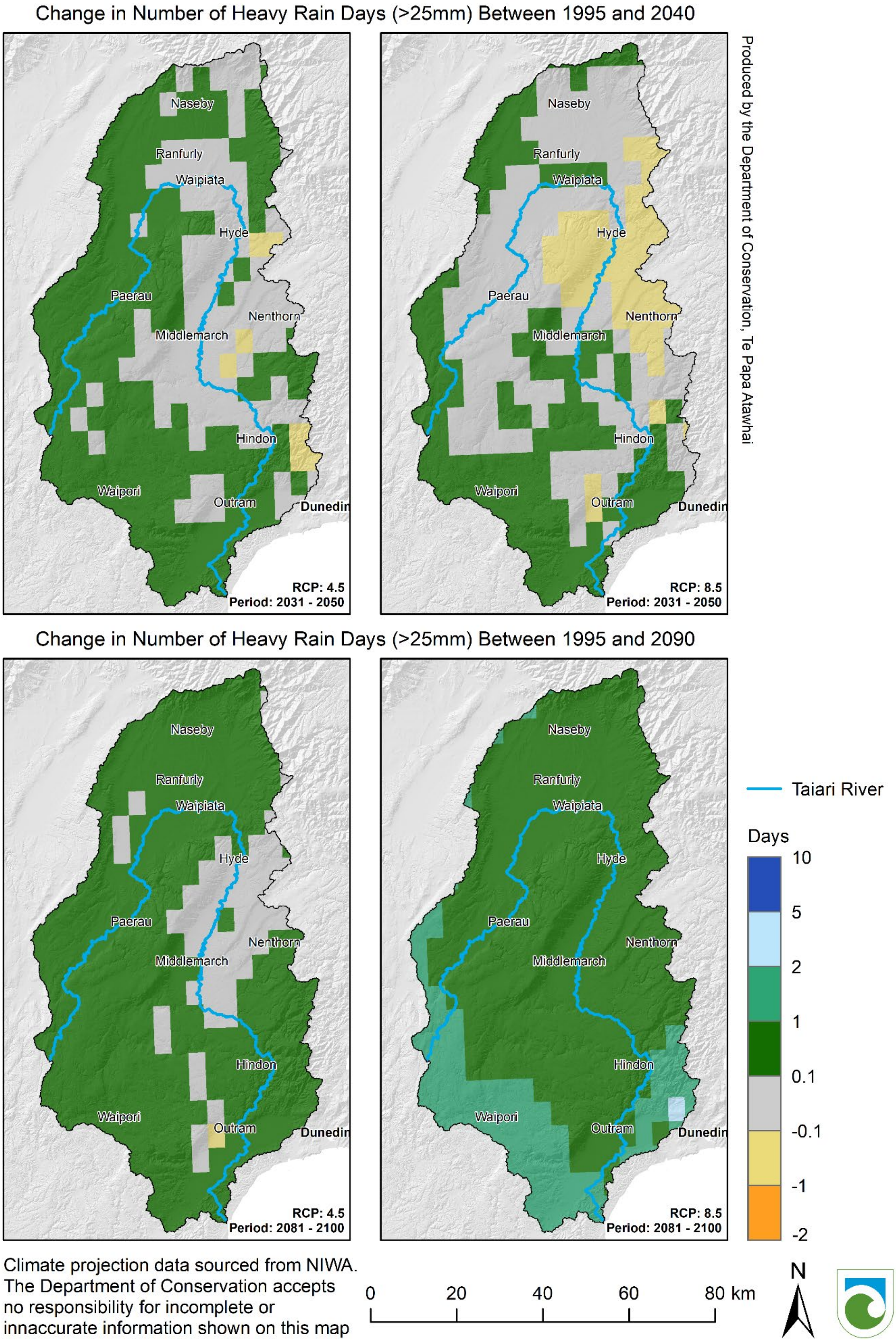


Figure 4-10 Changes in the number of heavy rain days predicted for the Taiari catchment under two climate change scenarios. The top images show predicted changes in the number of heavy rain days by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show the predicted changes by 2090 under a low-mid (left) and high range (right) emission scenario.

4.2.3 Looking to the future – predicted changes in the number of dry days

With annual rainfall generally predicted to increase, it is reasonable to assume fewer dry days; however, this isn't the case throughout the entire catchment. Presently, the area experiences between 200 and 275 dry days per year [4], depending on topography and location. NIWA's predictions show that the number of dry days (those where less than 1 mm of rain is recorded) that occur each year will increase in some areas, while decreasing in others. The main changes for the three key study areas, as modelled by NIWA (Figure 4-12) include:

- ***Māniatoto.*** *Ranfurly, which is already very dry (with up to 275 dry days per year) may experience an additional four dry days per year by 2040, and Naseby may experience an additional six days by 2090. In the upper catchment (upstream of Paerau, and across Pātearoa/Rock and Pillar Range), an additional six to ten dry days may be experienced by 2090, under the high range scenario (RCP 8.5).*
- ***Strath Taiari.*** *Most of the Strath Taiari basin also receives about 275 dry days per year. Modelling suggests the number of dry days in the basin will not change by more than one or two by the end of the century. However, Pātearoa (the Rock and Pillar Range) to the west may experience up to ten additional dry days.*
- ***Lower Taiari Plain.*** *This area currently receives between 225 and 250 dry days each year. Between four and six days fewer dry days per year are expected by 2090.*

Figure 4-11 Strath Taiari farmer Ron Jones and his dog Pip walk across bone-dry ground in August 1998, after a winter of little rain (Source: Otago Daily Times)

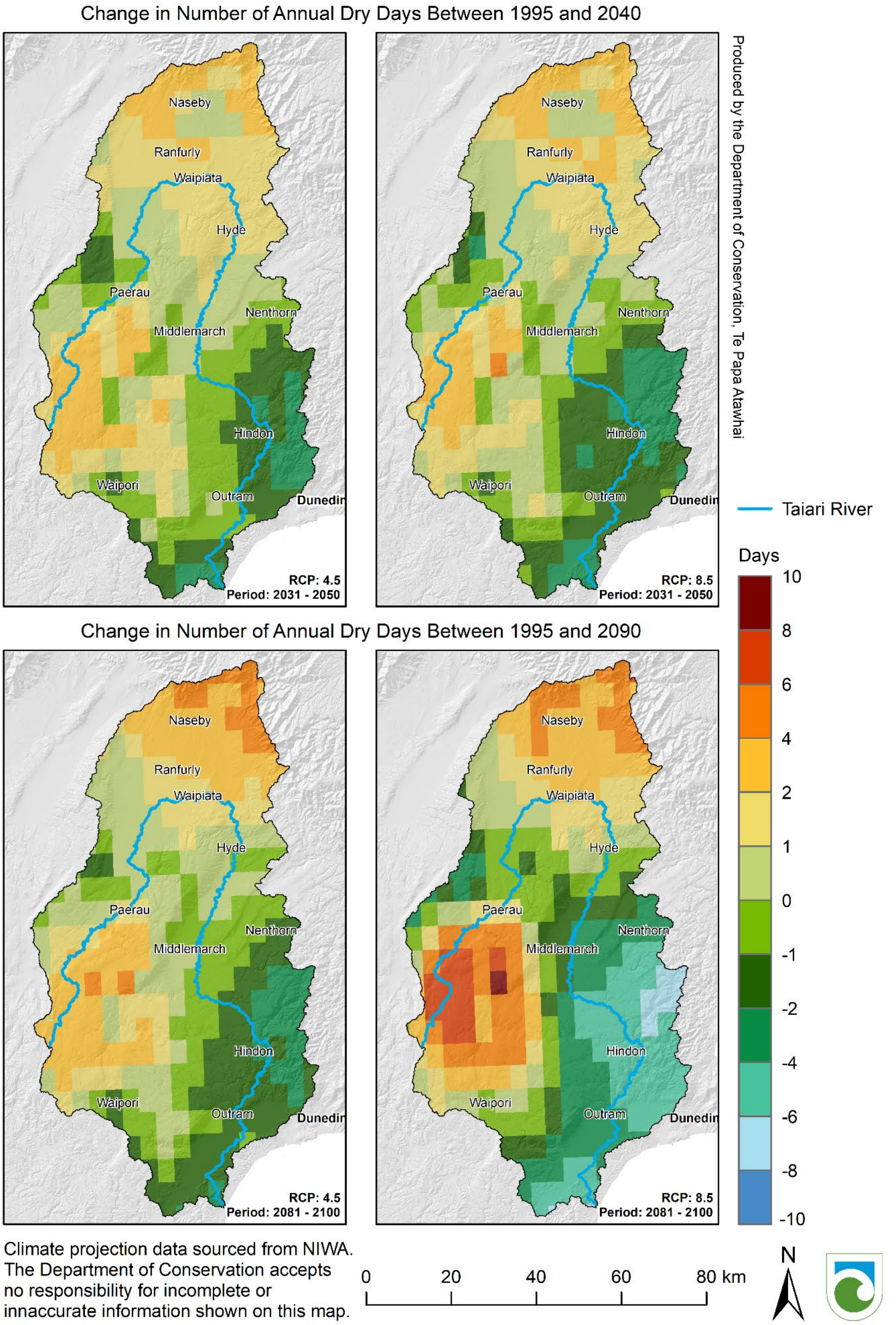


Figure 4-12 Predicted changes in the number of dry days predicted for the Taiari catchment under two climate change scenarios. The top two images show changes in the number of dry days by 2040 under a low-mid (left) and high range (right) emissions scenario. The bottom two images show changes in the number of dry days by 2090 under a low-mid (left) and high range (right) emissions scenario.

4.3 SNOW

Most of the low-lying parts of the Taiari catchment currently receive, on average, less than one snow day per year,[n] while more elevated areas (such as Pātearoa/Rock and Pillar, Kakanui and Te Papanui/Lammerlaw ranges) can receive up to 20 days of snow each year [3].

In the future, the number of snow days reduces everywhere, with the largest reduction (>15 days) in the coldest mountainous areas where there are a relatively large number of snow days in the present climate. The duration of snow cover is also likely to decrease, particularly at lower elevations.

Less winter snowfall and an earlier spring melt may cause marked changes in the annual cycle of river flow in the region. Places that currently receive snow are likely to see increasing rainfall as snowlines rise to higher elevations due to rising temperatures [18]. So, for tributaries of the Taiari River where the winter precipitation currently falls mainly as snow and is stored until the snowmelt season, there is the possibility for larger winter floods.

NIWA [3] state that further research is required on potential changes in snow amounts. In general, climate simulations show a reduction in snow days. However, it is possible snow amount could increase with rising temperatures in certain circumstances; a warmer atmosphere can hold more moisture, and on a day where temperatures are higher but still cool enough to snow, there is potential for increased heavy snowfalls. No analysis of snow extremes has been carried out at this point, however.

Figure 4-13 Snow coats the Lammermoor Range (Te Papanui), July 2020 (Source: Otago Daily Times)

[n] NIWA [3] acknowledge that their modelling of present (1986-2005) snow days is probably underestimated, particularly for low elevation locations where snowfall can still occur when the ambient air temperature is at or above 0°C.

5.0 WIND

Wind patterns vary considerably across the Taiari catchment, and any part of the catchment can experience extreme winds on occasion (Figure 5-1). In general, higher and more exposed areas can experience windier conditions, and higher wind gusts.

Figure 5-1 Trees downed by high winds near Mosgiel, September 2020. Source: www.mylittlelocal.co.nz/dunedin-notifications/dunedin-roads/fallen-trees-block-road-in-mosgiel/

5.1.1 Understanding the past – historical changes in wind

Historical changes in mean wind speed and the highest daily wind run at three climate stations in the Taiari catchment are shown in Figure 5-2. The data suggests that over the last 20-30 years, these sites have become less windy, with most showing a slight downward trend, particularly for mean annual wind speed at the Dunedin Aero site on the Taiari Plain.

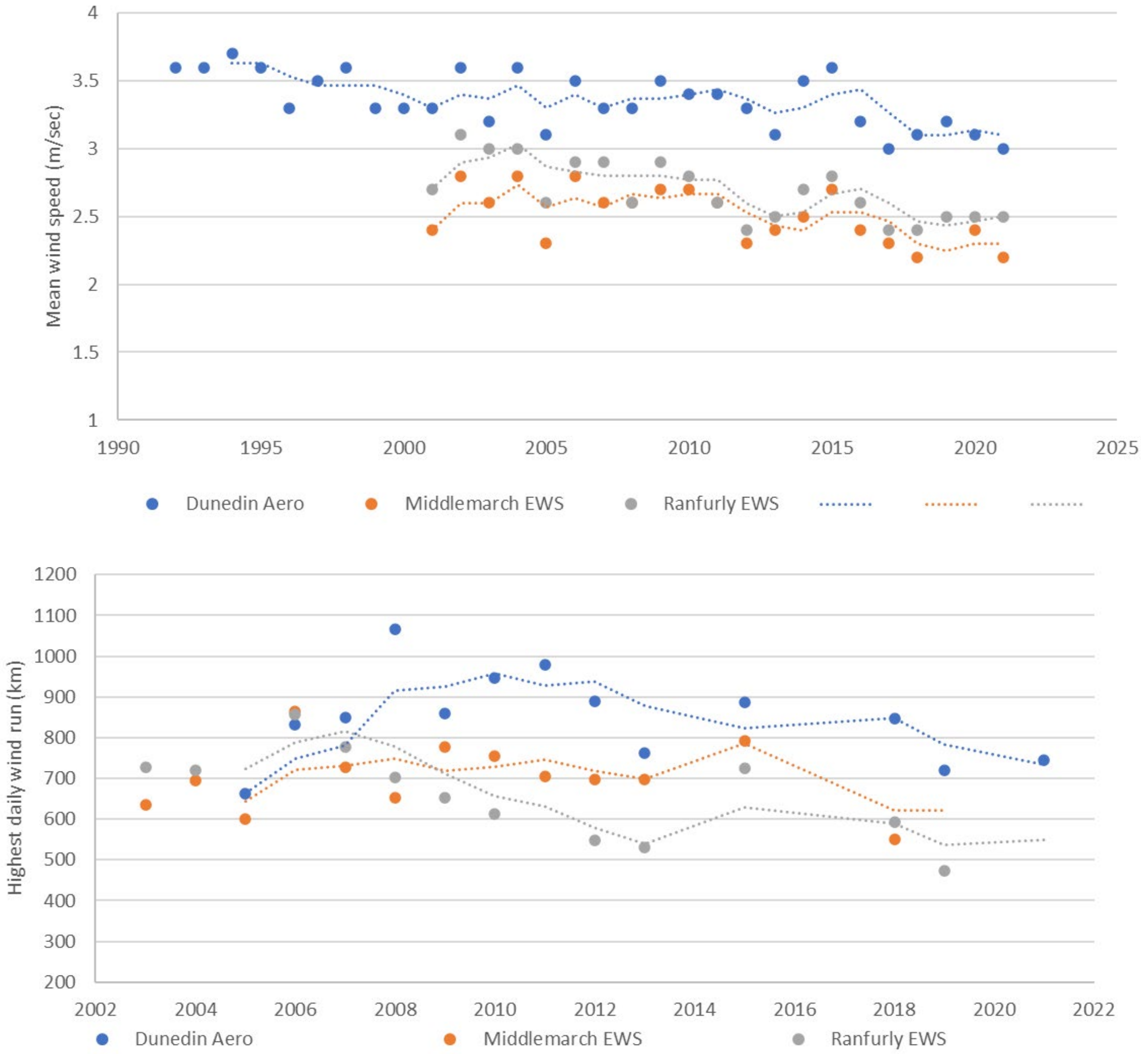


Figure 5-2 Historic wind data from Ranfurly, Middlemarch and the Taiari Plain (Dunedin Aero). Top: mean annual wind speed in m/sec. Bottom: highest daily wind run (km). Three-year moving averages are shown.

5.1.2 Looking to the future – predicted changes in wind

Changes in air temperature will also impact local wind conditions and NIWA have modelled changes in extremely windy days (Figure 5-3). Extreme wind is defined here as the top 99th percentile of daily wind speeds, which roughly equates to the top three windiest days that are experienced each year [4].

Across most of the catchment, the modelling shows little change (or in some areas, even a slight decrease) in extreme daily wind speed during the rest of this century, under the RCP4.5 emissions scenario. However, under the RCP8.5 emissions scenario, there are some significant increases in extreme daily wind speed in some areas, particularly around Ranfurly and Naseby by 2090.

As noted above, a general downward trend is evident at the Dunedin Aero site on the Taiari Plain over the last 30 years. The NIWA modelling suggests that this trend will continue, and Figure 5-3 shows that extreme daily wind speed will decrease by 1 to 2% across in the lower catchment by 2090.

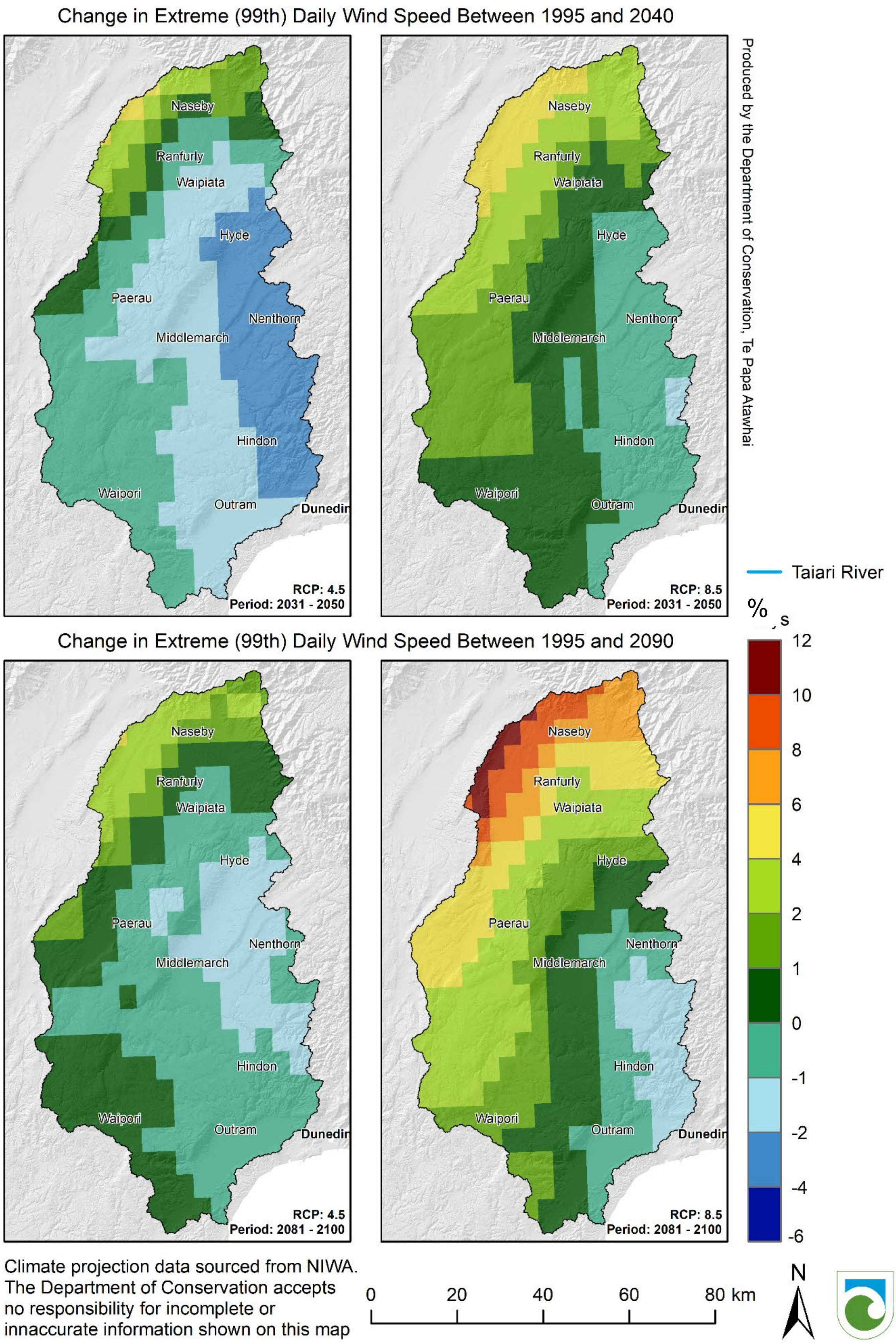


Figure 5-3 Changes in extreme daily wind speeds (as a percentage) under two climate change scenarios. The top images show changes in extreme daily wind speed percentages by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom images show changes in extreme daily wind speed percentages by 2090 under a low-mid (left) and high range (right) emission scenario.

6.0 HYDROLOGICAL IMPACTS OF CLIMATE CHANGE

Changes in low flow, mean annual flow and mean annual flood across the Taiari catchment were modelled by NIWA using the TopNet model under the RCP4.5 and RCP8.5 emission scenarios [3]. The key changes for each of these parameters are summarised in this section.

6.1 OVERVIEW

The hydrological modelling undertaken by NIWA for river conditions at the end of this century can be summarised as follows:

- *There will generally be less water in the Taiari River and its tributaries during extended dry periods,[o] particularly in the mid and upper catchment.*
- *High flow and flood events will generally be larger across most of the Taiari River catchment, especially under the RCP8.5 (business as usual) scenario.*
- *The average flow in the Taiari River and its tributaries will remain about the same. It is noted however that the upper and lower flow limits (i.e., floods and low flows) are predicted to become more pronounced.*

Box 3: Measuring river hydrology

Hydrological parameters such as low flow, mean annual flow and mean annual flood can be determined at a specific location within a catchment, based on continuous measurements from a monitoring station, taken over a number of years. The longer the period of record, the more accurately the hydrology can be described. These site-specific measurements can then be extrapolated to other parts of the catchment using modelling such as that described in Box 1.

See ORC's Environmental Data Portal for more information about the hydrology of the Taiari River and its tributaries.

River monitoring site on the Taiari River at Tiroiti. Records commenced at this site in 1982. (Source: GHC)

[o] i.e., periods of low flow and droughts.

6.2 LOW FLOW

The parameter used to describe low flow is Q95 (the flow that is exceeded 95 percent of the time). Modelled changes in Q95 by the end of this century are shown in Figure 6-1, and are described for two RCP scenarios as follows:

- **RCP4.5**: Low flows are predicted to decrease across the whole catchment by mid-century, particularly the small tributaries which drain to the south from the Kakanui Mountains (northern Māniatoto) and towards the west from Taiari Ridge (towards the Strath Taiari). This pattern generally remains consistent by the end of the century.
- **RCP8.5**: Under this scenario, low flows are also predicted to decrease across most of the catchment. By the end of the century, Q95 is expected to decrease by 20 to 50% in the northern part of the catchment (tributaries which flow from the Kakanui Mountains towards Waipiata). A similar decrease in low flow is expected in tributaries which drain towards the west from Taiari Ridge (towards the Strath Taiari). The exception is the Silver Stream catchment which flows into the Taiari Plain from the north, where Q95 is expected to increase by between 20 and 50%.

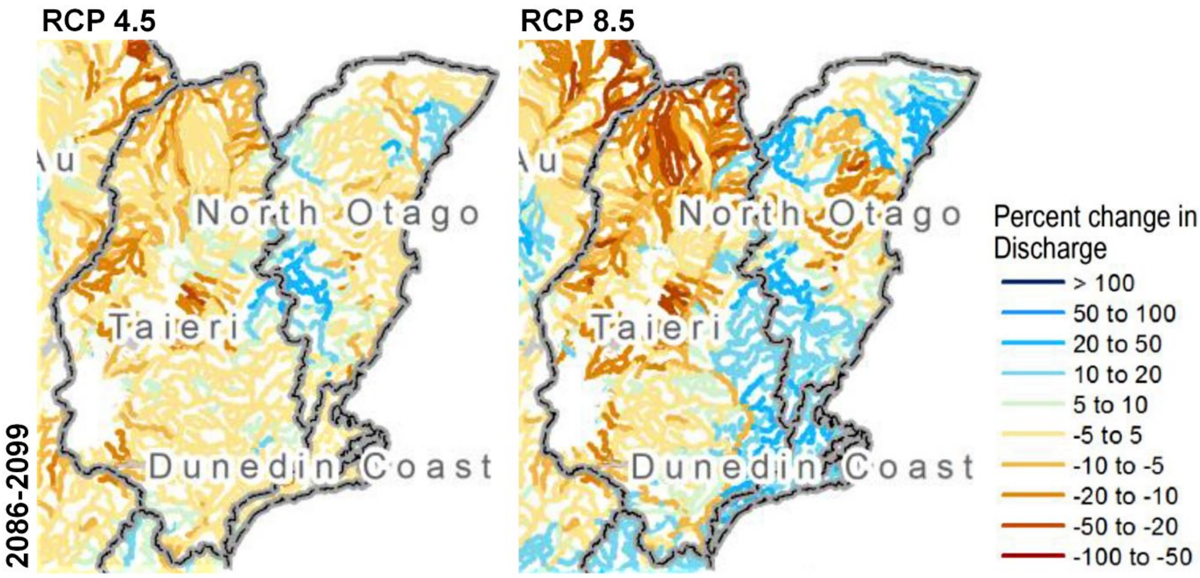


Figure 6-1 Predicted changes in low flow in tributaries of the Taiari catchment by late century under RCP4.5 (left) and RCP8.5 (right). Figures adapted from Macara et al [4].

6.3 MEAN ANNUAL FLOW

Mean annual flow means the average flow of a river, or stream (measured in cubic litres or cubic metres per second). Modelled changes in mean annual flow by the end of this century are shown in Figure 6-2, and are described for two RCP scenarios as follows:

- **RCP4.5:** Mean annual flows are predicted to remain reasonably steady (from -5 to +5%) across the whole catchment by mid-century. This pattern continues late-century, with the exception of the Silver Stream catchment which flows into the Lower Taiari Plain from the east, where mean annual flow is expected to increase by between 5 and 20%.
- **RCP8.5:** Under this scenario, mean annual flow remains reasonably steady through until mid-century. However, increases across much of the catchment are predicted by the end of the century, by as much as 50% in the southeast (Silver Stream) and west (streams draining from Rough Ridge).

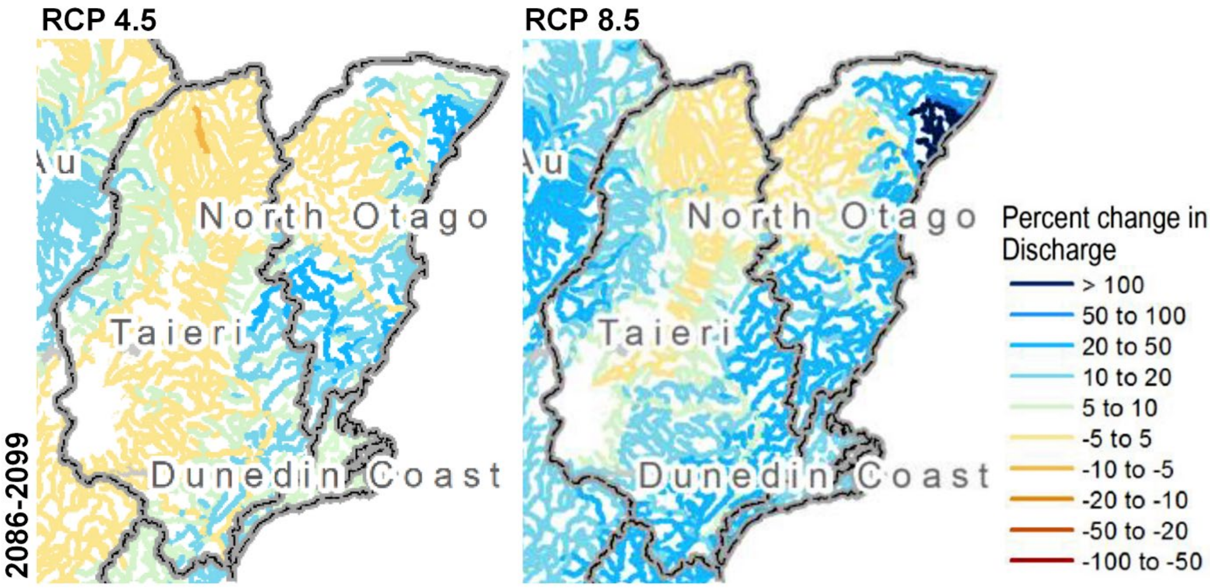


Figure 6-2 Predicted changes in mean annual flow in tributaries of the Taiari catchment by late century under RCP4.5 (left) and RCP8.5 (right). Figures adapted from Macara et al [4].

6.4 MEAN ANNUAL FLOOD

Mean annual flood is the mean of the maximum flood discharges experienced at a particular stream gauge (Box 3) over a series of years. It is noted that the mean annual flood is an event which occurs reasonably frequently, and therefore modelled changes in this parameter do not necessarily represent potential changes in the size or frequency of large, rare (and destructive) floods. Modelled changes in mean annual flood by the end of this century are shown in Figure 6-3, and are described for two RCP scenarios as follows:

- **RCP4.5:** The size of the mean annual flood is expected to increase across much of the catchment by the end of the century under this emissions scenario.
- **RCP8.5**: Under this scenario, mean annual flood increases across the whole catchment by late century, with the largest increases (of between 50 and 100%) predicted for the tributaries which flow into the Māniatoto.

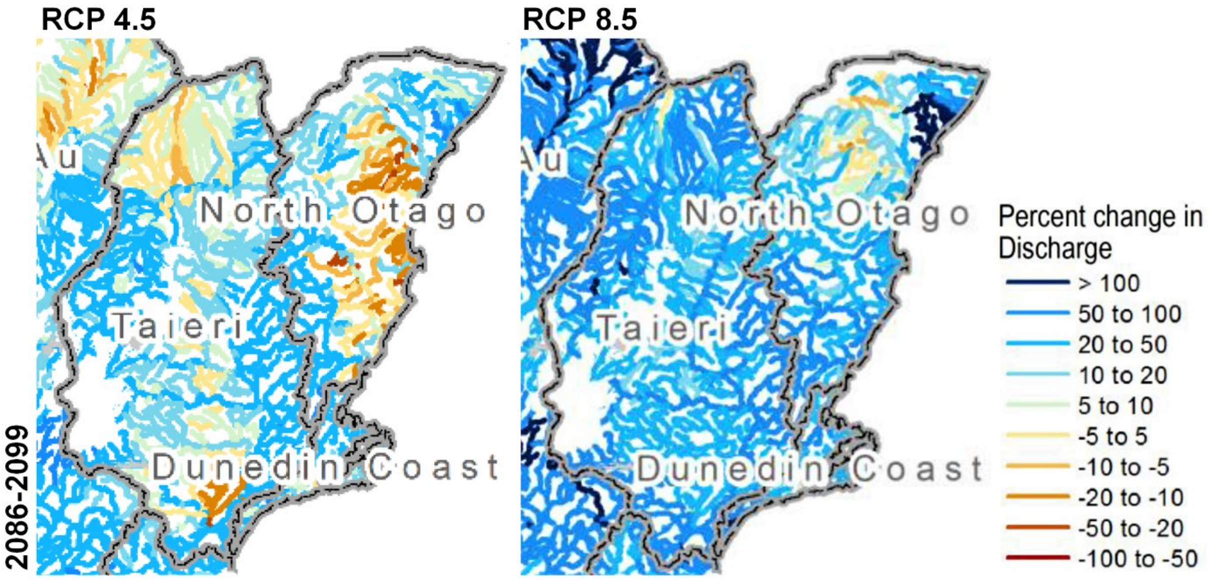


Figure 6-3 Predicted changes in mean annual flood in tributaries of the Taiari catchment by late century under RCP4.5 (left) and RCP8.5 (right). Figures adapted from Macara et al [4].

7.0 RISKS

This section broadly describes the risks associated with climate change for freshwater ecosystems, wetland ecosystems, and water quality/quantity.

7.1 INTRODUCTION

To provide a broad overview of the risks associated with climate change (particularly for freshwater ecosystems), this report summarises the results of a previous risk assessment undertaken by Tonkin & Taylor (T&T) for the Otago Regional Council (ORC). The Otago Climate Change Risk Assessment (OCCRA) [22] provides a regional summary of risks to Otago from climate change, and the objectives of this work are summarised in Appendix 1. The OCCRA groups risks according to five domains: natural environment, human, economy, built environment, and governance. This section extracts risk information from the natural environment chapter of the OCCRA that are relevant to waterways in the Taiari catchment.

A number of case studies from the Taiari catchment are included within this chapter. These are intended to illustrate the risks associated with changes in climate, using sites in the Taiari catchment as examples. These case studies have been informed by previous consultation with stakeholders in 2022 and 2023,[p] as part of the development of Matatū ki te Taiao (climate resilience strategy) for the Te Mana o Taiari Ngā Awa river restoration programme.[q] Photos and drone footage across the Taiari catchment were collected in April 2023, and images from this field work are also used to help illustrate potential risks.

7.1.1 Limitations of this risk assessment

It is noted that the OCCRA is focused on regional, rather than localised risks and was conducted utilising knowledge and research available at the time, augmented by stakeholders and subject matter experts within the region. The T&T report also includes the following acknowledgement regarding the limited involvement of Kai Tahu Rūnaka in the development of the OCCRA:

> *"…Kai Tahu Rūnaka were unable to participate in the early stages of the OCCRA to the level at which they…would have desired. The feedback received from Aukaha…identified some limitations to the methodology of this risk assessment, resulting from the lack of mana whenua region-specific knowledge, values and tikaka being incorporated. The Rūnaka considered that the approach used did not reflect a Māori worldview, particularly as the approach involved assessing risks within discrete domains, thereby creating limitations to assessing the interrelatedness of climate change risks. It is recognised that many risks are inherently interconnected, however a full assessment of interconnected and cascading risks was outside the scope of this assessment."*

This report is limited in that it attempts to describe risks at a local or community scale, by extracting the relevant (and admittedly limited) information from the regional-scale OCCRA. It also does not fully assess how climate change impacts and risks may be interconnected across all domains, including those valued by Māori. This report provides a starting point by bringing together existing information relevant to freshwater values of the Taiari River, so that this can be used to inform further discussion about changes already observed, and what is at risk in the future.

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[p] Representatives from Te Rūnaka o Ōtākou, Kāti Huirapa Rūnaka ki Puketeraki, Department of Conservation, Otago Regional Council staff and Councillors, Te Nukuroa o Matamata staff, and the local community attended rautaki (strategy) sessions in June 2002 [32] and May 2023 [33].

[q] The key results from this previous consultation are included in Appendix 2.

As noted in section 1.0, the present report is aimed at mana whenua, and could be significantly improved with additional input from Kai Tahu Rūnaka. It is a first step at collating current climate change information that can be used to inform future river restoration work in the main stem and tributaries of the Taiari River.

7.2 OVERVIEW

The OCCRA found that the highest (or 'extreme') risks to waterways are as follows:

1. *Risks to freshwater (rivers and lakes) ecosystems from increasing temperatures and extreme weather events.*
2. *Risks to coastal and inland wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice.*
3. *Risks to water quality and quantity from changes in rainfall, higher temperatures, flooding, drought and reduced snow and ice.*

7.3 RISKS TO FRESHWATER ECOSYSTEMS FROM CLIMATE CHANGE

The ability of freshwater ecosystems to respond to climate change hazards will largely be dependent on the flow of water [22]. Fluctuations of river flows to levels that either cause excessive erosion (floods) or flows too low to maintain ecosystem services (droughts) will stress freshwater communities. If extreme high and extreme low flows become more common over time, then the adaptive capacity of freshwater communities will reduce. The vulnerability of freshwater communities to projected changes in climate are discussed below.

7.3.1 High flows and storm events

The ORC prepared a strategy for managing river morphology and riparian margins in the Strath Taiari in 2016 [14]. Although the strategy's scope is limited to the Strath Taiari, it is also relevant to other parts of the catchment. The strategy describes the morphology of this section of the river as follows:

> *"The active channel of the Taieri River is a dynamic system where flood events and sediment transport movement regularly cause changes in riverbed morphology… Human activities, such as gravel extraction and physical works, can also result in significant morphological change…near these works, but…also across the wider river system."*

Previous sections of this report show that the severity of extreme storm events is predicted to increase throughout the Taiari catchment, along with more frequent and intense floods. A changing climate may also result in smaller flood events (or freshes) becoming more frequent (as noted in sections 6.3 and 6.4). Previous stakeholder engagement [32] also noted risks associated with extreme storm and flood events in the Taiari catchment. These predicted changes are likely to contribute to a higher loading of sediment in rivers and lakes through greater erosion from surrounding landscapes [4]. Box 4 below illustrates some of the physical impact of intense flood events, while Box 5 discusses potential tools for managing bank erosion.

Box 4: Case study – impact of intense flood events.

The impacts of previous flood events in the Taiari River where it crosses SH87 at Kokonga are illustrated below. They include erosion and undercutting on the outer (left) bank left of the river, a broad, armoured gravel bed on the inside (right) bank, and a predominantly single, incised channel.

Flooding in the Taiari River at Kokonga, looking towards the bridge, downstream is to the right, in November 2018 (Stuff).

Looking downstream from the Kokonga Bridge, April 2023 (Source: GHC).

Box 5: Tools for managing bank erosion.

The Taieri River Morphology and Riparian Management Strategy [14] lists a number of tools to address bank erosion. The strategy notes that traditional methods such as gravel extraction, moving gravel within the channel ('cross-blading') and spraying should still be considered where appropriate. However, it also notes that 'natural' methods such as establishing a vegetative cover of strongly rooted plants can be a more effective means of controlling riverbank erosion, as *"vegetation roots increase bank stability by protecting soils against entrainment from flood flows, and root mass and density provide soil shear strength, thereby protecting against gravity collapse of undercut banks."*

The strategy found there are often other benefits associated with riparian planning, including trapping of fine sediment and nutrients, shade, shelter, and improved aesthetic and recreational values. The strategy notes that the local community expressed a strong desire to see the form of the river include riparian plantings, particularly native species.

Bank erosion on the true left bank of the Kyeburn at Scott Lane (Source: GHC)

The OCCRA found that extreme weather events present a high level of risk to freshwater communities (both in lakes and rivers), and that freshwater ecosystems can be significantly impacted by extreme flood events. In terms of the risks associated with extreme flood events, the OCCRA notes that:

- *Fish and invertebrates can be removed from much of the river due to extreme flood flows.*
- *Increased flow and velocity in the river during extreme flood events can cause riverbank erosion, and that this can lead to the loss of spawning habitats for native fish and invertebrates.*
- *Extreme floods often lead to a reduction in the diversity of freshwater ecosystems. Native fish species can take longer to recover due to their slower reproductive rates (noting that some galaxiids can live at least 10 years). Species with short generations, and those which can find refuge deep in the riverbed can recover more quickly following an extreme event.*

The OCCRA notes that a key risk to freshwater ecosystems in lakes is that sediment loads are predicted to increase due to upstream erosion, particularly where the catchment includes land-uses with high nutrient uses (e.g., agriculture and forestry). Lakes Waihora and Waipōuri are located in the lower catchment and may face additional risks due to sediment input from upstream, combined with the low velocities and tidal nature of the lowest reaches of the Taiari.

The OCCRA notes that there may be some benefits for freshwater ecosystems associated with small, regular flood events, including:

- *The recovery time for freshwater communities is normally much quicker than after extreme events, although there will still be some losses.*
- *Smaller flood events can help to remove mats of algae and cleanse fine sediment accumulations.*

A further risk noted in the OCCRA for shallow lakes (such as Waihora and Waipōuri) is that they will be more prone to increasing temperature, particularly in summer, and may develop stratified layers with higher trophic levels [25]. Waihora is already classified as supertrophic (i.e., highly nutrient enriched). Such changes could result in negative outcomes such as deoxygenation events, fish and/or shellfish die offs, macrophyte collapse (which then destabilises lake sediments), and algal blooms, including toxic cyanobacterial blooms.

7.3.2 Low flows and droughts

As noted in section 6.2, there will generally be less water in the Taiari River and its tributaries during extended dry periods, particularly in the mid and upper catchment. More dry days, warmer temperatures, and more hot days may lead to increasing frequency and duration of drought conditions, particularly in summer. The areas which are most likely to be affected by drought and low flows include the Māniatoto and Strath Taiari basins. These impacts may be more moderate in the lower half of the catchment where mean annual flow is expected to increase by the end of the century, particularly under the RCP8.5 scenario (Figure 6-2).

Over the short term the general increase in temperature may be buffered by the capacity of rivers and lakes to absorb heat, and the general increases in temperature may be tempered by increasing annual rainfall (section 4.1.2). However (and particularly in the two upper catchment basins), if river levels drop significantly during summer months this buffering capacity will be reduced, exposing the freshwater communities to additional stress [4].

Flow fluctuations are controlled in parts of the Taiari catchment to provide water for abstraction – and hence the resilience of freshwater communities in these reaches may be artificially reduced (Box 6). That is, unless maintaining minimum instream flows for irreplaceable stream biota (i.e., native plants, invertebrates and fish) and downstream river health are prioritised over abstraction for anthropogenic use.

Figure 7-1 shows an upper Taiari tributary where flow is artificially controlled, and where changes in climate may pose a risk to freshwater ecosystems, due to an increase in low flows and droughts.

The OCCRA [22] notes that the capacity for biota in lakes and rivers to tolerate increasing temperatures will reduce towards the end of this century. This regional risk assessment found that lakes in Otago may experience a "threshold response to climate change hazards – with little change over a number of decades followed by more rapid changes". The OCCRA also found that the capacity of many lakes to adapt will depend on the level of nutrient discharges resulting from human activities. It notes that:

> *"Those lakes with little or no riparian vegetation or control of discharges from surrounding land (particularly farmland) or urban developments will have a much lower adaptive capacity compared to lakes located in areas with little or no human land use."*

Previous stakeholder engagement [32] also identified risks associated with gradual changes in temperature, baseline flows and water usage in the Taiari catchment.

Figure 7-1 The Loganburn in April 2023, high in the Rock & Pillar Range (top) and where it transitions from the high country out onto the upper Māniatoto plain (bottom). Source: GHC.

These issues (i.e., nutrient enrichment, riparian planting, water abstraction) represent choices and management opportunities to mitigate the impacts of climate change and increase the resilience of the Taiari. A multi-faceted approach that provides for future generations is required to address the complex challenges presented by climate change.

We provide a Greek proverb below, modified for our times:

“A civilisation is truly great when old people plant trees under whose shade they know they will never sit.”

Box 6: Water allocation in the Taiari catchment

The Taiari catchment is heavily over-allocated, largely as a result of the use of historic deemed permits to allocate water [23]. The Otago Water Plan includes provisions to address this through the conversion of all deemed permits to resource consents by their expiry time in 2021, although at the time of writing this has yet to be completed. The Māniatoto Irrigation Company operates a large irrigation scheme that supplies water from the upper Taiari, and water stored in Loganburn Reservoir to three irrigation companies in the Māniatoto Basin. There are many other permits to extract water across the catchment, both from the main stem of the Taiari River, and its tributaries. Irrigation is the main abstraction activity along the length of the Taieri River mainstem, with small amounts also taken for drinking water [24].

Loganburn Reservoir (Source: GHC)

Water storage and canal above the Maniototo Plain, at Stonehenge (Source: GHC)

7.3.3 Summary of risks to freshwater ecosystems

The impacts of climate change on freshwater ecosystems, and risk ratings assigned by the OCCRA [22] are summarised in the following table.

Table 7-1 Risk ratings for freshwater ecosystems, and key risk information identified in the OCCRA.

Risk statement		**Risk rating[r]**			**Other comments[s]**
		Present	**2040**	**2090**	
	Risk to native ecosystems and species due to change in rainfall	L	L	M	• Climate hazards and the associated impacts on river and lake ecosystems are most likely to be measured by changing composition of freshwater communities and a general loss of biodiversity markers over time, as well as changes in physical and chemical water quality parameters (e.g., temperature, dissolved oxygen). • Considering the likely effects of projected climate change alone[t] it is likely that by the end of the century, many lakes & rivers will have suffered significant losses to freshwater communities. • Losses are most likely to occur following large event-type disturbances such as severe floods, rather than in response to gradual changes. However, increasing temperature and changes in rainfall are likely to add stress to the freshwater systems, decreasing the recovery capacity to extreme events. • Smaller/shallower lakes may have increased trophic levels due to increasingly prolonged thermal stratification and increased nutrient loads. These changes will reduce the ecological support functions provided by many rivers and lakes and may result in an increased freshwater species extinction rate and loss of freshwater biodiversity. • These effects may be particularly pronounced for diadromous species including taoka and mahika kai species because they occupy different environments during different life stages and thus have multiple exposure scenarios. • The vulnerability of freshwater ecosystems to climate hazards, particularly to extreme weather events will depend (among other factors) on the success of juvenile recruitment, the retention of spawning habitats, and the minimisation of erosion and sedimentation of rivers and lakes.
	Risk to native ecosystems and species due to drought	L	L	M	
	Risk to native ecosystems and species due to higher temperature	M	M	E	
	Risk to native ecosystems and species due to extreme weather events (floods)	M	H	E	

[r] See Appendix A1.0 for an explanation of how risk ratings were determined in the OCCRA. The ratings incorporate assessments of hazard exposure, sensitivity and adaptive capacity. The four risks ratings are Low (L), Moderate (M), High (H) and Extreme (E).

[s] These comments summarise the key points noted in section 5.3.4 of the OCCRA (*Risks to freshwater ecosystems from increasing temperatures and extreme weather events*).

[t] i.e., assuming an absence of active management of freshwater ecosystems.

7.4 RISKS TO WETLAND ECOSYSTEMS

A wetland is an area of land that is flooded by water over a range of timescales – either permanently, seasonally, or irregularly. They support a distinctive array of natural ecosystems which have adapted to the unique conditions associated with regular inundation by water. Wetlands are recognised for their ecological, cultural, recreational and economic values (see Box 7) [26]. They play a key role in improving water quality and controlling floods [45], and support a high proportion of threatened native plants, fish, birds, and natural landforms.

Figure 7-2 Part of the Lower Taiari Wetland Complex at Titri (Source: GHC)

The Otago Regional Council provide information about wetlands on their website (link), including the values associated with wetlands in Otago, and information about specific wetlands in each part of the region. In the Taiari catchment, wetlands are found over a variety of landscapes, and within a broad range of climatic conditions. There are several Regionally Significant Wetlands, including the Upper Taiari Wetlands Complex in the Māniatoto (Figure 7-3), and the Te Nohoaka o Tukiauau/Sinclair Wetlands on the Lower Taiari Plain (Figure 7-4).

Predicted changes in climate across the Taiari catchment include changes in the supply and seasonality of water, with drought and flood conditions likely to become more common. Changes in the supply and seasonality of water could result in further decline of wetland ecosystems. In addition, wetland ecosystems typically have high sensitivities to sedimentation and increased erosion rates (due to rainfall changes and storm events) are expected to cause additional pressure on wetlands [22].

The OCCRA [22] notes that the vulnerability of wetlands to these changes will depend on the frequency of these extreme events, and how well their impacts can be managed (for example, through minimum flows, riparian plantings, land use and river management).[u] It also notes that as the severity of extreme events increases, the capacity of wetlands to respond and recover is expected to reduce.

Previous stakeholder engagement [32] found that wetlands in the Taiari catchment are likely to have a high sensitivity to climate change. Local stakeholder groups also identified risks due to

[u] The OCCRA notes that wetlands across Otago will likely remain at risk due to increasing pressure from intensification of human land-use and invasion by pest plants and animals [22].

sedimentation events (caused by floods), sea level rise and increasing salinity, and changes in baseline flows in the Taiari catchment. These changes may pose significant risks to wetlands across the catchment.

Climate change impacts and the associated risks for inland, alpine and coastal wetlands are described in more detail below.

Box 7: Economic value of wetlands

A 2013 study [29] provided an economic valuation of New Zealand ecosystems. It found that even though wetlands cover less than 1% of New Zealand's land area, they generate 13% of the direct (e.g., commodities) and indirect (e.g., supporting or protecting direct value) value obtained from land-based ecosystems. The study assigned value to the following services:

- *Water regulation (storage and retention)*
- *Disturbance regulation (e.g., storm protection, flood control, drought recovery).*
- *Cultural services (aesthetic, education, scientific values)*
- *Waste treatment*

An earlier case study [30] assessed the direct and indirect values of different types of ecosystems in the Manawatu-Wanganui Region. Wetlands had by far the highest annual value per hectare compared to other types of land use, as listed below (original values have been adjusted to 2022 using the Reserve Bank inflation calculator).

Ecosystem	***Total direct and indirect value per hectare***
• *Wetlands*	*$64,000*
• *Horticulture*	*$28,000*
• *Native forest*	*$3,000*
• *Dairy*	*$2,600*
• *Sheep and Beef*	*$1,000*

7.4.1 Alpine wetlands

Alpine wetlands are defined in the OCCRA [22] as those found above 800 m altitude. In the Taiari catchment they are found in places such as the headwaters of the first order streams of the Māniototo and in the Rock and Pillar range. They are inhabited by unique alpine bog plants, herbs and shrubs. The fish fauna is usually limited in diversity due to poor downstream connectivity, but rare non-migratory galaxias populations inhabit many of the alpine wetlands in the Taiari. They support diverse and unique invertebrates as well as alpine birds [46].

Although annual average rainfall is generally predicted to increase across alpine areas of the Taiari, there is likely to be greater seasonality (i.e., higher rainfall in winter and lower in summer). There may also be a reduction in the amount of water captured from the atmosphere by tussocks in alpine areas, and this is an important hydrological source for wetlands in the high country [47].

When combined with reduced snow and ice, increased air temperatures, and more dry days, these wetlands are more likely to dry out and decrease in size in summer months. Many of the alpine wetland plants are adapted to colder climates and are expected to be adversely affected by climate change. Competition is expected to increase from both native and exotic species expanding their range into alpine regions.

Alpine wetlands are the wetland habitat in the Taiari that is most likely to be impacted by projected climate change (ref). They are at extreme risk of impact by 2040 due to drought, rainfall change and reduced snow and ice.

7.4.2 Inland wetlands

Inland wetlands and unique scroll plains occur in the upper Taiari catchment between the central Otago block mountain ranges. The OCCRA notes that:

> *"These wetlands support a wide range of threatened native species including lamprey, longfin eel, non-migratory galaxiids, copper tussock, native starwort, New Zealand mousetail, and water birds including marsh crake and Australasian bittern, and high value landforms including oxbow lakes, old braids and backwaters [28]. These wetlands are expected to become increasingly exposed to changes in rainfall, prolonged drought periods, and increasing temperatures."*

The key vulnerabilities for inland wetlands noted in the OCCRA include:

- *The Maniototo and Strath Taiari are, in general, predicted to experience more dry days, warmer annual average temperatures, and more extreme hot days.*
- *This will tend to have a negative impact on wetlands, with a reduction in wetland area and some wetlands becoming more ephemeral.*
- *This may cause additional stress for wetland species, and lead to a decline in the local population of some species.*
- *Habitat damage may also occur due to extreme weather events, increased erosion, and increased pressure from exotic plant and animal pests.*

The OCCRA identified a high to extreme risk rating for inland wetlands in Otago due to changes in rainfall, temperature and drought (Table 7-3).

Figure 7-3 The Māniatoto Basin wetlands, part of the Upper Taiari Wetlands Complex (Source: GHC).

Box 8: Tunaheketaka

In the 1850s, Tunaheketaka (Taiari Lake) was a productive freshwater lake and was an important mahika site and source of tuna for Māori. By the late 19th century, the lake was silting up due to the movement of silt and gravel from upstream gold diggings. The run-off from gold sluicing filled the Taiari River and its tributaries with sediment, which was eventually deposited in the lake. As a result, the lake transformed into more of a swampy wetland environment. The water was drained in the 1940's and legend has it that a natural rock dam was removed using dynamite, deployed at night after the instigators had spent an evening at the local Waipiata Hotel. This drained the land for farming.

Tunaheketaka, near Waipiata in April 2023 (Source: GHC)

Today, the area is known as Taiari Lake and is a gazetted Recreation Reserve, currently used for grazing. The vegetation was described in 1985 as "highly modified and predominantly of exotic species", and the riverbank has been colonised by willow. Two distinct areas of wetland remain.

The *Taieri Lakes Working Party* includes representatives from DOC, Central Otago District Council and the Taieri Lakes Recreation Reserve Committee. It aims to provide for both wildlife management and grazing on the reserve. Restoration of this area is a priority for mana whenua, and there are opportunities to improve its natural values through changes in land use, hydrology (connections to the river) and vegetation.

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1. *Central Otago District Council (2016). Maniototo Ward Reserve Management Plan*
2. *Allen, R. (1985). Vegetation Report, Taieri Lake. Botany Division DSIR Report*
3. *Central Otago Rail Trail website [link].*
4. *C. Kavazos (personnel communication, June 6, 2023)*

Other wetland restoration links:

- https://www.lakestoriesnz.org/taiari
- https://www.doc.govt.nz/our-work/freshwater-restoration/nga-awa/taiari-river-restoration/

7.4.3 Coastal wetlands

There is a large wetland complex on the Taiari Plain where the river drains the Waihora-Waipōuri Wetlands. At this point in the past the river would have joined waters from Waihoropuka, which included three lakes (Tatawai, Waipōtaka and Marama Te Taha). However, these systems that are important to mana whenua were drained by early European settlers [19, 31] (see also section 1.3.3).

Coastal wetlands such as those found on the Taiari Plain are likely to become more frequently inundated by large flood events as the severity of extreme weather events increases over the coming decades [4]. The OCCRA [22] notes that these events could cause large-scale habitat destruction within coastal wetland ecosystems. A further impact noted is that sea level rise means these coastal wetlands are likely to experience increased salinity as the ability of the river to flush sea water from the lower catchment is diminished.[v] This will favour more salt tolerant species and disadvantage those species with a lower tolerance for salinity. Also, species with a high dispersal ability may be able to respond with range changes (e.g., moving inland if suitable habits are available), however those species with limited dispersal ability have limited ability to adapt because of the fragmented nature of coastal wetland habitat. This may result in the loss of these species locally. Table 7-3 shows that the highest climate change risks for coastal wetlands are linked to salinity stress, coastal flooding and sea level rise.

Figure 7-4 Te Nohoaka o Tukiauau / Sinclair Wetlands, part of Lake Waihora-Waipōuri wetland complex on the Lower Taiari Plain (Source: GHC)

[v] Due to its low-lying nature and flat topography, the interface between fresh and sea water in the lower Taiari is likely to move further inland as a result of sea-level rise.

7.4.4 Summary of risks to wetland ecosystems

The impacts of climate change on alpine, inland and coastal wetlands ecosystems, and risk ratings assigned by the OCCRA [22] are summarised in Table 7-3 and Table 7-3.

Table 7-2 Risk ratings for alpine wetlands, and key risk information identified in the OCCRA.

Risk statement	**Risk rating**			**Other comments**[w]
	Present	**2040**	**2090**	
Risk to *montane and alpine wetlands* due to higher temperature	M	H	E	• The increased seasonality of rainfall, coupled with decreased snow and ice cover is likely to contribute to water deficits in alpine wetlands in summer months. • Alpine wetlands are therefore likely to decrease in size, and may change along a spectrum from permanent to temporary and ephemeral in nature. • Many species of wetland plants have limited dispersal ability and thus limited or no capacity to adapt to the projected climate changes.
Risk to *montane and alpine wetlands* due to drought and change in rainfall	M	E	E	
Risk to *montane and alpine wetlands* due to reduced snow and ice	H	E	E	

[w] Summarising key points in section 5.5.4 of the OCCRA (*Risks to wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice*).

Table 7-3 Risk ratings for wetland ecosystems, and key risk information identified in the OCCRA.

Risk statement	Risk rating Present	Risk rating 2040	Risk rating 2090	Other comments[x]
Risk to *inland wetlands* due to higher temperature	L	M	E	• Wetlands have some high risk ratings due to their low adaptive capacity and high sensitivity to the impacts of climate change. • The risk rating for inland wetlands due to changes in rainfall will increase over this century, with an extreme rating by 2090. Increasing temperature and drought are also expected to lead to extreme impacts by 2090. • Inland wetlands are considered to be at risk from increasing seasonality of rainfall and increasing/prolonged drought periods leading to a contraction of wetland habitat and associated stress on populations of wetland species. • Changes are likely to be slightly more moderate for coastal wetlands, with the highest risk ratings associated with salinity stress/sea level rise and changes in rainfall. • Changes in moisture volume and availability, together with changes in sediment loading, increasing temperature, extreme weather events, and drought conditions are expected to lead to declines in wetland diversity and geographic range across Otago. • As a result of predicted changes in climate, impacts on wetlands are likely to include a reduction in habitat due to changing moisture balances, declines in populations of wetland species, and reduced wetland biodiversity. These factors are likely to be exacerbated by continuing changes in land-use for human development/production purposes, and sedimentation due to increased erosion rates and extreme weather events.
Risk to *inland wetlands* due to drought	M	M	E	
Risk to *inland wetlands* due to change in rainfall	M	H	E	
Risk to *coastal wetlands* due to drought	L	L	H	
Risk to *coastal wetlands* due to higher temperature	L	M	H	
Risk to *coastal wetlands* due to change in rainfall	L	M	E	
Risk to *coastal wetlands* due to salinity stress, coastal flooding and sea level rise	L	H	E	

[x] Summarising key points in section 5.5.4 of the OCCRA (*Risks to wetland ecosystems from drought, higher temperatures, changes in rainfall and reduced snow and ice*).

7.5 RISKS TO WATER QUALITY AND QUANTITY

The LAWA website (link) includes data for the ten water quality monitoring stations in the Taiari catchment, and shows that water quality varies considerably across the catchment (Box 9). Water quantity data is available on the ORC Water Info website (link).

The key risks to water quality and quantity due to predicted changes in climate are discussed below.

7.5.1 River water quality and low flows

Water quality is closely linked to the amount of flow in the river, with low flows resulting in less frequent flushing of sediment/nutrient. Warmer water (during extended periods of low flow) is also more likely to promote algal growth. Predictions are for less water in the Taiari River and its tributaries during extended dry periods, particularly in the mid and upper catchment (section 6.2). Persistent low flow or drought conditions will have a negative impact on water quality in the river, and the OCCRA [22] identifies an extreme risk to river water quantity and quality due to changes in rainfall, drought and higher temperatures combined (Table 7-4).

Similar findings were noted by Orchard [32] through kōrero with local stakeholders. Water quantity and quality in the Taiari catchment were both assessed as having a high sensitivity to climate change, along with native fish and aquatic invertebrates. Relevant climate-related risks which were noted include:

- *Disturbances in food webs and ecological processes*
- *Invasive species behaviours and ecology, and*
- *Shifts in species distributions.*

Figure 7-5 shows the Taiari River near Waipiata, where there is already pressure on water quality due to upstream land use, [y] and where predicted changes in climate may result in further deterioration in water quality and quantity over the coming decades. LAWA [23] states that at Waipiata, the water was suitable for swimming on 77% of the occasions sampled and unsuitable for swimming 9% of the time. Further analysis revealed that the source of bacteria at Waipiata is ruminant (sheep/cows), and the website recommends people *"stay out of the water for 48 hours after rainfall or after high river flows to avoid swimming in rural run-off that can contribute to high bacteria concentrations."*

Modified river channels:

There are several sections of the Taiari River and its tributaries where human activity has significantly changed the natural characteristics of the channel. These include the lower Silver Stream (Figure 7-6), the Taiari River between Outram and Henley, and the Waipōuri River between Berwick and Lake Waipōuri. The OCCRA notes that sections of river with altered morphology are already more prone to developing poor water quality under low flow conditions due to a lack of riparian vegetation, increased sediment and nutrient run-off.

[y] C. Kavazos (personnel communication, June 6, 2023)

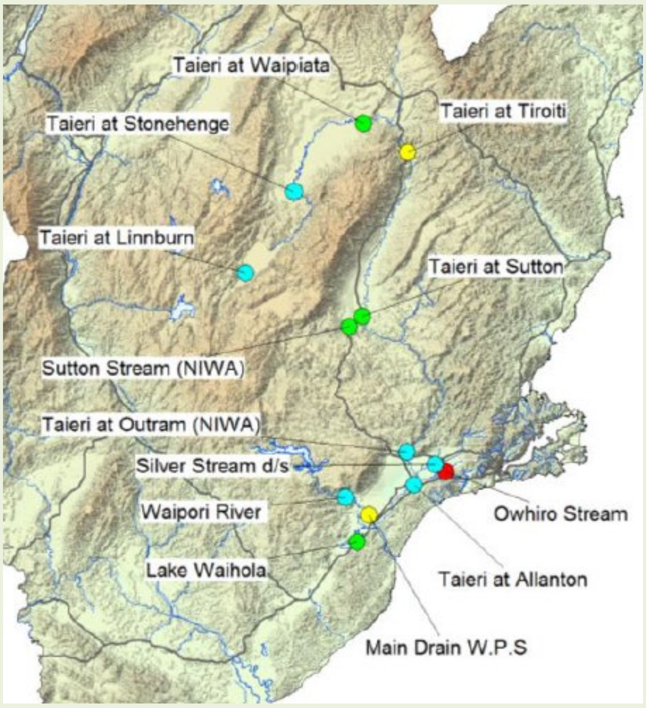
Figure 7-5 The Taiari River from the Central Otago Rail Trail Bridge near Waipiata, April 2023 (Source: GHC)

Figure 7-6 Silver Stream at Riccarton Road, looking downstream, April 2023 (Source: GHC).

Box 9: Taiari catchment water quality

The map to the right is from a 2010 ORC report on Taiari water quality [39]. This showed water quality was generally 'very good' or 'good' in the Māniototo and Strath Taiari, while there was one site on the Lower Taiari Plain with 'poor' water quality (Owhiro Stream).

Very Good	All six values comply with guideline values
Good	Five median values comply
Fair	Three or four median values comply
Poor	Two or fewer median values comply with guideline values



Summary map showing 2010 water quality index for Taiari catchment sites.

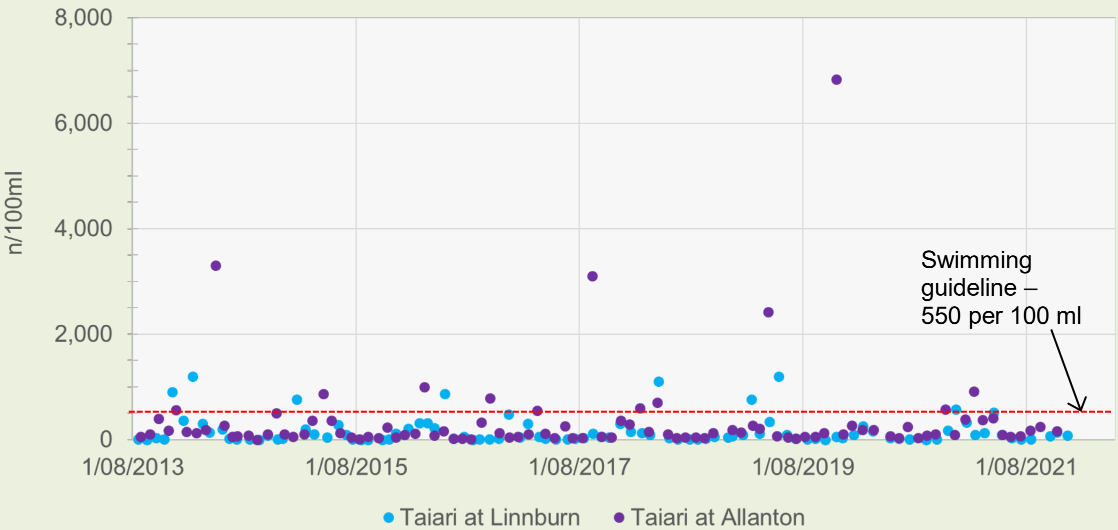
The LAWA website [23] shows that although variable, water quality is still generally better upstream than in the lower catchment. The table below shows recent data for a similar suite of water quality indicators to the 2010 ORC report, for two sites in the upper catchment and two on the Lower Taiari Plain.

Parameter	Linnburn	Tiroiti	Silver Stream	Allanton
Bacteria	B	A	D	D
Water Clarity	B	D	A	D
NH4	A	A	B	A
NN	A	A	A	A
DRP	A	A	B	B

A B C D

Water quality parameters at four sites. The colour-coded bands (A-D) describe the likely effect of each parameter and are explained further on the LAWA website [23].

This trend is illustrated in the graph below, which shows bacteria levels (*E. coli*) in the Taiari River can, at times, be much higher at Allanton compared to upstream at Linnburn. The presence of *E. coli* can indicate that the water has been contaminated with faecal matter, and it may contain pathogens that can cause illness. Swimming is not recommended when *E. coli* levels exceed 550 per 100 ml [23].



7.5.2 Lake water quality and floods

High flow and flood events will generally be larger across most of the Taiari catchment, especially under the RCP8.5 scenario (section 6.4). The impact of larger, and more frequent flood events on the water quality of lakes, as noted in the OCCRA, includes:

- **Inland lakes.** Flooding and/or extreme weather events are likely to lead to large injections of sediment and organic detritus to inland lakes which will increase the available nutrients for algal and macrophyte growth that may contribute to water quality deterioration. Inland lakes include the Loganburn Reservoir, Lake Sutton, and Lake Mahinerangi.
- **Coastal lakes.** Extreme weather events are likely to contribute larger volumes of sediment and detritus to coastal lakes, which may lead to shallowing of some lakes – further exacerbating negative water quality and quantity trends. Coastal lakes in the Taiari catchment include Lakes Waipori and Waihora (Waihola).

The impacts of climate change on water quality and quantity, and risk ratings assigned by the OCCRA [22] are summarised in Table 7-4.

Figure 7-7 Discharge from the Waihora Wastewater Treatment Plant, in the Waipōuri River in April 2023. Inset: warning sign near the discharge point (Source: GHC)

7.5.3 Summary of risks to water quality and quantity

Table 7-4 Risk ratings for water quality and quantity, and key risk information identified in the OCCRA.

Risk statement	Risk rating			Other comments[z]
	Present	2040	2090	

Risk to *river water quantity & quality* due to change in rainfall, drought and higher temperature.	L	H	E	• *River water quality and quantity* is likely to deteriorate quickly, with high to extreme impacts projected to occur in the short term (by 2040) due to changes in climate-related hazards.
				• Small and higher elevation *inland lakes* are also rated at a high and extreme risk of water quality and quantity deterioration by 2040.
				• *Water quality in coastal lakes* is expected to deteriorate more slowly, with medium risks by 2040 and high to extreme risks of deterioration by 2090.
				• The risk ratings for *water quality and quantity* tend to show relatively large step changes – with some risks jumping from low to high by 2040. This is due to the likely decrease in adaptive capacity of water systems, i.e., the deterioration of water quality may be gradual for a period, followed by a period of rapid deterioration across multiple systems throughout the region.
				• Management of water quality risks associated with climate hazards is not straightforward. Options identified in the OCCRA include:
				  ○ establishing primary controls such as catchment nutrient limits, erosion management, and widespread riparian planting.
				  ○ Managing land-use around river margins (e.g., retiring of marginal/flood-prone land) & re-naturalisation of river margins.
				  ○ Prioritisation of environmental flows over water takes is another management option that the community will need to decide upon.

Risk to *river water quantity & quality* due to inland flooding and reduced snow and ice.	M	E	E	
Risk to *inland and alpine lakes water quantity & quality* due to extreme weather events.	L	M	H	
Risk to *inland and alpine lakes water quantity & quality* due to drought & higher temperature.	L	H	E	
Risk to *inland and alpine lakes water quantity & quality* due to inland flooding.	M	H	E	
Risk to *inland and alpine lakes water quantity & quality* due to reduced snow & ice	M	E	E	
Risk to *coastal lakes water quality* due to extreme weather events	L	L	M	
Risk to *coastal lakes water quality* due to drought.	L	M	H	
Risk to *coastal lakes water quality* due to salinity stress (related to sea level rise)	L	M	E	
Risk to *coastal lakes water quality* due to higher temperature	L	H	E	

[z] Summarising the key points in section 5.6.4 of the OCCRA (*Risks to water quality and quantity from changes in rainfall, higher temperatures, flooding, drought and reduced snow and ice*).

8.0 SUMMARY & MANAGEMENT OPTIONS

Climate change presents a complex set of challenges to our catchment community. The sooner we respond to these challenges, the greater the chances are that we can increase the resilience of the Taiari to climate change.

Climate change predictions for the catchment are summarised below, focussing on the highest risk issues, and identifying whether they affect the Māniototo, the Strath Taiari, or the lower Taiari. A selection of management options are provided to prompt discussion and future work (see also Table 8-1 below).

8.1 WETLANDS – ALPINE AND INLAND (MĀNIOTOTO, STRATH TAIARI)

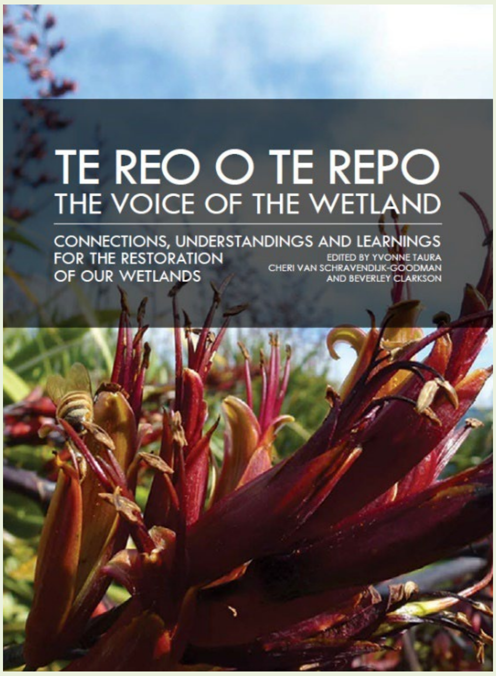
Wetlands of all types (alpine, inland, or coastal) provide a wide range of important ecosystem services including water storage and treatment, flood mitigation, cultural values, improved biodiversity and food supply [45]. They can also contribute to climate change mitigation through carbon storage. As a result, wetland protection and restoration are some of the most useful management options to improve climate change resilience of a catchment (Box 10).

Box 10: Wetland restoration

Successful wetland restoration hinges on two things: understanding the hydrology of the system; and establishing clear goals for the project (e.g., restoring bird habitat or water treatment) [48]. Restoration may then include reducing drainage of these systems (where possible), and if possible, allocating more water to these systems, as well as strategic planting and fencing.

Manaaki Whenua Landcare Research has published '*Te Reo o te Repo: The Voice of the Wetland'*, which focuses on the importance of repo (wetland) values from a cultural perspective and provides a number of repo restoration case studies (e.g., Ngā Rongoā o Ngā Repo) [49].

The Lake Stories website describes work being led by mana whenua to restore lakes and wetlands on the Lower Taiari Plain [50].



Front cover of Te Reo o te Repo

Of all the freshwater environments in the Taiari, alpine wetlands (>800 m altitude) are those at highest and most immediate risk to climate change impacts (i.e., they are already at medium to high risk, and this is expected to increase to high or extreme risk by 2040). Reduced snow and ice, increased drought, and air temperatures along with increased seasonality of rainfall are combining to dry, and decrease the extent and permanence of these wetlands, particularly in summer.

Controlling invasive exotic species (such as pine) should be considered as a management option for reducing these impacts on Taiari catchment alpine wetlands. Control actions may also be required for native species expanding their range into formerly alpine areas. It may be desirable to develop translocation techniques for unique native species that will otherwise fail to disperse to more suitable habitat. Mitigating the impacts of fire and subsequent loss of tussocks (which are important for water capture) should also be considered.

Inland wetlands (<800 m) face the same suite of impacts (excluding reduced snow and ice) with the risks increasing more slowly than for alpine wetlands (currently low to medium and increasing to medium or high by 2040).

8.2 INLAND LAKES – (MĀNIATOTO, STRATH TAIARI)

Inland and alpine lakes are also already at medium risk of impacts from reduced snow and ice, and inland flooding. As lake levels decrease, smaller, shallower and more sheltered lakes will be impacted sooner than deep lakes, particularly in summer. Flooding can inject sediment and organic detritus (e.g., plant matter) into lakes increasing nutrient availability, which then cascades through to decreased water quality, and sometimes mass die-offs of fish and/or invertebrates (e.g., freshwater mussels).

Management options include lake restoration (e.g., strategic riparian planting, fencing, reducing nutrient inputs) to improve their resilience. There are artificial lakes/reservoirs in the Taiari which may provide some capacity to manage (select) lake levels. The tributaries to lakes can also be restored to improved water quality entering lakes (i.e., sediment, temperature, nutrient concentrations).

8.3 REDUCED RIVER FLOWS AND WATER QUALITY (WHOLE CATCHMENT)

The OCCRA [22] identifies a medium risk at present, increasing to extreme by 2040 onward, of reduced river water quantity and quality due to inland flooding and reduced snow and ice. Depending on greenhouse gas emissions, drought, higher air temperatures and increased seasonality of rainfall will make these impacts worse. Reduced river flows in the upper Taiari will impact on the lower catchment. More highly modified waterways (e.g., straightened, with modified banks) will be most sensitive to these changes.

Management options include prioritising 'environmental flows' in water allocations, riparian and wetland restoration and giving the river 'room to move' thereby creating more instream habitat diversity and resilience to low flows.

8.4 EXTREME FLOODS (WHOLE CATCHMENT)

While changes to rainfall mean summers will be drier, winters will be wetter. There is also a medium risk at present of extreme floods impacting native ecosystems and species. This risk is expected to increase to high by 2040 and extreme by 2090 depending on climate emissions.

Management options include riparian planting of headwaters, strategic riparian planting along waterways, stabilisation of erosion prone land (e.g., plantings), installing sediment traps and 'giving rivers room to move' for example by moving flood banks further from the river and planning for 'sacrificial flood storage areas'. Maintaining the 'buffering' capacity of the Upper Taiari Wetlands Complex should be considered as a tool for mitigating extreme flood flows in the main stem of the Taiari River. Managing willows on river margins is another consideration, as excess growth can confine rivers within a narrower channel, increasing velocity and reducing the ability of the river to naturally meander across the floodplain.

Broad, catchment-scale strategies to manage the impacts of flooding have been successful in reducing existing and avoiding additional flood risk in some locations – for example, the Milton 2060 project [6].

8.5 COASTAL WETLANDS AND COASTAL LAKES (LOWER TAIARI)

At present, coastal wetlands and lakes in the Taiari are both considered to be at low risk from climate change impacts. By the mid-century however, the OCCRA predicts a high risk that sea level rise, associated salinity stress and coastal flooding will impact the Waihora and Waipōuri wetlands.

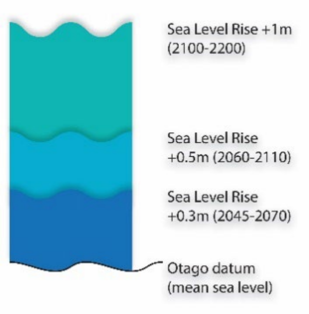
Management options include wetland restoration tailored to increasing salinisation. The various flood drainage systems in the lower catchment may offer some ability to manage ‘where’ salinity impacts occur first, although this would require a multi-faceted decision-making process involving mana whenua and catchment stakeholders.

By adequately predicting where important habitats to native fish may shift upstream, managers will be able to actively restore areas to ensure populations have access to critical spawning areas [33].

Coastal lakes are thought be at higher risk from high air temperatures than salinity stress. Management options include planting shading vegetation around lake margins and around headwaters and tributaries that flow into the lake. Management of nutrient inputs will also be an important method for mitigating the impact of increased temperature.

Table 8-1 A compilation of potential management responses to climate change impacts. This list is intended to assist discussions about options and is not a comprehensive analysis.

Climate projection	Impact	Management option
Drought and less rainfall in summer	Lower flows	Prioritise retaining 'environmental flows' in waterways to support native species, especially those found only in the Taiari/Otago region (e.g., non-migratory galaxiids).
		Irrigation systems already in place offer opportunities to manage storage and flows for values community selects.
		Change land use proactively to anticipate drought and other climate change impacts. Don't assume irrigation will be able to keep pace with drought.
Air temperature increases	Water temperature increases in lakes	Plant (drought-resistant) shading vegetation around headwaters, and along riparian margins of smaller streams/tributaries. 'Canopy closure' across these small waterways will shade them, help keep water temperatures lower, and provide refuges for mobile species like fish.
	Water temperature increases in lakes	Plant the shoreline with trees, plant riparian margins of all tributaries to the lake (as above).
	Temperature increases in alpine wetlands	Control invasive exotic species, consider translocation of rare native species to higher altitude habitats.
Extreme weather events	Increased rates of erosion and sedimentation	Riparian planting of headwaters.
		Strategic riparian planting along waterways (e.g., wider buffers at critical source areas).
		Install sediment traps/constructed wetlands (e.g., in headwater systems or to intercept sediments from critical source areas). Over time well-designed sediment traps can function as wetlands offering additional biodiversity benefits.
		Plant erosion prone areas with species suited to climate projections and community values.
		Reduce nutrient inputs to wetlands and lakes to increase their resilience to extreme events (e.g., when floods introduce detritus and sediments that increase lake/wetland nutrient status).
	Flooding & sedimentation	Wetland restoration - healthy wetlands are more resilient to sedimentation events and can also buffer flows and store water for dry periods.
		Plant riparian margins of streams to stabilize them – select species tolerant to projected climate (e.g., drought tolerant). Also plant strategically (i.e., where plantings have a greater chance of enduring), and

		using species suited to need (e.g., *Carex* species close to the river where they will protect the banks during high flows).
		'Give rivers room to move' - allow a wider corridor for the river to move within and to absorb high flow events. This will also create habitat diversity, and high flow refuges for native species.
Sea level rise 	Coastal flooding	Managed retreat of infrastructure
		Restore wetlands, as these buffer high flow events, provide increased habitat diversity as well as numerous other ecosystem services (e.g., water storage during dry periods, increased biodiversity).
	Coastal salinisation	Planting salt-tolerant/estuarine species in wetland restoration
		Focus inanga spawning habitat restoration at the 'upstream' limit of their current extent to enable inland migration of the habitat.
		Ensure fish passage is provided for to enable native fish to migrate to suitable habitat as it changes.

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APPENDICES

A1.0 APPENDIX 1: OTAGO CLIMATE CHANGE RISK ASSESSMENT

The Otago Regional Council (ORC) commissioned the Otago Climate Change Risk Assessment (OCCRA) in 2020 [22], and it includes the following objectives relevant to this report:

1. *Undertake a stocktake of knowledge and initiatives relating to climate change.*
2. *Provide a broad understanding of climate risks and opportunities within the Otago region and how risks may change over time.*
3. *Support decision makers to better understand regional risks and inform…other planning activities.*

The project provided an opportunity to engage with a range of stakeholders around Otago's current and future climate risks.

The OCCRA report by Tonkin & Taylor provides an overview of how Otago may be affected by climate change related hazards, and documents the highest ranked risks to the region, as well as some opportunities - identified through stakeholder elicitation and subsequent literature review.

Their report provides a regional snapshot of current and future climate scenarios and the highest ranked climate change related risks for the region. Their report is intended to inform stakeholders about both risks and opportunities faced in the region due to climate change. It provides context for future steps and can be utilised by ORC and all stakeholders as a reference to enable adaptation planning.

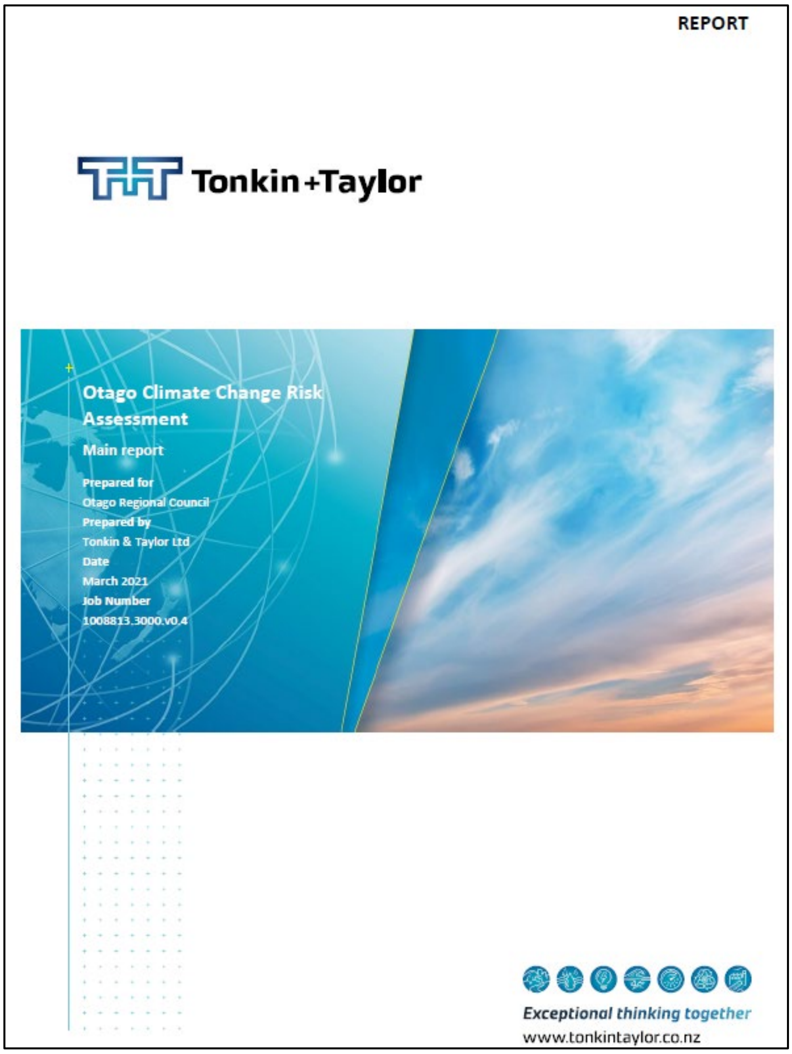

Figure A1.1 Cover of the Otago Climate Change Risk Assessment

A1.1 INTENTIONS OF THE OCCRA REPORT

What the OCCRA report provides:

1. *The first regional, collective summary of the risks to Otago from climate change assigning a risk value (based on exposure and vulnerability).*
2. *Groups risks according to five value domains (in alignment with the NCCRA) these are: natural environment, human, economy, built environment, and governance.*

3. *Highlights opportunities that may be possible in the face of climate changes.*
4. *Identifies some research and knowledge gaps to be filled to better understand the risks.*
5. *Identifies some interactions between risks (however does not provide a comprehensive assessment of cascading impacts).*
6. *Identifies the need for adaptation to mitigate the impact of climate change.*

How the OCCRA is intended to be used:

1. *All stakeholders will be able to utilise the list of risks from this report to guide both current and planned work programmes. For example, the findings from this assessment may be used in the development of long-term plans.*
2. *The report has developed a baseline of climate change related risk understanding that can be used to track changes to these risks and improve understanding over time.*
3. *The findings can help to guide development of a regional adaptation approach.*
4. *The report can help inform councils, stakeholders, organisations and individuals within the region on the climate change risks we may face. It can be used as a guide to understand what risks might need further research or understanding both at a regional and local scale.*

What the OCCRA doesn't provide:

1. *The report is based at a regional scale, and therefore does not provide an assessment of risks at a local or community level scale. The identified risks do not provide a breakdown of components, for example specific species, locations or infrastructure elements at risk, other than certain examples that are used to explain and illustrate the risks within the discussion sections.*
2. *The identified risks were not prioritised beyond the direct climate change related risk ranking.*
3. *The report does not plan a way forward for adaptation or comment on specific adaptation actions, as this forms part of the next steps.*

A1.2 RISK ASSESSMENT

The OCCRA defines climate change risk as the interaction between a hazard, exposure, and vulnerability (Figure A1.2). Hazard refers to physical events, present or predicted, such as floods, drought and sea level rise. Exposure refers to the presence of an element of the built environment in a hazardous location. Vulnerability refers to the sensitivity or susceptibility of the built environment to be harmed by the impacts of climate change, and its capacity to cope and adapt. These three elements interact to create climate change risk.

A comprehensive explanation of how the OCCRA defines risk is included in the Tonkin & Taylor report [22].

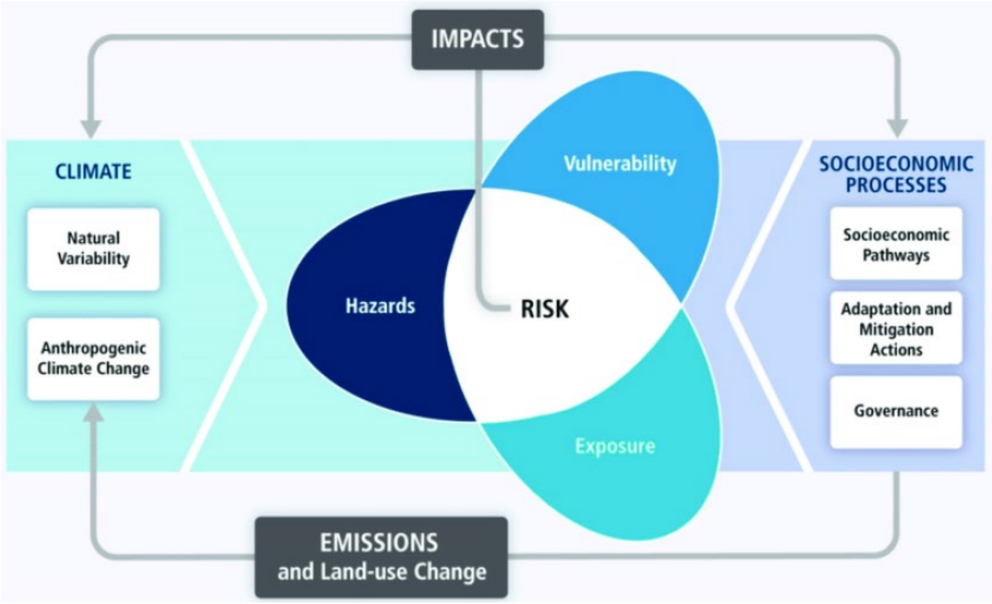

Figure A1.2 The IPCC AR5 conceptual framework with risk at the centre

A2.0 APPENDIX 2: RESULTS FROM TAIARI RIVER RESTORATION PROGRAMME CONSULTATION

Table A2.1 Results of the values identification exercise with stakeholders in 2022 [32]

Identified values	Climate change sensitivity (assigned by group)

Tikaka maori
• Wāhi tīpuna
• Wāhi taoka
• Spiritual connection to the awa
• Spiritual connection to places
• Understanding/ knowledge of the awa and the catchment
• Whānau/memories
• Restoring our names
Water health
• Water quantity
• Water flows
• Water quality (e.g., drinking)
• Water yield
Species and mahika kai
• Native fish
    • Tuna
    • Kanakana
    • Kōkopu
    • Non-migratory galaxiids
    • Bullies
• Manu
    • Kererū
    • Weka
    • Kākāpō
    • Kākā
    • Kārearea
• Aquatic invertebrates
    • Kōura
    • Kākahi
• Other animals
    • Other invertebrates (e.g., wētā)
    • Geckos
• Plants
    • Rākau
    • Taramea
    • Podocarps
Natural environment
• Healthy/functioning ecosystems
    • Mauri of te Taiari
    • Wetlands/Repo
    • Mahere
    • Mauka
    • Plants supporting mahika kai
    • Soil health/integrity
    • Native fish spawning grounds
    • Habitat connectivity
Human activities/Usage
• Water usage
	High

Human activities/Usage • Linking communities along the river • Recreational use of waterways • Access to mahika kai • Access to the awa • Access to the mountains • Walking Natural environment • Vegetation processes • Landscape • Harakeke	Medium

Table A2.2 Results of the climate risk identification exercise with stakeholders in 2022 [32]

Type of risk	Climate-related hazards and associated risks
Extreme events	• Storms • Droughts • Floods • Sedimentation events (resulting from floods) • Fires • Heatwaves
Slow changes	• Temperatures • Sea level • Salinity • Water levels/baseline flows • Seasonal cycles • Sedimentation • Water usage • Other catchment usage (e.g., grazed floodbanks) • Infrastructure development/adaptation • Shifts in species distributions • Disturbances in foodwebs and ecological processes • Invasive species behaviours/ecology • Pathogens/parasites • Political/legislative landscape for conservation (inertia) • Shifting baselines of knowledge • Shifting baselines of human attitudes/ behaviours in response to crisis