Traverse Environmental

Water quality in the upper Taiari/Taieri River catchment

A summary of monitoring activities and findings

Prepared for: Upper Taieri Wai

October 2024

Water quality in the upper Taiari/Taieri River catchment: A summary of monitoring activities and findings

Prepared for:	Upper Taieri Wai
Prepared by:	Juliet Milne and Dimitrios Rados
Date of issue:	11 June 2024 (original) Re-issued 31 October 2024 with minor updates and revisions

Quality Assurance		
Reviewed by:	Laura Keenan	
Approved for release by:	Dr Olivier Ausseil	
Report status:	Final	

Disclaimer: This report has been prepared for the sole use of our client, for the particular brief and on the terms and conditions agreed with our client. It may not be used or relied on (in whole or part) by anyone else, or for any other purpose or in any other contexts, without our prior written agreement.

Cover photo: Taieri River at Cogens Bridge (J. Milne).

Recommended citation: Milne J, Rados D. (2024) Water quality in the upper Taiari/Taieri River catchment: A summary of monitoring activities and findings. Report prepared for the Upper Taieri Wai by Traverse Environmental. 56 p.

Executive summary

The Taiari/Taieri River (Taieri) is the fourth longest river in New Zealand and has significant natural, ecological, recreational and cultural values. The Upper Taieri Wai, a community-led catchment group dedicated to resource management issues in the upper Taieri catchment, is both overseeing and supporting activities to understand and enhance water quality throughout the entire Taieri catchment, including through the Healthy Taieri Integrated Farm Planning (IFP) project. Although the IFP project operates catchment-wide, separate reports have been prepared for each of the upper, mid and lower Taieri plain communities to provide a focus on water quality at a more localised scale. This report addresses the upper Taieri catchment, incorporating the 183,000 ha area upstream of Tiroiti.

This report:

- outlines details of current and historic water quality monitoring carried out by the Otago Regional Council (ORC) and other organisations to date,
- summarises what is known about water quality state and trends from monitoring and investigations, drawing on existing readily available reports and previously unreported water quality investigation data collected between 2017 and 2023, and
- identifies water quality issues and associated information gaps and monitoring priorities.

A detailed summary of each of these topics is included within the body of the report.

Monitoring activities and information

A considerable amount of information exists on the upper Taieri River catchment, with one or more aspects of water quality measured at more than 70 surface water locations on at least several occasions in recent years. The ORC currently monitors five long-term surface water state of the environment (SOE) sites, although the focus to date has largely been physical, chemical and/or microbiological aspects of water quality which, together with flow information, only address two of the five components of river health described in the National Policy Statement for Freshwater Management (NPS-FM) 2020. More recent additions to SOE monitoring, including periphyton biomass monitoring (limited to two sites between November 2019 and April 2022) and high frequency logging of dissolved oxygen (DO) levels in the Taieri River at Waipiata, has started to address some of the gaps, as have the ecological-focused monitoring efforts of Tiaki Maniototo and the Department of Conservation. The recent extension of ORC's groundwater quality SOE monitoring from two to 12 sites should further improve understanding of the interactions between land use and ground and surface water quality.

Current state and trends in water quality

Based on recent ORC state and trend assessments, and the results of other monitoring and investigations carried out over the last five or so years, water quality in the upper Taieri River catchment is relatively 'good'. Both the Taieri River and its tributaries are characterised by very low concentrations of plant-available forms of nitrogen and phosphorus relative to median concentrations reported in other rural upland rivers in New Zealand. The primary exception is dissolved reactive phosphorus (DRP), which is present at higher concentrations in the lower reaches of Eden Creek and, to a lesser extent the Gimmer Burn and Ewe Burn, as well as the mainstem of the Taieri River (downstream) at Waipiata and Tiroiti. Elevated DRP concentrations in the tributaries on some occasions coincide with increased turbidity and high *E. coli* counts suggesting some contamination arises from above ground sources, such as stock access and/or irrigation bywash. Inputs from shallow groundwater also appear to increase plant-available nutrient concentrations in several tributaries during periods of low stream flow. This includes nitrate-nitrogen (nitrate-N) in the Pig Burn and Sow Burn and possibly DRP in the lower reaches of the Gimmer Burn, Eden Creek and Ewe Burn. Overall, there is a marked degradation in water quality between Cogen's Bridge near Patearoa and Waipiata.

E. coli indicator bacteria counts generally fall within recommended guidelines for recreation in the mainstem of the Taieri River but are high at times at both Linnburn Runs Road and the popular swimming site at Waipiata, particularly in summer. Frequent and significant faecal contamination has been recorded in the lower reaches of the Wether Burn/Gimmer Burn, Eden Creek and Ewe Burn.

Water quality improved in some aspects over the 10-year period ending June 2022, with decreasing trends reported in both plant-available and total phosphorus concentrations across all five SOE surface water sites. However, there are some areas of degradation relating to sediment, nutrient enrichment and faecal contamination, which appear to be impacting ecological health and recreational values. In addition, increasing trends (i.e., deteriorating water quality) in plant-available nitrate-N concentrations were reported for two mainstem sites and in one of the two shallow groundwater monitoring wells. The Taieri River appears to be nitrogen-limited, suggesting that any increase in nitrate-N concentrations has the potential to stimulate growth of nuisance periphyton (algae) and/or macrophytes (aquatic plants), particularly in summer when water temperatures are above 20°C and flows are often low for extended periods. Macrophyte cover is already at nuisance levels in a few locations, supported by (and likely contributing further to) high riverbed coverage of fine sediment. Further increases in macrophyte growth could increase fluctuations in DO levels, which have already reached critically low levels once (in summer 2021) since high frequency DO monitoring began.

Indices of macroinvertebrate community health, a common indicator of river health, are poor at the mainstem sites with higher fine sediment and macrophyte cover. Overall, few sites monitored to date have scored better than 'fair', although water depth and the natural slow meander of the river contribute to lower scores for mainstem sites within the scroll plain.

Information gaps and monitoring considerations

Visual clarity (the suspended fine sediment attribute in the NPS-FM) is currently estimated by the ORC from turbidity measurements using a national equation that was not intended to apply to tannin-stained waters such as the Taieri mainstem. As such, even the relatively unimpacted mainstem SOE sites at Linnburn Runs Road and Stonehenge fall into Band B (rather than Band A). Visual clarity measurements are needed for a more meaningful assessment of the suspended fine sediment attribute.

Long-term ecological and physical stream habitat quality data are lacking for the upper Taieri catchment, with only the Kye Burn at SH 85 routinely monitored for these aspects of stream health.

Information on subcatchment-scale land use and land management practices is needed to help understand the drivers and direction of water quality trends in the upper Taieri. While it is likely that changes in land management practices account for some of the reported improvements in water quality over the last 10 years, evidence that could help confirm this, such as quantitative information on *changes* in irrigation, stocking, fertiliser and riparian management practices, is not readily available.

Monitoring-related suggestions include:

- establishing a site-specific relationship between turbidity and visual clarity at the ORC's Taieri River SOE sites to inform assessments of the suspended fine sediment attribute under the NPS-FM, and enable a meaningful catchment-specific target attribute state to be set,
- carrying out annual surveys of macrophyte abundance and at least quarterly assessments of fine deposited sediment cover at locations on the main tributaries and the mainstem coupled with at least two habitat and macroinvertebrate community assessments,
- tracking bank and other forms of erosion in the catchment (e.g., using annual photo points and mapping),
- additional high frequency water temperature and DO monitoring at selected sites over summer, and
- targeted wet weather water sampling of the lower reaches of the main tributaries to assist with understanding the relative contributions of sediment, nutrients and *E. coli* to the Taieri River under these conditions.

Contents

Executive summary 3

1 Introduction 7

1.1 Report purpose and scope 7
1.2 Limitations 8

2 Upper Taieri catchment 9

2.1 Climate 10
2.2 Hydrology 10
2.3 Land cover, soils, land use and irrigation 10
2.4 Aquatic ecological and recreational values 11

3 Water quality monitoring – who has done and is doing what? 12

3.1 Otago Regional Council 12
3.2 NIWA 18
3.3 Central Otago District Council 18
3.4 Environment Canterbury 19
3.5 Maniototo Irrigation Company 19
3.6 Upper Taieri Wai 19
3.7 Department of Conservation 20
3.8 University of Otago 21
3.9 Summary 21

4 Current state – what we know 23

4.1 Recent ORC State of the Environment reporting 23
4.2 Insights from other recent monitoring and investigations 29
4.3 Summary – key points 37

5 Trends – is water quality getting better or worse? 38

5.1 Surface water quality 39

5.2 Groundwater quality 40
5.3 What might be behind the trends? 40
5.4 Summary 41

6 Issues, gaps and priorities 42

6.1 Sediment 42
6.2 Nutrients 44
6.3 *E. coli* 47
6.4 Gaps and priorities 49

Acknowledgements 53

References 54

1 Introduction

The Taiari/Taieri[1] River is the fourth-longest river in New Zealand and has significant natural, ecological, recreational and cultural values. The river's headwaters originate in the Lammermoor and Lammerlaw Ranges in inland Otago. The river flows through three plains – the Upper Taieri, Strath Taieri and Lower Taieri – enroute to the sea, 30 km south of Dunedin. The Otago Regional Council (ORC) carries out water quality monitoring within each of the plains as part of its statutory role in managing river health. In recent years, consistent with a nationwide trend, landowners and catchment-based groups have also carried out monitoring, helping to fill important gaps in understanding of river health.

This report was commissioned by the Upper Taieri Wai (UTC), a multi-stakeholder group that is working to enhance environmental and community values throughout the upper Taieri River catchment. The group is a collaboration between landowners, farmers, interested members of the public and numerous stakeholders, including the Maniototo Irrigation Company (MIC), Department of Conservation (DOC), Ngai Tahu and Otago Fish and Game. In 2021, UTC received Freshwater Improvement Funding from the Ministry for the Environment to run the Tiaki Maniototo project. This project involves fencing along waterways, native planting in river and wetland areas, weed and pest control, and improving recreational access. Environmental monitoring is also being carried out as part of the project.

This report was prepared to inform the activities of UTC and others working locally to understand and improve water quality in the upper Taieri catchment, including the MIC and two UTC projects – Tiaki Maniototo and the (whole of catchment) Healthy Taieri Integrated Farm Planning (IFP) project. For the purposes of this report, the upper Taieri catchment incorporates the 183,000 ha area upstream of Tiroiti to align with the catchment area covered by the Tiaki Maniototo project.

1.1 Report purpose and scope

The primary aim of the report was to collate what has been done and is known about water quality in the upper Taieri so that the UTC and MIC have a useful reference to inform future monitoring, restoration and other activities. The report also attempts to tease out and translate what the current state and trends mean at a finer scale within the catchment and some of the likely drivers. The last known report that looked at subcatchment scale water quality was Kitto (2012).

Specifically, this report:

- outlines details of current and historic water quality monitoring carried out by different organisations,
- summarises what is known about water quality state and trends from monitoring and investigations carried out to date, based on existing readily available reports and a review of previously unreported ORC and MIC water quality data collected between 2017 and 2023, and
- identifies water quality issues and associated information gaps and monitoring priorities.

A series of ArcGIS layers have been provided with the report containing the key details of surface water quality monitoring and investigation sites, as well as groundwater quality, river level/flow and rainfall monitoring sites. These layers also include monitoring sites across the mid and lower Taieri; separate reports, similar in format to this one, have been prepared for those areas (see Milne 2024a & Milne 2024b).

[1] The Taiari River and Māniototo are the correct Māori names for the Taieri River and Maniototo. These names are yet to be formally adopted within the catchment. To avoid potential confusion with the names of long-established monitoring sites and local roads and businesses, the more widely known spellings of Taieri and Maniototo are used in this report except where the correct spellings form part of an established identity or project name.

1.2 Limitations

This report has relied heavily on existing reports and collated or summarised data from third parties. Incomplete details, conflicting information and errors were followed up where possible, but it was beyond the scope of this project to re-examine data sets. Additional analyses of already reported data were also out of scope but some further analysis was done to help illustrate or understand particular issues.

Although water quality information associated with university research projects and resource consents is summarised, the search was not exhaustive and it is likely that additional information exists to that captured here.

2 Upper Taieri catchment

The Taieri River originates in the relatively undeveloped rolling tussock grasslands on the northern side of the Lammerlaw Range at an altitude of 1,150 m. The river flows north through Canadian Flat before entering the Styx Basin and then, via the Paerau Gorge, the Maniototo Basin, bordered on the west by Rough Ridge and on the east by the Rock and Pillar Range. Both basins have extensive scroll plains characterised by many oxbow lakes and wetlands. Together they represent a unique environment in New Zealand (Ryder & Tocher 2020).

Once it reaches the northern end of the Rock and Pillar Range, the Taieri River turns east around the range, before turning southeast at Kokonga and continuing to Middlemarch and the Strath Taieri Plain. The north-eastern boundary of the catchment is formed by the Ida Range and the Kakanui Mountains (Figure 2-1).

The upper Taieri catchment is home to Great Moss Swamp, dammed in the 1980s to create the Logan Burn Reservoir. The reservoir lies at the southern end of the Rock and Pillar Range and forms part of a combined irrigation and hydroelectric power scheme for the Maniototo. A secondary reservoir for this scheme is located near Paerau. Irrigation water is supplied to over 60 farmers, covering about 9,300 ha of land. Power is generated when water is released for irrigation.

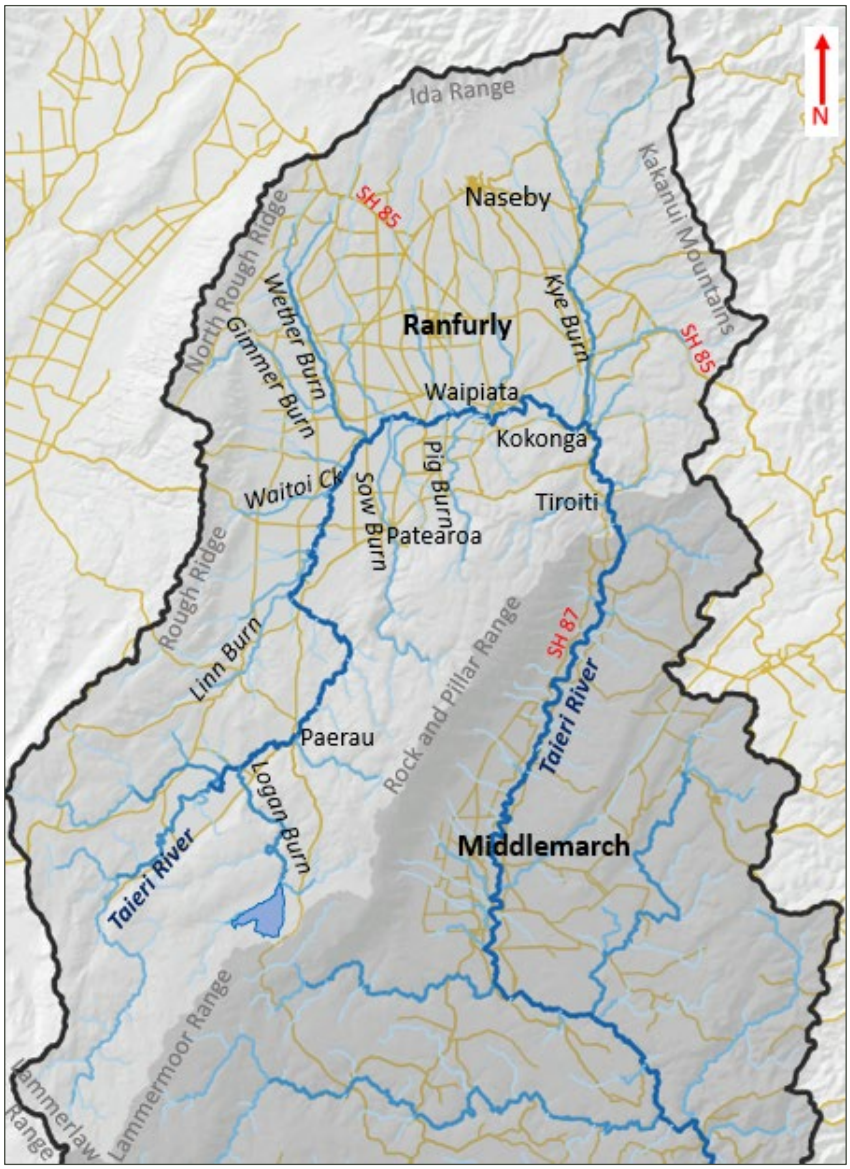

Figure 2-1: The upper Taieri catchment (with part of the mid catchment in grey) and some of the key locations and tributaries referred to in this report. Tiroiti marks the downstream boundary of the upper catchment.

Several reports describe the topography, soils, vegetation, land use, climate, hydrology and the natural, ecological, recreational and cultural values of the upper Taieri catchment (e.g., Kitto 2012, Ryder & Tocher 2020, ORC 2021). Selected key points drawn from these reports are summarised below to provide some context for understanding water quality in the upper Taieri catchment.

2.1 Climate

- The upper Taieri is one of the driest, coldest and hottest areas in New Zealand, with an annual potential evapotranspiration rate that commonly exceeds rainfall by more than 400 mm.
- Maximum temperatures greater than 30ºC are common in summer and minimum temperatures as cold as -15ºC have been recorded near Naseby.[2]
- Average annual rainfall varies from around 400 mm (Patearoa) to 760 mm at the northern catchment boundary (Dansey's Pass). Rainfall is typically highest in December.
- The Ida Range and Kakanui Mountains contain the highest elevations in the catchment (over 1,650 above sea level) and are snowcapped for several months of the year.

2.2 Hydrology

- Flows in the upper Taieri River are generally lowest towards the end of summer and in winter, and highest during snowmelt in spring. Peaks in flow are relatively sharp at Canadian Flat in the Styx Basin but are buffered further downstream by the extensive scroll plain wetlands. The wetlands have the most holding capacity during the drier period, from February to March. High river flows in spring spread out over the meander belt and remain ponded in oxbows for several months.
- Many streams flow from the surrounding high ranges through gorges and down alluvial fans on the Maniototo to the Taieri River. These include the Linn Burn and Waitoi Creek from Rough Ridge, the Logan Burn, Sow Burn and Pig Burn from the Rock and Pillar Range, the Wether Burn and Kye Burn from the Ida Range, and the Swin Burn from the Kakanui Mountains.
- The groundwater of the upper Taieri catchment and its interaction with the scroll plain wetlands are not well understood. Two main aquifer systems are known to exist; a shallow unconfined aquifer that interacts with the overlying land and surface water, and a deeper aquifer. Although the deep aquifer is considered confined, meaning it is separate from the shallow aquifer above, it is thought that abstraction of water from this aquifer may create some leakage of water from the unconfined aquifer above (ORC 2014). New groundwater monitoring wells being drilled in both aquifers by the ORC (see Section 3.1.1) are expected to provide more information on interactions between the aquifers and the extent to which groundwater abstraction depletes flow in the Taieri River.
- Groundwater flow direction is generally to the southeast, broadly following surface topography, and discharging into the Taieri River as baseflow. Some tributaries, such as the Kye Burn and Sow Burn, lose flow to groundwater along specific reaches as they come out of the hillside and flow over the alluvial gravels. Surface flow is then re-established before the streams discharge into the Taieri River.

2.3 Land cover, soils, land use and irrigation

- The upper catchment is a mosaic of tussock grasslands, farmland and wetlands.
- The main soil types are upland and high country yellow-brown earths. Brown-grey earths and recent alluvial soils are found around the historical channels and flood plains of the main tributaries. Some of

[2] Ranfurly boasts the lowest official air temperature of all time for New Zealand; -25.6°C on 17 July 1903 (Macara 2015).

- New Zealand's only semi-arid soils are located in the upper Taieri catchment. Semi-arid soils are usually free draining but receive insufficient rainfall to remove soluble salts which, unless flushed out by irrigation water, may build up in the subsoil and impact soil-water-plant relationships.
- Land use is dominated by low intensity mixed sheep and beef farming, interspersed with dairy and small areas of deer farming. Exotic forestry is present in the north of the catchment in and around Naseby.
- The majority of surface and ground water abstraction in the upper Taieri catchment is used for irrigation to support pasture production. Flood/contour/border-dyke irrigation was once widespread across much of the Maniototo but has progressively been replaced with spray irrigation over the last 20 or so years.

2.4 Aquatic ecological and recreational values

- Eight native fish species are known to be found in the upper Taieri catchment. Two species, the Eldon's and Dusky galaxiids, are classified as nationally endangered. A further two galaxiid species, the Roundhead and Flathead galaxiids, are nationally vulnerable. Both the longfin eel and lamprey are classified as declining.
- The Taieri River supports a regionally significant trout fishery, with many tributaries providing important habitat for trout spawning and juveniles.
- Swimming spots include the Sow Burn at Patearoa and the Taieri River at Green Bridge (Waipiata).

3 Water quality monitoring – who has done and is doing what?

Routine water quality monitoring in the upper Taieri catchment dates back to 1989. While the ORC has carried out most of the monitoring to date, other organisations and groups have also collected data on a one-off, short-term or ongoing basis to fulfil research interests, meet resource consent requirements or support community interests and initiatives. This section presents a summary of the readily available monitoring and investigation activities carried out to date, with a focus on what each organisation or entity has monitored, where and when. Collating a record of monitoring activities in the catchment provides an important first step in identifying gaps in understanding and priorities for future monitoring.

Water quality and ecosystem health

Water quality includes physical, chemical and biological characteristics. Water quality in rivers, streams and groundwater is usually described and assessed in terms of its suitability to support particular uses or values, such as recreation, ecosystem health, drinking and food gathering.

Good water quality is important for supporting healthy freshwater ecosystems but is only one of five components of river health defined under the National Policy Statement for Freshwater Management (NPS-FM) 2020. The other components are *aquatic life* (e.g., plants, macroinvertebrates, fish), *habitat* (e.g., the composition of the riverbed, shade), *ecosystem processes* (e.g., nutrient cycling) and *water quantity* (e.g., flows).

Although water quality is the focus of this report, current and historical monitoring activities are summarised across all five components of river health. Soil quality monitoring is also summarised because of the known linkages between soil health and water quality.

3.1 Otago Regional Council

The ORC carries out both routine State of the Environment (SOE) monitoring and recreational water quality monitoring in the upper Taieri catchment. On occasion the ORC also carries out one-off or short-term investigations targeting specific water quality issues or information gaps.

3.1.1 State of the Environment monitoring

A primary goal of SOE water quality monitoring is to track changes in water quality over time. This requires consistency in monitoring site locations, indicators and methods. In reality, sites, indicators and methods do change, primarily as a result of reviewing the cost and value of the information gained from monitoring, the emergence of new national legislation (e.g., the NPS-FM 2020) or environmental pressures, and developments in monitoring practices (e.g., National Environmental Monitoring Standards) and technology.

Surface water quality and ecology

The ORC currently has five SOE monitoring sites in the upper Taieri catchment (Figure 3-1): four on the Taieri River between Linnburn Runs Road and Tiroiti, and one on the lower reaches of its largest tributary, the Kye Burn (at SH 85). In the past, SOE monitoring was also carried out at Maniototo Road (Halls Bridge). The longest running site is the Taieri River at Stonehenge, with an unbroken record that extends back over 30 years. The remaining four sites now have a continuous record of at least 10 years.

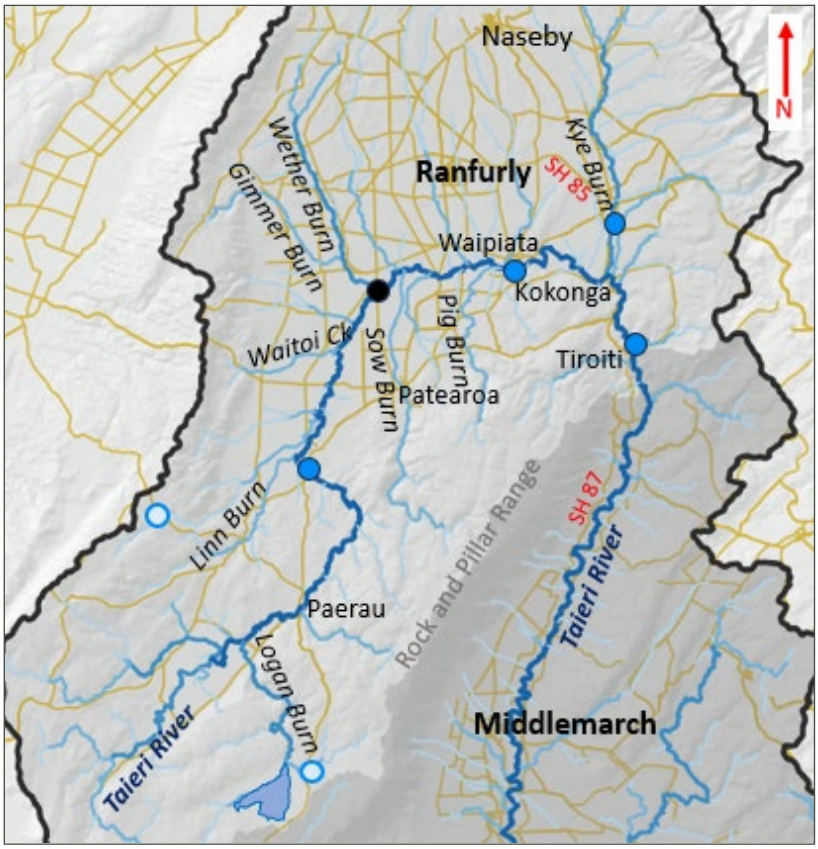

Figure 3-1: ORC surface water quality SOE monitoring sites in the upper Taieri catchment. The blue circles are current sites, the black circle is a historical site (at Halls Bridge) and the open blue circles are recently added reference sites.

At each SOE site, water samples are collected monthly[3] and measured for water temperature, pH, turbidity and concentrations of dissolved oxygen (DO), conductivity, plant-available nutrients (ammoniacal nitrogen, nitrate-nitrite-nitrogen and dissolved reactive phosphorus (DRP)), total nitrogen (TN), total phosphorus (TP) and *E. coli* indicator bacteria. This measurement suite is similar to that adopted by most regional councils, the main difference being that most councils also routinely measure visual clarity (as discussed later in this report, the ORC estimates this from turbidity measurements).

Once a year during stable river flows in late summer/early autumn, the riverbed invertebrate community (e.g., insects, snails and worms) is sampled and rapid assessments made of physical habitat quality (e.g., bank stability, riparian vegetation, shade) at wadeable sites, notably the Kye Burn at SH 85. In addition, at Waipiata:

- water temperature has been monitored at high frequency (every 5-15 minutes) since February 2004,
- DO has been monitored at high frequency since late October 2020, and
- the amount of riverbed periphyton (algae) was assessed monthly – when river flows allowed – as chlorophyll *a* biomass (rock scrapings)[4] between November 2019 and April 2022.

The periphyton and DO monitoring additions were made in response to requirements of the NPS-FM 2020 and provide additional information on the ecological health of the river. No further chlorophyll *a* monitoring is proposed at this time (R. Ozanne, ORC, pers. comm.).

The ORC also carries out fish monitoring in the upper Taieri catchment. The only site that would likely be considered a SOE site based on regularity of monitoring is the Kye Burn upstream of SH 85 (fished annually in summer since 2015). A site on the Spec Gully tributary has also been fished for the last few years and the Sow Burn near Patearoa was fished annually between 2015 and 2018 (M. Cunningham, ORC, pers. comm.).

[3] Prior to July 2014, water sampling was two-monthly and, in some years, samples were only collected on five occasions.
[4] Periphyton biomass was also measured at the Kye Burn SOE site at SH 85.

Groundwater quality

Routine monitoring of groundwater quality dates back to March 1997 following a one-off sampling exercise of 30 wells across the Maniototo (ORC 2014). At this time, water samples were collected from three wells (H41/0106, H42/0132 and H42/0137, Figure 3-2) twice a year and tested for a typical groundwater SOE suite, including ammoniacal nitrogen, nitrate nitrogen, DRP, metals and *E. coli* bacteria. The water level in these wells was also monitored (at quarterly intervals). Monitoring of these wells ceased in April 2007 and although another well was sampled for 18 months, routine monitoring of groundwater quality did not re-commence until late 2015 following the drilling of two new purpose-built wells in October 2014. Both wells are located within the shallow unconfined aquifer, one (H42/0213, 5.6 m deep) close to Eden Creek near the Maniototo Road/Gimmerburn-Waipiata Road intersection, and one (H42/0214, 9 m) east of the Sow Burn at the Patearoa-Ranfurly/Greer Road intersection (Figure 3-2). Water quality is monitored on a quarterly basis and groundwater levels are measured continuously (A. Levy, ORC, pers. comm.).

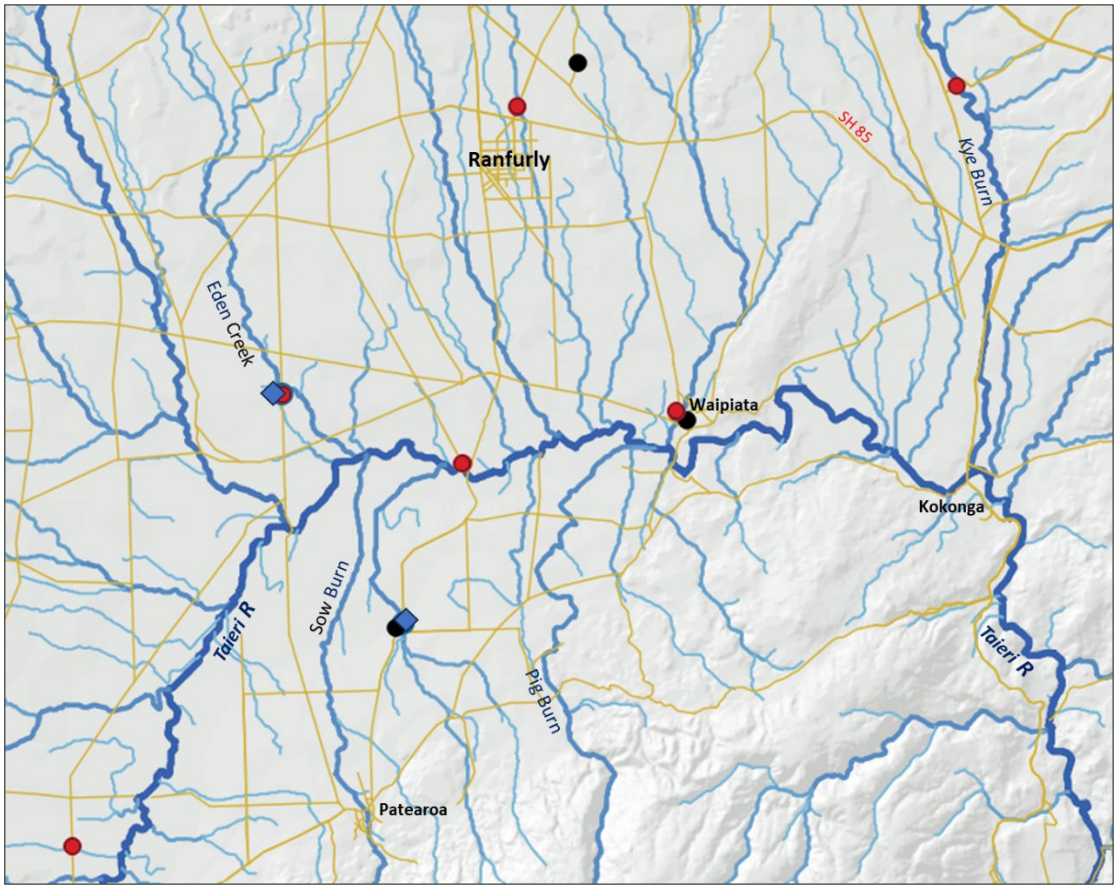

Figure 3-2: ORC groundwater quality SOE monitoring sites in the upper Taieri catchment. The two blue diamonds are the long-term shallow monitoring wells and the three black circles are shallow wells monitored between 1997 and 2007. The red circles indicate the locations of new piezometers drilled in 2023 – some locations have a piezometer in both the shallow and deep aquifers.

Although no individual groundwater wells have more than a 10-year monitoring record, well H42/0214 was drilled to serve as a replacement for one of the earlier privately owned monitored wells (H42/0132). Assuming the groundwater samples taken from H42/0132 were representative of the underlying aquifer, then the records from the two wells may be able to be combined to give some insights into groundwater quality (in one part of the catchment) over the last 20 years.

In late winter 2023, the ORC added 10 piezometers to the groundwater quality SOE monitoring programme. Nine of these piezometers were drilled to enable paired monitoring of the shallow aquifer and deep confined aquifer in the same location: Puketoi, Eden Creek adjacent to the existing SOE site, Creamery Bridge, and just

north of Ranfurly. The remaining piezometer taps the deep aquifer beside the Kye Burn at Scott's Lane (Figure 3-2).

River flow/level and rainfall

River flow and/or water level monitoring is currently carried out at four sites, each with a different start date:

- Taieri River at Waipiata (since May 1982)
- Tiroiti River at Tiroiti (August 1992)
- Pig Burn 400 m upstream of Top Intake (September 2009)
- Kye Burn at Water Take 300 m downstream – Scotts Lane (October 2012).

For many years flow was also recorded on the Taieri River at Stonehenge. This flow site was decommissioned in 2011.

Based on the ORC's data portal, the ORC does not carry out any routine monitoring of rainfall in the upper Taieri catchment. However, rainfall is monitored by NIWA (see section 3.2) and Environment Canterbury (see section 3.4).

Soil quality

Soil quality is a relatively new (and still developing) addition to SOE monitoring in Otago and is based around a subset of sites on different land uses (e.g., drystock farming, dairying, cropping, forestry) that are monitored at different frequencies. Inappropriate land use practices, such as overstocking and over-cultivation, can result in a long-term reduction in soil quality. Poor soil quality can also produce lower agricultural yields, a less resilient soil and land ecosystem, and increase the risks of contamination of underlying groundwater and nearby surface water bodies.

To date, three monitoring sites in the upper Taieri catchment have been sampled once each. Two of these sites, located on sheep and beef farmland (in the vicinity of Orangapai and Puketoi), were sampled in March 2022 while the third, located in Naseby Forest, was sampled in October 2023. Soil properties tested include soil acidity (pH), nutrient and organic carbon content, and two indicators of soil compaction (bulk density and macroporosity).

3.1.2 Recreational water quality monitoring

During December to February each year, the Taieri River at Waipiata is monitored at approximately weekly intervals for *E. coli* as part of the ORC's summer recreational water quality programme. This monitoring is additional to the monthly SOE water quality monitoring carried out at Waipiata. All *E. coli* test results are reported on the Land Air Water Aotearoa (LAWA) website. Additional 'follow-up' testing is usually carried out when a routine sample result exceeds 260 *E. coli*/100mL, the amber/alert level of the MfE/MoH (2003) national microbiological water quality guidelines. At this level, there is an elevated (but still acceptable) level of risk of infection from contact recreation. Any result exceeding the red/action level of 540 *E. coli*/100 mL[5] is deemed to pose an unacceptable health risk (MfE/MoH 2003).

3.1.3 Targeted investigations and monitoring

Five main surface water quality investigations or short-term monitoring programmes have been carried out to date (Table 3-1), with reports available for three of these. Results of the most recent monitoring are summarised in Section 4.2.1. Most of this monitoring was focused on tributaries of the Taieri River (Figure 3-3).

[5] The MfE/MoH (2003) guidelines specify a red/action level of 550 *E. coli*/100 mL but this became 540 *E. coli*/100 mL when *E. coli* was included in the NPS-FM as a human health attribute for primary contact recreation.

Table 3-1: Summary of the ORC's surface water quality monitoring and investigations in the upper Taieri catchment. More details are available as ArcGIS data files.

Programme/ investigation and rationale	Monitoring focus	Where and when
SOE river water quality programme State and trends in river health (ongoing programme)	Water quality: Water temperature, pH, turbidity and concentrations of dissolved oxygen, conductivity, ammoniacal nitrogen, nitrate nitrogen, total nitrogen (TN), dissolved reactive phosphorus (DRP), total phosphorus (TP) and *E. coli* indicator bacteria. Other: Periphyton biomass was monitored at two sites for three years and fish and ecosystem metabolism are monitored at one site each. Macroinvertebrates and physical habitat quality are monitored at wadeable sites.	Five current sites* – includes monthly water quality sampling (and for the Kye Burn, annual macroinvertebrate sampling): • Taieri R at Linnburn Runs Rd – routinely (for water quality) since Aug 2014 • Taieri R at Stonehenge (Hore's Br) – since May 1990 • Taieri R at Waipiata (Green Br) – since Mar 2014 • Kye Burn at SH 85 – since Jul 2003 • Taieri R at Tiroiti – since May 2014. Earlier data exists for most of these sites but with breaks in the monitoring record. The Taieri River at Maniototo Rd (Halls Br) was also monitored at times, most recently between mid-2014 and mid-2018. * Two additional 2 sites (Totara Creek and a tributary of the Logan Burn) were introduced in 2022 as part of a new regional ecological reference network (R. Ozanne, ORC, pers. comm).
2001—02 investigation Changes in water quality in the Taieri River between Stonehenge and Waipiata	Similar water quality measurements to the SOE programme at the time, with periphyton and macroinvertebrate samples collected once during the summer. See ORC (2003).	12-month investigation between Nov 2001 and Dec 2002 covering eight sites: • Taieri River at six locations between Stonehenge and Waipiata • Pig Burn downstream of O'Neill Rd • Ewe Burn at Gimmerburn-Waipiata Rd
2004—06 investigation Effects of irrigation bywash on water quality	Focused on the SOE water quality measurement suite. Formed part of a wider investigation that included the Manuherikia and Waitaki catchments. See ORC (2006a).	Three sets of paired sites were sampled on various occasions between Feb 2004 and Feb 2006: • Gimmer Burn at Sharkey Rd and Wilson Rd • Sow Burn at Patearoa Styx Rd and Taieri R confluence • Pig Burn at Hamilton Rd and 900 m d/s of O'Neill Rd.
2010—11 investigation Initiated in response to SOE monitoring indicating signs of degrading trends in water quality in the Taieri River at Tiroiti and Sutton	SOE water quality suite and a one-off ecological assessment of tributary sites for macroinvertebrate diversity, fish abundance and condition, and streambed condition in terms of deposited fine sediment cover and depth (including particle size and shuffle index measurements). See Kitto (2012).	12-month investigation between Sept 2010 and Sept 2011 incorporating 18 sites across the upper and part of the mid-catchment reaches, including: • Seven sites on the Taieri mainstem between Linnburn Runs Rd and Tiroiti • sites on the upper and lower Pig Burn, Gimmer Burn and Kye Burn • a site on each of the lower reaches of the Sow Burn and Sheppard's Creek Drain.
2017—19 catchment programme Community awareness of water quality	A subset of SOE water quality variables (nutrients, turbidity and *E. coli*) with limits in the Regional Water Plan – various combinations across sites	52 sites across the upper Taieri catchment, mostly located on tributaries of the Taieri River (see Figure 3-3), with a few sites also located on water races and drains. Large variation in the number of samples collected and the date range over which they were collected.
2018—19 catchment programme Community awareness	A subset of SOE water quality variables (nutrients, turbidity and *E. coli*) with limits in the Regional Water Plan	15 sites in the Kye Burn subcatchment were sampled monthly between Nov 2019 and Jul 2019. All but one of the sites were located on tributaries of the Kye Burn.

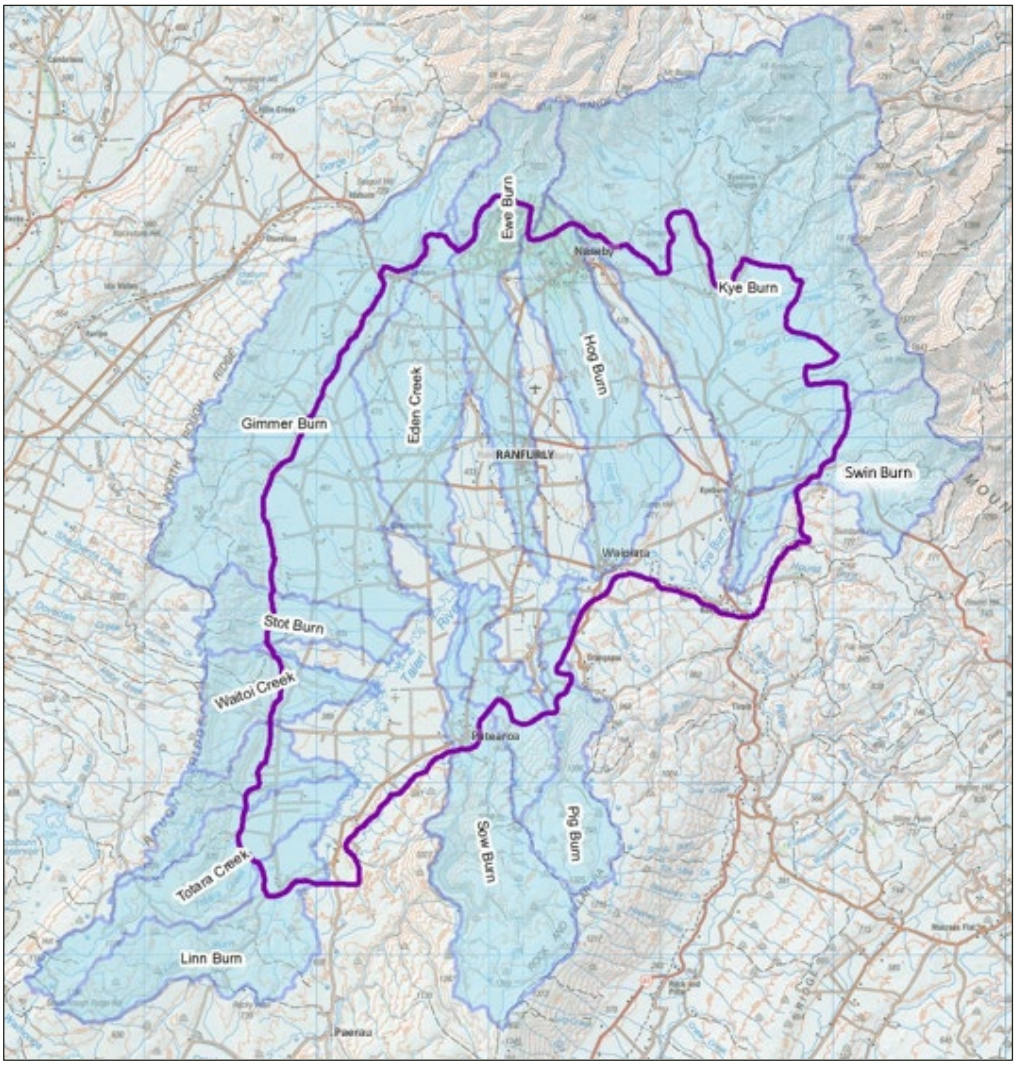

Figure 3-3: Major subcatchments of the Taieri River in the Maniototo Basin. Water quality was sampled within these subcatchments by the ORC over 2017–19 as part of two community awareness programmes. The MIC then sampled sites within Gimmer Burn/Wether Burn and Eden Creek subcatchments between late 2020 to early 2023. Map from ORC (2014).

In addition to these investigations, the ORC recently started deploying water quality sensors for short periods of time at different locations across the upper Taieri catchment to measure water temperature and DO at high frequency (continuous 5-15 minute intervals). Both water temperature and DO vary across the day and seasonally, so high frequency monitoring is needed to capture the extreme lows and highs that can influence river and stream health. The NPS-FM also requires these measurements for calculation of ecosystem metabolism, an attribute which can be used to indicate how well a river is functioning.

What is ecosystem metabolism and why does it matter?

Ecosystem metabolism is a measure of how much organic carbon is produced and consumed in river ecosystems. It provides a direct measurement of the food base of rivers and so helps to determine their life-supporting capacity. Some research suggests it may also give an indication of the likely capability of a river to remove nutrients from the water (Young et al. 2004).

Ecosystem metabolism combines gross primary production (GPP) from aquatic plant growth (photosynthesis) and ecosystem respiration (ER) from respiration of plants and other organisms. High frequency water temperature and DO data are needed to calculate ecosystem metabolism.

The ORC has also carried out one-off or periodic flow gaugings in various tributaries of the Taieri River, such as the Sow Burn, Pig Burn and Gimmer Burn, to support water quality or minimum flow setting investigations. Some one-off fish monitoring has likely also been undertaken and in mid-2022, three piezometers were established along each of four transects within the wetlands of the Styx and Maniototo Basins to investigate the hydraulic connection between groundwater and the wetlands (Figure 3-4). As part of this, water quality is being measured two-monthly in each piezometer and at the edge of the Taieri River (initially monthly over the first 12–18 months). This investigation is expected to last for at least five years (A. Levy, ORC, pers. comm).

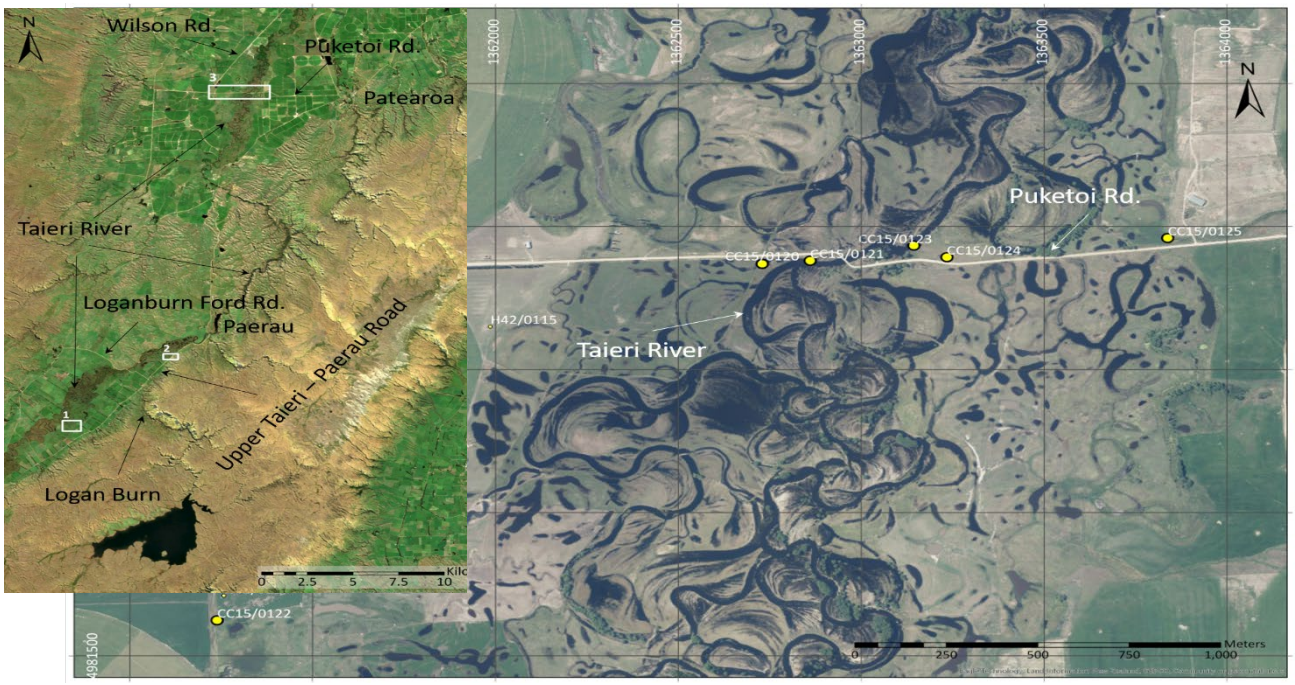

Figure 3-4: General locations of new groundwater piezometers drilled in 2022 (white boxes in inset, left) and close-up of the sites along transects 3 and 4 (within box 3) near Patearoa (right). Each transect extends from above the flood zone of the Taieri River down to the river's edge. Images provided by the ORC.

3.2 NIWA

The National Institute of Water and Atmospheric Research (NIWA) monitored river water quality monthly in the Taieri River at Tiroiti between January 1989 and January 2016 as part of its National River Water Quality Monitoring Network. Water samples were tested for a similar range of tests to the ORC's SOE programme but, unlike the ORC (and most long-term council programmes), consistency in laboratory provider and test methods was able to be maintained for the majority of the 27-year monitoring record. The monitoring also included monthly assessments of riverbed periphyton cover and annual macroinvertebrate sample collection.

NIWA monitors both river flows and rainfall at Canadian Flat upstream of the Styx (Paerau) Basin, with records dating back to 1982 and 2005, respectively. Since 2000, NIWA has also operated a weather station at Ranfurly (climate records are also available for Naseby Forest dating back to 1983).

3.3 Central Otago District Council

The Central Otago District Council (CODC) carries out water quality monitoring in Bandy's Creek in Ranfurly and the Hog Burn in Naseby as part of resource consent requirements associated with discharges from the wastewater treatment plants (WWTPs) in these towns. While treated wastewater at Ranfurly is discharged directly into Bandy's Creek (a tributary of the Ewe Burn), treated wastewater at Naseby is applied to land adjacent to the Hog Burn.

There have been changes over time in what is monitored and when, reflecting changes in WWTP operation and consent requirements. The most recently granted consents require sampling of treated wastewater and water quality upstream and downstream of the discharge (Ranfurly) and land disposal area (Naseby) four times a year. The testing requirements differ between the sample types and consents but include nutrients and *E. coli*.

The CODC also carries out monitoring of water quality in the Sow Burn, Ewe Burn and Mount Ida Water Race in at or near the raw water intakes for Patearoa, Ranfurly and Naseby public water supplies. Current sample collection and test requirements differ across the systems to meet requirements introduced by Taumata Arowai, the national drinking water regulator, in 2022. In the case of Ranfurly, samples of the raw drinking source water are currently tested fortnightly for *E. coli*, monthly for nitrate-nitrogen, iron, manganese and colour, and annually for a wider suite of chemical variables (e.g., selected metals). The length and scope of the historic water testing data record was not provided by CODC.

3.4 Environment Canterbury

Environment Canterbury (ECan) has monitored rainfall at Dansey's Pass on the northern-eastern boundary of the upper Taieri catchment since May 1996.

3.5 Maniototo Irrigation Company

Between October 2020 and March 2023, the MIC monitored *E. coli* at a subset of 15 surface water sites that formed part of the ORC's 2017–19 water quality investigation. Most sites were located in the Wether Burn/ Gimmer Burn and Eden Creek subcatchments (refer Figure 3-3) where irrigation bywash discharges still occur. The frequency and duration of sampling differed between sites. The results of this monitoring are briefly summarised in Section 4.2.2.

3.6 Upper Taieri Wai

In autumn 2022, as part of its Tiaki Maniototo project, the Upper Taieri Wai engaged University of Otago science graduates to carry out an ecological survey of six sites on the Taieri River (between Canadian Flat and Kokonga) and a site on the lower reaches of each of three tributaries (Serpentine Creek, Logan Burn and Kye Burn). The primary focus was periphyton cover and biomass, macroinvertebrates, fish and stream habitat quality. The amount of fine sediment deposited on the riverbed was also assessed. The results of the monitoring are documented in Vermeulen et al. (2022) and summarised in Section 4.2.4. Some fish assessments were also carried out in autumn 2023.

Monitoring during summer 2023/24 was a combined effort with the Department of Conservation and involved instream ecological assessments at 23 sites, including the seven sites surveyed in autumn 2022. Most of the remaining sites were located on tributaries of the Taieri main stem (Figure 3-5).

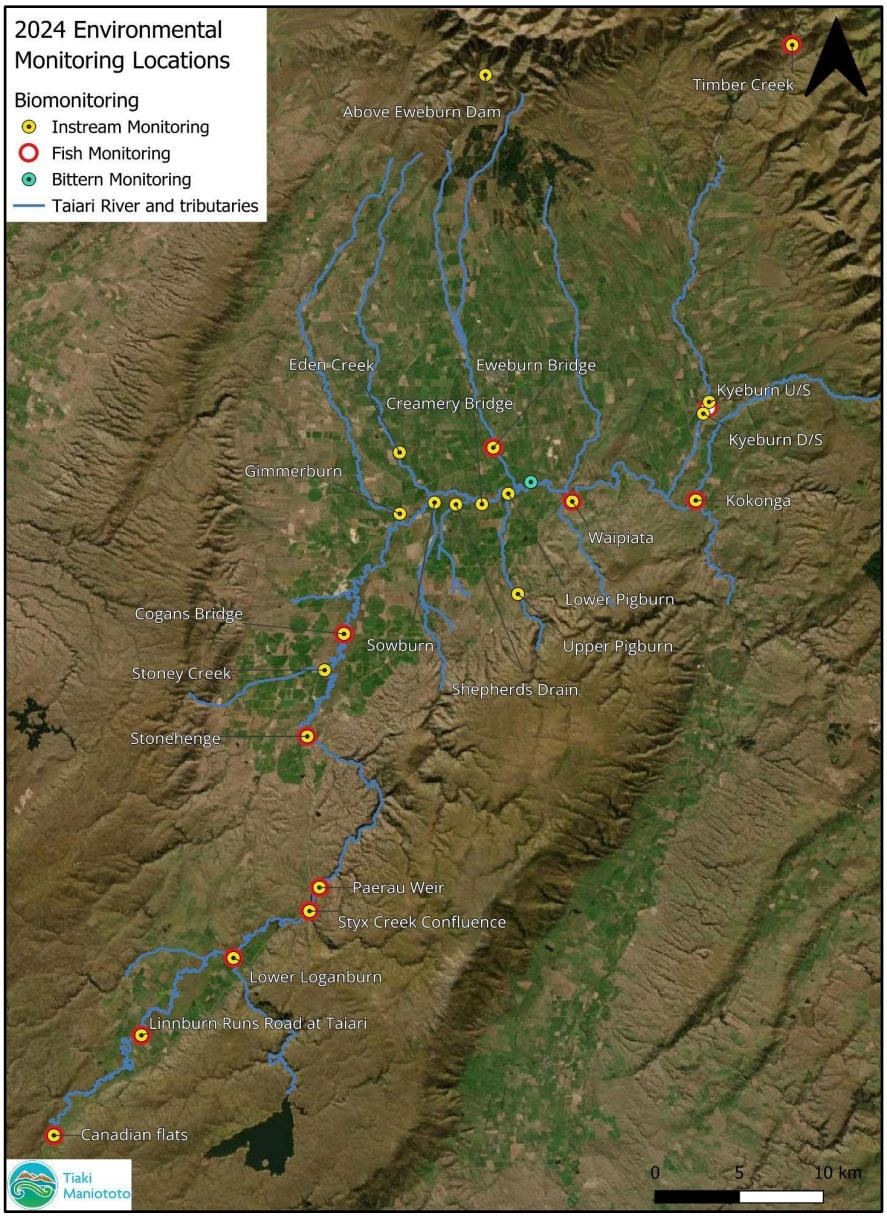

Figure 3-5: River and stream sites monitored by the Upper Taieri Wai between December 2023 and April 2024. Reproduced from Hogan and Trotter (2024).

3.7 Department of Conservation

The Department of Conservation (DOC) has carried our various fish surveys in the upper Taieri catchment as part of its freshwater conservation mandate. In the last few years, there has been more intensive ecological monitoring through Te Mana o Taiari, a project within Ngā Awa, a whole of catchment ('mountains to the sea') river restoration programme launched by DOC in 2019. This has included the use of eDNA testing to complement existing fish monitoring methods. Surveys in 2023/24 also incorporated assessments of water and sediment quality at multiple sites. Kai Tahu is a partner in the catchment-wide project and has been involved in the monitoring, including cultural health monitoring.

As part of Te Mana o Taiari, DOC has also commissioned comprehensive assessments of the predicted impacts of climate change on aquatic and terrestrial ecosystems in the Taieri catchment. Predicted changes in rainfall and river flows have been assessed as part of this. These assessments are reported in Goldsmith (2023) and Closs et al. (2024).

3.8 University of Otago

The University of Otago has carried out research throughout most of the Taieri catchment. The Kye Burn subcatchment has often featured in this research. For example:

- Townsend et al. (1997a) investigated the relationship between land use and stream conditions on stream macroinvertebrate communities. This work involved the collection of a range of physical, chemical, food web-related and invertebrate data from 54 stream sites across the Taieri catchment, including two sites on the Kye Burn. Related pieces of research involving some of the same sites looked at the effects of streambed disturbances on aquatic macroinvertebrate communities (Townsend et al. 1997b) and the influence of different bedform, stream reach and catchment scale environmental features on stream invertebrate diversity (Brosse et al. 2003).
- Young et al. (1994) investigated differences in the breakdown of tussock leaf litter by macroinvertebrate communities in tussock dominated versus agriculturally developed subcatchments of the Taieri River. The Kye Burn and a tributary of the Kye Burn were two of the six sites sampled as part of this work.

The Kye Burn also features as a key focus for a current student Masters research project investigating strategies to increase the resilience of the endangered Central Otago roundhead galaxiid *(Galaxias anomalus)* in the face of invasive salmonids, water abstraction and climate change.

3.9 Summary

- Routine ORC SOE surface water quality monitoring in the upper Taieri catchment commenced in late 1989, the same year that NIWA started monitoring water quality in the Taieri River at Tiroiti. Current SOE monitoring sites are on the Taieri River (at Linnburn Runs Road, Stonehenge, Waipiata and Tiroiti) and the lower Kye Burn (at SH 85). All five sites have been sampled monthly since 2014; all sites but Linnburn Runs Road have a longer data record but sampling was less frequent pre-2014 and, with the exception of Stonehenge, there were significant periods when no monitoring was carried out. Surface water sample tests include nutrients, turbidity and *E. coli*. In addition, both water temperature and dissolved oxygen are measured at high frequency in the Taieri River at Waipiata.
- Macroinvertebrates and fish are currently monitored annually at a few sites. Periphyton biomass monitoring was carried out monthly on the Taieri River at Waipiata and Kye Burn at SH 85 between mid-2019 and mid-2022.
- *E. coli* testing is carried out at Waipiata weekly over the summer months as part of the ORC's regional recreational water quality monitoring programme.
- Short-term investigations or monitoring campaigns into specific aspects of water quality were carried out by the ORC in 2001, 2004–06, 2010–11 and 2017–2019. Of these, the 2010–11 investigation (Kitto 2012) was the most comprehensive and incorporated both water quality and ecological variables. The 2017–19 campaigns were focussed on community awareness and limited to five water quality variables for which there are 'good water quality' limits in the ORC's Regional Plan Water. These campaigns incorporated sampling:
    - between one and 26 times at 52 sites in the Styx and Maniototo basin area (with a subset of these sites picked up by MIC and monitored for *E. coli* between October 2020 and March 2023), and
    - over a nine-month period in 2018–19, at 15 sites in the Kye Burn subcatchment.
- River level/flow monitoring dates back to 1982 (Taieri River at both Canadian Flat (NIWA) and Waipiata (ORC)) and has been in place at Tiroiti since 1992. The ORC also monitors flow in the Pig Burn and Kye Burn (since 2009 and 2012) and has carried out flow gaugings in various tributaries.
- Rainfall is monitored by NIWA at Canadian Flat and at their weather station at Ranfurly, and at Dansey's Pass by Environment Canterbury.

- Routine groundwater quality monitoring commenced in early 1997 and ran for 10 years, prior to the establishment of two new wells that have been sampled quarterly since September 2015. Water level and concentrations of nutrients, metals and *E. coli* are some of the variables monitored. In 2023, 10 new piezometers were drilled; there are now five locations in the Maniototo Basin where both the shallow unconfined and deep confined aquifers are monitored.
- In mid-2022, a series of piezometers were established along several transects within the wetlands of the Styx and Maniototo Basins to investigate the hydraulic connection between groundwater and the wetlands. Water quality is also being monitored.
- The ORC has recently established soil quality monitoring in the upper catchment. Two drystock farmland sites and one forestry site have been sampled once to date for various properties, including pH, nutrient and organic carbon content, and indicators of soil compaction.
- The CODC monitors water quality in Bandy's Creek in Ranfurly and the Hog Burn in Naseby as a requirement of resource consents for treated wastewater discharges. Water quality is also monitored in the Sow Burn, Ewe Burn and Mount Ida Water Race at/near the raw water intakes for Patearoa, Ranfurly and Naseby public water supplies. Monitoring variables and frequency differ across each wastewater and water treatment plant.
- Both Upper Taieri Wai and DOC have completed ecological surveys at different locations in the upper Taieri catchment over the last few years as part of the Tiaki Maniototo and Te Mana o Taiari projects. Tiaki's autumn 2022 survey focused on six Taieri River sites between Canadian Flat and Kokonga and a site on the lower reaches of each of Serpentine Creek, Logan Burn and Kye Burn. Sampling in summer 2023/24 occurred at 23 sites, including 14 sites on nine tributaries of the Taieri main stem.
- The University of Otago has collected water quality and ecological data in the upper Taieri catchment, including from multiple streams sites in the Kye Burn catchment as part of various research projects.

4 Current state – what we know

In this section we summarise what is known about current condition (state) of water quality in the upper Taieri catchment. As well as recently reported information about the ORC's routine surface water quality monitoring sites, we briefly summarise water temperature and dissolved oxygen monitoring results for the Taieri River at Waipiata. Because of the interactions between surface and ground water, we also consider the ORC's most recent assessment of groundwater quality and the results of recent soil quality testing. We then look at the results of recent additional monitoring and investigations.

Note: A mixture of nitrate nitrogen (nitrate-N) and nitrite-nitrate nitrogen (NNN) are used in this section, reflecting differences in what was monitored or reported across different time-periods. In essence these two forms of plant-available nitrogen are broadly equivalent as nitrite-N concentrations are typically very low in surface waters. Ammoniacal nitrogen (ammoniacal-N) is the other main form of plant-available nitrogen.

4.1 Recent ORC State of the Environment reporting

4.1.1 Surface water quality

The most recent assessment of surface water quality state in the upper Taieri catchment was carried out as part of an Otago-wide assessment of river, lake and ground water quality prepared by Ozanne et al. (2023), for the period July 2017 to June 2022. The primary focus of the report was SOE variables that are mandatory ecosystem health attributes in the NPS-FM 2020. Consequently, not all of the available data were examined and the current state assessment only classified or graded each attribute into NPS-FM bands of A to D (or A to E in the case of *E. coli*). Where readily available, we draw on the results of other recent state assessments (e.g., ORC 2021, LAWA) to fill in some of these gaps.

What is an attribute and what do Bands A to E mean?

An attribute is a specific term used in the NPS-FM 2020. It refers to a measurable characteristic, such as the concentration of nitrate nitrogen, that is used to assess how well a certain freshwater value (e.g., ecosystem health, recreation) is provided for within a river or lake. Attribute state is generally:

- calculated from regular measurements over a fixed time period (e.g., as a median of monthly measurements over five years), and
- expressed as one of four or five numerically defined bands (A to D or A to E).

In many cases, the NPS-FM specifies a minimum acceptable state (or national bottom line) for an attribute. Councils must monitor and regularly assess current attribute states to track progress towards meeting the future target states established with community input. Target states must be set to maintain or improve river health from a baseline state that was established at a set time (typically 2017).

Attribute bands can be thought of as a bit like a report card where A is the highest and D/E the lowest. However, a lower grade for a particular attribute does not always mean a river is in poor health. A river's natural characteristics, such as the brown tannin staining of the Taieri River or local geology, mean Band A may be an unrealistic and unnecessary target, even in near pristine headwaters. In this section, attribute states of band C or lower are identified to flag potential issues that are then revisited in Section 6.

Not all variables monitored in SOE programmes and investigations are NPS-FM attributes (e.g., water temperature, stream habitat). However, national guidelines can be used to assess these variables.

The ORC's 2017–2022 state assessment (Table 4-1) found all four Taieri River sites and the Kye Burn at SH 85 had 'good' water quality in terms of low potential for ammoniacal-N or nitrate-N toxicity (Band A) and *E. coli* (Band A or B). However:

- suspended fine sediment (measured as visual clarity under the NPS-FM and estimated by the ORC using turbidity data) in the Taieri River at Waipiata and Tiroiti was graded Band D (i.e., below the national bottom line), and
- DRP concentrations in the Taieri River at Waipiata and Tiroiti were graded Band C.

Table 4-1: Summary of overall* NPS-FM 2020 attribute grades assigned to ORC SOE sites in the upper Taieri catchment. Summarised from Ozanne et al. (2023). Suspended fine sediment is visual clarity, estimated from measurements of turbidity.

Site	Ammonia toxicity	Nitrate toxicity	DRP	Suspended fine sediment	*E. coli*
Linnburn Runs Rd	A	A	A	B	B
Stonehenge	A	A	A	B	A
Waipiata	A	A	C	D	B
Kye Burn SH 85	A	A	A	A	A
Tiroiti	A	A	C	D	A

* For many NPS-FM attributes, more than one metric (e.g., median, 95th percentile) is graded but the metric with the lowest grade determines the overall grade.

Toxicity versus other effects

Bands A to D of the NPS-FM for ammoniacal nitrogen and nitrate nitrogen only relate to toxic effects on aquatic life. As such, the band thresholds are set at very high concentrations relative to the median concentrations reported for the majority of rivers in New Zealand (which commonly fall into band A or B). However, adverse effects on river ecosystems can occur at much lower nitrogen concentrations through stimulating nuisance growth of periphyton (algae) and macrophytes (aquatic plants). Excessive nutrients and algal/plant growth are often referred to as eutrophication (enrichment). Eutrophication can significantly affect stream life, including through depletion of water column oxygen levels when algae/plants die and break down.

Whether nuisance periphyton or plant growth occurs is dependent not only on nutrient concentrations but other factors such as water temperature, shading, and the frequency of river flows of a sufficient magnitude to 'flush' the riverbed clean. Some guidance has been developed by MfE (2020, 2022) to provide a starting point for deriving nutrient concentrations for managing periphyton biomass, as required by the NPS-FM. The 2020 guidance was used in ORC (2021) to estimate river trophic state in Otago in the absence of any significant periphyton biomass monitoring data.

Water quality deteriorates in the Taieri River between Linnburn Runs Road and Tiroiti, with the most marked deterioration occurring between the intermediate sites of Stonehenge (Paerau) and Waipiata. This can be seen more clearly by comparing median turbidity and median nutrient concentrations at each Taieri River site over the five-year period ending June 2022 (Figure 4-1). Median *E. coli* counts were also higher at Waipiata and Tiroiti than at the two upstream sites, although they fell within the A Band (i.e., it is the other NPS-FM *E. coli* metrics that drive the Band B grading for Waipiata – and also Linnburn Runs Road).

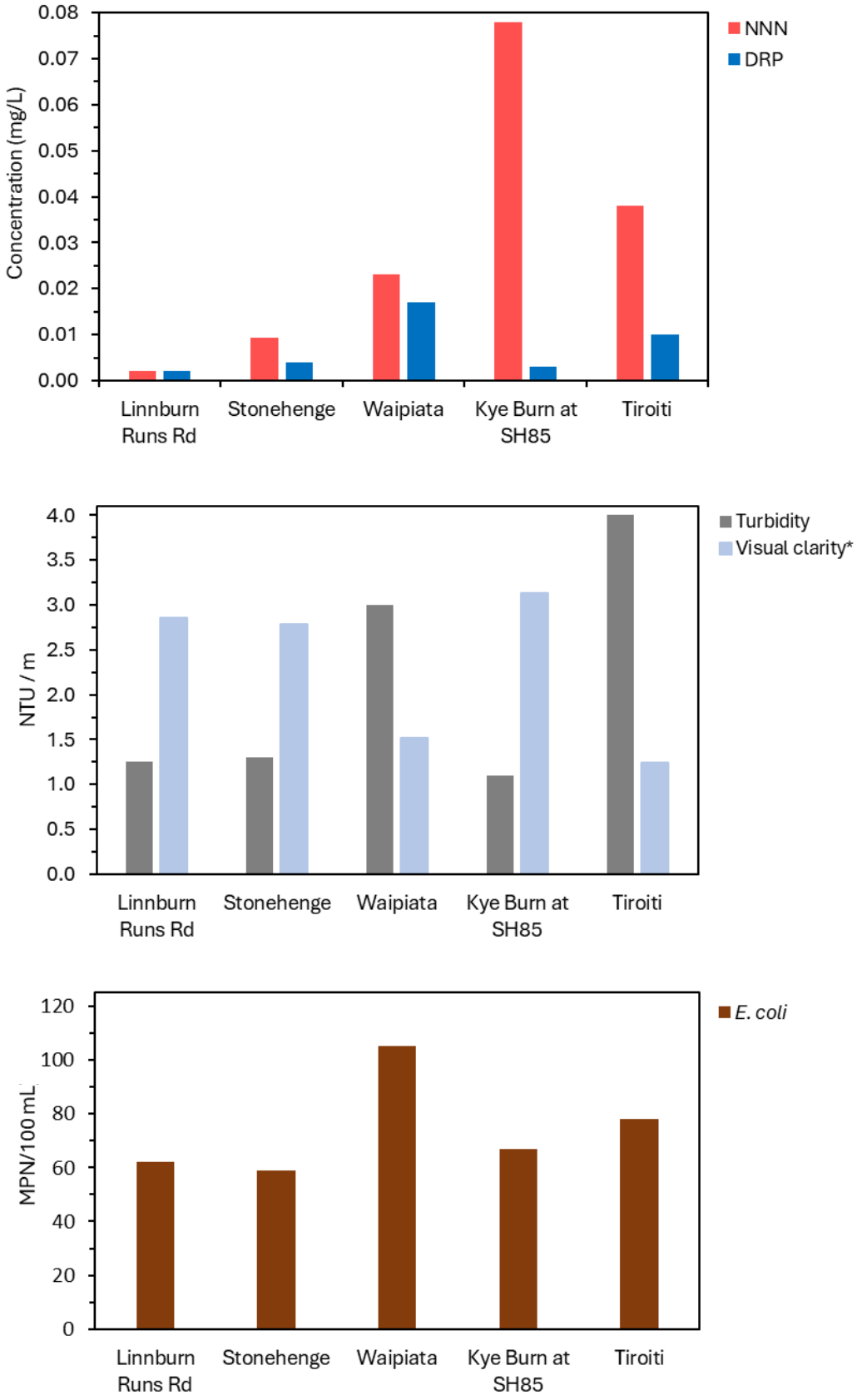

Figure 4-1: Median nutrient, turbidity, visual clarity* and *E. coli* values at ORC's Taieri River and Kye Burn SOE water quality monitoring sites. Based on monthly sampling between July 2017 and June 2022, reported in Appendix 1 of Ozanne et al. (2023). Although nitrate-N is much higher in the Kye Burn, based on LAWA (accessed October 2024), the median concentration is in the best 50% of all monitored rural upland streams.

* estimated from turbidity and a national equation.

ORC (2021) included an assessment of current state for the two former Taieri River SOE sites (Halls Bridge and Creamery Bridge) that were monitored for a portion of the five-year reporting period. This assessment provisionally placed:

- Halls Bridge in Band C for both suspended fine sediment and DRP, and
- Creamery Bridge in Band D for both suspended fine sediment and DRP
  (sites at Waipiata and Tiroiti over this same period were also graded as Band D).

These findings are consistent with earlier ORC SOE reporting (e.g., ORC 2006b) and investigations (e.g., ORC 2003) that identified higher turbidity and concentrations of DRP at Creamery Bridge and Waipiata. Two main tributaries enter the river in the vicinity of Creamery Road, the Gimmer Burn/Wether Burn (immediately upstream of Halls Bridge) and Eden Creek, with several further tributaries entering between Creamery Bridge and Waipiata. Information on water quality in these tributaries is summarised later in this section.

Water temperature and dissolved oxygen (DO)

The upper Taieri River regularly records summer water temperatures above 20°C (Figure 4-2). High frequency measurements at Waipiata over 20-year period ending 18 February 2024 indicate that water temperature at this location exceeded 20°C around 30% of the time, and 23°C just over 11% of the time. The highest water temperature recorded to date is 27.9°C on the afternoon of 29 January 2018 which followed an extended period (starting in early December 2017) of peak daily water temperatures above 25°C. Water temperatures above 25°C were also recorded in other summer periods, including over multiple afternoons in February 2005 and between mid-January and early February 2023.

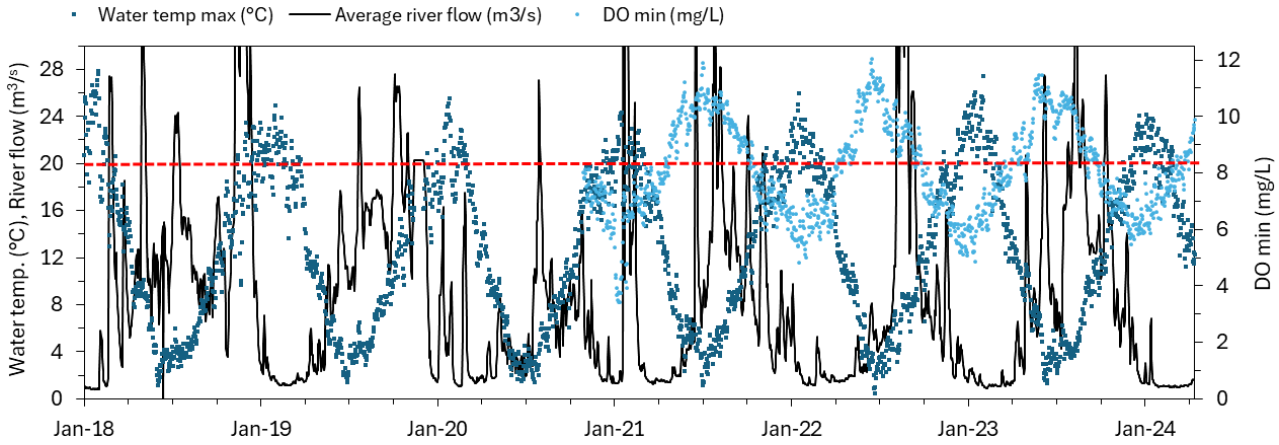

Figure 4-2: Daily maximum water temperatures recorded in the Taieri River at Waipiata between January 2018 and January 2024. Also shown are daily minimum dissolved oxygen (DO) concentrations (monitored since late 2020) and average daily flow. Summarised from 5–15-minute interval measurements downloaded from the ORC's Environmental Data Portal. The red dashed line represents an indicative threshold above which some sensitive aquatic fish and macroinvertebrate species may start to experience stress.

In New Zealand, the Cox Rutherford Index (CRI) is commonly used to characterise summertime water temperatures and interpret the potential effects of water temperature on aquatic ecosystems. The CRI is the midpoint between the daily average and daily maximum temperatures and can be averaged over the five hottest days of a summer from a continuous water temperature record (Davies-Colley et al. 2013). Table 4-2 summarises the two component values of the CRI for the warmest summer (2017/18) and, for convenience, the following 2018/19 summer and most recent summer, calculated from ORC's Waipiata monitoring data. The values are graded in accordance with bands A to D developed by Davies-Colley et al. (2013).

Table 4-2: Cox Rutherford Index water temperature values for the Taieri River at Waipiata for the warmest five days in summer 2017/18 and 2018/19. Calculated from ORC data collected at 5-minute intervals.

Summer	5-day period	Water temperature (°C)		Davies-Colley et al. (2013) *	
		Average daily	Average daily maximum	Band	Description
2017/18	26 Jan–30 Jan	24.3	27.9	D	Significant thermal stress on a range of aquatic organisms
2018/19	28 Jan–01 Feb	21.4	23.8	C	Some thermal stress on occasion, with loss of certain sensitive insects and absence of certain sensitive fish
2023/24	21–25 Dec	21.5	23.2	C	

* Suggested bands only – water temperature is not an NPS-FM attribute.

One consequence of elevated summertime water temperatures is a reduction in dissolved oxygen (DO) levels (warm water holds less oxygen), which can further stress invertebrate and fish life. While DO levels in many rivers are often close to 100% saturation, the upper reaches of the Taieri River are characterised by lower DO levels, with a median of around 80% at Waipiata[6]. This likely reflects a combination of the river's slow meandering flow, elevated water temperatures and inputs (e.g., decaying organic matter) from the associated wetlands in the Styx and Maniototo basins.

The lowest DO measurements recorded at Waipiata since continuous monitoring began in late October 2020 occurred in January 2021 when DO levels dropped below 50% on 7 January and remained low for several weeks (minimum 36.2% saturation, or 3.4 mg/L, on 10 January, refer Figure 4-2). A report prepared for Tiaki Maniototo identified that these lower DO levels were most likely due to a flood event a few days prior; either from stagnant flood waters draining back into the river system or increased in-river bacterial respiration from large inputs of organic matter (Wansbrough 2023). Following this flood event, both the 1-day minimum DO and the 7-day mean minimum DO fell into Band D of the NPS-FM 2020 (Figure 4-3). DO concentrations this low can create significant stress for aquatic life. At other times during summer 2020/21 (and during subsequent summers), DO routinely fell into Band C.

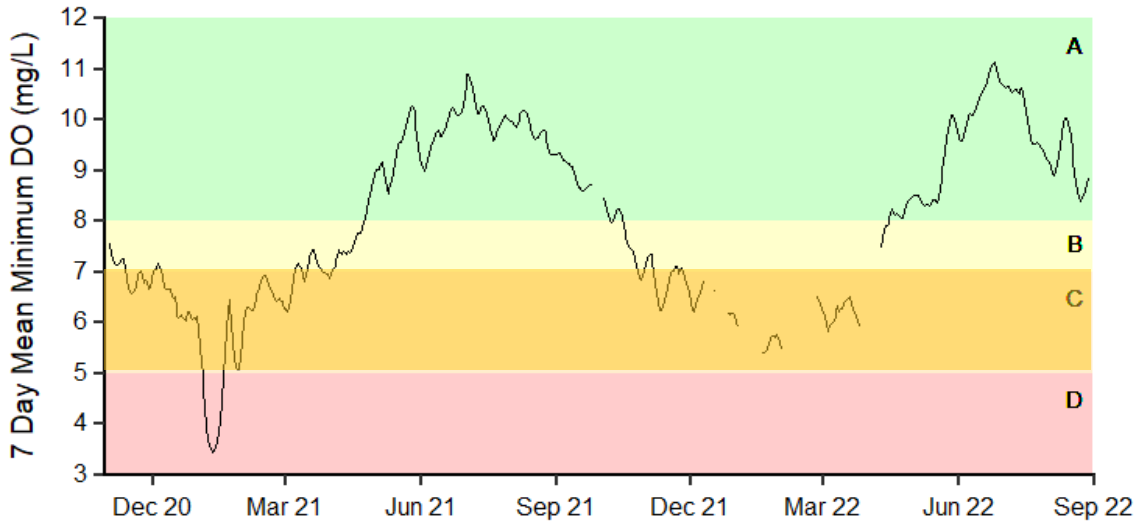

Figure 4-3: 7-day mean minimum dissolved oxygen (DO) concentrations for the Taieri River at Waipiata. Coloured bands indicate the NPS-FM 2020 attribute bands. Reproduced from Wansborough (2023) based on ORC data.

[6] Based on high frequency measurements made by the ORC between October 2020 and October 2023.

Ecological health

Ecological variables were not included in the ORC's most recent state and trend report. However, a separate ORC (2023) biomonitoring report card for the 2017–2022 period assigned overall macroinvertebrate community health grades[7] of Band C to four of the five SOE sites, with the uppermost site, Taieri River at Linnburn Runs Road, assigned Band D (below the national bottom line). Some of these median grades were based on less than five years of data given that only two of the sites were included in the ORC's (2021) state and trend report. This earlier report placed the Taieri River at Waipiata and the Kye Burn at SH 85 in Band C, based on the five-year median macroinvertebrate community index (MCI) metric. The NPS-FM narrative description for Band C is "moderate to severe loss of ecological integrity". Macroinvertebrate health is revisited in section 6.

In the ORC (2021) report, periphyton biomass was graded as Band C or Band D across all five SOE sites, translating under the NPS-FM to "periodic short-duration" and "regular and/or extended" nuisance (algal) blooms. However, these grades were estimated from water column nutrient concentrations provided in MfE (2020) and are at odds with actual periphyton biomass data collected by the ORC at Waipiata and Kye Burn at SH 85 between November 2019 and April 2022. Based on this monitoring, both sites would have a provisional grade of Band A ("rare algal blooms").

4.1.2 Groundwater quality

The 2017–2022 groundwater quality state assessment included in Ozanne et al. (2023) was limited to three variables: nitrate nitrogen (nitrate-N), *E. coli* and arsenic. Monitoring data were compared against the Maximum Acceptable Values (MAV) of the NZ Drinking Water Standards (NZDWS).

For the two shallow SOE wells in the upper Taieri:

- nitrate-N concentration in both wells were well below the NZDWS on all sampling occasions but the median concentration of 4.5 mg/L in well H42/0214 located east of the Sow Burn was well above the 2.5 mg/L threshold for low intensity land use (Morgenstern & Daughney 2012) (in contrast, the median for well H42/0213 near Eden Creek was just 0.019 mg/L),
- *E. coli* was detected in both wells on at least five occasions, breaching the NZDWS, and
- arsenic on one occasion was measured close to the NZDWS MAV of 0.01 mg/L in H42/0213.

The median nitrate-N result for well H42/0214 was similar to that reported in the previously monitored well nearby (H42/0132, ORC 2014).

An earlier assessment of groundwater quality across Otago (Levy et al. 2021) incorporated data on additional nutrients for wells H42/0214 and H42/0213 and graded the results against the NPS-FM 2020 attribute bands. While these attribute bands only apply to surface waters and the concentrations do not necessarily reflect those in the groundwater at the point of entering surface water, this comparison recognises that groundwater – particularly shallow groundwater – interacts with the overlying surface water. The results (Table 4-3) highlight that groundwater nitrate-N concentrations in the vicinity of the lower Sow Burn and groundwater DRP concentrations near Eden Creek are elevated compared to surface water concentrations.

[7] Overall refers to the Average Score Per Metric (ASPM) in the NPS-FM. This index combines three other metrics that are averaged to indicate river/stream health: the MCI, the richness of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (EPT taxa) and %EPT abundance.

Table 4-3: Summary of nutrient concentrations (mg/L) measured in, and indicative NPS-FM 2020 attribute grades assigned to, ORC groundwater SOE monitoring wells in the upper Taieri catchment. Based on the results of water samples collected quarterly between late 2014 and December 2019, reported in Levy et al. (2021).

Site	Ammonia toxicity		Nitrate toxicity		DRP	
	Median	95th-ile	Median	95th-ile	Median	95th-ile
H42/0213 (near Eden Ck)	0.235 B	0.550 C	0.050 A	0.222 A	0.113 D	0.198 D
H42/0214 (E of Sow Burn)	0.003 A	0.250 B	4.0 C	5.9 C	0.043 D	0.050 C

4.1.3 Soil quality

The test results for soil samples collected from two drystock farms in 2022 and a site in Naseby Forest in 2023 have recently been reported as part of a regional soil quality 'report card' (Button 2024). The report card provides a summary by land use across Otago rather than by catchment, so for this report we compared the upper Taieri sample results against soil quality indicator targets developed for regional councils by McKay et al. (2013). This exercise found that the only result of potential concern was Olsen-P at the Puketoi site, which at 52.2 mg/kg, significantly exceeded the upper end of its target range (the Naseby site also exceeded the upper end of its target range by a small amount). Very high Olsen P concentrations are a concern as Olsen P is a measure of the amount of phosphorus in the soil that is available to plants; excessive levels can increase loss to waterways, contributing to nutrient enrichment and other impacts on water quality.

4.2 Insights from other recent monitoring and investigations

4.2.1 ORC-led catchment programmes

2017–19 catchment programme – Styx and Maniototo basins

Between September 2017 and June 2019, the ORC ran a monitoring programme aimed at raising community awareness of water quality across the upper Taieri catchment. Most of the monitoring sites were located on tributaries of the Taieri, with a few sites also located on water races and drains. The Kye Burn subcatchment was not included as this was the focus of a separate investigation in 2018/19 (summarised next).

The catchment programme spanned 52 sites, with wide variation in what was measured[8], where and when, in response to landowner interests and initial sampling results. While the different sampling and testing performed prevents a robust comparison of water quality between sites, water quality can be looked at on an individual site basis and contextualised, as the ORC did[9], against data from the ORC's Taieri mainstem SOE sites. For the sites sampled 20 times or more[10]:

- There was often significant faecal contamination in the lower reaches of the Ewe Burn and Eden Creek, with more than 25% of sample results at each site above 1,000 *E. coli*/100mL (Figure 4-4), a once commonly used stock drinking water guideline. The lower reaches of the Gimmer Burn also exceeded this threshold on 15% of sampling occasions.

[8] Samples from all sites were routinely tested for *E. coli*. At approximately 60% of the sites, water samples were also measured for nutrient concentrations and turbidity on one or more occasions. At some sites, both dissolved and total nutrients were measured.
[9] ORC staff discussed the water sampling results at a meeting with the local community in relation to the ORC's Water Plan Schedule 15 "good water quality" limits and targets. Data from the ORC's Taieri River SOE sites were included for context but it should be noted that the mainstem sites were sampled on a different day (R. Ozanne, ORC, pers. comm.).
[10] At least 20 times for *E. coli* (12 sites) and at least 18 times (11 sites) for turbidity and nutrients.

- The Taieri River at Tiroiti was the only site not to exceed the action level (540 *E. coli*/100mL) of the national recreational water quality guidelines on any sampling occasion (Figure 4-4), the threshold above which swimming is considered to pose an unacceptable health risk. Nine of the other 11 sites exceeded a combination of this threshold or the stock drinking water *E. coli* threshold on two or more occasions.
- Turbidity was highest in the lower reaches of Eden Creek, Ewe Burn and Gimmer Burn, and in the Taieri River at Tiroiti (Figure 4-5).

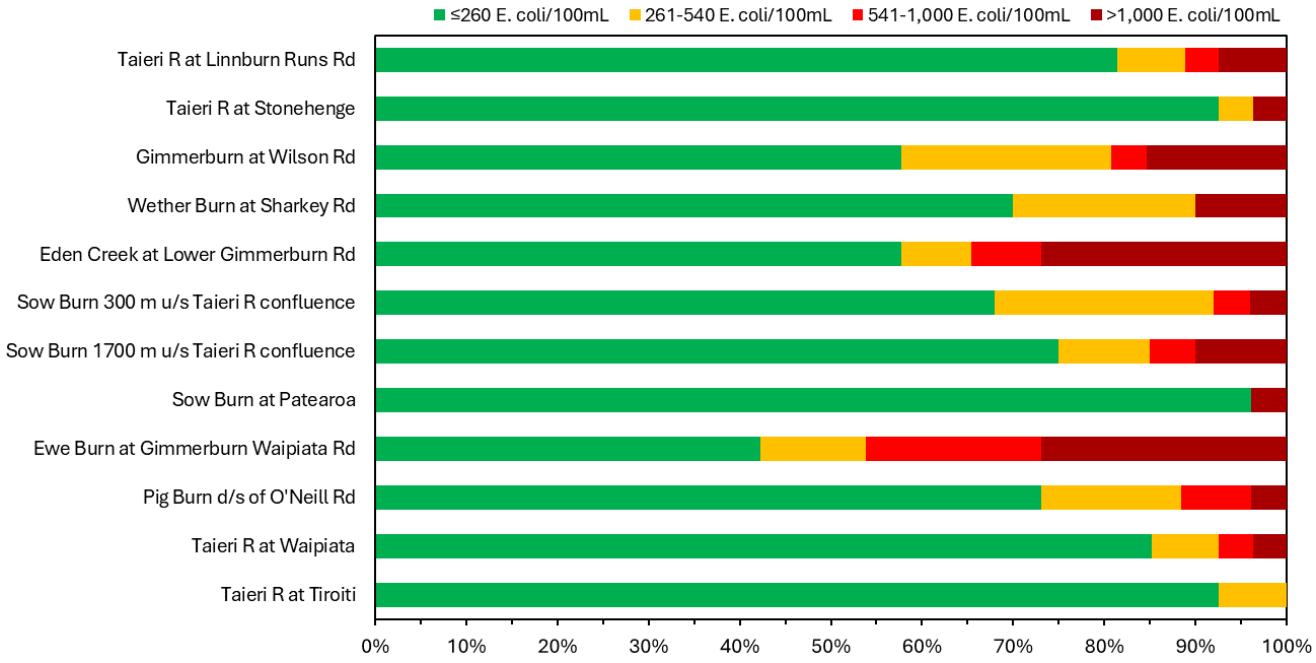

Figure 4-4: *E. coli* sample results recorded at 12 sites in the upper Taieri catchment over 2017–19. The results are summarised in the form of percentages falling into the green/surveillance, amber/alert and red/action levels of the national contact recreation guidelines and a once commonly applied stock watering guideline.[11]

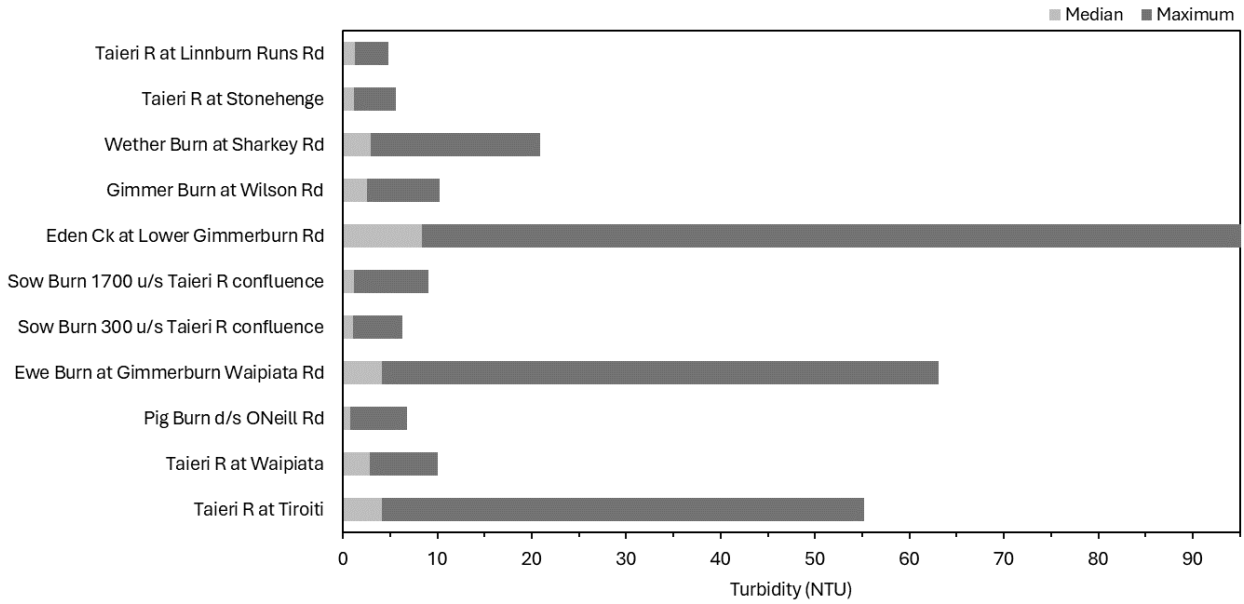

Figure 4-5: Median and maximum turbidity results recorded at 12 sites in the upper Taieri catchment over 2017–19. The ORC has a target/limit of <5 NTU for 'good water quality' but this only applies at less than median river flows.

[11] From ANZECC (1992), based on faecal coliforms. The current guideline is much more stringent (median of 100 per 100mL).

- Median concentrations of plant-available nutrient forms (ammoniacal-N, nitrate-N and DRP) made up small proportions of the total nitrogen (Figure 4-6) and phosphorus measured (Figure 4-7), indicating that the majority of the nutrients are in organic form. The main exceptions were median DRP concentrations at sites on the lower reaches of Eden Creek and, to a lesser extent, the Gimmer Burn and Ewe Burn, all of which had median and 95th percentile concentrations that would provisionally be graded as Band D under the NPS-FM 2020. The Eden Creek DRP median of 0.28 mg/L was around 10 times higher than the median concentrations recorded in the Gimmer Burn and Ewe Burn and the NPS-FM bottom line of 0.018 mg/L. It was also 100 times higher than most other sites.

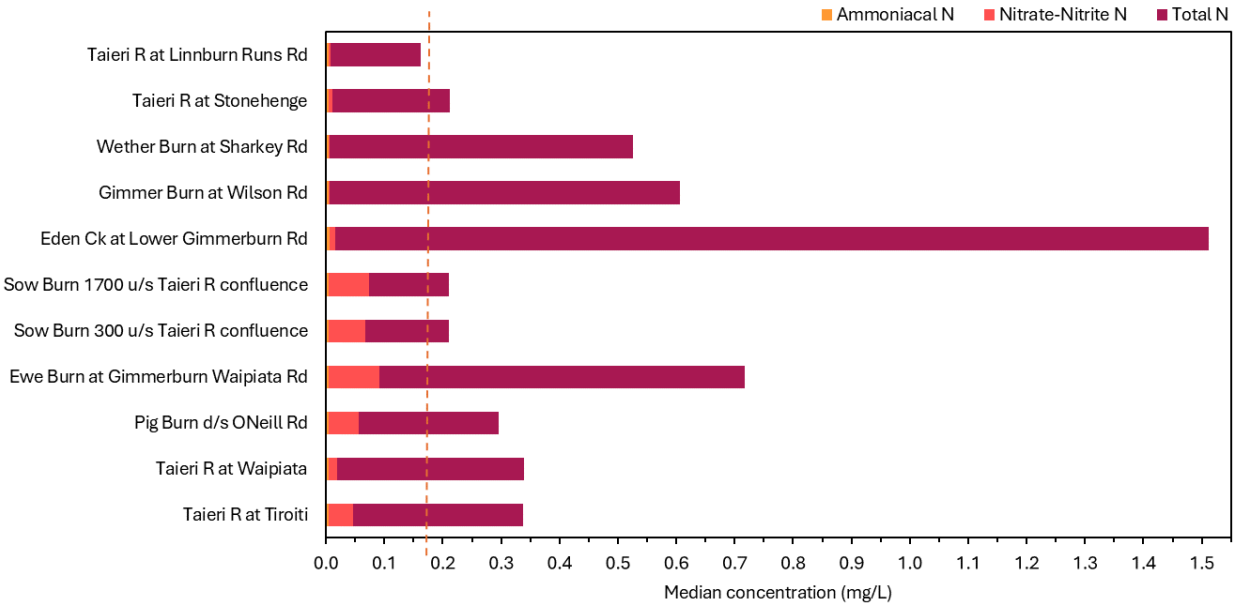

Figure 4-6: Median nitrogen concentrations recorded at 12 sites in the upper Taieri catchment over 2017–19. The full length of each bar represents the total N concentration, with the lighter coloured portions representing the plant-available fractions. The once commonly applied national nitrate-N 'benchmark' for upland rivers from the ANZECC (2000) is presented for context only (dashed red line).

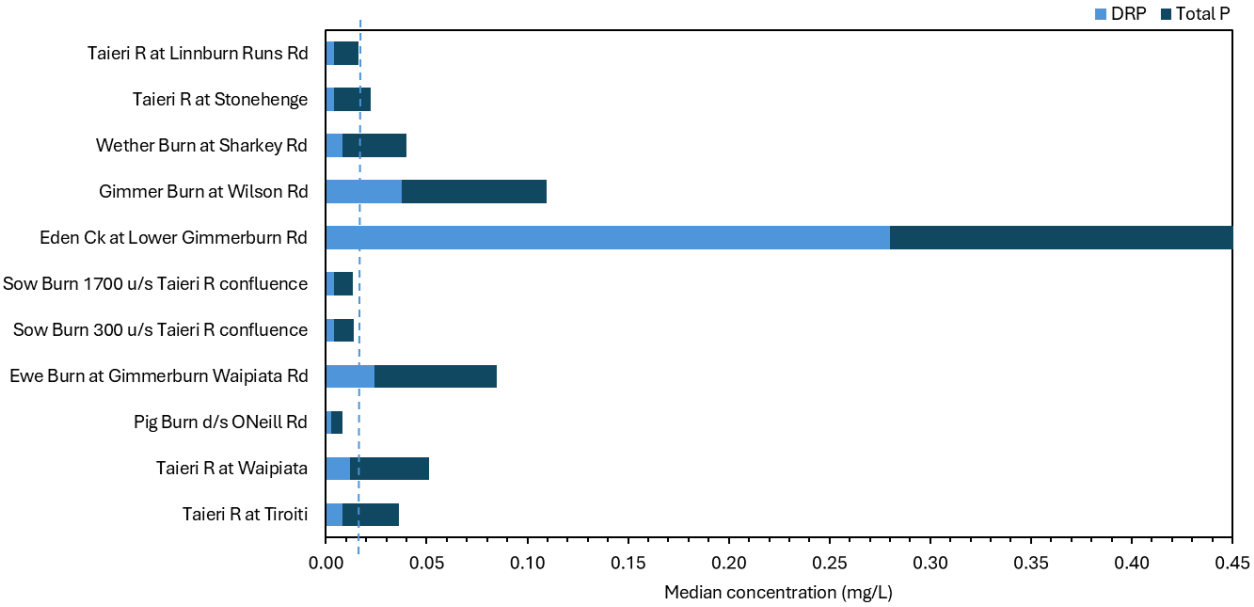

Figure 4-7: Median phosphorus concentrations recorded at 12 sites in the upper Taieri catchment over 2017–19. The full length of each bar represents the total P concentration, with the light blue portion representing the plant-available (DRP) fraction. The vertical dashed line represents the boundary of Bands C/D for DRP under the NPS-FM 2020 (note there is no national bottom line for DRP) and is presented for context only.

In a few tributaries, the highest concentrations of readily available plant nutrients were recorded between November 2017 and January 2018 (Figure 4-8, Figure 4-9). This differs from the commonly observed patterns of higher nutrient concentrations in winter/spring, and coincided with an extended period of low flows in the Taieri River (0.8–1.3 m^3/s). Shallow groundwater inputs likely account for the elevated nitrate-N concentrations in the Pig Burn and Sow Burn at this time, as both streams are known to gain flow from (and lose flow to) groundwater over parts of their length (e.g., Hickey 2020, Xiaofeng & Ravenscroft 2017). Higher DRP concentrations in the lower reaches of the Gimmer Burn, Eden Creek and the Ewe Burn may also have resulted from shallow groundwater inputs. However, given the levels of faecal contamination and turbidity recorded in these streams on some occasions, stock access and/or irrigation bywash discharges may also have contributed to some of the higher DRP concentrations.

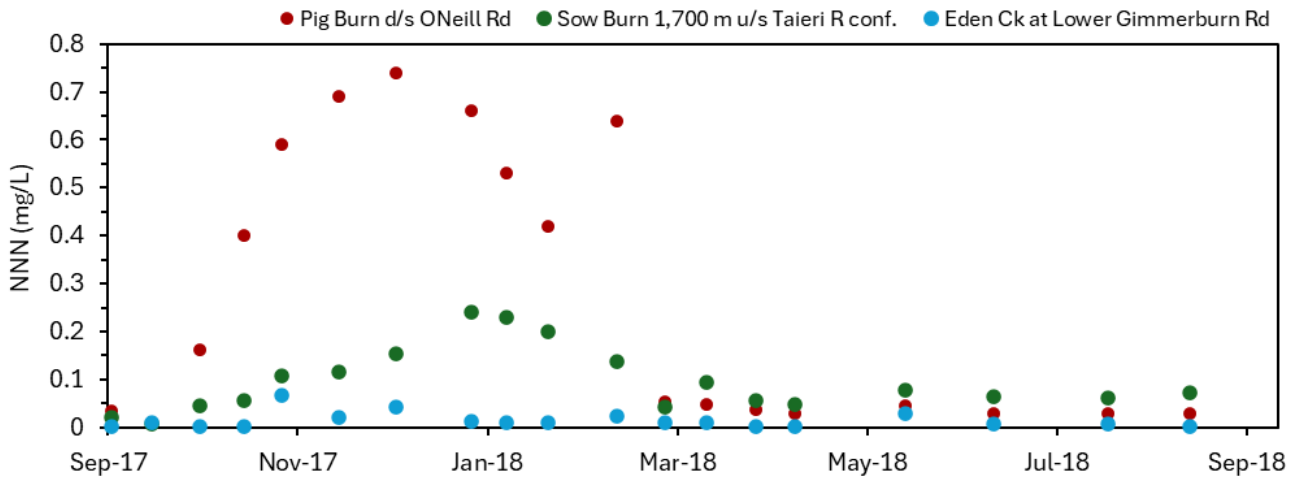

Figure 4-8: Nitrate-nitrite N (NNN) concentrations recorded at selected Taieri River tributary sites between September 2017 and August 2018. Concentrations were highest in late spring/early summer.

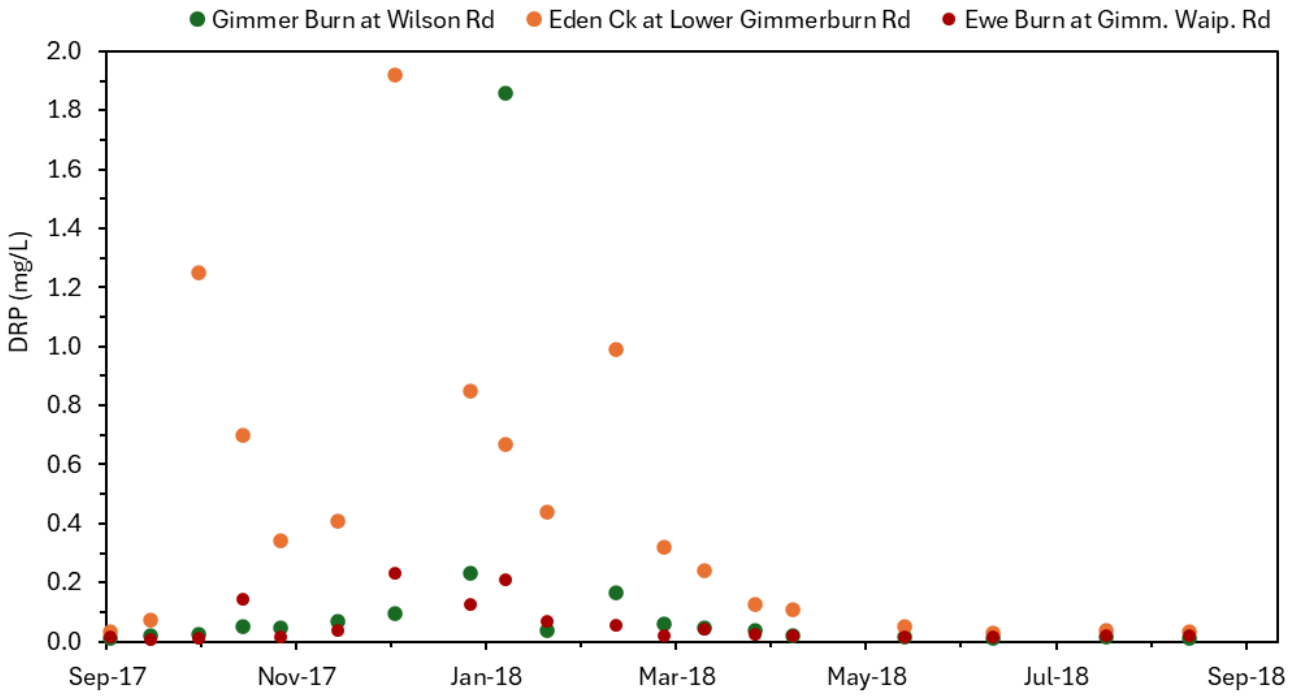

Figure 4-9: DRP concentrations recorded at selected Taieri River tributary sites between September 2017 and August 2018. Similar to NNN, DRP concentrations were highest in late spring/early summer.

2018/19 catchment programme – Kye Burn subcatchment

Between November 2018 and July 2019, water samples were collected at approximately monthly intervals from 15 sites in the Kye Burn subcatchment[12] and tested for plant available nutrients, *E. coli* and turbidity. All but one of these sites were located on tributaries of the Kye Burn.

The following observations are made, with the caveat that the results only span a nine-month period:

- Nutrient concentrations were consistently very low across most sites, with ammoniacal-N and DRP regularly at or below the laboratory's detection limits. The highest NNN concentrations were recorded in Boundary Creek at Swinburn Back Road (median 0.26 mg/L, max 1.42 mg/L), followed by the mainstem of the Kye Burn at Danseys Pass Road (median 0.14 mg/L), Spec Gully 2 at Kye Burn River Road (median 0.11 mg/L) and Home Gully at Waipiata Kyeburn Road (0.10 mg/L).
- Turbidity values were highest in Home Gully at Danseys Pass Road (median 11.8 NTU) and Geddes Road (5.3 NTU).
- *E. coli* counts were frequently low (below 100 MPN/100mL) across most sites, with the exception of sites on Home Gully and Spec Gully. All sites on these tributaries recorded maximum *E. coli* counts over 1,000 MPN/100mL. Elevated results recorded at many sites on 5 December 2018 and 8 January 2019 coincided with rainfall and higher turbidity values.

4.2.2 MIC monitoring

Between October 2020 and March 2023, in response to the findings from the ORC-led 2017-19 water quality catchment programme, MIC monitored *E. coli* at a subset of 15 surface water sites included in the original programme. Most sites were located in the Wether Burn/Gimmer Burn and Eden Creek subcatchments where elevated *E. coli* counts had been recorded previously. Although the frequency and duration of sampling differed between sites, the results showed significant faecal contamination across most sites (Figure 4-10), including in dry weather. The exception was the Wether Burn water race at Gibson Road; none of the 20 samples collected from this site exceeded even the amber/alert level of the MfE/MoH (2003) national recreational water quality guidelines.

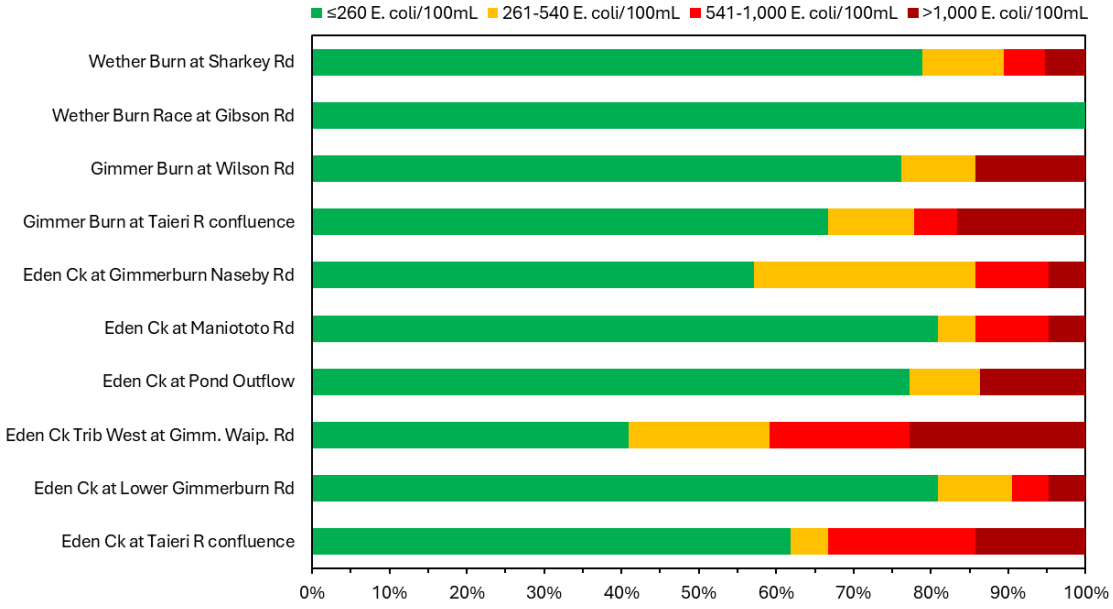

Figure 4-10 The percentage of *E. coli* sample results recorded at 10 sites in the Gimmer Burn, Wether Burn and Eden Creek subcatchments between October 2020 and May 2023 within different guideline values. (For explanation of colour coding, see Figure 4-4.)

[12] Some sites were only sampled seven or eight times.

4.2.3 CODC WWTP monitoring

Ranfurly WWTP

The Ranfurly WWTP discharges to Bandy's Creek on the southern side of the Waipiata Back Road. Although tertiary treated, the discharge contributes significantly to background nutrient loads in Bandy's Creek. Additionally, up until around five years ago, nutrient and pathogen-rich septic tank effluent in the Maniototo area was discharged directly to unlined septage pits located within 300 m of Bandy's Creek.

Based on data presented in Black (2015), median plant-available nutrient concentrations downstream of the discharge during 2006 to 2014 were significantly higher than those upstream. The median concentrations were:

- 0.06 mg/L for ammoniacal-N,
- 1.15 mg/L for nitrate-N, and
- 1.06 mg/L for DRP (compared with ~0.04 mg/L upstream).

Although the discharge volume has not been monitored, this is expected to be similar to the inflows (Black 2015) which, for the period June 2010 to October 2014, averaged 22 m^3/hr (528 m^3/day). This is on the high side for a population of approximately 1,000 people with no significant industrial inputs; it is likely due to groundwater infiltration which, together with stormwater inflow, is identified as a major contributor of inflows to the WWTP in wet weather (Pritchard 2012).

Taking the assumed 528 m^3/day discharge volume and daily median nutrient concentrations from monitoring between July 2012 and July 2014, the discharge is estimated to contribute the following to Bandy's Creek:

- 3.7 kg/day of total nitrogen, and
- 1.2 kg/day of total phosphorus.

For context, these nitrogen and phosphorus loads are estimated to be in the order of 3 and 10 times higher, respectively, than dry weather loads in the Ewe Burn downstream at Lower Gimmerburn-Waipiata Road.

It is not known how much of the nutrient load from the Ranfurly WWTP site or discharge reaches the Ewe Burn or the Taieri River. Bandy's Creek is choked with macrophytes and is believed to run dry in its lower reaches (Black 2015). This suggests that some of the nutrient load in the creek is feeding macrophyte growth. With an underlying fine gravel and sand creek bed (Pritchard 2012), some nutrients are probably also lost to shallow groundwater.

Naseby WWTP

The Naseby WWTP discharges a peak dry weather average of 150 m^3/day of treated wastewater to land beside the Hog Burn (Pritchard 2016), just south of Naseby township. Previous monitoring of the Hog Burn identified elevated nitrate-N concentrations and increased plant growth in the creek downstream of the land disposal field. The most recent consent granted in 2016 included an upgrade of the disposal area to achieve more even distribution and infiltration of wastewater into the ground and reduce any direct runoff to the Hog Burn. The discharge occurs some 18 km north of the Hog Burn's confluence with the Taieri River so any nutrient losses from the system are likely to have a relatively localised impact on the underlying groundwater and the Hog Burn.

4.2.4 Tiaki Maniototo ecological surveys

The results of Tiaki Maniototo's autumn 2022 survey of six Taieri River and three tributary sites are reported in detail by Vermeulen et al. (2022). This survey was the first since the 2010/11 ORC investigation (Kitto 2012) to look at a range of ecological and habitat variables and, along with the 2023/24 survey (Hogan & Trotter

2024[13]), provides the most comprehensive picture of current ecological health in the Taieri River mainstem. The uppermost site located within tussockland in Canadian Flat may also provide a useful reference site for the upper Taieri River system.

The key findings from Vermeulen et al. (2022) are summarised in Table 4-4. Overall, the Taieri River at Cogen's Bridge (Puketoi Runs Road) was in the poorest condition. This site had a modest habitat score (48 out of 100), with more than 50% of the riverbed covered in fine sediment, well above the commonly adopted guideline of 20% cover from Clapcott et al. (2011) to protect stream biodiversity and fish habitat). Macrophyte cover was also well above the provisional national guideline recommended by Matheson et al. (2013). This, together with low riparian shade and poor habitat diversity translated to 'poor' macroinvertebrate health, including extremely low abundance of sensitive mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) (collectively known as EPT taxa).

The Taieri River at Waipiata also had high coverage of fine sediment (over 80%) and macrophyte growth, although indices of invertebrate health were higher here than at Cogen's Bridge. The most downstream site at Kokonga scored the highest across almost all metrics, with good macroinvertebrate health supported by a very diverse range of flow and habitat types. Unlike most sites, there was also some riparian shade at this location.

Vermeulen et al. (2022) reported periphyton growth (as chlorophyll *a* biomass from rock scrapings) above Ministry for the Environment (2000) guideline values to protect aesthetics/recreation and trout habitat/angling at many sites. However, these results are at odds with the mostly low riverbed periphyton cover that was observed in the field and the ORC's March-April 2022 Waipiata chlorophyll *a* biomass results. A check of the sample collection details and lab results suggests a calculation error was made; the results presented in Table 4-4 have been amended to take this into account.

Brown trout and longfin eel were the most common fish found.

[13] As this report was in a draft state when this report was prepared, only the 2022 survey results are summarised.

Table 4-4: Selected results from Tiaki Maniototo's autumn 2022 ecology survey. Summarised from Vermeulen et al. (2022). In the case of both the macroinvertebrate index and stream habitat quality scores, the higher the score, the better the condition. Shading: green = 'very good/excellent', yellow = 'good', orange = 'fair', red = 'poor'. Although periphyton biomass, MCI and deposited fine sediment are NPS-FM attributes, a band cannot be assigned to the results of a one-off survey.

Site	Periphyton		Macrophytes	Macroinvertebrates			Stream habitat quality		Fish recorded
	Nuisance mat or filamentous cover	Biomass* (mg/m^2 chlorophyll *a*)	Average cover (%)	MCI	Semi-Quantitative MCI	EPT (%)	Score (/100)	Deposited fine sediment cover (%)	
Taieri R at Canadian Flat	No	10.5	-	113	5.33	41	73	0	Brown trout
Serpentine Creek	No	10.0	-	99	5.99	60	39	24	Brown trout
Logan Burn	No	1.5	-	102	6.73	69	60	9	Brown trout
Taieri R at Styx Ck conf.	No	22.1	-	95	4.84	60	73	0	*Not fished*
Taieri R at Stonehenge	No	5.4	-	111	5.37	52	62	12	Brown trout, longfin eel, redfin perch, common bully
Taieri R at Cogen's Br (Puketoi Runs Rd)	No	5.1	78	84	3.97	1	48	52	Longfin eel
Taieri R at Waipiata	No	8.2	39	89	6.28	64	45	81	Brown trout, longfin eel
Kye Burn at SH 85	No	2.1	-	111	4.95	55	64	15	Brown trout, longfin eel, Central Otago roundhead galaxias
Taieri R at Kokonga	No	12.4	-	118	6.95	82	70	8	Brown trout, longfin eel

* The values reported in Vermeulen et al. (2022) are 10 times higher owing to a suspected calculation error.

4.3 Summary – key points

Based on recent ORC state assessments (2017–2022 and, in some cases 2016–2021) and the results of various other monitoring and investigations carried out over the last five or so years:

- The upper Taieri River catchment has low concentrations of plant-available nutrients (ammoniacal-N, nitrate-N and DRP) relative to total nitrogen and phosphorus concentrations, median concentrations reported in other pastoral upland rivers in New Zealand, and national guideline values. The primary exception is DRP, which is present at higher concentrations in the lower reaches of Eden Creek and, to a lesser extent the Gimmer Burn and Ewe Burn, as well as the mainstem of the Taieri River (downstream) at Waipiata and Tiroiti.
- Inputs from shallow groundwater appear to increase plant-available nutrient concentrations in several tributaries during periods of low stream flow. This includes nitrate-N in the Pig Burn and Sow Burn and possibly DRP in the lower reaches of the Gimmer Burn, Eden Creek and Ewe Burn. Elevated DRP concentrations on some occasions coincide with increased turbidity and high *E. coli* counts suggesting some contamination arises from above ground sources, such as stock access and/or irrigation bywash.
- Treated wastewater from Ranfurly township contributes to elevated nutrient concentrations and prolific plant growth in Bandy's Creek, a tributary of the Ewe Burn. Although this creek is reported to frequently run dry, it is unclear if some nutrients are lost to shallow groundwater and, from there reach the Ewe Burn and/or Taieri River.
- Taieri River sites at Waipiata and Tiroiti are rated as having 'poor' visual clarity, based on a conversion of turbidity measurements and comparison against NPS-FM attribute bands. However, as will be addressed in Section 6, this assessment is problematic for tannin-stained waters. Of the tributaries, turbidity is highest in the lower reaches of Eden Creek, Ewe Burn and Gimmer Burn.
- *E. coli* indicator bacteria counts generally fall within recommended guidelines for recreation in the mainstem of the Taieri River but are high at times at both Linnburn Runs Road and the popular swimming site at Waipiata, particularly in summer.
- There is frequently significant faecal contamination in the lower reaches of the Ewe Burn and Eden Creek; more than 25% of *E. coli* results at each site over a 21-month period between September 2017 and June 2019 exceeded 1,000 MPN/100mL. Monitoring by MIC also showed frequent faecal contamination in the Wether Burn/Gimmer Burn subcatchment.
- Water temperatures frequently exceed 20°C in the Taieri River at Waipiata in summer and over multiple summers consecutive daily average and peak temperatures have been above 25°C, suggesting high potential for thermal stress on some forms of aquatic life. Recent continuous recording of dissolved oxygen concentrations showed a period of reduced concentrations following a flood event in early 2021.
- At the limited sites monitored, periphyton cover and biomass are generally low.
- Macroinvertebrate health falls into Band C of the NPS-FM at SOE sites, and based on Tiaki Maniototo's 2022 ecological survey, is poorer than that in the Taieri River at Cogen's Bridge. This site, and to a lesser extent Waipiata, has high riverbed coverage of macrophytes and deposited fine sediment.
- Brown trout and longfin eel are the most abundant fish in the mainstem of the Taieri.

5 Trends – is water quality getting better or worse?

The most recent assessment of trends in water quality over time in the upper Taieri catchment was made as part of a regionwide assessment of river, lake and ground water quality in Otago. This assessment was carried out by LWP Ltd (Fraser et al. 2023a, 2023b) and reported in Ozanne et al. (2023). This section summarises the key findings of trends in water quality reported for:

- four sites on the Taieri River (Linnburn Runs Rd, Stonehenge, Waipiata and Tiroiti) and the Kye Burn at SH 85 over 10- and (where sufficient data existed) 20-year periods ending on 30 June 2022, and
- two groundwater wells (H42/0213 and H42/0214) over a 5-year period ending on 30 June 2022.

The LAWA website also reports trends in river health (for the last 5 and 10 years), with the assessments updated annually around September (for the most recent 5 and 10-year periods).

Understanding trend assessments

Assessment of trends over time complements information on current state by providing information on whether the state of water quality is getting *better or worse*. State and trend results therefore need to be considered together to understand river health.

Trend assessment methods applied to water quality and ecological data in New Zealand are statistically based and have evolved over time, resulting in differences in interpretation and reporting. The current recommended approach (Snelder et al. 2021) has been used in national and most regional SOE reporting for at least five years. This approach is based on the view that a trend always exists, but often there is not enough precision in the dataset to confidently say if the trend is increasing or decreasing. Previously trend results falling into this category were classified as "no trend" and where trends were detected, they were only reported if they had a very high of level of statistical significance.

Trend assessments are now reported based on bands of statistical confidence and associated descriptions, ranging from a low confidence of 33-66% ("as likely increasing as decreasing") to >99% confidence ("virtually certain"). The same bands and descriptions are not always universally applied.

Trend direction is sometimes reported on its own (e.g., LAWA, Ozanne et al. 2023) but this only provides a part of the picture. The *trend magnitude* or size is also important as this indicates the *rate of change* (increase or decrease) in water quality over the time period assessed. There may be a virtually certain increase in nitrate-N concentrations at a site over a 10-year period, indicating a deterioration in water quality, but the environmental significance of that increase depends on:

- what the current state of water quality is (e.g., is it above, below or approaching a critical guideline or standard?), and
- how quickly it is increasing (i.e., the rate of change).

Trend assessments also require the data analyst to make decisions about what data to include or exclude to ensure a robust assessment. Some of these 'data filtering' decisions are subjective, meaning two sets of assessments may not produce exactly the same results. This is often the case when multiple sites and long timeframes are being assessed (e.g., regional or national reporting) because of changes in the measurement frequency or methods that, if not accounted for, would prevent a robust comparison between sites. This applies to the ORC's SOE data and effectively means that sometimes not all of the data available for an individual site are used in regionwide trend assessments.

5.1 Surface water quality

The 10- and 20-year periods show different trends in water quality. All four of the sites with sufficient data for the 20-year assessment showed increasing trends in one or more of turbidity and concentrations of *E. coli* and NNN, indicating a deterioration in water quality over this time period. The highest confidence in deteriorating trend direction was associated with the Taieri River at Waipiata which also showed increasing DRP concentrations.

The more recent trend results provide a more positive picture of water quality. For the 10-year period ending 30 June 2022, both forms of phosphorus and turbidity showed decreasing (i.e., improving) trends across all five monitoring sites. However, increasing (i.e., deteriorating) trends in nitrogen were also reported for some sites. Overall, the only directions of trend (i.e., improving or deteriorating) classified as 'extremely likely' (95% confidence) or higher and with a trend rate that could be quantified (Table 5-1) were:

- decreasing DRP and/or total P concentrations (between 2.7% and 9.9% per year) in the Taieri River at Linnburn, Waipiata and Tiroiti, and in the Kye Burn at SH 85 (i.e., improving trends),
- increasing total N concentrations (over 2% per year) in the Taieri River at Stonehenge and Tiroiti (i.e., a deteriorating trend), and
- decreasing turbidity (i.e., improving visual clarity) at Stonehenge (2% per year).

An earlier trend assessment (ORC 2021) for the 10-year period ending on 31 August 2020 indicated a much higher (and likely incorrectly calculated) rate of total N increase for the Taieri River at Tiroiti (0.0135 mg/L per year).

Table 5-1: Summary of key trends in water quality at five upper Taieri catchment SOE sites for the 10-year period ending 30 June 2022. Simplified from the results reported by Ozanne et al. (2023) – green and red cells indicate improving and deteriorating trends, respectively, and yellow cells indicate the trend direction was unclear. Black arrows indicate both high confidence in the trend direction and a trend rate that was able to be quantified (presented as percentage change per year, extracted from LWP data files provided by the ORC). Amm. N is ammoniacal-N; NNN is nitrate-nitrite N.

Site	Amm. N	NNN	Total N	DRP	Total P	Turbidity	*E. coli*
Taieri R at Linnburn Runs Rd		Not analysed			↓ 2.9%		
Taieri R at Stonehenge			↑ 2.8%			↓ 2.0%	
Taieri R at Waipiata				↓ 2.7%			
Kye Burn at SH 85					↓ 9.9%		
Taieri R at Tiroiti			↑ 2.1%	↓ 4.3%	↓ 3.5%		

There is limited information available on macroinvertebrate trends over time. The only recently documented information is for the Kye Burn at SH 85 which was reported as "likely" having an improving trend in MCI scores over the 10-year period ending 31 August 2020 (ORC 2021). In contrast, in May 2024 (for the 10-year ending in December 2022) LAWA reported a "very likely" deteriorating trend. Some earlier trend information is also available for the Taieri River at Tiroiti based on data collected by NIWA and reported in the *Our freshwater 2023* national SOE report[14]. This site showed a "very likely" deteriorating trend in MCI score of 2.2% per year for the 10 year-period ending in 2017. Neither "likely" nor "very likely" trends are associated with high statistical confidence.

[14] Accessed from the MfE website (May 2024): https://data.mfe.govt.nz/table/109669-river-water-quality-macroinvertebrate-community-index-trends-1991-2020/.

5.2 Groundwater quality

The groundwater quality trend assessment results reported by Ozanne et al. (2023) were limited to nitrate-N and arsenic but additional variables and information on rates of change were included in the trend assessment output files provided by the ORC. For the five-year period ending 30 June 2022, directions of trend classified as 'extremely likely' or higher and with a trend rate that could be quantified were:

- increasing concentrations of nitrate-N (Figure 5-1), total N and chloride (5.6%, 5.8% and 2.7% per year, respectively) in well H42/0214 located east of the lower reaches of the Sow Burn, and
- decreasing concentrations of total P (21% per year) in well H42/0213 located beside Eden Creek.

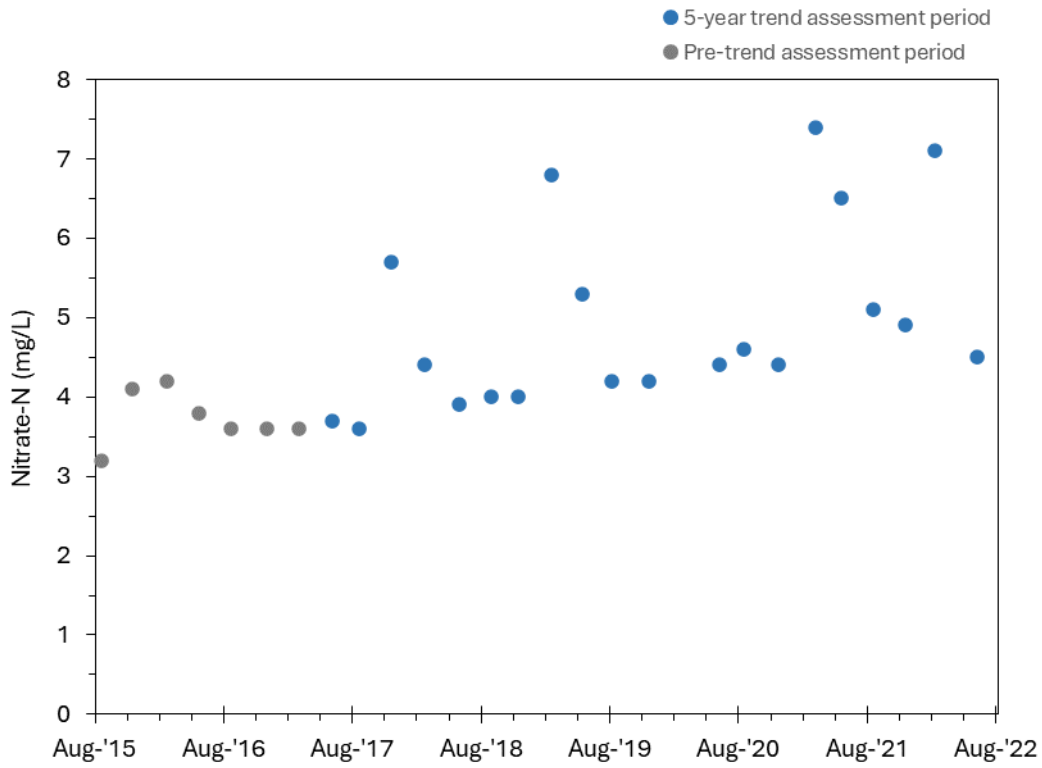

Figure 5-1: Nitrate-nitrogen concentrations measured quarterly in well H42/0214 in the Maniototo Basin. Data for the five-year trend assessment reported in Ozanne et al. (2023) are shown together with earlier data since monitoring began in September 2015. Data accessed from the ORC's Environmental Data Portal.

5.3 What might be behind the trends?

Ozanne et al. (2023) and earlier regionwide SOE state and trend reports (e.g., Uytendaal et al. 2018), point to a lack of information on catchment and local-scale land use and land management practices to provide evidence-based commentary on drivers and direction of water quality trends. This makes it difficult to state with confidence the reasons behind the trends summarised in this section. However, it is known that the area of farmland irrigated by border dyke or contour flood irrigation has decreased significantly over the last decade or more, with a progressive shift to more water efficient sprinkler systems (e.g., centre pivot and low-rate sprinklers). As flood irrigation carries with it significant quantities of phosphorus and other water quality contaminants (McDowell & Kitto 2013), a reduction in this form of irrigation may have contributed to the improving trends in turbidity and phosphorus observed over the last 10 years. Increased stock exclusion from streams over this period may also be contributing to improvements through reduced bank erosion. New fencing was reported in the lower reaches of the Pig Burn and Sheppard's Creek Drain during the ORC's 2010/11 upper Taieri catchment investigation (Kitto 2012) and riparian planting has also been carried out in places across the upper catchment (e.g., through the Tiaki Maniototo project).

One possible contributing factor to the increasing trends in nitrate-N concentrations at some surface water sites and in one of the two shallow groundwater monitoring wells might be increased leaching from farmed soils (e.g., through a change in irrigation, stocking or fertiliser application types and/or rates). Nitrate losses are also known to be higher under dairy and cropping than beef and sheep and although still small, the area of farmland under dairy in the upper Taieri catchment has likely increased in the last decade or so.

5.4 Summary

- The most recent trend assessments indicate multiple aspects of water quality in the upper Taieri catchment improved over the 10-year period ending June 2022 compared with the 20-year period ending on this date. Over the ten years, turbidity and concentrations of phosphorus decreased across almost all sites. However, there was also evidence of increasing nitrate-N concentrations in the Taieri River at Stonehenge and Tiroiti, and in the shallow groundwater at a site monitored east of the Sow Burn. The reasons for the observed trends are unclear but may be due to changes in irrigation and other farming practices, including a shift from flood-based to spray irrigation methods and improved stock exclusion.
- Very limited information is available on trends in ecological variables such as macroinvertebrates. Fewer sites are monitored for these variables. The most recent 10-year trend assessment of macroinvertebrate health was limited to the Kye Burn at SH 85 and the results did not indicate an improving or deteriorating trend with high statistical confidence.

6 Issues, gaps and priorities

The monitoring and investigation results summarised in sections 4 and 5 indicate that water quality in the upper Taieri catchment looks to be in 'reasonable' condition, and has improved in some aspects over the last 10 years. However, there are some areas of degradation relating to sediment, nutrient enrichment and faecal contamination, which appear to be impacting ecological health and recreational values. There are also some gaps in knowledge and understanding about the ecological condition of the river ecosystem, some of which recent additional, and potential new, monitoring/investigations could assist with filling.

6.1 Sediment

Fine sediment (<2 mm in diameter) is a known 'master' stressor on river and stream health. In naturally cobble- and gravel-bedded rivers and streams like the Taieri River and its tributaries, fine sediment:

- reduces water clarity when suspended in the water column, reducing aesthetic values, light penetration for plant growth and the ability of fish to see their prey,
- can smother the bed, reducing the diversity and quality of the cobble substrate habitat for aquatic life with flow-on impacts (e.g., reduced diversity of aquatic life, loss of trout spawning habitat), and
- carries contaminants that readily attach to it, most commonly phosphorus, pathogens and metals, with flow-on effects for ecosystem health and reduced water quality for recreational and other uses.

The NPS-FM includes two sediment attributes, one for the water column (suspended fine sediment) and one for the riverbed (deposited fine sediment). There is more than one method to measure suspended and deposited fine sediment but the NPS-FM defines:

- suspended fine sediment as visual clarity, not the closely related measures of turbidity or concentration of suspended sediment, and
- deposited fine sediment as the percentage bed cover of fine sediment, determined as an average of visual estimates of cover made at 20 locations across the river.

In terms of suspended fine sediment, the ORC currently only routinely measures turbidity at SOE sites and uses a national equation established by Franklin et al. (2020) to convert turbidity measurements to an estimate of visual clarity so that an NPS-FM band can be determined. Although the NPS-FM allows for this, neither the national equation nor the NPS-FM attribute thresholds are applicable to naturally highly coloured brown-water streams (Franklin et al. 2019). This is because, while turbidity and visual clarity are usually closely correlated, visual clarity measurements (unlike turbidity) reflect both the concentration of suspended fine sediments and water colour (e.g., because of tannin staining). The current assignment of B (C in earlier reporting periods) bands to the Taieri River at Linnburn Runs Road and Stonehenge, and D bands at Waipiata and Tiroiti are therefore questionable. Visual clarity does reduce between Stonehenge and these sites (refer Figure 4-1) but with tannin-staining already contributing to "reduced" visual clarity at all sites, assignment of D band (i.e., below the national bottom line or minimum acceptable state due to a *"high impact of suspended fine sediment on instream biota"*) is questionable. It is also worth noting that a river with visual clarity that is affected by natural processes such as tannin-staining is exempt from meeting the national bottom line.

Although the ORC monitors deposited fine sediment cover across some SOE sites, the Taieri River mainstem sites are considered non-wadeable so limited, if any, data have been collected (or reported) to date.

6.1.1 Is fine sediment impacting river health?

Ecological data are lacking for the upper Taieri catchment, especially long-term data. This makes it difficult to confidently state what impact fine sediment is having on aquatic ecosystem health. However, the results of Tiaki Manitoto's autumn 2022 ecological survey found that the two Taieri River mainstem sites with the

poorest macroinvertebrate health – Cogen's Bridge (Puketoi) and Waipiata – had high coverage of fine sediment (81 and 52%, respectively) compared with the other sites surveyed. These sites also had significant macrophyte (aquatic plant/weed) cover of 78 and 39%, respectively. Macrophytes generally thrive in environments with finer substrates, deeper water and stable flows (Matheson et al. 2012) and as beds of rooted macrophytes thicken and expand across the river channel they will increasingly trap more fine sediment.

Are macrophytes good or bad?

Macrophytes produce oxygen while photosynthesising during the day, provide refuge for fish and habitat for invertebrates, and contribute to nutrient cycling. However, in high volumes, macrophytes can impact swimming or fishing, impede river flow (increasing flooding risk), clog water intakes, contribute to depleted dissolved oxygen levels at night, and cause fine sediment to settle on the river bed (see Figure 6-3, page 50). Some macrophytes (e.g., hornwort, *Egeria* and *Lagarosiphon*) are invasive or noxious weeds and can quickly form large dense beds that choke waterways and outcompete other plant and animal species.

Provisional national guidelines for macrophyte abundance (Matheson et al. 2012) recommend:

- macrophytes by channel cross-sectional area or volume should not exceed 50% to protect ecological condition, flow conveyance and recreation values, and
- macrophytes by channel water surface area should not exceed 50% to protect aesthetic and recreation values.

While deposited fine sediment is almost certainly impacting macroinvertebrate health at some locations of the main stem, it does need to be recognised that the river reaches within the scroll plain are characterised by deeper water and a slow-flowing meander. These habitat and flow conditions are very different from the upper reaches of most New Zealand rivers that tend to have a much higher proportion of wadeable and broken water (riffle) habitat that naturally support a greater abundance of sensitive invertebrates. This again highlights that the NPS-FM macroinvertebrate attribute bands – which see higher bands assigned to sites that support a greater range and number of sensitive invertebrates – are probably not well suited to some reaches of the upper Taieri River. It would be worth investigating if specific upper Taieri reference conditions could be established to support interpretation of macroinvertebrate health.

6.1.2 The tributaries

The only site on a tributary of the upper Taieri River with a long and ongoing monitoring record is the Kye Burn at SH 85. While the Kye Burn has often historically been cited as a major source of sediment to the Taieri River (e.g., ORC 2021), the current five-year median turbidity value for the site at SH 85 is much lower than that for the Taieri River SOE sites upstream (Waipiata) and downstream (Tiroiti) of its confluence (refer Figure 4-1). This suggests that the contribution of sediment occurs at high stream flows and that there are other sources of sediment contributing to the more turbid waters of the Taieri River at Tiroiti at lower (base or median) flows (Note: this may change in the future, at least temporarily, with significant instream sedimentation arising following stream works carried out at the SH 85 bridge by the New Zealand Transport Authority (NZTA) in January 2024, Figure 6-1).

Several short-term water quality monitoring campaigns by the ORC across tributaries in the Styx and Maniototo Basins regularly found elevated turbidity levels in Eden Creek, the Ewe Burn and Gimmer Burn/Wether Burn. A short period of monitoring in the Kye Burn subcatchment found turbidity was highest in Home Gully and Spec Gully. All of these watercourses enter, directly or indirectly, the Taieri River between Halls Bridge (Maniototo Road) and Waipiata, draining areas of upstream farmland that are understood to still be under some border dyke or contour-type flood irrigation.

Figure 6-1: Extensive fine sediment deposition in the Kye Burn at SH 85 following stream works by NZTA in January 2024. The photo was taken on 2 April 2024 looking upstream from the bridge.

There are limited ecological data for these more turbid tributaries but the ORC's 2010/11 upper Taieri catchment investigation (Kitto 2012) included an ecological and partial habitat survey of eight tributary sites, including the upper and lower Gimmer Burn (at Puketoi-High Field Road and Wilson Road, a short distance from the Taieri River confluence). The lower Gimmer Burn site, together with sites on the lower reaches of Sheppard's Creek Drain and the Pig Burn all had *"excessive fine sediment build-up".* Streambed fine sediment cover in the lower Gimmer Burn was estimated at 65% and attributed to a combination of current and historic stock access and the effects of irrigation runoff. In contrast, sediment cover was described as low in the upper Gimmer Burn. Overall, when compared with upstream, ecological condition was much poorer at Wilson Road. For example:

- all four macroinvertebrate community health metrics were lower, including MCI and semi-quantitative MCI scores of 78 and 3.9 ('poor') compared with 100 ('fair') and 5.8 ('good') upstream, and
- brown trout condition was rated as 'poor/fair' compared with 'fair' upstream.

6.2 Nutrients

6.2.1 Nitrogen

The forms of nitrogen most readily taken up by periphyton and macrophytes are the dissolved inorganic forms (ammoniacal-N, nitrite-N and nitrate-N), which are present at very low concentrations in the Taieri River, especially when compared with other upland rivers in New Zealand under pasture. Total nitrogen concentrations are much higher (Figure 6-2), indicating that most nitrogen is present in organic forms such as amino acids, plant tissue and detritus. Nutrient forms are not fixed; under the right conditions, one form can convert to another and become available, 'locked up' or lost from the system (e.g., by denitrification).

Median concentrations of plant-available nitrogen are also low in most of the tributaries monitored to date. The main exceptions are those that gain flow from shallow groundwater, such as the Sow Burn, Sheppard's Creek Drain and Pig Burn. The ORC's only long-term monitoring well in this area had a median concentration of

4.5 mg/L over the five-year period ending June 2022 and concentrations increased over this period at an average rate of 5.6% per year. Increasing trends in nitrate-N of over 2% per year were also reported for the Taieri River at Stonehenge and Waipiata over the last 10 years.

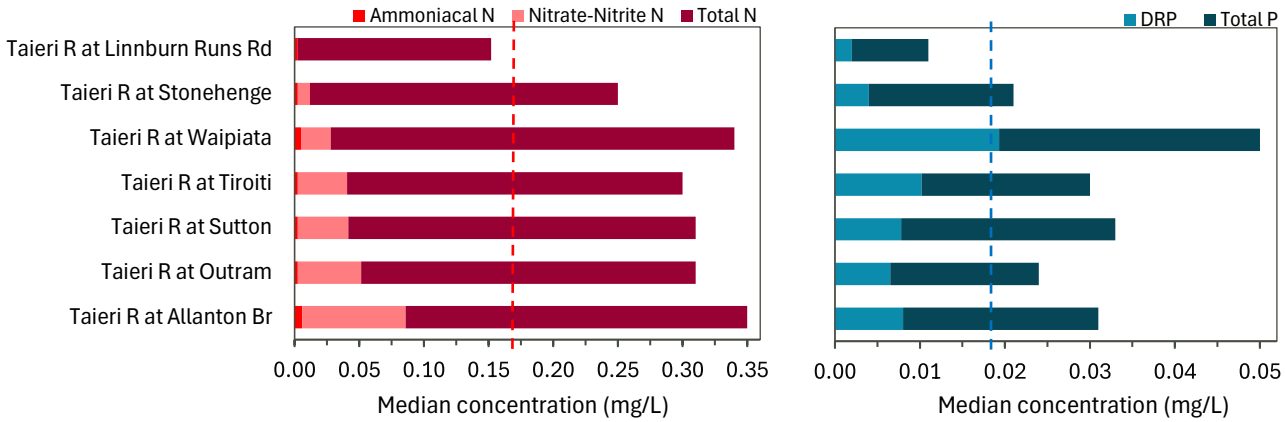

Figure 6-2: Median concentrations of nitrogen (left) and phosphorus (right) recorded by the ORC in mainstem Taieri River sites. ORC data drawn from LAWA in May 2024. The full length of each bar represents the total N or P concentration, with the lighter coloured portions representing the plant-available fractions. The vertical red dashed line represents the once commonly applied ANZECC (2000) NNN 'benchmark' for upland rivers (presented for context only, to illustrate that NNN concentrations are low). The vertical blue dashed line represents the boundary of Bands C/D under the NPS-FM 2020 (note there is no national bottom line for DRP).

The low concentrations of plant-available nitrogen relative to concentrations of the equivalent plant-available form of phosphorus (DRP) indicate that the Taieri River is nitrogen-limited (McDowell & Kitto 2013, Kitto 2012). This means that adding nitrogen would likely stimulate plant growth more than additional phosphorus would (which is already elevated at some sites). There is extensive macrophyte growth in places along the mainstem, including at Cogens Bridge/Puketoi, Halls Bridge and downstream of Creamery Bridge. These macrophytes are likely stripping nitrogen from the water column. High denitrification rates through anoxic soils in the oxbow wetlands will likely also be removing nitrogen from the system.

The ORC's recent establishment of additional SOE monitoring piezometers in the Maniototo Basin and along selected transects across the Taieri Scroll Plain wetlands should provide valuable information to better understand groundwater nitrate-N concentrations across the upper Taieri Plain, and flow and nutrient interactions between the shallow unconfined groundwater, wetlands and the river.

6.2.2 Phosphorus

Similar to nitrogen, median concentrations of plant-available phosphorus (DRP) are relatively low across most of the upper Taieri catchment compared with other upland pastoral catchments, and compared with total phosphorus concentrations (Figure 6-2). Concentrations of both forms also decreased across all four Taieri River SOE sites over the 10-year period ending June 2022, at average rates of up to 4.3% per year (where able to be quantified, refer Table 5-1). As noted in Section 5, the reasons for these observed trends are unclear but it is plausible that a progressive shift away from border and contour flood irrigation towards spray irrigation was a contributing factor. Phosphorus concentrations are known to be elevated in runoff from flood-based systems and were suggested as a primary factor behind previous observed increasing phosphorus trends between 1998 and 2012 (McDowell & Kitto 2013). Although data are lacking to confirm this, changes in other farming practices, including improved stock exclusion and riparian planting may also have contributed to recent improving trends in phosphorus (and turbidity).

Despite the improving trend direction for DRP and total P, the current five-year median DRP concentrations at both Waipiata and Tiroiti are graded as Band C under the NPS-FM (refer Table 4-1). Although there is insufficient data to assign a grade to many tributaries, results from various monitoring between 2017 and

2023 indicate that the lower reaches of Eden Creek and the Gimmer Burn and Ewe Burn would likely also fall into Band C or, more likely, Band D (refer Figure 4-7). The narrative description for Band C is that these concentrations are moderate and impacting aquatic ecological communities. This is revisited in Section 6.2.3.

The ORC's monitoring of shallow groundwater at two locations shows elevated concentrations of DRP relative to surface water, particularly at the site near Eden Creek (five-year median of 0.11 mg/L). In contrast with all other sites monitored in the ORC's 2017–19 catchment programme, Eden Creek had a very high median DRP concentration relative to the total P concentration (refer Figure 4-7). The soils in the vicinity of the creek and surrounding area of the Maniototo have been described as having low phosphorus retention (commonly 10-15%), with an increased likelihood of phosphorus being lost from sub-surface runoff (McDowell & Kitto 2013). Typically, most phosphorus is lost via overland or surface runoff, together with sediment and *E. coli* (McDowell et al. 2008). Managing sub-surface losses may present a greater challenge for irrigation management than overland runoff.

The only known documented assessment of nutrient loads in the upper Taieri catchment was carried out as part of the ORC's 2010/11 water quality investigation (Kitto 2012). This identified that, of the four tributaries considered, the greatest plant-available nitrogen and phosphorus loads (when expressed as an annual load on a per hectare basis for the upstream catchment area) came from Sheppard's Creek Drain and the Pig Burn. The nitrate-N loads at both sites on the lower reaches of these watercourses were higher than those for all five Taieri mainstem sites between Linnburn Runs Road and Tiroiti. The Sheppard's Creek Drain also had the highest annual load of DRP by catchment area, but the loads for the Taieri River at Puketoi and Halls Bridge were higher than those of the lower Sow Burn. The calculations were based on a limited dataset and did not include high flow events, which are known to export the most nutrients (and sediment) to rivers.

Concentrations vs loads

This report has largely presented information on nutrient *concentrations*, based on available water quality monitoring and investigation data. While concentration data are important for understanding the potential for nuisance algae/plant growth and toxic effects on aquatic life, the actual amount of nutrient exported from a tributary to the Taieri River, or from the river itself to a point further downstream, depends on both the concentration and flow at that location. Multiplying the concentration by flow gives a *load* that can be expressed on different time scales (e.g., kg N/day, tonnes N/year) or, as done by Kitto (2012), scaled to the area of the catchment upstream of each monitoring location (e.g., kg N/yr/ha).

Management actions may be required in response to both elevated concentrations as well as loads. If water quality is impacted downstream, it is useful to identify which upstream tributaries are contributing the greatest load. In systems like the upper Taieri, groundwater will also contribute nutrients to the river. As yet, this contribution has not been quantified.

Some additional insights into the contribution of nutrients from irrigated land in the Maniototo Basin were drawn from the 2010/11 investigation. Nutrient loads were calculated from the Gimmer Burn, Pig Burn and Sow Burn, three tributaries that flow into the Taieri River between Puketoi and Waipiata and collectively drain a significant proportion of the irrigated land (approx. 40,000 ha). The analysis (McDowell & Kitto 2013) showed that:

- the total nitrogen, DRP and total phosphorus loads from these tributaries were greater than the area-specific nutrient loads at either mainstem site, and
- when the relative loadings of each of these tributaries were compared to those of the receiving segment of the Taieri River (Waipiata minus Puketoi), the tributaries accounted for less than 25% of the total annual nutrient load to the river. However, this increased to almost 100% during the irrigation season.

6.2.3 Are nutrients impacting river health?

Concentrations of both ammoniacal N and nitrate-N are well below levels that would be toxic to aquatic life (both graded Band A under the NPS-FM). The other concern with nutrients is their potential to cause nuisance plant growth, in the form of periphyton and/or macrophytes. Again, monitoring data are limited but based on the results of ORC's monthly periphyton monitoring at Waipiata between late 2019 and autumn 2022, and Tiaki Manioto's one-off ecological survey in autumn 2022, both the bed coverage and biomass of periphyton are below levels that would degrade ecosystem health or other values (e.g., recreation). The water's dark tannin-staining (and in places, its depth) likely reduces the risk of periphyton blooms but, as noted above, nitrate-N concentrations are currently the limiting factor and further increases in nitrate-N might result in an increased risk of periphyton blooms.

Despite no formal monitoring, there is extensive macrophyte growth in places along the Taieri River and a high likelihood that this growth is fuelled by macrophytes stripping nitrate-N from the water column. High riverbed coverage of fine sediment also provides an additional source of nutrients for rooted macrophytes. One of the significant effects dense beds of macrophytes have is the ability to create large swings in dissolved oxygen (DO) levels (refer macrophyte blue box, page 43), with the potential to stress some aquatic life. Although the upper Taieri River already routinely – and naturally, owing to the adjoining scroll plain wetland system – has DO levels below 100% saturation, high frequency monitoring at Waipiata for the three years ending in November 2023 has shown that DO drops below 70% saturation approximately 10% of the time, usually in late summer when water temperatures regularly exceed 20°C. As noted in Section 4.1.1, DO concentrations dropped below 40% saturation (and 3.5 mg/L) in early 2021 following a flood event.

With very little data available on macrophyte cover or abundance, we don't know if either has increased in recent years. There is also no information to indicate if there has been a change in the types or species of macrophyte (e.g., a shift to often more 'aggressive' introduced or pest species). Ongoing macrophyte data collection would be beneficial (e.g., annual surveys at the time of highest biomass).

As noted for sediment, the lack of ecological data limits the ability to comment on the effects of macrophyte cover and abundance on macroinvertebrates and fish. However, the Tiaki Maniototo autumn 2022 survey did indicate poorer macroinvertebrate health at sites where macrophyte growth and fine sediment were abundant (Puketoi and Waipiata). While the deepness and slow meander of the river will also contribute to poorer macroinvertebrate health scores at Puketoi, this appears less likely at Waipiata.

6.3 *E. coli*

The most recently reported five-year median concentrations of *E. coli* are low across the mainstem of the Taieri River and graded in Band A of the NPS-FM across all four SOE sites and the Kye Burn at SH 85. The lower overall *E. coli* Band B grading assigned to sites at Linnburn Runs Road and Waipiata reflect poorer grades across two of the other three metrics that make up the overall grade. For example, 20-30% of monthly sample results at both sites breached the amber/alert mode of the national microbiological water quality guidelines (260 *E. coli*/100mL), a level above which there is deemed an increased risk of infection from exposure to pathogens. Overall though, the grade for Waipiata is an improvement on an earlier state assessment for 2012 to 2017 which placed this site in Band D (Uytendaal et al. 2018).

The ORC has designated the Taieri River at Waipiata as a primary contact recreation (swimming) site and therefore monitors *E. coli* counts weekly over summer when recreational use is highest. The NPS-FM has a separate process for assessing and grading the suitability of swimming sites, based on the MfE/MoH (2003) guidelines. The current grade was not included in the ORC's latest state and trends report as this report was limited to assessing monthly results from SOE sites. However, the weekly test results are reported on the LAWA website along with the 'long-term' site grade. This grade is determined as a 95th percentile value from routine results collected over the last five summer seasons (i.e., results of re-testing carried out following receipt of a result above 260 *E. coli* per 100mL are excluded). The current long-term grade, based on the 2019/20–2023/24 summer periods, is "poor" and indicates that the 95th percentile is >540 *E. coli* per 100mL.

Will we get sick if we swim?

The guidelines for primary recreation are set conservatively to protect human health. In the case of fresh waters, they have an added layer of protection built in because they are based on the risk of *infection* (from campylobacter, a common pathogen in New Zealand fresh waters), not the risk of *illness*. Not all people who become infected by a pathogen will become ill as a result.

For the Taieri River at Waipiata, based on definitions in the NPS-FM, the assignment of:

- a Band B (Table 9 of the NPS-FM, based on year-round monitoring) translates to, for at least half the time, an estimated risk of <1 in 1,000 (0.1% risk) and a predicted average infection risk of 2%
- a summertime "poor" grade (Table 22 of the NPS-FM) translates to an estimated risk of *Campylobacter* infection over 5% at least 5% of the time.

One of the challenges of managing human health risks at Waipiata is that summertime monitoring results indicate elevated *E. coli* counts are not restricted to wet weather when runoff is known to impact water quality; they also occur in dry weather when swimming is more likely.

The ORC has carried out faecal source tracking investigations to identify the sources of elevated *E. coli* counts. The results identified both ruminant (e.g., cattle and sheep) and wildfowl (e.g., ducks and geese) (R. Ozanne, ORC, pers. comm.). Multiple sources of faecal contamination are common in fresh waters and testing in New Zealand is not yet sophisticated enough to robustly quantify which is the most dominant amongst different sources. In the case of the Taieri, evidence from monitoring of the tributaries indicates that significant faecal contamination arises from farmland (e.g., Ewe Burn, Eden Creek, and Gimmer Burn subcatchments, refer to Figures 4-4 and 4-10). Overland runoff from irrigation bywash has been shown to be a significant dry weather source of contamination in some of these tributaries (e.g., ORC 2006a), along with stock access (e.g., ORC 2003, Kitto 2012). While stock access appears to have reduced over the past decade with increasing fencing and riparian planting in place, this has not been quantified to date and stock access will still be contributing to faecal contamination in places (see Figure 6-3, page 50).

Limitations with the current *E. coli* guidelines

E. coli is a long-established and accepted, but imperfect, indicator of the risks to human health from pathogens that are much more expensive to test for.

One limitation with the MfE/MoH (2003) guidelines on which the NPS-FM *E. coli* attributes bands are based is that they do not account for different levels of pathogenicity that may be associated with different sources of faecal matter. For example, in combining the results of faecal source tracking with a quantitative microbial risk assessment (QMRA)* in a rural catchment in Texas, Gitter et al. (2020) found that the highest health risk was associated with Norovirus, the pathogen representing human sewage. This was despite faecal indicator bacteria from non-human sources being the most frequently present in repeated water testing. After humans, dairy cow faecal matter presented the next greatest risk, ahead of the wildlife sources (including birds). This suggests that the proportion a single source contributes to the overall *E. coli* count does not indicate the overall human health risk.

The risks of gastrointestinal illness from exposure to recreational waters were also found to vary by source in the US; the risk differed little between waters impacted by human sources and fresh cattle faeces, but the impacts of gull, chicken and pig faeces appeared to be much lower (Soller et al. 2011).

* A QMRA is currently the most robust method available to assess the risks to human health from exposure to faecally contaminated water. QMRAs are regularly carried out in New Zealand when assessing the effects of wastewater treatment plant discharges to rivers, lakes or coastal waters.

High numbers of Canadian geese have been identified as a problem in the scroll plain wetlands by the local community and it is likely that these geese will also contribute significant amounts of faecal contamination at times. Higher *E. coli* concentrations have been found in the faeces of Canadian geese than those of dairy cows and deer (Afolabi et al. 2023). This does not necessarily equate to a higher health risk (see text box, previous page) and higher *E. coli* concentrations have been found in ducks, black swans and gulls in New Zealand but, in terms of *campylobacter*, Canadian geese had the highest average concentrations amongst these four bird types and ducks the lowest (Moriarty et al. 2011). Faeces from Canadian geese are therefore a known source of pathogens in fresh water.

6.4 Gaps and priorities

Probably the largest information gap is subcatchment-scale land use and land management practices to help understand the drivers and direction of water quality trends in the upper Taieri catchment. While it is likely that changes in land management practices account for some of the reported improvements in water quality over the last 10 years, the evidence that could help confirm this, such as quantitative information on *changes* in irrigation, stocking, fertiliser and riparian management practices, is not readily available. The ORC's new Land and Water plan (currently in development) is expected to establish data collection requirements for some (presumably consented) activities (Ozanne et al. 2023); collation of existing and collection of new information is already likely underway at the farm or subcatchment scale to support the development of freshwater farm plans (e.g., mapping of critical source areas)[15]. On the list of information to record should be details of management actions taken to improve water quality and restore catchment health. A national register is now available to capture this information in a standardised way.

Most of the monitoring in the upper Taieri catchment to date has focused on physical, chemical and/or microbiological aspects of surface water quality. This, together with flow information that is also being collected, only addresses two of the five components of a 'healthy' river under the NPS-FM. The other three components are aquatic life, physical habitat and ecosystem processes.

There is a lack of unbroken long-term ecological data in the catchment, with only the Kye Burn at SH 85 yielding sufficient annual macroinvertebrate data for trend analysis in the ORC's (2021) SOE report. One challenge with the Taieri mainstem is that much of its upper reaches are not wadeable and so macroinvertebrate sampling using conventional methods can be difficult. However, macroinvertebrates are an important indicator of ecological health and there are locations that are likely suitable for long-term monitoring that have been sampled in the past (e.g., at Stonehenge and Kokonga).

Macrophyte abundance is high in several locations in the Taieri River but no formal monitoring has been carried out. Therefore, it is not known if macrophyte growth is increasing and/or spreading, particularly in response to signs of increasing plant-available nitrogen concentrations in the mainstem and shallow groundwater in the Maniototo Basin. Deposited fine sediment cover is not able to be routinely monitored on the Taieri mainstem due to water depth (R. Ozanne, ORC, pers comm.) but, based on observations of extensive macrophyte growth and Tiaki Maniototo's 2022 habitat survey, fine sediment cover is high in places and degrading the quality of riverbed habitat for invertebrates and fish. The possible sources of this sediment need investigating; while sediment inputs from stock access and irrigation runoff in the tributaries are very likely sources, bank erosion in the Taieri River itself is very likely another given the tight meandering nature of the river through the Scroll Plain (Ryder & Tocher 2020, Figure 6-3). Other sources are likely to be cultivation of winter forage crops in close proximity to the river (M. Trotter, Tiaki Maniototo, pers. comm.) and possible sheet erosion in parts of the catchment, both of which will result in overland flow of soil under heavy rainfall.

[15] A recent example of good farm-scale data collation is the maps of land parcels under different types of irrigation methods (e.g., border dyke, centre pivot) included in a multi-water take resource consent application for the Pig Burn catchment (see Dicey 2020).

As well as stock access to some parts of the river margins, macrophytes and willows may be contributing to localised bank erosion through altering flow patterns and velocities. For example, macrophyte beds can act as semi-permeable dams, slowing velocity and increasing water depth (Champion & Tanner 2000); the water that is diverted around the beds flows faster, increasing erosion downstream (Collins et al. 2011). Similarly, despite their effective role at stabilising river banks, the invasive nature of willows can result in thickets that grow into the channel and block its flow and capacity, diverting water around the blockage, causing local scouring, erosion and increased sedimentation (Philips & Daly 2008, Pope et al. 2006). A better understanding of the effects of macrophyte and willow management may be needed, as any large-scale removal – especially of willows – will also alter flow dynamics and increase velocity, with the potential for increased erosion further downstream (Figure 6-4). Any large-scale removal will also remove shade and habitat for invertebrates and fish.

There is limited knowledge of subcatchment sediment and nutrients loads as well as nutrient contributions from groundwater to the Taieri mainstem and Scroll Plain wetlands. This gap may be partially filled by the ORC's current investigation of hydrology and groundwater quality across the Scroll Plain. The additional piezometers for groundwater quality monitoring drilled in winter 2023 will also provide information on plant-available nutrient concentrations in the shallow groundwater across a wider area of the Maniototo Basin than has been captured to date, as well as information on possible leakage between the shallow aquifer and the deeper confined aquifer.

Figure 6-3: Photos taken in February 2024 illustrating some sediment-related issues in the upper Taieri catchment. Top: The relatively clean bed of the Taieri River at Stonehenge (left) compared with at Cogen's Bridge/Puketoi-Runs Road (right) where fine sediment and macrophytes dominate. Bottom (left to right): Build-up of fine sediment in the river, signs of recent stock access in the lower reaches of a tributary, and a segment of eroding river bank. Photos: Eilis Hogan.

Figure 6-4: Willows upstream of Cogen's Bridge following spraying, with obvious bank erosion (January 2020).

Lastly, while DOC has had reports completed on the likely impacts of climate change across the whole of the Taieri catchment, the potential effects of climate change on surface and ground water chemistry is a knowledge gap. For example, we do not know what potential exists for a change in leaching rates of tannins from wetland soils or the ratio of organic to (more readily plant-available) inorganic nutrients, and what might this mean for the existing river ecosystem.

6.4.1 Monitoring-related considerations

Apart from the Kye Burn, the ORC's current long-term monitoring is limited to the mainstem of the Taieri River and a primary focus on water quality. To improve understanding about the ecological condition of the river, it might be useful for the ORC to consider:

- annual surveys of macrophyte cover and cross-sectional abundance at different locations along the Taieri mainstem, carried out at the time of greatest biomass (typically late summer), including a note of any significant changes in species composition,
- regular assessments (e.g., at least quarterly) of fine deposited sediment cover at locations on the main tributaries and the mainstem, coupled with at least two annual habitat and macroinvertebrate community assessments,
- tracking of bank (and other forms of) erosion in the catchment (e.g., through annual photo points and mapping), and
- additional high frequency water temperature and dissolved oxygen monitoring at selected locations over the summer months.

As well as monitoring the impacts of the NZTA's recent stream works in the Kye Burn at SH 85, some targeted wet weather water sampling of the lower reaches of the main tributaries would assist with understanding the relative contributions of sediment, nutrients and *E. coli* under these conditions. This will also require an estimate of flow at the time of sample collection, such as through stream gaugings, to allow calculation of loads.

Monitoring smaller streams is likely to detect impacts or improvements associated with land use actions quicker than monitoring the main stem of higher order rivers such as the Taieri (McDowell et al. 2024). This should be kept in mind by the Upper Taieri Wai and others interested in carrying out monitoring. From an irrigation effects perspective, there may be value in MIC establishing a regular water quality monitoring site on one or two tributaries in the Maniototo Basin (e.g., one each under predominantly drystock and dairy land use).

These sites should be selected factoring in the location of ORC's existing and new groundwater quality monitoring sites as well as tributary sites previously monitored as part of earlier ORC investigations. An estimate of flow will also need to be collected.

Lastly, a site-specific relationship between turbidity and visual clarity should be established at the ORC's Taieri River SOE sites to inform assessments of the suspended fine sediment attribute under the NPS-FM. Establishing this relationship at the uppermost site at Linnburn Runs Road (or Stonehenge) will enable a more meaningful catchment-specific target attribute state to be set for the upper Taieri compared with the ORC's current use of a national equation to estimate visual clarity. Some historic paired turbidity and visual clarity data do exist, with NIWA's 1989–2016 record for Tiroiti the most comprehensive available. However, sediment properties can change over time and some additional (upstream) data collection is recommended.

Acknowledgements

This report was funded by the Ministry for the Environment's A2E Fund and the Healthy Taieri Integrated Farm Planning Project. Thanks to Sally Dicey (Whirika Consulting), Janine Smith (Upper Taieri Wai) and Renee Weir (Maniototo Irrigation Company) for initiating this work and providing valuable background information.

Many people and organisations contributed information to this report. Thanks to:

- Morgan Trotter (Technical Advisor for Tiaki Maniototo) for catchment insights and supply of monitoring reports
- Wayne Worth, Rachel Ozanne, Amir Levy, Sami Khan and Erik Button and Matt Cunningham (Otago Regional Council) for supply of monitoring and investigation data and reports, discussions on current and recent monitoring/investigations, and checking details of a draft version of this report
- Leah Day (ORC) for supply of resource consent information
- Eilis Hogan (Tiaki Maniototo) for supply of photographs from recent monitoring
- Chris Kavazos, Oliver Wigmore and Sue Clearwater (Department of Conservation) for supply of catchment reports and monitoring programme details
- Central Otago District Council's infrastructure team for monitoring information associated with the water treatment plants in the Maniototo
- Chris Garden (Whirika Consulting) for supply of GIS layers.

References

Australian and New Zealand Environment and Conservation Council (ANZECC). (1992) Australian water quality guidelines for fresh and marine waters. National Water Quality Management Strategy Paper No. 4, Australian and New Zealand Environment and Conservation Council, Canberra.

Australian and New Zealand Environment and Conservation Council (ANZECC). (2000) Australian and New Zealand guidelines for fresh and marine water quality, volume 1, the guidelines. Agriculture and Resource Management Councils of Australia and New Zealand, Canberra.

Afolabi EO, Quilliam RS, Olive DM. (2023) Persistence of *E. coli* in streambed sediment contaminated with faeces from dairy cows, geese, and deer: Legacy risks to environment and health. *International Journal of Environmental Research and Public Health,* 20: 5375.

Biggs BJF. (2000) New Zealand periphyton guidelines: Detecting, monitoring and managing enrichment of streams. Prepared for the Ministry for the Environment, Wellington.

Black K. (2015) Discharge Permit Application RM15.004.01-RM15.004.02 by Central Otago District Council to discharge septage to land and treated wastewater/septage to water from the operation of the Ranfurly Wastewater Treatment Plant, Ranfurly. Otago Regional Council Recommending Report (A734902) prepared for Staff Consents Panel. 24 p.

Brosse S, Arbuckle CJ, Townsend CR. (2003) Habitat scale and biodiversity: Influence of catchment, stream reach and bedform scales on local invertebrate diversity. *Biodiversity and Conservation* 12: 2,057–2,075.

Button E. (2024) Land and soil monitoring update. Report No. SPS2404 prepared for the Otago Regional Council's Environmental Science and Policy Committee, 27 June 2024.

Champion PD, Tanner CC. (2000) Seasonality of macrophytes and interaction with flow in a New Zealand lowland stream. *Hydrobiologia* 441: 1–12.

Clapcott JE, Young RG, Harding JS, Matthaei CD, Quinn JM, Death RG. (2011) Sediment assessment methods: Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values. Cawthron Institute, Nelson. 105 p.

Collins JI, Colins AL, Naden PS, Sear DS. (2011) The relationship between fine sediment and macrophytes in rivers. *Journal: River Research and Applications*, 1,535–1,467.

Davies-Colley R, Franklin P, Wilcock B, Clearwater SJ, Hickey CW. 2013. National Objectives Framework – temperature, dissolved oxygen and pH. NIWA Client Report No. HAM2013-056 prepared for Ministry for the Environment.

Dicey S. (2020) Pig Burn – collective replacement of permits to take and use surface water: Resource consent application and supporting information. McKeague Consultancy Ltd client report. 103 p + appendices.

Franklin P, Stoffels R, Clapcott J, Booker D, Wagenhoff A, Hickey C. (2019) Deriving potential fine sediment attribute thresholds for the National Objectives Framework. Client report to the Ministry for the Environment, 2019039HN. 290 p.

Franklin P, Stoffels R, Booker D. (2020) Contract 23184: Task 2 – Turbidity and visual clarity threshold conversion. Client memorandum prepared for the Ministry for the Environment, 13 March 2020. 10 p.

Gerard P, Closs GP, Matthaei CD, Mora-Teddy A, Schallenberg M. (2024) Impacts of climate change on the Tāiari River and tributaries. Report prepared for the Department of Conservation.

Gitter A, Mena KD, Wagner KL, Boellstor DE, Borel KE, Gregory LF, Gentry TJ, Karthikeyan R. (2020) Human health risks associated with recreational waters: Preliminary approach of integrating Quantitative Microbial Risk Assessment with Microbial Source Tracking. *Water:* 12, 327.

Goldsmith MJ. (2023) Climate change impacts and risks for the Taiari catchment. Report prepared for the Department of Conservation by GHC Consulting Ltd. 83 p.

Hickey M. (2020) Assessment of effects on instream ecology due to water takes from the Pig Burn. Report prepared for the Pig Burn Water Users Group. Water Resource Management Ltd, January 2020. 22 p.

Hogan E, Trotter M. (2024) Upper Taiari/Taieri biomonitoring report 2024. Tiaki Maniototo report prepared for the Ministry for the Environment. 53 p. Draft report, August 2024.

Kitto J. (2012) Water quality effects on instream values in the Upper Taieri. Otago Regional Council. 57 pp.

Levy A, Ettema M, Xiaofeng L. (2021) State of the Environment groundwater quality in Otago. Otago Regional Council science report. 192 p.

Macara GR. (2015) The climate and weather of Otago. 2nd edition. NIWA Science and Technology Series No. 6. 42 p.

Mackay A, Dominati E, Taylor MD. (2013) Soil quality indicators: The next generation. AgResearch Client Report RE500/2012/025 prepared for Land Monitoring Forum of regional councils. 155 p.

Matheson F, Quinn J, Hickey C. (2012) Review of the New Zealand instream plant and nutrient guidelines and development of an extended decision making framework: Phases 1 and 2 final report. NIWA Client Report HAM2012-08 prepared for MBIE Envirolink. 127 p.

McDowell RW, Houlbrooke DJ, Muirhead RW, Müeller K, Shepherd M, Cuttle SP. (2008) Grazed pastures and surface water quality. Hauppage, New York, Nova Science Publishers. 238 p.

McDowell RW, Kitto JA. (2013) Assessment, modelling and management of land use and water quality in the upper Taieri River catchment. *New Zealand Journal of Agricultural Research*, 56(4): 261–278.

McDowell RW, Noble A, Kittridge M, Ausseil O, Doscher C, Hamilton DP. (2024) Monitoring to detect changes in water quality to meet policy objectives. *Scientific Reports* 14(1):1914. https://doi.org/10.1038/s41598-024-52512-7.

Milne J. (2024a) Water quality in the mid Taiari/Taieri River catchment: A summary of monitoring activities and findings. Report prepared for the Upper Taieri Wai by Traverse Environmental Ltd. 41 p.

Milne J. (2024b) Water quality in the lower Taiari/Taieri River catchment: A summary of monitoring activities and findings. Report prepared for the Upper Taieri Wai by Traverse Environmental Ltd. 53 p.

Ministry for the Environment. (2020) Action for healthy waterways: Guidance on look-up tables for setting nutrient targets for periphyton. Ministry for the Environment, Wellington.

Ministry for the Environment. (2022) Guidance on look-up tables for setting nutrient targets for periphyton. 2nd edition. Ministry for the Environment, Wellington.

Ministry for the Environment/Ministry for the Environment. (2003) National microbiological water quality guidelines for marine and fresh water recreational areas. Ministry for the Environment, Wellington.

Morgenstern U, Daughney C. (2012) Groundwater age for identification of baseline groundwater quality and impacts of land-use intensification — the National Groundwater Monitoring Programme of New Zealand. *Journal of Hydrology*, 456/457: 79–93.

Moriarty EM, Karki N, Mackenzie M, Sinton LW, Wood DR, Gilpin BJ. (2011) Faecal indicators and pathogens in selected New Zealand waterfowl. *New Zealand Journal of Marine and Freshwater Research*, 45(4): 679–688.

ORC (2003) Report on the surface water quality of the upper Taieri River catchment, November 2001 to December 2002. Otago Regional Council science report. 69 p.

ORC (2006a) The effect of irrigation runoff on water quality. Otago Regional Council science report. 47 p.

ORC (2006b) River and stream health: Taieri River annual monitoring summary 2005. Report card. 4 p.

ORC (2014) Maniototo Basin groundwater review. Unfinished draft report, Otago Regional Council. 77 p.

ORC (2021) Taieri FMU river & lake water quality: State and trends. Otago Regional Council science report. 39 p.

ORC (2023) Biomonitoring report card: 2017 to 2022. Otago Regional Council. 16 p. https://www.orc.govt.nz/media/14656/bio-monitoring-report-card.pdf

Ozanne R, Levy A, Borges H. (2023) State and trends of rivers, lakes, and groundwater in Otago: 2017–2022. Otago Regional Council science report, May 2023. 159 p.

Phillips C, Daly C. (2008) Use of willows and natives for stream bank control in New Zealand: A survey of regional councils. Motueka Integrated Catchment Management (Motueka ICM) Programme Report Series. Landcare ICM Report No. 2008–2009/01. 22 p.

Pope L, Rutherfurd I, Price P, Lovett S. (2006) Controlling willows along Australian rivers. *River Management Technical Guideline No. 6*. Land & Water Australia, Canberra. 20 p.

Pritchard N. (2012) Discharge Permit Application RM11.110 by Central Otago District Council to discharge treated wastewater to water from the operation of the Ranfurly Wastewater Treatment Plant, Ranfurly. Otago Regional Council Staff Recommending Report 2011/0795 prepared for Staff Consents Panel. 15 p.

Pritchard N. (2012) Discharge Permit Application RM15.258 by Central Otago District Council to discharge treated wastewater to land from the Naseby Wastewater Treatment Plant, Naseby. Otago Regional Council Recommending Report (A843838) prepared for Staff Consents Panel. 26 p.

Ryder G, Tocher M. (2020) Review of values, freshwater restoration programmes and research needs within the Taieri Catchment. Report prepared by Ryder Consulting for the Department of Conservation. Department of Conservation, Dunedin. 144 p.

Snelder T, Larned S, Whitehead A. (2021) Guidance for the analysis of temporal trends in environmental data. NIWA Client Report 2021017WN prepared for Horizons Regional Council and MBIE Envirolink.

Soller JA, Schoen ME, Bertrand T, Ravenscroft JE, Ashbolt NJ. (2011) Estimated human health risks from exposure to recreational waters impacted by human and non-human sources of faecal contamination. *Water Research*, 44 (16) 4,674–4,691.

Townsend CR, Arbuckle CJ, Crowl TA, Scarsbrook MR. (1997a) The relationship between land use and physicochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri River, New Zealand: A hierarchically scaled approach. *Freshwater Biology* 37, 177–191.

Townsend CR, Scarsbrook MR, Doledec S. (1997b) The intermediate disturbance hypothesis, refugia and biodiversity in streams. *Limnology and Oceanography*, 42: 938–949.

Uytendaal A, Ozanne R. (2018) State of the environment surface water quality in Otago: 2006 to 2017. Otago Regional Council science report. 218 p.

Vermeulen M, Wansborough J, Hogan E. (2022) Upper Taieri biomonitoring survey. Tiaki Maniototo report prepared for the Ministry for the Environment. 37 p.

Wansbrough J. (2023) Assessment of dissolved oxygen levels of the Taieri River at Waipiata. Draft report prepared for the Upper Taieri Wai, January 2023 (Draft 2). 16 p.

Xiaofeng L, Ravenscroft P. (2016) Management flows for aquatic ecosystems in the Pig Burn. Otago Regional Council science report. 30 p.

Young R, Townsend C, Matthaei C. (2004) Functional indicators of river ecosystem health – an interim guide for use in New Zealand. Cawthron Report No. 870 prepared for the Ministry for the Environment. 54 p.