State and Trends of
Rivers, Lakes, and Groundwater
in Otago
2017 – 2022

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Contents

Executive Summary

This study analysed and reviewed the state and trends of water quality data for rivers, lakes, and groundwater in the Otago Region. The data was collected from the ORC's State of Environment (SoE) monitoring network for rivers (107 sites), lakes (34 sites/depths), and groundwater (55 sites). The current water quality state was calculated for the period between 01 July 2017 and 30 June 2022. Water quality for each river and lake site was graded based on the attribute bands in the National Policy Statement – Freshwater Management 2020 [NPS-FM]. However, as the NPS-FM does not contain attribute states for groundwater, its state was assessed against the Maximum Acceptable Values (MAV) in the Drinking Water Standards for New Zealand (DWSNZ) for E. coli, nitrate, and dissolved arsenic. Trends and the confidence in the evaluated trend direction were only assessed at a subset of sites for which there was sufficient data.

This report analysed surface water quality against the NPS-FM attributes for toxicity (ammonia-N; NH_3-N and nitrate-N; NO_3-N), Dissolved Reactive Phosphorus (DRP), Chlorophyll A (Chl-a), *E. coli*, Total Nitrogen (TN), Total Phosphorus (TP), and suspended fine sediment. The results show that the state of river and lake water quality is spatially variable across Otago. Water quality is best at lakes, river and stream reaches located at high elevations under predominantly native land cover. These sites tend to be located in the upper catchments of the large lakes (e.g., Hawea, Whakatipu and Wanaka) and some tributaries of the Clutha Mata-Au (e.g., Lindis River, Nevis River, Dart River). Other areas, such as urban streams in Dunedin, intensified catchments in North Otago and some tributaries in the Lower Clutha Rohe have poorer water quality.

The trend analysis for rivers returned mixed results. The 10-year trend analysis showed fewer degrading trends compared to the 20-year trend analysis, with overall improvement in *E. coli*, TN, Nitrate Nitrite Nitrogen (NNN as a proxy for NO_3-N) and turbidity. However, this should be interpreted with caution due to the varied length of monitoring at different sites. Tributaries in the Lower Clutha Rohe show many 'extremely likely' or 'virtually certain' improvements across multiple attributes over a 10 year period. This Rohe is intensively farmed and is characterised as having high rainfall and heavy soils compared to other FMU/Rohe in the region and is therefore extenively drained. Catchment groups have been working in the area for 10+ years and the improving water quality may be due to increased awareness and on the ground action promoted through farmer-led groups.

Five year lake trends showed degradation at most sites. However, this may be attributed to the short monitoring duration assessed, which increases the influence of climatic-driven variables on water quality over those derived from changes within lake catchments. In particular, lower rainfall and higher temperatures in the past few years alongside land use and urbanisation pressures could be responsible for driving incresead chl-a and nutrients in lakes. Five year trends were assessed because monitoring records are limited for many lake sites.

Similar to the rivers and lakes data, the state of groundwater quality is also mixed across Otago. Spatial variability was also observed with *E. coli* and nitrate exceedances usually an issue in the same areas, while high dissolved arsenic concentrations were more site-specific.

The highest nitrate concentrations were usually measured in unconfined aquifers that underlie areas of intensive nitrate application (e.g., dairy farming, market garden) or septic tanks. This report highlighted elevated nitrate concentrations in areas that fit these characteristics e.g., especially in the North Otago FMU, where nitrate concentrations in many sites exceed the DWSNZ MAV. The *E. coli* data indicates that potential faecal contamination is a serious threat across Otago. However, it is also important to note that elevated *E. coli* can be a local issue and is strongly dependent on borehead security and land use, hence the SoE monitoring data does not provide a complete mapping of this risk. It is strongly recommended that bore owners ensure adequate borehead security to prevent

contaminant entry into the aquifer through the borehead. It is also recommended that groundwater used for drinking is regularly tested in an accredited laboratory, with testing being particularly important after periods of heavy rainfall. The arsenic data shows high spatial variability across Otago, with several areas where arsenic concentrations exceeded or are near the DWSNZ MAV. Most of the exceedances and high concentrations were in the Upper Lakes Rohe (Glenorchy and Kingston) but also included sites in the Dunstan Rohe, Lower Clutha Rohe, and the Taieri FMU. It is likely that these results are due to geologically sourced arsenic, which originates in schist lithology or organic sediments. Due to the high abundance of geological arsenic sources in Otago and its spatial variability in groundwater it is therefore strongly recommended that bore owners regularly test their bore water in an accredited laboratory for arsenic. Concentrations at most sites in the North Otago and Taieri FMU were low.

As reported in previous ORC state and trend water quality reports, there has been a lack of detailed information on land use, land management, and their changes at the local or catchment scale. This limits the ability to comment on the drivers of water quality trends observed in Otago. However, since 2020 the ORC has refined its water quality management frameworks, notably via Plan Change 8 (PC8) and the upcoming Land and Water Regional Plan (LWRP). PC8 targets specific issues or activities that contribute to water quality problems in parts of Otago (e.g., intensive grazing and earthworks) by improving rules around activities such as effluent storage and application, sediment management, and stock access to waterways.

The objective of the new LWRP is to ensure that the health and well-being of water bodies and freshwater ecosystems is maintained or improved. The LWRP will include rules and limits on water and land use in line with the NPS-FM. The progress towards LWRP notification has included collecting detailed information on land use and the effect of land use mitigation practices on water quality alongside water quality modelling under different land use mitigation scenarios. All of these will enable evidence-based commentary on drivers and direction of water quality trends now and into the future.

1 Introduction

Otago Regional Council (ORC) operates a long-term State of Environment (SoE) water quality monitoring network in lakes, rivers, and streams throughout Otago. Its objectives include providing information that underpins SoE reporting according to obligations under s35 of the Resource Management Act (1991). This monitoring improves the efficiency of Council policy initiatives and strategies, provides information on the effectiveness of Council's plans, as well as helping to identify the large-scale and/or cumulative impact of contaminants associated with varying land uses.

To meet Council's reporting obligations under s35 of the Resource Management Act (1991), ORC provides annual summaries on a site by site basis relative to attribute tables found in Appendix 2A and Appendix 2B of the National Policy Statement-Freshwater Management (NPS-FM) (Ministry for Environment, 2020) as well as more detailed analysis of general state and long-term trends every 5-years. ORC conducted the last analysis of general state and trends for the period 2000 to 2020 (ORC, 2020).

State analysis (rivers, lakes, and groundwater) was based on water quality samples collected over a five-year period from 1 July 2017 to 30 June 2022 (Fraser, 2023a). Where available, the state for the five-year period 1 July 2012 to 30 June 2017 has also been calculated, which may be defined as the interim[1] baseline state (NPSFM, 2020). As the NPS-FM does not contain attribute states for groundwater, and as groundwater is widely used for drinking and domestic supply in Otago, groundwater state was assessed against the Maximum Acceptable Values (MAV) in the Drinking Water Standards for New Zealand (Department of Internal Affairs, 2022 (DWSNZ, 2022)).

Trend analysis and confidence in the evaluated trend direction was carried out for 5-year, 10-year and 20-year periods ending on 1 July 2022 for all site and water quality variable combinations that met a minimum requirement for numbers of observations (Fraser, 2023b). It was decided to include five-year trends for groundwater and lake sites as monitoring records are limited, results from these short-term trends needs to be treated with caution.

This report does not benchmark water quality state against Schedule 15 of the current Water Plan. Several reasons are behind this; the receiving water groups specified in Schedule 15 of the Water Plan differ spatially to the Freshwater Management Units of the upcoming LWRP, the Schedule 15 numerical targets and limits differ according to the receiving water groups and the receiving water numerical targets and limits are applied as five-year, 80th percentiles, when flows are at or below median flow at the relevant flow reference site.

This report assesses the water quality attributes in Appendix 2A and 2B of the NPSFM but does not report against the ecological components. This information is available as an annual summary and found on ORC's website[2], a water quality report card summarising this technical report is also located on ORC's website.

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[1] ORC has not yet defined baseline state.

[2] https://www.orc.govt.nz/plans-policies-reports/reports-and-publications/water-quality/annual-water-quality-reports

2 Otago Region

2.1 Regional Description

The Otago region covers a land area of 32,000 km^2, from the Waitaki River in the north to Brothers Point in the south, and inland to Lake Whakatipu, Queenstown, Hawea, Haast Pass and Lindis Pass. The distinctive and characteristic landscapes of Otago include the Southern Alps and alpine lakes; large high-country stations; dry central areas with tussock grassland and tors; and dramatic coastlines around the Otago Peninsula and the Catlins. Lowland pasture country is common in the west. The character of the region's water bodies is diverse, reflecting the variation in environmental conditions throughout the region.

The Clutha /Mata-Au River drains much of the Otago region. Its catchment area totals 21,000 km^2, and 75% of its total flow at Balclutha comes from the outflows of Lakes Hawea, Wanaka, and Whakatipu. Larger rivers feeding into the Clutha catchment include the Matukituki, Cardrona, Lindis, Shotover, Nevis, Fraser, Manuherekia, Teviot, Pomahaka, Waitahuna and Waiwera rivers. The Clutha and its principal tributary, the Kawarau River, pass through gorges, two of which are dammed for hydro-electricity generation. The Kawarau flows out of Lake Whakatipu, which is fed by the Dart and Rees Rivers and the surrounding mountain catchments.

The second largest catchment in Otago is the Taieri River (5,060 km^2). It rises in the uplands of Central Otago and meanders between mountain ranges before passing through an incised gorge and crossing the Taieri Plain, where it joins the catchments of Lake Waipori and Waihola and becomes tidal before flowing through another gorge to the sea at Taieri Mouth.

Other significant Otago rivers drain the coastal hills in catchments of varying character. In the north, the Kakanui, Waianakarua, Shag and Waikouaiti rivers rise in high country and pass through mainly dry downlands. The Tokomairiro River, which flows through Milton, south of Dunedin, drains rolling country between the Taieri and Clutha catchments. Rivers in the south of Otago, particularly the Catlins area, emerge from wetter, often forested hills.

Groundwater is used across Otago for drinking, irrigation, stock water, frost-protection, and industry. In addition to that, groundwater discharges also significantly impact flow, water quality, and ecology in various rivers across the region (e.g., the Kakanui, Shag). However, overlying land uses impact groundwater quality and levels. In contrast to other regions in New Zealand that are underlain by extensive aquifer systems (e.g., Canterbury, Hawke's Bay), the aquifers in Otago are generally small, most of which are composed of disconnected basins associated with alluvial depositions in river valleys (ORC, 2021).

The environmental context in which Otago's water bodies exist is characterised by high rainfall in the Southern Alps and occasional, very low rainfall and high evaporation in the semi-arid central Otago valleys. Hence, despite the large water volumes in some parts of Otago, other parts are among the driest in New Zealand. Several rivers and tributaries are characterised as 'water-short', including the Lindis, Manuherekia, Taieri, Shag and Kakanui rivers (ORC, 2004; 2017).

2.2 Freshwater management units

To give effect to the NPS-FM (2020) and take a more localised approach to water and land management, Otago Regional Council (ORC) mapped Freshwater Management Unit (FMU) boundaries incorporating the concept of *ki uta ki tai* (from the mountains to the sea).

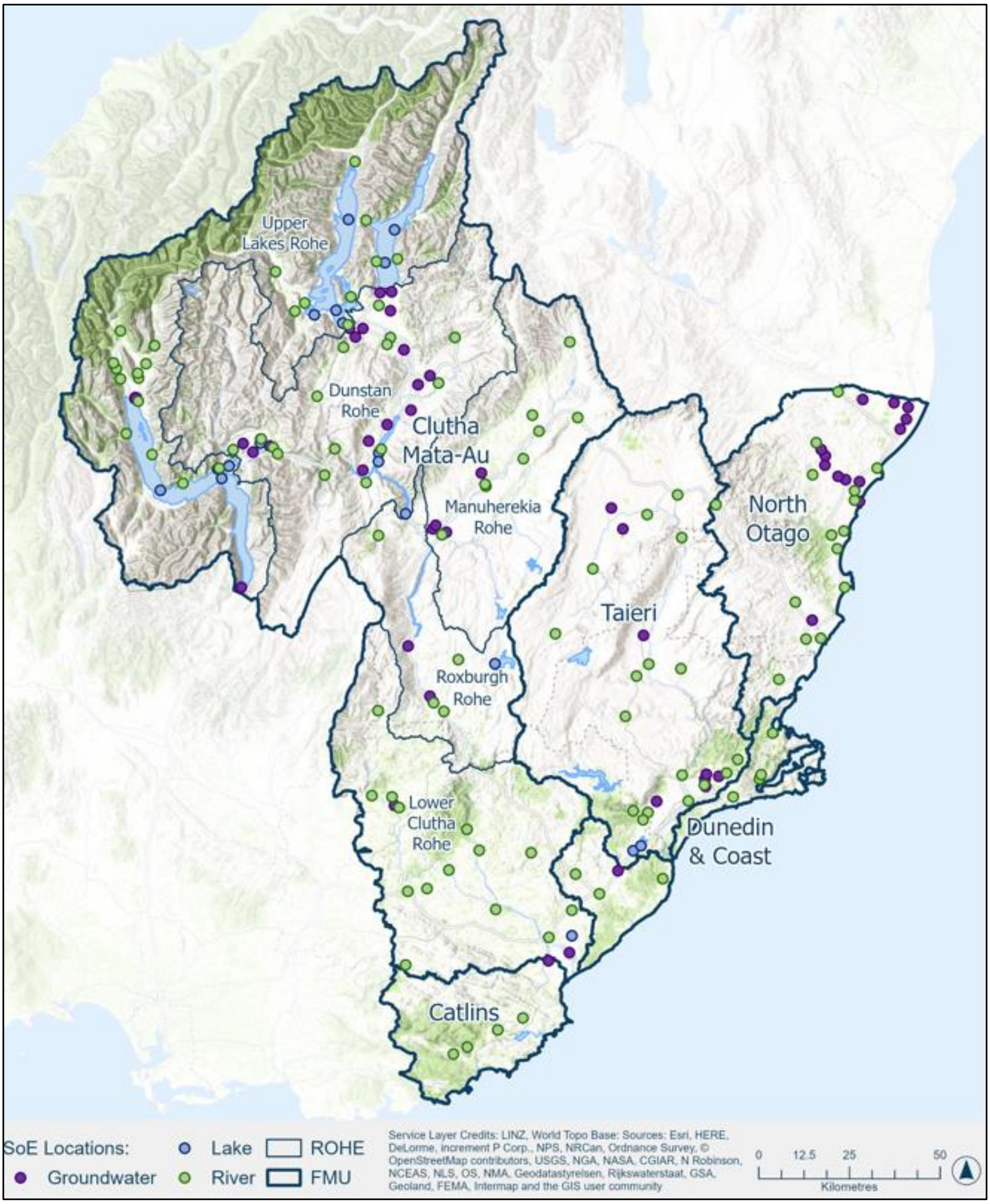

Figure 1 Map showing the FMU and Rohe boundaries, State of Environment monitoring site locations are also shown.

All regional councils are required to set Freshwater Management Units (FMUs) under the NPS-FM (MfE, 2020). A Freshwater Management Unit is a spatial area including a water body or multiple water bodies and catchments. FMUs are intended to be the framework within which freshwater planning takes place and should be at a scale where freshwater can be appropriately cared for and give effect to Te Mana o te Wai. This can be a river catchment, part of a catchment, or a group of catchments.

In the Otago region, FMUs have been based around larger river catchments or multiple smaller catchments and communities of interest. They extend from the smallest headwaters to the coast. All land that drains to that catchment, additional waterbodies within this area and receiving environments (lakes, wetlands), are also included

Five FMUs were identified and mapped in Otago, which are listed below. Due to its large size and variability, the Clutha/Mata-Au FMU was further divided to five sub-areas, or Rohe. These provide a more tailored water management approach.

Figure 1 shows boundaries associated with the Otago Region, the FMU and Rohe. Locations of the lake, river and groundwater monitoring sites are also shown. Further information on aquifers, and SoE monitoring sites can be found in ORC (2017; 2021).

- Clutha/Mata-Au FMU
    - Upper Lakes Rohe
    - Dunstan Rohe
    - Manuherekia Rohe
    - Roxburgh Rohe
    - Lower Clutha
- Taieri FMU
- North Otago FMU
- Dunedin & Coast FMU
- Catlins FMU

3 ORC monitoring programme

3.1 Water Quality Sites

State of the Environment (SoE) monitoring sites covered in this report include 107 river sites, eight lakes (27 sites/depths[3]) and 55 groundwater bores. NIWA monitors an additional five river sites in the Otago region as part of the National River Water Quality Network (NRWQN). The locations of the monitoring sites are shown in Figure 1 .

Following a review of ORC's SoE network by NIWA (2017), more extensive river and lake SoE monitoring programmes commenced in mid-2018. Forty-one sites were added to the river SoE network so that the monitoring sites were proportionally representative of environmental classes of rivers found in Otago, based largely on the River Environment Classification[4] (REC) (MfE, 2004).

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[3] Many lakes had more than one sample location and some sample locations had two or more depths associated with their water quality sampling. The different depths were treated as independent sampling sites.

[4] River Environment Classification (REC) is a system that classifies New Zealand's rivers at six hierarchical levels: Climate, Source-of-Flow, Geology, Land-Cover, Network-Position and Valley-Landform

Significant changes to the SoE monitoring programme have occurred during the last twenty years, more significant changes include:

- Up to June 2013, ORC collected surface water quality samples on a bi-monthly basis. From July 2013, sampling frequency increased to monthly sampling
- Prior to mid-2018, there were fewer monitoring sites in the Region, following a review (NIWA, 2017), a more extensive monitoring programme commenced in mid-2018 and the number of monitoring sites increased from 65 to 107. The river monitoring network not consist of 110? Sites.
- Prior to mid-2018 SoE lake monitoring sites consisted of a mix of lake-outlet sites (Lakes Wanaka, Wakatipu and Hawea) and lake shore sites (Lakes Dunstan, Hayes, Johnson, Onslow, Waihola and Tuakitoto). From July 2018, lake outlet monitoring sites were discontinued and all lake sites other than Tuakitoto and Onslow are now mid-lake sampled with the full vertical water column profiled on every sampling occasion.
- The sampling frequency for groundwater became quarterly in March 2011.
- A new SoE groundwater bore was drilled in Bendigo (CB13/0159) in May 2019, and due to loss of access, bore G44/0136 is no longer monitored.

3.2 Surface water quality variables

River and lake water quality is assessed using a range of variables that characterise physical, chemical, and microbiological conditions. In this state and trends report, only those variables included as attributes in Appendix 2A or 2B of the NPS-FM (MfE, 2020) were assessed, these variables are detailed further in section 3.21 - 3.24. The NOF water quality attributes do not include dissolved inorganic nitrogen (NNN), however NNN is needed to set nutrient outcomes. This is discussed further in section 3.2.1.

There are no specific standards for groundwater in the NPS-FM. Groundwater quality state was, therefore, assessed against the DWSNZ (DIA, 2022) MAV for *E. coli*, nitrate-N, and dissolved arsenic, following a similar approach to ORC (2021) and other councils (e.g., Foster and Johnson, 2021; Environment Canterbury 2018; Hawkes Bay Regional Council 2017). The groundwater quality parameters are described in section 3.3. The results are reported at the FMU/Rohe scale followed by a regional summary. This contrasts with ORC's previous groundwater quality SoE report (ORC, 2021), where results from each monitoring bore are described. That report also contains a full description of the aquifers and monitoring bores.

Although some of the assessed monitoring parameters are the same for groundwater and surface water, the standards/limits that the data was assessed against are different. It is also important to note that although the groundwater results were assessed against the DWSNZ, the SoE monitoring is not designed for drinking water compliance, hence this report should not be used to infer whether specific groundwater sources are safe for drinking. Further information about drinking water can be found on the drinking water (3 Waters) regulator, Taumata Arowai's website https://www.taumataarowai.govt.nz/.

Site statistics for all variables are available in the accompanying reports ORCRiverState-072017to062022, ORCGWState_072017to062022 and ORCLakeState_072017to062022[5], including statistics for NNN. A summary of site statistics is available in Appendix 1.

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[5] https://www.orc.govt.nz/plans-policies-reports/reports-and-publications/water-quality

3.2.1 Phytoplankton, Periphyton and Nutrients

Healthy freshwater ecosystems have low (oligotrophic) to intermediate (mesotrophic) levels of living material and primary production (growth of plants or algae). High levels of nutrients, primarily nitrogen and phosphorus, can cause water bodies to become eutrophic. Eutrophic states are associated with periodic high biomass (blooms) of plants and/or algae, including suspended algae (phytoplankton) in lakes and algae on the beds of streams and rivers (periphyton).

Chlorophyll-a is a common method for estimating stream periphyton biomass (MfE, 2000) because all algal types contain chlorophyll-a, this metric reflects the total amount of live algae in a sample. The trophic state of a water body is the amount of living material (biomass) that it supports. The NPS-FM specifies attributes for trophic state based on phytoplankton biomass in lakes (Table 1, Appendix 2A) and periphyton biomass in rivers (Table 2, Appendix 2A), both measured by chlorophyll *a*.

Dissolved inorganic nitrogen (nitrate-N + nitrite-N + ammonia-N), dissolved reactive phosphorus (DRP), total nitrogen (TN) and total phosphorus (TP) all influence the growth of benthic river algae (periphyton), lake planktonic algae (phytoplankton) and vascular plants (macrophytes). The NPS-FM specifies attributes for TN and TP in lakes (Table 3 and Table 4, Appendix 2A).

The NPS-FM does not specify nutrient concentrations (nutrient outcomes) to manage the trophic state of rivers, because the relationship between trophic state and nutrient concentrations varies between rivers even at the regional scale. MfE (2018) recommended that nutrient criteria (now referred to as nutrient outcomes) to achieve periphyton biomass objectives in rivers are river-specific and should be derived at the local level. Further guidance was provided by MfE (2020 and 2022) for defining nutrient concentrations to manage the NPS-FM periphyton attribute states in rivers.

The guidance provides nutrient (DIN, DRP, TN and TP) look-up tables for managing periphyton to different attribute states (i.e., nutrient concentrations required to achieve attribute band ‘A’ is more stringent than nutrient criteria required to achieve attribute band ‘B’), there are also lookup tables for shaded and non-shaded sites and different levels of under protection risk[6].

Regional councils select the nutrient lookup tables (i.e., total, or dissolved nutrients and shaded or non-shaded) most relevant to their region and environmental outcomes sought. ORC (2020) describes the under-protection risk (formerly spatial exceedance) and nutrient outcomes adopted for the Otago Region at that time. An updated report on under protection risk and nutrient outcomes, following a recent update to the national guidance, will be available prior to notification of the LWRP. Once this report is prepared analysis of the region’s rivers nutrient concentrations against target concentrations to achieve periphyton outcomes will be able to be undertaken.

As DIN is not reported as an NPS-FM attribute, Appendix 1 provides numerical concentrations of both DRP and DIN (reported as NNN) for each site to provide information for interpreting periphyton results,

The NPS-FM provides an attribute table for DRP in rivers to protect ecosystem health (Table 20, Appendix 2B). It describes that at DRP concentrations below attribute band C ‘*Ecological communities impacted by substantial DRP elevation above natural reference conditions. In combination with other conditions favouring eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia are lost.*’

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[6] The under-protection risk refers to a river location. Choosing a level of under-protection risk means that a proportion of locations can be expected to have biomass higher than the nominated target despite being compliant with the criteria. Under-protection risks of 30%, 20% and 10% correspond to objectives to maintain biomass below the target level at 70%, 80% or 90% of sites across the domain, respectively.

Further DRP enrichment (attribute band D) is described as driving '*excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia are lost'*. It is unclear whether the DRP attribute or phosphorus nutrient outcomes to manage periphyton will be more environmentally conservative.

Cyanobacteria (NPS-FM Attribute Table 10) has not been assessed in this report, it is monitored as part of ORC's contact recreation programme and reported separately.

3.2.2 Toxicants

When ammonia-N (NH_3-N)[7] is present in water at high enough concentrations, it is difficult for aquatic organisms to sufficiently excrete the toxicant, leading to toxic build-up in internal tissues and blood, and potentially death. Environmental factors, such as pH and temperature, affect the proportion of ammonia-N present in water and, therefore, the toxicity to aquatic animals. The NPS-FM has developed an ammoniacal-N toxicity risk framework (Table 5, Appendix 2A), when toxicity concentrations are below the national bottom line, toxicity starts impacting regularly on the 20% most sensitive species.

Nitrate-N (NO_3-N) generally impacts on trophic state at much lower concentrations than those that are toxic. Because of this, nitrate will generally be managed well within toxic levels by the requirement to manage trophic state (e.g., periphyton, section 3.2.1). The NPS-FM has developed a nitrate-N toxicity risk framework (Table 6, Appendix A, NPS-FM) when toxicity concentrations are below the national bottom line, toxicity has growth effects on up to 20% of species.

3.2.3 Suspended sediment

Suspended fine sediment (SFS) can severely affect recreational and ecosystem health values. High concentrations of SFS have a '*high impact on instream biota and ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost'* (NPS-FM, 2020). Suspended fine sediment can be monitored by clarity or turbidity measurements.

Clarity is a measure of light attenuation due to absorption and scattering by dissolved and particulate material in the water column. Clarity is monitored because it affects primary production, plant distributions, animal behaviour, aesthetic quality, and recreational values, and because it is correlated with suspended solids, which can impede fish feeding and cause riverbed sedimentation. Clarity is the metric used in the NPS-FM attribute table for suspended fine sediment (Table 8, Appendix A)

Turbidity refers to light scattering by suspended particles. Nephelometric turbidity is generally inversely correlated with visual water clarity (Davies-Colley and Smith 2001), but unlike visual clarity, turbidity measurements do not account for the optical effects (i.e., absorption) of dissolved materials. The NPS-FM allows for the conversion of turbidity to visual clarity. ORC does not measure visual clarity and applies this conversion (Franklin, 2020).

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[7] Ammoniacal nitrogen (NH_4-N), is the concentration of nitrogen present as either ammonia (NH_3) or ammonium (NH_4). Ammonia (NH_3) is a gas that reacts to form the ammonium ion (NH_4) when it is dissolved in water.

3.2.4 *Escherichia coli* (*E. coli*)

The concentration of the bacterium *E. coli* is used as an indicator of human and/or animal faecal contamination, from which the risk to humans arising from infection or illness from waterborne pathogens during contact-recreation may be estimated.

Water contaminated by human or animal faeces may contain a range of pathogenic (disease-causing) micro-organisms. Viruses, bacteria, protozoa, or intestinal worms can pose a health hazard when the water is used for drinking or recreational activities. It is difficult and impractical to routinely measure the level of all pathogens that may be present in fresh water. Instead, indicator bacteria are used to indicate the likely presence of untreated sewage and effluent contamination.

E. coli is a bacterium commonly found in the gut of warm-blooded organisms and is relatively easy to measure which makes it a useful indicator of faecal presence and therefore of disease-causing organisms that may be present. *E. coli* is the attribute for specifying human health for recreation objectives for fresh water because it is moderately well correlated with *Campylobacter* bacteria and numeric health risk levels can be calculated. Campylobacteriosis has the highest reporting rate of all New Zealand's 'notifiable' diseases' (MfE, 2018)

The NPS-FM uses *E. coli* to assess the risk of *Campylobacter* infection and therefore river swimmability. The attribute state is calculated using four statistical measures of *E. coli* concentrations, and the overall state is determined by satisfying all numeric attribute states (Table 9, Appendix 2A)[8].

3.2.5 Ecological Assessments

Appendix 2 of the NPS-FM has attribute tables for ecological attributes. ORC monitors submerged plants, fish index of biotic integrity, macroinvertebrates, deposited sediment, and ecological processes and results from these monitoring programmes have been reported separately as an annual report card[9].

3.3 Groundwater quality parameters

3.3.1 Escherichia coli (*E. coli*)

E. coli is used in the DWSNZ (DIA, 2022) as the indicator organism for bacterial compliance testing where its presence suggests contamination of drinking water by faecal material and pathogenic microorganisms. Faecal bacteria contamination in (drinking) water can originate from livestock, wastewater discharges, effluent application, and stormwater discharge, with contamination risk increasing following heavy rainfall. Although groundwater is less vulnerable than surface water to contamination by potentially pathogenic microorganisms, groundwater may still manifest instances of microorganism occurrence.

3.3.2 Dissolved arsenic

Arsenic is a toxic, though naturally occurring, element, present at low levels in soil, water, plants, animals, and food. Exposure to elevated arsenic can lead to a range of cancers, with bladder or lung cancer being the most common, and other non-cancer effects (Piper and Kim, 2006). Arsenic in groundwater can originate from either anthropogenic or geological (natural) sources. The former includes sources such as sheep dips and treated timber posts. The latter includes schist lithology reduced peat deposits, and volcanic rocks (e.g., Piper and Kim, 2006). And. Schist is particularly

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[8] This report does not assess compliance with Table 22, Appendix 2B (E. coli at primary contact sites)

[9] https://www.orc.govt.nz/plans-policies-reports/reports-and-publications/water-quality/annual-water-quality-reports

relevant in Otago due to its abundance (Bloomberg *et al*., 2019). In addition to geological factors and economic activities that use or formerly used arsenic, dissolved arsenic concentrations in groundwater are also controlled by water level fluctuations and geochemical oxidation/reduction where groundwater with low Dissolved Oxygen concentrations can increase arsenic mobility (Piper and Kim, 2006). These are likely to occur in areas with high carbon input (which increase microbial activity that consumes oxygen) that can be sourced from septic tank discharge, for instance in Glenorchy (E3, 2018). This can increase concentrations in areas with low dissolved oxygen, caused by high septic tank discharges, e.g., Glenorchy (E3, 2018).

3.3.3 Nitrate nitrogen

Nitrate is a dissolved, inorganic form of nitrogen (N), which is a key nutrient required for the growth of plants and algae. Nitrate-N is the most readily available nutrient for uptake by plants, hence it is widely used as fertiliser. However, excess nitrate can adversely impact water quality and ecosystem health. Nitrate in drinking water can also cause human health issues, the primary being the formation of methemoglobinemia, or “blue baby syndrome”, which impedes oxygen transport around the body in infants (MoH, 2018). There is also increasing research regarding the connection between nitrate-N in drinking water and cancer (e.g., Rogers *et al*., 2023). For instance, a study from Denmark suggests that the risk of colorectal cancer increases for drinking water with nitrate-N concentrations above 0.87mg/L (Schullehner *et al*., 2018). Despite this research, the DWSNZ (2022) MAV remains 11.3mg/L. Therefore, this report used this value for assessment of groundwater nitrate-N concentrations, following the same approach taken in ORC (2021). The nitrate-N MAV for drinking water is substantially higher than the nitrate-N thresholds specified in the NPS-FM (2020) for periphyton and toxicity, hence, although groundwater nitrate-N concentrations in many sites are below the MAV, this does not necessarily indicate good water quality from an ecological perspective. Therefore, in addition to the DWSNZ, groundwater nitrate-N concentrations were also compared to a published threshold for nitrate-N concentrations impacted by low intensity agriculture (2.50mg/L, Morgenstern and Daughney, 2012). This can be particularly important for shallow bores in areas of high interaction between groundwater and surface water. However, in contrast to ORC (2021), groundwater nitrate-N concentrations were not assessed against the NPS-FM limits for rivers and lakes.

4 Methods

4.1 Water Quality State Analysis

Water quality state was assessed at river and lake monitoring sites in Otago using data between July 1, 2017, and June 30, 2022. The available monitoring data was used to evaluate water quality state for rivers and lakes and to grade each site into relevant attribute based on the bands designated in Appendix 2A and 2B of the National Policy Statement – Freshwater Management. Groundwater was assessed against the DWSNZ (DIA, 2022).

This section details the data used in state analysis and the grading of monitoring sites. Appendix 1 gives a full explanation of the methods LWP used for state analysis and is taken directly from Fraser *et al.* (2023a).

4.1.1 Data Collection and Grading of Attributes

4.1.1.1 River and Lakes

The data used in this assessment were generally collected by Otago Regional Council (ORC) in accordance with the National Environmental Monitoring Standards (NEMS)[10]. ORC also obtained and provided data for river sites within Otago that are monitored by the National Institute of Water and Atmosphere (NIWA) as part of the national river water quality network. Full details concerning data preparation (i.e., removal of duplicates, correcting censor inequalities) and data availability can be found in Appendix 1 (Fraser, 2023a).

The water quality state for river and lake monitoring sites is graded based on attributes and associated attribute state bands defined by the National Objectives Framework (NOF) of the NPS-FM (2020) detailed in Table 1, this report does not assess water quality compliance with Schedule 15 of the Water Plan.

Each table of Appendix 2 of the NPS-FM (2020) represents an attribute that must be used to define an objective that provides for a particular environmental value. For example, Appendix 2A, Table 6 defines the nitrate-N toxicity attribute, which is defined by nitrate-N concentrations that will ensure an acceptable level of support for 'Ecosystem health (water quality)' value. Objectives are defined by one or more numeric attribute states associated with each attribute. For example, for the nitrate-N attribute there are two numeric attribute states defined by the annual median and the 95th percentile concentrations.

For each numeric attribute, the NOF defines categorical numeric attribute states as four (or five) attribute bands, which are designated A to D (or A to E, in the case of the *E. coli* attribute). The attribute bands represent a graduated range of support for environmental values from high (A band) to low (D or E band). The ranges for numeric attribute states that define each attribute band are defined in Appendix 2 of the NPS-FM (2020). For most attributes, the D band represents a condition that is unacceptable (with the threshold between the C and the D band being referred to as the national 'bottom line'). In the case of the nitrate-N and ammoniacal N toxicity attributes in the 2020 NPS-FM, the C band is unacceptable, and for the DRP and *E. coli* (Appendix 2A; Table 9) attribute, no bottom line is specified.

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[10] The current suite of National Environmental Monitoring Standards (NEMS) documents, Best Practice Guidelines, Glossary and Quality Code Schema can be found at http://www.nems.org.nz.

The primary aim of the attribute bands designated in the NPS-FM is as a basis for objective setting as part of the NOF process. The attribute bands are intended to be simple shorthand for communities and decision makers to discuss options and aspirations for acceptable water quality and to define objectives. Attribute bands may avoid the need to discuss objectives in terms of technically complicated numeric attribute states and associated numeric ranges. Each band is associated with a narrative description of the outcomes for values that can be expected if that attribute band is chosen as the objective. However, it is also logical to use attribute bands to provide a grading of the current state of water quality; either as a starting point for objective setting or to track progress toward achieving objectives (i.e., achieving target attribute states).

Table 1 River water quality variables included in this report, including NPS-FM reference and water body type

NPS-FM Reference - NOF Attribute	Water body type	Minimum Sample Requirements	Numeric attribute state description	Units
A2A; Table 1 - Phytoplankton	Lakes		Median of phytoplankton chlorophyll-a	mg chl-a m^{-3}
			Annual maximum of phytoplankton chlorophyll-*a*	mg chl-a m^{-3}
A2A; Table 2 – Periphyton	Rivers	Minimum of 3 years of data	92nd percentile of periphyton chlorophyll-*a* for default river class	mg chl-a m^{-3}
			83rd percentile of periphyton chlorophyll-*a* for productive river class[1]	mg chl-a m^{-3}
A2A; Table 3 – Total Nitrogen	Lakes		Median concentration of total nitrogen	mg m^{-3}
A2A; Table 4 – Total Phosphorus	Lakes		Median concentration of total phosphorus	mg m^{-3}
A2A; Table 5 - Ammonia	Rivers and Lakes		Median concentration of Ammoniacal-N	mg l^{-1}
			95th %ile of Ammoniacal-N	mg l^{-1}
A2A; Table 6 - Nitrate[11]	Rivers		Median concentration of Nitrate	mg l^{-1}
			95th %ile concentration of Nitrate	mg l^{-1}
A2A.; Table 8 - Suspended fine sediment[12]	Rivers	Median of 5 years of at least monthly samples (at least 60 samples)	Median visual clarity	m
A2A; Table 9 - *Escherichia coli*	Rivers and Lakes	Minimum of 60 samples over a maximum of 5 years	% exceedances over 260 cfu 100 mL^{-1}	%
			% exceedances over 540 cfu 100 mL^{-1}	%
			Median concentration of *E. coli*	cfu 100 ml^{-1}
			95th %ile concentration of *E. coli*	cfu 100 ml^{-1}
A2B; Table 20 - DRP	Rivers		Median concentration of DRP	mg l^{-1}
			95th percentile concentration of DRP	mg l^{-1}

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[11] Nitrate Nitrite Nitrogen has been used as a proxy for Nitrate-N

[12] The SFS attribute state has four different sets of numeric thresholds to correct for natural variability in catchment geology, climate, and topography

A site can be graded for each attribute by assigning it to attribute bands (e.g., a site can be assigned to the A band for the nitrate-N toxicity attribute). A site grading is done by using the numeric attribute state (e.g., annual median nitrate-N) as a compliance statistic. The value of the compliance statistic for a site is calculated from a record of the relevant water quality variable (e.g., the median value is calculated from the observed monthly nitrate-N concentrations). The site's compliance statistic is then compared against the numeric ranges associated with each attribute band and a grade assigned for the site (e.g., an annual median nitrate-N concentration of 1.3 mg/l would be graded as 'B-band', because it lies in the range >1.0 to ≤2.4 mg/l). Note that for attributes with more than one numeric attribute state, we have provided a grade for each numeric attribute state (e.g., for the nitrate-N (toxicity) attribute, grades are defined for both the median and 95th percentile concentrations).

Further details of methods used for handling censored values, the time period for assessments, calculation of water clarity, pH adjustment of Ammoniacal-N and Evaluation of compliance statistics are given in Appendix 1 (Fraser, 2023a).

4.1.1.2 Groundwater

This report analysed the state and trend of groundwater quality from 55 SoE monitoring bores which are located across Otago's five FMUs. The bores are located on both private and public land and have varying degrees of borehead protection (ORC, 2021). However, it is important to remember that the SoE monitoring bores only provide a representative snapshot of groundwater quality in an aquifer/FMU rather than provide the total picture of groundwater quality in the aquifer/FMU. This is particularly relevant in the Dunedin and Coast and Catlins FMU, that currently only have one SoE monitoring bore each. Groundwater quality is assessed by collecting quarterly grab samples from the bores and their analysis in an accredited laboratory for microbiological (*E. coli*) and geochemical (major anions and cations, metals) parameters (ORC, 2021). In addition to that, water level and physicochemical parameters (temperature, pH, Electrical Conductivity, Dissolved Oxygen) are also measured on site during the sample collection, in accordance with the National Environmental Monitoring Standards for groundwater sampling, measurement, processing, and data archiving (NEMS, 2019). Further description of the sampling methodology is found in ORC (2021).

Drinking water quality is assessed against the DWSNZ (DIA, 2022) with a focus on *E. coli*, dissolved arsenic, and nitrate-N. These parameters were selected for assessment in this report due to their relevance for drinking water (ORC, 2021). An assessment of all the variables collected as part of the groundwater SoE monitoring programme is presented in ORC, 2021.

The DWSNZ Maximum Acceptable Value (MAV) for *E. coli* is <1 MPN (Most Probable Number)/100mL. Although any measurement above and including this value exceeds the DWSNZ MAV, a single exceedance is not always a reliable indication for contamination risk status, as groundwater quality can vary temporally. This report therefore assesses the percentage of exceedances above the MAV for each site and FMU/Rohe, following a similar approach to Environment Canterbury (ECan, 2018) and Hawkes Bay (HBRC, 2017). The percentage of *E. coli* detections was grouped using the delineation and colours shown in Table 2 and the proportion of exceedance was then reported at the FMU/Rohe (Sections 5-9) and regional (Section 10) scales. Bores delineated in green and yellow suggest low risk, with no exceedances and <5% exceedance, respectively. Bores delineated in orange are at a higher risk (5-50% exceedances) and may not be suitable for drinking water without treatment. Bores delineated in red are at the highest risk, with >50% of the samples exceeding the DWSNZ (DIA, 2022) MAV.

The DWSNZ MAV for nitrate-N is 11.3mg/L–N. Using groundwater dating techniques, the baseline nitrate-N concentration for natural groundwater (i.e., groundwater unimpacted by anthropogenic activity) in New Zealand was identified at around 0.25mg/L NO_3-N. The threshold for groundwater impacted by low intensity agriculture is between 0.25 and 2.5mg/L mg/L NO_3-N, hence groundwater with nitrate-N concentrations >2.5mg/L NO_3-N can be impacted by high intensity agriculture (Morgenstern and Daughney, 2012). The current state of nitrate-N in groundwater was based on the 5-year median for each bore, following a similar approach to other regional councils (e.g., Foster and Johnson, 2021). The median nitrate-N concentrations were grouped using the delineation and colours shown in Table 2 and are reported at the FMU/Rohe (Sections 5-9) and regional (Section 10) scale.

The DWSNZ MAV for arsenic is 0.01mg/L (equivalent to 10 µg/L), based on a lifetime excess bladder or lung cancer risk (MoH, 2018). The prevalence of arsenic in Otago groundwater was determined by computing the maximum concentration from each bore and its relation to the MAV, following a similar approach to ORC (2021). The maximum arsenic concentrations were grouped using the delineation and colours shown in Table 2 and are reported at the FMU/Rohe (Sections 5-9) and regional (Section 10) scale.

Table 2 Groundwater state classification bands for E. coli, nitrate-N and dissolved arsenic using DWSNZ (2022) MAV criteria

	Lowest risk	**Low to Moderate Risk**	**Moderate Risk**	**Highest Risk**
E. coli	No detection	<10% detection	10-50% detection	>50% detection
Nitrate-N	below MAV to <2.50 mg/L	2.50 - 5.50 mg/L Threshold to ½ MAV	5.50 - 11.3 mg/L 1/2 to MAV	>11.3 mg/L or >MAV
Dissolved Arsenic	<0.0025 mg/L to <1/4 of MAV	0.0025 - 0.005 mg/L 1/4-1/2 of MAV	0.005 - 0.01 mg/L ½ to MAV	>0.01 mg/L or >MAV

4.2 Water Quality Trend Analysis

LWP (Fraser, 2023b) assessed trends in water quality data collected at river, groundwater, and lake monitoring sites for two time-periods (10 and 20 years) for a selection of variables monitored as part of the SoE programmes. Only a subset of variables and sites had sufficient data and/or met the data requirements/rules for trends analysis (Appendix 1). Thus, the overall number of sites assessed for each variable and timeframe was significantly less than the overall number of sites that are monitored. Additionally, because monitoring records are limited for many lake and groundwater sites, 5-year trends were also assessed for these environments. This section details the data used in trend analysis and the interpretation of trend data. Appendix 1 gives a full explanation of the methods LWP used for trend analysis and is taken directly from Fraser (2023b).

The river data analysed in this report were collected from 107 river monitoring sites and analysed for the nine variables as shown in Table 1.

For lakes trends assessment, nine variables from eight lakes were assessed. Many lakes had more than one sample location and some sample locations had two or more depths associated with their water quality sampling. The different depths were treated as independent sampling sites. In total there were 27 sites (sample location x depth combinations).

The groundwater quality data used in this study were supplied by ORC for 55 SoE monitoring bores. A summary of the site numbers that were included in the final trend assessment and the variables analysed is given in

Table 3.

Table 3 River, Lake, and Groundwater. Water quality variables, measurement units and site numbers for which 10- and 20-year trends were analysed by this study.

Variable	**Number of sites that complied with filtering rules**		
	5 years	**10 years**	**20 years**
Rivers			
Ammoniacal Nitrogen	n/a	59	41
Chlorophyll a	n/a	0	0
Dissolved inorganic nitrogen	n/a	0	0
Dissolved reactive phosphorus	n/a	59	39
E. coli	n/a	59	41
Nitrate/Nitrite nitrogen	n/a	59	41
Total Nitrogen	n/a	59	41
Total Phosphorus	n/a	59	38
Turbidity	n/a	59	40
Lakes			
Ammoniacal Nitrogen	19	5	3
Chlorophyll a	23	3	2
Dissolved inorganic nitrogen	25	5	3
Dissolved reactive phosphorus	16	3	3
E. coli	30	5	3
Nitrate/Nitrite nitrogen	18	0	0
Total Nitrogen	30	5	3
Total Phosphorus	29	4	3
Turbidity	9	3	3
Groundwater			
Arsenic Dissolved	45	27	0
E. coli	45	18	3
Nitrate Nitrogen	45	27	0

4.2.1 Interpretation of Trends

The trend for each site/variable combination was assigned a categorical level of confidence that the trend was decreasing according to its evaluated confidence, direction and the categories shown in Table 4. Improvement is indicated by decreasing trends for all the water quality variables in this study. For groundwater, there is currently only one monitoring bore in the Dunedin & Coast and Catlins FMUs. The trends for dissolved arsenic concentrations in many sites were also not analysed due to a high number of samples with concentrations below the analytical limit of detection. A full description of the methods for interpreting trends is given in Appendix 1.

Table 4 Level of confidence categories used to convey the confidence that the trend (or step change) indicated improving water quality. The confidence categories are used by the Intergovernmental Panel on Climate Change (IPCC; Stocker et al., 2014).

Categorical level of confidence trend was decreasing	*Colour used in report*	*Value of C_d (%)*
Virtually certain	🟩	0.99–1.00
Extremely likely	🟩	0.95–0.99
Very likely	🟩	0.90–0.95
Likely	🟩	0.67–0.90
About as likely as not	🟨	0.33–0.67
Unlikely	🟧	0.10–0.33
Very unlikely	🟧	0.05–0.10
Extremely unlikely	🟥	0.01–0.05
Exceptionally unlikely	🟥	0.0–0.01

5 Clutha Mata-Au FMU

5.1 Upper Lakes Rohe

Figure 2 Location of water quality monitoring sites in the Upper Lakes Rohe

The Upper Lakes Rohe encompasses Lake Whakatipu, Lake Wanaka, and Lake Hawea and all the tributaries that flow into them. The headwaters of the catchment are predominantly located in rugged, steep terrain with the highest point, Mt. Aspiring, reaching 3027 m.

Catchments in the Upper Lakes Rohe include the Dart, Hunter, Matukituki and Rees Rivers, as well as many smaller tributaries to the lakes, including the Greenstone River, Bullock Creek, Motatapu, Invincible Creek and Scott Creek. The lakes' upper catchments have very high natural values, extending into Mt Aspiring National Park and many of the catchments originate along the eastern boundary of the Southern Alps and are fed by permanent glaciers. These pristine catchments feed the Southern Great Lakes with large volumes of water of exceptional quality.

A map of the Upper Lakes Rohe and water quality monitoring sites are shown in Figure 2. ORC monitors 23 river sites and three lakes in the Upper Lakes Rohe. Many of the river sites were established in 2018. There are five groundwater SoE monitoring bores in the Upper Lakes Rohe, which are found in two aquifers/Groundwater Management Zones (GWMZ): Glenorchy (4 bores) and Kingston (1 bore). Groundwater monitoring in Glenorchy started in October 2019.

5.1.1 River and Lake State Analysis Results

The results of grading the SoE sites in the Upper Lakes Rohe according to the NPS-FM NOF criteria are mapped in Figure 3 and summarised in Figure 4 (rivers) and Figure 5 (lakes). Many sites in the Upper Lakes Rohe did not meet the sample number requirements (Table 1) and accordingly are shown as white cells with coloured circles. Chl-a was only monitored at a subset of sites, white cells indicates that the variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements. In the Upper Lakes Rohe only the Dart and Matukituki meet this requirement.

Lakes are monitored at different depths, '10m' denotes sample was taken at 10m depth and 'HYP' means that the sample was taken 5m off the bed of the lake.

Figure 3 Maps showing Upper Lakes Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines.

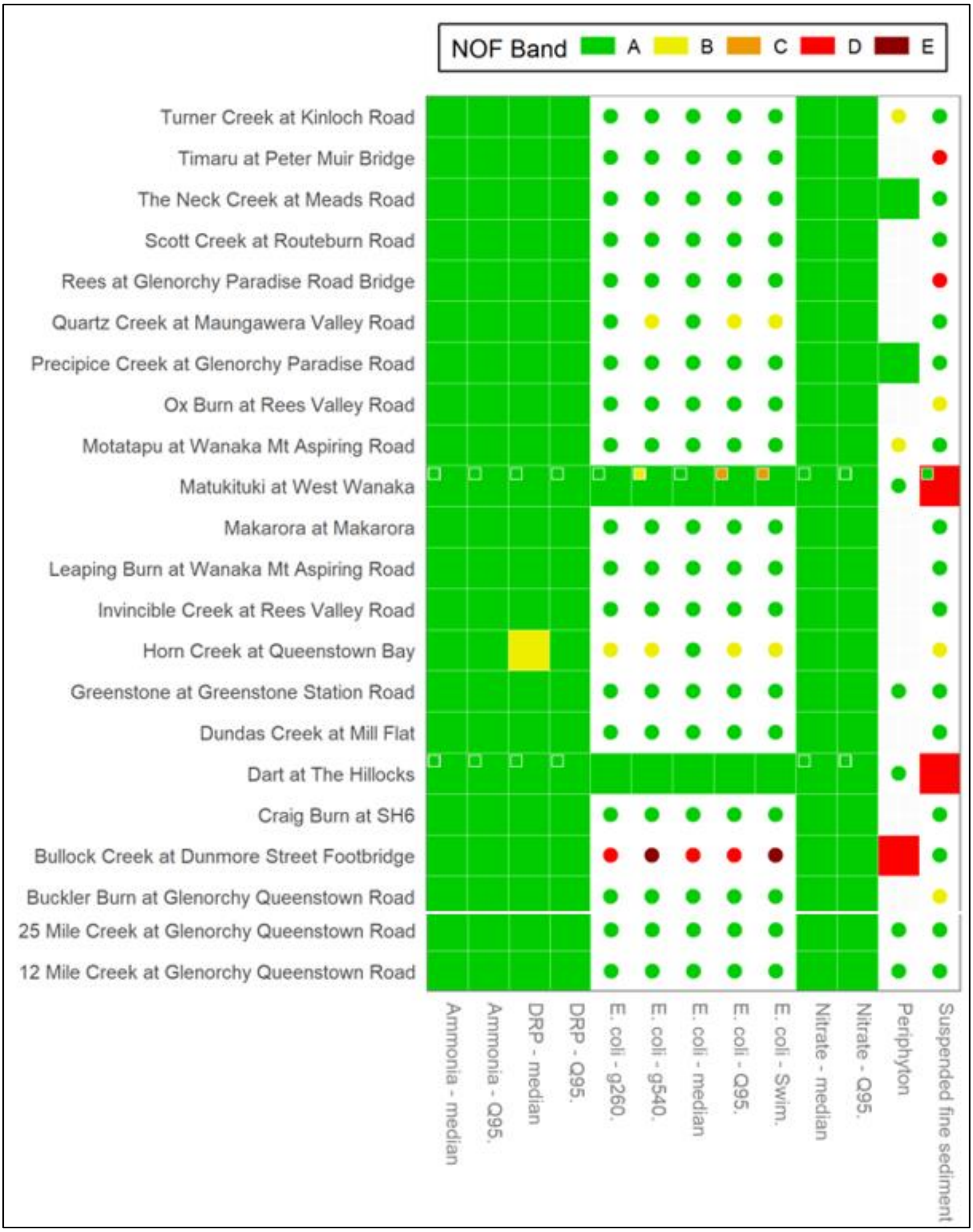

Figure 4 Grading of the river sites of the Upper Lakes Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

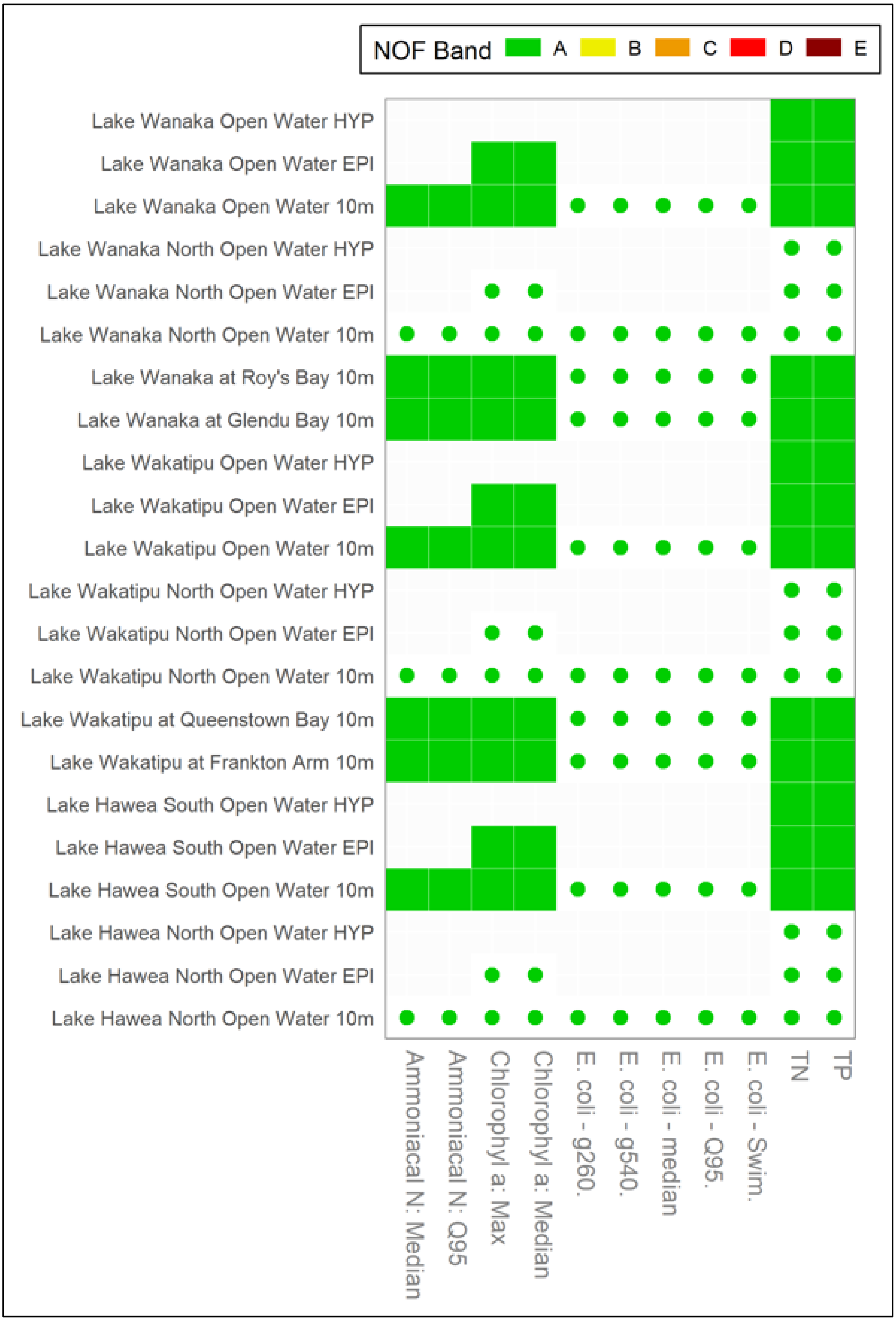

Figure 5 Grading of the lake sites of the Upper Lakes Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

5.1.2 Phytoplankton, Periphyton and Nutrients

Results for the river periphyton trophic state are shown in Figure 3 and Figure 4 (periphyton). No sites met the sample requirements, but interim results show that of the ten sites monitored for periphyton, seven sites in the Upper Lakes Rohe are in attribute band 'A' as few results exceed 50 chl-*a*/m^2 reflecting negligible nutrient enrichment. Bullock Creek, a spring fed stream that runs through Wanaka township has a result of 'D' which places it below the national bottom line, this reflects a higher nutrient enrichment, borne out by elevated NNN concentrations. Appendix 1 shows that this site has a median NNN concentration of 0.73 mg/l, which is by far the highest in the Rohe, the second highest being Horn Creek in Queenstown. Turner Creek and the Motatapu are in attribute band 'B' which reflects low nutrient enrichment and/or alteration of the natural flow regime or habitat.

The results for DRP in the Upper Lakes Rohe show that every site has achieved an attribute state of 'A', other than the median DRP concentration at Horn Creek which achieves an attribute band of 'B'.

Results for the lakes are also shown in Figure 5 . Trophic status is a common method for describing the health of lakes and an indicator of growth or productivity which is directly related to the availability of nutrients (ORC, 2017). Lakes in pristine condition typically have very low nutrient and algal biomass levels. As lakes become more enriched due to changes in land-use and land management practices, lake nutrient levels and algal productivity increases. The NPS-FM (2020) describes how phytoplankton affects lake ecological communities. If phytoplankton is in the 'A' band, then '*Lake ecological communities are healthy and resilient, similar to natural reference conditions'*. Figure 5 shows that this is the case for all the lake sites in the Upper Lakes Rohe. The results for total nitrogen and total phosphorus are also shown in Figure 5, all results are in the 'A' band reflecting low levels of total nutrients, indicating that associated ecological communities are healthy and resilient.

5.1.2.1 Toxicants

NOF attribute bands for NH4-N and nitrate-N (measured as NNN) toxicity (Figure 4) show excellent protection levels against toxicity risk for all Upper Lakes Rohe river and lake SoE monitoring sites, with all sites returning an 'A' band (highest level of protection) for NH4-N; and all sites returning an 'A' band for NNN.

5.1.2.2 Suspended fine sediment (Rivers)

The clarity results for the Upper Lakes Rohe are shown in Figure 4 and Appendix 2 gives the clarity numerical results and sediment classes for each site. All sites were either sediment Class 1 or 3. Sites that have a high degree of glacial flour present in the river are exempt from the NOF process, these include the Dart (Wakatipu), Rees (Wakatipu) and Matukituki (Wanaka) rivers which all return some high turbidity (and suspended sediment) levels despite the rivers being close to natural state. Timaru Creek (Hawea) also returned suspended sediment concentrations below the national bottom line. The rest of the Upper Lakes sites achieve attribute 'A', other than Buckler Burn (Glenorchy), Horn Creek (Queenstown) and Ox Burn (Rees Valley) which achieve attribute band 'B'.

5.1.2.3 Human health for recreation

Figure 4 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading with the national bottom line being a 'D' band. Compliance for rivers is generally excellent across in the Upper Lakes Rohe, with all sites other than Bullock Creek returning bacterial water quality above (i.e., meeting) the national bottom line
For the lakes, compliance is excellent across in the Upper Lakes Rohe, with all sites achieving attribute band 'A'.

5.1.3 River and Lake Trend Analysis Results

Trend analysis results for rivers and lakes in the Upper Lakes Rohe is shown in Figure 6.

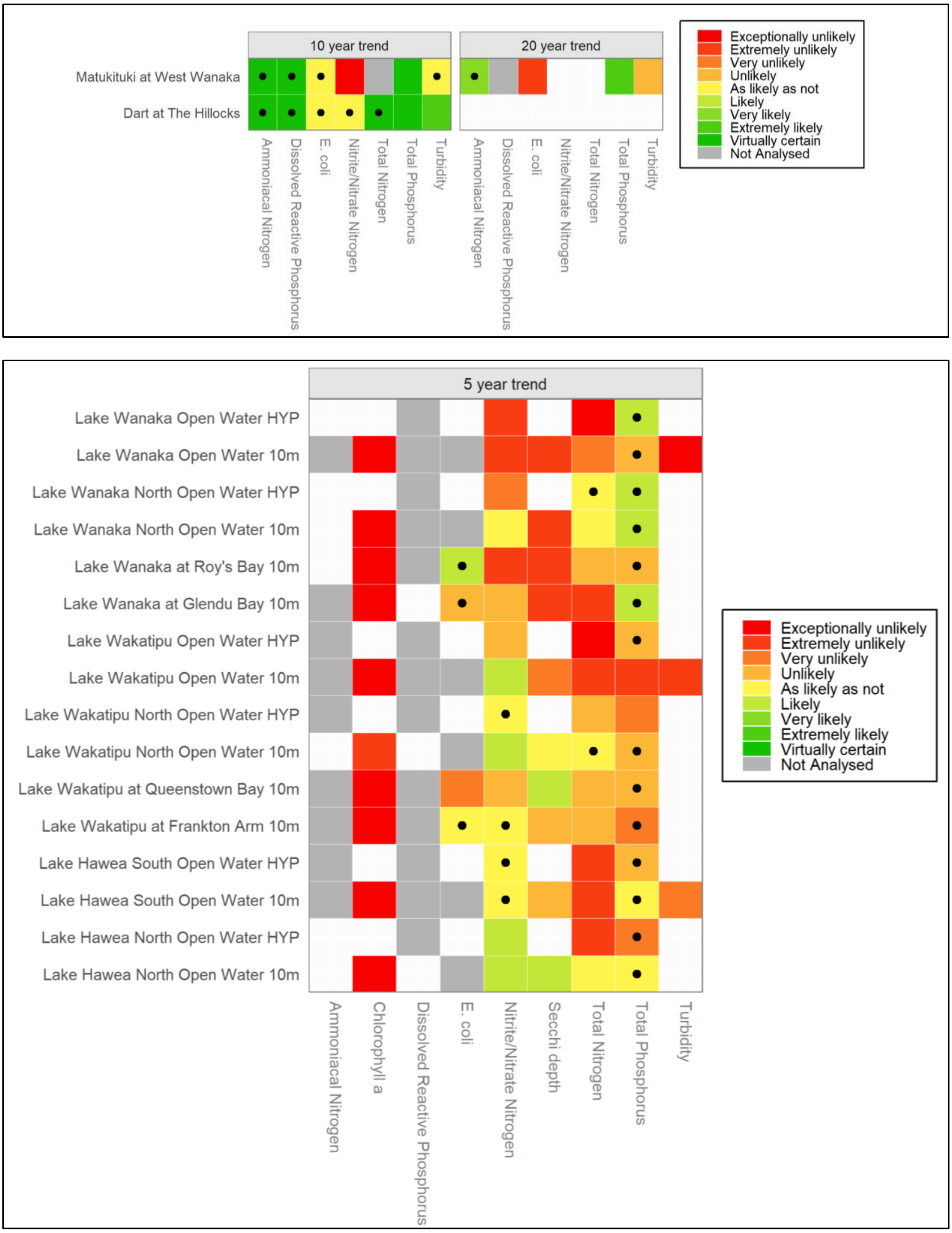

Figure 6 Summary of Upper Lakes sites (rivers top, lakes bottom) categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero

(i.e., a trend rate that cannot be quantified given the prevision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

Trend analysis results are available for two river sites, the Dart and the Matukituki (Figure 6). Over the 10-year period, at both sites, NH4-N, TN, and TP showed ‘extremely likely’ improvement. Over the same time period the Matukituki returned an ’exceptionally unlikely’ improving trend for NNN. Trend analysis over a 20-year period was only available for the Matukituki. During this time period *E. coli* returned an ’exceptionally unlikely’ improving trend

Trend analysis for the Upper Lakes Rohe lakes is shown in Figure 6. The time period is only for five years, which is a very short timeframe to establish a trend. Of the 16 sites analysed, no sites showed improving Chl-a or TN concentrations. Four sites in Lake Wanaka showed improving TP concentrations. Two sites in Lake Whakatipu and two sites in Lake Hawea showed improving NNN concentrations.

Secchi depth showed unlikely to extremely unlikely improvement at all sites in Wanaka, two sites in Whakatipu and one site in Lake Hawea, which is consistent with the Chl-a results.

5.1.4 Groundwater State Results

The current state for groundwater in the Upper Lakes is shown in Table 5. The results generally show good groundwater quality in the Upper Lakes Rohe. All bores had either no E. coli exceedances or <10% exceedances. Median nitrate-N concentrations are also low, with all the results below the 2.50mg/L threshold for land not affected by intensive agriculture (Morgenstern and Daughney, 2012). In contrast to these, groundwater arsenic concentrations in the Rohe are very high, with the maximum concentrations in four out of five bores exceeding the MAV. Furthermore, the spatial variability of groundwater arsenic concentrations can also be high, even within close proximity (e.g., different monitoring bores in Glenorchy).

Table 5 Groundwater current state results for the Upper Lakes Rohe. The key for the colour classification is shown at the bottom of the table

Site	**Aquifer/location**	**No. of samples**	***E. coli* % exceed-ance**	**Median Nitrate concentration (mg/L)**	**Max. arsenic concentration (mg/L)**
E41/0182	Glenorchy GWMZ	12	0	0.0005	0.91
E41/0183	Glenorchy GWMZ	12	0	0.26	0.0035
E41/0184	Glenorchy GWMZ	12	8	0.0005	0.2
E41/0185	Glenorchy GWMZ	13	8	2.25	0.0171
F42/0113	Kingston GWMZ	20	0	0.00047	0.0116

E. coli	No detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

5.1.5 Groundwater Trends

Bore F42/0113, located in the Kingston GWMZ, is the only one with sufficient data for calculating a trend. The trends shown in Figure 7 suggest a virtually certain improvement in arsenic for the 10-year period and likely improvement in the 5-year period. The trend for nitrate-N was not analysed.

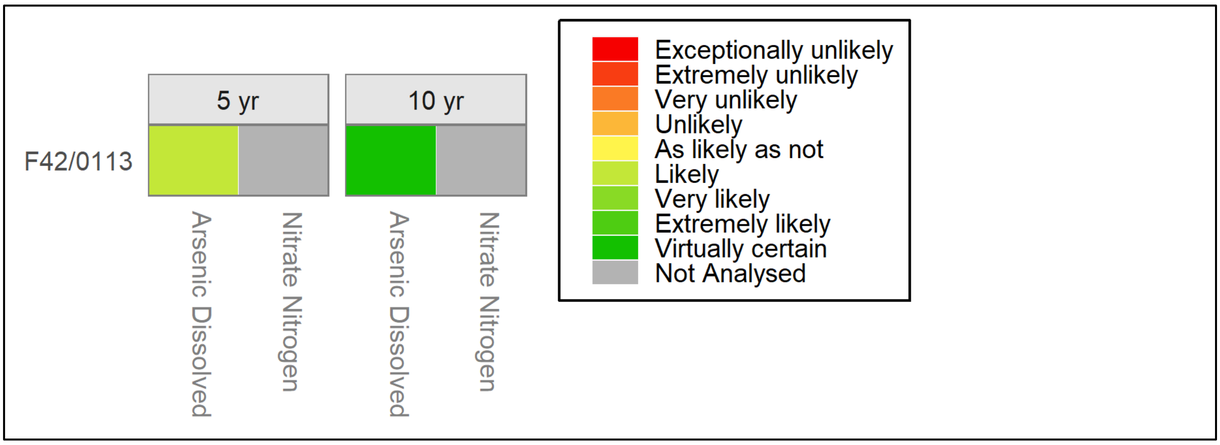

Figure 7 Summary of the Upper Lakes groundwater monitoring sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement.

5.1.6 Water quality summary and discussion: Upper lakes Rohe

Land use in the Upper Lakes Rohe is currently dominated by Conservation estate (45%) and dry-stock farming (36%), comprising of predominantly sheep and beef (24%); and mixed sheep, beef, and deer (12%). Lakes and rivers cover 11% of the Rohe. Urban land use occurs on less than 1% of the Rohe. The notable trends in land use change over the past three decades have been an increase in the extent of urban area by 53%, despite only occurring on less than 1% of the area. Conservation estate increased by 74%, largely driven by high country tenure review and offset by the decrease in sheep and beef dry-stock farming by 26%, and ungrazed pastures (~50%).

Many of the rivers are fed by glaciers and extremely high rainfall in the mountains. Water quality in the stream reaches located in high or mountainous elevations under predominantly native cover can be considered natural state.

All sites return an ‘A’ band for the toxicity attribute states of ammonia and nitrate-N, all sites other than rivers fed by glaciers (Matukituki, Rees and Dart) have high clarity (low concentrations of suspended fine sediment), with Timaru Creek being the only exception. Across the Rohe there was very good compliance with the *E. coli* attribute, only Bullock Creek fell below the ‘C’ band. The clear, spring-fed Creek runs through the heart of Wanaka; hence, it is likely that a combination of stormwater discharges and resident wildfowl are the reason behind the poor grade. Bullock Creek also fell below the national bottom line for periphyton, likely due to it being spring fed, with a stable flow, very low turbidity and high NNN concentrations[13], conditions which are ideal for periphyton growth.

For trends, only the Dart and Matukituki have been monitored for a sufficiently long time period for trend analysis to be undertaken. NNN has shown an increase over the last 10 years in the Matukituki, the monitoring site is in the lower catchment just above the lake confluence. The reason for this trend may be due to localised, more intensive farming on the surrounding river flats.

Trend analysis in the lakes has only been done over 5-years, hence, some caution should be applied with the interpretation of trends over such short time periods. It has been demonstrated that the shorter the time period over which a river water quality trend is assessed, the greater the level of influence of climatic variation (Snelder, 2021). Although Chl-a is in the ‘A’ band, where ‘ecological communities are healthy and resilient, similar to natural reference conditions’, the 5-year trend is that

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[13] See accompanying report ‘ORCRiverState_072017to062022’ and Appendix 1

there are no improving trends for Chl-a at any of the sites, which in essence describes some movement towards the ‘B’ band in Chl-a concentrations. The lake monitoring programme now incorporates monthly monitoring profiles and Lake Wanaka has a monitoring buoy that continuously measures the Chl-a profile, which will allow ORC to closely monitor this situation.

Groundwater quality in the Upper Lakes Rohe is good with low E. coli exceedances and nitrate-N concentrations. However, arsenic concentrations in some monitoring bores (located in the Glenorchy and Kingston GWMZ) are high, with some exceeding the MAV. These high arsenic concentrations are likely geological and are likely sourced from the abundant schist in the Rohe (ORC, 2021). The 10-year trend analysis for groundwater dissolved arsenic in bore F42/0113 showed ‘virtually certain’ improvement while the 5-year trend was ‘likely’ improvement, hence, a slight degradation. However, as arsenic concentrations are strongly influenced by geology, geochemistry, and water levels, which are not directly managed, these trends may not be very meaningful. Furthermore, arsenic trend analysis for some sites may be skewed due to the high number of results below the analytical limit of detection. This issue is likely to affect many FMU/Rohe.

In addition to the abundant schist, the high arsenic concentrations are also likely exacerbated by increased arsenic mobility, caused by reducing geochemical conditions due to low dissolved oxygen in groundwater. This is caused by inputs of organic carbon and bacteria from wastewater systems (septic tanks), which consume oxygen (E3, 2018). Therefore, although the main arsenic source in the Rohe is geological, which is impractical to remove, dissolved arsenic in groundwater may be potentially improved, in addition to other major environmental benefits, by upgrading septic tanks, improving their operations and standards, and ideally switching rapidly expanding areas such as Glenorchy and Kingston to reticulated wastewater systems. Nevertheless, although these reported results are from bores solely used for monitoring, and due to the high abundance of schist and the reported spatial variability of arsenic in groundwater in the Upper Lakes Rohe, it is strongly advised that bore owners in the Rohe regularly test their groundwater for arsenic. This may require specifically requesting this analysis as some laboratories may not include it in their routine monitoring suites.

In summary, the majority of river and lake sites across the Upper Lakes Rohe have excellent water quality, which is the best in Otago. This is expected considering much of the Rohe is in a National Park dominated by tussock grasslands and indigenous forests along with extremely high precipitation rates in the Southern Alps. Groundwater quality is generally good, with low *E. coli* and nitrate-N concentrations. However, there are also elevated arsenic concentrations in many sites, likely to be sourced from the local geology and exacerbated by high density of septic tanks in unreticulated settlements (Kingston and Glenorchy). It is therefore strongly recommended that bore owners regularly test their bores and maintain good bore security.

5.2 Dunstan Rohe

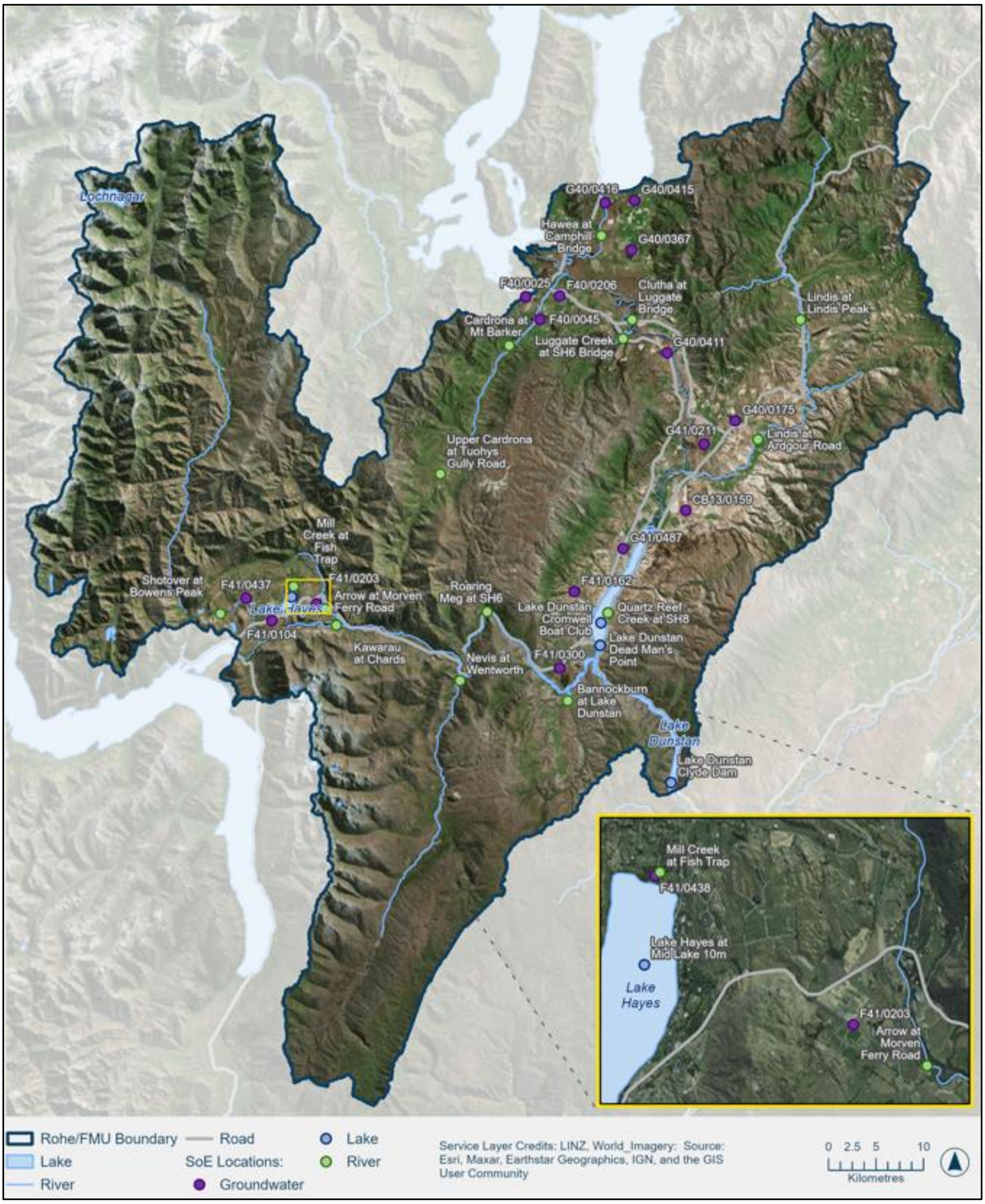


Figure 8 Location of water quality monitoring sites in the Dunstan Rohe

5.2.1 Dunstan Rohe Description

The Dunstan Rohe is essentially the mid-section of the Clutha FMU. The Dunstan Rohe runs from the outlets of lakes Wānaka, Whakatipu and Hāwea down to the Clyde Dam. The major tributaries of the Clutha Mata-Au located in the Dunstan Rohe include the Kawarau, Nevis, Shotover, Hāwea, Cardrona, Arrow, and Lindis Rivers. Many smaller tributaries of the Clutha/Mata-au such as the Lowburn, Amisfield Burn, Bannock Burn and Luggate Creek are also included in the Rohe. Outflows of Lakes Wānaka and Whakatipu are unregulated whereas the outflow of Lake Hāwea is controlled by the Hāwea Dam. This Rohe also includes Lake Dunstan, a run of river hydro-electricity reservoir created by the Clyde Dam. Diverse landforms include the rugged Kawarau gorge, tracts of native bush in the remote Shotover catchment to extensive agriculture, fruit-growing, and viticulture areas. This Rohe also includes the urban centres of Queenstown and Wanaka and has high growth in urbanisation and land use intensification.

ORC monitors 14 river sites, three lakes and 17 groundwater sites in the Dunstan Rohe. The groundwater bores are located within several groundwater basins/GWMZ/aquifers – Wanaka/Cardrona basin, Hawea Basin, Whakatipu Basin, Cromwell Terrace aquifer, Lowburn Alluvial aquifer, Pisa/Luggate/Queensberry GWMZ, and the lower Tarras aquifer. The monitored sites are shown in Figure 8.

5.2.2 River and Lake: State Analysis

The results of grading the SoE river sites in the Dunstan Rohe according to the NPS-FM NOF criteria are mapped in Figure 9 and summarised in Figure 10. Many sites in the Dunstan Rohe did not meet the sample number requirements as they were introduced to the monitoring programme in July 2018 and accordingly are shown as white cells with coloured circles. Chl-a was only monitored at a subset of sites, white cells indicates that this variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

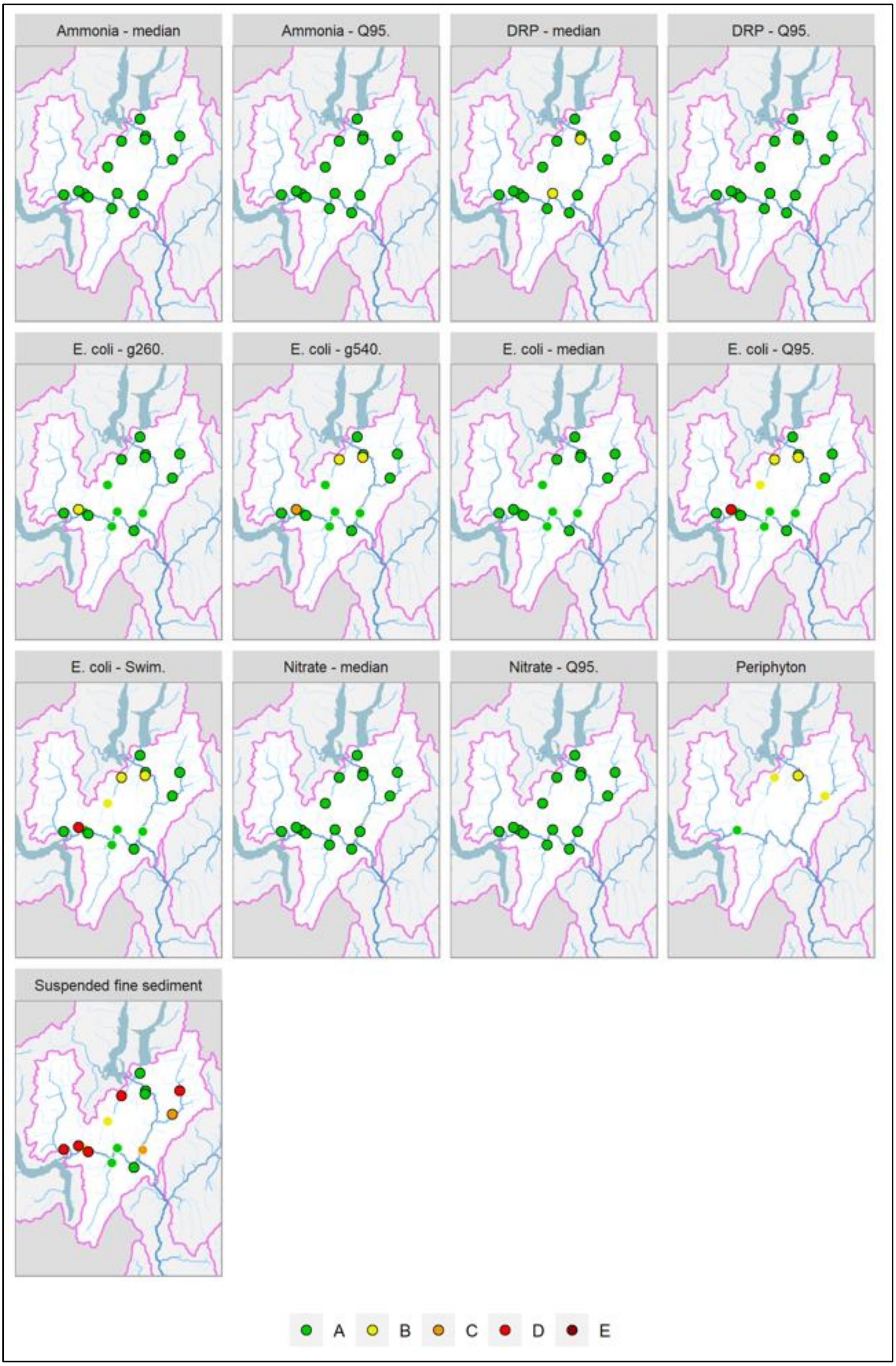


Figure 9 Maps showing Dunstan Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.

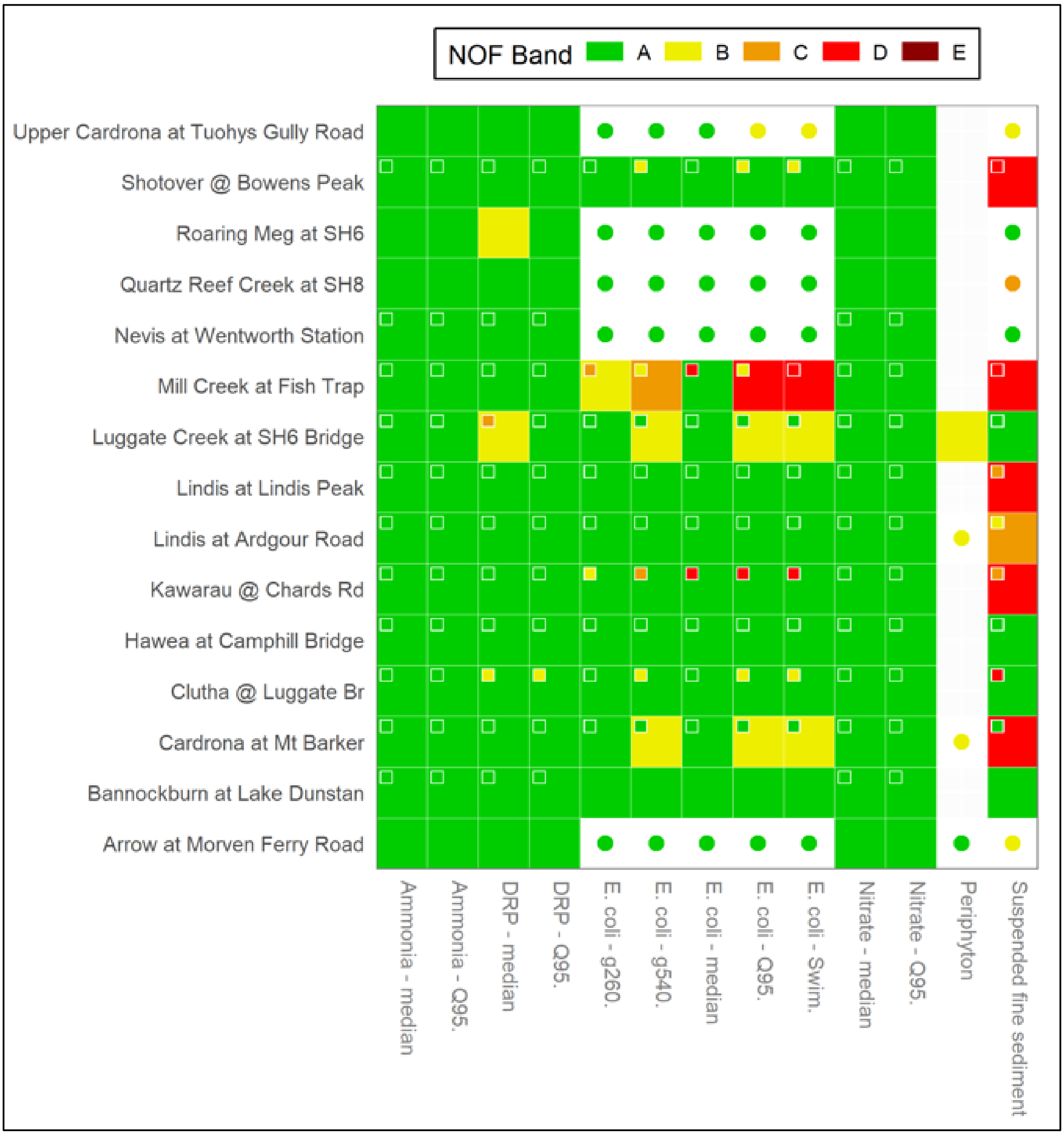


Figure 10 Grading of the river sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline.

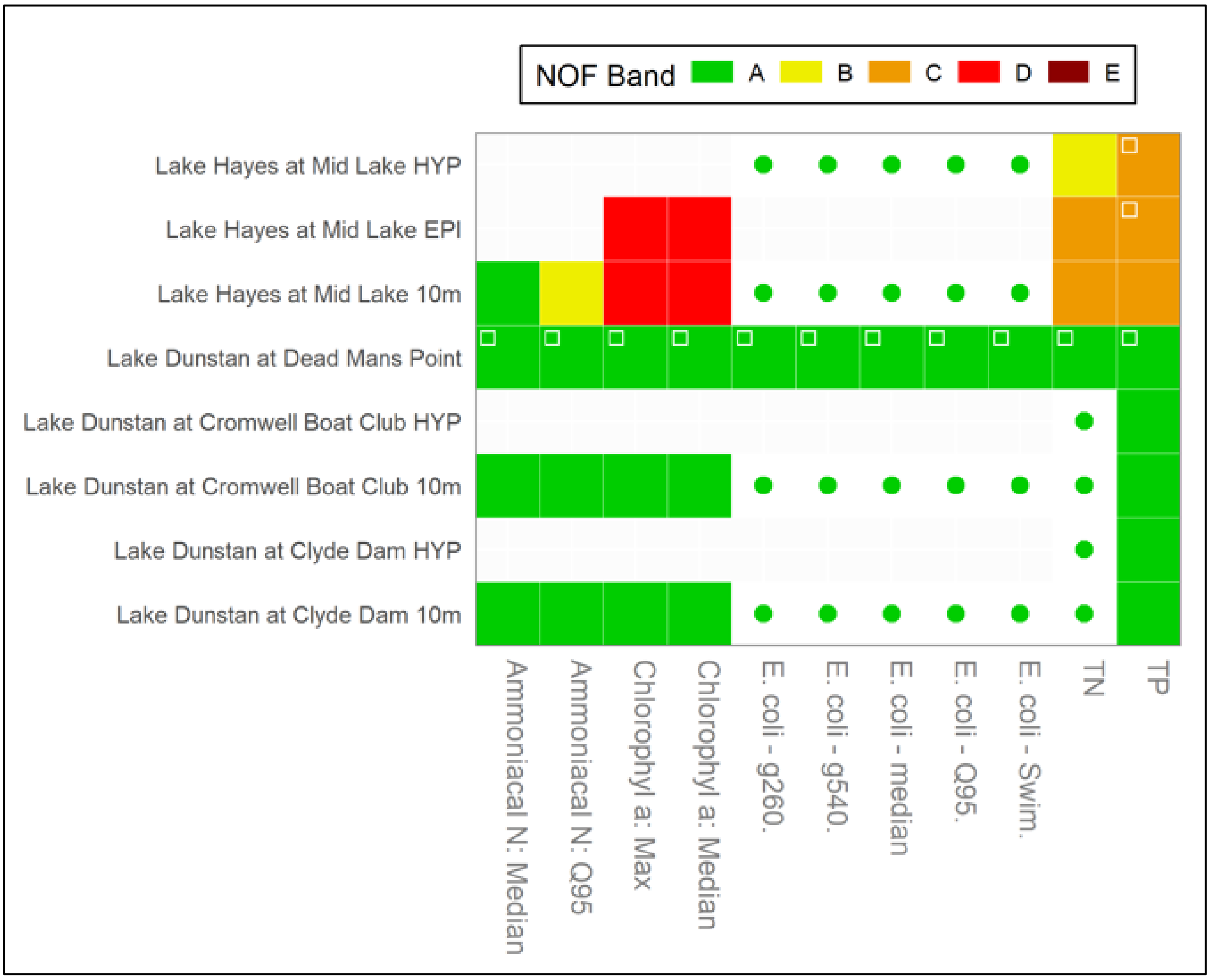


Figure 11 Grading of the lake sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

5.2.2.1 *Phytoplankton, Periphyton and Nutrients*

Four sites in the Dunstan Rohe were monitored for periphyton (Figure 9 and Figure 10), the Arrow River is provisionally assigned to the NOF attribute 'A' band as less than 8% of sampling results collected to date exceed 50 chl-*a*/m^2 indicating that blooms are rare and nutrient enrichment is negligible. The Lindis at Ardgour Rd, Cardrona at Mt Barker and Luggate Creek meet the 'B' band, this reflects low nutrient enrichment and the possibility of occasional algal blooms.

Figure 9 and Figure 10, also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Dunstan Rohe show that every site achieves band 'A', other than Luggate Creek and Roaring Meg which achieve a 'B' band. The NPS-FM (2020) describes the 'B' band as '*Ecological communities are slightly impacted by minor DRP elevation above natural reference conditions. If other conditions also favour eutrophication, sensitive ecosystems may experience additional algal and plant growth, loss of sensitive macroinvertebrate taxa, and higher respiration and decay rates'.*

Appendix 1 gives DRP and NNN results, as both are required for periphyton growth. Mill Creek has the highest median NNN concentration (0.35 mg/l) and the third highest DRP concentration. Luggate

Creek, although having the highest DRP concentration, has a low NNN concentration (0.0018 mg/l) compared to other sites in the Rohe.

Results for the lakes are given in Figure 11. Chlorophyll a concentration is in the 'A' band shows that '*Lake ecological communities are healthy and resilient, similar to natural reference conditions'*, this is the case for all Lake Dunstan sites; however, Lake Hayes (10m) is assigned to 'D' band and below (i.e., not meeting) the national bottom line. The results for total nitrogen and total phosphorus are also shown in Figure 11, Lake Dunstan achieves 'A' bands for both, indicating low levels of total nutrients and that ecological communities are healthy and resilient. Lake Hayes monitoring sites had higher concentrations of TN and TP and were generally assigned to the 'C' band. The NPS-FM (2020) describes the 'C' band for both TN and TP as *'Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions'*.

5.2.2.2 Toxicants

NOF attribute bands for NH_4-N and nitrate-N (measured as NNN) toxicity are shown in Figure 9 , Figure 10 and Figure 11 show the results for rivers have excellent protection levels against toxicity risk for all Dunstan Rohe SoE monitoring sites returning an 'A' band for NH4-N and NNN. For lakes all Lake Dunstan and Lake Hayes sites returned an 'A' band other than Lake Hayes (mid lake 10m) that returned a 'B' band for NH4-N (Figure 11).

5.2.2.3 Suspended fine sediment (Rivers)

The clarity results for the Dunstan Rohe are shown in Figure 9 and Figure 10 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3. Of the 15 sites, six sites achieve then 'A' band which the NPS-FM describes as having '*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions'* (NPS-FM, 2020). Two sites achieve the 'B' band, two sites achieve the 'C' band, and five sites return a 'D' band: the Shotover at Bowens Peak, Mill Creek, Lindis at Lindis Peak, Kawarau at Chards Road and the Cardrona River and were below the national bottom line.

5.2.2.4 Human health for recreation (Rivers and lakes)

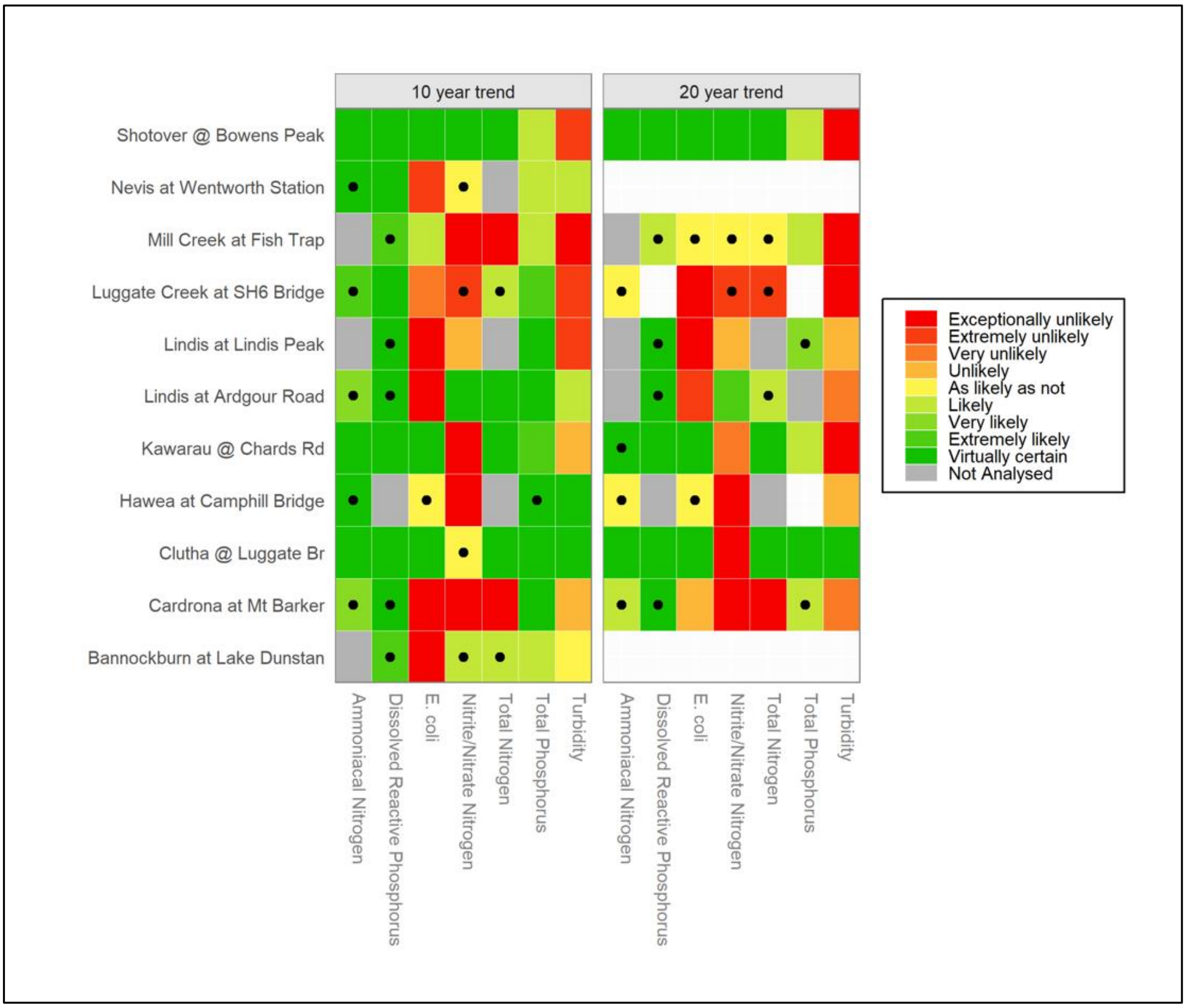
Figure 10 summarise river compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Compliance is generally excellent across in the Dunstan Rohe, with all sites other than Mill Creek having bacterial water quality above (better than) attribute band 'C'.

Figure 10 show that many of the sites have fewer than the required 60 samples over a maximum of five years, so the grades are interim. For example, the Upper Cardrona returns 'A' grades for all statistical tests bar the 95th percentile, however as it only has 44 samples over 3 years it is unknown if the 95th percentile would remain at the 'B' band over required the time period. Roaring Meg, Quartz Creek, the Nevis and the Arrow also do not meet minimum sample requirements, but return 'A' grades across the four statistics.

Figure 10 summarise compliance for *E. coli* for lakes against the four statistical tests of the NOF *E. coli* attribute. All lakes in the Dunstan Rohe achieve an 'A' band denoting the lowest risk to health.

5.2.3 River and Lake Trend Analysis

Trend analysis results for the Dunstan Rohe is shown in Figure 12.



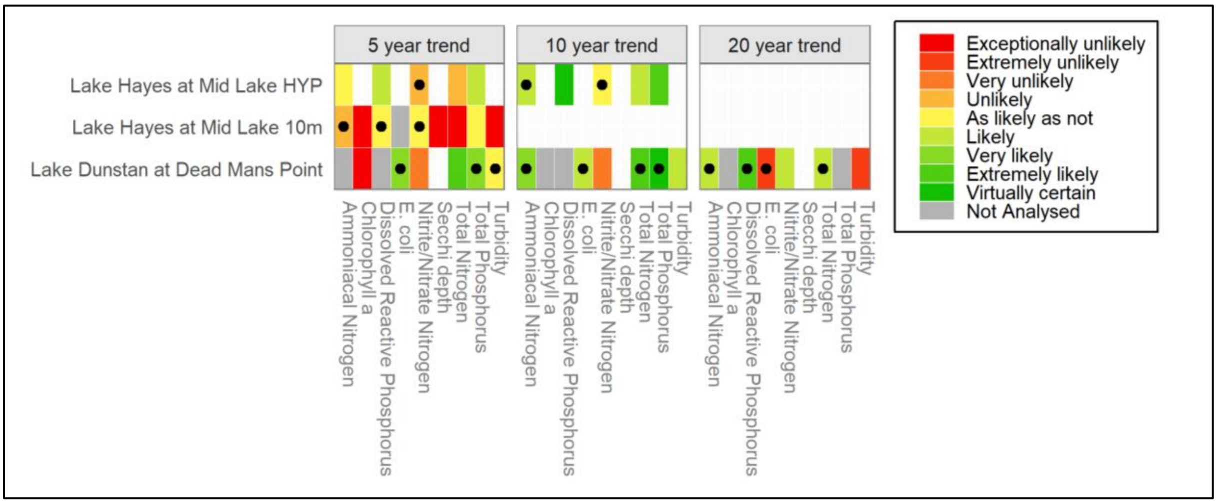


Figure 12 Summary of Dunstan Rohe trends categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend.

Trend analysis for both rivers and lakes show that many of the trends analysed were influenced by censored values, where true values are too low to be measured with precision, shown by the black dot in the square. Over a 10-year time period four sites; the Cardrona, Mill Creek, Luggate Creek and the Lindis at Lindis Peak have three variables each showing trends that are ‘very unlikely’ to ‘exceptionally unlikely’ to be improving. Over the same time period, there were eight sites with at least three variables each showing trends are ‘very likely’ to ‘virtually certain’ to be improving. The Hawea River shows an ’exceptionally unlikely’ improving trend for NNN over both the 10- and 20-year time periods. Over a 20-year time period, the Cardrona and Luggate show ‘exceptionally unlikely’ or ‘extremely unlikely’ improving trends for TN and NNN.

Trends for the lake data were assessed across three time periods, 5- 10- and 20-years. Only Lake Dunstan at Dead Man’s Point has been monitored for over 20-years. Some caution should be applied with the interpretation of trends over 5-years, however, during this period the trend in Chl-a was ‘exceptionally unlikely’ to be improving in both Lake Dunstan and Lake Haye., Lake Hayes also had ‘exceptionally unlikely’ improving trends for TN. Lake Dunstan had ‘very likely’ to ‘extremely likely’ improving trends for *E. coli*, TN, and TP, and Lake Hayes hypolimnion results showed ‘likely’ improving trends for TP and DRP, over this 5-year period. Over the 10-year period there were no ‘exceptionally unlikely’ trends for any site or any attribute, however at Lake Dunstan over a 20-year period *E. coli* and Turbidity had ‘extremely unlikely’ improving trends.

5.2.4 Groundwater State

The current state of groundwater in the Dunstan Rohe is shown in Table 6. The *E. coli* results generally show good compliance with the DWSNZ MAV, where 65% of the sites (11 bores) had no exceedances and four of the sites (24%) had <10% exceedances. Higher exceedance proportion was measured in two bores, F40/0045 and F41/0438. It is important to note that bore F41/0438 is solely used for monitoring and has been sampled more frequently as part of the Lake Hayes project. The bore is shallow, near a public toilet block, and often frequented by rabbits, which likely contribute to the E. coli exceedances.

Median nitrate-N concentrations also generally suggested good groundwater quality. None of the sites exceeded the DWSNZ MAV of 11.3.g/L and median nitrate-N concentrations in 14 out of 17 of the sites were below the 2.50mg/L threshold for low intensity land use. Three of the sites are between the above threshold and ½ of the MAV of 11.3mg/L, with the highest median concentrations measured in bore G40/0411 (Luggate). These are potentially due to cultivation of a paddock near the bore or to septic tanks (ORC, 2021)

Maximum arsenic concentrations in most monitoring bores in the Dunstan Rohe are substantially below the NZDWS MAV of 0.01mg/L, with concentrations ranging from below detection limit to 0.002mg/L. The only exception is bore F41/0104, located in Howard Drive, Queenstown. This is a deep bore (60m) and the arsenic concentrations in it have been persistently above the MAV.

Table 6 Groundwater state results for the Dunstan Rohe. The key for the colour classification is shown at the bottom of the table current state

Site	Aquifer/ location	Total no. of samples	*E. coli* % exceedance	Median Nitrate concentration (mg/L)	Max. arsenic concentration (mg/L)
CB13/0159	Bendigo	6	0	0.275	0.001
F40/0025	Wanaka	19	5	0.520	0.001
F40/0045	Wanaka	18	17	2.900	0.000
F40/0206	Wanaka	19	0	0.790	0.001
F41/0104	Whakatipu Basin	11	0	0.004	0.018
F41/0162	Low Burn	19	0	0.345	0.000
F41/0203	Whakatipu Basin	20	0	2.050	0.001
F41/0300	Cromwell	19	0	1.140	0.002
F41/0437	Whakatipu Basin	17	0	2.500	0.000
F41/0438	Whakatipu Basin	42	45	0.109	0.001
G40/0175	Tarras	18	6	0.910	0.000
G40/0367	Hawea	22	0	1.595	0.001
G40/0411	Luggate	20	5	5.250	0.002
G40/0415	Hawea	18	0	0.056	0.001
G40/0416	Hawea	18	0	0.435	0.002
G41/0211	Tarras	15	7	1.145	0.002
G41/0487	Pisa	7	0	0.310	0.001

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005	0.005 - 0.01	>0.01 mg/L

5.2.5 Groundwater Trends

Trends for groundwater nitrate-N concentrations were calculated for 14 sites in the Dunstan Rohe (missing sites are CB13/0159, G41/0487, and F41/0104). These are summarised in Figure 13 and are shown spatially for the 5- and 10-year trend analysis in Figure 14. The results show a mixed pattern for nitrate-N across the Rohe. The 5-year trend shows a ‘likely’ or ‘extremely likely’ improvement trend for five of the sites. Conversely, five other sites had ‘very unlikely’ to ‘exceptionally unlikely’ improving trends. The trend for the remaining four sites was ‘as likely as not improving’. A 10-year trend was only available for eight sites. These results are more sobering, with only two sites having improving trends, categorised as ‘very/extremely likely improving’. Four sites had ‘extremely/exceptionally unlikely improvement’ trends and two were ‘as likely as not’ improving. Only two sites had improving trends, categorised as ‘very/extremely likely improving’. There were no changes between the 10 and 5-year trends for most sites apart from two sites, with one improving (F41/0203) and one not improving (F40/0045).

The 5-years trend for groundwater dissolved arsenic concentrations was only available for four sites, due to the high number of results below detection limits. Results show 'unlikely' or 'very unlikely' improving trends in three of the sites. Conversely, the trend in the remaining site (G40/0411) was 'likely improving'. The 10-year trend analysis was only obtained for one site, which was calculated as 'as likely as not improving'.

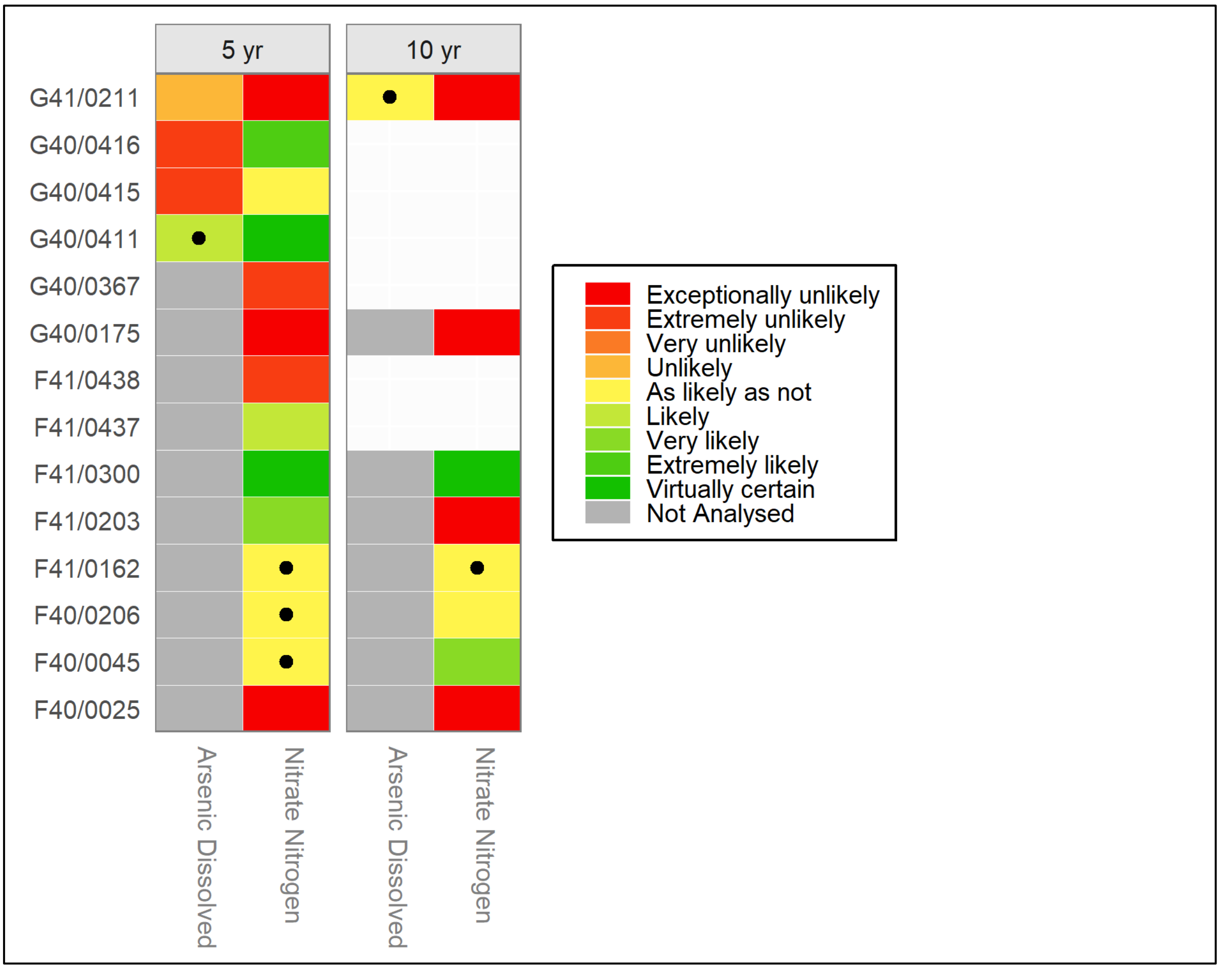


Figure 13 Summary of groundwater quality trends for the Dunstan Rohe

The mapping of groundwater nitrate-N trends shows a mixed picture, with no clear patterns across the Rohe (Figure 14). This shows that some sites are either 'extremely/virtually likely' improving or 'not improving'. This is observed in the Hawea and Whakatipu basins and around Tarras. The trends for the sites in Wanaka either are 'extremely unlikely improving' or as 'likely as not improving'. This is generally similar for the 10-year trend, although one of the sites in Wanaka changed from as 'likely as not to very likely improving'. The spatial trend for dissolved arsenic shows that most sites are unlikely/extremely unlikely improving, around Hawea and Tarras, whilst the Luggate bore is likely improving.

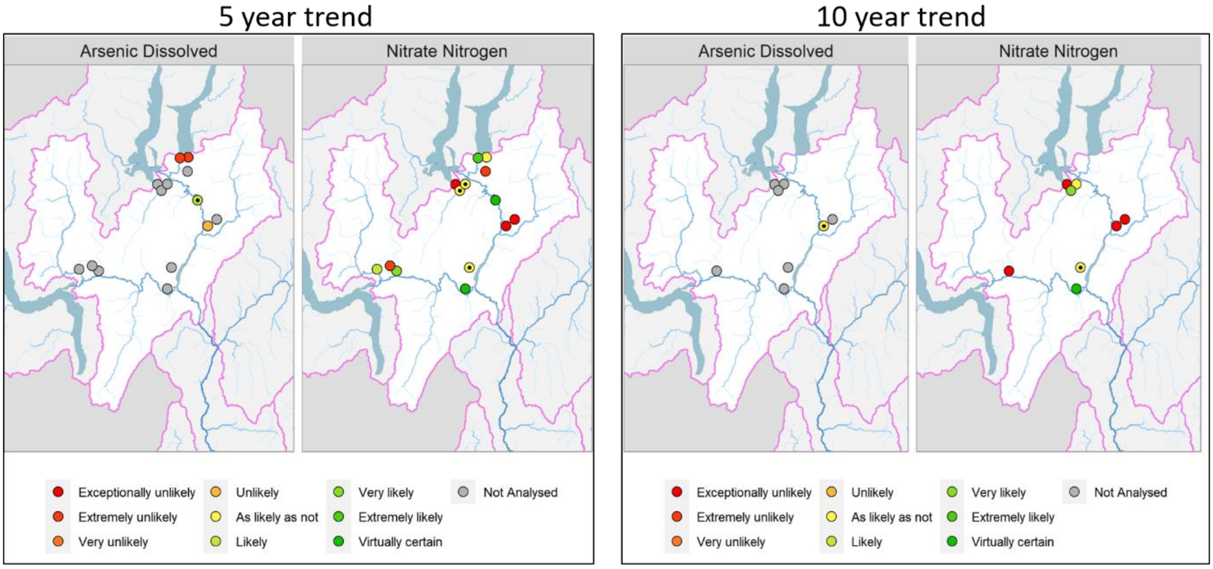


Figure 14 Groundwater quality 5-year and 10-year trend results for the Dunstan Rohe (LWP, 2023)

5.2.6 Water quality summary and discussion: Dunstan Rohe

Land use in the Dunstan Rohe is currently dominated by dry-stock farming (65%), comprising of sheep and beef (45%); mixed sheep, beef, and deer (15%); and sheep farming (5%). Conservation estate occurs on approximately 23% of the Rohe. Dairy, nurseries/vineyards/orchards occur on 1% of the area. The notable trends in land use change over the past three decades have been an increase in the extent of conservation estate (by 293%), nurseries, vineyards, and orchards (by 33%). The extent of dry-stock farming decreased by 25%, although it remains the dominant land use activity in the Dunstan area.

The Dunstan Rohe generally has very good compliance with NPS-FM NOF attribute states, largely because of the large area of high country and the relatively small (although growing) area occupied by intensive farming and urban development. Figure 10 shows that the majority of sites meet the 'A band for all attributes other than suspended fine sediment. All sites, other than Mill Creek return an 'A' band for the toxicity attribute state of ammonia. All sites return an 'A' band for the toxicity attribute state of nitrate-N.

Bacterial water quality is excellent across most sites, Mill Creek is the only exception as *E. coli* Q95 does not meet the national bottom line. Suspended fine sediment falls below the national bottom line at five of the 15 sites, this includes the Shotover and Kawarau Rivers where suspended fine sediment is determined by glacial meltwater, which is a naturally occurring process and therefore this attribute at these sites are exempt from the NPS-FM NOF process.

Of the two lakes monitored, Lake Dunstan meets the 'A' band for every attribute measured, this reflects the very good water quality in the Clutha River. The upstream site, Clutha at Luggate also achieves the 'A' band across all parameters. Lake Hayes lies in a shallow depression formed by glaciation, over the years it has become a eutrophic lake, water clarity can be low due to frequent algae blooms. Monitoring shows that Chl-a in Lake Hayes falls below the national bottom line and TN, and TP are in the 'C' band – this all reflects the eutrophic status of the lake.

Mill Creek has 'likely' to 'extremely likely' improving trends in DRP, *E. coli*, and TP. This is good news for a catchment with increasing development pressure, however the turbidity over both the 10-and 20-year time periods show an 'exceptionally unlikely' improving trend. The catchment has a very strong community group who are key in driving improvements in the catchment. The monitoring buoy in the lake, as well as comprehensive ongoing monitoring of water quality in Mill Creek (continuous turbidity, nitrate-N, flow) is enabling a better understanding of what drives water quality in Lake Hayes.

Groundwater quality state results also generally show good compliance with the DWSNZ across the Dunstan Rohe, with most bores having no or low exceedances of the E. coli MAV. The median nitrate-N concentrations in most sites were also below the threshold for intensive land use, with all median concentrations lower than ½ of the DWS MAV. With the exception of one site, dissolved arsenic concentrations are also substantially below the MAV.

The trends in groundwater quality for nitrate-N do not show a clear pattern across the Rohe. The results show that around 1/3 of the sites are ‘likely’ or ‘extremely likely’ improving, another 1/3 are ‘very likely’ not improving, while the remaining are ‘as likely as not’ improving. There is also no clear spatial variability in the trends, as some areas (e.g., Hawea, Whakatipu Basin) have opposite trends observed in sites located in close proximity. This is likely due to local factors such as geology and land use (farming, septic tanks) impacting some of the results.

Although most sites show compliance with the DWSNZ, it is important that bore owners ensure good bore security and good land management practices to prevent contaminant ingressing and nitrate-N leaching into bores. However, considering the pressures in parts of this Rohe from irrigation expansion and urban development it will be challenging to maintain good groundwater quality. Due to the prevalence of schist in the Dunstan Rohe it is also strongly recommended that bore owners regularly test their water for arsenic and exercise bore security.

5.3 Manuherekia Rohe

Figure 15 Location of water quality monitoring sites in the Manuherekia Rohe

5.3.1 Manuherekia Rohe Description

The Manuherekia catchment (3035 km^2) is located north-east of Alexandra, Central Otago, and is the largest sub-catchment of the Clutha/Mata-au catchment. The Manuherekia catchment has highly modified hydrology and high-water use.

The Manuherekia catchment can be divided into two major sub-catchments. The eastern Ida Valley drains the eastern and south-eastern Otago uplands (Rough Ridge) and the western Manuherekia Valley. The river's headwaters are in the Hawkdun Range, and the catchment is surrounded by mountainous terrain, except to the south-west, where it joins the Clutha River/Mata-Au at Alexandra (Kiensle, 2008).

Low rainfall in the valley bottoms led to the early development of extensive water storage and irrigation schemes. For instance, Falls Dam has a capacity of 11 million m^3. Poolburn Reservoir has a capacity of 26 million m^3 and the Manorburn Reservoir has a capacity of 51 million m^3 (Kiensle, 2008).

Flow of the Manuherekia River is partly controlled by releases from Falls Dam. Several irrigation schemes (Blackstone Hill, Omakau, Manuherekia, and Galloway) take water out of the Manuherekia River and distribute the water through a network of open water channels to irrigate the Manuherekia Valley. The Poolburn Reservoir is used to store water to irrigate the Ida Valley and water from the Manorburn Reservoir is either taken by the upper Galloway Irrigation Scheme or used for irrigation in the Ida Valley (Kiensle, 2008).

ORC monitors eight river sites and four groundwater sites in the Manuherekia Rohe. The groundwater SoE bores are located in the Manuherekia GWMZ, Manuherekia alluvial aquifer, and the Manuherekia Claybound aquifer. Monitored sites are shown in Figure 15.

5.3.2 River: State Analysis

The results of grading the SoE sites in the Manuherekia Rohe according to the NPS-FM NOF criteria are mapped in Figure 16 Maps showing Manuherekia Rohe sites coloured according to their *state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.*

and summarised in Figure 17. Many sites in the Manuherekia Rohe did not meet the sample number requirements accordingly are shown as white cells with coloured circles. Chl-a was only monitored at four sites, white cells indicates that this variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements. Baseline state is available for five sites, Thomsons Creek, Manuherekia at Ophir, Galloway and Blackstone and Dunstan Creek.

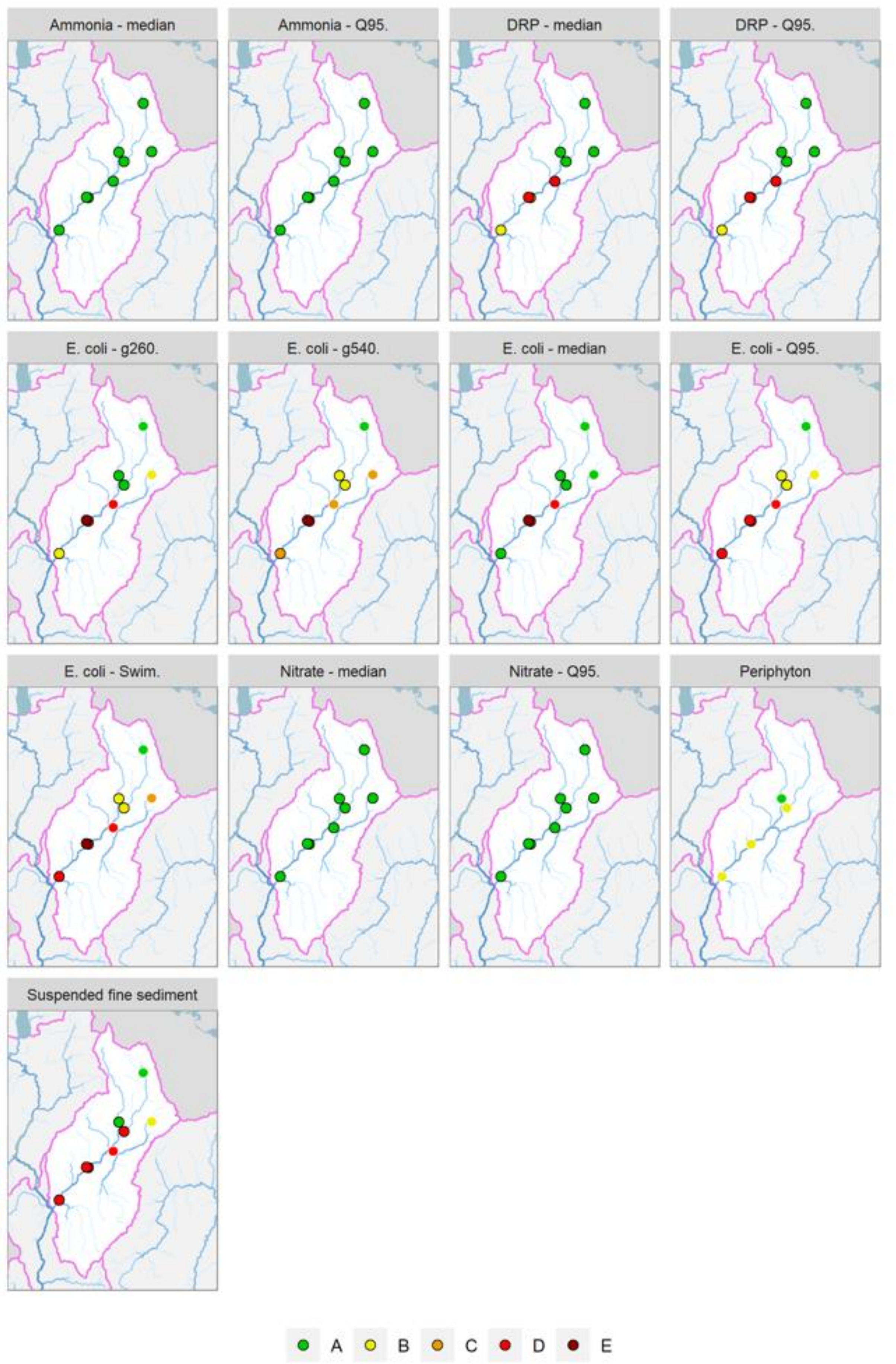

Ammonia - median
Ammonia - Q95.
DRP - median
DRP - Q95.
E. coli - g260.
E. coli - g540.
E. coli - median
E. coli - Q95.
E. coli - Swim.
Nitrate - median
Nitrate - Q95.
Periphyton
Suspended fine sediment
A
B
C
D
E

Figure 16 Maps showing Manuherekia Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

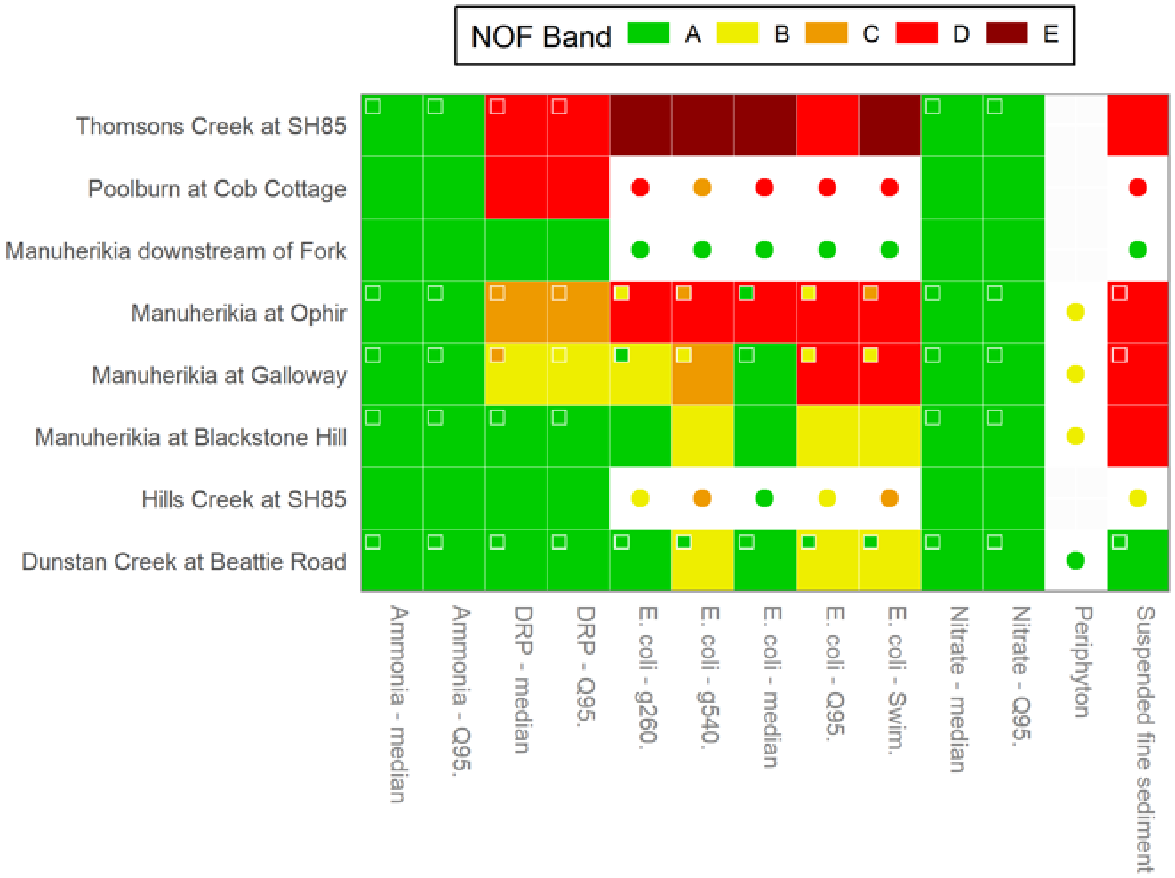


Figure 17 Grading of the river sites of the Manuherekia Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline.

5.3.2.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 16 and Figure 17 (periphyton). Grades are interim as the sample size did not meet sample number requirements. The mainstem Manuherekia sites, Blackstone (24 samples), Galloway (29 samples), and Ophir (26 samples) *are likely to be in attribute band 'B' as few results exceed 120 chl-*a*/m2. Dunstan Creek achieves an interim 'A' band for periphyton indicating that algae blooms are rare due to* negligible nutrient enrichment.

Figure 16 and Figure 17 also show DRP attribute states for ecosystem health (DRP median and Q95). The Manuherekia d/s Fork*, Manuherekia at Blackstone, Hills Creek, and Dunstan Creek have the lowest DRP median concentration and achieve an 'A' band indicating DRP is similar to natural reference condition. The mainstem Manuherekia at Ophir achieves a 'C' band and the Manuherekia at Galloway achieves a 'B' band.*

DRP in Thomsons Creek and the Poolburn achieve a 'D' band and fails the national bottom line, the NPS-FM (2020) describes this as *'ecological communities are impacted by substantial DRP elevation above natural reference conditions. In combination with other conditions favouring eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia are lost'*.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. Thomsons Creek has the highest median NNN concentration (0.25 mg/l) and the second highest median DRP concentration (0.0187mg/l). Dunstan Creek at Beattie Road has the second highest median concentration of NNN (0.084 mg/l) and the Manuherekia at Ophir also has a high NNN concentration (0.081 mg/l) but the second lowest DRP concentration in the FMU (0.01 mg/l).

5.3.2.2 Toxicants

NOF attribute bands for NH4-N and nitrate-N (measured as NNN) toxicity are shown in Figure 16 and Figure 17 the results show excellent protection levels against toxicity risk. All sites return an 'A' band for NH4-N and NNN.

5.3.2.3 Suspended fine sediment

The clarity results for the Manuherekia Rohe are shown in Figure 16 and Figure 17 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3. Five sites return a NOF band of 'D' which the NPS-FM (2020) describes as *'High impact of suspended sediment on instream biota. Ecological communities are significantly altered, and sensitive fish and macroinvertebrate species are lost or at high risk of being lost'.* Only Dunstan Creek and Manuherekia downstream of Fork return a NOF band of 'A' for sediment.

5.3.2.4 Human health for recreation

Figure 16 and Figure 17 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Thomsons Creek, the Poolburn, the Manuherekia at Ophir and the Manuherekia at Galloway fall below the national bottom line achieving with an attribute band of 'D' or 'E'. Only the upper catchment site, the Manuherekia d/s of Fork (above Falls Dam) achieves 'A' bands for all four statistical tests. Dunstan Creek and Hills Creek achieve a 'B' band for E. coli.

5.3.3 River: Trend Analysis

Trend analysis results for the Manuherekia Rohe is shown in Figure 18. Three sites, Manuherekia at Ophir, Manuherekia at Galloway, and Dunstan Creek at Beattie Road have been monitored long enough to establish their 20-year trends. All sites have 'unlikely' to 'exceptionally unlikely' improving trends for E. coli, NNN, TN and turbidity. All sites have 'likely' to 'virtually certain' improving trends for DRP and TP. The only site not showing an 'improving' trend for NH4-N is the Manuherekia at Ophir.

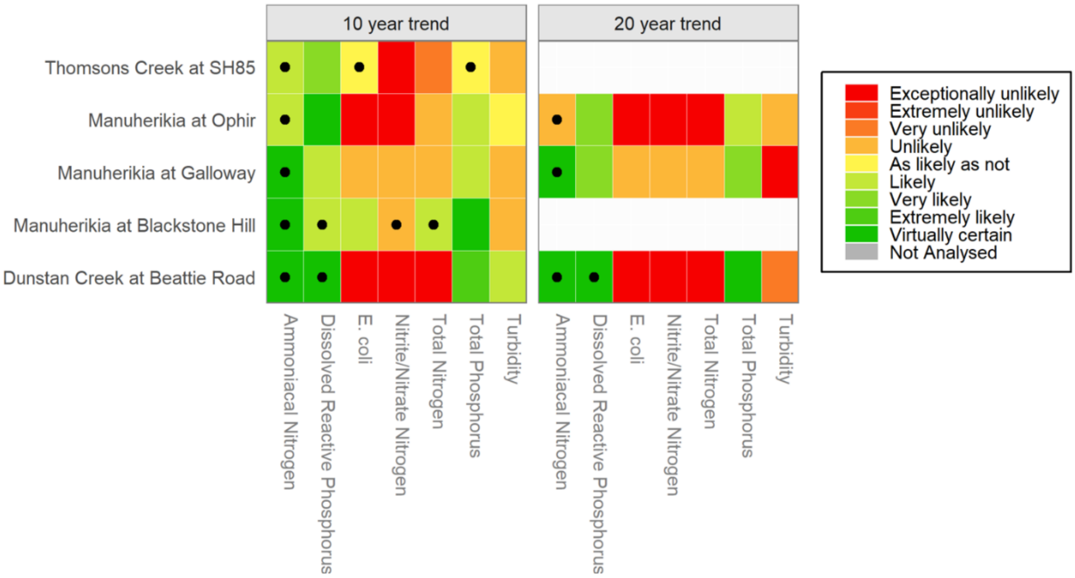


Figure 18 Summary of Manuherekia sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement.

Over ten years, the trends for Dunstan Creek and the Manuherekia at Galloway have not changed, at Ophir there has been an improvement in the trend for ammoniacal nitrogen and turbidity from the 20-year trend.

Two sites, Thomsons Creek and Manuherekia at Blackstone only have 10-year trends. Both sites have 'unlikely' to 'exceptionally unlikely' improving trends for NNN and turbidity. Thomsons Creek also has a 'very unlikely' improving trend for TN. Both sites have 'as likely as not' to 'virtually certain' improving trends for NH4-N, DRP, *E. coli* and TP.

5.3.4 Groundwater: State Analysis

The state results for the Manuherekia Rohe are provided in Table 7. The results generally show good compliance with the DWSNZ in the Manuherekia SoE bores. E. coli was not detected in three bores, whilst the remaining one, G41/0254, only had one detection. Median nitrate concentrations in the Rohe were also low, with three out of four bores having concentrations below the 2.50mg/L threshold for low intensity land use (Daughney and Morgenstern, 2012). Higher median concentrations were observed in bore G41/0254, which are above the low intensity threshold but less than ½ of the DWSNZ MAV of 11.3mg/L. Arsenic concentrations in all bores were substantially below the DWSNZ limit of 0.01mg/L.

Table 7 Groundwater current state results for the Manuherekia Rohe. The key for the colour classification is shown at the bottom of the table

Site	Aquifer	Total no. of samples	No. of detections	*E. coli* % exceedance	Median Nitrate concentration (mg/L)	Max. arsenic concentration (mg/L)
G41/0254	Manuherekia GWMZ	20	1	5	4.100	0.001
G42/0123	Manuherekia Claybound	20	0	0	1.045	0.001
G42/0290	Manuherekia Claybound	20	0	0	2.300	0.001
G46/0152	Manuherekia Alluvium	20	0	0	1.100	0.000

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01	>0.01 mg/L

5.3.5 Groundwater: Trend Analysis

The results of the trend analysis for groundwater quality in the Manuherekia Rohe are shown in Figure 19 and the spatial variability of groundwater quality trends is shown in Figure 20. Most of the trends for nitrate-N are ‘unlikely’/’very unlikely’ improving.

The five-year trends show that nitrate-N trends in three bores (G42/0123, G42/0290 both situated in a residential area near Alexandra), and G41/0254 (situated on a farm near Omakau) are ‘unlikely’/’very unlikely’ improving. The trend in the other bore (G46/0152, located on Galloway Road) is ‘extremely likely’ improving.

The 10-year trend shows a mixed pattern, where bore G41/0254 has become worse, falling from ‘very unlikely’ to ‘extremely unlikely’ improving. Conversely, bore G42/0290 has improved slightly, going from ‘unlikely’ improved to ‘as likely as not’ improved. The comparison between the 10 and 5-year trends also shows a mixed pattern, with bore G41/0254 slightly improving, going from “exceptionally unlikely” to “very unlikely”, no change in bore G42/0123, and bore G42/0290 degrading slightly, going from “as likely as not” improving to “unlikely” improving. The 10-year trends for bore G46/0152 was not assessed. No trends were assessed for dissolved arsenic.

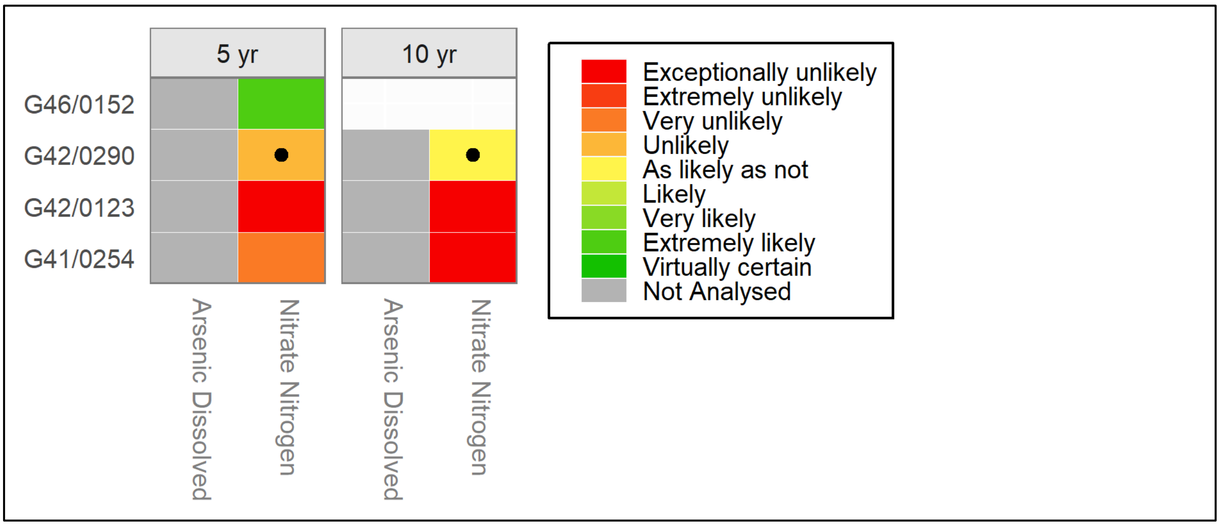


Figure 19 Summary of Manuherekia Rohe sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend

rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

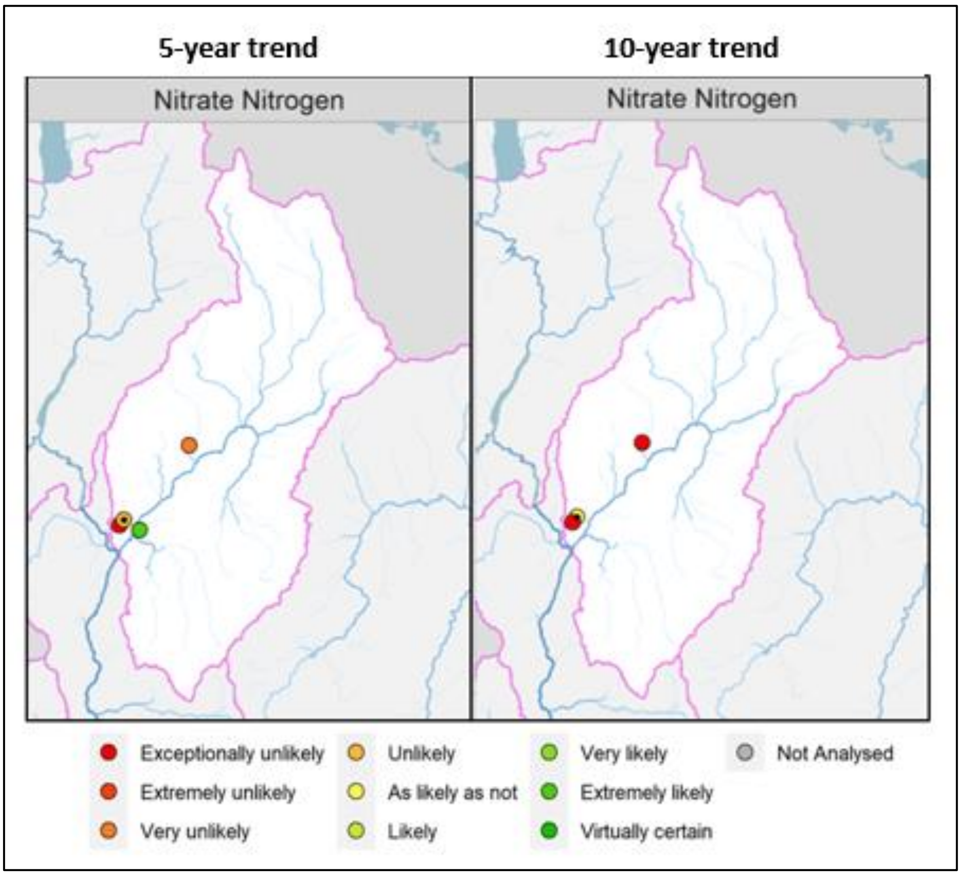


Figure 20: Groundwater quality 5- and 10-year trend results for the Manuherekia Rohe (LWP, 2023)

5.3.6 Water quality summary and discussion: Manuherekia Rohe

Water quality patterns in the Manuherekia catchment are complicated, as downstream of Falls Dam flows and the distribution of water in the Rohe are highly modified. Water races, along with natural water courses, are used to convey water for irrigation, stock water and domestic supplies. This has created an expansive and complex distribution network that moves water around the catchment. Water quality in the lower Manuherekia catchment and in lower reaches of tributaries, may well be influenced by the irrigation network (water conveyed to it, or water taken from it), rather than the immediate catchment.

State analysis in the Manuherekia identified that upstream of Falls Dam water quality was generally very good and achieved the NPS-FM attribute band ‘A’ for all attributes measured. The Manuherekia at Blackstone and Dunstan Creek also have exceptional water quality, with all attributes measured achieving an ‘A’ band other than *E. coli* which achieves a ‘B’ band.

For *E. coli* the upper Manuherekia achieved attribute band ‘A’ or ‘B’ but the lower Manuherekia main-stem and all tributaries other than Hills Creek achieved an attribute band ‘D’. The *E. coli* attribute bands are calculated using all data regardless of flow, it is acknowledged that the actual risk will generally be less if a person does not swim during high flows (NPS-FM, 2020). Faecal source tracking undertaken over the last two years as part of primary contact recreation monitoring (at Shaky Bridge near Alexandra) indicates the source of *E. coli* is both avian and ruminant.

In the Manuherekia catchment soils with poorer drainage characteristics are found on the true right of the Manuherekia River, particularly around the Thomsons Creek and Lauder Creek catchments. The implication of poor soil drainage is that water runs-off land rather than infiltrates through the soil. Run-off entrains soil, bacteria and nutrients which is transported to the nearest watercourse. Poor water quality in is common in all smaller creeks originating in the Dunstan Mountains with water quality deteriorating as the tributaries flow over productive farmland towards the Manuherekia (ORC, 2011). The tributaries, Poolburn and Thomsons Creek, have poor water quality across all attribute states other than NH4-N and NNN toxicity, mainly achieving band 'D', below the NPS-FM bottom line.

In the mainstem Manuherekia, between Blackstone and Ophir, DRP concentrations increase from an 'A' band to a 'C' band and E. coil concentrations increase from a 'B' band to a 'D' band. Between Ophir and Galloway, DRP decreases from a 'C' band to a 'B' band. Omakau WWTP discharges directly to the Manuherekia just upstream of Ophir and is likely to have some bearing on the Ophir water quality results.

Five of the eight sites monitored had elevated suspended sediment concentrations, historical gold mining tailings in the area below Falls Dam may contribute to elevated suspended solid concentrations in the main-stem Manuherekia (Blackstone, Ophir and Galloway) during higher flows. The Upper Catchment site, just below Falls Dam and Dunstan Creek both achieved an attribute band of 'A'.

Across the Manuherekia Rohe all sites have 'unlikely' to 'exceptionally unlikely' improving trends in at least one attribute as shown in Figure 18. Tributary sites which are below the national bottom line are most likely contributing to the degrading trends in the mainstem. At Ophir an 'exceptionally unlikely' improving trend for *E. coli* could be due to the influence of both Thomsons Creek and the WWTP, which discharge to the Manuherekia just upstream of Ophir. Dunstan Creek has 'unlikely' to 'exceptionally unlikely' improving trends for *E. coli*, NNN and turbidity, it is unclear what is causing the degrading trends.

Groundwater quality in the Manuherekia SoE monitoring bores is generally good, with no *E. coli* detections and low-median nitrate-N concentrations in most bores. However, one bore, G41/0254, had an E. coli exceedance and higher median nitrate-N concentrations, they were still below ½ of the DWSNZ MAV. The bore is situated near an irrigation pond on a farm that may have contributed to these results. Arsenic concentrations in all bores were substantially below the DWSNZ limit of 0.01mg/L. Despite that, it is important that bore owners in the area maintain good bore security in order to prevent contamination and regularly test their water.

The trends in groundwater quality are fairly sobering, with most sites show 'unlikely' to 'very unlikely' improving trends in nitrate-N for both the 5 and 10-year trends. The monitoring bores in the Rohe are situated on a farm and lifestyle blocks, where nitrate-N was potentially sourced from land effluent application or discharge from septic tanks. Conversely, the trend in the other bore (G46/0152, located on Galloway Road) is 'extremely likely' improving. The 10-year trend shows a mixed pattern, where bore G41/0254 has fallen, from 'very unlikely' to 'extremely unlikely' improving. This, again, may be due to inputs from the surrounding land use. Conversely, bore G42/0290 shows a positive movement, changing from 'unlikely' improved to 'as likely as not' improved. The causes for this are not clear. It may be due to better land management around the bore, e.g., improvement of wastewater management.

5.4 Roxburgh Rohe

Figure 21 Location of water quality monitoring sites in the Roxburgh Rohe

5.4.1 Roxburgh Rohe Description

The Roxburgh Rohe extends from the Clyde Dam to Beaumont, and includes the townships of Alexandra, Clyde, and Roxburgh. The Rohe covers around 180,000 hectares of land, with grassland being the most common land cover. Low producing grasslands such as that found on steep hill and high country, occupy 32% of the Rohe while high-producing grasslands such as intensified grazing occupy 2%. Tall tussock grasslands cover 24% and exotic forests cover 2% of the Rohe.

The Roxburgh Rohe is in the heart of Central Otago and subject to the typical weather conditions for this area with hot, dry summers and cold, frosty, dry winters. Mean annual rainfall ranges from about 1200mm on the Obelisk/Old Man Mountain ranges, around 900mm on the hills south of the mountains, to about 360mm near Alexandra, and 450-500mm further south. However, the evaporation is also high, and at times exceeds precipitation, leading to soil moisture deficits. Temperatures can range from above 38°C in summer to around -10°C in winter. Rivers and streams originating in this Rohe do not have large flows and generally have very low flows in summer. The main exception is the Clutha/Mata-Au River, which runs through the centre of this Rohe.

The Rohe includes some important tributaries for the Clutha/Mata-Au, such as the Fraser River (also known as The Earnscleugh), Benger Burn, Teviot River, and Beaumont River. There are several man-made lakes across the Rohe, used for irrigation and power generation. Lake Roxburgh is located roughly in the middle of the rohe along the Clutha Mata-Au River, while the Fraser and Teviot river catchments host the Fraser Dam and Lake Onslow, respectively.

ORC monitors four river and one lake sites in the Roxburgh Rohe. There are four groundwater SoE monitoring bores, situated in the Roxburgh basin and Ettrick aquifer. The monitoring sites are shown in Figure 21.

5.4.2 River and Lake: State Analysis

The results of grading the SoE sites in the Roxburgh Rohe according to the NPS-FM NOF criteria are mapped in Figure 22 and summarised in Figure 23 and Figure 24. Many sites in the Roxburgh Rohe did not meet the sample number requirements and accordingly are shown as white cells with coloured circles

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements. The only site with grades for the baseline period is the Clutha at Millers Flat.

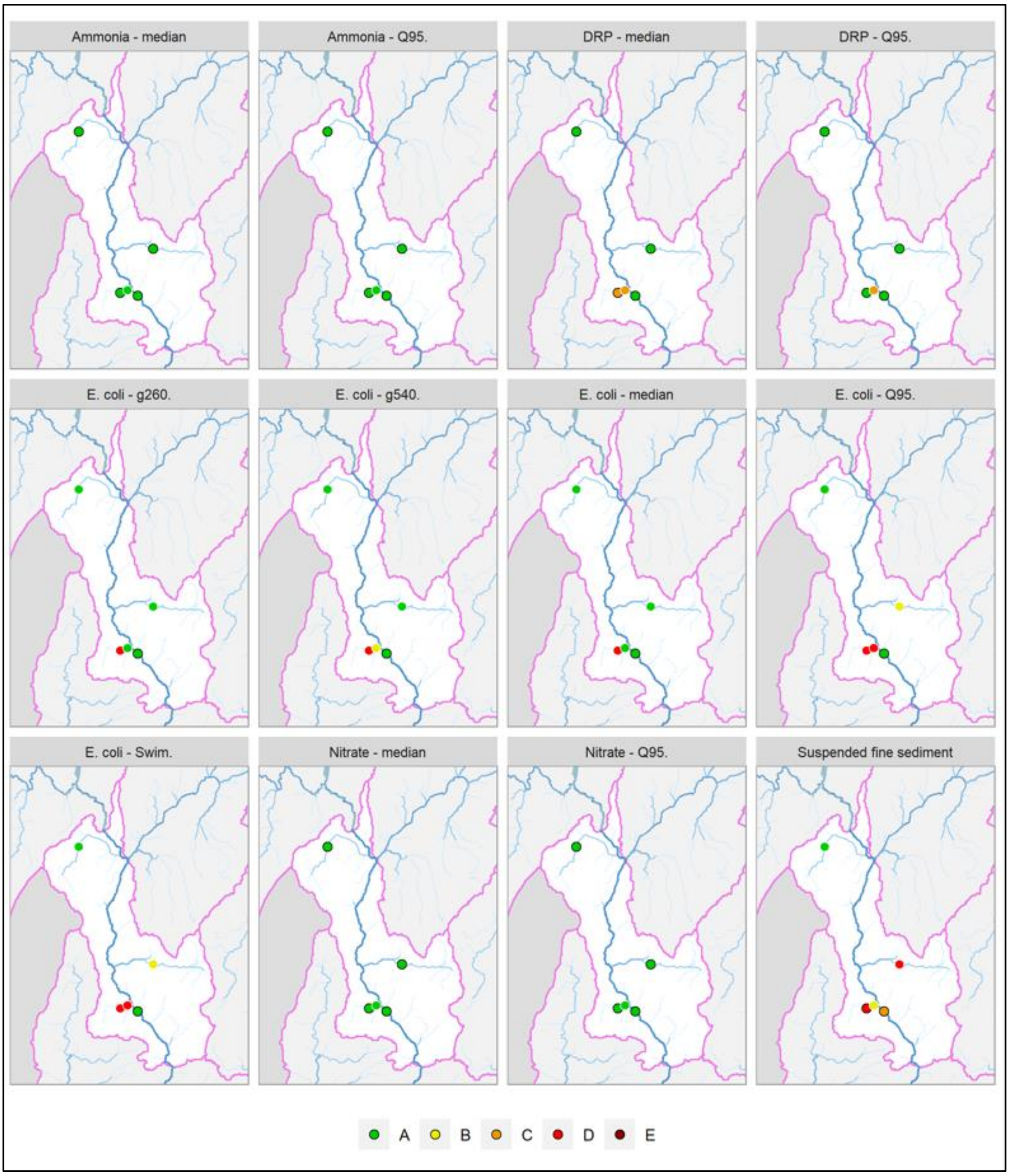
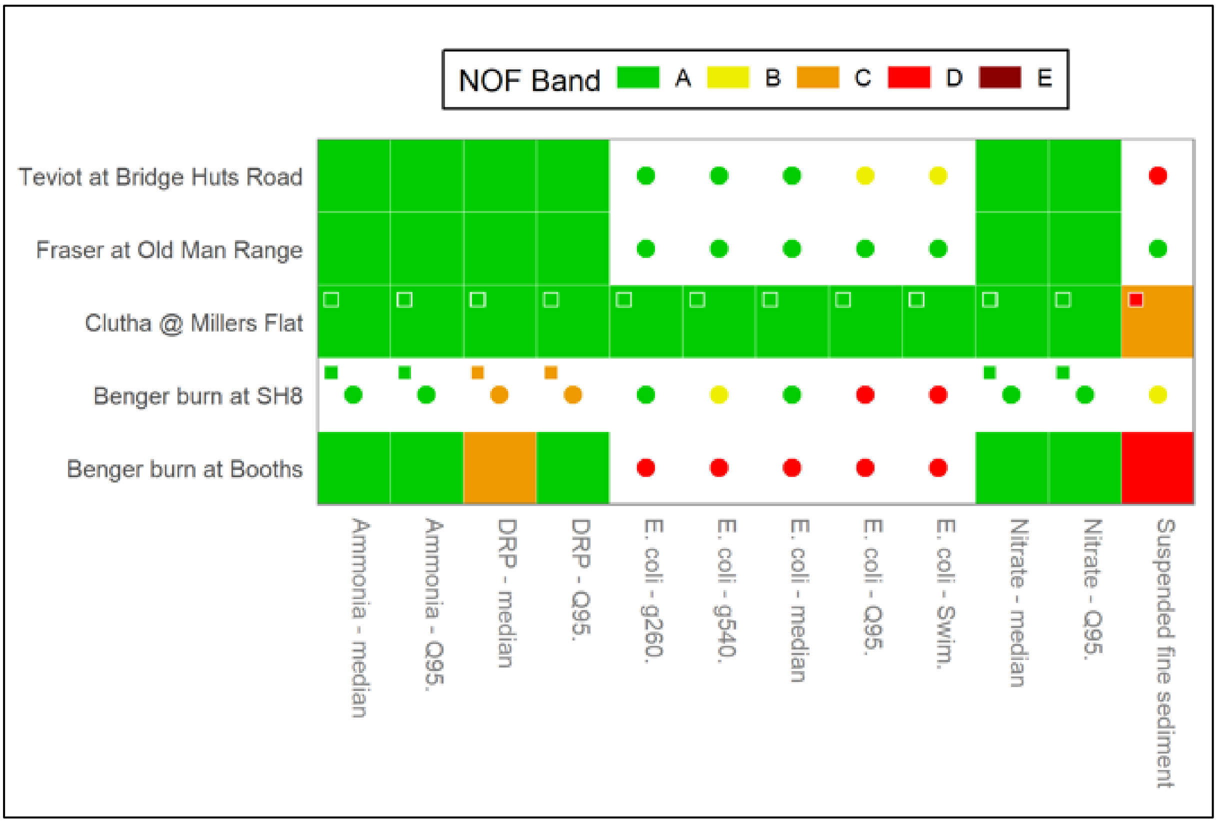


Figure 22 Maps showing Roxburgh Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.



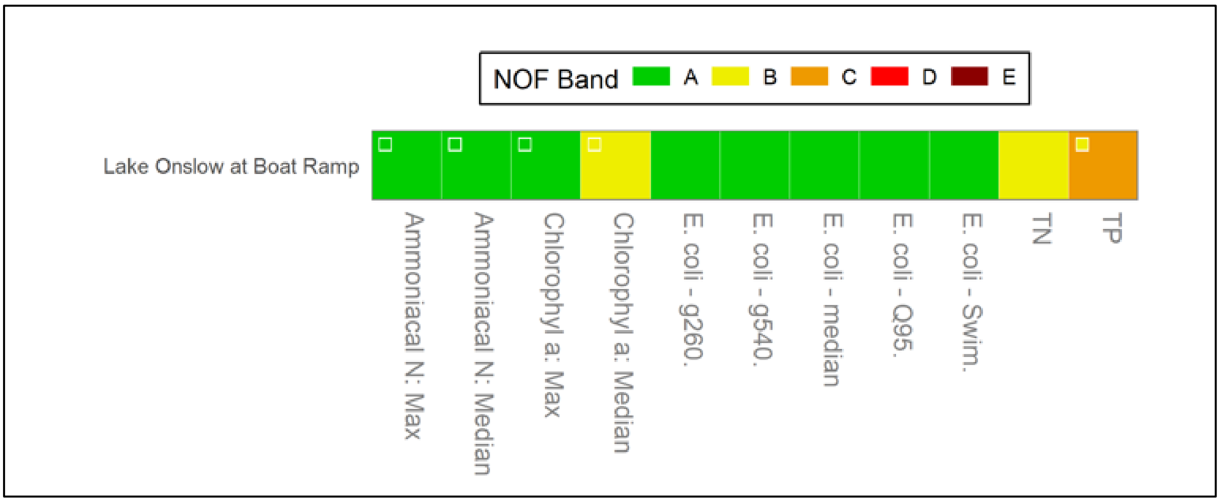


Figure 23 Grading of the river and lake sites in the Roxburgh based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

5.4.2.1 *Phytoplankton, Periphyton and Nutrients*

Figure 23 shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Roxburgh Rohe show that every site achieves a band 'A', other than the Benger burn which achieves band 'B' for DRP median. The NPS-FM (2020) describes band 'A' as *'Ecological communities and ecosystem processes are similar to those of natural reference conditions. No adverse effects attributable to dissolved reactive phosphorus (DRP) enrichment are expected.' Results for NNN are given in Appendix 1.* No periphyton monitoring is undertaken in the Roxburgh Rohe.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. In the Roxburgh Rohe, the Benger Burn at Booths has the highest concentration of both nutrients (NNN 0.182mg/l and DRP 0.01 mg/l) the other sites have much lower nutrient concentrations.

The NPS-FM (2020) describes how phytoplankton affects lake ecological communities. If the chlorophyll a concentration is in the 'A' band, then '*Lake ecological communities are healthy and resilient, similar to natural reference conditions'*. Results for Lake Onslow are shown in Figure 23 , the lake achieves an 'A' band for maximum chlorophyll a, but drops to a 'B' band for median chlorophyll a. Lake Onslow achieves a 'B' band for TN and a 'C' band for TP. The NPS-FM (2020) describes the C band for TP as *'Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions'*.

5.4.2.2 Toxicants

In the Roxburgh Rohe the NOF attribute bands for NH4-N and NNN toxicity at river sites and Lake Onslow show excellent protection levels against toxicity risk as all monitoring sites return an 'A' band for NH4-N and NNN.

5.4.2.3 Suspended fine sediment

The clarity results for the Roxburgh Rohe are shown in Figure 23 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3. The Fraser River returns a NOF band of 'A' which denotes '*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions'* (NPS-FM, 2020). The Clutha at Millers Flat returns a NOF band of 'B' and the Benger burn and Teviot return a NOF band of 'D' for suspended fine sediment, which is below the national bottom line.

5.4.2.4 Human health for recreation

Figure 23 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading.

Lake Onslow, the Fraser River, and the Clutha at Millers Flat return 'A' bands across all four statistical tests, the Teviot achieved a 'B' band because it's 95th percentile was just above the 'A' band criteria. The Benger Burn achieved a 'D' band across all four statistical tests.

5.4.3 River and Lake: Trend Analysis

Results from trend analysis for the Roxburgh Rohe is shown in Figure 24.

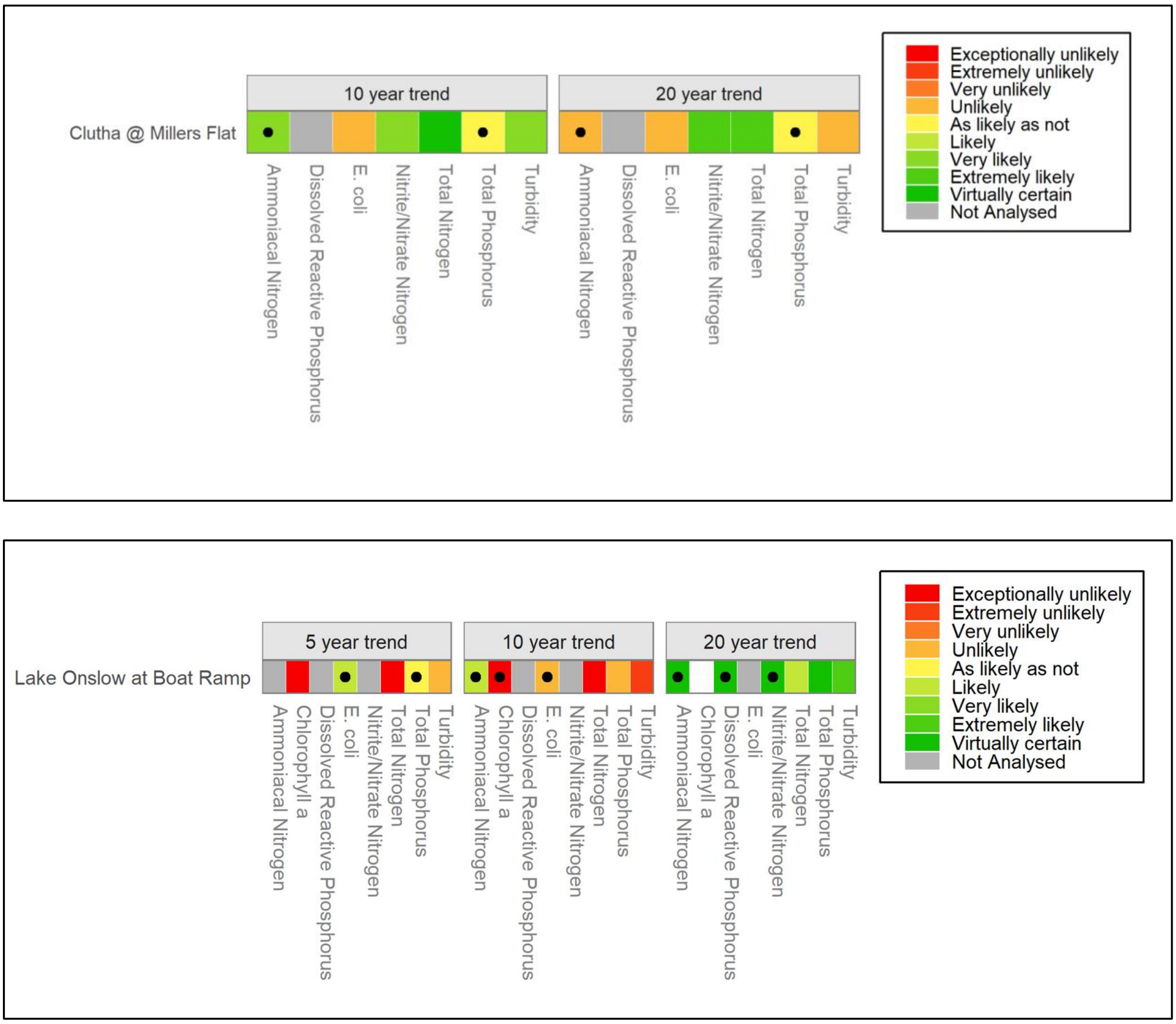


Figure 24 Summary of Roxburgh Rohe sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend.

Trend analysis for both rivers and lakes are given in Figure 24. In the 20-year time frame, Lake Onslow shows that all attributes are likely to be improving. In the 10-year time frame this is reversed with all attributes other than NH4-N 'unlikely' to 'exceptionally unlikely' to be improving. In the 5-year trend analysis it is only *E. coli* that is 'likely' to be improving.

For the Clutha River at Millers Flat, trend analysis shows a 20-year 'unlikely' improvement in turbidity, NH4-N and *E. coli* and an 'extremely likely' improvement in NNN and TN. Over the 20-year period NH4-N, however nutrient concentrations have improving trends, NNN is 'virtually certain' to have improved over 10-years, *E. coli* is 'unlikely' to have improved, but all other attributes are 'as likely as not' to virtually certain' to have improved.

5.4.4 Groundwater: State Analysis

The current state of groundwater quality in the Roxburgh Rohe is shown in Table 8. The results show some groundwater quality issues, notably *E. coli* exceedances in most bores and median nitrate-N concentrations between 4.750 and 8.400mg/L, which exceeds the threshold for low intensity land use (Morgenstern and Daughney, 2012) and approaches ¾ of the DWSNZ MAV. Dissolved arsenic concentrations in most bores are substantially below the DWSNZ MAV, with the exception of bore G43/0072 (situated in Roxburgh), where a maximum concentration of 0.006mg/L, above ½ of the DWSNZ MAV of 0.01mg/L, was measured. The other bores are situated in Ettrick, where bore G43/0224 a/b is a multi-level bore, with two monitoring piezometers at different depths (G43/0224a is shallower, screened between 9.73 and 12.73m and G43/0024b is screened between 17.33 and 20.33m). The monitoring results show high nitrate-N concentrations in this bore, which are close to the DWSNZ MAV. Furthermore, these concentrations are much higher than the NPS-FM (2020) nitrate-N limits for surface water.

Table 8 Groundwater current state results for the Roxburgh Rohe. The key for the colour classification is shown at the bottom of the table

Site	**Aquifer/ location**	**Total no. of samples**	**No. of detections**	***E. coli* % exceedance**	**Median Nitrate concentration (mg/L)**	**Max. arsenic concentration (mg/L)**
G43/0009	Ettrick	25	1	4	4.750	0.000
G43/0072	Roxburgh	20	0	0	4.450	0.006
G43/0224a	Ettrick	29	3	10	8.400	0.000
G43/0224b	Ettrick	29	1	3	8.300	0.000

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Dissolved Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

5.4.5 Groundwater: Trend Analysis

The groundwater trend analysis is summarised in Figure 25 and is shown spatially in Figure 26 The five-year trend for nitrate-N concentrations was computed for the four monitoring bores in the Rohe. The results are mixed, with ‘extremely likely’ improvement for bores G43/0072 and G43/0009. Conversely, nitrate-N concentrations in bore G43/0224 are “extremely unlikely” improving. A 10-year trend was only available for bore G43/0009, which shows a worsening trend over the longer time period, going from “extremely likely improving” to “unlikely improving”.

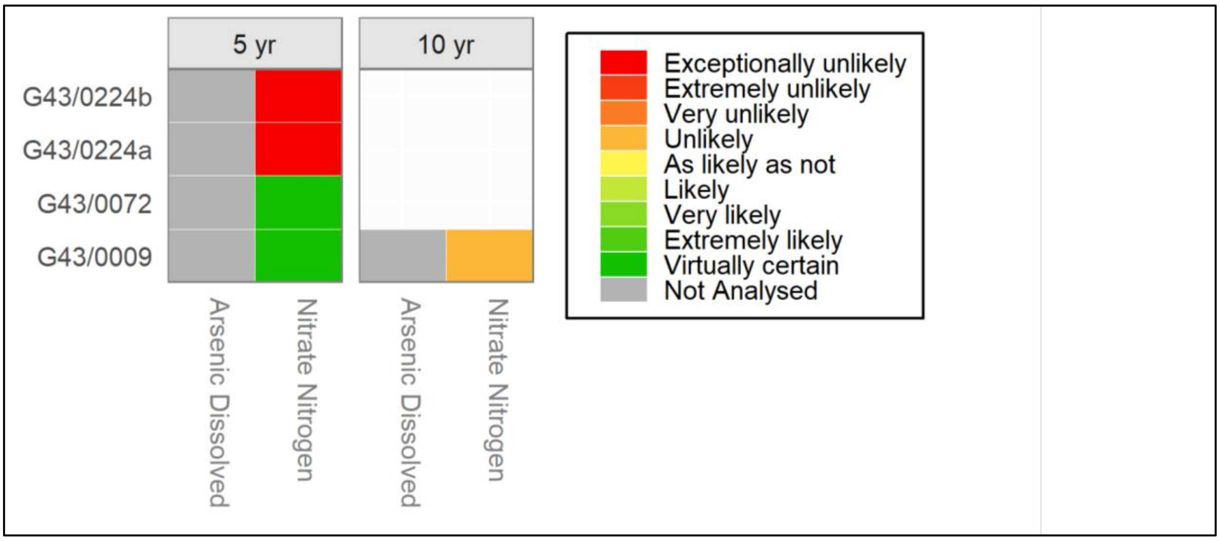


Figure 25: Summary of Roxburgh Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 4. White cells indicate site/variables where there were insufficient data to assess the trend

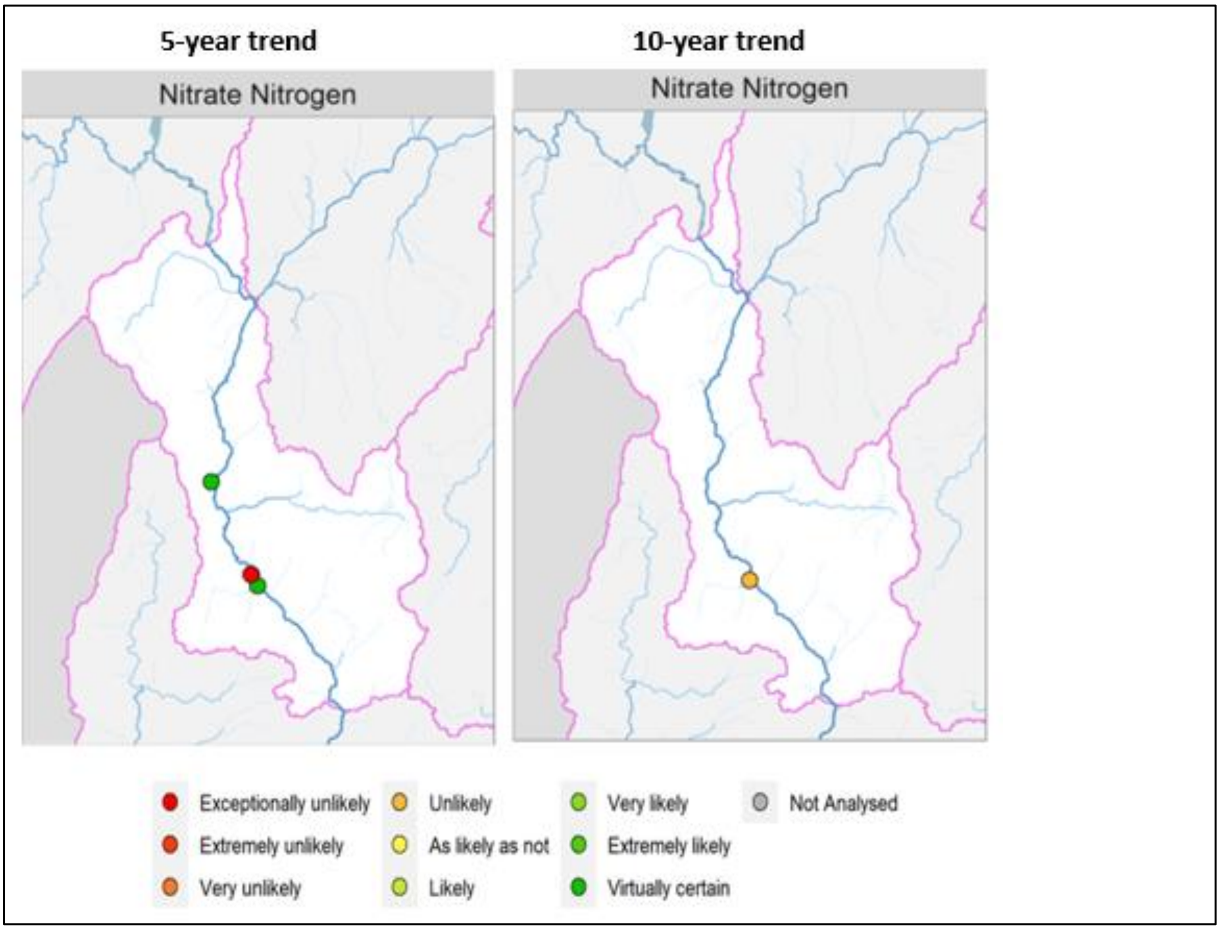


Figure 26: Groundwater quality 5 -and 10-year trend results for the Roxburgh Rohe (LWP, 203)

5.4.6 Water quality summary and discussion: Roxburgh Rohe

The dominant land use in the Roxburgh Rohe is drystock farming (77%), comprising of sheep and beef (65%); mixed sheep, beef, and deer (6%); and sheep farming (6%). Conservation estate occurs on approximately 10% of the Rohe. Forestry, and nurseries/vineyards/orchards occur on 2% of the area. The notable trends in land use change over the past three decades have been an increase in the extent of conservation estate (by 980%), forestry (by 156%), nurseries/ vineyards/orchards (by 17%) and urban area (by 8%). The extent of dry-stock farming decreased by 12%, although it remains the dominant land use activity in the Roxburgh area.

The analysis identified that water quality state in three of the four rivers monitored (Teviot River, Fraser River and Clutha at Millers Flat) are generally good and the NPS-FM band 'A' was achieved for most attributes other than for suspended fine sediment in the Teviot and Clutha. Both these rivers have naturally low water clarity due to their water source, i.e., glacial meltwater in the Clutha and tannin staining from tussock of the high country between the Knobby Range and the Lammerlaw Range for the Teviot. In contrast to that, the Benger Burn falls below the national bottom for all four statistics for *E. coli.* The source of the river is in the Mt Bengerburn, where land use in the higher country is mainly extensive sheep and beef, although this becomes more intensive when the river reaches the flat of the Ettrick basin. The reason for both the high bacteria concentration and the low clarity has not been established.

Lake Onslow is a man-made lake, formed in 1890 by the damming of the Teviot River and Dismal Swamp. TN achieves a 'B' band and TP a 'C' band. This grading should be considered typical of a shallow lake draining a tussock environment. Chl-a receives a grading of 'B' reflecting the higher nutrient concentration.

Trend analysis is only available for the Clutha River at Millers Flat, a comparison of the 20 and 10-year trends indicate that generally water quality has improved in the last 10 years, however due to the volume and size of the Clutha/Mata-Au catchment, any trend should be looked at with caution, it is preferable to look at the trends from tributaries discharging to the Clutha.

Groundwater quality state results highlight some issues in the Roxburgh Rohe, notably *E. coli* detections in most bores and high median nitrate-N concentrations. The nitrate-N concentrations from the bore in Ettrick (G43/0224a/b) approach ¾ of the DWSNZ MAV and exceed the threshold for low intensity land use (Morgenstern and Daughney, 2012) and the NPS-FM (2020) nitrate-N limits for surface water. These results are potentially due to the intensive farming and septic tanks in the Ettrick area, where further land use intensification and housing expansion continues to occur. Dissolved arsenic concentrations in most monitoring bores are substantially below the DWSNZ MAV, with the exception of bore G43/0072 (situated in Roxburgh), where a maximum concentration of 0.006mg/L was measured. This is above ½ of the DWSNZ MAV of 0.01mg/L. However, further look in the data shows that this was an isolated incident, and the concentrations usually range between 0.001 – 0.002mg/L (ORC, 2021). Nevertheless, it is strongly recommended that bore owners regularly test their water.

The 5-year trend for groundwater nitrate-N concentrations shows mixed results, with 'extremely likely' improvement for bores G43/0072 and G43/0009. Conversely, nitrate-N concentrations in bore G43/0224 are 'extremely unlikely' to have improved. This is likely due to the intensification of farming in the area. A 10-year trend was only available for bore G43/0009, which goes from 'unlikely improving' to 'extremely likely improving'. As the bore is located in a residential area, this is potentially due to improvements to wastewater system around the bore.

In light of these results, it is strongly recommended to practice good land and nutrient management to reduce nitrate-N leaching while continuing the nitrate-N monitoring in the area. It is also important to maintain good bore security to prevent the entry of contaminants into bores and to regularly test bore water. In addition to that, it is strongly recommended to ensure all septic tanks are well maintained and upgrade aging wastewater systems. If housing expansion continues in the Rohe it may also be worth considering replacing septic tanks with a centralised reticulated wastewater system.

5.5 Lower Clutha Rohe

Figure 27 Location of water quality monitoring sites in the Lower Clutha Rohe

5.5.1 Lower Clutha Rohe Description

The Lower Clutha Rohe runs from Beaumont to the Pacific Ocean where the Clutha /Mata-Au River discharges to the sea near Balclutha. The Rohe includes the catchments of the Pomahaka River (catchment area of 2,060 km^2), Waitahuna River (406 km^2), Waipahi River (339 km^2), Tuapeka River (249 km^2), and Waiwera River (208 km^2).

The most common land cover is high-producing grassland which supports intensive agriculture. Dry stock farming consists mainly of pasture grazing beef cattle, sheep, and deer for meat, wool, and velvet production. While dry stock farming has decreased by 9%, it still remains the main land use in the Lower Clutha area at 56%. Dairy farming occurs on approximately 17% of land and has notably increased by 37% between 1990 and 2018, as has forestry which increased by 39% between 1990 and 2018 and now covers 9% of the Rohe. The Lower Clutha Rohe has about 7% conservation estate which has increased by 40% in the last 30 years.

The Pomahaka River is the largest catchment of the Lower Clutha Rohe. The upper reaches of which are steep and dominated by tussock, while the lower reaches are primarily pastoral rolling hill country with intensive land use. Soils in the lower catchment are generally poorly drained, requiring artificial drainage, predominantly in the form of tile and mole drains. The main urban settlements in the Rohe are Balclutha and Tapanui.

ORC monitors 14 river sites and one lake in the Lower Clutha Rohe. There are three groundwater SoE monitoring bores in the Rohe, located in the Pomahaka Alluvial Ribbon aquifer and the Inch Clutha aquifer. The monitoring sites are shown in Figure 27.

5.5.2 River and Lake State Analysis Results

The results of grading the SoE sites in the Lower Clutha Rohe according to the NPS-FM NOF criteria are mapped in Figure 28 and summarised in Figure 29 . Some sites in the Lower Clutha Rohe did not meet the sample number requirements and accordingly are shown as white cells with coloured circles. Chl-a (periphyton) was only monitored at four sites, white cells indicates that this variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicates the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

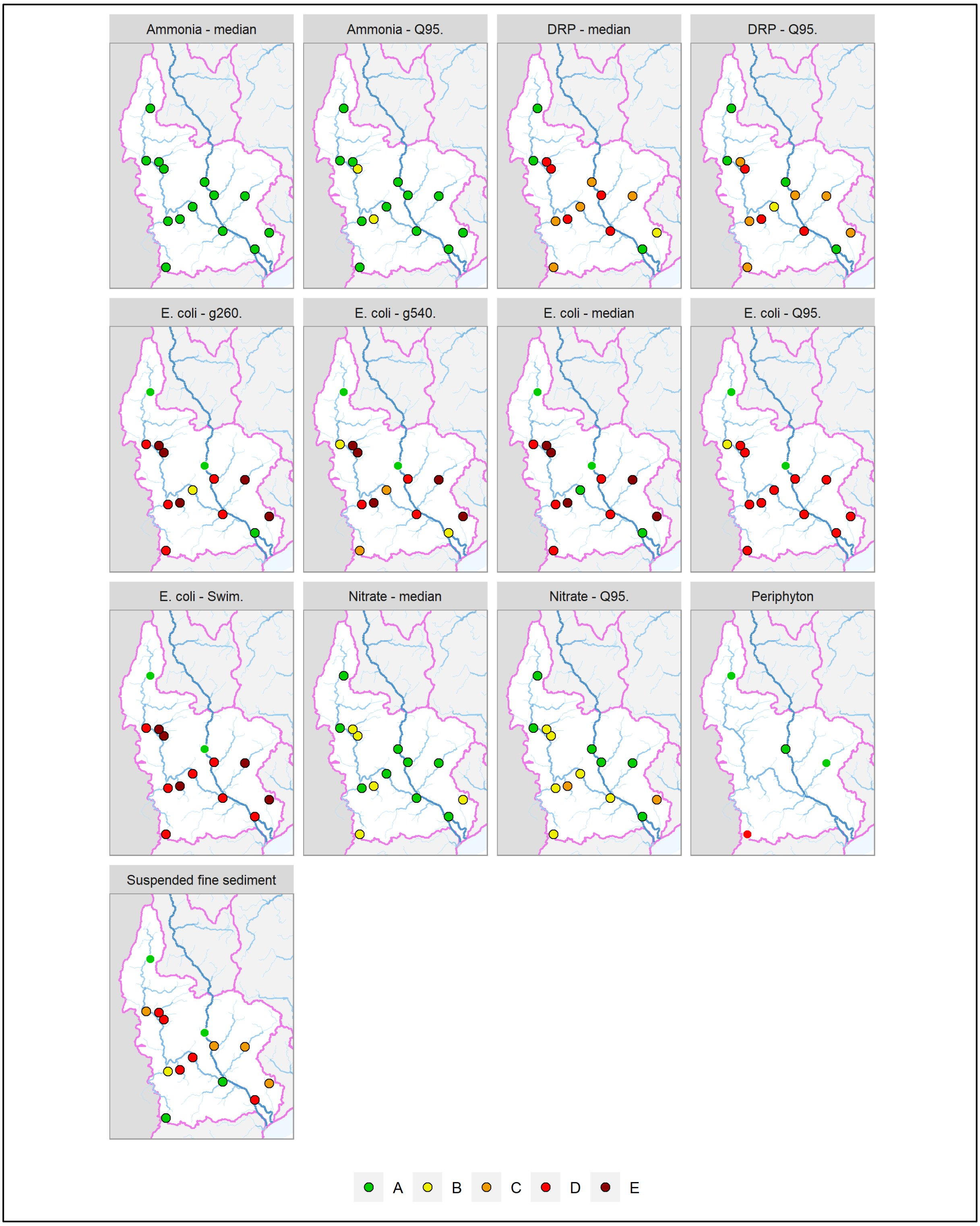


Figure 28 Maps showing Lower Clutha Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.

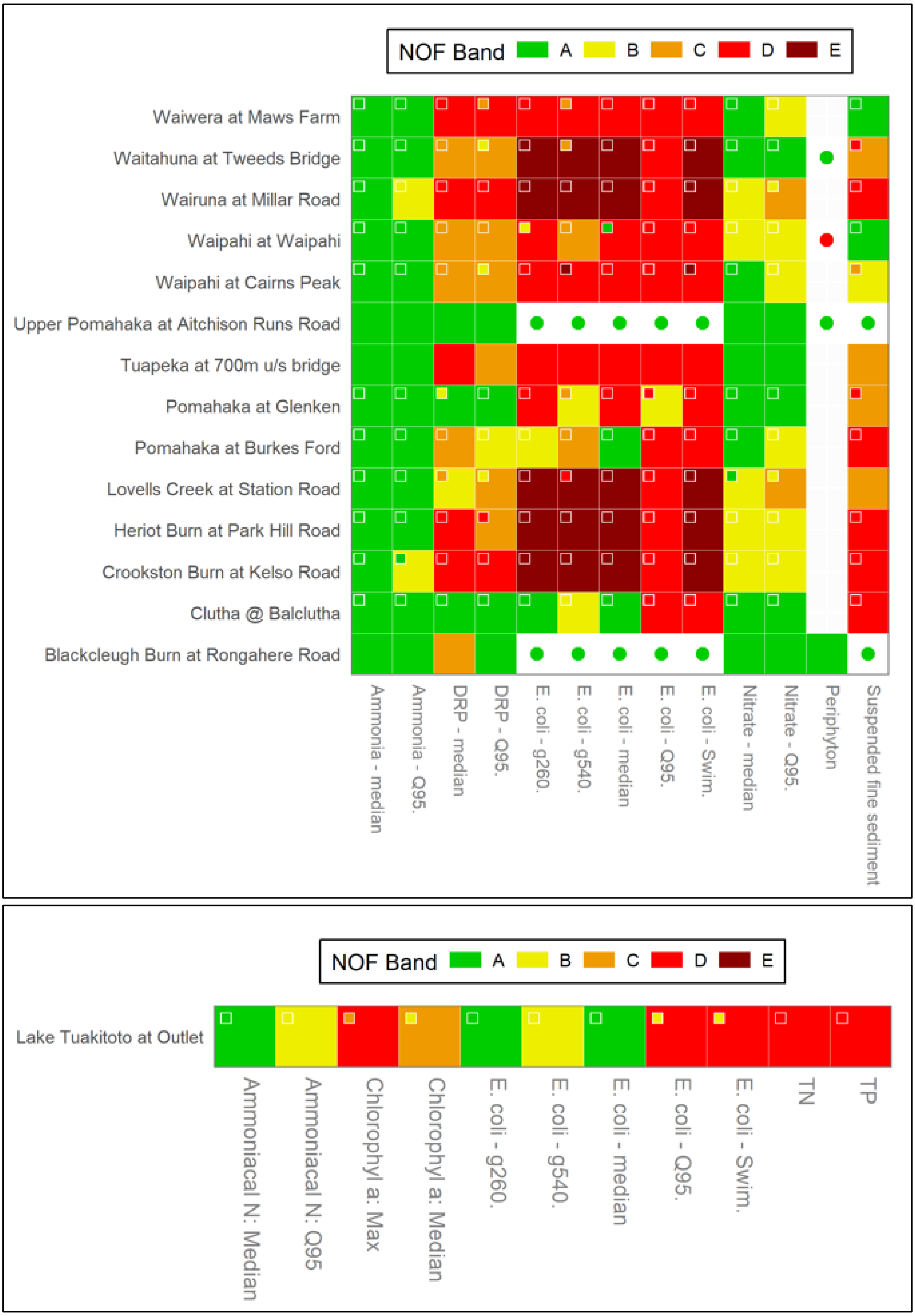


Figure 29 Grading of River and Lake sites in the Lower Clutha Rohe, based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells

with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline.

5.5.2.1 Phytoplankton, Periphyton and Nutrients

Periphyton trophic state results for the four sites monitored are given in Figure 29 and show that the Lower Clutha Rohe returns a band 'A' at three sites and a 'D' band for Waipahi at Waipahi, the NPS-FM (2020) describes this attribute state as '*regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat*'.

Figure 29 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Lower Clutha Rohe are varied. Sites with elevated DRP (achieving 'D' band for at least one of the DRP attribute statistics include the Waiwera, Wairuna, Crookston Burn, Waitahuna, Waipahi at Waipahi, Waipahi at Cairns Peak and Heriot Burn. All other sites achieved 'B' band or higher with three sites achieving an 'A' band across both statistics. including the two upper Pomahaka sites (Upper Pomahaka and Pomahaka at Glenken) as well as the Clutha at Balclutha.

The Pomahaka catchment has eight sites, the upper two sites (Upper Pomahaka and Pomahaka at Glenken) achieve 'A' bands. The tributaries entering the Pomahaka tend to have very high DRP, for example the Crookston Burn, Heriot Burn and Wairuna achieve band 'D'. High DRP tributary inputs to the Pomahaka River, result in an increase from 'A' band at Glenken to a 'C' band at Burkes Ford.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. The Crookston Burn (NNN 1.24 mg/l, DRP 0.026 mg/l), Heriot Burn (NNN 1.32 mg/l, DRP 0.026 mg/l) and Wairuna (NNN, 1.385 mg/l, DRP 0.031 mg/l) have the highest concentrations of NNN and DRP in the Rohe, the Pomahaka at Aitchison Runs Road has the lowest median NNN concentration (0.0132 mg/l) and the second lowest median DRP concentration (0.0047 mg/l).

The NPS-FM (2020) describes how phytoplankton (measured as Chl-a) affects lake ecological communities. If phytoplankton is in the 'A' band, then '*Lake ecological communities are healthy and resilient, similar to natural reference conditions*'. Figure 29 shows that Lake Tuakitoto is in the 'D' band, which is described as '*ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients'*. Lake Tuakitoto achieves 'D' bands for both TN and TP, a 'D' band reflects high nutrient enrichment, which is consistent for a shallow (normal lake levels of about one metre) freshwater wetland (ORC, 2004).

5.5.2.2 Toxicants

NOF attribute bands for NH4-N are given in Figure 29. The national bottom line for NH4-N is below band 'B'. In the Lower Clutha Rohe, all sites achieve band 'A' band other than the Crookston Burn, Waiwera at Maws Farm and the Wairuna which achieve a band 'B', which affords a 95% species protection level.

NOF attribute bands for nitrate-N (measured as NNN) toxicity are given in Figure 29, again the national bottom line is below band 'B'. In the Lower Clutha Rohe, most sites achieve either an 'A' or 'B' band, other than Wairuna and Lovells Creek which achieve a 'C' band (annual 95th percentile). The NPS-FM describes the 'C' band as NNN having *'growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.'*

Lake Tuakitoto returns a 'B' band (95% species protection level) for NH4-N toxicity, this still shows good protection levels against toxicity risk.

5.5.2.3 Suspended fine sediment

The clarity results for Lower Clutha Rohe are shown in Figure 29 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3 other than Waipahi at Cairns Peak which is in sediment class 4. Of the 14 sites monitored, six return a NOF band of 'D', which the NPS-FM describes as *'high impact of suspended sediment on instream biota. Ecological communities are significantly altered, and sensitive fish and macroinvertebrate species are lost or at high risk of being lost'.* Of these sites, two have naturally low clarity, the Upper Waipahi site at Cairns Peak and the Clutha at Balclutha. Four sites; Waiwera at Maws, Waipahi at Waipahi, Upper Pomahaka and Blackcleugh Burn, return an 'A' band.

5.5.2.4 Human health for recreation

Figure 29 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grade of the four.

Compliance is generally poor across the Lower Rohe, with 13 of 15 sites returning bacterial water quality below band 'C'. The NPS-FM (2020) describes band 'D' as *'30% of the time the estimated risk of Campylobacter infection is ≥50 in 1,000 (>5% risk). The predicted average infection >3%'*. Band 'D' is generally considered not safe for primary contact (i.e., swimming).

In the Pomahaka catchment, of the eight sites monitored one site, the Upper Pomahaka achieved an 'A' band, three sites (the Crookston Burn, Heriot Burn and Wairuna) achieved an 'E' band, four sites (Waipahi at Cairns Peak, Pomahaka at Burkes Ford, Waipahi at Waipahi and Pomahaka at Glenken) achieved a 'D' band. Lake Tuakitoto is graded a 'D' band.

5.5.3 River and Lake: Trend Analysis

Trend analysis results for the Lower Clutha Rohe are shown in Figure 30 and Figure 31

Trend analysis for the Lower Clutha Rohe rivers is shown in Figure 30. Of immediate note is the 10-year trend block shows very few trends that are considered degrading (‘unlikely’ to ‘exceptionally unlikely’ to be improving)

A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods. Generally, across the Lower Clutha Rohe the predominance of degrading 20-year trends for NNN, TN and turbidity shifted to a predominance of improving 10-year trends for the same analytes. In addition, three sites, the Heriot Burn, the Waitahuna and the Waipahi at Waipahi saw a shift from the predominance of degrading 20-year trends to a predominance of improving 10-year trends.

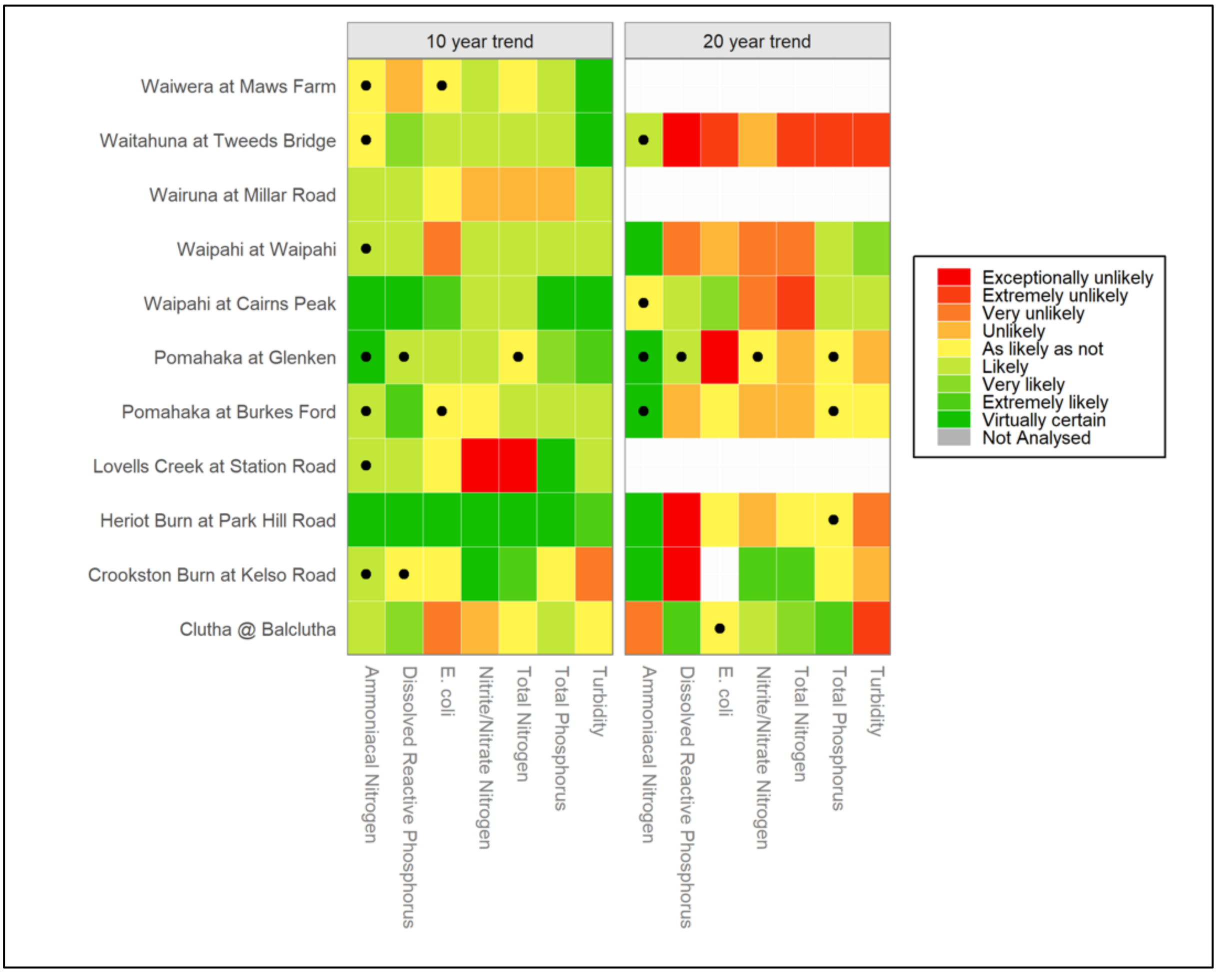


Figure 30 Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend.

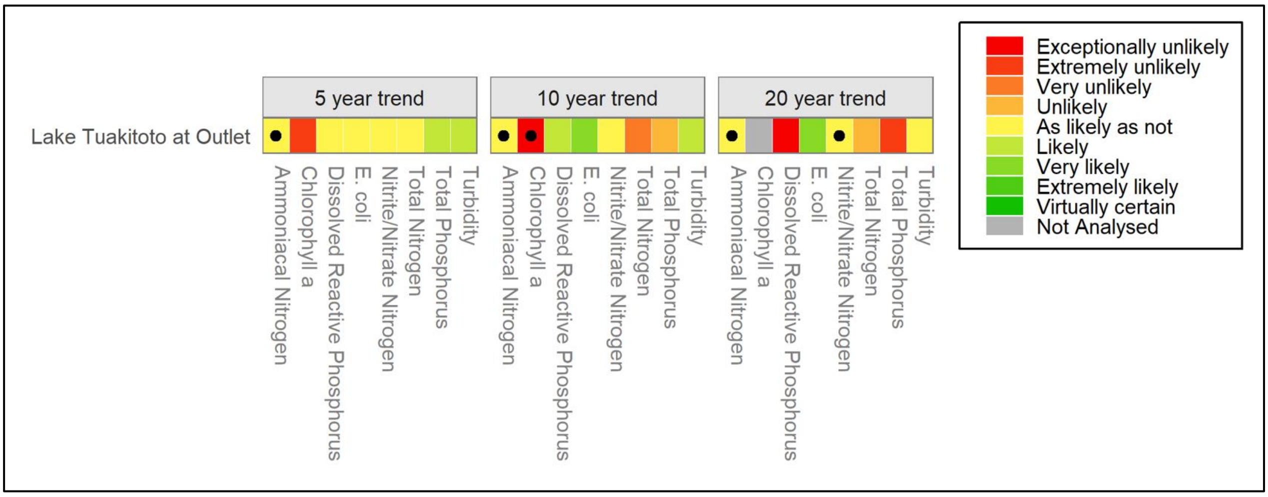


Figure 31 Summary of Lake Tuakitoto trends, categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring).

A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods. Generally, across the Lower Clutha Rohe the predominance of degrading 20-year trends for NNN, TN and turbidity shifted to a predominance of improving 10-year trends for the same analytes. In addition, three sites, the Heriot Burn, the Waitahuna and the Waipahi at Waipahi saw a shift from the predominance of degrading 20-year trends to a predominance of improving 10-year trends.

Trend analysis for 5-, 10-and 20-years for Lake Tuakitoto is shown in Figure 31 TP and DRP have changed from degrading over 20-years, to the five-year trend indicating stability or improvement. The only degrading trend for lake Tuakitoto over the five-year period is for Chl-a, which is consistent with the 10-year trend.

5.5.4 Groundwater: State Analysis

The results for the groundwater state analysis are shown in

Table *9*. Further description of the monitoring sites and aquifers in the Rohe is found in ORC (2021). These show a mixed pattern, with differences between the monitoring sites in the Inch Clutha (H46/0144) and Pomahaka (G44/0127 & G45/0225) aquifers. The data from the Pomahaka bores shows some exceedances of the DWSNZ MAV for E. coli and median nutrient concentration above the threshold for low intensity land use (Morgenstern and Daughney, 2012). Conversely, the dissolved arsenic concentrations are substantially below the DWSNZ MAV of 0.01mg/L.

The results for bore H46/0144 (situated in the Inch Clutha) highlight different issues, with maximum dissolved arsenic concentrations that substantially exceed the DWSNZ MAV of 0.10mg/L. Conversely, there were no *E. coli* detections in the bore and the median concentrations are below the threshold for low intensity land use.

Table 9 Groundwater current state results for the Lower Clutha Rohe. The key for the colour classification is shown at the bottom of the table

Site	Aquifer/ location	Total no. of samples	No. of detections	*E. coli* % exceed-ance	Median Nitrate concentration (mg/L)	Maximum arsenic concentration (mg/L)
G44/0127	Pomahaka Alluvial Ribbon	18	3	17	3.350	0.000
G45/0225	Pomahaka Alluvial Ribbon	18	3	17	4.05	0.001
H46/0144	Inch Clutha	18	0	0	0.000	0.018

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Dissolved Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

5.5.5 Groundwater: Trend Analysis

The 5- and 10-year trends for groundwater nitrate-N and dissolved arsenic concentrations are shown in Figure 32. The trend for nitrate-N in bore G44/0127 is 'extremely likely' improving' for both the 5 and 10-year trends. Nitrate-N trends for bore H44/0144 were not analysed, likely due to the high number of results below the analytical limit of detection.

The trends for dissolved arsenic for bore H44/0144 are 'unlikely' improving for the 5-year trend and 'extremely unlikely' improving for the 10-year trend. The dissolved arsenic trends for bore G44/0127 were not analysed, as most results were below the analytical limit of detection.

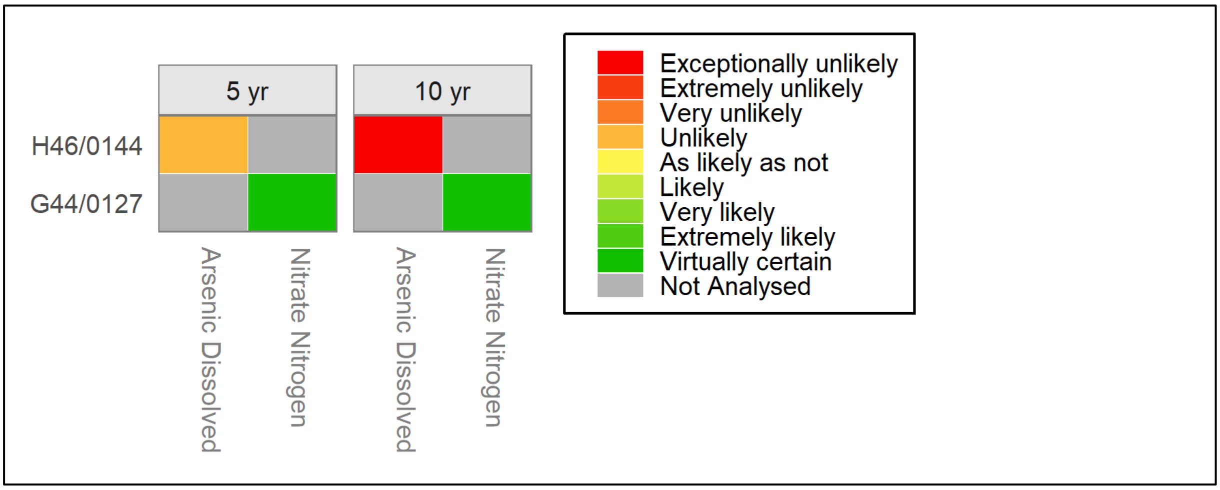


Figure 32: Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

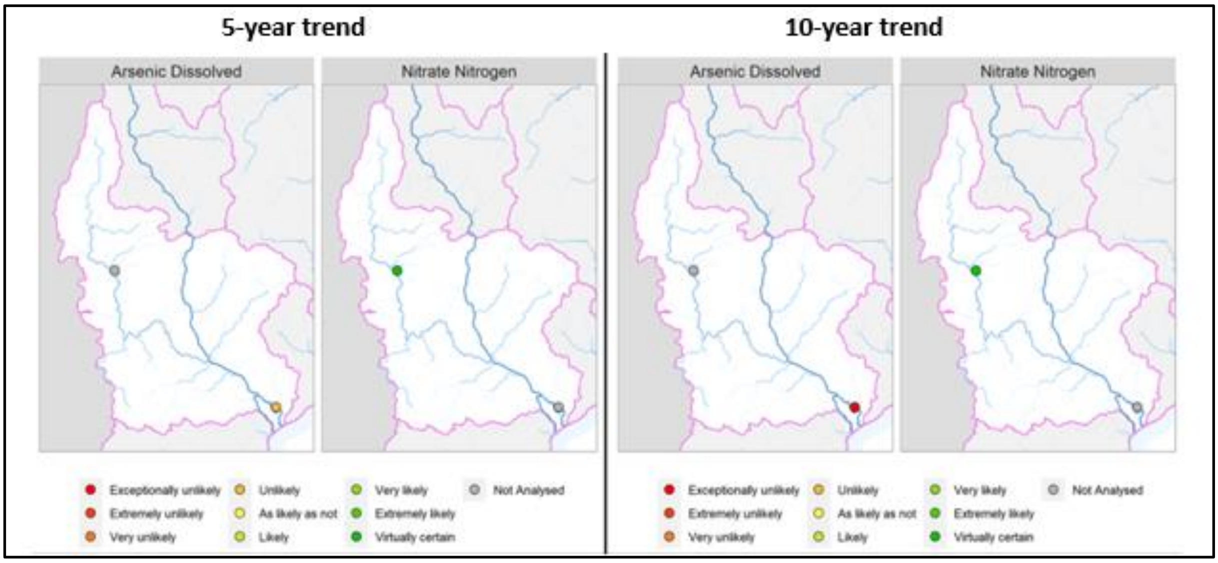


Figure 33: Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Water quality summary and discussion: Lower Clutha Rohe

5.5.6 Water quality summary Lower Clutha Rohe

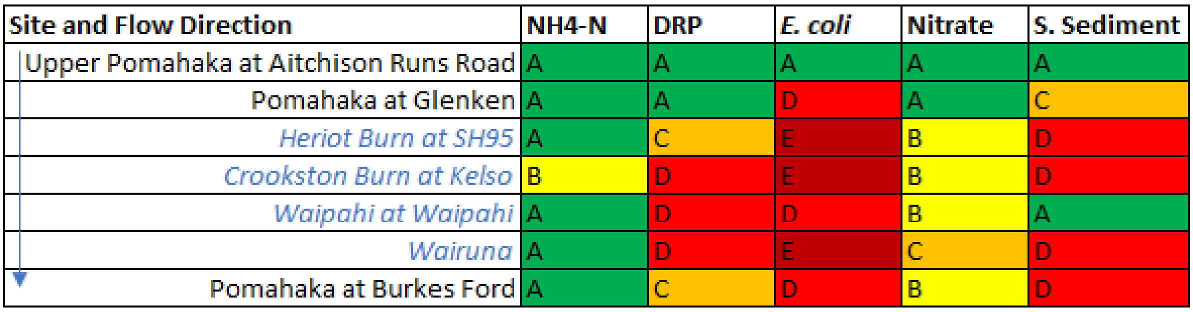
The Pomahaka catchment is the largest in the Rohe and is characterised by poor draining pallic soils, which has resulted in tile and mole drainage being installed to improve grazing land use. Tile drains influence water quality in the streams they discharge into, with the level of influence depending on several factors, including the frequency and volume of flow from individual tile or mole drains, the concentration of nutrients carried by the flowing drain, the total number of flowing drains in the area, land use and land management (ORC, 2011).

The need to improve water quality in the catchment has long been recognised and in 2014 the Pomahaka Water Care Group was established (https://www.pwcg.co.nz/), a farmer-led group to address and improve water quality, this is now supported by NZ Landcare Trust. A large part of this effort is focused on improving bacterial water quality. The high *E. coli* and nutrient concentrations are most likely because of a prevalence of mole and tile drains as well as instances of insufficient effluent storage. Provisions of farm effluent management has been addressed through Plan Change 8 (ORC, 2022).

In the Lower Clutha Rohe, of the 14 sites monitored, eight are in the Pomahaka catchment, six of which have been monitored for more than 20 years. The mainstem Pomahaka shows a gradual deterioration from the Upper Pomahaka (which has good water quality and achieves NPS-FM band 'A' across all attributes), to the Pomahaka at Glenken (which achieves 'A' bands across all attributes, other than a 'D' band for *E. coli* and a 'B' band for suspended fine sediment), to the Pomahaka at Burkes Ford (which achieves a 'C' band for DRP, 'D' band for E. coli, 'C' band for nitrate-N toxicity and 'C' band for suspended sediment). This is illustrated in

Table 10 which shows how the water quality of the Pomahaka degrades from the Upper Pomahaka to the lower Pomahaka at Burkes Ford, the sites in blue are the downstream tributary sites that enter the mainstem Pomahaka.

Table 10 Pomahaka Monitoring Sites, Mainstem sites shown in black, tributary sites shown in blue. The arrow shows the direction of river flow.



Site and Flow Direction	NH4-N	DRP	*E. coli*	Nitrate	S. Sediment
Upper Pomahaka at Aitchison Runs Road	A	A	A	A	A
Pomahaka at Glenken	A	A	D	A	C
Heriot Burn at SH95	A	C	E	B	D
Crookston Burn at Kelso	B	D	E	B	D
Waipahi at Waipahi	A	D	D	B	A
Wairuna	A	D	E	C	D
Pomahaka at Burkes Ford	A	C	D	B	D

The Waipahi River originates in a wetland and water quality is monitored just downstream of the wetland at Waipahi at Cairns Peak. The low clarity found at this site is likely to be due to tannin from the wetland, rather than suspended sediment. Tributaries of the Pomahaka returning high suspended fine sediment results contribute to the ‘D’ grade of the lower Pomahaka at Burkes Ford, compared to the upper reaches that return an ‘A’ grade. The Clutha at Balclutha receives a ‘D’ band for suspended fine sediment due to its source water being meltwater from glaciers in the Upper Lakes Rohe.

The Waipahi at Waipahi receives a ‘D’ band for periphyton. The Waipahi is a nutrient rich river and at Waipahi the river is generally dominated by macrophytes. Abundant periphyton growth will occur during the summer months particularly in the absence of flushing flows. The other three sites (Upper Pomahaka, Blackcleugh Burn and Waitahuna) all achieved ‘A’ bands which may reflect that water quality is low in nutrients, but also that higher rainfall in the area dislodges algal growth to prevent prolific growth.

The *E. coli* NOF attribute state was below attribute band ‘C’ in 12 of the 14 sites monitored, with five sites graded ‘E’, of these five sites three were smaller tributaries in the Pomahaka catchment and most likely reflect the contaminants associated with tile and mole artificial drainage of the heavier soils. Suspended fine sediment was below the national bottom line in seven of the 14 sites and DRP was below attribute band ‘C’ in five of the monitored sites.

Lake Tuakitoto is a large freshwater wetland situated in the Lower Clutha River Rohe, Lovells Creek is the main inflow into the Lake. Lovells Creek scores poorly across all attribute states other than NH4-N and reflects the catchment, which is dominated by intensively grazed pasture supporting sheep, beef, dairy farming, and plantation forestry. Lake Tuakitoto scores ‘D’ bands for *E. coli*, TP, TN and Chl-a (phytoplankton), this situation is unlikely to change, due to the shallow nature of the lake and poor flushing flows.

Although water quality state is generally poor, trend analysis shows that the predominance of degrading 20-year trends has generally shifted to a predominance of improving 10-year trends. An example of this is the ‘virtually certain’ improving trend is *E. coli* concentrations in the Heriot Burn. Although state results are still elevated (‘E’ band) the direction of the trend indicates a substantial improvement in water quality. The lower Pomahaka site at Burkes Ford also shows encouraging results, with DRP showing ‘extremely likely’ improvement. The Waitahuna which had degrading trends for DRP, *E. coli*, NNN, TN, TP, and turbidity over the 20-year period, has no degrading trends over the 10-year period.

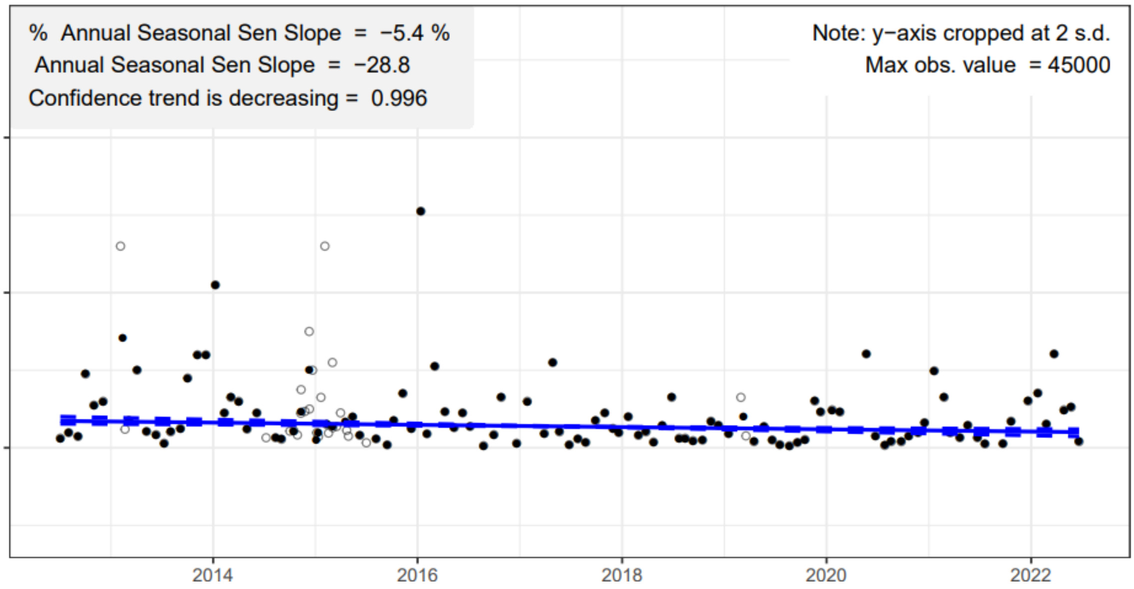


Figure 34 Heriot Burn trend graph showing a 'virtually certain' improving trend in E. coli.

The 5-, 10- and 20-year trends in Lake Tuakitoto show a degrading trend for Chl-a over the three time periods. The major inflow to Lake Tuakitoto, Lovells Creek has degrading trends for TN and NNN, as well as a 'C' band for state analysis for DRP. The added input of nutrients into a wetland that is already nutrient rich is conducive to phytoplankton growth.

Groundwater state analysis show a mixed pattern in the Rohe, with substantial differences between the monitoring sites. The data from the bores in the Pomahaka (G44/0127 and G45/0225) show several exceedances of the DWSNZ MAV for E. coli and median nitrate-N concentrations above the threshold for low intensity land use (Daughney and Morgenstern, 2012). Conversely, the dissolved arsenic concentrations are substantially below the DWSNZ MAV of 0.01mg/L. The E. coli and nitrate-N concentrations are likely due to land use around the bores (e.g., farming), their shallow depths, and poor bore security, which allows easy entry of contaminants to the bore (ORC, 2021).

The results from the Inch Clutha bore (H46/0144) highlight different issues, particularly dissolved arsenic concentrations that substantially exceed the DWSNZ MAV of 0.10mg/L. The causes for these are unclear, although may be attributed to arsenic sourced from organic matter or schist sediments (e.g., Piper and Kim, 2006). The low nitrate-N concentrations may potentially be due to the bore's depth and reducing conditions (which may also increase arsenic mobility), where nitrates break down. Hence nitrate-N concentrations in groundwater may be masked by these geochemical processes which may not reflect the impact of land use on groundwater quality (e.g., Close *et al.*, 2016). It is also important to note that, as there are currently only three monitoring bores in the Rohe, these results do not necessarily provide a comprehensive representation of groundwater quality in it. In light of this, ORC is planning to expand its monitoring network in the Rohe within the next 1-2 years. Nevertheless, it is strongly recommended that bore owners in the Rohe maintain good borehead security, land use and nutrient management, and regularly test their bore water.

6 Taieri FMU

Figure 35 Location of water quality monitoring sites in the Taieri FMU

6.1.1 Taieri FMU Description

The Taieri River is the fourth-longest river in New Zealand, draining the eastern Otago uplands and following an almost circular path from its source to the sea. The Taieri River rises in the Lammerlaw (1210m) and Lammermoor Ranges (1160m) and flows through the dry Maniototo Plain, Strath Taieri Plain and the low-lying Taieri Plain before reaching the Pacific Ocean about 30km south-west of Dunedin. The main tributaries of the Taieri River are the Kye Burn, Sutton Stream, Deep Stream, Lee

Stream, Silverstream and the Waipori River. Water from the Taieri and its tributaries feed seven small rural water supply schemes, three small urban supply schemes, and Dunedin city. The main urban settlements in the Taieri FMU are Mosgiel, Middlemarch, and Ranfurly.

The upper Taieri headwaters drain a relatively undeveloped area of native tussock country on the northern side of the Lammerlaw Range. The river then flows through the dry Maniototo Plain (660km²) which features an intensely meandering channel, oxbow lakes and wetlands and is the best example of a 'scroll plain' in New Zealand. The Maniototo Irrigation Company (MIC) distributes water from the Taieri River, and water stored in the Loganburn Reservoir.

Beyond the northern end of the Rock and Pillar Range, the Kye Burn flows into the Taieri and contributes high levels of sediment to the river. These high sediment loads are in part due to historic gold mining activities in the Kye Burn Catchment. The midreaches of the Taieri River flow through the smaller Strath Taieri Plain, occupying an area of 85km², past Middlemarch, and through the Taieri Gorge onto the Taieri Plain. Many small tributaries join the main stem of the river along this sub-region.

The lower Taieri is dominated by a large floodplain and the associated Lake Waipori/Waihola wetland complex. Part of the lower Taieri plain lies below sea level, and the potential for flooding has resulted in extensive flood protection works, including floodbank construction and channel straightening (e.g., the lower Silverstream) which has significantly altered the physical habitat quality of some river reaches. Lake Mahinerangi (hydro-electricity generation) is situated in the upper Waipori River catchment, and the Waipori confluence with the Taieri is located near Henley.

The main urban settlements in the Taieri FMU are Mosgiel, Middlemarch, and Ranfurly.

ORC monitors 17 river sites and one lake in the Taieri FMU. There are nine SoE groundwater monitoring bores, situated across the Maniototo Tertiary aquifer, the Strath Taieri aquifer, and the Lower Taieri aquifer. Monitoring sites are shown in Figure 35.

6.1.2 State Analysis Results

The results of grading the SoE sites in the Taieri FMU according to the NPS-FM NOF criteria are mapped in Figure 36 and summarised in Figure 37 and Figure 38. Many sites in the Taieri FMU did not meet the sample number requirements and accordingly are shown as white cells with coloured circles. Chl-a was only monitored at a subset of sites, white cells indicates that the variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

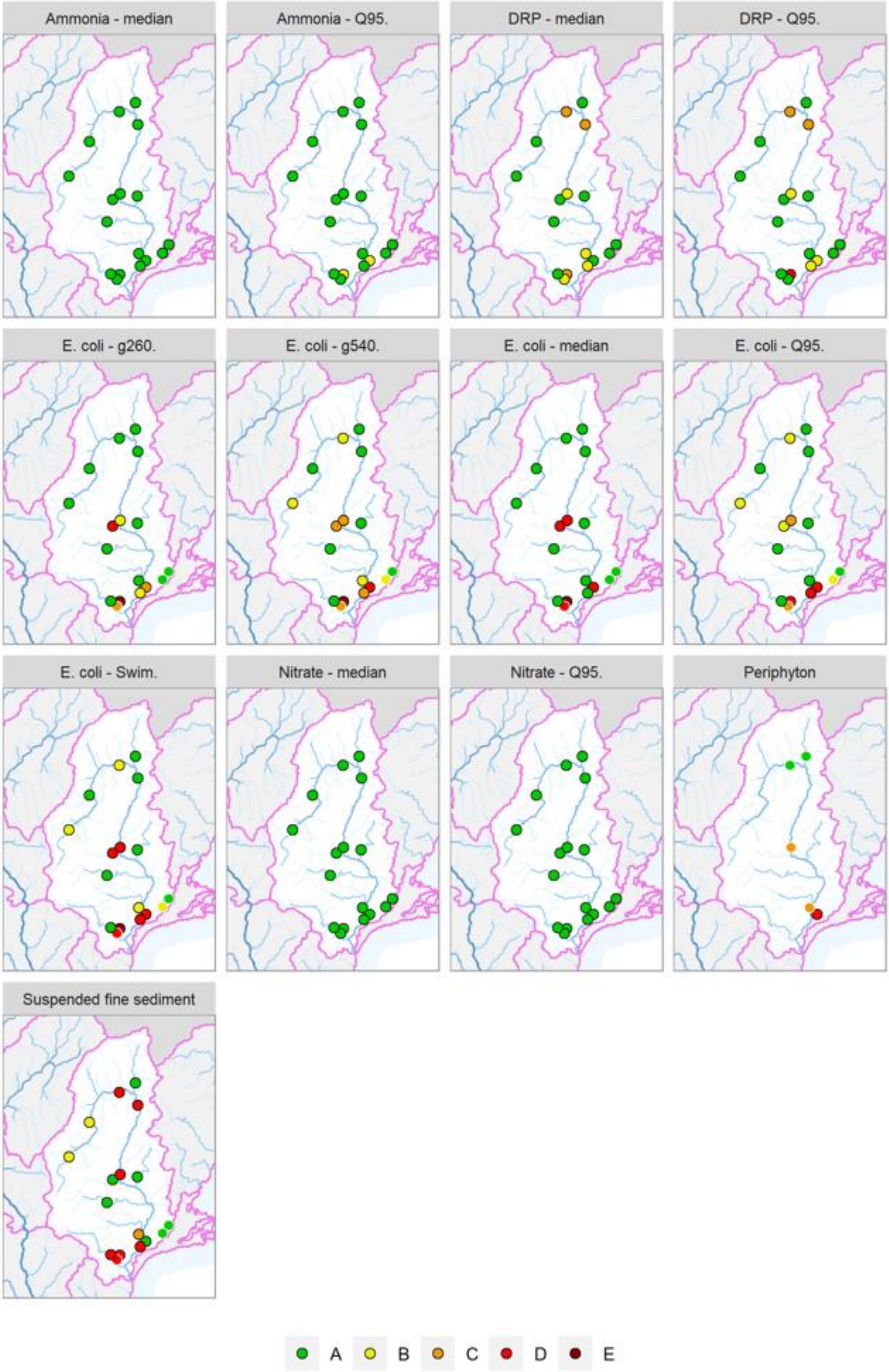

Ammonia - median
Ammonia - Q95.
DRP - median
DRP - Q95.
E. coli - g260.
E. coli - g540.
E. coli - median
E. coli - Q95.
E. coli - Swim.
Nitrate - median
Nitrate - Q95.
Periphyton
Suspended fine sediment
● A
● B
● C
● D
● E

Figure 36 Maps showing Taieri FMU river sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines

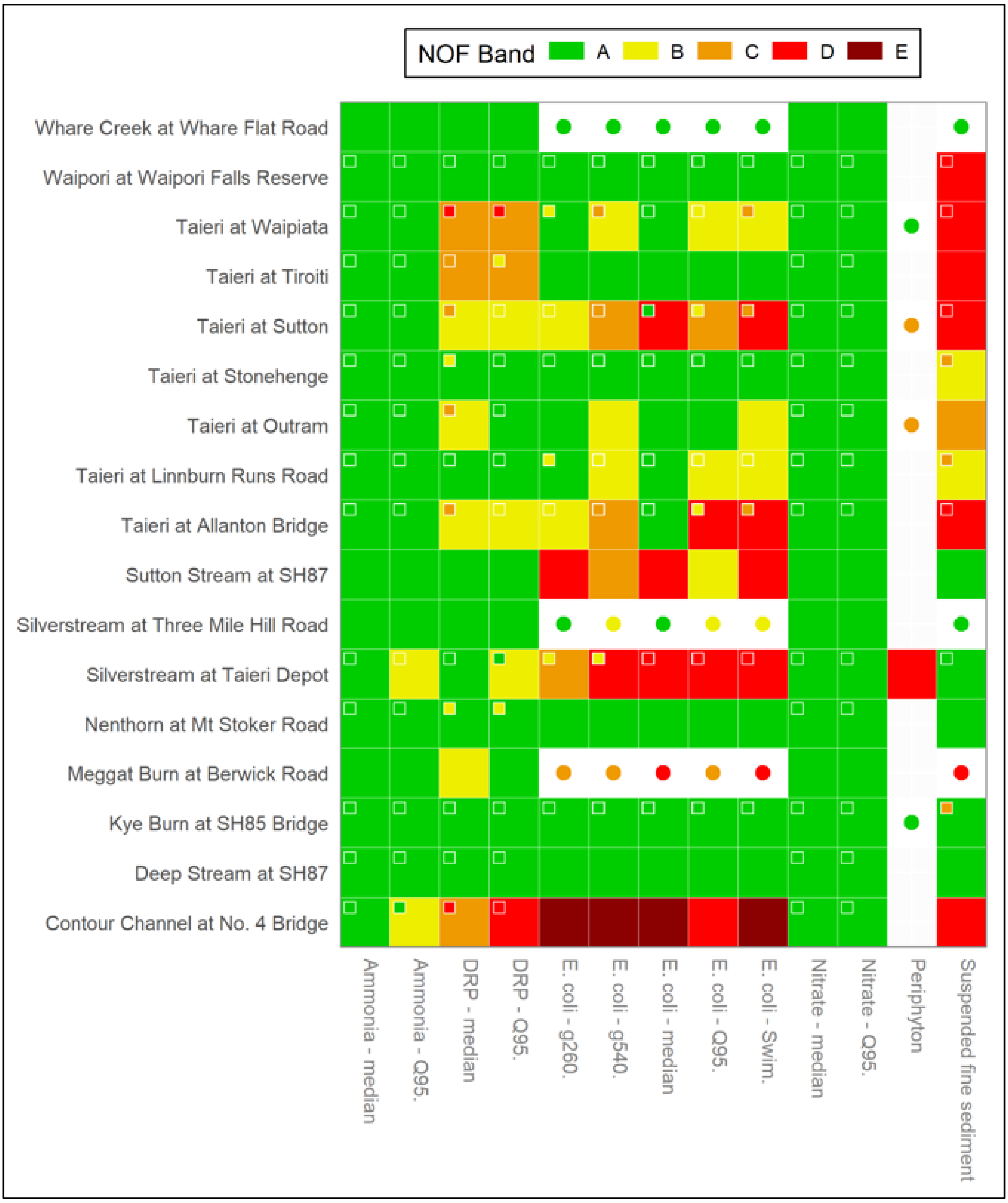


Figure 37 Grading of the river sites of the Taieri FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

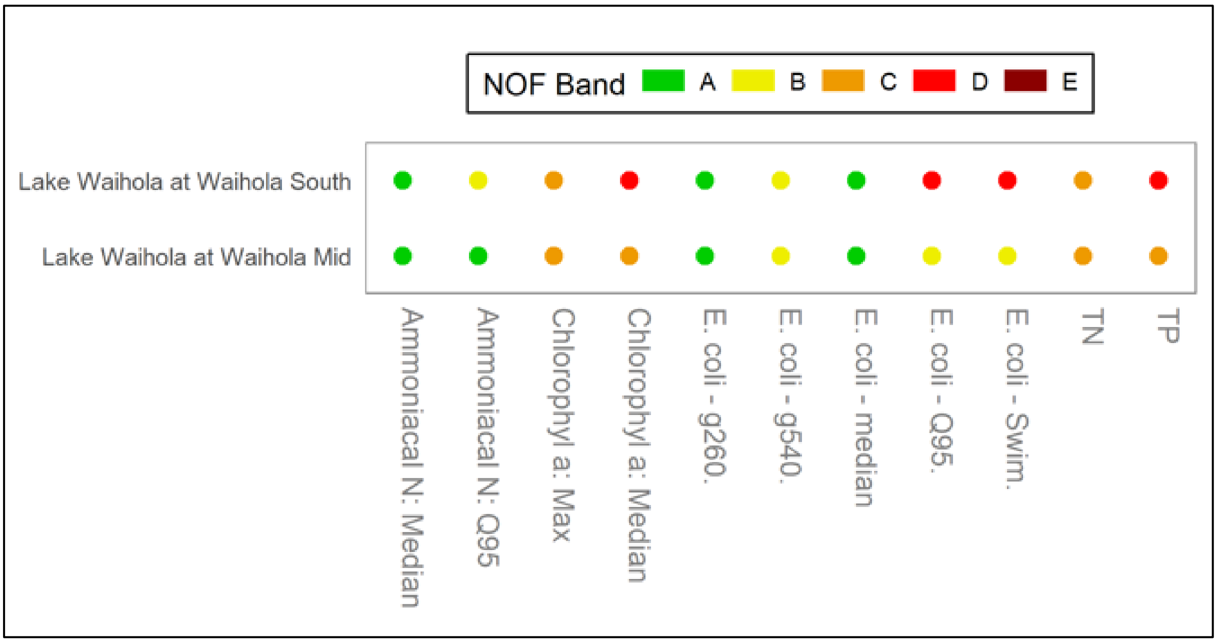


Figure 38 Grading of the lake sites of the Taieri FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements shown as white cells with coloured circles.

6.1.2.1 Phytoplankton, Periphyton and Nutrients

Periphyton trophic state results for the five sites monitored are shown in Figure 37. Results are interim as the monitoring programme started in July 2018, interim results show that the Kye Burn (26 samples) and Taieri at Waipiata (17 samples) achieve an interim 'A' band as few results exceed 50 chl-*a*/m^2, reflecting negligible nutrient enrichment. The Taieri at Sutton (15 samples) and Taieri at Outram (19 samples) achieve an interim 'B' band and the Silverstream (31 samples) is graded 'D' which the NPS-FM, 2020 describes *'regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat low nutrient enrichment but the possibility of occasional blooms'*

Figure 37 shows median DRP for an attribute state around wider ecological health. The results in the Taieri FMU show that most sites achieve either an 'A' or 'B' band, indicating that DRP concentrations are similar to, or only slightly elevated from natural reference conditions. Two sites achieved a 'C' band, including two mainstem Taieri sites (Taieri at Tiroiti and Taieri at Waipiata). The Contour Channel on the Lower Taieri Plain achieved a band 'D' for the DRP Q95 statistic.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. In the Taieri FMU, the Taieri Plain had the highest nutrient concentrations. The Silverstream at Taieri Depot has the highest median NNN concentration (0.41 mg/l) but the DRP at this site was #12 of 16 sites in the FMU (0.0031 mg/l). The contour channel had the highest DRP concentration at 0.017 mg/l, this site had the second highest NNN concentration. Deep Stream had some of the lowest nutrient concentrations.

The NPS-FM (2020) describes how phytoplankton affects lake ecological communities. If phytoplankton is in the 'A' band, then 'Lake ecological communities are healthy and resilient, similar to natural reference conditions'. Figure 38 shows that Lake Waihola is generally in the 'C' band, which the NPS-FM (2020) describes as '*ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state, due to impacts of elevated nutrients*'. Lake Waihola Mid achieves

‘C’ bands for both TN and TP, a ‘C’ band reflecting nutrient enrichment well above natural reference conditions, which is consistent for a shallow freshwater wetland (ORC, 2004), Lake Waihola South has a TP grade of ‘D’ band.

6.1.2.2 Toxicants

The NOF attribute bands for NH4-N are shown in Figure 37 and Figure 38 show excellent protection levels against toxicity risk. All sites return an ‘A’ band other than the Contour Channel and Silverstream which both achieve a ‘B’ band. Lake Waihola Mid returns an ‘A’ band for NH4-N toxicity, at the South site a ‘B’ band is achieved.

The NOF attribute bands for nitrate-N toxicity (measured as NNN) are shown in Figure 37. All sites return an ‘A’ band. The NPS-FM (2020) describes this state as ‘*high conservation value system. Unlikely to be effects even on sensitive species*’.

6.1.2.3 Suspended fine sediment

The suspended fine sediment results for the Taieri FMU are shown in Figure 37 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3 other than Whare Creek which was in sediment class 2. Of the 17 sites monitored, eight sites return a NOF band of ‘D’ which the NPS-FM (2020) describes as ‘high *impact of suspended sediment on instream biota’.* Four of these sites are mainstem Taieri sites; Taieri at Waipiata, Taieri at Tiroiti, Taieri at Sutton and Taieri at Outram, at these mainstem sites the ‘D’ band is due to natural tannin staining of the river, originating from the tussock country and the significant wetland in the Maniototo plain. At the other end of the scale, six sites returned ‘A’ band, they are all tributary sites and include Whare Creek, Sutton Stream, Silverstream (upper and lower), Nenthorn, Kyeburn, and Deep Stream.

6.1.2.4 Human health for recreation

Figure 37 and 38 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Compliance is generally good across the Taieri FMU, of the 17 sites, seven achieve an ‘A’ band, four a ‘B’ band (Taieri main-stem sites at Linnburn, Waipiata and Outram and the Silverstream), the other sites returned bacterial water quality below the national bottom line (five ‘D’ bands and one an ‘E’ band). Lake Waihola graded as a ‘B’ band mid lake and a ‘D’ band at the Waihola South site.

6.1.3 Trend Analysis

Trend analysis results for the Taieri FMU is shown in Figure 39 and Figure 40.

Trend analysis for the Taieri rivers is shown in Figure 39. A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods.

Generally, across the Taieri FMU in the last 10-years compared to the 20-year period there are more improving trends 'likely to virtually certain to be improving' than degrading trends 'unlikely to exceptionally unlikely to be improving'. In the most recent 10-years the degrading trends for *E. coli*, NNN, TN still outweigh improving trends for these analytes, however the trend direction is good as certainty has changed from mainly 'exceptionally unlikely to be improving' to 'unlikely' to be improving.

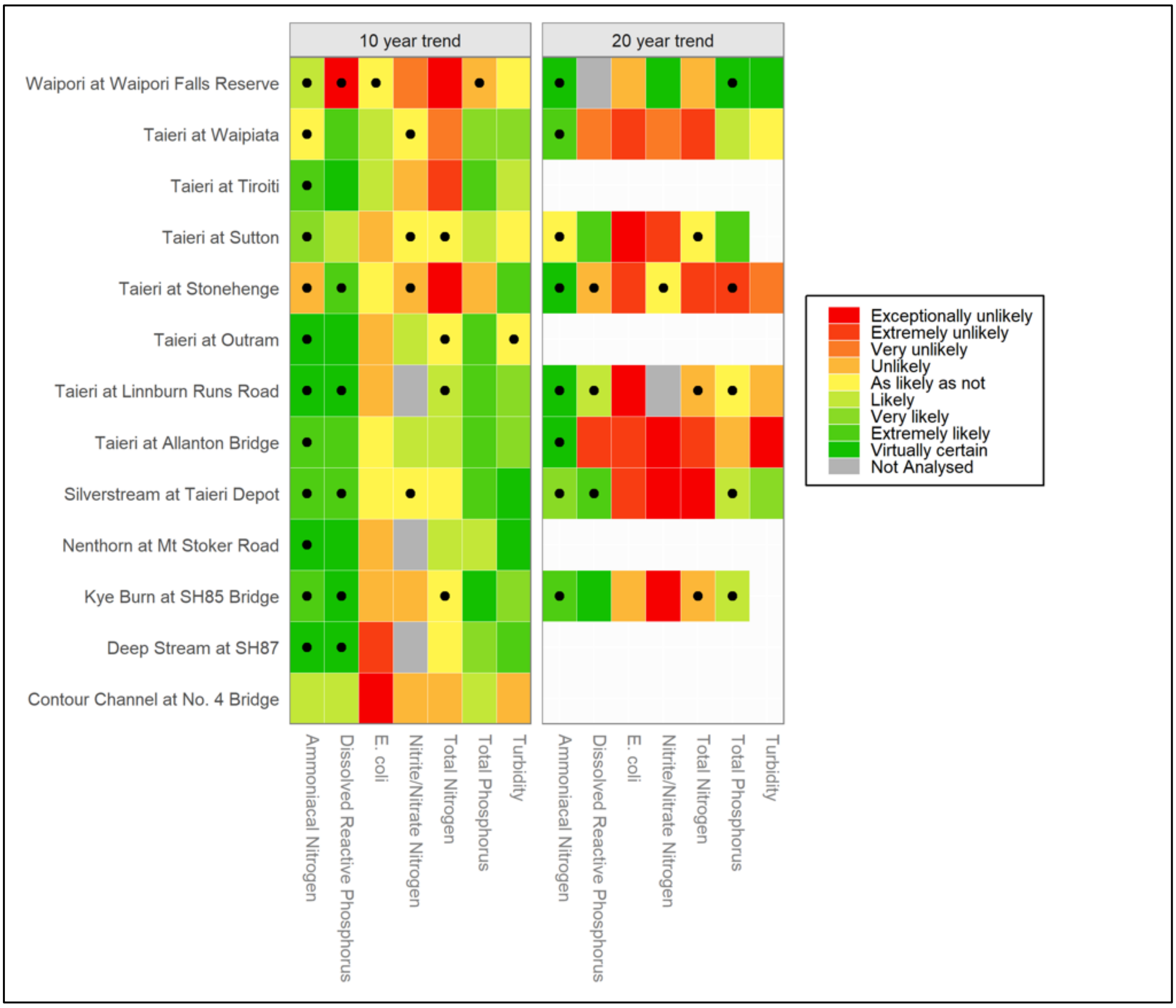


Figure 39 Summary of Taieri FMU river sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend.

Three sites, the Taieri at Waipiata, Taieri at Allanton, Silverstream at Taieri saw a change from the predominance of degrading 20-year trends to a predominance of improving 10-year trends. Conversely, Waipori at Waipori Falls shows more degrading trends in the 10-year analysis, compared to the 20-year analysis.

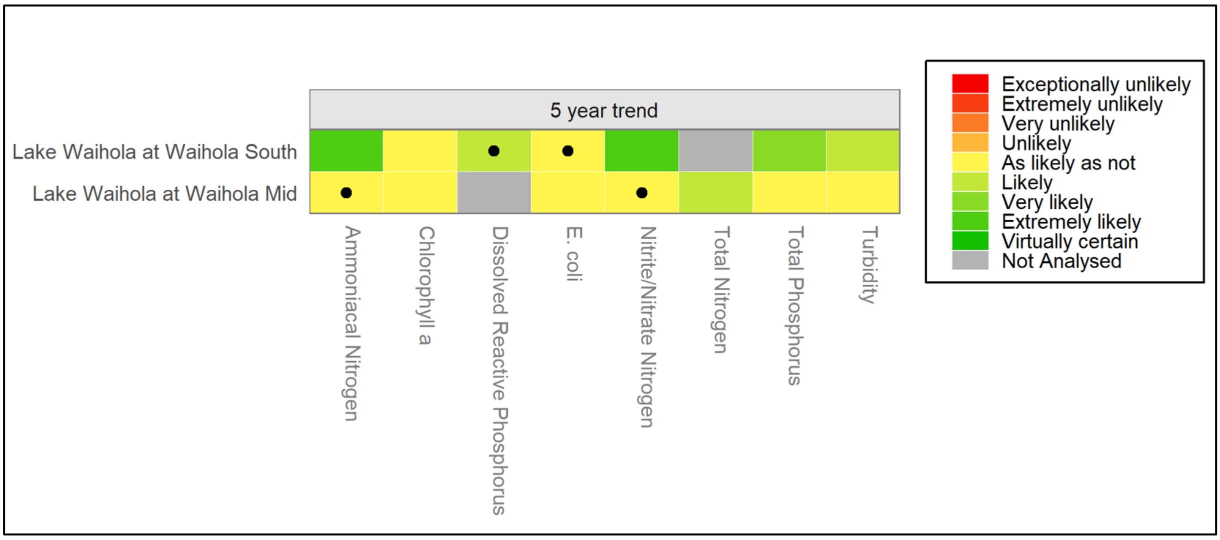


Figure 40 Summary of Taieri FMU lake sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

Trend analysis for the Taieri rivers is shown in Figure 39. A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods.

Generally, across the Taieri FMU in the last 10-years compared to the 20-year period there are more improving trends 'likely to virtually certain to be improving' than degrading trends 'unlikely to exceptionally unlikely to be improving'. In the most recent 10-years the degrading trends for *E. coli*, NNN, TN still outweigh improving trends for these analytes, however the trend direction is good as certainty has changed from mainly 'exceptionally unlikely to be improving' to 'unlikely' to be improving.

Three sites, the Taieri at Waipiata, Taieri at Allanton, Silverstream at Taieri saw a change from the predominance of degrading 20-year trends to a predominance of improving 10-year trends. Conversely, Waipori at Waipori Falls shows more degrading trends in the 10-year analysis, compared to the 20-year analysis.

Trend analysis for 5-year for Lake Waihola is shown in Figure 40. There are no degrading trends during this short time period.

6.1.4 Groundwater

6.1.4.1 Groundwater State

Groundwater quality state for the Taieri FMU is shown in Table 11. The results show high risk of potential faecal contamination, with most bores in the FMU having exceedances of the E. coli DWSNZ MAV, comprising between 10-33% of the samples. All median nitrate-N concentrations are below the DWSNZ nitrate-N MAV of 11.3mg/L. However, nitrate-N concentrations in three bores (H42/0214, situated in the Maniototo Tertiary Aquifer, I44/0519 and I44/0821, both situated in the Lower Taieri aquifer) are above the 2.50mg/L threshold for low intensity land use (Daughney and Morgenstern, 2012), with concentrations in bore I44/0821 exceeding ½ of the DWSNZ MAV. Dissolved arsenic concentrations in the FMU are generally substantially below the DWSNZ MAV of 0.01mg/L. However, much higher concentrations (0.0096mg/L, rounded up in Table 11 i.e., just below the MAV) were measured in bore H42/0213 (situated in the Maniototo Tertiary Aquifer).

Table 11 Groundwater current state results for the Taieri FMU. The key for the colour classification is shown at the bottom of the table.

Site	**Location/ aquifer**	**Total no. of *E. coli* samples**	**No. of Detects**	***E. coli* % exceed-ance**	**Median Nitrate concentration (mg/L)**	**Max. Arsenic concentration (mg/L)**
H42/0213	Maniototo	20	5	25	0.019	0.010
H42/0214	Maniototo	18	6	33	4.500	0.000
H43/0132	Strath Taieri	18	2	11	1.510	0.002
H44/0007	Lower Taieri	11	3	27	0.230	0.000
I44/0495	Lower Taieri	20	2	10	0.006	0.000
I44/0519	Lower Taieri	20	5	25	3.150	0.001
I44/0821	Lower Taieri	20	0	0	5.700	0.000
I44/0964	Lower Taieri	13	0	0	1.570	0.001

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

6.1.4.2 Groundwater Trends

The groundwater trend analysis for the Taieri FMU is summarised in Figure 41 and is shown spatially in Figure 42. The results show that nitrate-N concentrations are 'very'/'extremely unlikely' improving in most bores in the FMU. This includes most bores in the lower Taieri and Strath Taieri (H43/0132) aquifers. The only exceptions, where the trend is 'likely improving' (bore H42/0213) or 'extremely likely improving' (Bore I44/0821), are located in the Maniototo Tertiary the Lower Taieri aquifers, respectively Figure 42. The 10-year trends show a mixed, and more positive outlook, with 'likely' or 'very likely improving' trends in three bores, all located in the lower Taieri aquifer. Conversely, other two bores in the aquifer show 'exceptionally unlikely improving' (I44/0519) or 'unlikely improving' (I44/0964) trends. The comparison between the 10 and 5-year trends was generally not favourable, with most trends either remaining in the same confidence level (e.g., I44/0821, I44/0519) or degrading (e.g., I44/0964, H43/0132). The 10-year trends were not assessed for the bores in the Maniototo Tertiary aquifer (H42/0213, H42/0214) as they were only monitored since 2015. The five-year trend for dissolved arsenic was only analysed for bore H42/0213, which shows that arsenic concentrations are ‘exceptionally unlikely improving’. Ten-year trends for arsenic were not analysed due to lack of data and high number of samples below the analytical limit of detection.

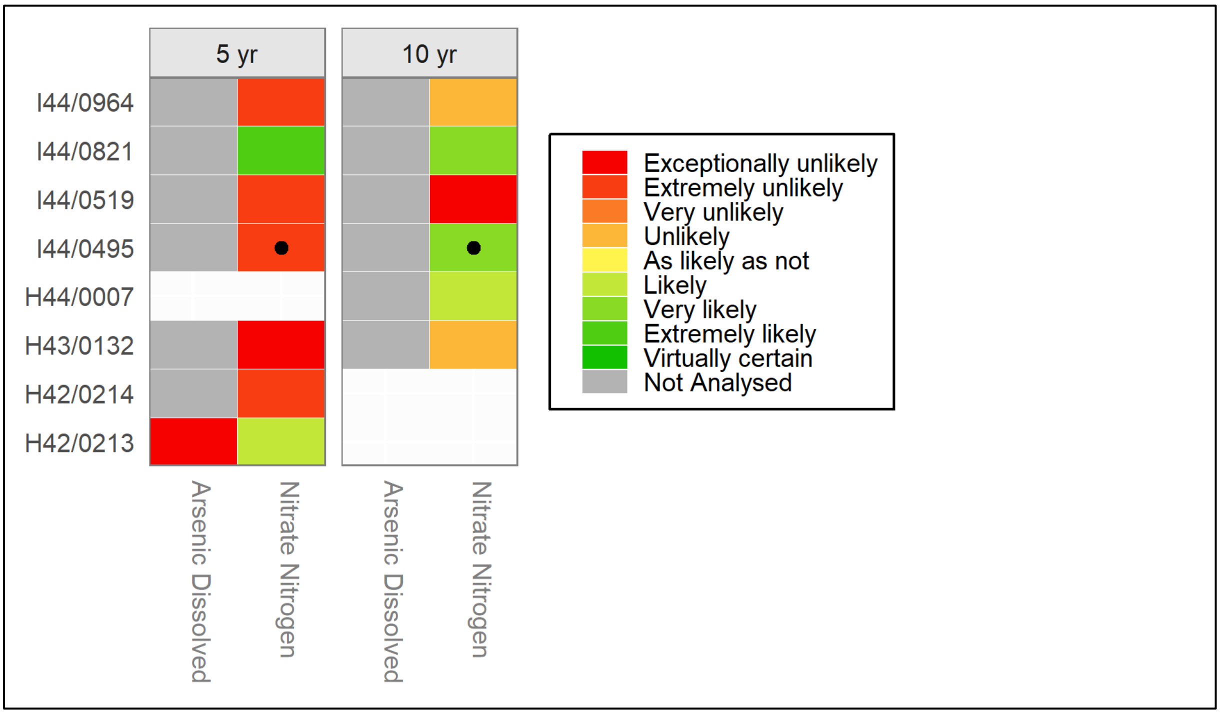


Figure 41: Summary of Taieri FMU sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

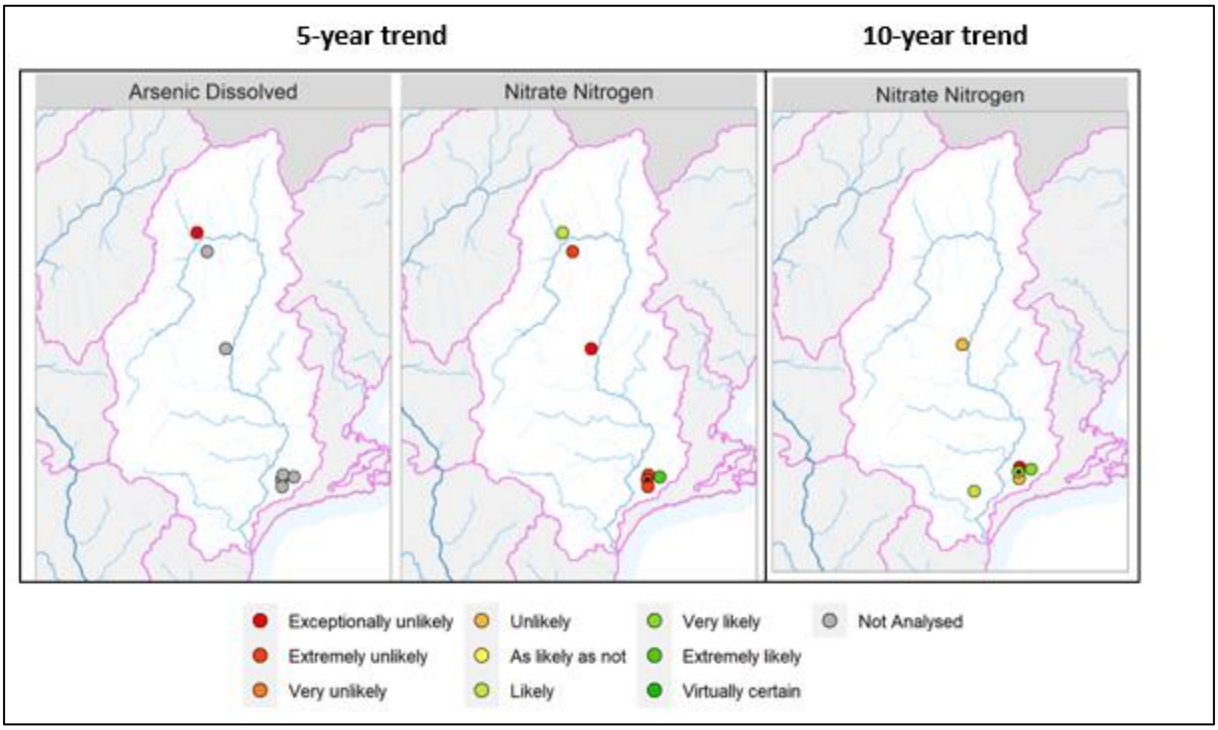


Figure 42: Groundwater quality 5 -and 10-year trend results for the Taieri FMU (LWP, 2023). Note that the 10-year trend for dissolved arsenic were not analysed.

6.1.5 Water quality summary Taieri FMU

The Taieri FMU covers about 570,000 hectares of land. The dominant land use in the Taieri FMU is dry-stock farming (71%), comprising of sheep and beef (57%); mixed sheep, beef, and deer (8%); and sheep farming (6%). Conservation estate occurs on approximately 10% of the Rohe. Forestry and Dairy farming occur on 5% and 4% of the FMU, respectively. The notable trends in land use change over the past three decades have been an increase in the extent of dairy farming (31%), conservation estate (by 58%), forestry (by 7%), urban area (by 15%), and nurseries/ vineyards/orchards (by 18%). The extent of dry-stock farming decreased by 8%, although it remains the dominant land use activity in the Taieri area.

Water quality in the Taieri FMU is generally good with the majority of sites and attributes achieving 'A' and 'B' bands, as seen in Figure 37, however some of the tributaries on the lower Taieri plain have some of the poorest water quality in the region. Two streams are monitored in the Plain: the Contour Channel and the Silverstream. Both these watercourses are maintained for flood protection purposes with contoured bed and banks, have little riparian vegetation and drain a catchment that is predominantly intensively farmed in their lower reaches, as well as hosting the largest settlement in the Taieri, Mosgiel, with its associated stormwater infrastructure in the township and many lifestyle blocks that use septic tanks for their wastewater.

Although the upper Silverstream has good water quality and meets NOF attribute 'A' or 'B' bands, the lower Silverstream has a poorer outcome. The lower Silverstream returned 'D' bands for three of four *E. coli* statistics and periphyton. Although the Silverstream has low DRP concentrations, the lack of shade and few flushing flows create ideal conditions for cyanobacteria, which blooms in the lower reaches of the Silverstream most years. Appendix 1 shows that NNN concentrations in the Silverstream increase from a median of 0.0076 mg/l at Three Mile Hill Road to 0.41 mg/l at the lower Silverstream site. The high NNN concentrations allow for prolific algal growth.

The Contour Channel achieves a 'D' band for *E. coli,* DRP and suspended fine sediment. The Contour Channel is a manmade channel that conveys water off the Maungatua's directly to Lake Waipori, it will also drain some of the low-lying agricultural land on the Taieri Plain. It is similar to the Silverstream, being open with no riparian vegetation.

Despite relatively good bacterial water quality throughout the Taieri FMU, *E. coli* is the worst performing attribute with six of the 17 sites failing to meet the national bottom line. The six include two mainstem Taieri sites; Sutton and Allanton. The change from 'A' band *E. coli* at Tiroiti at the top of the Strath Taieri, to a 'D' band at Sutton at the bottom of the Strath Taieri is concerning.

Lake Waihola shows nutrient and phytoplankton concentrations generally in the NOF 'C' bands, this is typical of a productive lake (wetland complex) where elevated concentrations of nutrients are expected compared to deep alpine lakes. Lake Waihola has episodic algal blooms typical of such a eutrophic lake.

Trend analysis shows that the generally degrading 20-year trends has shifted to a predominance of improving 10-year trends. An example of this is the Taieri at Waipiata, which over 20-years had degrading trends for DRP, *E. coli*, NNN and TN, however over the last 10-years the trends for DRP and *E. coli* are 'likely to 'extremely likely' to be improving. The upper Taieri catchment group (Upper Taieri Wai) are instrumental in pushing for improvement, the multistakeholder group's goals are to enhance environmental and community values throughout the Upper Taieri catchment. The recent 5-year Tiaki Maniototo project received funding from the Ministry for the Environment (MfE) and is run by the Upper Taieri Wai with the aim of improving freshwater quality, ecosystem values and biodiversity in the Upper Taieri catchment.

An example of the possible impact of improved farming practice and catchment group work in the Upper Taieri is that in the 20-year period there were 19 attributes with ‘very unlikely to extremely unlikely’ improving trends, whereas in the 10-year period, this had decreased to eight.

Groundwater quality state analysis from the Taieri FMU showed a high potential risk for faecal contamination, with E. coli exceedances measured in most monitoring bores. All median nitrate-N concentrations are below the DWSNZ MAV of 11.3mg/L. However, nitrate-N concentrations in some bores are above the 2.50mg/L threshold for low intensity land use (Morgenstern and Daughney, 2012) and one exceeds ½ of the DWSNZ MAV. Dissolved arsenic concentrations in the FMU are generally substantially below the DWSNZ MAV of 0.01mg/L. However, the maximum concentration in bore H42/0213 (situated in the Maniototo Tertiary Aquifer) was much higher, at just below the DWSNZ MAV. The trend analysis of groundwater nitrate-N concentrations in the FMU paints a sombre picture. The 10-year trends show a mixed, pattern, with ‘likely’ or ‘very likely improving’ in three bores, all in the lower Taieri aquifer. Conversely, other two bores in the aquifer show ‘exceptionally unlikely improving’ (I44/0519) or ‘unlikely improving’ (I44/0964) trend. However, the 5-year trends within most bores in the FMU, with all bores apart from I44/0821 falling to ‘very’/’extremely unlikely’ improving, which suggesting that groundwater quality is not improving for this period. The 5-year trend for dissolved arsenic was only analysed for bore H42/0213, which shows that arsenic concentrations are ‘exceptionally unlikely improving’. However, as arsenic concentrations are likely to be mainly controlled by factors such as geology this result is probably not very meaningful. Ten-year trends for arsenic were not analysed due to lack of data and high number of samples below the analytical limit of detection.

The *E. coli* exceedances and nitrate-N concentrations are likely because most monitoring bores in the FMU are located in areas of intensive farming and/or septic tanks, particularly in the Lower Taieri plain aquifer. In addition to that, most monitoring bores are poorly secured, hence these results are not surprising. Dissolved arsenic concentrations in the FMU are generally much lower than the DWSNZ MAV of 0.01mg/L, apart from bore H42/0213 (situated in the Maniototo Tertiary Aquifer). The source of the arsenic is unknown, although it is likely to be the local schist lithology of the ridges surrounding the Maniototo basin. The variability in arsenic concentrations between this bore and the other ones further illustrates the spatial variability of arsenic in groundwater, which was also illustrated in other parts of the region, e.g., the Upper Lakes (Section 5.1.5). Based on these results, it is therefore strongly recommended that bore owners across the FMU maintain good bore security, practice good land/nutrient management and septic tank maintenance, and regularly test their bore water.

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7 Dunedin & Coast FMU

Figure 43 Location of water quality monitoring sites in the Dunedin & Coast FMU

7.1.1 Dunedin & Coast Description

The Dunedin & Coast Freshwater Management Unit (FMU) spans over 1,000 square kilometres and runs from just south of Karitane down to the mouth of the Clutha/Mata-Au. Dunedin city is the largest urban area in the FMU and has the largest population in Otago. Many of the rivers are short river or stream catchments, some associated with estuaries and/or wetlands, especially where the Taieri River cuts through the FMU.

The main catchments are the Waitati River, Leith Stream and Kaikorai Stream catchments within Dunedin city and the Tokomairaro (Tokomairiro) River in the south near Milton.

The Waitati River has a catchment area of 46.5 km^2, the main stem flows for approximately 5.5km in a north easterly direction from Swampy Summit to join Blueskin Bay at Waitati. The Leith Stream catchment covers an area of 42 km^2. The headwaters of the Leith Stream originate at the saddle between Mount Cargill and Swampy Summit and flow for 12 km in a south-easterly direction to discharge directly to Otago Harbour, Dunedin. The Kaikorai Stream has a total catchment area of 55 km^2 and flows in a south westerly direction for approximately 15 km down the Kaikorai Valley into Kaikorai Estuary. The Tokomairiro River, located about 48 km south-west of Dunedin, has a catchment area of 403 km^2.

The area has a marine-temperate climate and outstanding features, including a natural character and form of coastal landscape, e.g., Otago Peninsula; ecological values, e.g., cloud forests of the Leith and Ōrokonui Ecosanctuary; healthy estuaries, e.g., Hoopers/Papanui, Blueskin, Akatore, Pūrākaunui; wetlands, e.g., Swampy Summit Swamp; notable wildlife, e.g., hoiho, northern royal albatross, seals, sea lions, red-billed gulls, black-billed gulls; and healthy marine habitats. It is also home to threatened species, including lamprey in coastal streams.

ORC monitors seven river sites and one groundwater site in the Dunedin & Coast FMU. There is currently only one monitoring bore with this FMU, situated in the Tokomairaro GWMZ. Monitoring sites are shown in Figure 43.

7.1.2 State Analysis Results

The results of grading the SoE sites in the Dunedin & Coast FMU according to the NPS-FM NOF criteria are mapped in Figure 44 and summarised in Figure 45. Many sites in the Dunedin & Coast FMU did not meet the sample number requirements and accordingly are shown as white cells with coloured circles. Periphyton (Chl-a) was only monitored at a subset of sites, white cells indicate that this variable was not monitored at a site. A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements

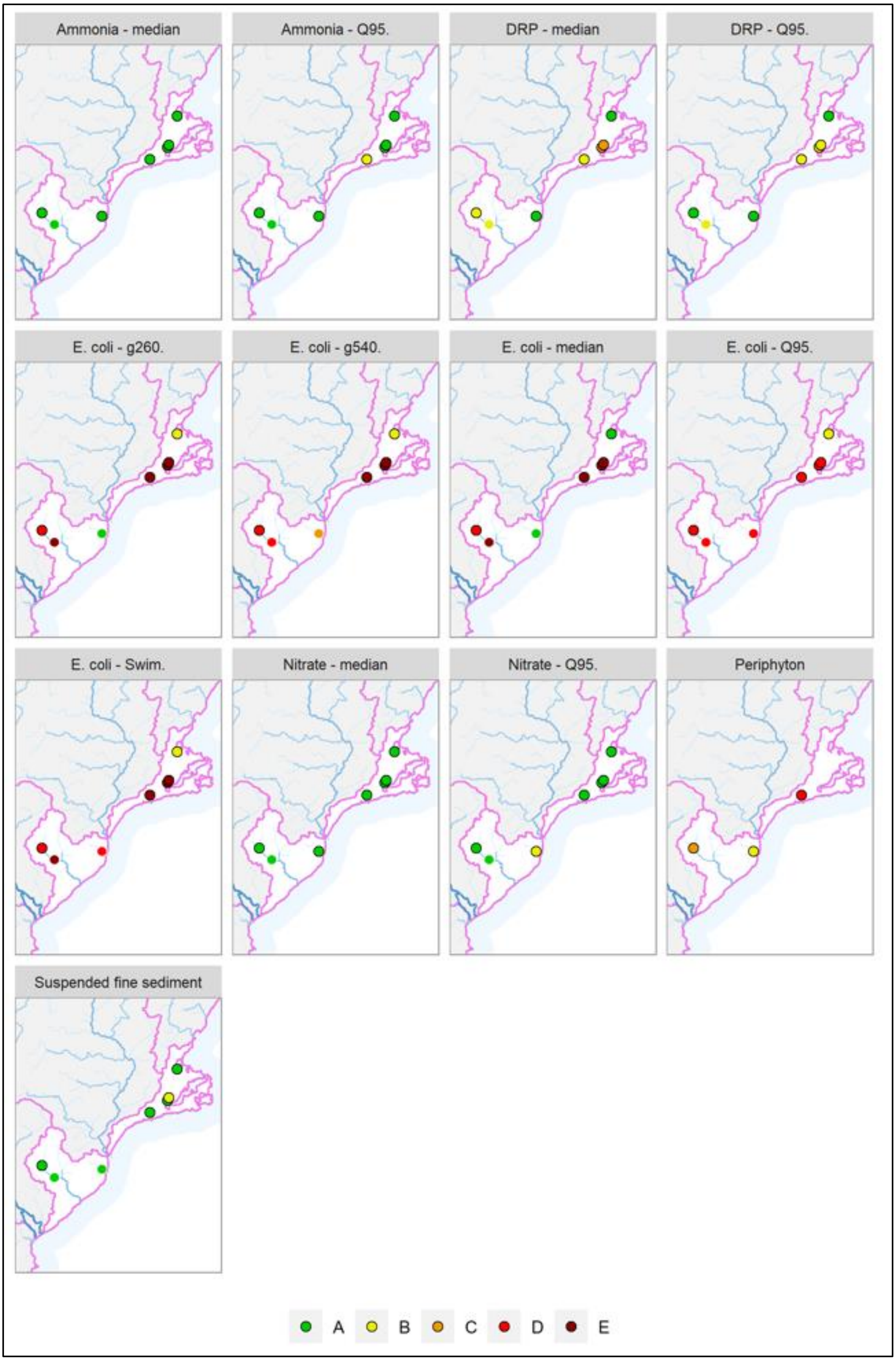


Figure 44 Maps showing Dunedin & Coast FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines.

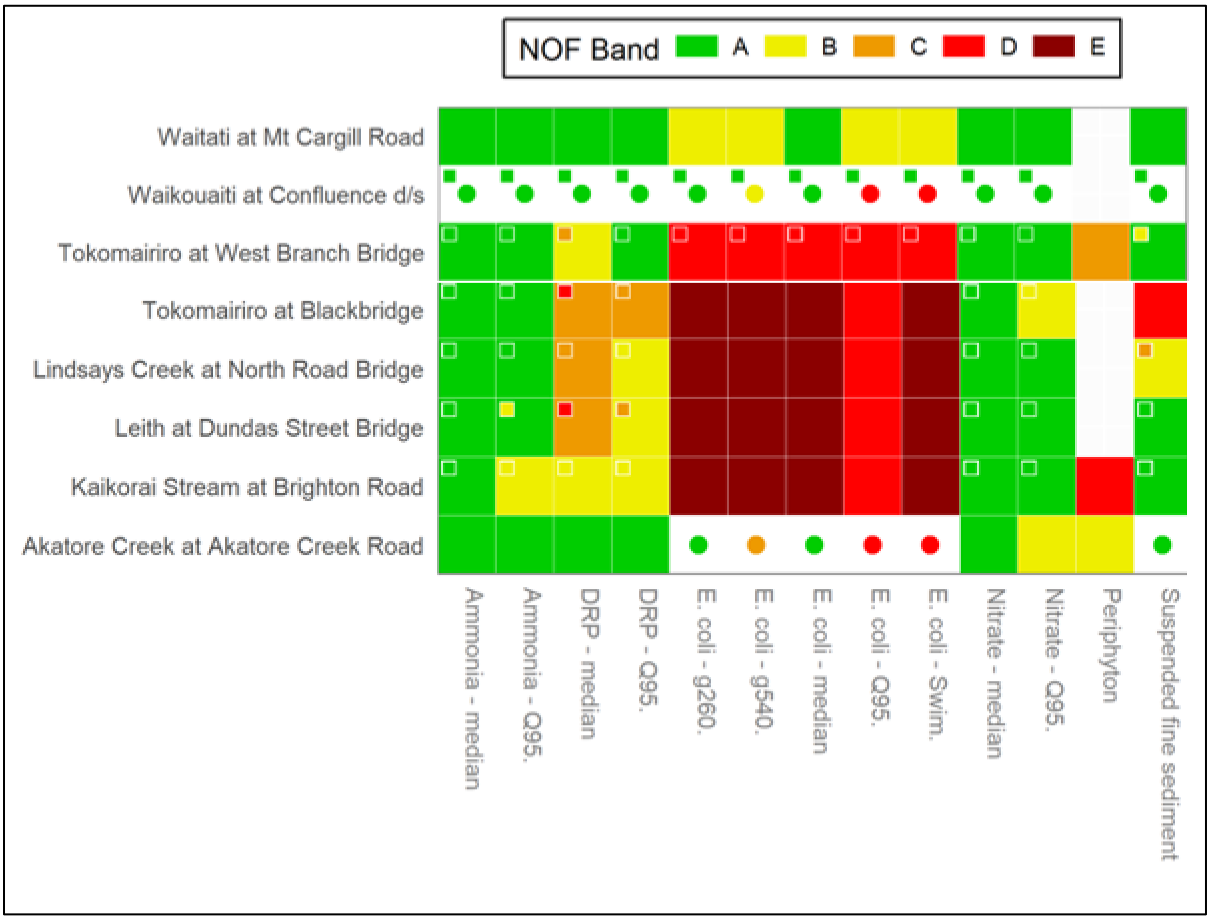


Figure 45 Grading of the river sites of the Dunedin & Coast FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

7.1.2.1 *Periphyton and Nutrients*

Results for the river periphyton trophic state results are shown in Figure 44 and Figure 45 (periphyton). Periphyton trophic state results to date show that Akatore Creek is in attribute band 'B' as results tend to be between >50 and ≤120 chl-*a*/m^2 meaning low nutrient enrichment. The Kaikorai Stream is in attribute band 'D' for periphyton as results tend to be >200 chl-*a*/m^2 reflecting high nutrient enrichment and the possibility of regular nuisance blooms and the Tokomairiro has an attribute band of 'C' indicating moderate nutrient enrichment.

Figure 44 and Figure 45 show DRP attribute states for ecosystem health (DRP median and Q95). The results in the Dunedin & Coast FMU show that three sites achieve an 'A' band for DRP (Waitati River, Waikouaiti River, Akatore Creek), two sites achieve a 'B' band (Kaikorai Stream, Tokomairiro at West Branch Bridge) and three sites a 'C' band (Leith at Dundas Street, Lindsay's Creek, Tokomairiro at Blackbridge). The NPS-FM (2020) describes band 'C' as *'Ecological communities impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate and fish taxa, and high rates of respiration and decay'.*

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. Sites with the highest median NNN concentrations are Lindsay's Creek at North Road Bridge (0.58 mg/l), the Leith at Dundas Street (0.46 mg/l), Kaikorai Stream (0.4 mg/l) and Tokomairiro at Blackbridge (0.39 mg/l) respectively. These four sites also have the highest median DRP concentrations.

7.1.2.2 Toxicants (Rivers)

NOF attribute bands for NH4-N are shown in Figure 44 and Figure 45, the national bottom line for toxicants (NH4-N and NNN is below band 'B'. In the Dunedin & Coast FMU, of the nine sites monitored, eight sites have excellent protection levels against ammonia toxicity returning an 'A' band (highest level of protection) for NH4-N. Only the Kaikorai Stream returned a 'B' band for the Q95 statistic. The NPS-FM describes the 'B' band as *'95% species protection level: Starts impacting occasionally on the 5% most sensitive species'.*

NOF attribute bands for nitrate-N (measured as NNN) toxicity are shown in Figure 44 and Figure 45, again the national bottom line is below band 'B'. In the Dunedin & Coast FMU all sites achieve an 'A' band across both statistics, other than Tokomairiro at Blackbridge and Akatore Creek which achieved 'B' band for the Q95 statistic.

7.1.2.3 Suspended fine sediment (Rivers)

The clarity results for the Dunedin & Coast FMU are shown in Figure 44 and Figure 45 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 2. Of the eight sites monitored, six returned a NOF attribute band of 'A' which denotes '*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions'* (NPS-FM, 2020). Lindsay's Creek returns a NOF band of 'B' and the Tokomairiro at Blackbridge achieves a 'D' band, which the NPS-FM describes as *'moderate to high impact of suspended sediment on instream biota. Sensitive fish species may be lost'*

7.1.2.4 Human health for recreation (Rivers)

Figure 44 and Figure 45 summarise compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Compliance is generally poor across the Dunedin & Coast FMU, with all sites other than the Waitati River (Band 'B') and Waikouaiti River (Band 'A') returning bacterial water quality below the 'C' band.

7.1.3 Trend Analysis: Rivers

Trend analysis results for the Dunedin & Coast FMU is shown in Figure 46.

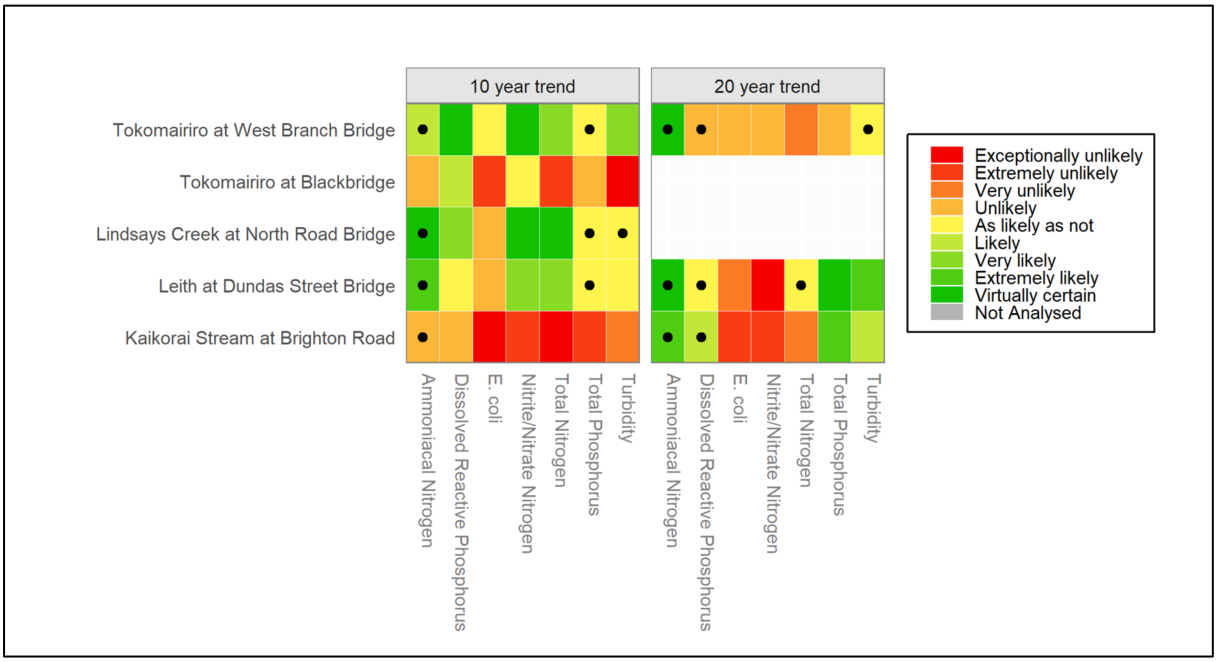


Figure 46 Summary of Dunedin & Coast surface water FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

Trend analysis for the Dunedin & Coast FMU rivers is shown in Figure 46. The Tokomairiro at Blackbridge and Lindsay's Creek at North Road only have 10-year trends available, the other three sites have both 10- and 20-year trends available.

Comparing sites with both 10- and 20-year trends (Tokomairiro at Blackbridge, Leith at Dundas, Kaikorai at Brighton Road) the Tokomairiro and Leith saw a change from the predominance of degrading 20-year trends to a predominance of improving 10-year trends. The converse was the case for the Kaikorai Stream with a change from predominantly improving trends, to one of degrading trends over the 20-year period. The Tokomairiro at Blackbridge, has 'extremely unlikely' to 'exceptionally unlikely' improving trends for *E. coli*, TN, and turbidity, when the upstream site at West Branch Bridge shows improving trends. The Leith and it's tributary, Lindsay's Creek have similar 10-year trends with *E. coli* being the only degrading ('unlikely' to be improving) trend of the analytes monitored.

7.1.4 Groundwater

7.1.4.1 Groundwater State

The state of groundwater quality in the Dunedin & Coast FMU is summarised in Table 12. The results generally show good groundwater quality, with no exceedances of the DWSNZ MAV. There were no detections of E. coli in the bore. The median nitrate-N concentration, 0.001mg/L, is substantially lower than the threshold for low intensity land use (and Daughney, 2012). Conversely, the maximum arsenic concentrations are high, at 0.0047mg/L (rounded up in Table 12). However, concentrations have dropped since 2018, and were below the limit of detection since September 2020 (ORC, 2021).

Table 12 Groundwater current state results for the Dunedin & Coast FMU. The key for the colour classification is shown at the bottom of the table.

Site	**Aquifer**	**Total no. of *E. coli* samples**	**No. of *E. coli* Detections**	***E. coli* % exceedance**	**Median Nitrate concentration (mg/L)**	**Max. Arsenic concentration (mg/L)**
H45/0314	Tokomairiro GWMZ	18	0	0	0.001	0.005

E. coli	nitrate	diss. Arsenic
no detections	<2.50 mg/L	<0.0025 mg/L
<10%	2.50 - 5.50 mg/L	0.0025 - 0.005 mg/L
10-50%	5.50 - 11.3 mg/L	0.005 - 0.01 mg/L
>50%	>11.3 mg/L	>0.01 mg/L

7.1.4.2 Groundwater Trends

The five-year trends for the Dunedin & Coast FMU are shown in. Dissolved arsenic is the only parameter analysed and the analysis was only done for a five-year period. Nitrate-N is likely not to have been analysed due to the low concentrations. The results show that dissolved arsenic concentrations are ‘extremely likely’ improving.

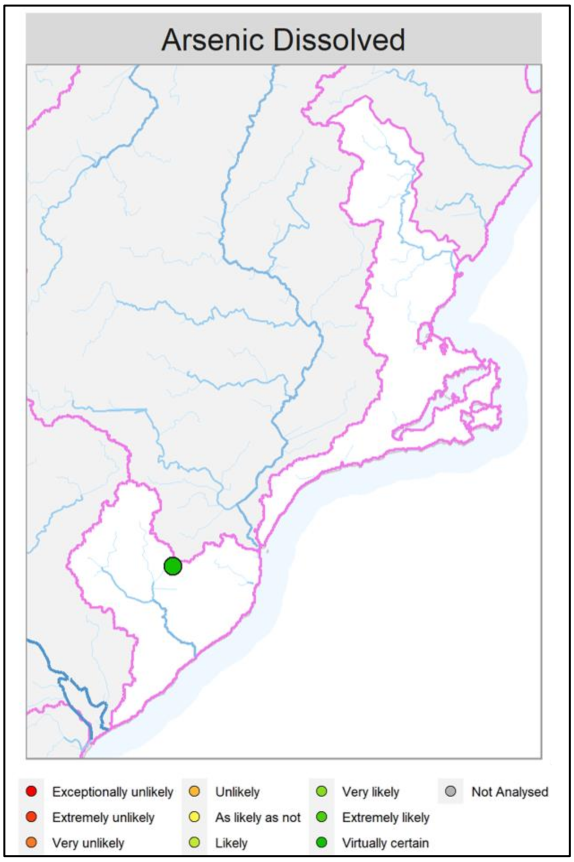


Figure 47 Summary of Dunedin & Coast groundwater FMU sites categorised according to the level of confidence that their 5-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend.

7.1.5 Water quality summary Dunedin & Coast FMU

The dominant land use in the Dunedin & Coast FMU is plantation forestry (28%). Dry-stock farming comprising of sheep and beef (19%); mixed sheep, beef and deer (4%); beef (5%) and sheep farming (8%), also cover a significant portion of the FMU. Dairy farming occurs on approximately 8% of the area. Approximately 7% of the FMU is for urban use. The notable trends in land use change over the past three decades have been an increase in the extent of dairy farming (38%), public conservation estate (by 55%), plantation forestry (by 19%), and urban land use (by 4%). The extent of dry-stock farming decreased by 14%, although it remains amongst dominant land use activities in the Dunedin & Coast area.

In the Dunedin & Coast FMU water quality generally has high bacteria and nutrient concentrations. The Kaikorai has an ammonia toxicity band of 'C' placing it below the national bottom line, it is the only site in Otago that has a NH4-N toxicity below band 'B'. Nitrate-N toxicity across the FMU achieved an 'A' band, other than the Tokomairaro at Blackbridge and the Kaikorai Stream which achieved 'B' band when compared to the Q95 nitrate-N statistic.

E. coli was below attribute band 'C' in six of the eight sites monitored. The Kaikorai, Leith and Lindsay's Creek are Dunedin urban streams, their catchments have a high degree of urbanisation in their lower reaches. Urbanisation comes with associated stormwater drains that discharge directly into the rivers. The quality of stormwater is generally poor with elevated nutrients and *E. coli* concentrations.

All urban sites and sites in the Tokomairaro catchment have high median bacteria concentrations which may indicate an *E. coli* source that is affecting water quality even under low flow conditions. In agricultural settings this could be the presence of waterfowl, stock, or artificial drainage and in urban streams this could be due to point source discharges. Both the Tokomairiro River sites are located in rural settings, the upper site, West Branch Bridge is located just downstream of hill country and the Manuka Gorge, whereas Blackbridge is located downstream of the intensive farming area of the Tokomairaro flats to the West of Milton township. Although both sites return *E. coli* results below the national bottom line, median *E. coli* at the lower site was over four times that of the upper site. The disparity may be due to differences in land use and the soil type below the gorge being generally fine textured silt or clay requiring artificial drainage to lower the water table and improve soil drainage. Although this allows more oxygen into the soil limiting the reduction capacity and minimising the occurrence of runoff, it creates a pathway for water to transport contaminants through the soil to the river.

Alongside the poor state, trend analysis shows that water quality trends over 10-years is improving for all sites other than the Kaikorai Stream and the Tokomairiro at Blackbridge. Of the urban streams, the Kaikorai stream continues to degrade over the 10-year trend (all attributes), however the Leith and Lindsay's creek show improving trends across all attributes, other than for DRP with is 'unlikely' to be improving at both sites.

The Tokomairiro at Blackbridge has degrading trends for *E. coli*, TN, and turbidity, when the upstream site at West Branch Bridge shows improving trends. The poor water quality with high nutrient concentrations at the bottom of the Tokomairaro catchment will likely affect ecosystem health of the Tokomairiro estuary.

The groundwater monitoring results show good compliance with the DWSNZ, particularly for E. coli and nitrate-N. The median nitrate-N concentration is substantially lower than the threshold for low intensity land use (Daughney and Morgenstern, 2012). However, as there is grazing around the bore this may be due to the potentially reducing conditions in the area, which may lead to nitrate-N breakdown (Close *et al.,* 2016) and mask nitrate-N use in the catchment. This may also affect dissolved arsenic concentrations.

The trend assessment for arsenic shows improvement. However, arsenic is more likely to be geologically sourced hence this trend may not be very meaningful. Although the state and trend results are generally good, there is only monitoring bore in the FMU, hence it does not provide a representative reflection of groundwater quality in the FMU. Nevertheless, it is recommended that groundwater users regularly test their bore water, maintain good bore security, and practice good land/nutrient management.

8 North Otago FMU

Figure 48 Location of water quality monitoring sites in the North Otago FMU

8.1.1 North Otago FMU Description

The North Otago Freshwater Management Unit (FMU) covers about 296,000 hectares and extends from Waitaki Bridge down through Oamaru, Moeraki, and Palmerston townships to the bottom of the southern branch of the Waikouaiti River. It includes coastal margins to the north and east of Waitaki and Oamaru and the coastal strip from Glen Creek to the Waikouaiti River. Some major rivers within the FMU include the Waitaki, Kakanui, Shag, Waikouaiti, Waianakarua, and Pleasant. High natural character values exist in the upper catchments of the Kakanui and Waianakarua rivers, Trotters Gorge, and the south branch of the Waikouaiti River.

From its source in the Kakanui Mountains, the Kakanui River flows north-east for about 40 km, through gorges incised in rolling or downland country, before emerging onto plains at Clifton. The Kakanui River's water resource is heavily used for irrigation. The North Otago Irrigation Scheme services much of the lower Kakanui River and Waiareka Creek. In contrast, land use in the Kauru and upper Kakanui are typified by red tussock, native forest, plantation forestry or pasture for red deer, sheep, and beef. Large areas of the North Otago FMU are underlain by volcanic soils, where market garden farming is common. This leads to high nitrate-N concentrations in groundwater in the area (ORC, 2021).

The Waianakarua River is a small river with a catchment area of 262 km^2 which rises in the Horse Range and Kakanui Mountains in North Otago. Much of the catchment consists of extensively grazed grasslands and scrub, native forest, and plantation forestry but intensification of land use in the lower catchment has occurred in recent years.

The Shag River catchment covers an area of 550 km^2. The Shag is a medium sized river with its headwaters originating on the south-western slopes of Kakanui Peak in the Kakanui Mountains. From here it flows 90km in a south-easterly direction past the township of Palmerston before entering the Pacific Ocean to the south of Shag Point.

The Waikouaiti catchment area covers 421 km^2, the river has two main branches, the North Branch (283 km^2) and South Branch 86 km^2.

ORC monitors 15 river sites and 13 groundwater sites in the North Otago FMU. The groundwater bores are found in the lower Waitaki Plains aquifer, the North Otago Volcanic Aquifer (NOVA), the Kakanui-Kauru Alluvial Aquifer, and the Shag Alluvial Aquifer. Monitoring sites are shown in Figure 48.

8.1.2 State Analysis Results

The results of grading the SoE sites in the North Dunedin FMU according to the NPS-FM NOF criteria are mapped in Figure 49 and summarised in Figure 50. Many sites in the North Otago FMU did not meet the sample number requirements and are shown as white cells with coloured circles. Chl-a was only monitored at five sites in the North Otago FMU, white cells indicate that this variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

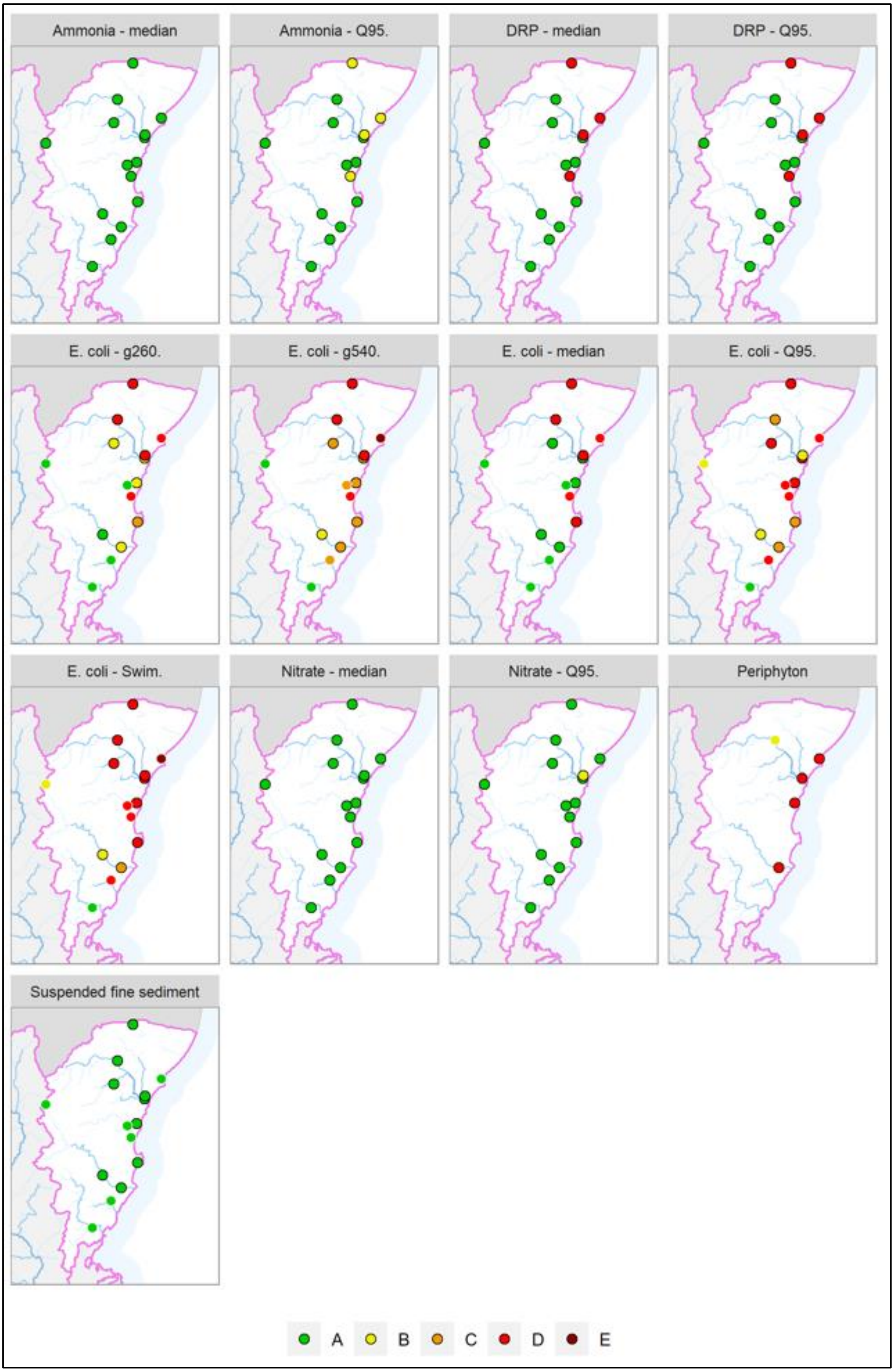

Ammonia - median
Ammonia - Q95.
DRP - median
DRP - Q95.
E. coli - g260.
E. coli - g540.
E. coli - median
E. coli - Q95.
E. coli - Swim.
Nitrate - median
Nitrate - Q95.
Periphyton
Suspended fine sediment
A
B
C
D
E

Figure 49 Maps showing North Otago FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines

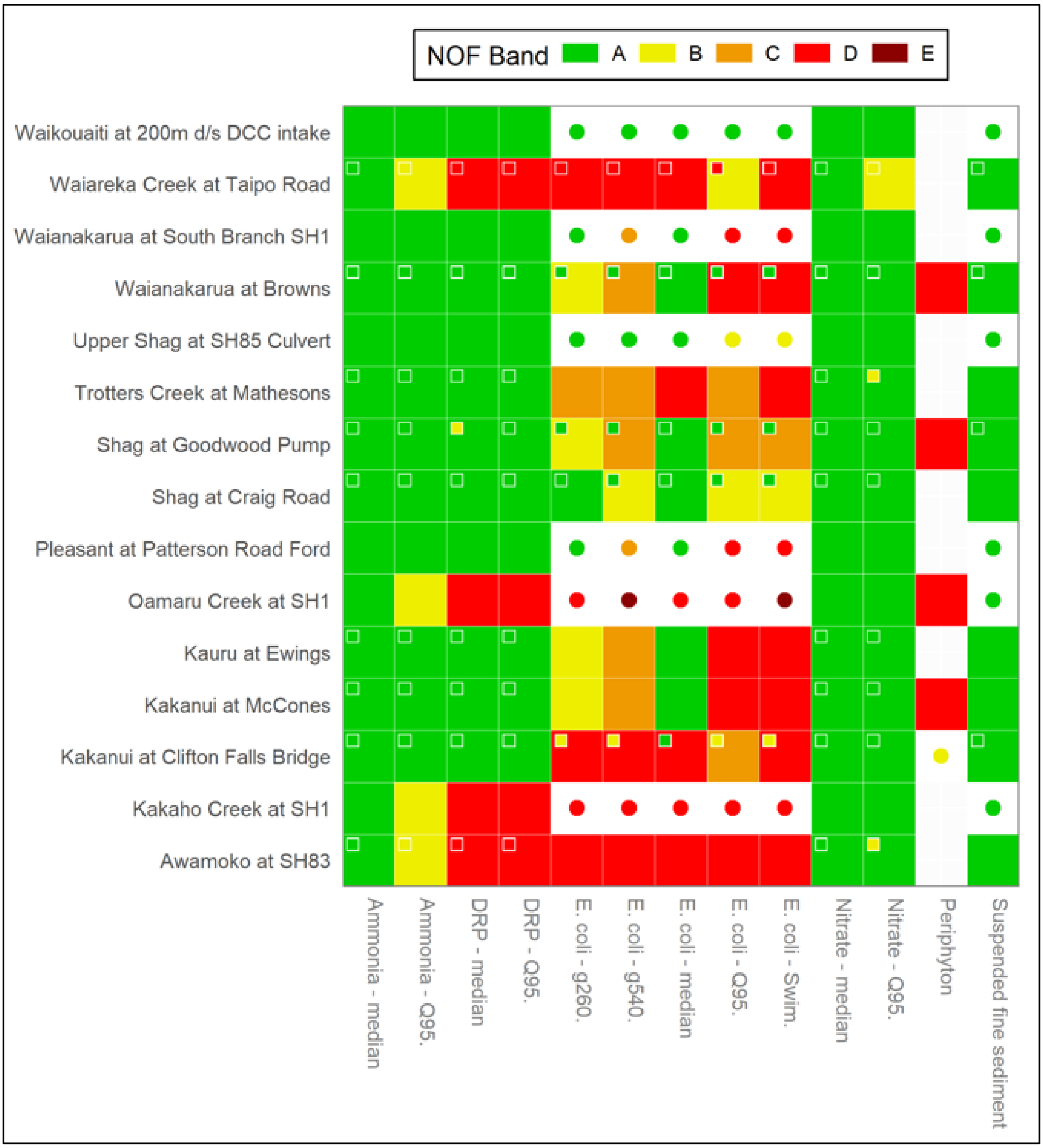


Figure 50 Grading of the river sites of the North Otago FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 *are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline*

8.1.2.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 49 and Figure 50. Periphyton trophic state results to date show that the North Otago FMU returns mainly ‘D’ bands which is below the national bottom line, this reflects elevated nutrient enrichment and the possibility of regular nuisance blooms. The Kakanui River at Clifton Falls achieves a NOF attribute band of ‘B’.

Figure 49 and Figure 50 also show DRP attribute states for ecosystem health (DRP median and Q95). The results in the North Otago FMU show that of the 15 sites monitored, 11 achieve NOF attribute band ‘A’. Four sites, Awamoko, Kakaho Creek, Oamaru Creek and Waiareka Creek achieve attribute band ’D’, which the NPS-FM (2020) describes as ‘*ecological communities impacted by substantial DRP elevation above natural reference conditions*’.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. Sites with the highest median NNN concentrations are Oamaru Creek (0.52 mg/l), Waiareka Creek (0.48 mg/l) and the Awamoko (0.48 mg/l). These sites also have the highest DRP concentrations.

8.1.2.2 Toxicants (Rivers)

NOF attribute bands for NH4-N are shown for the North Otago sites in Figure 49 and Figure 50. In the North Otago FMU 11 sites have excellent protection levels against ammonia toxicity. Waiareka Creek, Oamaru Creek, Kakaho Creek and Awamoko Stream return a ‘B’ band for the Q95 statistic. The NPS-FM describes the ‘B’ band as *‘ammonia starts impacting occasionally on the 5% most sensitive species’.*

NOF attribute bands for nitrate-N (measured as NNN) toxicity are given for North Otago FMU sites in Figure 49 and Figure 50. All sites achieve an ‘A’ band across both the median and Q95 other than Waiareka Creek, which achieved a ‘B’ band for Q95. The NPS-FM describes ‘B’ band as NNN having *‘some growth effect on up to 5% of species’*

8.1.2.3 Suspended fine sediment (Rivers)

The clarity results for the North Otago FMU are shown in Figure 49 and Figure 50. All sites return a NOF band of ‘A’ which denotes ‘*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions’* (NPS-FM, 2020).

8.1.2.4 Human health for recreation

Figure 49 and Figure 50 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading.

Compliance is in the North Otago FMU is poor, with eleven of 15 sites returning bacterial water quality below attribute band ‘C’. The NPS-FM (2020) describes band ‘D’ as *‘30% of the time the estimated risk is ≥50 in 1,000 (>5% risk). The predicted average infection >3%’*. Only the Waikouaiti River achieved an ‘A’ band, the upper Shag River sites (SH85 and Craig Road) achieved ‘B’ bands, and the lower Shag River site (Goodwood) achieved a ‘C’ band.

8.1.2.5 Trend Analysis: Rivers

Trend analysis results for the North Otago FMU is shown in Figure 51.

A comparison of 10- and 20-year trends in river water quality revealed that generally, across the North Otago FMU the predominance of degrading 20-year trends for *E. coli*, NNN, TN and turbidity shifted to a predominance of improving 10-year trends for the same analytes. In addition, the Shag River at Craig Road and the Shag River at Goodwood shifted from mainly degrading 20-year trends to a predominance of improving 10-year trends.

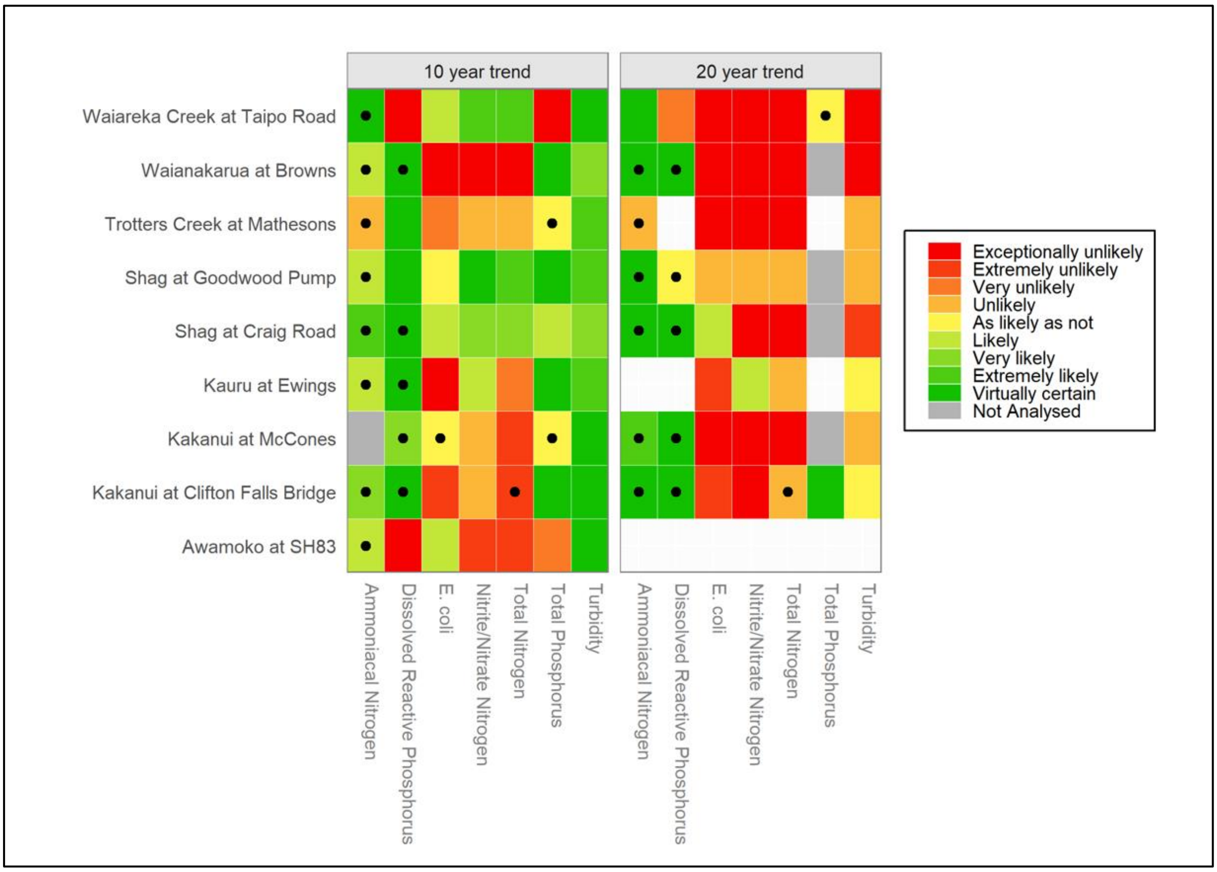


Figure 51 Summary of North Otago FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

In the Kakanui catchment, the Waiareka at Taipo Road showed that the TN and NNN changed from a degrading 20-trend to an improving 10-year trend, but during the same timeframes, TP and DRP have shown 'exceptionally unlikely' improvement. The Kakanui at Clifton shows little change and the Kakanui at McCones shows that E. coli has shifted from a 'exceptionally unlikely improving' degrading 20-year trend to a 10-year stable 'as likely as not' improving trend.

The Waianakarua at Browns continues to show 'exceptionally unlikely' improvement in E. coli, NNN and TN, although turbidity has changed from degrading over the 20-year period to improving over the most recent 10-year period.

The Awamoko Stream, only has 10-year trends, which are generally degrading, other than for NH4-N, E. coli and turbidity.

8.1.3 Groundwater

8.1.3.1 Groundwater State

The groundwater quality current state for the North Otago FMU is shown in Table 13. The results indicate substantial groundwater quality issues, with many exceedances of the DWSNZ MAV for *E. coli* and very high nitrate-N concentrations. Conversely, dissolved arsenic in all the monitoring sites across the FMU were substantially below the DWSNZ MAV of 0.010mg/L.

The *E. coli* data shows many exceedances in almost all the SoE sites in the FMU (apart from two bores). Most exceedances were between 10-50% of the results, with higher proportion of exceedances in two bores (situated in the North Otago Volcanic Aquifer [NOVA] and the Kakanui-Kauru Alluvial Aquifer). Median nitrate-N concentrations in the FMU also show significant issues, with the highest concentrations in Otago. Concentrations in four sites in the NOVA and the Kakanui-Kauru Alluvial Aquifer exceeded the DWSNZ MAV of 11.3mg/L. The median concentrations in three other bores are 50-75% of the DWSNZ MAV, whilst concentrations in four bores exceed the threshold for low intensity land use (Morgnestern & Daughney, 2012). Median concentrations below the threshold were measured in only two SoE bores, situated in the lower Waitaki aquifer and the Shag Alluvial Aquifer.

Table 13 Groundwater current state results for the North Otago FMU. The key for the colour classification is shown at the bottom of the table.

Site	**Aquifer/ location**	**Total no. of *E. coli* samples**	**Detection**	***E. coli* % exceedance**	**Median Nitrate concentration (mg/L)**	**Max. Arsenic concentration (mg/L)**
J41/0008	NOVA	19	4	21	26.000	0.000
J41/0249	NOVA	14	2	14	4.200	0.001
J41/0317	Lower Waitaki	20	13	65	5.750	0.000
J41/0442	Lower Waitaki	21	4	19	0.530	0.001
J41/0571	Lower Waitaki	21	1	5	4.600	0.001
J41/0576	Lower Waitaki	20	7	35	6.400	0.000
J41/0586	Lower Waitaki	21	2	10	6.800	0.001
J41/0762	Kakanui-Kauru	14	2	14	4.800	0.001
J41/0764	Kakanui-Kauru	18	0	0	3.100	0.001
J41/0771	Kakanui-Kauru	17	2	12	11.600	0.001
J41/1403	Kakanui-Kauru	8	6	75	11.750	0.001
J42/0126	NOVA	19	0	0	19.700	0.000
J43/0006	Shag	17	2	12	0.645	0.000

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

8.1.3.2 Groundwater Trends

The 5- and 10-year trends for groundwater concentrations are summarised in Figure 51 and presented spatially in Figure 53. The trend analysis was only done for nitrate-N as most dissolved arsenic concentrations were below the analytical detection limit. The 10-year trend was only analysed for five SoE bores, as the other ones were not monitored for a sufficiently long period.

The 5-year trend analysis for nitrate-N shows that eight of 11 of the sites in the North Otago FMU are either ‘extremely likely improving’ or ‘likely improving’. Two sites were ‘as likely as not improving’ whilst the remaining two, situated in the Kakanui-Kauru Alluvial aquifer, are ‘unlikely improving’.

The 10-year trends generally show an improving pattern, notably in bore J41/0317, which changed from ‘extremely unlikely improving’ to ’extremely likely’ improving, and bore J41/0008, which changed from ‘unlikely’ to ‘as likely as not’ improving. The other bores were in the green confidence levels (i.e., ‘likely’, ’very likely’ or ‘extremely likely’ improving) and either moved up or down one level (the 10-year trend for J41/0249 was ‘virtually certain’ improving, but there was no 5-year trend calculated for this bore).

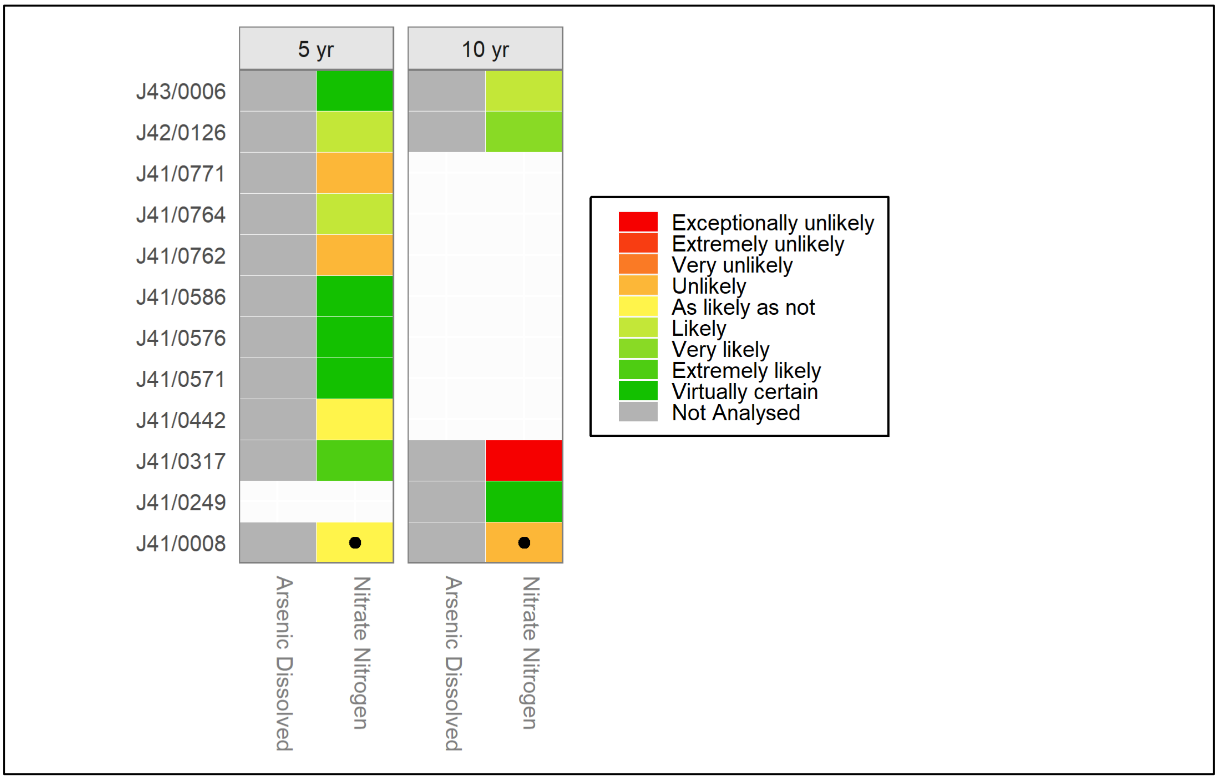


Figure 52: Summary of North Otago FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

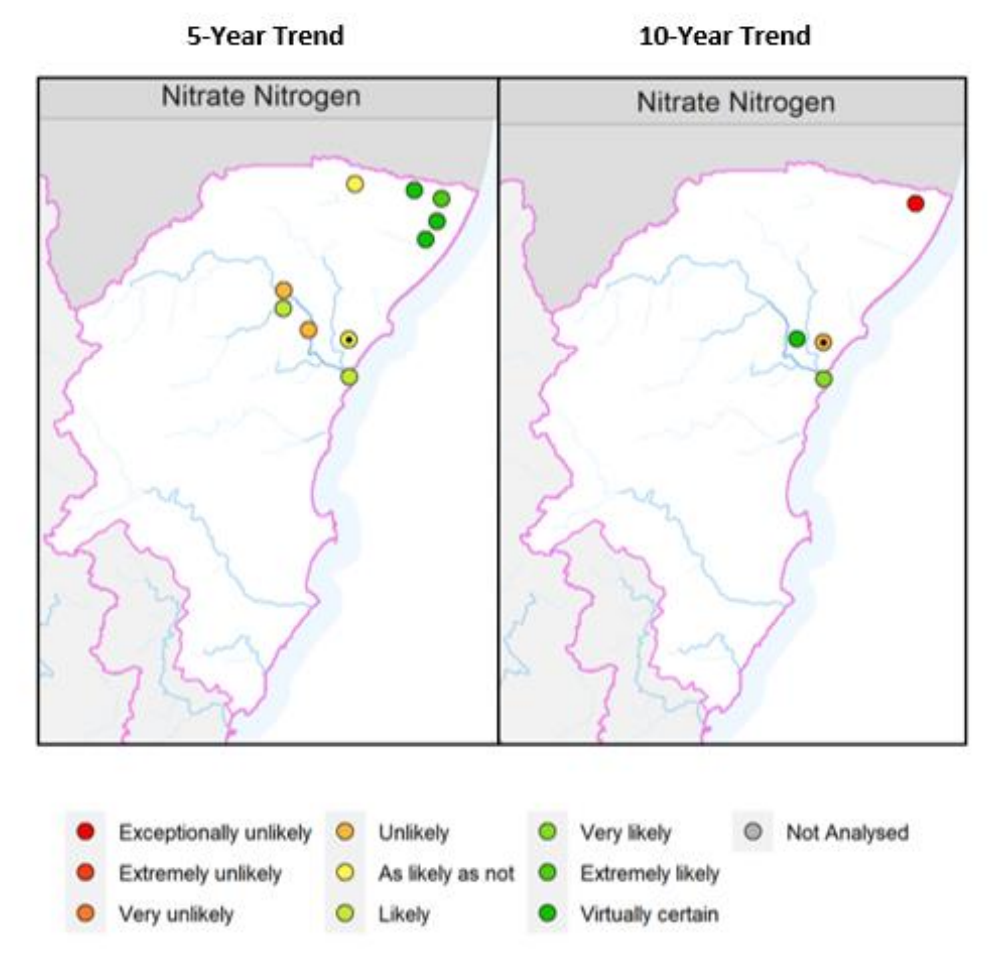


Figure 53: Maps showing summary of North Otago FMU sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 4

8.1.4 Water quality summary North Otago FMU

Land use in North Otago is currently dominated by dry-stock farming (58%), comprising predominantly of sheep and beef (45%); mixed sheep, beef, and deer (6%); beef (5%); and sheep farming (2%). Dairy farming occurs on approximately 12% of the Rohe. Forestry, and conservation estate occur on 7% and 6% of the area, respectively. The notable trends in land use change over the past three decades have been an increase in the extent of dairy farming (by 57%), forestry (by 67%), and conservation estate (by 117%). The extent of dry-stock farming decreased by 12%, although it remains the dominant land use activity in the North Otago area.

Oamaru Creek has poor water quality, mainly returning ‘D’ bands, likely due to the influence of its urban setting. High nutrient concentrations are reflected in the ‘D’ band obtained for periphyton and drain discharges to the Creek are likely to add to bacteria concentrations. Waiareka Creek, Kakaho Creek and the Awamoko also return mostly ‘D’ bands, these sites are in a rural settings and ruminant or avian sources are the most likely sources of bacteria in these catchments.

Trend analysis identifies many ‘exceptionally unlikely’ improving trends over both the 10- and 20-year periods. In the last 10 years, four sites continue to show degrading trends ‘exceptionally unlikely improving’, these are Waiareka Creek (DRP, TP), Waianakarua (*E. coli*, NNN, TN), Kauru (*E. coli*), Kakanui at Clifton Falls (*E. coli*) and the Awamoko Stream (DRP). The source of *E. coli* at Kakanui at

Clifton has been identified as red billed gulls roosting in the gorge upstream of the monitoring site. When sites have a zero sen slope alongside a reasonably high-level of confidence in trend direction the rate of the trend (i.e., the Sen slope) is at a level that is below the detection precision of the monitoring programme. In the North Otago FMU, these sites include NH4-N and DRP at the Kakanui at Clifton site, DRP at Ewings, NH4-N at the Shag at Craig Road and the Waianakarua, and DRP at the Waikouaiti and the Shag at Goodwood.

Previous reports have identified land-use intensification as a driver of poor water quality however ORC do not collect detailed information on land-use, land management practices or changes in either of the two that allow for inference as to the drivers of degrading or improving trends in water quality.

Groundwater quality results indicate significant issues in the North Otago FMU, notably very high nitrate-N concentrations, and E. coli exceedances. Nitrate-N concentrations in the FMU are the highest in Otago, with concentrations in several bores also substantially exceeding the DWSNZ MAV. Conversely, dissolved arsenic concentrations in all the monitoring sites across the FMU were substantially below the DWSNZ MAV of 0.010mg/L.

Very high groundwater nitrate-N concentrations are a major issue in the North Otago FMU and are the highest in Otago. Concentrations in four sites, situated in the North Otago Volcanic Aquifer and the Kakanui-Kauru Volcanic Aquifer, exceed the DWSNZ MAV of 11.3mg/L (Table 2). The median concentrations in three other bores are 50-75% of the DWSNZ MAV. These nitrate-N concentrations are also much higher than the NPS-FM limits for surface water, which can adversely impact surface water. These issues are likely to adversely impact river quality and ecosystem health (ORC, 2021), and are particularly important in North Otago due to the strong groundwater-surface water interaction in some of the FMU's rivers (e.g., Kakanui). The E. coli results also indicate groundwater quality issues, with exceedances of the DWSNZ MAV measured in most SoE bores in the FMU. Most exceedances were between 10-50% of the results, with higher proportion of exceedances in two bores (situated in the NOVA and the Kakanui Kauru Alluvial Aquifer).

The trend analysis generally shows improvement, with most sites in the green (i.e., 'improving') categories for the 5-year trend. A 10-year trend was only calculated for 5 sites, of which two are showing improvements (from green to red and orange to yellow) and the others are moving one level either up or down the green categories. However, although these are positive results, nitrate-N concentrations in most bores in the FMU are still very high and exceed the DWSNZ and NPS-FM limits. The elevated nitrate-N concentrations and E. coli exceedances are likely due to a combination of poor bore security, shallow bores, intensive land use and fertiliser application (dairy farming, market garden), and septic tanks (ORC, 2021). These are exacerbated in the North Otago FMU due to the high permeability (providing high infiltration rates) and shallow groundwater in some aquifers (e.g., Kakanui-Kauru Alluvial Aquifer) whilst the slow groundwater velocity in the NOVA (which reduces dilution) also contribute to the excessive nitrate-N concentrations in this aquifer. ORC also recently expanded the SoE monitoring network in the FMU with 11 new, dedicated monitoring bores. This will enable to determine whether some of the issues, such as E. coli exceedances, are local and due to poor bore security or more of an aquifer/FMU wide issue. Nevertheless, it is important that bore owners ensure adequate bore security and good land/nutrient management practices. Due to the high nitrate-N concentrations in the NOVA and Kakanui-Kauru it is also recommended that raw groundwater (untreated) in these aquifers is not used for drinking/domestic supply.

9 Catlins FMU

Figure 54 Location of water quality monitoring sites in the Catlins FMU

9.1.1 Catlins FMU Description

The Catlins Freshwater Management Unit (FMU) is located along the southern coast of Otago.

This FMU contains Otago's portion of the Catlins Conservation Park. The coast is dominated by sandy bays and cliffs and from there, the land rises steadily from the south-east to north-west, reaching its maximum altitude (720 m) at Mt Pye, in the headwaters of the Tahakopa and Catlins Rivers, and then it falls again, through rolling country, towards the Mataura River (in Southland) and the Clinton lowlands. The forested ridges provide a contrast to the cleared valleys, where more intensive agricultural activities are concentrated. Headwaters of all major rivers rising from within the Catlins have their vegetation intact.

ORC monitors four rivers in the Catlins FMU. The Catlins River (42km) and Owaka River (30km) share an estuary. The Tahakopa River (32km) flows south-east to the Pacific Ocean 30 km east of Waikawa, close to the settlement of Papatowai. The Maclennan River is 17.5 km long and enters the Tahakopa River near Maclennan.

There is one groundwater SoE bore in the Catlins FMU, although geographically it is more appropriate to have been included in the Inch Clutha aquifer (located in the Lower Clutha Rohe). The monitoring sites are shown in Figure 54.

9.1.2 State Analysis Results

The results of grading the SoE sites in the Catlins FMU based on the NPS-FM NOF criteria are mapped in Figure 55 and summarised in Figure 56. Many sites in the Catlins FMU did not meet the sample number requirements (shown in Table 1) and accordingly are shown as white cells with coloured circles. Most sites for some variables have white cells, this indicates that the variable was not monitored.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

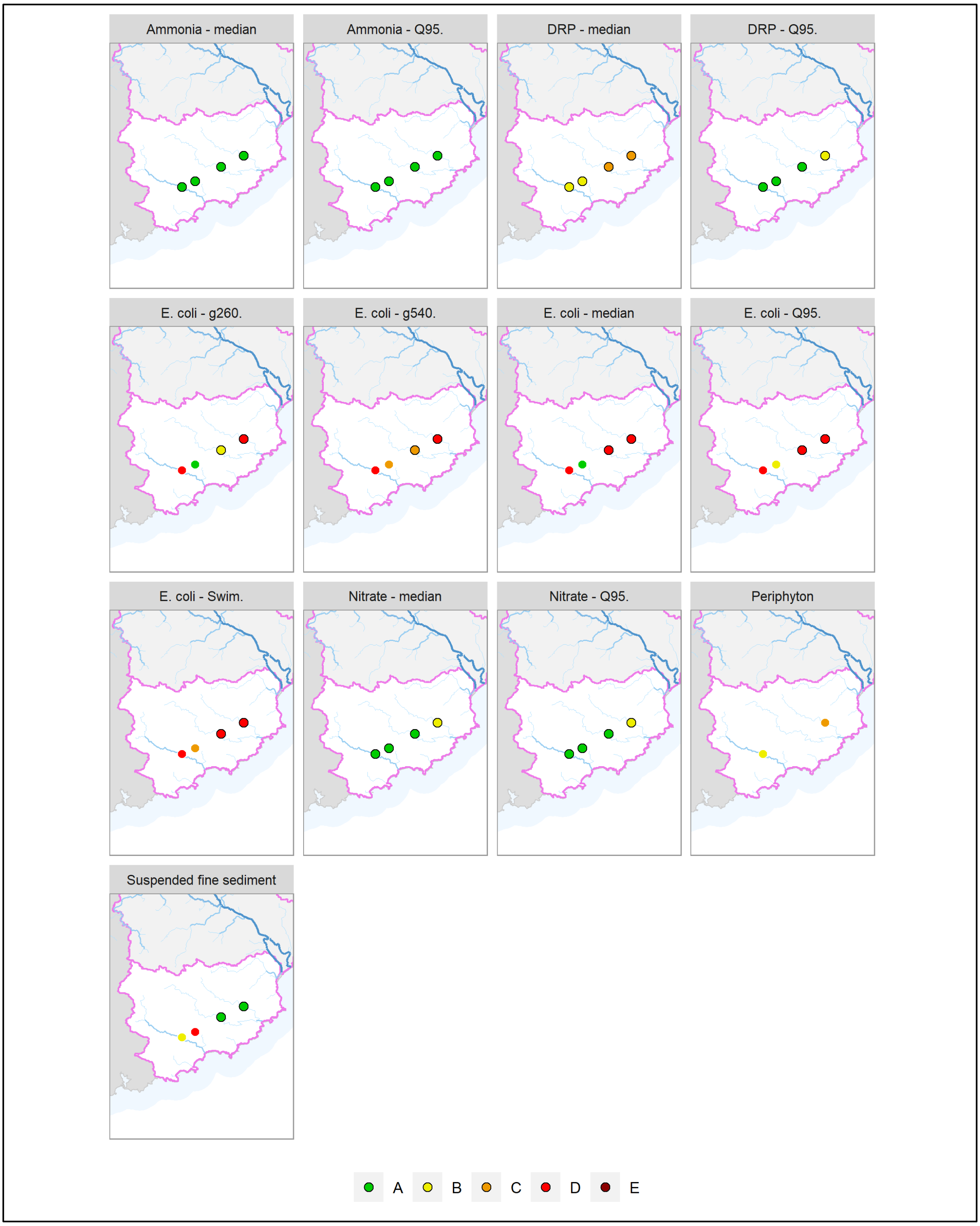


Figure 55 Maps showing Catlins FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines.

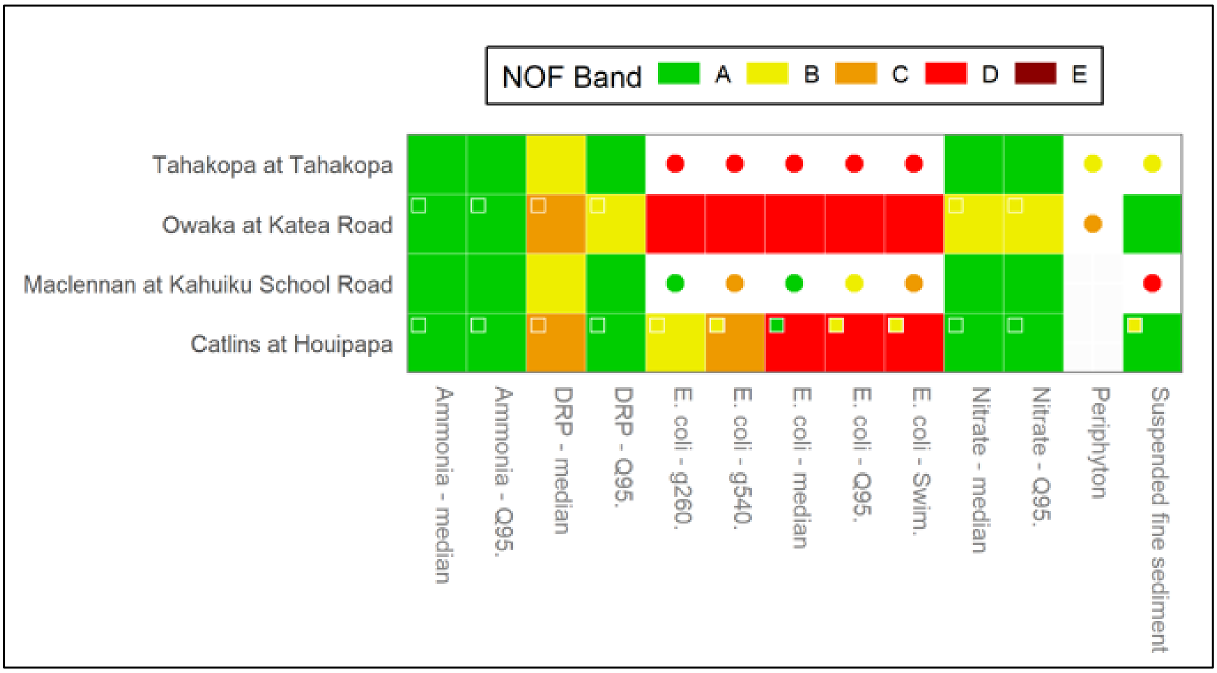


Figure 56 Grading of the river sites of the Catlins FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

9.1.2.1 Periphyton and Nutrients

Periphyton trophic state results to date are given in Figure 55 and Figure 56 and show that of the two sites monitored in the Catlins FMU, the Tahakopa returns an interim 'B' band as few results exceed 120 chl-*a*/m^2 reflecting low nutrient enrichment and the Owaka returned a 'C' band reflecting a more nutrient rich environment.

Figure 55 and Figure 56 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Catlins FMU show that the Tahakopa River and Maclennan River achieve a 'B' band, while the Owaka River and Catlins River achieve a 'C' band. The NPS-FM (2020) describes band 'C' as *'Ecological communities impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate and fish taxa, and high rates of respiration and decay'*

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. Sites in the Catlins FMU with the highest NNN concentration are the Owaka River (1.04 mg/l) and the Catlins at Houipapa (0.4 mg/l), these sites also have the highest median DRP concentration.

9.1.2.2 Toxicants (Rivers)

NOF attribute bands for NH4-N are given in Figure 55 and Figure 56, the national bottom line for toxicants is below band 'B'. All sites in the Catlins FMU achieve an 'A' band (highest level of protection) for NH4-N. The NPS-FM describes the 'A' band as *'99% species protection level: No observed effect on any species tested'.*

NOF attribute bands for nitrate-N (measured as NNN) toxicity are given in Figure 55 and Figure 56. In the Catlins FMU all sites achieve an 'A' band, other than the Owaka which achieves a 'B' band across both statistical metrics, the NPS-FM describes 'B' band as NNN having *'some growth effect on up to 5% of species'*

9.1.2.3 *Suspended fine sediment (Rivers)*

The clarity results for the Catlins FMU are shown in Figure 55 and Figure 56. All rivers in the Catlins have a high degree of tannin staining due to the forested catchments. Only the Maclennan River returns a NOF band of ‘D’ which denotes ‘*high impact of suspended sediment on instream biota. Ecological communities are significantly altered, and sensitive fish and macroinvertebrate species are lost or at high risk of being lost*’ (NPS-FM, 2020). The Owaka and Catlins, despite tannin staining, achieve a band ‘A’.

9.1.2.4 *Health for recreation (Rivers)*

Figure 55 and Figure 56 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading.

Compliance is quite poor across the Catlins FMU, with the Tahakopa, Owaka and Catlins Rivers returning bacterial water quality below attribute band ‘C’ on all four statistical metrics. The Maclennan River returned an overall ‘C’ band despite returning an ‘A’ band in the median and g260 statistic.

9.1.2.5 *Trend Analysis Results – Rivers*

Trend analysis results for the Catlins River is shown in Figure 57. Over a 20-year period the Catlins has ‘exceptionally unlikely’ improving trends for *E. coli,* NNN and TN. In the shorter timeframe the Catlins River has ‘extremely likely’ or ‘virtually certain’ improving trends for NH4-N and DRP and no degrading trends. Most trends over 10-years in the Owaka are improving (‘likely’ to ‘extremely likely’) apart from *E. coli* which is degrading (‘unlikely’ to be improving).

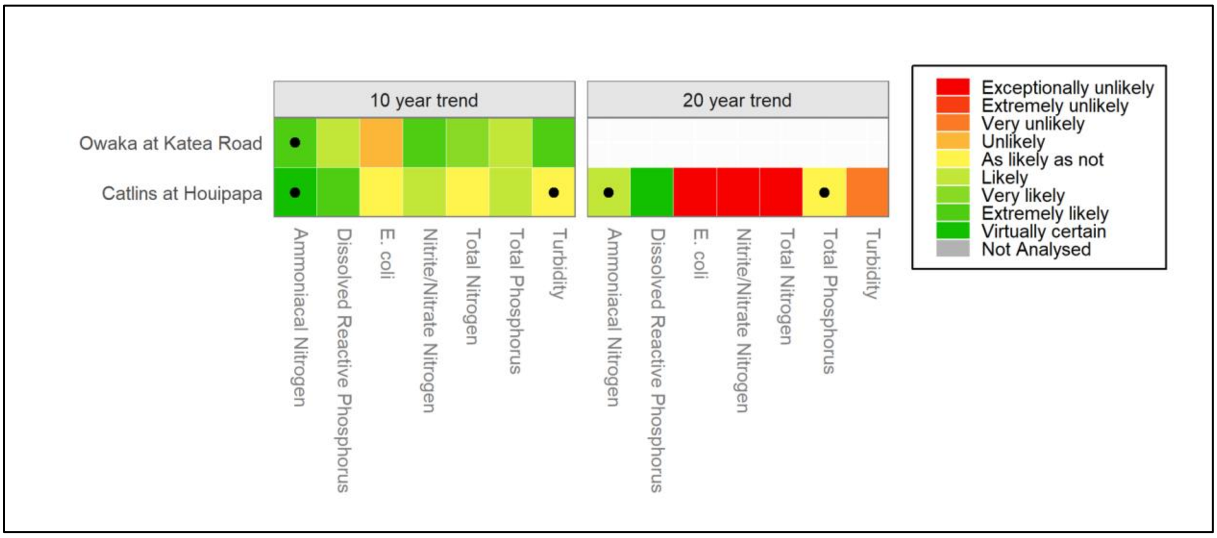


Figure 57 Summary of Catlins FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

9.1.3 Groundwater

9.1.3.1 State

There is currently only one SoE monitoring bore in the Catlins FMU, no. H46/0118. A description of the bore can be found in ORC (2021). The current state of groundwater quality from this bore is shown in Table 14. There are no exceedances of any of the DWSNZ MAV. The main issue is a single detection of E. coli in the bore. The median nitrate-N concentrations are substantially below the DWSNZ MAV and also below the threshold for low intensity land use (Morgenstern and Daughney, 2012). Dissolved arsenic concentrations are also substantially below the DWSNZ MAV.

Table 14 Groundwater current state results for the Catlins FMU. The key for the colour classification is shown at the bottom of the table.

Site	**Aquifer/ location**	**Total no. of *E. coli* samples**	**No. of Detects**	***E. coli* % exceed-ance**	**Median Nitrate concentration (mg/L)**	**Max. Arsenic concentration (mg/L)**
H46/0118	Inch Clutha	18	1	6	0.240	0.000

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

9.1.3.2 Trends

The trends for groundwater quality for the Catlins FMU are shown in Figure 58. The results show 'extremely unlikely' improving trend for groundwater nitrate-N for both the 5- and 10-year analysis periods.

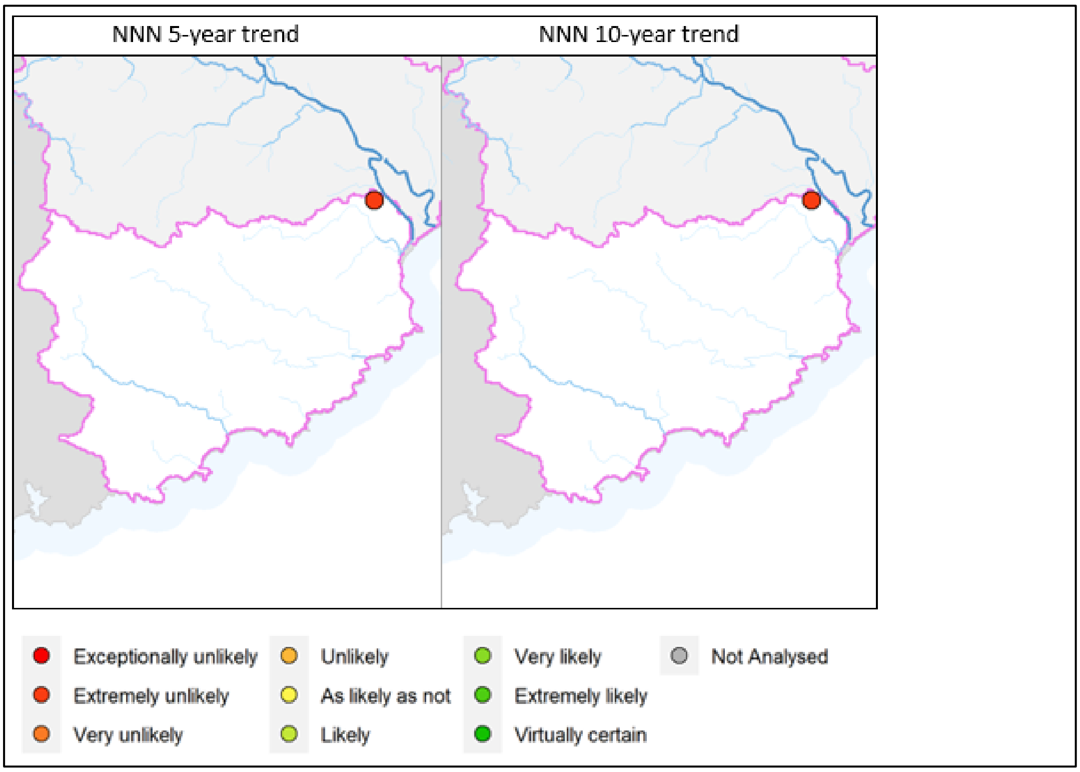


Figure 58: Catlins FMU site categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement.

9.1.4 Water quality summary Catlins FMU

The Catlins FMU is expected to have good water quality, due to the intact nature of the headwaters and native vegetation, however cleared valleys allow intensive farming activities. When comparing to the NOF attribute states, water quality is variable. All sites return ‘A’ or ‘B’ bands for ammonia and nitrate-N toxicity. The Owaka, Catlins and Tahakopa return ‘D’ bands for *E. coli*. Suspended fine sediment returns ‘D’ bands at all sites. Water in the Catlins FMU has naturally highly coloured brown water or tannin stained, the Catlins Rivers are an exception because the low the clarity is naturally occurring, rather than occurring through high sediment input.

In the Catlins River, over 20-years, *E. coli*, NNN and TN showed degrading trends (‘exceptionally unlikely to be improving), this was not the case in the 10-year trend analysis. In the Owaka River the only degrading trend over 10-years was for E. coli (‘unlikely’ to be improving)

Groundwater quality results from the SoE monitoring bore are generally good. The median groundwater nitrate-N concentrations are substantially below the DWSNZ MAV and also below the threshold for low intensity land use. The dissolved arsenic substantially below the DWSNZ MAV. The only issue was one exceedance of the E. coli MAV. It is unclear why the trend analysis for nitrate-N is ‘‘exceptionally unlikely improving’. Although the results from this monitoring bore are generally good, it does not necessarily reflect groundwater quality in the Catlins FMU, as this is currently the only SoE bore in the Catlins FMU. Furthermore, this bore is found in the Inch Clutha aquifer, and its surrounding land use and lithological setting (dairy farming) is likely to be more reflective of the Inch Clutha aquifer and delta (which is located in the Lower Clutha Rohe). ORC is planning, however, to drill dedicated SoE monitoring bores in the Catlins FMU.

10 Otago Regional Summary

10.1.1 State analysis results

10.1.1.1 Rivers

Figure 59 gives an overview of river water quality in the Otago Region, sites are coloured according to their state grading as indicated by NOF attribute bands.

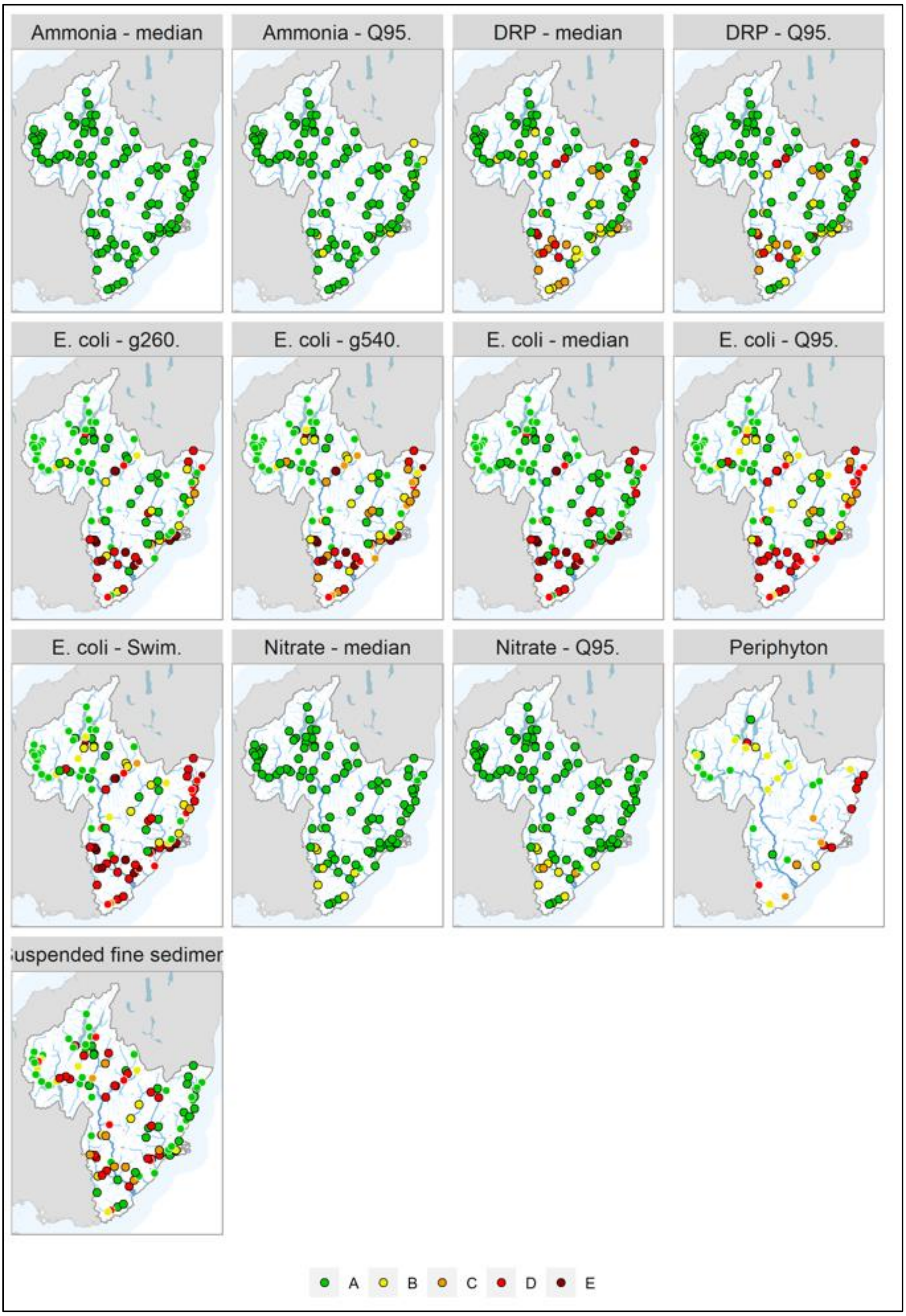


Figure 59: Maps showing river SoE monitoring sites across Otago coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines

Results for ammonia and nitrate-N toxicity show low concentrations across the region. The national bottom line for nitrate-N and ammonia toxicity is below the 'B' band. Nitrate-N toxicity results generally meet NOF band 'A' for the median statistic, with five sites in the Lower Clutha Rohe meeting band 'B'. For NH4-N toxicity (median) all sites met NOF band 'A'.

E. coli results show a clear spatial pattern across Otago. Figure 59 shows *E. coli* -SWIM which is the worst grade of the four statistics (G260, G540, Median and P95). Across Otago 46 sites did not meet the national bottom line with 13 sites (including five sites in the Lower Clutha Rohe as well as five urban stream sites*)* achieving an *'E' gr*ade. At the other end of the scale, in the Upper Lakes Rohe 19 of 23 sites achieve an 'A' band *E. coli* 'swim' grade.

DRP follows a similar spatial distribution as *E. coli*. Although there is no bottom line for DRP, eleven sites achieved an attribute band of 'D', four sites in the North Otago FMU, two sites in the Manuherekia Rohe and five sites in the Lower Clutha Rohe.

Periphyton, monitored as Chl-a is shown in Figure 59. Only Akatore Creek, Kaikorai Stream and Oamaru Creek fall into the NPS-FM 'productive class' for periphyton (Table 2), all other sites fit the 'default class' category. Eight sites fall below the national bottom line for periphyton, including four in North Otago, and one each in Dunedin & Coast Rohe, Dunstan Rohe, Taieri FMU and Catlins FMU. The North Otago FMU coastal sites stand out has having the highest concentration of Chl-a. The median concentration of DRP is highest at Oamaru Creek, which also has a 'D' band for periphyton. The median NNN at this site is also elevated at 0.25 mg/l (#17 of 107 sites). Bullock Creek, although having an elevated median nitrate-N concentration, has DRP concentration of 0.011 mg/l (#52 of 107 sites).

Suspended fine sediment fell below the national bottom line at 30 sites in Otago. SFS can be elevated due to natural processes, tannin affects water colour in the Catlins FMU and the Taieri FMU (seven of 17 sites achieve a 'D' band). Glacial flour elevates suspended fine sediment in the Clutha Mata/Au FMU (Matukituki, Dart and Rees Rivers achieve 'D' band). Much of the Lower Clutha FMU does not meet the national bottom line for suspended fine sediment, this is probably due to land use practice, lack of riparian vegetation coupled with erodible banks rather than natural causes.

10.1.1.2 Lakes

Figure 60 shows results for all lakes in the Otago Region, all lakes achieve NOF band A for all attributes, other than Lake Tuakitoto, Lake Onslow, Lake Hayes, and Lake Waihola. Lakes with NOF attribute bands below the national bottom line are Lake Tuakitoto (*E. coli*, TN, TP, and Chl-a max), Lake Hayes (Chl-a) and Lake Waihola (Chl-a, *E. coli* and TP).

Lakes were graded across the range from 'A' to 'D' for all attributes other than NH4-N which consistently achieved an 'A' or 'B' band at all sites. The pattern of grades for Chl-a, *E. coli,* TN and TP was consistent with expectations, with lakes grade 'A' in mountainous and hilly areas with low, land use pressure with poorer grades becoming dominant in low elevation parts of the region, or parts of the region with land use pressure.

Figure 60: Maps showing lake SoE monitoring sites across Otago coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines

10.1.1.3 Groundwater

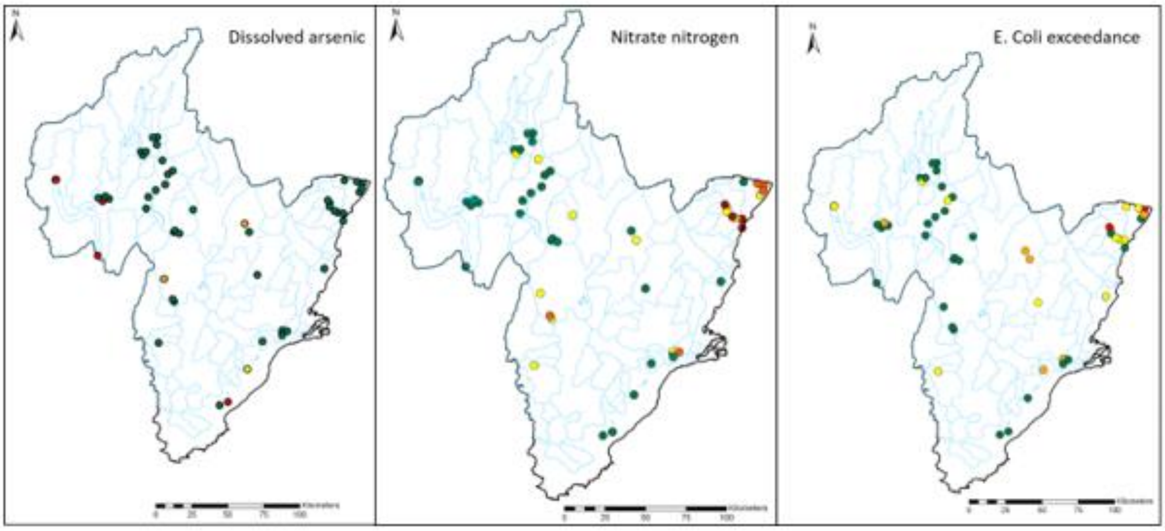
This report analysed groundwater quality against the DWSNZ MAV for *E. coli*, nitrate-N, and dissolved arsenic (*Table* 2). Similar to the river and lakes water data, the state of groundwater quality also varies across Otago, where groundwater quality is good in some areas and poor in others. There was also spatial variability for the different parameters, where *E. coli* exceedances and elevated nitrate-N concentrations were usually observed in the same areas while high dissolved arsenic concentrations were more site-specific. The regional variability in groundwater quality state is shown in Figure 61, where sites shown in green show results below the MAV whilst sites in red show exceedances of the MAV.

The mapping shows wide spatial variability in groundwater quality state between the Rohe of the Clutha Mata-Au FMU. Groundwater quality in the Upper Lakes, Dunstan, and the Manuherekia Rohe is generally good in relation to the DWSNZ MAV for E. coli, with either no exceedances or <10% exceedances in most bores. Median nitrate-N concentrations in these Rohe are also generally low, with most sites below the 2.50mg/L threshold for low intensity land use (Morgenstern and Daughney 2012). Although concentrations in two sites exceeded this threshold, all median nitrate-N concentrations in the Rohe were less than ½ of the DWSNZ MAV (i.e., below 5.50mg/L). In contrast to that, dissolved arsenic concentrations in these Rohe highlighted some issues, with several bores in the Upper Lakes (Glenorchy and Kingston) and one in the Dunstan Rohe (F41/0104) exceeding the DWSNZ MAV. Conversely, concentrations in other bores in the Rohe were substantially below the DWSNZ MAV.

The results indicate more serious groundwater quality issues in the Roxburgh and Lower Clutha Rohe, particularly median nitrate-N concentrations. None of the sites exceeded the DWSNZ MAV, however, concentrations in the Roxburgh Rohe (in Ettrick and Roxburgh) and the Lower Clutha (Pomahaka) were, respectively, between ½ and ¾ of the MAV (and over the low land use intensity threshold). There were also E. coli exceedances in most of the sites, although the proportions were relatively low, usually between 10-17%. Dissolved arsenic concentrations in the Roxburgh Rohe and most sites in the Lower Clutha Rohe are generally below the DWSNZ MAV. However, concentrations in one bore in the Lower Clutha (H44/0144) are persistently high.

Groundwater quality results for the Taieri FMU showed some issues, particularly high frequency of E. coli exceedances, which were measured in all but two monitoring bores. All median nitrate-N concentrations are below the DWSNZ MAV. However, the spatial pattern is mixed, with some concentrations in the lower Taieri and one in the Maniototo Tertiary aquifer elevated above the low land use intensity threshold (Daughney and Morgenstern, 2012) while concentrations in the other bores were below the threshold. The maximum dissolved arsenic concentrations are below the DWSNZ MAV. However, concentrations in one bore in the Maniotioto Tertiary aquifer are high and almost at the MAV while concentrations in the other monitoring bore are much lower. This again illustrates the high spatial variability of dissolved arsenic concentrations across Otago (e.g., ORC, 2021).

The results show significant groundwater quality issues in the North Otago FMU, especially very high nitrate-N concentrations, which are the highest in the region, and many E. coli exceedances. Median nitrate-N concentrations in many sites in the NOVA and the Kakanui Kauru aquifer exceed the DWSNZ MAV while concentrations in other sites are 50%-75% of the MAV. Intrinsically, as the state on this report refers to the median concentrations, the maximum concentrations will be even higher. In contrast to those, dissolved arsenic concentrations in all bores in the FMU were substantially below the DWSNZ MAV. The results from the Catlins and the Dunedin & Coast FMU were below the DWSNZ MAV and do not highlight any immediate issues. However, there is currently only one monitoring bore in each of these FMU, hence, this does not provide adequate representation of groundwater quality state in these FMU.



E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

Figure 61 Regional groundwater quality state against the DWSNZ (2022) MAV.

10.1.2 Trend Analysis results

10.1.2.1 Rivers

Figure 62 and Figure 63 show 10- and 20-year trend periods, respectively, indicating improving and degrading water quality. Interpretation of these plots should be made with caution as there were variable numbers of sites included in the different time periods.

The worst performing variables over 10 years were *E. coli*, NNN and TN where close to 50% of sites had a degrading trend ('unlikely' to 'exceptionally unlikely' to be improving) over both the 10--year period. Conversely, NH4-N and DRP had approximately 90% of sites showing an improving trend ('likely' to 'virtually certain' to be improving)

Comparison of 10-and 20-year trends is difficult because sites have changed. The pattern of degrading and improving trends is similar, with *E coli*, NNN, TN and turbidity having a higher percentage of degrading compared to improving trends across the region. Over the 20-year period, NH4-N, DRP and TP showed a higher percentage of improving, compared to degrading, trends.

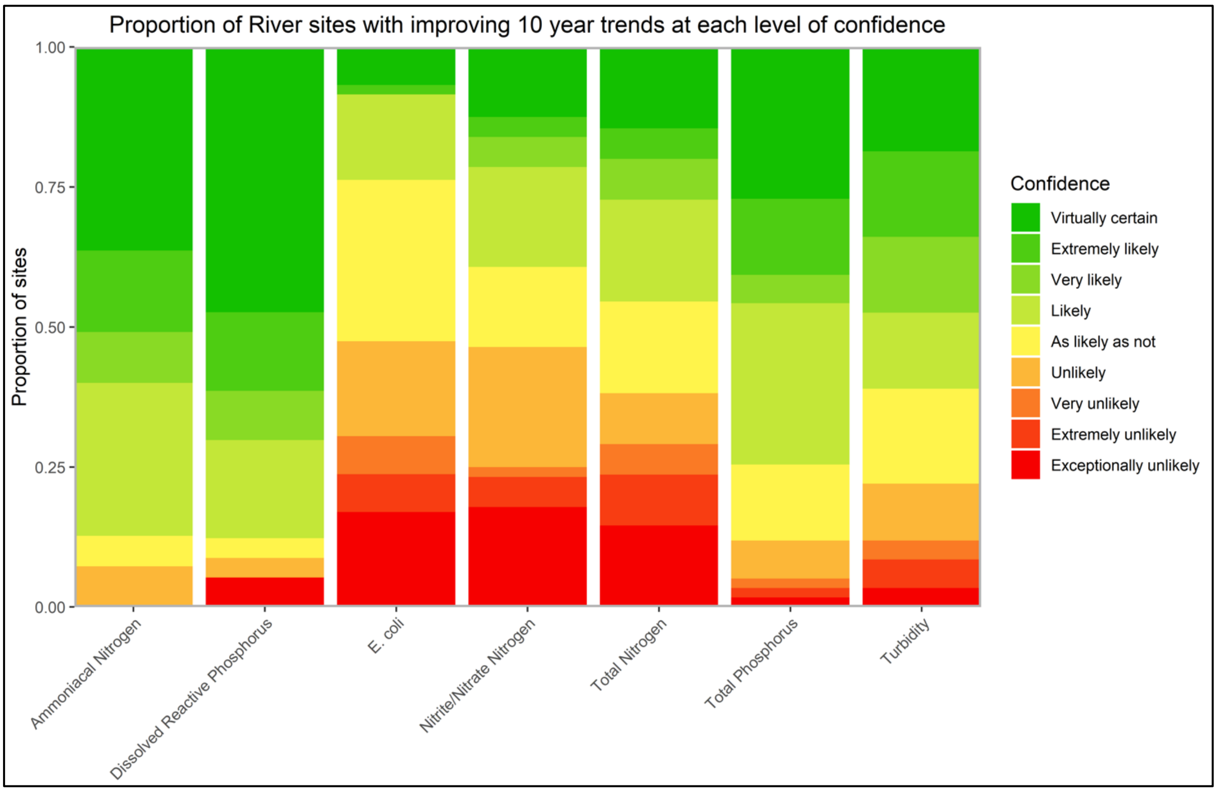


Figure 62 River sites classified by confidence that their 10-year raw water quality trend direction indicated improving water quality. LWP (2020b). Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

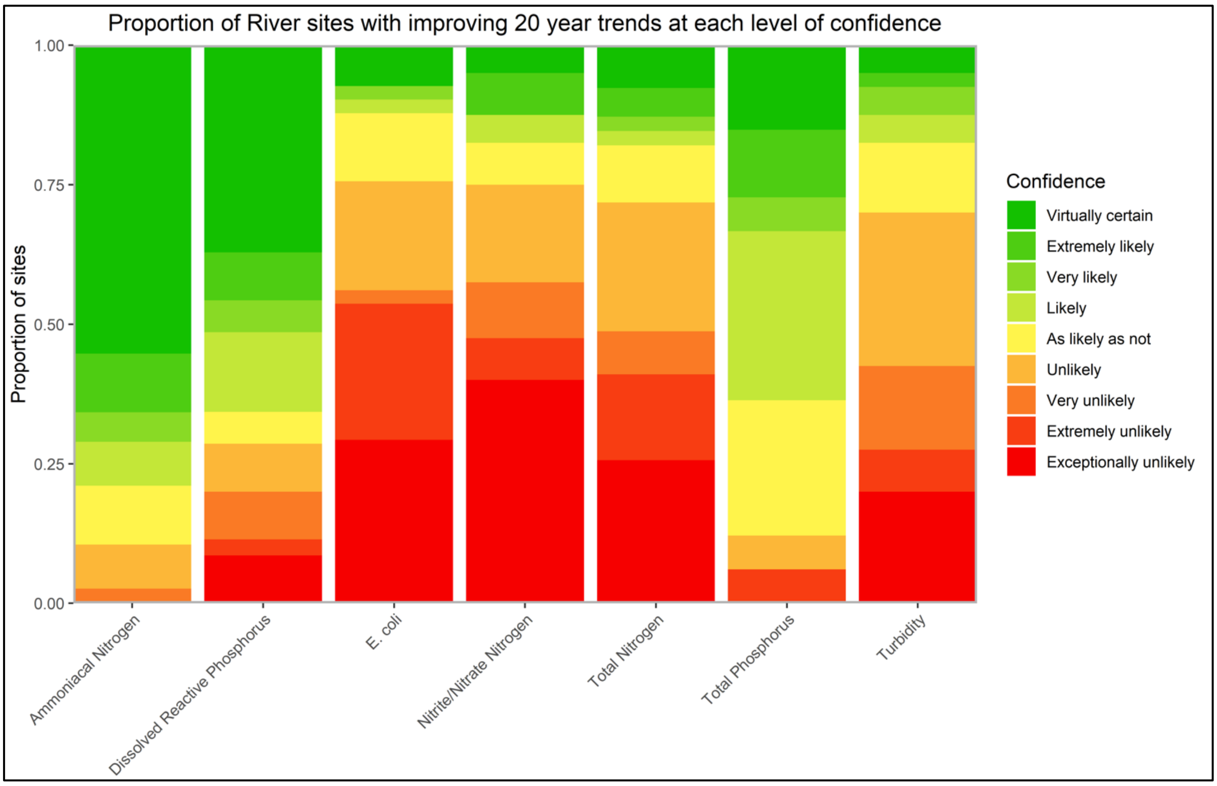


Figure 63 River sites classified by confidence that their 20-year raw water quality trend direction indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends

10.1.2.2 Lakes

Figure 64 shows a summary grid of lake sites by water quality variable classified by confidence that their 5-year water quality trend direction indicated improving water quality. These results should be interpreted with caution as previous studies have shown that trends for shorter timescales are strongly influenced by interannual climate variability.

Over the 5-years trend, variables such as Chl-a (14 out of 16 analysed sites) and TN (15 out of 22 analysed sites) showed the highest degrading trends (‘unlikely’ to ‘exceptionally unlikely’ to be improving) amongst all variables. The variable that showed most improving trends was TP, 8 sites in total.

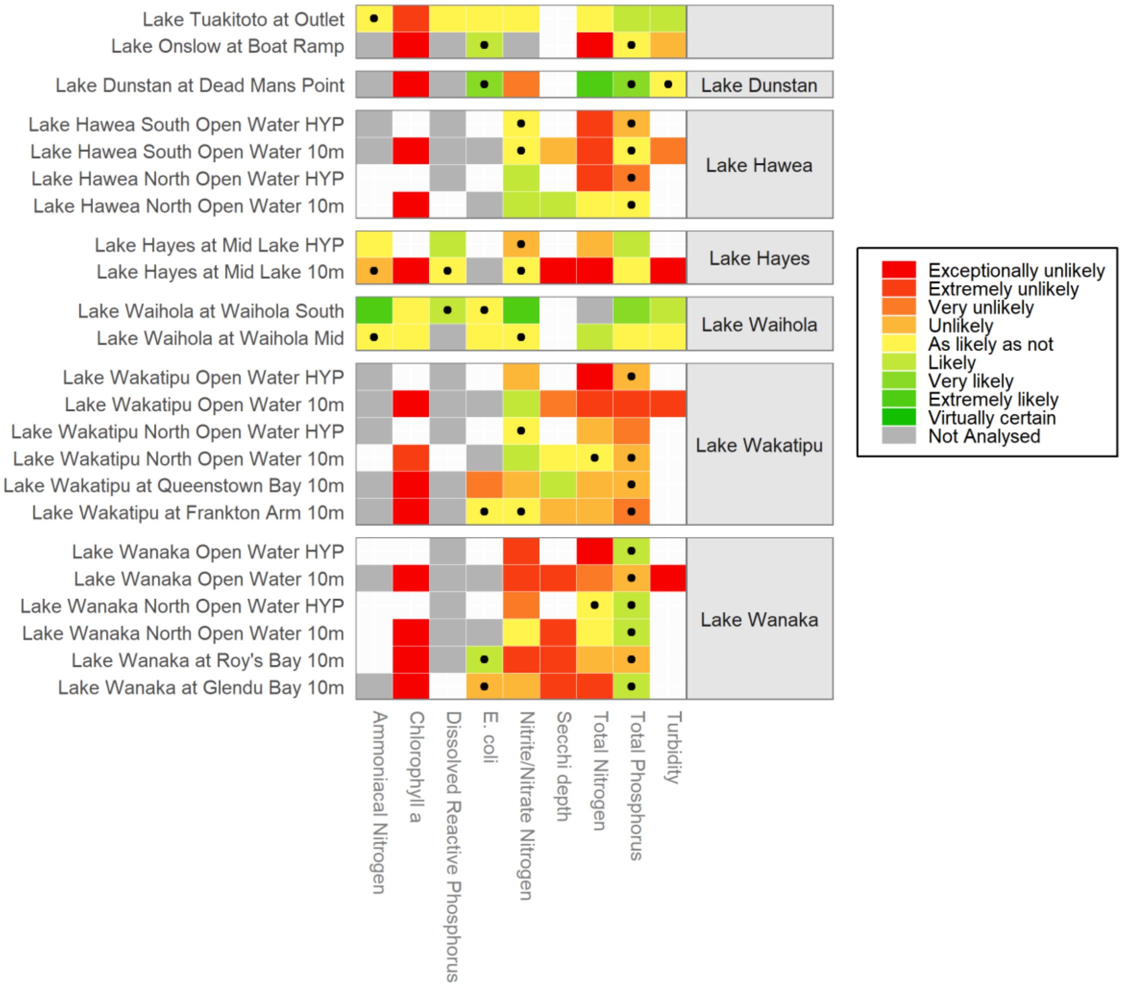


Figure 64 Summary of Otago Lake sites categorised according to the level of confidence that their 5-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables

where there were insufficient data to assess the trend. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

With the review of our SOE programme in 2017 and addition of new fit for purpose mid-lake sites to ORC's lakes network, only 4 sites had enough data for the 10-years trend analysis, and 3 for the 20-years (Figure 65). Again, Chl-a showed degrading trends on both analysed sites for the 10-years trends. Conversely, NH4-N, DRP, *E. coli*, TN, TP, and Turbidity showed improving trends ('likely' to 'virtually certain' to be improving) in two out of the four sites.

Over the 20-years trend analysis, most variables showed improving trends with the exception of Lake Tuakitoto at Outlet's DRP, TN and TP variables, and Lake Dunstan at Deadman's Point *E. coli* and Turbidity, indicating degrading water quality. When comparing the 10- and 20-years trend of Lake Onslow at Boat Ramp site, 100% of the variables analysed are improving over 20 years, while over 10 years only NH4-N showed an improving trend.

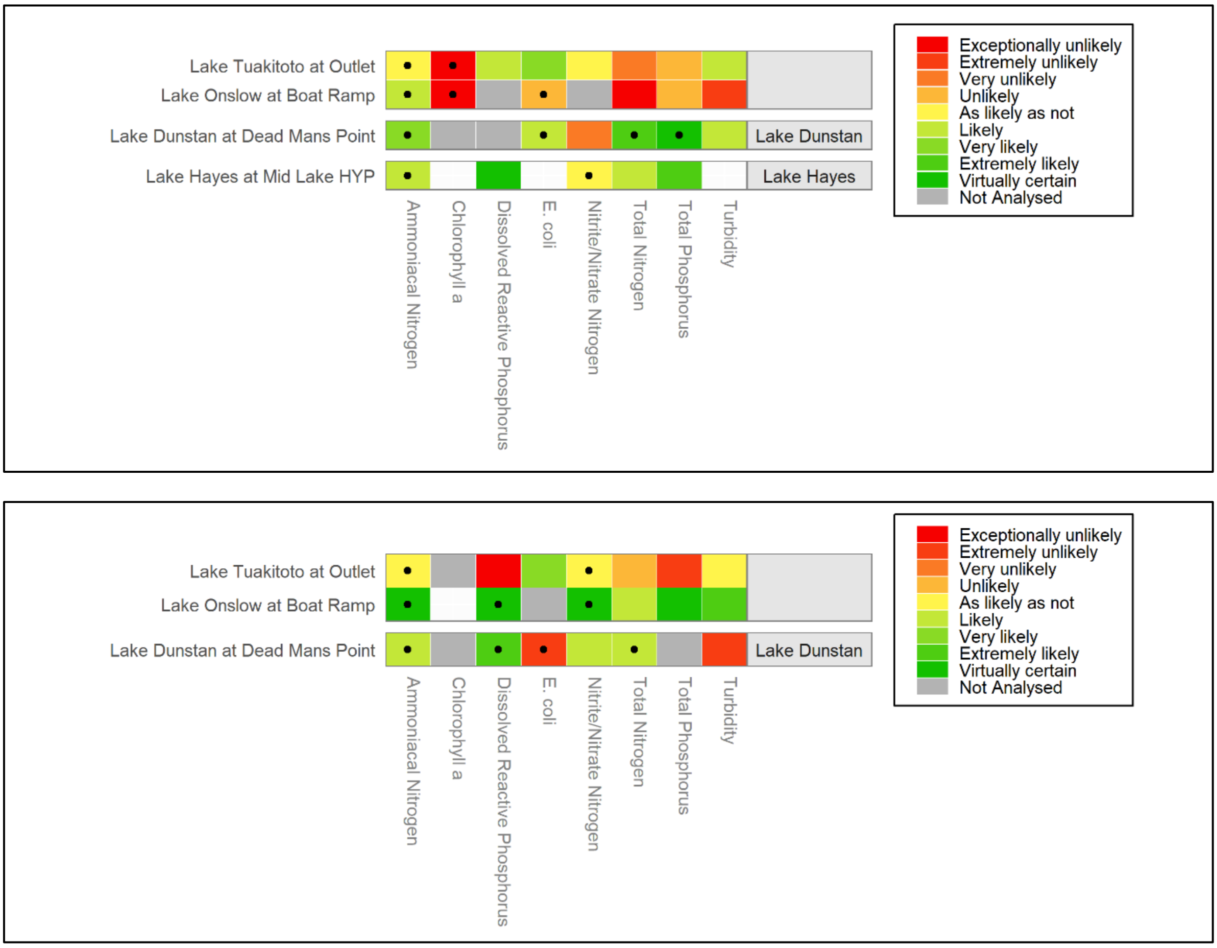


Figure 65 Summary *of Otago Lake sites categorised according to the level of confidence that their 10- and 20-year (top and bottom figures, respectively) raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.*

10.1.2.3 Groundwater

The proportion of sites in each confidence level for an improving 5- and 10-year trends in groundwater nitrate-N concentrations are shown in Figure 66. This shows that the proportion of sites with a 5-year improving (green) trend are similar to those not improving (orange/red), at around 40%. The 10-year trends generally show worse results, with around 48% of the sites having trends that are not improving (orange/red). Trends in dissolved arsenic were not obtained for many sites due to the high number of results below the analytical detection limit. However, when available, they are discussed in the relevant FMU/Rohe sections of this report.

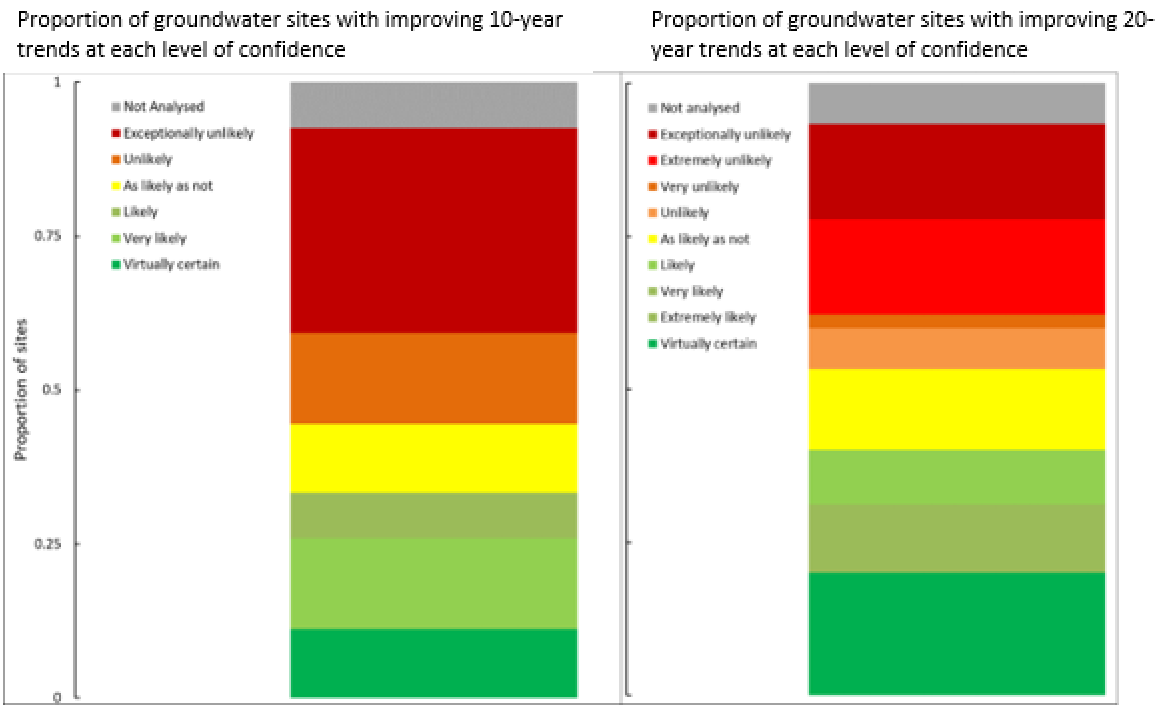


Figure 66: Groundwater sites classified by confidence that their 10- and 20-year trends in groundwater nitrate-N concentrations indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends

The spatial variability of the confidence level for improving trends is shown in Figure 67. This shows that the 10-year trends in most of the Rohe within the Clutha Mata-Au FMU are not improving (red/orange colours). The results for the Taieri and North Otago are more encouraging, with around half the sites showing improvement (i.e., green colours). The trends in the Catlins FMU are not improving.

The 5-year trend analysis intrinsically included more sites, which shows a more complex picture. Comparison between the 10-year and 5-year trends showed that most sites in the Dunstan Rohe do not show change. However, one site was getting worse (F40/0045) whilst another was improving (F41/0203). The 5-year analysis showed a mixed pattern in Hawea and the Whakatipu Basin. Mixed patterns were also observed in the Manuherekia and Roxburgh Rohe. There was no change in the Lower Clutha.

The trends in the Taieri FMU are also mixed, with some sites slightly improving between the 10- and 5-year trends while others getting worse. The 5-year trends for newer bores in the Maniototo (which did not have sufficient data for a 10-year trend analysis) are not improving. The North Otago FMU had some sites improving between the 10- and 5-year trends, and more improvements for the 5-year trend.

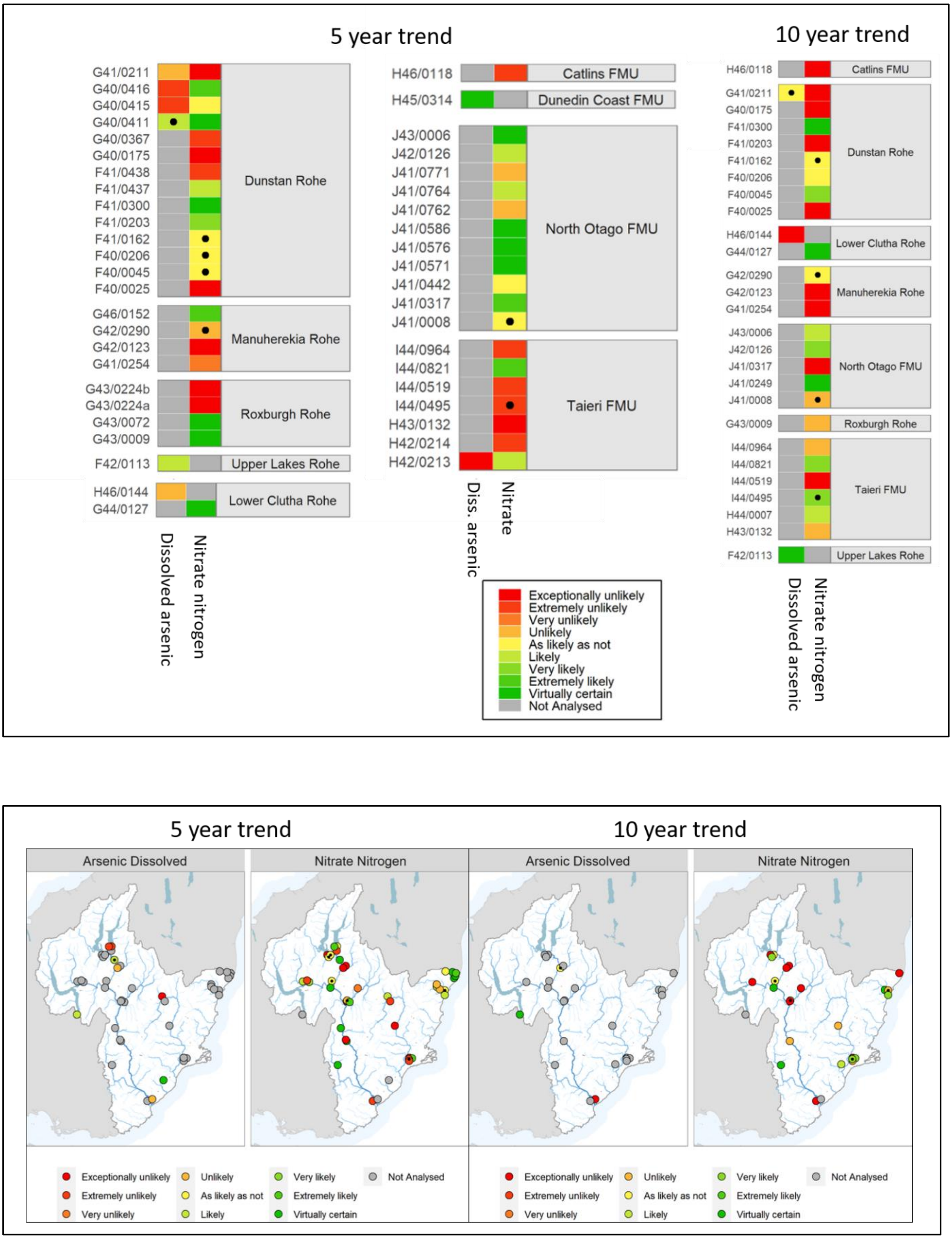


Figure 67: Map of groundwater sites classified by confidence that their 5-year and 10-year raw water quality trend direction indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

10.1.3 Otago water quality summary and discussion

This report assessed state and trends in rivers, lakes, and groundwater quality across Otago. Water quality was assessed against attributes in Appendix 2A and 2B of the NPS-FM; NH4-N, NNN, DRP, Chl-a, *E. coli*, TN, TP, suspended fine sediment, comment was also made on NNN concentrations as a driver of periphyton growth. River and lake state results show that water quality across Otago is spatially variable, water quality is best at lakes, river and stream reaches located at high or mountainous elevations under predominantly native cover. These sites tend to be associated with the Upper Lakes Rohe and the upper catchments of larger rivers (e.g., Lindis River, Pomahaka River, Nevis River) and the large lakes (e.g., Hawea, Whakatipu and Wanaka). Other areas, such as urban streams in the Dunedin, intensified catchments in North Otago and some tributaries in the Lower Clutha FMU have poorer water quality.

Trend analysis returned a mix of results, the 10-year trend analysis showed fewer degrading trends compared to the 20-year trend analysis, in particular there was an overall improvement in *E. coli*, TN, NNN and turbidity, however caution should be made interpreting this as variable numbers of sites were included in the different time periods. Tributaries of the Lower Clutha FMU, over a 10 year period, show many ‘extremely likely’ or ‘virtually certain’ improvements across multiple attributes. The Lower Clutha FMU is intensively farmed in challenging conditions, with artificial drainage and higher rainfall patterns. Catchment groups have been working in the area for 10+ years and the improving water quality may be due to increased awareness and on ground action promoted through farmer led groups.

Although lake state results across Otago are mainly placed in the A-band for most attributes , the 5-years trends show degradation in most sites. We note here that on time scales of this period, there is potential for climate driven changes in water quality to dominate those derived from changes within lake catchments (Snelder *et al*. 2021). In particular, lower rainfall and higher temperatures in the past few years associated with land use pressures could be responsible for driving incresead chl-a and nutrients in lakes.

As reported in previous ORC state and trend water quality reports (2007, 2012, 2020) there has been a lack of detailed information held by ORC on local or catchment scale land use change or land management practice changes which has severely limited the ability to comment on drivers of trends of water quality evident across Otago. Since 2020, there has been a shift in water quality management. The first was Plan Change 8 (PC8) becoming operative (September 2022) and the second the upcoming Land Water Regional Plan (LWRP).

Plan Change 8 introduced a range of amendments targeting specific issues or activities known to be contributing to water quality problems in parts of Otago. Promoting good farming practices was addressed, including better managing contaminant loss from intensive grazing and stock access to water bodies as well as incentivising the use of small in-stream sediment traps.

In areas of Otago which are intensively farmed with heavier soil, direct losses of animal waste can occur when it is applied to soils that have limited capacity to store moisture (resulting in ponding), or on slopes, where there is increased risk of overland flow. Effluent storage and application to land has been addressed through new minimum standards. Water quality in the Lower Clutha FMU is likely to benefit from PC8, as in this area nutrient-enriched discharges in this area have been found to be the result of inappropriate effluent application when the soil was saturated, or the application rate was too high for soils to absorb (ORC, 2011). Rivers in the Lower Clutha FMU generally have shown high *E. coli* concentrations, which is likely to be caused, at least in part, by animal waste storage issues as well as a high prevalence of subsurface drainage (Uytendaal & Ozanne, 2018).

In many areas of Otago, intensive grazing (winter grazing) forms an integral part of pasture-based livestock farming due to low pasture growth (during winter months) and large areas of poorly drained soils. Intensive grazing can also have adverse effects on water quality and soil, particularly from pugging which increases the risk of overland flow. Prior to PC8 there were no controls on intensive grazing practices, these are now covered by either permitted or prohibited activity rules. PC8 has two other key focus areas, mitigating against sediment loss (i.e., from earthworks) by enabling the installation and maintenance of sediment traps as a permitted activity, subject to standards and restrictions to stock access, depending on stock type, water body and slope. The water quality outcome of amendments introduced by PC8 will be positive and measurable in the long term.

ORC is in the process of developing a new Land and Water Regional Plan (LWRP), in partnership with Kāi Tahu iwi. The objective of the LWRP (and NPS-FM) is to ensure that the health and well-being of degraded water bodies and freshwater ecosystems is improved, and that the health and well-being of all other water bodies and freshwater ecosystems is maintained or improved. The LWRP will include rules and limits on water and land use in line with the NPS-FM (2020) and ORC is required to act if there is degradation or a deteriorating trend in water quality. This is a significant change in direction for water management in Otago, accordingly resources in the science team have increased to manage this change. where E. coli exceedances and nitrate-N concentrations were usually an issue in the same areas, while high dissolved arsenic concentrations were more site-specific.

The groundwater nitrate-N data shows a considerable spatial variability across Otago. The highest median nitrate-N concentrations are in the North Otago FMU, where median concentrations in around half the sites exceeded the MAV of 11.3mg/L or were at least ¾ of it. Conversely, most median nitrate-N concentrations in the Clutha Mata-Au and Taieri FMU are much lower, with most concentrations lower than ½ of the MAV and many below the 2.50mg/L threshold for low intensity land use (Morgenstern and Daughney, 2012).

The highest nitrate-N concentrations were usually measured in unconfined aquifers that underlie areas of intensive nitrate-N application (e.g., dairy farming, market garden) or septic tanks. This report highlighted high nitrate-N concentrations in many areas that fit these characteristics e.g., the Ettrick basin (Roxburgh Rohe), Pomahaka basin (Lower Clutha Rohe), the NOVA, the Kakanui-Kauru, the Lower Waitaki Plains (North Otago FMU), and the Lower Taieri (Taieri FMU). In addition to land use, these results can also be attributed to variability in geology, water table depth and geochemical conditions which impact nitrate-N breakdown (e.g., ORC, 2021). Geology influences nitrate-N concentrations as high permeable substrate allow rapid nitrate-N leaching into the aquifer, as was observed in the Kakanui-Kauru. Geology also contributes to the high nitrate-N concentrations in the NOVA, where slow groundwater velocity, due to low permeability, encourages nitrate-N accumulation. Nitrate-N concentrations can also be impacted by groundwater geochemistry, where reducing (i.e., low oxygen) conditions can lead to nitrate-N decomposition (e.g., Close *et* al., 2016). This process can mask the impact of nitrate-N application and may help explain low groundwater nitrate-N concentrations in areas underlain by intensive land use (Lower Taieri, Tokomairiro GWMZ, Inch Clutha). However, this hypothesis was not tested further in this report.

The *E. coli* data indicates that potential faecal contamination is a serious threat across Otago. However, it is also important to note that elevated *E. coli* can be a local issue and is strongly dependent on bore security and land use, hence the SoE monitoring data does not provide a complete mapping of this risk. ORC is currently upgrading the groundwater SoE monitoring programme, replacing many insecure bores with dedicated new ones. This will help determine whether the E. coli exceedances are site-specific or indicate wider issues. Nevertheless, it is strongly recommended that bore owners ensure adequate borehead security to prevent contaminant entry into the aquifer through the borehead. It is also recommended that groundwater used for drinking is regularly tested in an accredited laboratory, with testing being particularly important after periods of heavy rainfall. If *E. coli* is detected, water should be boiled or disinfected (MoH, 2018). Further information regarding bore security can be found in the ORC website (https://www.orc.govt.nz/media/5634/bore-brochure.pdf) or through the drinking water regulator Taumata Arowai https://www.taumataarowai.govt.nz/.

The arsenic data shows high spatial variability across Otago, with several areas where arsenic concentrations exceeded or are near the DWSNZ MAV. Most of the exceedances and high concentrations were in the Upper Lakes Rohe (Glenorchy and Kingston) but others were also measured in the Dunstan Rohe (Howards Drive), the Maniototo, and the Lower Clutha. Conversely, concentrations in most bores in the North Otago and Taieri FMU were low. Furthermore, high spatial variability in arsenic groundwater concentrations was observed on much smaller scales, including in bores situated within close proximity in some areas (e.g., Glenorchy). It is likely that these results are due to geologically sourced arsenic, which originates in schist lithology (in the Upper Lakes/Dunstan Rohe) or organic sediments (Lower Clutha) [Piper and Kim, 2006; ORC, 2021]. Combined with arsenic from these sources, groundwater concentrations can also increase due to enhanced arsenic mobility, caused by reducing geochemical (low oxygen) conditions. These are caused by microbial activity stimulated by organic carbon, usually sourced from septic tanks. These processes were attributed to the high arsenic concentrations in some bores in Glenorchy (ORC, 2021). Due to the high abundance of geological arsenic sources in Otago and its spatial variability in groundwater it is therefore strongly recommended that bore owners regularly test their bore water in an accredited laboratory for arsenic. As concentrations can also be impacted by fluctuations in groundwater levels, it is further recommended that testing is also conducted during different seasons (e.g., MoH, 2018).

In summary, similar to surface water, groundwater quality also varied across Otago. The main issues are elevated *E. coli* and nitrate-N concentrations, generally observed in areas of intensive land use, septic tanks, and insecure bores. Arsenic in groundwater is also an issue in many areas of Otago, although this is mainly geologically controlled. The report highlights the importance of good bore security, land use management, and frequent testing of bore water to ensure it is suitable for the intended use. Some of these issues are aimed to be improved with the new Land and Water Regional Plan and the addition of new, dedicated monitoring bores. However, under the current land use and management practiced found in some parts of the region it is unlikely that groundwater quality will improve.

11 References

Bloomberg, S., Davis, G., Bull D., Rowley F, Pritchard C., Keenan D., and Beardmore S. (2019). *Geological controls of enriched arsenic soils: case studies from Otago.* E3 Scientific presentation at the Ecoforum conference, Auckland.

Close, M. E., Abraham P., Humphries, B., and Lilburne L. 2016. Predicting groundwater redox status on a regional scale using linear discriminant analysis. *Journal of Contaminant Hydrology* 191: 19-32.

Department of Internal Affairs. 2022. Water services (Drinking Water Standards for New Zealand) Regulations 2022. Accessed online https://www.legislation.govt.nz/regulation/public/2022/0168/latest/whole.html

E3 Scientific Limited. 2018. *Environmental effects of On-site Sewage Management in Glenorchy Stage 2: Investigations*. Objective ID A1321757.

Environment Canterbury (2018). *Annual Groundwater Quality Survey*. 2018. https://www.ecan.govt.nz/document/download?uri=3588758 Accessed online May 2020.

Foster, C and K Johnson (2021). Groundwater quality state and trends in Tāmaki Makaurau/ Auckland 2010-2019. State of the environment reporting. Auckland Council technical report, TR2021/03.

Fraser. C; Snelder, T. 2023a. State of Lake and River Water Quality in the Otago Region. For records up to 30 June 2022

Fraser. C; Snelder, T. 2023b. ORC River, Groundwater and Lake water quality Trend analysis. For 10 and 20-year periods up to September 2022.

Franklin, P., D. Booker, and R. Stoffels, 2020. Contract 23184: Task 2 - Turbidity and Visual Clarity Threshold Conversion. NIWA. https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/technical-report-2-comparison-of-clarity-and-turbidity-bottom-lines.pdf.

Hawkes Bay Regional Council (2017). Groundwater Quality State of Environment State and Trends. Report no. 4803. Prepared by D. Gordon. ISSN 2324-4135.

Helsel, D.R., 2012. Reporting Limits. Statistics for Censored Environmental Data Using Minitab and R. John Wiley & Sons, pp. 22–36.

Helsel, D.R., R.M. Hirsch, K.R. Ryberg, S.A. Archfield, and E.J. Gilroy, 2020. Statistical Methods in Water Resources. Report, Reston, VA.

Hirsch, R.M., J.R. Slack, and R.A. Smith, 1982. Techniques of Trend Analysis for Monthly Water Quality Data. Water Resources Research 18:107–121.

Hickey, C., 2014. Derivation of Indicative Ammoniacal Nitrogen Guidelines for the National Objectives Framework. Memo prepared for Ms Vera Power, Ministry for the Environment, by NIWA.

Kienzle (S.W) and Schmidt (J). Hydrological impacts of irrigated agriculture in the Manuherekia catchment, Otago, New Zealand. Journal of Hydrology (NZ) 47 (2): 67-84 2008

Larned, S., A. Whitehead, C.E. Fraser, T. Snelder, and J. Yang, 2018. Water Quality State and Trends in New Zealand Rivers. Analyses of National-Scale Data Ending in 2017. prepared for Ministry for the Environment, NIWA.

Larned, S., T. Snelder, M. Unwin, G. McBride, P. Verburg, and H. McMillan, 2015. Analysis of Water Quality in New Zealand Lakes and Rivers. Prepared for the Ministry for the Environment. Wellington: Ministry for the Environment.

Larned, S., A. Whitehead, C.E. Fraser, T. Snelder, and J. Yang, 2018. Water Quality State and Trends in New Zealand Rivers. Analyses of National-Scale Data Ending in 2017. prepared for Ministry for the Environment, NIWA.

McBride, G.B., 2005. Using Statistical Methods for Water Quality Management: Issues, Problems and Solutions. John Wiley & Sons.

McBride, G.B., 2019. Has Water Quality Improved or Been Maintained? A Quantitative Assessment Procedure. Journal of Environmental Quality.

McBride, G., R.G. Cole, I. Westbrooke, and I. Jowett, 2014. Assessing Environmentally Significant Effects: A Better Strength-of-Evidence than a Single P Value? Environmental Monitoring and Assessment 186:2729–2740.

Ministry for the Environment. 2018. A Guide to Attributes in Appendix 2 of the National Policy Statement for Freshwater Management (as amended 2017). Wellington: Ministry for the Environment

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

Ministry for Environment, 2020. National Policy Statement for Freshwater Management 2020.

Ministry for Environment and Ministry of Health, 2003. Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment. https://www.mfe.govt.nz/sites/default/files/microbiological-quality-jun03.pdf.

Ministry for the Environment & National Institute for Water and Atmosphere (2004). New Zealand River Environment Classification User Guide. Ministry for the Environment, Wellington. Updated June 2010.

Ministry of Health. 2018. *Drinking-water Standards for New Zealand 2005 (revised 2018)*. Wellington: Ministry of Health. ISBN 978-1-98-853979-9 (online) HP 4660.

Morgenstern, U and 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.

National Environmental Monitoring Standards [NEMS]. 2019. Water quality part 1 – sampling, measuring, processing and archiving of discrete groundwater quality data. http://www.nems.org.nz/documents/water-quality-part-1-groundwater/ . Accessed online July 2020.

Otago Regional Council, 2017. State of the Environment: Surface water quality in Otago. 2006 to 2011. Otago Regional Council.

Otago Regional Council, 2020. State and Trends of River and Lake Water Quality in the Otago Region. 2000 to 2020. Otago Regional Council.

Otago Regional Council (2021). State of the Environment Groundwater Quality in Otago. Dunedin. Prepared by A. Levy, M. Ettema, and X. Lu. ISBN: 978-0-908324-68-2.

Piper J. and Kim N .2006. *Arsenic in Groundwater of the Waikato Region*. Environment Waikato Technical Report 2006/14. ISSN: 1172-4005

Rogers, KM, van der Raiij, R., Phillips, A., and Stewart, M. 2023. A national isotope survey to define the sources of nitrate contamination in New Zealand freshwater. *Journal of Hydrology* 617.

Schullehner, J., Hansen, B., Thygesen, M., Pedersen, C.B., Sigsgaard, T., 2018. Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study. *International Journal of Cancer* 143 (1): 73–79.

Snelder, T. and C. Fraser, 2021. The LWP-Trends Library; V2102 November 2021. LWP Ltd Report.

Snelder, T. H., Larned, S. T., Fraser, C., and De Malmanche, S., 2021. Effect of climate variability on water quality trends in New Zealand rivers. Marine and Freshwater Research. [Published online 30 September 2021].

Stocker et al., 2014, IPCC Climate Change 2013: The Physical Science Basis - Findings and Lessons Learned

12 Appendix 1 Water Quality Summary Results

12.1 River - Dissolved Reactive P and Nitrate-N

FMU	***Site Name***	***# values***	***NNN Median***	***NNN Q95***	***DRP Median***	***DRP Q95***
Catlins FMU	Catlins at Houipapa	58	0.4	0.75	0.01005	0.01378
Catlins FMU	Maclennan at Kahuiku School Road	45	0.021	0.06475	0.0096	0.0139
Catlins FMU	Owaka at Katea Road	58	1.04	2.38	0.0152	0.0268
Catlins FMU	Tahakopa at Tahakopa	45	0.31	0.5925	0.0068	0.01032
Dunedin & Coast	Akatore Creek at Akatore Creek Road	43	0.185	1.853	0.0047	0.00975
Dunedin & Coast	Kaikorai Stream at Brighton Road	57	0.4	1.012	0.0078	0.0245
Dunedin & Coast	Leith at Dundas Street Bridge	56	0.46	0.786	0.017	0.02875
Dunedin & Coast	Lindsay’s Creek at North Road Bridge	57	0.58	1.0625	0.01515	0.0237
Dunedin & Coast	Tokomairiro at Blackbridge	59	0.39	2.81	0.0161	0.04865
Dunedin & Coast	Tokomairiro at West Branch Bridge	59	0.25	1.1065	0.0074	0.01422
Dunedin & Coast	Waitati at Mt Cargill Road	57	0.022	0.4095	0.00326	0.00805
Dunstan Rohe	Arrow at Morven Ferry Road	46	0.084	0.1586	0.00141	0.00309
Dunstan Rohe	Bannockburn at Lake Dunstan	58	0.00048	0.0117	0.0028	0.0054
Dunstan Rohe	Cardrona at Mt Barker	57	0.078	0.21	0.0016	0.004
Dunstan Rohe	Clutha @ Luggate Br	57	0.03	0.04965	0.0002	0.00119
Dunstan Rohe	Hawea at Camphill Bridge	58	0.0172	0.04	0.0014	0.00296
Dunstan Rohe	Kawarau @ Chards Rd	56	0.0185	0.032	0.0008	0.00523
Dunstan Rohe	Lindis at Ardgour Road	57	0.033	0.17775	0.00185	0.00442
Dunstan Rohe	Lindis at Lindis Peak	57	0.0196	0.078	0.00202	0.00528
Dunstan Rohe	Luggate Creek at SH6 Bridge	57	0.0044	0.01626	0.0089	0.01247
Dunstan Rohe	Mill Creek at Fish Trap	59	0.35	0.49	0.00365	0.01212
Dunstan Rohe	Nevis at Wentworth Station	46	0.0018	0.01178	0.00287	0.00575
Dunstan Rohe	Quartz Reef Creek at SH8	45	0.0061	0.05025	0.00171	0.00332
Dunstan Rohe	Roaring Meg at SH6	46	0.0114	0.0404	0.0065	0.00946
Dunstan Rohe	Shotover @ Bowens Peak	58	0.0155	0.0344	0.0005	0.00176
Dunstan Rohe	Upper Cardrona at Tuohys Gully Road	44	0.01905	0.0461	0.00093	0.00242
Lower Clutha Rohe	Blackcleugh Burn at Rongahere Road	42	0.0515	0.1556	0.01425	0.021
Lower Clutha Rohe	Clutha @ Balclutha	59	0.06178	0.35834	0.0011	0.00604
Lower Clutha Rohe	Crookston Burn at Kelso Road	56	1.24	2.41	0.03	0.06175
Lower Clutha Rohe	Heriot Burn at Park Hill Road	56	1.32	1.96	0.026	0.04475
Lower Clutha Rohe	Lovells Creek at Station Road	59	1.11	3.655	0.01	0.03375
Lower Clutha Rohe	Pomahaka at Burkes Ford	56	0.65	2.47	0.0104	0.02625
Lower Clutha Rohe	Pomahaka at Glenken	56	0.0585	0.374	0.0058	0.01458
Lower Clutha Rohe	Tuapeka at 700m u/s bridge	57	0.168	1.036	0.0195	0.03665
Lower Clutha Rohe	Upper Pomahaka at Aitchison Runs Rd	45	0.0132	0.049	0.0047	0.00915
Lower Clutha Rohe	Waipahi at Cairns Peak	56	0.79	1.955	0.01105	0.0491
Lower Clutha Rohe	Waipahi at Waipahi	56	1.215	2.88	0.01345	0.0334
Lower Clutha Rohe	Wairuna at Millar Road	56	1.385	6.86	0.031	0.1907
Lower Clutha Rohe	Waitahuna at Tweeds Bridge	59	0.175	1.3515	0.0114	0.0352
Lower Clutha Rohe	Waiwera at Maws Farm	59	0.98	3.02	0.022	0.06085
Manuherekia Rohe	Dunstan Creek at Beattie Road	58	0.084	0.1928	0.0027	0.00634
Manuherekia Rohe	Hills Creek at SH85	45	0.041	0.26	0.0022	0.00688
Manuherekia Rohe	Manuherekia at Blackstone Hill	58	0.00455	0.0776	0.00255	0.00666

FMU	Site Name	# values	NNN Median	NNN Q95	DRP Median	DRP Q95
Manuherekia Rohe	Manuherekia at Galloway	58	0.0485	0.23	0.009	0.0282
Manuherekia Rohe	Manuherekia at Ophir	58	0.081	0.286	0.01085	0.0354
Manuherekia Rohe	Manuherekia downstream of Fork	47	0.0017	0.01188	0.0037	0.00602
Manuherekia Rohe	Poolburn at Cob Cottage	47	0.064	0.38	0.027	0.0673
Manuherekia Rohe	Thomsons Creek at SH85	57	0.25	0.6165	0.0187	0.1049
North Otago FMU	Awamoko at SH83	55	0.48	1.1125	0.0535	0.145
North Otago FMU	Kakaho Creek at SH1	33	0.142	0.812	0.022	0.07285
North Otago FMU	Kakanui at Clifton Falls Bridge	55	0.024	0.10775	0.00145	0.00872
North Otago FMU	Kakanui at McCones	55	0.38	0.845	0.00283	0.01304
North Otago FMU	Kauru at Ewings	55	0.014	0.05925	0.00246	0.00616
North Otago FMU	Oamaru Creek at SH1	43	0.52	1.1145	0.25	0.4735
North Otago FMU	Pleasant at Patterson Road Ford	43	0.0152	1.201	0.00229	0.0105
North Otago FMU	Shag at Craig Road	56	0.11025	0.4927	0.00323	0.0121
North Otago FMU	Shag at Goodwood Pump	55	0.23	0.6875	0.0045	0.01375
North Otago FMU	Trotters Creek at Mathesons	55	0.46	1.29	0.0036	0.00868
North Otago FMU	Upper Shag at SH85 Culvert	46	0.0154	0.0682	0.0019	0.00356
North Otago FMU	Waianakarua at Browns	55	0.3	0.59	0.00249	0.01092
North Otago FMU	Waianakarua at South Branch SH1	43	0.37	0.7605	0.0016	0.00553
North Otago FMU	Waiareka Creek at Taipo Road	54	0.48	1.99	0.187	0.3685
North Otago FMU	Waikouaiti at 200m d/s DCC intake	44	0.029	0.291	0.00116	0.00388
Roxburgh Rohe	Benger burn at Booths	54	0.182	1.146	0.01035	0.01942
Roxburgh Rohe	Clutha @ Millers Flat	59	0.02987	0.05804	0.00065	0.00293
Roxburgh Rohe	Fraser at Old Man Range	45	0.0035	0.01368	0.0024	0.0041
Roxburgh Rohe	Teviot at Bridge Huts Road	45	0.004	0.01842	0.0011	0.0037
Taieri FMU	Contour Channel at No. 4 Bridge	59	0.184	0.5875	0.0179	0.07865
Taieri FMU	Deep Stream at SH87	58	0.00105	0.0616	0.0019	0.00466
Taieri FMU	Kye Burn at SH85 Bridge	59	0.078	0.241	0.00328	0.00619
Taieri FMU	Meggat Burn at Berwick Road	46	0.0695	0.424	0.00905	0.019
Taieri FMU	Nenthorn at Mt Stoker Road	58	0.00128	0.029	0.0058	0.01828
Taieri FMU	Silverstream at Taieri Depot	59	0.41	0.8595	0.00314	0.02408
Taieri FMU	Silverstream at Three Mile Hill Road	46	0.00765	0.1116	0.0018	0.004
Taieri FMU	Sutton Stream at SH87	55	0.0049	0.0645	0.004	0.0086
Taieri FMU	Taieri at Allanton Bridge	57	0.08	0.2595	0.008	0.02525
Taieri FMU	Taieri at Linnburn Runs Road	58	0.00215	0.01168	0.002	0.00524
Taieri FMU	Taieri at Outram	60	0.05	0.1765	0.0065	0.0204
Taieri FMU	Taieri at Stonehenge	59	0.0093	0.0322	0.004	0.01096
Taieri FMU	Taieri at Sutton	59	0.039	0.13065	0.0078	0.0261
Taieri FMU	Taieri at Tiroiti	59	0.038	0.12785	0.0102	0.0333
Taieri FMU	Taieri at Waipiata	59	0.023	0.0922	0.0168	0.0466
Taieri FMU	Waipori at Waipori Falls Reserve	59	0.023	0.129	0.00214	0.00764
Taieri FMU	Whare Creek at Whare Flat Road	46	0.035	0.1748	0.00192	0.00354
Upper Lakes Rohe	12 Mile Creek at Glenorchy QT Rd	44	0.0024	0.00795	0.00255	0.00433
Upper Lakes Rohe	25 Mile Creek at Glenorchy QT Rd	44	0.00435	0.01189	0.00305	0.00666
Upper Lakes Rohe	Buckler Burn at Glenorchy QT Rd	44	0.01835	0.0536	0.00106	0.00226
Upper Lakes Rohe	Bullock Creek at Dunmore Street	45	0.73	0.815	0.0011	0.00195
Upper Lakes Rohe	Craig Burn at SH6	37	0.0038	0.01958	0.0028	0.00573
Upper Lakes Rohe	Dart at The Hillocks	56	0.0285	0.044	0.00185	0.00328

FMU	Site Name	# values	NNN Median	NNN Q95	DRP Median	DRP Q95
Upper Lakes Rohe	Dundas Creek at Mill Flat	43	0.032	0.05635	0.00236	0.00368
Upper Lakes Rohe	Greenstone at Greenstone Station Road	43	0.0119	0.024	0.00107	0.00201
Upper Lakes Rohe	Horn Creek at Queenstown Bay	45	0.147	0.205	0.0085	0.01498
Upper Lakes Rohe	Invincible Creek at Rees Valley Road	43	0.0093	0.02025	0.00065	0.00204
Upper Lakes Rohe	Leaping Burn at Wanaka Mt Aspiring Rd	45	0.0183	0.04925	0.00062	0.00215
Upper Lakes Rohe	Makarora at Makarora	45	0.044	0.07775	0.0011	0.0036
Upper Lakes Rohe	Matukituki at West Wanaka	58	0.0595	0.0954	0.0023	0.00416
Upper Lakes Rohe	Motatapu at Wanaka Mt Aspiring Road	45	0.031	0.053	0.0005	0.00198
Upper Lakes Rohe	Ox Burn at Rees Valley Road	43	0.014	0.02705	0.0012	0.00211
Upper Lakes Rohe	Precipice Creek at Glenorchy Paradise	44	0.0037	0.01797	0.0013	0.00223
Upper Lakes Rohe	Quartz Creek at Maungawera Valley Rd	41	0.059	0.15405	0.0015	0.00378
Upper Lakes Rohe	Rees at Glenorchy Paradise Road Bridge	44	0.01265	0.022	0.00097	0.00203
Upper Lakes Rohe	Scott Creek at Routeburn Road	44	0.0235	0.0343	0.00105	0.00274
Upper Lakes Rohe	The Neck Creek at Meads Road	45	0.0021	0.01135	0.0015	0.0026
Upper Lakes Rohe	Timaru at Peter Muir Bridge	43	0.0076	0.0207	0.0044	0.00705
Upper Lakes Rohe	Turner Creek at Kinloch Road	44	0.042	0.0533	0.0018	0.00306

12.2 Rivers - Clarity and *E. Coli*

FMU	*Site Name*	*Turbidity Median*	*SS Class App 2C*	*Clarity Median*	*E. coli G260*	*E. coli G540*	*E. coli Median*	*E. coli Q95*
Catlins FMU	Catlins at Houipapa	3.4	4	1.39	0.21	0.16	145	1540
Catlins FMU	Maclennan at Kahuiku	1.97	3	2.06	0.16	0.11	70	758
Catlins FMU	Owaka at Katea Road	2.6	4	1.69	0.44	0.23	231	2524
Catlins FMU	Tahakopa at Tahakopa	3.6	4	1.33	0.36	0.25	172	3927
Dun/ Coast	Akatore Creek at Akatore	0.96	2	3.45	0.16	0.14	91	2173
Dun/ Coast	Kaikorai Stream	3.3	2	1.42	0.91	0.73	1162	9908
Dun/ Coast	Leith at Dundas Street	2.15	1	1.93	0.88	0.70	707	2476
Dun/ Coast	Lindsay’s Creek at North	2.7	1	1.64	0.74	0.51	548	3106
Dun/ Coast	Tokomairiro at Blackbridge	6	1	0.92	0.81	0.73	980	8865
Dun/ Coast	Tokomairiro at West Br Br	2.4	1	1.79	0.44	0.29	225	2714
Dun/ Coast	Waitati at Mt Cargill Road	1.18	1	2.98	0.21	0.09	96	998
Dunstan Rohe	Arrow at Morven Ferry	1.38	3	2.66	0.04	0.02	15	287
Dunstan Rohe	Bannockburn at Lake D	1.12	3	3.09	0.09	0.02	43	316
Dunstan Rohe	Cardrona at Mt Barker	1.81	3	2.19	0.11	0.05	60	616
Dunstan Rohe	Clutha @ Luggate Br	0.805	3	3.92	0.00	0.00	4	47
Dunstan Rohe	Hawea at Camphill Bridge	0.37	3	6.86	0.00	0.00	2	18
Dunstan Rohe	Kawarau @ Chards Rd	2.7	3	1.64	0.05	0.02	6	253
Dunstan Rohe	Lindis at Ardgour Road	1.54	3	2.46	0.11	0.04	76	485
Dunstan Rohe	Lindis at Lindis Peak	2.3	3	1.84	0.13	0.04	75	500
Dunstan Rohe	Luggate Creek at SH6 Br	1.16	1	3.01	0.12	0.05	64	608
Dunstan Rohe	Mill Creek at Fish Trap	4.3	3	1.17	0.28	0.16	122	1296
Dunstan Rohe	Nevis at Wentworth St	0.885	1	3.66	0.00	0.00	11	162
Dunstan Rohe	Quartz Reef Creek at SH8	1.68	3	2.31	0.00	0.00	49	241
Dunstan Rohe	Roaring Meg at SH6	0.89	1	3.65	0.00	0.00	16	113
Dunstan Rohe	Shotover @ Bowens Peak	9.575	1	0.66	0.05	0.04	6	322
Dunstan Rohe	Upper Cardrona Tuohys	1.42	3	2.61	0.07	0.05	38	604
Lower Clutha	Blackcleugh Burn at Rong	1.05	3	3.24	0.05	0.00	12	155
Lower Clutha	Clutha @ Balclutha	3.865	3	1.27	0.14	0.08	50	1300
Lower Clutha	Crookston Burn at Kelso	5.05	3	1.05	0.80	0.55	579	2117
Lower Clutha	Heriot Burn at Park Hill	5.1	1	1.04	0.63	0.46	400	2290
Lower Clutha	Lovells Creek at Station	3.2	1	1.45	0.54	0.31	276	3411
Lower Clutha	Pomahaka at Burkes Ford	4.15	1	1.20	0.29	0.18	114	1986
Lower Clutha	Pomahaka at Glenken	1.715	3	2.27	0.39	0.05	192	836
Lower Clutha	Tuapeka at 700m u/s Br	3.5	1	1.36	0.49	0.26	236	5960
Lower Clutha	Upper Pomahaka ARR	0.77	3	4.05	0.13	0.04	73	480
Lower Clutha	Waipahi at Cairns Peak	3.9	4	1.26	0.36	0.23	193	1656
Lower Clutha	Waipahi at Waipahi	2.6	2	1.69	0.36	0.14	186	6635
Lower Clutha	Wairuna at Millar Road	9.05	1	0.69	0.86	0.55	625	5218
Lower Clutha	Waitahuna at Tweeds Br	3.5	1	1.36	0.63	0.31	326	5721
Lower Clutha	Waiwera at Maws Farm	2.5	2	1.73	0.46	0.22	248	1634
Lower Clutha	Dunstan Creek at Beattie	0.765	3	4.07	0.09	0.05	59	558
Manuherekia	Hills Creek at SH85	1.26	3	2.84	0.29	0.16	93	895

FMU	Site Name	Turbidity Median	SS Class App 2C	Clarity Median	*E. coli* G260	*E. coli* G540	*E. coli* Median	*E. coli* Q95
Manuherekia	Manuherekia Blackstone	2.65	3	1.66	0.10	0.05	52	748
Manuherekia	Manuherekia at Galloway	3.2	3	1.45	0.24	0.10	83	1228
Manuherekia	Manuherekia at Ophir	3.45	3	1.37	0.40	0.22	202	2702
Manuherekia	Manuherekia d/s of Fork	0.26	1	8.85	0.02	0.00	7	107
Manuherekia	Poolburn at Cob Cottage	2.5	3	1.73	0.36	0.15	179	2156
Manuherekia	Thomsons Creek at SH85	6	3	0.92	0.58	0.47	410	5228
North Otago	Awamoko at SH83	1.01	2	3.33	0.49	0.22	199	1720
North Otago	Kakaho Creek at SH1	2.9	2	1.56	0.36	0.27	147	26629
North Otago	Kakanui at Clifton Falls Br	0.35	3	7.14	0.36	0.29	214	1115
North Otago	Kakanui at McCones	0.5	3	5.52	0.22	0.13	107	1255
North Otago	Kauru at Ewings	0.32	3	7.62	0.25	0.15	119	3512
North Otago	Oamaru Creek at SH1	1.69	2	2.30	0.44	0.30	236	16424
North Otago	Pleasant at Patterson Rd	2.9	2	1.56	0.16	0.12	59	10090
North Otago	Shag at Craig Road	0.6	3	4.84	0.09	0.05	53	638
North Otago	Shag at Goodwood Pump	0.72	1	4.25	0.22	0.11	100	1074
North Otago	Trotters Creek Mathesons	1.63	2	2.36	0.33	0.16	148	1164
North Otago	Upper Shag at SH85	0.275	3	8.50	0.09	0.04	39	628
North Otago	Waianakarua at Browns	0.45	3	5.96	0.20	0.11	98	1518
North Otago	Waianakarua at S Brh SH1	0.37	3	6.86	0.19	0.12	101	2864
North Otago	Waiareka Creek at Taipo	1.78	2	2.21	0.44	0.20	212	856
North Otago	Waikouaiti at 200m d/s	0.655	3	4.55	0.07	0.02	43	317
Roxburgh Rohe	Benger burn at Booths	1.93	3	2.09	0.42	0.21	230	2716
Roxburgh Rohe	Clutha @ Millers Flat	1.75	3	2.24	0.03	0.02	15	162
Roxburgh Rohe	Fraser at Old Man Range	0.39	1	6.61	0.00	0.00	3	31
Roxburgh Rohe	Teviot at Bridge Huts Rd	4.1	3	1.21	0.13	0.04	28	562
Taieri FMU	Contour Channel No4 Br	3.9	1	1.26	0.54	0.44	340	4377
Taieri FMU	Deep Stream at SH87	0.755	3	4.11	0.12	0.02	75	420
Taieri FMU	Kye Burn at SH85 Bridge	1.1	3	3.13	0.09	0.03	67	407
Taieri FMU	Meggat Burn Berwick Rd	2.3	3	1.84	0.30	0.13	150	1100
Taieri FMU	Nenthorn at Mt Stoker Rd	0.91	3	3.59	0.10	0.02	44	387
Taieri FMU	Silverstream Taieri Dep	0.88	1	3.68	0.32	0.22	148	2324
Taieri FMU	Silverstream at 3 Mile Hill	0.64	1	4.62	0.09	0.07	48	704
Taieri FMU	Sutton Stream at SH87	1.07	3	3.19	0.40	0.15	219	821
Taieri FMU	Taieri at Allanton Bridge	4.7	3	1.10	0.28	0.14	127	2862
Taieri FMU	Taieri Linnburn Runs Rd	1.245	3	2.86	0.18	0.07	62	703
Taieri FMU	Taieri at Outram	3	1	1.52	0.08	0.05	62	437
Taieri FMU	Taieri at Stonehenge	1.3	3	2.78	0.05	0.03	59	284
Taieri FMU	Taieri at Sutton	4.5	1	1.14	0.24	0.12	148	1051
Taieri FMU	Taieri at Tiroiti	4	3	1.24	0.12	0.02	78	393
Taieri FMU	Taieri at Waipiata	3	3	1.52	0.19	0.05	105	836
Taieri FMU	Waipori at Waipori Falls	1.8	3	2.20	0.00	0.00	12	79
Taieri FMU	Whare Creek Whare Flat	1.02	2	3.31	0.00	0.00	13	142
Upper Lakes	12 Mile Creek at GQT Rd	0.23	1	9.66	0.00	0.00	3	20
Upper Lakes	25 Mile Creek at GQT Rd	0.275	1	8.50	0.00	0.00	14	60
Upper Lakes	Buckler Burn at GQT Rd	2.5	1	1.73	0.02	0.02	5	38

FMU	*Site Name*	Turbidity Median	SS Class App 2C	Clarity Median	*E. coli* G260	*E. coli* G540	*E. coli* Median	*E. coli* Q95
Upper Lakes	Bullock Creek at Dunmore	0.26	3	8.85	0.40	0.33	205	1706
Upper Lakes	Craig Burn at SH6	0.54	3	5.23	0.00	0.00	42	169
Upper Lakes	Dart at The Hillocks	19.1	3	0.40	0.07	0.02	9	361
Upper Lakes	Dundas Creek at Mill Flat	0.2	3	10.68	0.00	0.00	1	13
Upper Lakes	Greenstone at GS Station	0.32	1	7.62	0.00	0.00	19	139
Upper Lakes	Horn Creek at Queenstown	1.43	3	2.59	0.27	0.09	88	794
Upper Lakes	Invincible Creek at Rees V	1.2	1	2.94	0.00	0.00	1	8
Upper Lakes	Leaping Burn W Mt As Rd	0.27	1	8.61	0.12	0.05	31	491
Upper Lakes	Makarora at Makarora	0.97	3	3.43	0.09	0.05	23	523
Upper Lakes	Matukituki at W Wanaka	3.75	1	1.29	0.05	0.02	25	284
Upper Lakes	Motatapu at W Mt As Rd	0.73	1	4.21	0.02	0.02	23	113
Upper Lakes	Ox Burn at Rees Valley Rd	2.7	1	1.64	0.00	0.00	5	21
Upper Lakes	Precipice Creek at G P Rd	0.335	1	7.37	0.02	0.00	7	69
Upper Lakes	Quartz Creek at Maungatua	0.24	3	9.37	0.13	0.05	54	717
Upper Lakes	Rees at Glenorchy P Rd Br	6.05	1	0.92	0.05	0.05	10	424
Upper Lakes	Scott Ck at Routeburn R	0.49	1	5.60	0.02	0.00	7	42
Upper Lakes	The Neck Creek at Meads	0.17	1	12.01	0.02	0.00	5	118
Upper Lakes	Timaru at Peter Muir Br	14.5	1	0.49	0.00	0.00	5	18
Upper Lakes	Turner Creek Kinloch Rd	0.295	1	8.08	0.00	0.00	4	41

12.3 Rivers - Ammonia and Periphyton

FMU	*Site Name*	*NH4-N #*	*NH4-N Median*	*NH4-N Ann Max*	*Chla #*	*Chla Q83*	*Chla Q92*
Catlins FMU	Catlins at Houipapa	58	0.0030	0.0122	n/a	n/a	n/a
Catlins FMU	Maclennan Kahuiku Sch Rd	45	0.0035	0.0150	n/a	n/a	n/a
Catlins FMU	Owaka at Katea Road	58	0.0041	0.0167	28	136.84	178.06
Catlins FMU	Tahakopa at Tahakopa	45	0.0039	0.0076	28	46.01	110.82
Dunedin & Coast FMU	Akatore Creek at A-Ck Road	43	0.0028	0.0088	32	89.72	146.67
Dunedin & Coast FMU	Kaikorai Stream Brighton Rd	57	0.0062	1.9325	31	416.37	502.82
Dunedin & Coast FMU	Leith at Dundas Street Bridge	56	0.0046	0.0259	n/a	n/a	n/a
Dunedin & Coast FMU	Lindsay’s Creek North Road Br	57	0.0062	0.0157	n/a	n/a	n/a
Dunedin & Coast FMU	Tokomairiro at Blackbridge	59	0.0090	0.1759	n/a	n/a	n/a
Dunedin & Coast FMU	Tokomairiro West Branch B	59	0.0033	0.0293	30	112.28	175.45
Dunedin & Coast FMU	Waitati at Mt Cargill Road	57	0.0035	0.0443	n/a	n/a	n/a
Dunstan Rohe	Arrow at Morven Ferry Road	46	0.0019	0.0025	23	29.87	34.36
Dunstan Rohe	Bannockburn at Lake Dunstan	58	0.0019	0.0163	n/a	n/a	n/a
Dunstan Rohe	Cardrona at Mt Barker	57	0.0022	0.0061	28	36.39	56.37
Dunstan Rohe	Clutha @ Luggate Br	56	0.0028	0.0092	n/a	n/a	n/a
Dunstan Rohe	Hawea at Camphill Bridge	58	0.0009	0.0028	n/a	n/a	n/a
Dunstan Rohe	Kawarau @ Chards Rd	56	0.0026	0.0101	n/a	n/a	n/a
Dunstan Rohe	Lindis at Ardgour Road	57	0.0022	0.0054	23	111.37	114.61
Dunstan Rohe	Lindis at Lindis Peak	57	0.0012	0.0034	n/a	n/a	n/a
Dunstan Rohe	Luggate Creek at SH6 Bridge	49	0.0013	0.0061	32	66.46	96.51
Dunstan Rohe	Mill Creek at Fish Trap	51	0.0037	0.0584	n/a	n/a	n/a
Dunstan Rohe	Nevis at Wentworth Station	46	0.0005	0.0023	n/a	n/a	n/a
Dunstan Rohe	Quartz Reef Creek at SH8	45	0.0022	0.0054	n/a	n/a	n/a
Dunstan Rohe	Roaring Meg at SH6	46	0.0014	0.0022	n/a	n/a	n/a
Dunstan Rohe	Shotover @ Bowens Peak	55	0.0017	0.0063	n/a	n/a	n/a
Dunstan Rohe	Upper Cardrona Tuohys Gully Rd	44	0.0019	0.0022	n/a	n/a	n/a
Lower Clutha Rohe	Blackcleugh Burn Rongahere Rd	42	0.0012	0.0040	30	19.10	29.81
Lower Clutha Rohe	Clutha @ Balclutha	58	0.0024	0.0126	n/a	n/a	n/a
Lower Clutha Rohe	Crookston Burn at Kelso Road	56	0.0080	0.1341	n/a	n/a	n/a
Lower Clutha Rohe	Heriot Burn at Park Hill Road	56	0.0084	0.0282	n/a	n/a	n/a
Lower Clutha Rohe	Lovells Creek at Station Road	59	0.0056	0.0371	n/a	n/a	n/a
Lower Clutha Rohe	Pomahaka at Burkes Ford	56	0.0044	0.0299	n/a	n/a	n/a
Lower Clutha Rohe	Pomahaka at Glenken	56	0.0020	0.0046	n/a	n/a	n/a
Lower Clutha Rohe	Tuapeka at 700m u/s bridge	57	0.0039	0.0304	n/a	n/a	n/a
Lower Clutha Rohe	Upper Pomahaka Aitchison R Rd	45	0.0012	0.0037	29	23.19	35.76
Lower Clutha Rohe	Waipahi at Cairns Peak	56	0.0061	0.0187	n/a	n/a	n/a
Lower Clutha Rohe	Waipahi at Waipahi	56	0.0037	0.0339	25	166.05	234.70
Lower Clutha Rohe	Wairuna at Millar Road	56	0.0171	0.0835	n/a	n/a	n/a
Lower Clutha Rohe	Waitahuna at Tweeds Bridge	59	0.0041	0.0591	29	18.65	31.23
Lower Clutha Rohe	Waiwera at Maws Farm	59	0.0085	0.1160	n/a	n/a	n/a

FMU	*Site Name*	*NH4-N #*	*NH4-N Median*	*NH4-N Ann Max*	*Chla #*	*Chla Q83*	*Chla Q92*
Manuherekia Rohe	Dunstan Creek at Beattie Road	58	0.0014	0.0041	28	18.79	47.50
Manuherekia Rohe	Hills Creek at SH85	45	0.0011	0.0528	n/a	n/a	n/a
Manuherekia Rohe	Manuherekia at Blackstone Hill	58	0.0014	0.0369	24	49.96	67.18
Manuherekia Rohe	Manuherekia at Galloway	58	0.0021	0.0101	29	57.07	101.87
Manuherekia Rohe	Manuherekia at Ophir	58	0.0034	0.0243	26	81.22	102.98
Manuherekia Rohe	Manuherekia downstream of Fork	47	0.0011	0.0013	n/a	n/a	n/a
Manuherekia Rohe	Poolburn at Cob Cottage	47	0.0038	0.0292	n/a	n/a	n/a
Manuherekia Rohe	Thomsons Creek at SH85	57	0.0044	0.0558	n/a	n/a	n/a
North Otago FMU	Awamoko at SH83	55	0.0045	0.1666	n/a	n/a	n/a
North Otago FMU	Kakaho Creek at SH1	33	0.0148	0.1235	n/a	n/a	n/a
North Otago FMU	Kakanui at Clifton Falls Bridge	55	0.0016	0.0192	2	80.20	80.20
North Otago FMU	Kakanui at McCones	55	0.0027	0.0102	30	283.60	464.30
North Otago FMU	Kauru at Ewings	55	0.0019	0.0067	n/a	n/a	n/a
North Otago FMU	Oamaru Creek at SH1	43	0.0173	0.1470	34	485.40	568.83
North Otago FMU	Pleasant at Patterson Road Ford	43	0.0037	0.0171	n/a	n/a	n/a
North Otago FMU	Shag at Craig Road	56	0.0025	0.0248	n/a	n/a	n/a
North Otago FMU	Shag at Goodwood Pump	55	0.0034	0.0102	32	330.61	372.25
North Otago FMU	Trotters Creek at Mathesons	55	0.0061	0.0953	n/a	n/a	n/a
North Otago FMU	Upper Shag at SH85 Culvert	46	0.0017	0.0238	n/a	n/a	n/a
North Otago FMU	Waianakarua at Browns	55	0.0020	0.0056	33	179.16	220.05
North Otago FMU	Waianakarua S Branch SH1	43	0.0027	0.0055	n/a	n/a	n/a
North Otago FMU	Waiareka Creek at Taipo Road	54	0.0081	0.3198	n/a	n/a	n/a
North Otago FMU	Waikouaiti 200m d/s DCC take	44	0.0019	0.0077	n/a	n/a	n/a
Roxburgh Rohe	Benger burn at Booths	54	0.0033	0.0085	n/a	n/a	n/a
Roxburgh Rohe	Clutha @ Millers Flat	58	0.0015	0.0035	n/a	n/a	n/a
Roxburgh Rohe	Fraser at Old Man Range	45	0.0011	0.0025	n/a	n/a	n/a
Roxburgh Rohe	Teviot at Bridge Huts Road	45	0.0009	0.0079	n/a	n/a	n/a
Taieri FMU	Contour Channel at No. 4 Br	59	0.0102	0.0910	n/a	n/a	n/a
Taieri FMU	Deep Stream at SH87	58	0.0009	0.0081	n/a	n/a	n/a
Taieri FMU	Kye Burn at SH85 Bridge	59	0.0017	0.0046	26	25.20	32.80
Taieri FMU	Meggat Burn at Berwick Road	46	0.0039	0.0220	n/a	n/a	n/a
Taieri FMU	Nenthorn at Mt Stoker Road	58	0.0016	0.0070	n/a	n/a	n/a
Taieri FMU	Silverstream at Taieri Depot	59	0.0023	0.3150	31	159.14	273.31
Taieri FMU	Silverstream at 3 Mile Hill Rd	46	0.0019	0.0030	n/a	n/a	n/a
Taieri FMU	Sutton Stream at SH87	55	0.0013	0.0070	n/a	n/a	n/a
Taieri FMU	Taieri at Allanton Bridge	57	0.0036	0.0232	n/a	n/a	n/a
Taieri FMU	Taieri at Linnburn Runs Road	58	0.0011	0.0031	n/a	n/a	n/a
Taieri FMU	Taieri at Outram	60	0.0016	0.0138	19	121.94	197.33
Taieri FMU	Taieri at Stonehenge	59	0.0015	0.0175	n/a	n/a	n/a
Taieri FMU	Taieri at Sutton	59	0.0020	0.0127	15	79.86	128.55
Taieri FMU	Taieri at Tiroiti	59	0.0024	0.0116	n/a	n/a	n/a
Taieri FMU	Taieri at Waipiata	59	0.0029	0.0268	17	19.84	26.23
Taieri FMU	Waipori at Waipori Falls	59	0.0011	0.0273	n/a	n/a	n/a
Taieri FMU	Whare Creek at W Flat Rd	46	0.0012	0.0037	n/a	n/a	n/a
Upper Lakes Rohe	12 Mile Creek at G-QT Road	44	0.0013	0.0030	29	3.96	9.43
Upper Lakes Rohe	25 Mile Creek at G-QT Road	44	0.0017	0.0076	29	23.47	31.89
Upper Lakes Rohe	Buckler Burn at G-QT Road	44	0.0017	0.0022	n/a	n/a	n/a
Upper Lakes Rohe	Bullock Creek at Dunmore St	37	0.0017	0.0019	32	198.37	322.96

FMU	*Site Name*	*NH4-N #*	*NH4-N Median*	*NH4-N Ann Max*	*Chla #*	*Chla Q83*	*Chla Q92*
Upper Lakes Rohe	Craig Burn at SH6	37	0.0017	0.0082	n/a	n/a	n/a
Upper Lakes Rohe	Dart at The Hillocks	56	0.0011	0.0039	20	1.55	6.50
Upper Lakes Rohe	Dundas Creek at Mill Flat	43	0.0015	0.0019	n/a	n/a	n/a
Upper Lakes Rohe	Greenstone at G-Station Rd	43	0.0012	0.0029	29	4.16	6.79
Upper Lakes Rohe	Horn Creek at Queenstown Bay	45	0.0061	0.1140	n/a	n/a	n/a
Upper Lakes Rohe	Invincible Creek at Rees Val Rd	43	0.0019	0.0022	n/a	n/a	n/a
Upper Lakes Rohe	Leaping Burn at W-MtA Rd	37	0.0008	0.0034	n/a	n/a	n/a
Upper Lakes Rohe	Makarora at Makarora	45	0.0014	0.0017	n/a	n/a	n/a
Upper Lakes Rohe	Matukituki at West Wanaka	50	0.0025	0.0109	24	1.03	3.79
Upper Lakes Rohe	Motatapu at W-MtA Rd	37	0.0017	0.0022	28	26.82	50.27
Upper Lakes Rohe	Ox Burn at Rees Valley Road	43	0.0017	0.0061	n/a	n/a	n/a
Upper Lakes Rohe	Precipice Creek at G-Para Rd	44	0.0017	0.0022	32	10.62	13.88
Upper Lakes Rohe	Quartz Creek at Maung Val Rd	41	0.0017	0.0128	n/a	n/a	n/a
Upper Lakes Rohe	Rees at G-Para Rd	44	0.0016	0.0039	n/a	n/a	n/a
Upper Lakes Rohe	Scott Creek at Routeburn Road	44	0.0014	0.0030	n/a	n/a	n/a
Upper Lakes Rohe	The Neck Creek at Meads Road	45	0.0015	0.0019	31	8.60	32.31
Upper Lakes Rohe	Timaru at Peter Muir Bridge	43	0.0008	0.0028	n/a	n/a	n/a
Upper Lakes Rohe	Turner Creek at Kinloch Road	44	0.0011	0.0024	29	50.64	71.76

12.4 Lakes - Summary Results Total N, Total P, Phytoplankton

Site Name	*TN TP #*	*TN Median*	*TN Ann Max*	*TP Median*	*TP Max*	*# Chla*	*Chla Median*	*Chla Ann Max*
Lake Dunstan at Clyde Dam 10m	34	0.067	0.101	0.0026	0.008	34	1.4	3.3
Lake Dunstan at Clyde Dam HYP	32	0.067	0.09	0.00205	0.023	n/a	n/a	n/a
Lake Dunstan at Cromwell Boat Club 10m	34	0.0745	0.103	0.002	0.005	34	1.3	2.9
Lake Dunstan at Cromwell Boat Club HYP	32	0.0775	0.121	0.0022	0.021	n/a	n/a	n/a
Lake Dunstan at Dead Man’s Point	58	0.073	0.11	0.002	0.0175	59	1.2	2.6
Lake Hawea North Open Water 10m	20	0.036	0.075	0.001	0.006	20	0.535	1.4
Lake Hawea North Open Water HYP	20	0.042	0.189	0.001	0.003	n/a	n/a	n/a
Lake Hawea South Open Water 10m	56	0.036	0.063	0.001	0.004	56	0.56	1.3
Lake Hawea South Open Water HYP	55	0.041	0.192	0.001	0.005	n/a	n/a	n/a
Lake Hayes at Mid Lake 10m	56	0.36	0.78	0.043	0.101	56	25	94
Lake Hayes at Mid Lake HYP	56	0.31	0.51	0.044	0.129	n/a	n/a	n/a
Lake Onslow at Boat Ramp	55	0.27	0.41	0.023	0.044	55	3.3	8.1
Lake Tuakitoto at Outlet	59	1.1	3.2	0.117	0.31	59	8	103
Lake Waihola at Waihola Mid	16	0.515	1.23	0.0455	0.143	16	9.8	27
Lake Waihola at Waihola South	16	0.7	1.85	0.063	0.28	16	16	40
Lake Wakatipu at Frankton Arm 10m	56	0.051	0.29	0.001	0.0085	56	0.65	6
Lake Wakatipu at Queenstown Bay 10m	57	0.053	0.092	0.0017	0.013	57	0.71	1.7
Lake Wakatipu North Open Water 10m	19	0.054	0.082	0.001	0.002	19	0.55	1.3
Lake Wakatipu North Open Water HYP	19	0.061	0.09	0.001	0.0031	n/a	n/a	n/a
Lake Wakatipu Open Water 10m	55	0.053	0.128	0.001	0.0375	55	0.555	1.8
Lake Wakatipu Open Water HYP	52	0.059	0.45	0.001	0.053	n/a	n/a	n/a
Lake Wanaka at Glendu Bay 10m	58	0.0555	0.099	0.001	0.003	58	0.9	2.4
Lake Wanaka at Roy's Bay 10m	58	0.0565	0.083	0.001	0.002	58	0.82	1.8
Lake Wanaka North Open Water 10m	20	0.059	0.095	0.001	0.0025	20	0.78	2
Lake Wanaka North Open Water HYP	20	0.063	0.117	0.001	0.004	n/a	n/a	n/a
Lake Wanaka Open Water 10m	58	0.0565	0.08	0.001	0.005	58	0.755	2.1
Lake Wanaka Open Water HYP	56	0.0665	0.52	0.001	0.0048	n/a	n/a	n/a

12.5 Lake - Summary Results *E. coli* and Ammonia

Site Name	*# E. coli*	*E. coli Median*	*E. coli Q95*	*E. coli G540*	*E. coli G260*	*NH4-N #*	*NH4-N Median*	*NH4-N Ann Max*
Lake Dunstan at Clyde Dam 10m	33	1	31	0.000	0.000	34	0.0015	0.0017
Lake Dunstan Cromwell Boat Club 10m	33	3	24	0.000	0.000	34	0.0016	0.0048
Lake Dunstan at Dead Man’s Point	58	3	40	0.017	0.017	59	0.0014	0.0069
Lake Hawea North Open Water 10m	18	0	1	0.000	0.000	18	0.0014	0.0015
Lake Hawea South Open Water 10m	50	0	1	0.000	0.000	51	0.0014	0.0039
Lake Hayes at Mid Lake 10m	49	1	6	0.000	0.000	48	0.0142	0.1076
Lake Hayes at Mid Lake HYP	1	1	1	0.000	0.000	n/a	n/a	n/a
Lake Onslow at Boat Ramp	54	2	60	0.000	0.000	55	0.0014	0.0065
Lake Tuakitoto at Outlet	59	58	1689	0.085	0.136	59	0.0201	0.1544
Lake Waihola at Waihola Mid	16	38	597	0.063	0.125	16	0.0025	0.0189
Lake Waihola at Waihola South	16	7	1730	0.063	0.063	16	0.0039	0.1252
Lake Wakatipu at Frankton Arm 10m	50	0	2	0.000	0.000	50	0.0014	0.0223
Lake Wakatipu at QueensT Bay 10m	50	2	13	0.000	0.000	51	0.0002	0.0007
Lake Wakatipu North Open Water 10m	17	1	1	0.000	0.000	17	0.0014	0.0015
Lake Wakatipu Open Water 10m	49	1	1	0.000	0.000	49	0.0014	0.0030
Lake Wanaka at Glendu Bay 10m	51	0	3	0.000	0.000	52	0.0015	0.0043
Lake Wanaka at Roy's Bay 10m	51	0	2	0.000	0.000	52	0.0015	0.0019
Lake Wanaka North Open Water 10m	17	0	1	0.000	0.000	18	0.0015	0.0019
Lake Wanaka Open Water 10m	51	1	2	0.000	0.000	52	0.0008	0.0028

12.6 Groundwater - Summary Results *E. coli*, Nitrate-N, Arsenic

FMU	Bore	Analyte	#	Q5	Q20	Q25	Median	Q75	Q80	Q95	AnnMax
Catlins	H46/0118	Arsenic	18	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.0000275
Catlins	H46/0118	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	5.6	9
Catlins	H46/0118	Nitrate	18	0.185	0.21	0.21	0.24	0.41	1.166	1.506	1.53
D & Coast	H45/0314	Arsenic	18	0.00052	0.00077	0.00083	0.0012	0.0016	0.00223	0.00414	0.0047
D & Coast	H45/0314	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
D & Coast	H45/0314	Nitrate	18	0.0005	0.0005	0.0005	0.0005	0.0022	0.0022	0.00616	0.0088
Dunstan	CB13/0159	Arsenic	6	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	F40/0025	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	F40/0045	Arsenic	19	0.00015	0.00016	0.00016	0.00018	0.00019	0.0002	0.00021	0.0002092
Dunstan	F40/0206	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	F41/0104	Arsenic	11	0.00923	0.01391	0.01402	0.0146	0.01565	0.01609	0.01785	0.0179
Dunstan	F41/0162	Arsenic	20	0.00014	0.00014	0.00015	0.00016	0.00017	0.00017	0.00018	0.0001842
Dunstan	F41/0203	Arsenic	20	0.00009	0.00013	0.00014	0.00024	0.00041	0.00047	0.00081	0.0009142
Dunstan	F41/0300	Arsenic	20	0.0009	0.00098	0.00101	0.00118	0.00142	0.00149	0.00178	0.0018421
Dunstan	F41/0437	Arsenic	17	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006
Dunstan	F41/0438	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	G40/0175	Arsenic	19	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.0000325
Dunstan	G40/0367	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	G40/0411	Arsenic	20	0.00085	0.00096	0.001	0.0011	0.00115	0.0012	0.00135	0.0015
Dunstan	G40/0415	Arsenic	18	0.00093	0.001	0.001	0.0011	0.0012	0.0012	0.00126	0.0013
Dunstan	G40/0416	Arsenic	18	0.00124	0.0014	0.0014	0.0015	0.0016	0.0016	0.0017	0.0017
Dunstan	G41/0211	Arsenic	16	0.0012	0.0013	0.0013	0.0014	0.0014	0.00143	0.00157	0.0016
Dunstan	G41/0487	Arsenic	7	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	CB13/0159	E-Coli	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F40/0025	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	2.425	4
Dunstan	F40/0045	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	4.6	7
Dunstan	F40/0206	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0104	E-Coli	11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0162	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0203	E-Coli	20	0.07696	0.17751	0.22323	0.58929	1.35607	1.59269	2.58105	2.7898423
Dunstan	F41/0300	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0437	E-Coli	17	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0438	E-Coli	39	0.00027	0.00497	0.00949	0.13311	2.75	5.4	261.75	2420
Dunstan	G40/0175	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	2.6	4
Dunstan	G40/0367	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	G40/0411	E-Coli	20	0.25	0.25	0.25	0.25	0.25	0.25	0.625	1
Dunstan	G40/0415	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	G40/0416	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	G41/0211	E-Coli	15	0.25	0.25	0.25	0.25	0.25	0.25	0.8125	1
Dunstan	G41/0487	E-Coli	7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	CB13/0159	Nitrate	6	0.26	0.267	0.27	0.275	0.29	0.293	0.3	0.3
Dunstan	F40/0025	Nitrate	20	0.36	0.395	0.4	0.52	0.725	0.845	1.075	1.19
Dunstan	F40/0045	Nitrate	19	2.1	2.23	2.325	2.9	3.2	3.34	4.295	4.7
Dunstan	F40/0206	Nitrate	20	0.665	0.72	0.735	0.79	0.87	0.875	0.94	0.94
Dunstan	F41/0104	Nitrate	11	0.00064	0.00123	0.00148	0.00425	0.09625	0.1647	0.3565	0.36
Dunstan	F41/0162	Nitrate	20	0.295	0.33	0.33	0.345	0.37	0.37	0.415	0.42
Dunstan	F41/0203	Nitrate	20	1.08	1.175	1.205	2.05	3.35	4	6.5	6.8
Dunstan	F41/0300	Nitrate	20	0.71	0.855	0.87	1.14	1.49	1.515	1.79	2
Dunstan	F41/0437	Nitrate	17	2.235	2.39	2.4	2.5	2.6	2.61	2.865	2.9

FMU	*Bore*	*Analyte*	*#*	*Q5*	*Q20*	*Q25*	*Median*	*Q75*	*Q80*	*Q95*	*AnnMax*
Dunstan	F41/0438	Nitrate	40	0.044	0.0625	0.0765	0.1085	0.169	0.1855	0.2875	2.6
Dunstan	G40/0175	Nitrate	19	0.8545	0.863	0.875	0.91	0.9625	0.977	1.071	1.08
Dunstan	G40/0367	Nitrate	20	0.16395	1.2825	1.44	1.595	1.73	1.75	1.98	2.1
Dunstan	G40/0411	Nitrate	20	3.35	4.2	4.3	5.25	7.75	8.2	9.4	9.9
Dunstan	G40/0415	Nitrate	18	0.02242	0.0375	0.042	0.0555	0.076	0.0778	0.244	0.33
Dunstan	G40/0416	Nitrate	18	0.288	0.36	0.36	0.435	0.49	0.49	0.576	0.58
Dunstan	G41/0211	Nitrate	16	1.073	1.104	1.12	1.145	1.19	1.193	1.321	1.36
Dunstan	G41/0487	Nitrate	7	0.28	0.289	0.2925	0.31	0.31	0.312	0.33	0.33
Lower Clutha	G44/0127	Arsenic	18	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.000035
Lower Clutha	H46/0144	Arsenic	18	0.01363	0.01633	0.0166	0.01705	0.0175	0.01759	0.01832	0.0184
Lower Clutha	G44/0127	E-Coli	18	0.11779	0.16535	0.18484	0.32631	0.59832	0.68373	9.4	13
Lower Clutha	H46/0144	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Lower Clutha	G44/0127	Nitrate	18	2.28	2.62	2.8	3.35	3.9	4.44	5.34	5.7
Lower Clutha	H46/0144	Nitrate	18	0.00002	0.00007	0.0001	0.00034	0.00162	0.00196	0.0106	0.011
Manuherekia	G41/0254	Arsenic	20	0.00024	0.00028	0.00029	0.00037	0.0005	0.00054	0.00072	0.00076
Manuherekia	G42/0123	Arsenic	20	0.00009	0.00011	0.00012	0.00018	0.00029	0.00033	0.00051	0.0005599
Manuherekia	G42/0290	Arsenic	20	0.00013	0.00015	0.00016	0.00022	0.00032	0.00035	0.00049	0.0005291
Manuherekia	G46/0152	Arsenic	20	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000975
Manuherekia	G41/0254	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	3.25	6
Manuherekia	G42/0123	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Manuherekia	G42/0290	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Manuherekia	G46/0152	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Manuherekia	G41/0254	Nitrate	20	2.95	3.4	3.6	4.1	4.55	4.65	5.55	5.8
Manuherekia	G42/0123	Nitrate	20	0.84	0.93	0.95	1.045	1.165	1.175	1.225	1.23
Manuherekia	G42/0290	Nitrate	20	1.985	2.2	2.2	2.3	2.3	2.4	2.85	2.9
Manuherekia	G46/0152	Nitrate	20	0.925	0.99	1.005	1.1	1.17	1.205	1.35	1.36
North Otago	J41/0008	Arsenic	20	0.00022	0.00023	0.00023	0.00025	0.00026	0.00027	0.00028	0.0002804
North Otago	J41/0249	Arsenic	14	0.00075	0.00079	0.00081	0.00089	0.00098	0.00101	0.00109	0.0011
North Otago	J41/0317	Arsenic	20	0.00014	0.00015	0.00016	0.00017	0.00019	0.00019	0.0002	0.0002072
North Otago	J41/0442	Arsenic	21	0.0003	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0571	Arsenic	21	0.0003	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0576	Arsenic	20	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00004	0.00005
North Otago	J41/0586	Arsenic	21	0.0003	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0762	Arsenic	15	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0764	Arsenic	18	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0771	Arsenic	18	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/1403	Arsenic	8	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J42/0126	Arsenic	19	0.00015	0.00016	0.00017	0.00018	0.0002	0.0002	0.00022	0.000219
North Otago	J43/0006	Arsenic	18	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008
North Otago	J41/0008	E-Coli	19	0.5	0.5	0.5	0.5	0.5	1.55	21.6	27
North Otago	J41/0249	E-Coli	14	0.5	0.5	0.5	0.5	0.5	0.5	34	42
North Otago	J41/0317	E-Coli	20	0.29273	0.44049	0.50021	1	16.5	28	111.5	135
North Otago	J41/0442	E-Coli	21	0.5	0.5	0.5	0.5	0.575	1.16	2.45	3
North Otago	J41/0571	E-Coli	21	0.5	0.5	0.5	0.5	0.5	0.5	1.79	3
North Otago	J41/0576	E-Coli	20	0.5	0.5	0.5	0.5	1.5	2.5	76	115
North Otago	J41/0586	E-Coli	21	0.5	0.5	0.5	0.5	0.5	0.5	2.8	5
North Otago	J41/0762	E-Coli	14	0.5	0.5	0.5	0.5	0.5	0.5	233	291
North Otago	J41/0764	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
North Otago	J41/0771	E-Coli	17	0.25	0.25	0.25	0.25	0.25	0.25	1	1
North Otago	J41/1403	E-Coli	8	0.5	0.55	0.75	4	11	11.8	30	30
North Otago	J42/0126	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
North Otago	J43/0006	E-Coli	17	0.5	0.5	0.5	0.5	0.5	0.5	1	1

FMU	Bore	Analyte	#	Q5	Q20	Q25	Median	Q75	Q80	Q95	AnnMax
North Otago	J41/0008	Nitrate	20	17	25	25.5	26	27.5	28	29	29
North Otago	J41/0249	Nitrate	14	1.016	2.015	2.4	4.2	4.5	4.57	4.9	4.9
North Otago	J41/0317	Nitrate	20	3.95	4.45	4.75	5.75	6.4	6.5	8.5	8.6
North Otago	J41/0442	Nitrate	21	0.22585	0.418	0.4525	0.53	0.6925	0.727	1.013	1.09
North Otago	J41/0571	Nitrate	21	3.365	3.74	3.8	4.6	5.15	5.3	5.835	6
North Otago	J41/0576	Nitrate	20	5.7	5.95	6	6.4	7.55	7.65	7.85	7.9
North Otago	J41/0586	Nitrate	21	5.365	5.98	6.1	6.8	7.225	7.3	7.635	7.8
North Otago	J41/0762	Nitrate	15	0.09075	0.43	0.97	4.8	10.85	11.45	13.275	13.5
North Otago	J41/0764	Nitrate	19	1.6775	2.13	2.25	3.1	3.575	3.74	4.41	4.5
North Otago	J41/0771	Nitrate	18	9.06	10.62	10.8	11.6	13.4	13.67	15.02	15.5
North Otago	J41/1403	Nitrate	8	9.3	9.68	10.4	11.75	13.7	14.5	15.9	15.9
North Otago	J42/0126	Nitrate	19	17.725	19.2	19.2	19.7	19.975	20.7	21.55	22
North Otago	J43/0006	Nitrate	18	0.258	0.328	0.4	0.645	0.82	0.82	1.092	1.1
Roxburgh	G43/0009	Arsenic	26	0.00012	0.00013	0.00013	0.00015	0.00016	0.00016	0.0002	0.0003
Roxburgh	G43/0072	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0032	0.0059
Roxburgh	G43/0224a	Arsenic	25	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007
Roxburgh	G43/0224b	Arsenic	25	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006
Roxburgh	G43/0009	E-Coli	25	0.5	0.5	0.5	0.5	0.5	0.5	2.1	6
Roxburgh	G43/0072	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Roxburgh	G43/0224a	E-Coli	24	0.5	0.5	0.5	0.5	0.5	0.5	6.1	18
Roxburgh	G43/0224b	E-Coli	24	0.5	0.5	0.5	0.5	0.5	0.5	0.65	1
Roxburgh	G43/0009	Nitrate	26	4.24	4.47	4.5	4.75	5	5.3	5.86	6.5
Roxburgh	G43/0072	Nitrate	20	3.45	3.7	3.8	4.45	5.1	5.15	5.45	5.5
Roxburgh	G43/0224a	Nitrate	25	6.9375	7.775	7.8	8.4	10.15	10.3	10.775	11.6
Roxburgh	G43/0224b	Nitrate	25	7.5875	7.85	7.9375	8.3	8.725	8.9	9.45	9.9
Taieri	H42/0213	Arsenic	20	0.00029	0.00067	0.00081	0.002	0.00395	0.0044	0.0083	0.0096
Taieri	H42/0214	Arsenic	19	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.000075
Taieri	H43/0132	Arsenic	19	0.00019	0.00025	0.00028	0.00045	0.00084	0.00098	0.00169	0.002
Taieri	H44/0007	Arsenic	11	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.0000675
Taieri	I44/0495	Arsenic	20	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.000055
Taieri	I44/0519	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Taieri	I44/0821	Arsenic	20	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.0000275
Taieri	I44/0964	Arsenic	13	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Taieri	H42/0213	E-Coli	20	0.5	0.5	0.5	0.5	0.75	1	655.5	1300
Taieri	H42/0214	E-Coli	18	0.5	0.5	0.5	0.5	1	1	49	79
Taieri	H43/0132	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	380.5298	632.88303
Taieri	H44/0007	E-Coli	11	0.5	0.5	0.5	0.5	0.875	5.8	118.65	124
Taieri	I44/0495	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	11.5	22
Taieri	I44/0519	E-Coli	20	0.00201	0.00635	0.00911	0.05237	0.63403	1	34	66
Taieri	I44/0821	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Taieri	I44/0964	E-Coli	13	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Taieri	H42/0213	Nitrate	20	0.00147	0.00275	0.00325	0.01925	0.0735	0.1055	0.225	0.23
Taieri	H42/0214	Nitrate	19	3.735	4.06	4.2	4.5	5.6	6.26	7.265	7.4
Taieri	H43/0132	Nitrate	19	0.34593	0.777	0.91	1.51	1.695	1.741	4.934	7.4
Taieri	H44/0007	Nitrate	11	0.0319	0.22	0.22	0.23	0.2375	0.24	0.24	0.24
Taieri	I44/0495	Nitrate	20	0.00064	0.00151	0.00186	0.00606	0.0915	0.1465	0.38	0.38
Taieri	I44/0519	Nitrate	20	1.8	2.85	2.9	3.15	3.4	3.55	3.75	3.8
Taieri	I44/0821	Nitrate	20	5.15	5.4	5.4	5.7	5.95	6.05	6.35	6.4
Taieri	I44/0964	Nitrate	13	1.473	1.55	1.55	1.57	1.625	1.69	1.734	1.74

FMU	Bore	Analyte	#	Q5	Q20	Q25	Median	Q75	Q80	Q95	AnnMax
Upper Lakes	E41/0182	Arsenic	12	0.744	0.789	0.795	0.825	0.875	0.89	0.908	0.91
Upper Lakes	E41/0183	Arsenic	12	0.00069	0.00107	0.0011	0.0013	0.00155	0.00171	0.00333	0.0035
Upper Lakes	E41/0184	Arsenic	12	0.1602	0.1647	0.17	0.182	0.193	0.196	0.1996	0.2
Upper Lakes	E41/0185	Arsenic	12	0.00222	0.00258	0.00335	0.0053	0.0079	0.00868	0.0166	0.0171
Upper Lakes	F42/0113	Arsenic	20	0.00615	0.0077	0.00785	0.0082	0.00925	0.00965	0.0109	0.0116
Upper Lakes	E41/0182	E-Coli	12	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Upper Lakes	E41/0183	E-Coli	12	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Upper Lakes	E41/0184	E-Coli	12	0.25	0.25	0.25	0.25	0.25	0.25	0.925	1
Upper Lakes	E41/0185	E-Coli	12	0.5	0.5	0.5	0.5	0.5	0.5	4.55	5
Upper Lakes	F42/0113	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Upper Lakes	E41/0182	Nitrate	12	0.0005	0.0005	0.0005	0.0005	0.00079	0.00108	0.00182	0.0019
Upper Lakes	E41/0183	Nitrate	12	0.1089	0.1557	0.161	0.26	0.365	0.388	0.694	0.71
Upper Lakes	E41/0184	Nitrate	12	0.0005	0.0005	0.0005	0.0005	0.001	0.00113	0.00311	0.0032
Upper Lakes	E41/0185	Nitrate	12	0.381	1.056	1.55	2.25	3.75	3.91	4.18	4.2
Upper Lakes	F42/0113	Nitrate	20	0	0.00003	0.00005	0.00047	0.00575	0.00782	0.128	0.21

13 Appendix 3

13.1 State Assessment Methods

13.1.1 Handling censored values

Censored values were replaced by imputation for the purposes of calculating the compliance statistics. Left censored values (values below the detection limit(s)) were replaced with imputed values generated using ROS (Regression on Order Statistics; Helsel, 2012), following the procedure described in Larned *et al.* (2015). The ROS procedure produces estimated values for the censored data that are consistent with the distribution of the uncensored values and can accommodate multiple censoring limits. When there are insufficient non-censored data to evaluate a distribution from which to estimate values for the censored observations, censored values are replaced with half of their reported value.

Censored values above the detection limit were replaced with values estimated using a procedure based on 'survival analysis' (Helsel, 2012). A parametric distribution is fitted to the uncensored observations and then values for the censored observations are estimated by randomly sampling values larger than the censored values from the distribution. The survival analysis requires a minimum number of observations for the distribution to be fitted; hence in the case that there were fewer than 24 observations, censored values above the detection limit were replaced with 1.1* the detection limit. The supplementary file outputs provide details about whether and how imputation was conducted for each site by criteria assessment.

13.1.2 Time period for assessments

When grading sites based on NPS-FM attributes, it is generally good practice to define consistent time periods for all sites and to define the acceptable proportion of missing observations (i.e., data gaps) and how these are distributed across sample intervals so that site grades are assessed from comparable data. The time period, acceptable proportion of gaps and representation of sample intervals by observations within the time period are commonly referred to as site inclusion or filtering rules (e.g., Larned *et al.*, 2018).

The grading assessments were made for the 5-year time-period to end of June 2022. The start and end dates for this period were determined by the availability of quality assured data, reporting time periods and consideration of statistical precision of the compliance statistics used in the grading of sites. The statistical precision of the compliance statistics depends on the variability in the water quality observations and the number of observations. For a given level of variability, the precision of a compliance statistic increases with the number of observations. This is particularly important for sites that are close to a threshold defined by an attribute band because the confidence that the assessment of state is 'correct' (i.e., that the site has been correctly graded) increases with the precision of the compliance statistics (and therefore with the number of observations). As a general rule, the rate of increase in the precision of compliance statistics slows for sample sizes greater than 30 (i.e., there are diminishing returns on increasing sample size with respect to precision (and therefore confidence in the assigned grade) above this number of observations; McBride, 2005).

In this study, a period of five years represented a reasonable trade-off for most of the attributes because it yielded a sample size of 30 or more observations for many sites and attribute combinations. The five-year period for the state analyses is also consistent with national water-quality state analyses (e.g., Larned *et al.*, 2015, 2018), as well as guidance for a number of specific attributes within the NPS-FM (2020). Where no guidance was provided, a default filtering rule that required at least 30 observations in the 5-year time period was used. For annually sampled macroinvertebrate variables, which are generally less variable than physical or chemical water quality variables, the nominated minimum sample size requirement was reduced to 5.

For grading the suspended fine sediment and *E. coli* attributes, the NPS-FM requires 60 observations over 5 years. For monthly monitoring, this requires collection of all monthly observations (i.e., no missing data). All ORC records have at least one missing observation associated with the national COVID-19 lockdown in April 2020, and so no sites met this requirement for the selected time periods. For this study, the rule to require observations for 90% of months over the 5-year period (54 observations) was relaxed. Both this relaxation and default sample number are subjective choices. Therefore, within the supplementary files state assessments for all sites are provided regardless of whether they meet the filtering rules, as well as details about the number of observations and number of years with observations.

13.1.3 Calculation of water clarity

The NPS-FM suspended fine sediment attribute is based on observations of visual clarity. ORC river monitoring programme does not include visual clarity but does routinely collect turbidity observations. Franklin et al. (2020) define a relationship between median clarity and median turbidity, based on a regression of 582 sites across New Zealand as:

$$\ln(\text{CLAR}) = 1.21 – 0.72 \ln(\text{TURB})$$

where CLAR is site median visual clarity (m) and TURB is site median turbidity (NTU). In this study, median turbidity values over the 5-year time period were calculated first, and then calculated median clarity using the above relationship in order to grade the sites against the NPS-FM suspended fine sediment attribute.

Sites operated by NIWA as part of the national monitoring network include observations of clarity, and therefore for these sites performance against the NPS-FM suspended fine sediment attribute has been evaluated with the observed (rather than modelled) clarity values.

13.1.4 pH Adjustment of Ammonia

Ammonia is toxic to aquatic animals and is directly bioavailable. When in solution, ammonia occurs in two forms: the ammonium cation (NH_4^+) and unionised ammonia (NH_3); the relative proportions of the forms are strongly dependent on pH (and temperature). Unionised ammonia is significantly more toxic to fish than ammonium, hence the total ammonia toxicity increases with increasing pH (and/or temperature) (ANZECC, 2000). Standards related to ammoniacal-N concentrations in freshwater typically require a correction to account for pH and temperature. A pH correction to NH_4-N was applied to adjust values to equivalent pH 8 values, following the methodology outlined in Hickey (2014). For pH values outside the range of the correction relationship (pH 6-9), the maximum (pH<6) and minimum (pH>9) correction ratios were applied.

13.1.5 Evaluation of compliance statistics

For compliance statistics specified and 'annual' (maximum, median, 95th percentile) in the NPS-FM, have been calculated over the entire 5-year state period.

The results from the state analysis are provided in the supplementary file: ORCGWState_072017to062022, ORCLakeState_072017to062022, ORCRiverState_072017to062022. Provided on the ORC website https://www.orc.govt.nz/plans-policies-reports/reports-and-publications/water-quality

13.2 Trend Assessment Methods

13.2.1 Sampling dates, seasons, and time periods for analyses

In trend assessments, there are several reasons why it is generally important to define the trend period and seasons and to assess whether the observations are adequately distributed over time. First, because variation in many water quality variables is associated with the time of the year or 'season', the robustness of trend assessment is likely to be diminished if the observations are biased to certain times of the year. Second, a trend assessment will always represent a time period; essentially that defined by the first and last observations. The assessment's characterisation of the change in the observations over the time period is likely to be diminished if the observations are not reasonably evenly distributed across the time period. For these reasons, important steps in the data compilation process include specifying the seasons, the time period, and ensuring adequately distributed data.

Monitoring programs are generally designed to sample with a set frequency, (e.g., monthly, quarterly). The trend analysis 'season' is generally specified to match this sampling frequency (e.g., seasons are months, bi-months, or quarters). There is therefore generally an observation for each sample interval (i.e., each season, such as month or quarter, within each year). Sampling frequency for some variables is annually. For example, annual sampling is common for biological sampling such as macro-invertebrates. In this case the 'season' is specified by the year.

Two common deviations from the prescribed sampling regime are (1) the collection of more than one observation in a sample interval (e.g., two observations within a month) and (2) a change in sampling interval within the time period. Both of these deviations occurred in the ORC datasets, particularly type (2), as there was a network wide change in sampling frequency in 2013, largely moving from bi-monthly to monthly monitoring for rivers, and from biannual to quarterly for groundwater in 2011. For type (1) deviations, the median within each sample interval was taken. For type (2) deviations, the coarser sampling interval to define seasons was used. For the part of the record with a higher frequency, the observations in each season were defined by taking the observation closest to the midpoint of the coarser season. The reason for not using the median value in this case is that it will induce a trend in variance, which will invalidate the null distribution of the test statistic (Helsel *et al.*, 2020).

The trend at all sites was characterised by the rate of change of the central tendency of the observations of each variable through time. Because water quality is constantly varying through time, the evaluated rate of change depends on the time-period over which it is assessed (e.g., Ballantine *et al.*, 2010; Larned *et al.*, 2016). Therefore, trend assessments are specific for a given period of analysis. Trend periods of 10- and 20 years were evaluated for rivers, five-, 10- and 20- years for lakes, and trend periods of five and 10 years for groundwater.

For a regional study that aims to allow robust comparison of trends between sites and to provide a synoptic assessment of trends across a whole region, such as the present study, it is important that trends are commensurate in terms of their statistical power and representativeness of the time period. In these types of studies, it is general practice to define consistent time periods (i.e., trend duration and start date) so that all sites are subjected to the same conditions (i.e., equivalent political, climate, economic conditions). It is also general practice to define the acceptable proportion of gaps and how these are distributed across sample intervals so that the reported trends are assessed from comparable data. The acceptable proportion of gaps and representation of sample intervals by observations within the time period are commonly referred to as site inclusion or filtering rules (e.g., Larned *et al.*, 2018) but this is also termed 'site screening criteria' and 'completeness criteria'.

There are no specific data requirements or filtering rules for trend assessments performed over many sites and variables such as the present study. The definition of filtering rules is complicated by a trade-off: more restrictive rules increase the robustness of the individual trend analyses but will generally exclude a larger number of sites thereby reducing spatial coverage. In general, this trade-off is also affected by the duration of trend period. Steadily increasing monitoring effort in New Zealand over the last two decades means that shorter and more recent trend periods will generally have a larger number of eligible sites.

The application of filtering rules for variables that are measured at quarterly intervals or more frequently requires two steps. First, retain sites for which observations are available for at least *X*% of the years in the time period. Second, retain sites for which observations are available for at least *Y*% of the sample intervals. For variables that are measured annually such as MCI, the filtering rules are applied by retaining sites for which values are available for at least *X*% of the years in the trend period.

In this study, we used filtering rules applied by Larned et al. (2019), which set X and Y to 80%. Further, the definition of seasons was flexible in order to maximise the number of sites that were included. If the site failed to comply with filter rule (2) when seasons were set as months, a coarsening of the data to quarterly seasons was applied and the filter rule (2) was reassessed. If the data then complied with filter rule (2), the trend results based on the course (i.e., quarterly) seasons were retained for reporting. For groundwater sites we allowed further coarsening, to preferentially biannual (a historical monitoring frequency) or to an annual 'season' if the data did not comply with the filter rule for biannual. This is because much of the historic data was sampled at a very low frequency, and it is expected that groundwater water quality is less temporally variable than surface water quality.

It is noted that the filtering rules imply a tolerance of variable levels of statistical power and temporal representativeness across the sites that were included in the analysis. In these analyses, we also included bimonths as an intermediate coarseness between months and quarters, and biannual (only for groundwater), as these are historically used sampling intervals for ORC.

The trends presented in this study were for 10- and 20-year periods ending on 30 June 2022. For groundwater and lakes, we have additionally included 5-year trend assessments to provide some information about trends at the sites that have been established in recent past, which have short records (i.e., < 10 years). We advise that some caution is applied with the interpretation of trends over such short time periods. It has been demonstrated that the shorter the time period over which a river water quality trend is assessed, the greater the level of influence of climatic variation on the assessed trend (Snelder *et al.*, 2021).

13.2.2 Handling censored values

For several water-quality variables, true values are occasionally too low or too high to be measured with precision. These measurements are called censored values. The 'detection limit' is the lowest value that can be measured by an analytical method accurately (either a laboratory measurement or a measurement made in the field) and the 'reporting limit' is the greatest value of a variable that can be measured. Water-quality datasets from New Zealand rivers and lakes often include DRP, TP and NH4N measurements that are censored because they are below detection limits, and ECOLI and CLAR measurements that are censored because they are above reporting limits.

Censored values are managed in a special way by the non-parametric trend assessment methods. It is therefore important that censored values are correctly identified in the data. Detection limits or reporting limits that have changed through the trend time period (often due to analytical changes) can induce trends that are associated with the changing precision of the measurements rather than actual changes in the variable. This possibility needs to be accounted for in the trend analysis and this is another reason that it is important that censored values are correctly identified in the data.

We applied a 'high-censor' filter in the trend assessments to minimise biases that might be introduced due to changes in detection limits through the trend assessment period. The high-censor filter identifies the highest detection limit for each water quality variable in the trend assessment period and replaces all observations below this level with the highest detection limit and identifies these as censored values. This procedure generally had limited impact on the trend assessment, with the exception of Ammoniacal Nitrogen, as there was a significant shift in the detection limit, and most of the observations were generally very small (of similar magnitude to the detection limit).

13.2.3 Seasonality assessment

For many site/variable combinations, observations vary systematically by season (e.g., by month or quarter). In cases where seasons are a major source in variability, accounting for the systematic seasonal variation should increase the statistical power of the trend assessment (i.e., increase the confidence in the estimate of direction and rate of the trend). The purpose of a seasonality assessment is to identify whether seasons explain variation in the water quality variable. If this is true, then it is appropriate to use the seasonal versions of the trend assessment procedures at the trend assessment step.

We evaluated seasonality using the Kruskall-Wallis multi-sample test for identical populations. This is a non-parametric ANOVA that determines the extent to which season explains variation in the water quality observations. Following Hirsch *et al*. (1982), we identified site/variable combinations as being seasonal based on the *p*-value from the Kruskall-Wallis test with $\alpha=0.05$. For these sites/variable combinations, subsequent trend assessments followed the 'seasonal' variants.

The choice of α is subjective and a value of 0.05 is associated with a very high level of certainty (95%) that the data exhibit a seasonal pattern. In our experience there are generally diminishing differences between the seasonal and non-seasonal trend assessments for *p*-values values larger than 0.05 (Helsel *et al*., 2020).

13.2.4 Analysis of trends

The purpose of trend assessment is to evaluate the direction (i.e., increasing or decreasing) and rate of the change in the central tendency of the observed water quality values over the period of analysis (i.e., the trend). Because the observations represent samples of the water quality over the period of analysis, there is uncertainty about the conclusions drawn from their analysis. Therefore, statistical models are used to determine the direction and rate of the trend and to evaluate the uncertainty of these determinations.

Trends were evaluated using the LWPTrends functions in the R statistical computing software. A brief description of the theoretical basis for these functions is described below.

13.2.5 Trend direction assessment

The trend direction and the confidence in the trend direction were evaluated using either the Mann Kendall assessment or the Seasonal Kendall assessment. Although the non-parametric Sen slope regression also provides information about trend direction and its confidence, the Mann Kendall assessment is recommended, rather than Sen slope regression, because the former more robustly handles censored values.

The Mann Kendall assessment requires no *a priori* assumptions about the distribution of the data but does require that the observations are randomly sampled and independent (no serial correlation) and that there is a sample size of ≥ 8. Both the Mann Kendall and Seasonal Kendall assessments are based on calculating the Kendall *S* statistic, which is explained diagrammatically in Figure 68.

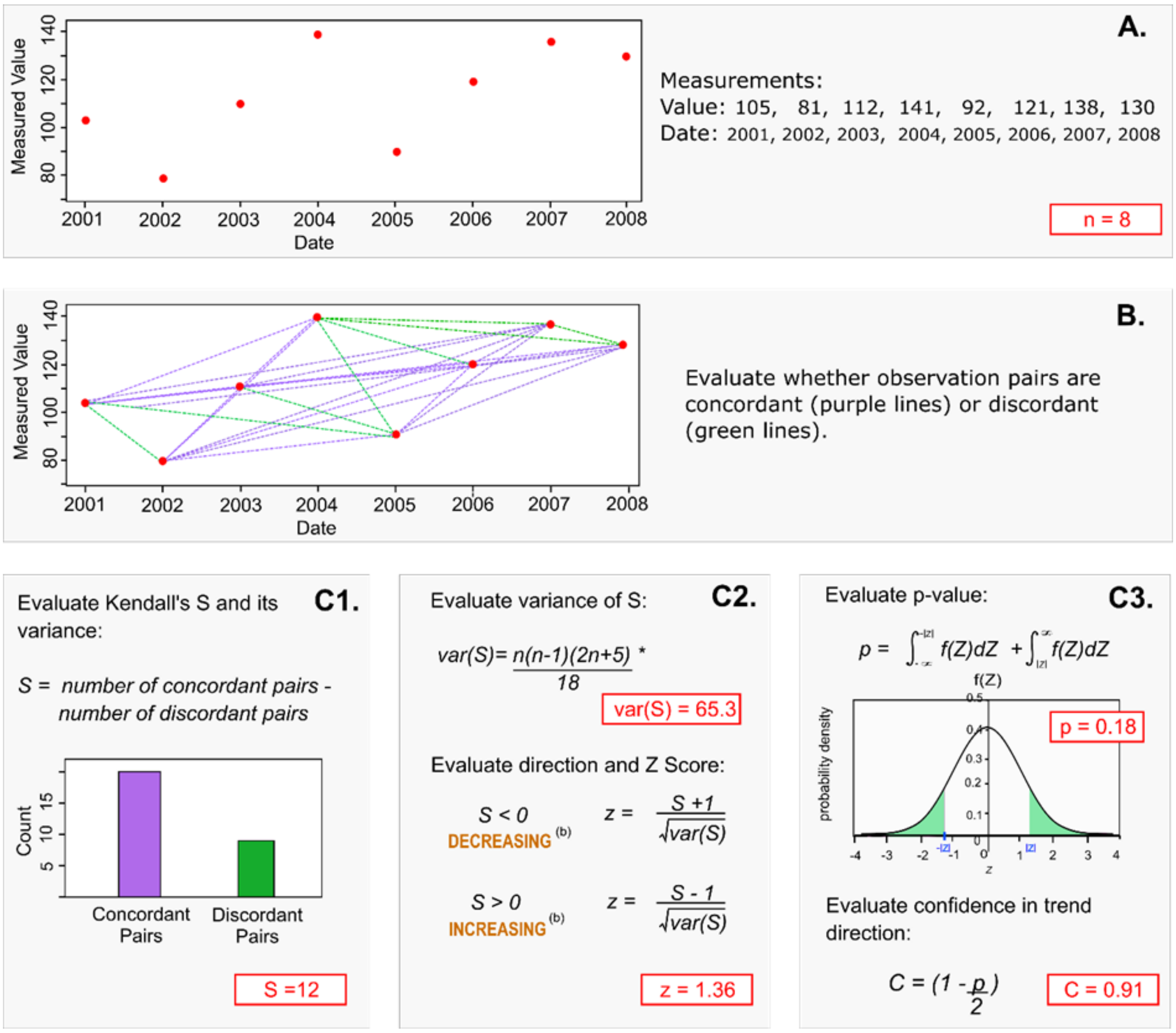


Figure 68. Pictogram of the steps taken in the trend direction assessment to calculate the Kendall S statistic and its confidence in trend direction. Notes: [a] the calculation of the variance in S has some adjustments to account for ties (numerically equal values) and censored values. Details of these adjustments can be found in (Helsel 2005, 2012). [b] There is a third alternative, where S=0. In this case C is 0.5, and the trend direction is classified as 'indeterminate'. Values of S equal to -1 or 1 will also result in a Z value of 0, a p-value of 1 and a C value of 0.5 and the trend direction is similarly classified as 'indeterminate'.

The Kendall *S* statistic is calculated by first evaluating the differences between all pairs of water quality observations (Figure 68, A and B). Positive differences are termed 'concordant' (i.e., the observations increase with increasing time) and negative differences are termed 'discordant' (i.e., the observations decrease with increasing time). The Kendall *S* statistic is the number of concordant pairs minus the number of discordant pairs (Figure 68, C1). The water quality trend direction is indicated by the sign of *S* with a positive or negative sign indicating an increasing or decreasing trend, respectively (Figure 68C2).

The seasonal version of the Kendall *S* statistic *S* is calculated in two steps. First, for each season, the *S* statistic is calculated in the same manner as shown in Figure 68 but for data pertaining to observations in each individual season. Second, *S* is the sum of values over all seasons ($S = \sum_1^n S_i$), where S_i is the number of concordant pairs minus the number of discordant pairs in the i^{th} season and n is the number of seasons. The variance of *S* is calculated for each season and then summed over all seasons.

The sign (i.e., + or -) of the *S* statistic calculated from the sample represents the best estimate of the population trend direction but is uncertain (i.e., the direction of the population trend cannot be known with certainty). A continuous measure of confidence in the assessed trend direction can be determined based on the posterior probability distribution of S, the true (i.e., population) difference in concordant and discordant pairs (Snelder *et al.*, 2022). The posterior probability distribution of *S* is given by a normal distribution with mean of *S* and variance of *var(S)*. The confidence in assessed trend direction can be evaluated as the proportion of the probability distribution that has the same sign as S.

In practice the integrals described above can be calculated by first transforming the value of $S = 0$ on the posterior probability distribution into a standard normal deviate, Z (panel C2). *C* is then calculated as area under the standard normal distribution to the left (Z>0) or right (Z<0) of the value of Z, using the quantile function for the normal distribution

The value C can be interpreted as the probability that the sign of the calculated value of *S* indicates the direction of the population trend (i.e., that the calculated trend direction is correct). The value C ranges between 0.5, indicating the sign of *S* is equally likely to be in the opposite direction to that indicated by the true trend, to 1, indicating complete confidence that the sign of *S* is the same as the true trend.

As the size of the sample (i.e., the number of observations) increases, confidence in the trend direction increases. When the sample size is very large, C can be high, even if the trend rate is very low. It is important therefore that C is interpreted correctly as the confidence in direction and not as the importance of the trend. As stated at the beginning of this section; both trend direction and the trend rate are relevant and important aspects of a trend assessment.

13.2.6 Assessment of trend rate

The method used to assess trend rate is based on non-parametric Sen slope regressions of water quality observations against time. The Sen slope estimator (SSE; Hirsch *et al.,* 1982) is the slope parameter of a non-parametric regression. SSE is calculated as the median of all possible inter-observation slopes (i.e., the difference in the measured observations divided by the time between sample dates).

The seasonal Sen slope estimator (SSSE) is calculated in two steps. First, for each season, the median of all possible inter-observation slopes is calculated in same manner as shown in Figure 69 but for data pertaining to observations in each individual season. Second, *SSSE* is the median of the seasonal values.

Uncertainty in the assessed trend rate is evaluated following a methodology outlined in Helsel and Hirsch (2002). To calculate the 100(1-α) % two-sided symmetrical confidence interval about the fitted slope parameter, the ranks of the upper and lower confidence limits are determined, and the slopes associated with these observations are applied as the confidence intervals.

The inter-observation slope cannot be definitively calculated between any combination of observations in which either one or both observations comprise censored values. Therefore, it is usual to remove the censor sign from the reported laboratory value and use just the ‘raw’ numeric component (i.e., <1 becomes 1) multiplied by a factor (such as 0.5 for left-censored and 1.1 for right-censored values). This ensures that in the Sen slope calculations, any left-censored observations are always treated as values that are less than their ‘raw’ values and right censored observations are always treated as values that are greater than their ‘raw’ values. The inter-observation slopes associated with the censored values are therefore imprecise (because they are calculated from the replacements). However, because the Sen slope is the median of all the inter-observation slopes, the Sen slope is unlikely to be affected by censoring when a small proportion of observations are censored. As the proportion of censored values increase, the probability that the Sen slope is affected by censoring increases. The outputs from the trend assessment provide an ‘analysis note’ to identify Sen Slopes where one or both of the observations associated with the median inter-observation slope is censored.

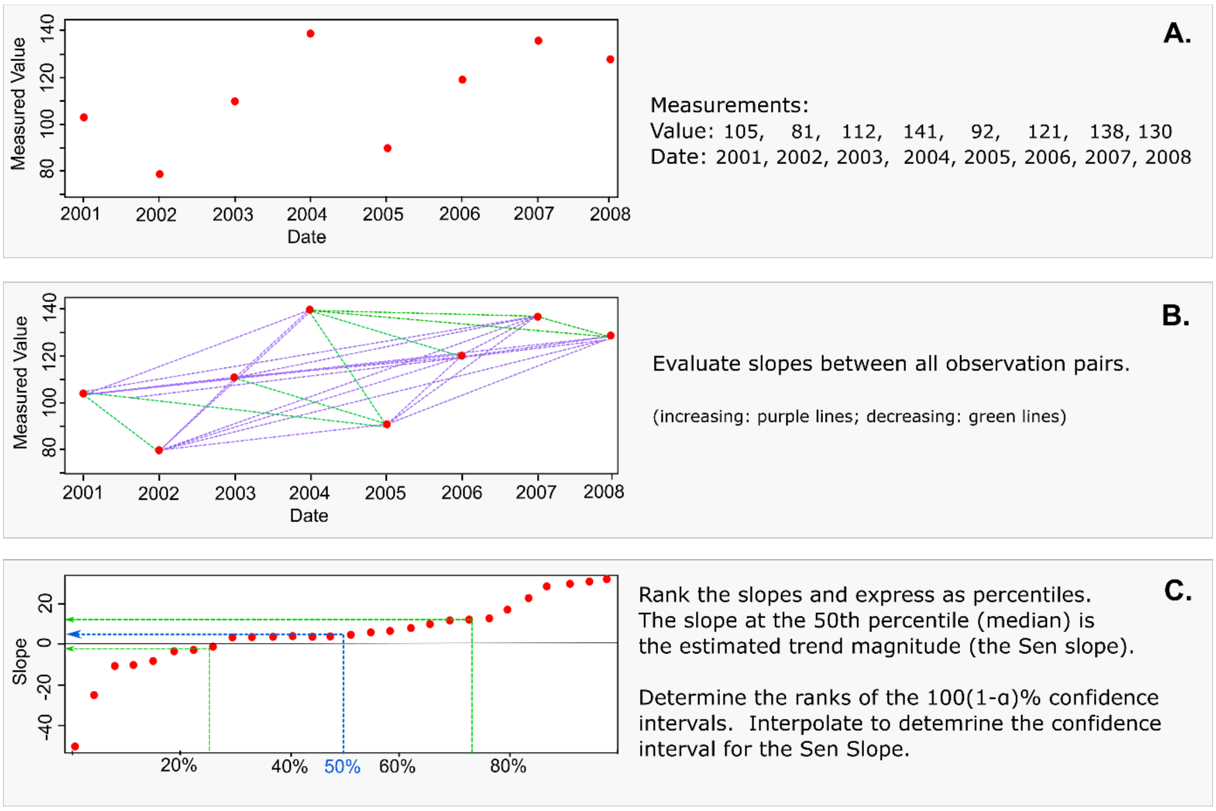


Figure 69 Pictogram of the calculation of the Sen slope, which is used to characterise trend rate.

13.2.7 Interpretation of trends

The trend assessment procedure used here facilitates a more nuanced inference than the ‘yes/no’ output corresponding to the chosen acceptable misclassification error rate. The confidence in direction (C) can be transformed into a continuous scale of confidence the trend was decreasing (C_d). For all trends with $S < 0$, $C_d = C$, and for all $S > 0$ a transformation is applied so that $C_d = 1-C$. C_d ranges from 0 to 1.0. When C_d is very small, a decreasing trend is highly unlikely, which because the outcomes are binary, is the same as an increasing trend is highly likely.

The approach to presenting levels of confidence of the Intergovernmental Panel on Climate Change (IPCC; Stocker *et al.*, 2014) is one way of conveying the confidence of trend directions (Table 15). These same categorical levels of confidence were used to express the confidence that water quality was improving[14] for each site and variable in this report. Note, the confidence of degradation is the compliment of the confidence of improvement.

The trend for each site/variable combination was assigned a categorical level of confidence that the trend was decreasing according to its evaluated confidence. Improvement is indicated by decreasing trends for all the water quality variables in this study except for MCI, SQMCI, and ASPM (for which increasing trends indicate improvement). The aggregate proportion of sites were calculated for sites and for each variable and these values were plotted as colour coded bar charts. These charts provide a graphical representation of the proportions of improving and degrading trends at the levels of confidence indicated by the categories.

Table 15. Level of confidence categories used to convey the confidence that the trend (or step change) indicated improving water quality. The confidence categories are used by the Intergovernmental Panel on Climate Change (IPCC; Stocker et al., 2014).

Categorical level of confidence trend was decreasing	*Value of C_d (%)*
Virtually certain	0.99–1.00
Extremely likely	0.95–0.99
Very likely	0.90–0.95
Likely	0.67–0.90
About as likely as not	0.33–0.67
Unlikely	0.10–0.33
Very unlikely	0.05–0.10
Extremely unlikely	0.01–0.05
Exceptionally unlikely	0.0–0.01

Outputs from the trend analyses were also classified into four direction categories: improving, degrading, indeterminate, and not analysed. An increasing or decreasing trend category was assigned based on the sign of the S statistic from the Mann Kendall test. An indeterminate trend category was assigned when the Z score equalled zero. Trends were classified as 'not analysed' for two reasons:

1) When a large proportion of the values were censored (data has <5 non-censored values and/or <3 unique non-censored values). This arises because trend analysis is based on examining differences in the value of the variable under consideration between all pairs of sample occasions. When a value is censored, it cannot be compared with any other value and the comparison is treated as a 'tie' (i.e., there is no change in the variable between the two sample occasions). When there are many ties there is little information content in the data and a meaningful statistic cannot be calculated.

2) When there is no, or very little, variation in the data because this also results in ties. This can occur because laboratory analysis of some variables has low precision (i.e., values have few or no significant figures). In this case, many samples have the same value, and this then results in ties.

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[14] Note the trend analysis outputs include a confidence of decreasing trend; the conversion of the trend confidence to improving (and its inverse, degrading) depends on whether decreasing represents improvement or degradation and varies between commonly used indicators of water quality.

13.3 LWP Output

The results from the analysis are provided in the supplementary file: ORC_River_GW_Lake_Trends_toJun2022_24Feb23.xlsx. There are worksheets for each of the water domain types (groundwater, lakes, rivers), A description of the data provided in these *sheets is provided in* Table 16

Table 16 Description of Supplementary Data: Trends

Column Name	**Description**
sID	Site ID
npID	Variable name
nObs	Number of observations
S	S-statistic
VarS	Variance
D	n * (n - 1)/2
tau	Kendall's tau
Z	Z-statistic
p	p-value for Mann-Kendall or Seasonal Kendall test
C	Confidence that trend direction is correct
Cd	Confidence that trend direction is decreasing
prop. censored	proportion of observations that are censored
prop.unique	proportion of observations that are unique
no.censorlevels	number of censor levels
Median	Median value for the time period
AnnualSenSlope	Annual Sen Slope (attribute units/year)
Sen_Lci	Lower confidence interval for annual sen slope
Sen_Uci	Upper confidence interval for annual sen slope
AnalysisNote	Relevant notes about the analysis
Percent.annual.change	Percent annual change in Sen slope
TrendDirection	The trend direction
Seasonal	TRUE if data is seasonal and Seasonal Kendall test performed
Freq	The sampling frequency used as seasons in the analysis (either monthly, bi-
Period	The time period of the trend assessment
EndYEar	The end year of the trend assessment
DecreasingConf	Categorical description of confidence of decreasing trend
ImprovementConf	Categorical description of confidence of improving trend

13.3.1 River data availability

Following the application of the filtering rules, the total number of sites that were included in the analyses was reduced, a summary of the site numbers that were included in the final trend assessment is presented in Table 17**.** Confidence that the trend direction indicated improving water quality, was mapped for the raw (with high censor filter) for the 10- and 20-year trend periods.

Table 17 River water quality variables, measurement units and site numbers for which 10- and 20-year trends (Raw, and Flow Adjusted FA) were analysed by this study.

Variable	Number of sites that complied with filtering rules (10-years)		Number of sites that complied with filtering rules (20-years)	
	Raw	FA	Raw	FA
Ammoniacal Nitrogen	50	32	34	18
Chlorophyll a	0	0	0	0
Dissolved Inorganic Nitrogen	0	0	0	0
Dissolved Reactive Phosphorus	50	32	33	18
E. coli	50	27	28	13
Nitrite/Nitrate Nitrogen	50	32	34	18
Total Nitrogen	50	32	33	18
Total Phosphorus	50	32	32	18
Turbidity	50	32	32	18

13.3.2 Evaluated trends

Timeseries plots of the evaluated trends are provided in the supplementary files: 10YearTrends_Rivers_hiCen02Feb23.pdf, 20YearTrends_Rivers_hiCen02Feb23.pdf.

13.4 Groundwater

13.4.1 Groundwater data availability

Following the application of the filtering rules the total number of sites that were included in the final analysis was reduced. A summary of the site numbers that were included in the final trend assessment is presented in Table 18.

Table 18 Groundwater quality variables, and site numbers that complied with the trend assessment filtering rules.

Variable	**Total number of monitoring sites**	**Number of sites that complied with filtering rules**		
		5-year	**10-year**	**20-year**
Ammoniacal Nitrogen	55	45	27	16
Arsenic Dissolved	55	45	27	0
Chloride	55	45	30	16
Dissolved Reactive Phosphorus	55	45	30	16
E-Coli MPN	55	45	18	3
Nitrate-N	55	45	27	0
Total Nitrogen	55	45	3	0
Total Phosphorus	55	45	3	0

13.4.2 Evaluated trends

Timeseries plots of the evaluated trends are provided in the supplementary files: 5YearTrends_GW_hiCen25Jan23.pdf , 10YearTrends_GW_hiCen25Jan23.pdf, 20YearTrends_GW_hiCen25Jan23.pdf.

13.5 Lakes

13.5.1 Lake Data Availability

Following the application of the filtering rules, the total number of sites that were included in the final analysis was reduced, a summary of the site numbers that were included in the final trend assessment is presented in Table 19.

Table 19 Lake water quality variables, measurement units and site numbers used in this study,

Variable	**Total number of monitoring sites**	**Number of sites that complied with filtering rules**		
		5-year	**10-year**	**20-year**
Ammoniacal Nitrogen	27	19	5	3
Chlorophyll a	26	23	3	2
Dissolved Reactive Phosphorus	27	25	5	3
E. coli	19	16	3	3
Nitrite/Nitrate Nitrogen	27	30	5	3
Secchi depth	31	18	0	0
Total Nitrogen	27	30	5	3
Total Phosphorus	27	29	4	3
Turbidity	20	9	3	3

13.5.2 Evaluated trends

Timeseries plots of the evaluated trends are provided in the supplementary files: 5YearTrends_LakesHICEN_03Mar23.pdf, 10YearTrends_LakesHICEN_03Mar23.pdf and 20YearTrends_LakesHICEN_03Mar23.pdf.