State and Trends of River and Lake Water Quality in the Otago Region 2000-2020

Otago Regional Council
Private Bag 1954, Dunedin 9054
70 Stafford Street, Dunedin 9016
Phone 03 474 0827
www.orc.govt.nz

ISBN
Report writer: Rachel Ozanne, Freshwater Science Team, Otago Regional Council
Data and statistical analyses performed by: Landwaterpeople (LWP Ltd)
Reviewed by: LWP Ltd
Published

Contents

List of Figures

List of Tables

Executive Summary

This study analysed the available water quality data in the Otago Region. The state of water quality in the region is reported, on a site by site basis, relative to targets specified in the National Objectives Framework (NOF) of the National Policy Statement-Freshwater Management (NPSFM, 2020). In addition, the study assessed water quality trends site by site, and across Otago as a whole. ORC engaged Landwaterpeople (LWP) to evaluate water quality state (LWP, 2020a) and undertake trend analysis (LWP, 2020b).

State analysis was based on water quality samples collected over a five-year period from 1 July 2015 to 30 June 2020 and compared to the five-year period 1 July 2012 to 30 June 2017, which is defined as the baseline state (NPSFM, 2020).

Water quality analysed represented 10 physico-chemical and microbiological variables and biological indicators for 124 monitoring sites in the region; the sites included ORC monitored river sites (110), NIWA monitored National River Water Quality Network (NRWQN) sites (5) and ORC monitored lake sites (9 lakes, 22 sites/depths). All variables were evaluated for state and trends at all sites (when sufficient data was available), this report describes only river state and trends for the variables that specifically relate to the NPSFM 2020; chlorophyll-a, total nitrogen, total phosphorus, ammoniacal-nitrogen, nitrate, suspended fine sediment, macroinvertebrate community index (MCI), macroinvertebrate average score per metric (ASPM), dissolved reactive phosphorus and E. coli. The state and trend outputs for all sites and variables are provided in supplementary files (a full list of these files is provided in Appendix A). Sites were graded as a NOF Band (A, B, C, D, and for E. coli) (for NOF Criteria) for each variable based on a comparison of the assessed state with the relevant criteria.

Trend analysis was carried out for 10-year and 20-year periods ending on 1 September 2020 for all site and water quality variable combinations that met a minimum requirement for numbers of observations. The methods used for statistical trend analyses were Kendall's test of rank correlation and the Sen slope estimator (SSE), which have both been used for trend analysis of water quality for several decades (Hirsch et al., 1982). LWP (2020b) considered flow adjustment as part of the trend assessment.

Individual site trend estimates were aggregated, to provide an overall picture of trends for the region. This was done graphically using stacked bar charts showing proportions of sites for each variable that fall into different trend direction confidence categories. For the 10-year trend period the predominant trend direction was variable by water quality analyte but that the 20-year trends were predominantly degrading for all variables apart from ammoniacal nitrogen.

The most obvious pattern associated with the assessment of water quality state was that almost all sites passed the NOF criteria for ammoniacal-N toxicity and nitrate toxicity. There are obvious spatial patterns associated with the variation in grades, water quality is best at river and stream reaches located at high or mountainous elevations under predominantly native cover. These sites tend to be associated with the upper catchments of larger rivers (e.g. Clutha River/Matau-Au) and the outlets from large lakes (e.g. Hawea, Wakatipu and Wanaka). Water quality is generally poorer at sites located on smaller, low-elevation streams that drain pastoral or urban catchments.

There is a lack of detailed information held by Otago Regional Council on local or catchment scale land use change or land management practice changes. This severely limits Council's ability to comment on drivers of trends evident across Otago. This is likely to be addressed by requirements in the NPSFM 2020, which requires that freshwater is managed in an integrated way that considers the effects of the use and development of land on a whole-of-catchment basis, including the effects on receiving environments.

1 Introduction

Otago Regional Council (ORC) operates a State of Environment (SoE) water quality monitoring network in lakes and rivers throughout the region for monitoring the state and trends in water quality and reporting on policy effectiveness. 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 to better represent environmental classes in the Otago region, based largely on the River Environment Classification (REC), (MfE, 2004).

This study analysed the available water quality data for rivers in the Otago Region. The state of water quality in the region is reported, on a site by site basis, relative to the attribute states specified in the National Objectives Framework (NOF) of the National Policy Statement-Freshwater Management (NPSFM, 2020). In addition, the study assessed water quality trends site by site and across the Otago region as a whole. All results are presented in Freshwater Management Unit (FMU) chapters.

The aims of this report are to:

- Report on the state of water quality and ecology indicators in rivers and lakes relative to attribute states in the NPSFM 2020 and to each FMU/Rohe;
- Identify significant trends in water quality and apply level of confidence categories to convey the confidence that the trend (or step change) indicates improving water quality.
- Meet Council's RMA obligations reporting the State of the Environment of Otago's rivers and lakes.

2 Otago Region

2.1 Region 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 Wakatipu, Queenstown, Hawea, Haast Pass and Lindis Pass. The distinctive and characteristic landscape of Otago includes 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 River/Mata-Au drains much of the Otago region. Its catchment area totals 21,000 km^2, and 75% of the total flow of the river at Balclutha comes from the outflows of Lakes Hawea, Wanaka and Wakatipu. Larger rivers feeding into the Clutha catchment include the 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 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 waters of the Lake Waipori and Waihola catchments and becomes tidal before making its way 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 to the south of Otago, particularly the Catlins area, emerge from wetter, often forested hills.

The environmental context in which Otago's water bodies exist is characterised by high rainfall in the Southern Alps and occasional very low rainfall in the semi-arid central Otago valleys. Despite the large water volumes in the region, parts of Otago are among the driest areas in New Zealand. Several rivers are characterised as 'water-short', including the Lindis, Manuherekia, Taieri, Shag and Kakanui rivers and their tributaries (Regional Plan: Water 2004) (ORC, 2017)

2.2 Freshwater management units

To give effect to the NPSFM 2020 and take a more localised approach to water and land management, ORC developed Freshwater Management Unit (FMU) boundaries incorporating the concept of ki uta ki tai (from the mountains to the sea).

In Otago five FMUs have been recognised, Figure 1 Map showing the FMU and Rohe boundaries, State of Environment monitoring site locations are also shown.Figure 1; Clutha/Mata-Au, Taieri, North Otago, Dunedin Coastal and Catlins. The Clutha/Mata-Au FMU has been further divided in to five sub-areas, or 'Rohe', for a more tailored water management approach in these areas. These include the Upper Lakes Rohe, Dunstan Rohe, Manuherekia Rohe, Roxburgh Rohe and Lower Clutha Rohe.

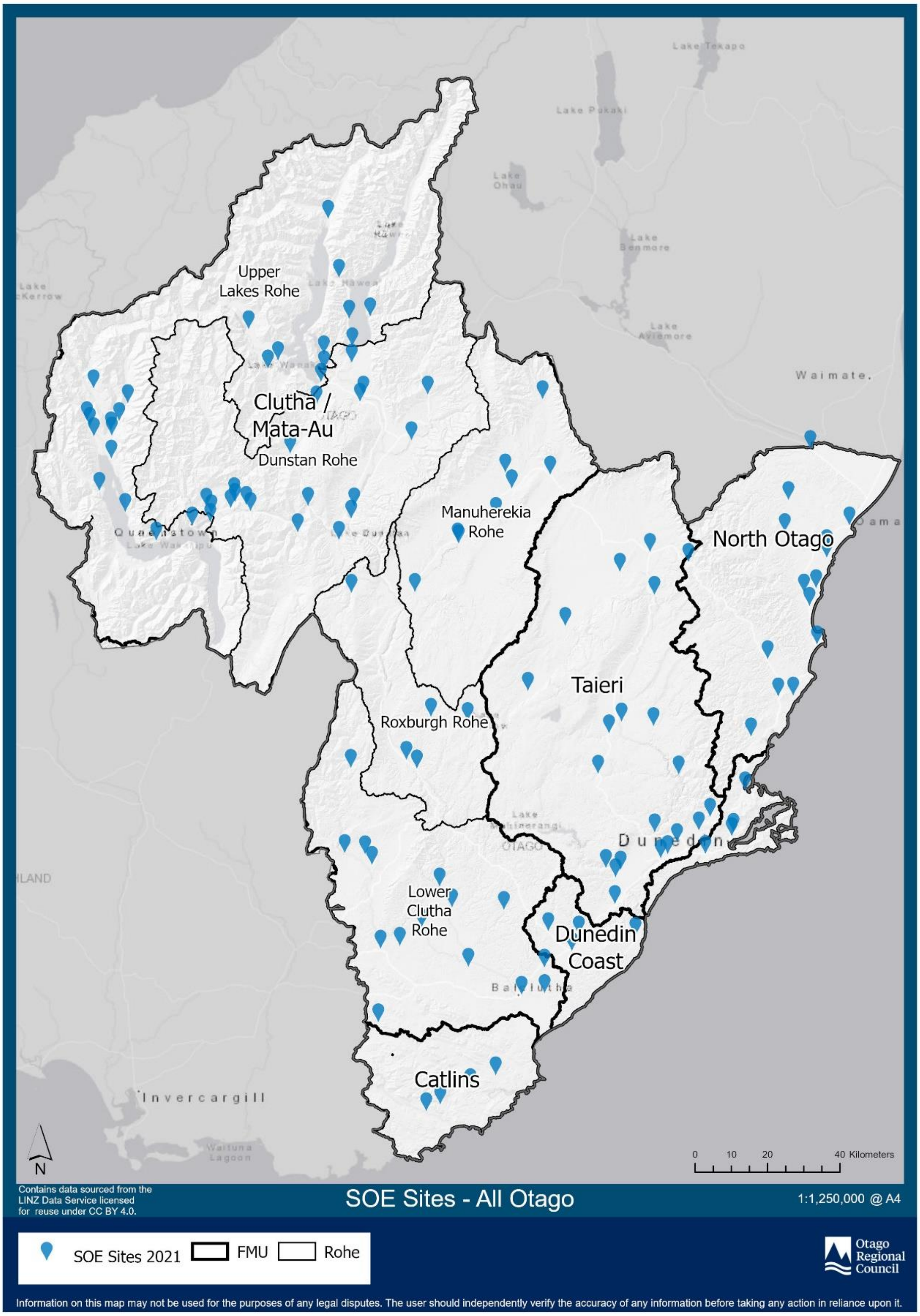


Figure 1 Map showing the FMU and Rohe boundaries, State of Environment monitoring site locations are also shown.

2.3 Upper Lakes Rohe (Clutha Matu/Au FMU)

The Upper Lakes Rohe encompasses Lake Wakatipu, Lake Wanaka, and Lake Hawea and all the tributaries that flow into them, effectively acknowledging this is a pristine, high value area. The headwaters of the catchment are predominantly in rugged, steep terrain with the highest point, Mt. Aspiring, reaching 3027 m. Numerous headwater streams such as the Dart River and Matukituki River originate along the eastern boundary of the Southern Alps and are fed by permanent glaciers.

The rivers and streams of the Upper Lakes FMU cover a broad range of river types, however based on the River Environment Classification (Appendix 1), cool/wet and cool/extremely wet rivers are a significant contributor to total river length throughout the Rohe. The REC classes 'wet' rivers as having a mean annual rainfall of 500 mm to 1500 mm; 'extremely wet' rivers are classed as having a mean annual rainfall greater than 1500 mm. Water yields from these streams and rivers is high. Also of significance is the proportion of glacial rivers. The high proportion of native cover in the upper catchments of the large lakes falls in areas of high to very high rain and snowfall. This provides large volumes flowing from pristine catchments of exceptional quality that feeds the Southern Great Lakes.

ORC monitors 23 river sites and three lakes in the Upper Lakes Rohe, many of the river sites were established in 2018.

2.4 Dunstan Rohe (Clutha Matu/Au FMU)

The Dunstan Rohe is essentially the mid-section of the Clutha FMU and encompasses the Kawarau River and the Clutha River from the outflows of Lakes Wanaka, Wakatipu and Hawea, the Rohe's boundary is at the Clyde Dam. The Rohe encompasses dryer catchments where water use is high and where there are water quality pressures and high growth. The major tributaries of the Dunstan Rohe include the Cardrona River (347 km2), Luggate Creek (123 km2), Lindis River (1039 km2) and the Shotover River (1091 km2). ORC monitors 16 river sites and three lakes in the Dunstan Rohe.

2.5 Manuherekia Rohe (Clutha Matu/Au FMU)

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

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'). The western Manuherekia Valley is separated from the Ida Valley by the central Raggedy Range, where the Idaburn River drains through a single gorge into the Manuherekia River. 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. Consequently, three reservoirs were established in the Manuherekia catchment to provide water for irrigation. Falls Dam was built in 1935 to capture the high rainfall water supply in the northern high-altitude part of the catchment and has a capacity of 11 Mm^3. Poolburn Reservoir was constructed in 1931, with a capacity of 26 Mm^3, while Manorburn Reservoir was built in 1935 and has a capacity of 51 Mm^3 (Kiensle, 2008).

There are several major irrigation schemes. Flow of the Manuherekia River is partly controlled by releases from Falls Dam. Blackstone Hill, Omakau, Manuherekia, and Galloway irrigation schemes 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 Ida Valley. Water from the Manorburn Reservoir is partly diverted into the Manuherekia Valley over an open water race to irrigate the upper Galloway Irrigation Scheme. The rest of the Manorburn water is used for irrigation in the Ida Valley (Kiensle, 2008).

The contribution of water from the Ida Valley to the mainstem Manuherekia is minimal during the summer months. For example, during the 2008-2009 irrigation season the Pool Burn at Cobb Cottage (after the confluence of the Idaburn and Poolburn, prior to entering the gorge) had a median flow of 50 l/s, compared to a median flow of 4433 l/s in the Manuherekia at Ophir.[1] This is important to note when considering the contribution of water quality contaminants in the lower Manuherekia River during the irrigation season. ORC monitors eight river sites in the Manuherekia Rohe.

2.6 Roxburgh Rohe (Clutha Matu/Au FMU)

The Roxburgh Rohe is bounded to the north by the Clyde Dam and to the South at Beaumont. The Rohe covers just over 1,000 square kilometres and encompasses catchments of the Fraser River (327 km2), Lake Onslow and the Teviot River (332 km2) and the Benger Burn (131 km^2) as well as small tributaries entering the Clutha between Clyde and Beaumont. Lake Onslow is a man-made 830ha lake at the head of the Teviot River, 700m above sea level. ORC monitors four river sites and one lake in the Roxburgh Rohe.

2.7 Lower Clutha Rohe (Clutha Matu/Au FMU)

The Lower Clutha Rohe runs from Beaumont to the Pacific Ocean where the Clutha River/Mata-Au discharges to the sea near Balclutha. The Lower Clutha Rohe includes the catchments of the Tuapeka River (249 km^2), Pomahaka River (2060 km^2), Waipahi River (339 km^2), Waiwera River (208 km^2) and the Waitahuna River (406 km^2).

The Pomahaka River is the largest catchment of the Lower Clutha Rohe. The upper reaches of the Pomahaka catchment are steep and dominated by tussock, while the lower reaches are primarily pastoral rolling hill country and intensively managed land. Soils are generally poorly drained requiring artificial drainage predominantly in the form of tile drains. If inappropriately managed, these tile and mole drains accelerate water and associated contaminant flows of nitrogen, phosphorous and bacteria to local watercourses. ORC monitors 14 river sites and one lake in the Lower Clutha Rohe.

2.8 Taieri FMU

The Taieri River rises in the Lammerlaw and Lammermoor Ranges at 1,150m above sea level. The river 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 Kyeburn, Sutton Stream, Deep Stream, Lee Stream, Silverstream and the Waipori River.

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, 660km^2 area of the Maniototo Plain, west of the Rock and Pillar Range. The river follows an extremely meandering course through large Scroll Plains in the Maniototo. These are unique and scientifically important features of the upper catchment. 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 may be in part due to historic gold mining activities in the Kye Burn Catchment.

[1] https://www.orc.govt.nz/media/2437/web-version-manuherkiaa2-report2.pdf.

The midreaches of the Taieri River flow through the smaller Strath Taieri Plain (occupying an area of 85km^2), past Middlemarch, and through the Taieri Gorge. Many small tributaries join the main stem of the river along this sub-region.

Most of the human settlement is in the lower Taieri Catchment on the Taieri Plain (occupying an area of 180km^2), where the town of Mosgiel is located. The floodplain area is intensively farmed (mostly dairying). The lower Taieri River is joined by the Silverstream, which provides high quality trout spawning and nursery habitats for the river fishery. A large floodplain and the associated Lake Waipori/Waihola wetland complex are the dominant features of the lower catchment. 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. ORC monitors 19 river sites and one lake in the Taieri FMU.

2.9 Dunedin Coast FMU

The Dunedin Coast FMU recognises the middle coast of Otago, starting south of Karitane, encompassing Dunedin city and Otago Peninsula and the coastal catchments to Clutha/Mata-Au mouth. All of these areas have similar water quality issues and water quantity demands. ORC monitors the catchments of Lindsay's Creek, the Leith Stream and the Kaikorai Stream in the Dunedin City area and the Tokomairiro River and Akatore Creek to the South.

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 Hill and flow for 12 km in a south-easterly direction to discharge direct to the Otago Harbour, Dunedin. There are numerous tributary streams to the Leith, the principal of which is Lindsays Creek which flows for 7 km to its junction with the Leith Stream at the Dunedin Botanical Gardens. Significant areas of the lower catchment of the Leith Stream and Lindsays Creek flow through urban areas of the Dunedin City.

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 headwaters originate in the Kaikorai Hills to the north. The catchment includes the western flanks of Dunedin city and all of Green Island. The remaining area includes the communities of Fairfield and Waldronville (ORC, 2008). Fraser's Stream is a major tributary of the Kaikorai Stream and the Dunedin City Council discharges up to 560 litres per second of high-quality water from the Mt Grand Water Treatment Plant to MacLeod's Creek (a tributary of Fraser's Stream). This flow significantly improves the water quality and instream values of the Kaikorai Stream downstream of the discharge point (ORC, 2008).

The Tokomairiro River is located about 48 km south-west of Dunedin and has a catchment area of 403 km^2. The catchment has indistinct boundaries, with no dividing mountain ranges between it and neighbouring catchments. It is bordered to the east by tributaries of the Waihola-Waipori wetland complex (including Meggat Burn and Boundary Creek) and a number of coastal tributaries including Akatore Creek. ORC monitors eight river sites in the Dunedin Coast FMU.

2.10 North Otago FMU

The North Otago FMU contains parts of the lower Waitaki Plains; the Kakanui catchment that includes the Kakanui River, Kauru River and Waiareka Creek; the Waianakarua Stream and Trotters Creek along with river catchments that drain independently to the sea; and to the south, the Shag River and 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. In recent times concern has been expressed about agricultural intensification and subsequent degradation of water quality. The lower Kakanui River and Waiareka Creek are dominated by a mixture of beef, sheep, deer, cropping and particularly since the introduction of irrigation water into the Waiareka Creek catchment by the NOIC irrigation scheme dairy farming. 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. The water quality in the alluvial gravels of the Kauru River and the main-stem Kakanui River, particularly upstream of Gemmels Crossing, is influenced by groundwater surface water interaction. There is very little groundwater surface water interaction in Waiareka Creek (Ozanne and Wilson, 2013).

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 River 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 Shag catchment is dominated by extensive agriculture and forestry with some short-rotation cropping in the lower catchment. There is currently no dairy farming in the Shag catchment, although some farms are used for dairy support (Olsen, 2014).

The Waikouaiti catchment area covers 421 km^2, the river has two main branches, the North Branch and South Branch. The North Branch has a catchment area of 283 km^2 and the South Branch a catchment area of 86 km^2. The remaining 52 km^2 includes the area downstream of the confluence of the two main branches along with the Waikouaiti Estuary. The headwaters of the north branch originate in the Macraes Flat area, whereas the south branch drains the northern slopes of the Silver Peaks. ORC monitors 15 river sites the North Otago FMU.

2.11 Catlins FMU

In the South of Otago, the Catlins FMU contains a collection of smaller catchments that feed into the sea south of the Clutha / Mata-au catchment. 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 present. 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, Owaka River, Maclennan River and the Tahakopa. The Catlins flows south-eastward. Its total length is 42 km and it shares its estuary with the Owaka River, which flows into the Pacific Ocean at Pounawea, 28 km south of Balclutha. The Owaka River is 30 km long and flows south-east. Its source is on the slopes of Mt Rosebery. The Tahakopa River flows south-east through the Catlins. Its total length is 32 km, and it flows into 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. ORC monitors four river sites Catlins FMU.

3 ORC monitoring programme

3.1 Water Quality Sites

SoE monitoring sites covered in this report include 110 river sites[2] and 22 monitoring sites/depths for lakes. NIWA monitors an additional five sites in the Otago region as part of the National River Water Quality Network (NRWQN). Figure 1 shows the location of the river and lake monitoring sites. Significant changes to the SoE monitoring programme have occurred over the years, the main changes are:

- 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 Otago, following a review (NIWA, 2017), a more extensive monitoring programme commenced in mid-2018 to better represent environmental classes in the Otago region, based largely on the River Environment Classification (REC). The number of river sites monitored expanded from 65 to 106.
- Prior to mid-2018 SoE lake monitoring sites consisted of a mix of lake-outlet (lakes Wanaka, Wakatipu and Hawea) and lake-shore (lakes Dunstan, Hayes, Johnson, Onslow, Waihola and Tuakitoto) sampling sites. Following NIWA's review, all lake sites other than Tuakitoto and Onslow now are mid-lake sampled with full vertical water column profiled on every sampling occasion.
- A review of the biomonitoring programme (NIWA, 2017) to better represent environmental classes in Otago, meant the cessation of several macroinvertebrate sites in 2018 and the adoption of several new sites.

3.2 Water quality variables

River and lake water quality was assessed using variables that characterise physical, chemical and microbiological conditions, and macroinvertebrate community composition. All variables included are attributes described in Appendix 2A or 2B of the NPS-FM

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 (nitrate) and phosphorus (phosphate), can cause water bodies to become eutrophic. Eutrophic states are associated with periodic high biomass (blooms) of plants 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 (Ministry for the Environment, 2000) because all types of algae 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 NPSFM 2020 specifies attributes for tropic state based on phytoplankton biomass in lakes (NPSFM 2020, Appendix 2A, Table 1) and periphyton biomass in rivers (NPSFM 2020, Appendix 2A, Table 2), chlorophyll *a* is the measure of biomass that the NOF phytoplankton and periphyton attributes are based on.

Nitrate (NO_3N), ammoniacal-N (NH_4N), dissolved reactive phosphorus (DRP), total nitrogen (TN) and total phosphorus (TP) influence the growth of benthic river algae (periphyton), lake planktonic algae

---

[2] SoE monitoring currently covers 106 river sites. Some sites were discontinued in 2018, but are reported.

(phytoplankton) and vascular plants (macrophytes). The NPSFM specifies additional attributes for TN and TP in lakes (NPSFM 2020, Appendix 2A, Table 3 and Table 4).

The NPSFM 2020 does not specify nutrient concentration criteria to manage the trophic state of rivers, because the relationship between trophic state and nutrient concentrations varies between rivers even at the regional scale. The nutrient criteria to achieve periphyton biomass objectives in rivers are river specific and should be derived at the local level (MfE, 2018).

The Ministry for the Environment has produced guidance (MfE, 2020) for defining nutrient concentrations to manage the NPSFM 2020 periphyton attribute states in rivers. The guidance is centered around spatial exceedances for TN and DRP. Spatial exceedance is used because deriving nutrient targets to achieve a target periphyton growth cannot be 100% certain due to natural variability, complex interactions in the environment, and the complexity of the relationship between nutrients and periphyton abundance (MfE, 2020). Given the short record of chlorophyll-a observations in the region, these nutrient concentration criteria provide a useful alternative for estimating trophic state in the region's rivers.

In this report TN and DRP median concentrations are compared to the spatial exceedance criteria of 20% (as opposed to 10% or 30%). At this level there is some risk (i.e., 20%) that the chlorophyll *a* response at some sites will exceed the desired chlorophyll *a* threshold, even if DRP or TN concentration targets are achieved.

In addition to the MfE guidance, the NPSFM 2020 provides an attribute table for DRP in rivers to protect ecosystem health. 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. The NPSFM 2020 (Appendix 2B, Table 20) describes that at concentrations below the national bottom line, it is expected that ecological communities are impacted by substantial DRP elevated above natural reference conditions.

3.2.2 Toxicants

When ammonia 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, potentially leading to death. Environmental factors, such as pH and temperature, can affect ammonia toxicity to aquatic animals. The NPSFM 2020 has developed an ammonia toxicity risk framework (NPSFM 2020, Appendix 2A, Table 5) when toxicity concentrations are below the national bottom line, toxicity starts impacting regularly on the 20% of the most sensitive species.

Nitrate 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). The NPSFM has developed a nitrate toxicity risk framework (NPSFM 2020, Appendix A, Table 6) when toxicity concentrations are below the national bottom line, toxicity has growth effects on up to 20% of species monitored.

3.2.3 Suspended sediment

Suspended fine sediment can severely affect values around water, particularly around ecosystem health. High concentrations of suspended sediment 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'*** (NPSFM, 2020). Suspended fine sediment can be monitored by clarity or turbidity measurements.

Clarity is a measure of light attenuation due to absorption and scattering of 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. Clarity is correlated with suspended solids, which can impede fish feeding and cause riverbed sedimentation. Clarity is the metric used in the NPSFM 2020 suspended fine sediment attribute table (NPSFM 2020, Appendix A, Table 8).

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 optical effects (i.e., absorption) of dissolved materials. The NPSFM 2020 allows for the conversion of turbidity to visual clarity. ORC does not measure visual clarity and applies this conversion.

3.2.4 Aquatic Life

Macroinvertebrates are an important component of streams and rivers because they aid ecosystem processes and provide food for fish and some birds. As macroinvertebrates have a relatively long-life span, they are good indicators of environmental conditions over a prolonged period. Macroinvertebrates are included in the NPSFM 2020 as attributes requiring an action plan (NPSFM 2020, Appendix 2B, Tables 14-15).

The main measure of macroinvertebrate communities, the MCI index, is designed specifically for stony-riffle substrates in flowing water. The MCI is responsive to multiple stressors, but not all stressors, and as such provides a good indicator of the overall condition of the macroinvertebrate component of stream ecosystem health.

MCI values can be affected by factors other than water quality, so it is more informative to consider changes in MCI values at the same site over a period, rather than among sites throughout the catchment. For example, a change in MCI value at a site may be due to human activities causing increased nitrogen or sedimentation with resulting ecological consequences (Clapcott et al. 2018). Sites with an MCI score of less than 80 are classified as poor, those scoring 80-100 as fair, those scoring 100-120 as good, and those scoring higher than 120 as excellent (Stark and Maxted, 2007).

The NPSFM has attribute states for Macroinvertebrate Community Index (MCI) score; Quantitative Macroinvertebrate Community Index (QMCI) score and Macroinvertebrate Average Score Per Metric (ASPM). Historical monitoring by ORC has included the Semi-Quantitative Macroinvertebrate Community Index (SQMCI) score, rather than QMCI. As the two are not directly comparable the QMCI metric is not shown.

The Average Score Per Metric (ASPM) was introduced by Collier (2008), it is an aggregation method for assessing wadeable stream ecosystem health considering the relative responses of core metrics and is composed of three individual metrics, the MCI, EPT richness to the total taxa found and % EPT abundance. EPT Richness Index estimates water quality by the relative abundance of three major orders of stream insects that have low tolerance to water pollution. EPT can be expressed as a percentage of the sensitive orders (E= Ephemeroptera, P= Plecoptera, T= Tricoptera) and % EPT is the total number of EPT individuals divided by the total number of individuals in the sample).

3.2.5 Escherichia coli (E. coli)

The concentration of the bacterium *E.coli* is used as an indicator of human 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 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 NPSFM 2020 assesses river swimmability and the attribute states uses four statistical measures of *E. coli* concentrations, the overall state is determined by satisfying all numeric attribute states (NPSFM 2020, Appendix 2A, Table 9). Analysis in this report does not cover primary contact sites (NPSFM 2020, Appendix 2B, Table 22)

4 Methods

4.1 Water Quality State Analysis

LWP evaluated state at ORC's river and lake monitoring sites for nutrients and bacteria, this section details the methods LWP used for state analysis and is taken directly from LWP 2020a.

4.1.1 Grading of monitoring sites

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 NPSFM 2020 detailed in Table 1.

Each table of Appendix 2 of the NPSFM 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 toxicity attribute, which is defined by nitrate-nitrogen 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, the nitrate-nitrogen attribute has 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 'bottom line') in any waterbody nationally. In the case of the NO_3N (toxicity) and NH_4N (toxicity) attributes in the 2020 NPS-FM, the C band is unacceptable, and for the DRP attribute, no bottom line is specified.

The primary aim of the attribute bands designated in the NPSFM 2020 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 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 objectives.

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[2]	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	Lakes and		Median concentration of Ammoniacal-N	mg l^{-1}
			Maximum concentration of Ammoniacal-N	mg l^{-1}
A2A; Table 6 - Nitrate	Rivers		Median concentration of Nitrate	mg l^{-1}
			95th percentile concentration of Nitrate	mg l^{-1}
A2A.; Table 8 - Suspended fine sediment	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 percentile concentration of *E. coli*	cfu 100 ml^{-1}
A2B; Table 14 - Macroinvertebrates	Rivers	State calculated as 5-year median	Median MCI score	-
A2B; Table 15 - Macroinvertebrates	Rivers		Median ASPM score	-
A2B; Table 20 - DRP	Rivers		Median concentration of DRP	mg l^{-1}
			95th percentile concentration of DRP	mg l^{-1}

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 NO_3N toxicity attribute). A site grading is done by using the numeric attribute state (e.g., annual median nitrate-nitrogen) 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 NO_3N 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 NO_3N 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, a grade for each numeric attribute state has been provided (e.g., for the NO_3N (toxicity) attribute, grades are defined for both the median and 95th percentile concentrations).

4.1.2 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.

4.1.3 Time-period for assessments

When grading sites based on NPS-FM attributes, it is general 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 2020. 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 NPSFM (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.

4.1.4 Calculation of water clarity

The NPSFM 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:

$$\ln(CLAR) = 1.21 – 0.72 \ln(TURB)$$

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 was 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.

4.1.5 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_4N 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.

4.1.6 Evaluation of compliance statistics

Ccompliance statistics specified as annual (maximum, median, 95th percentile) in the NPSFM, have been calculated over the entire 5-year state period.

4.2 Water Quality Trend Analysis

LWP evaluated 10 and 20-year trends at ORC's river and lake monitoring sites for each measured variable (primarily nutrients and bacteria), this section details the methods LWP used for trend analysis and is taken directly from LWP 2020b.

4.2.1 River water quality data

The river water quality data used in this study were supplied by ORC (110 sites) and NIWA (8 sites) and comprised 114,600 observations at 115 monitoring sites (3 sites overlapped between the ORC and NIWA data).

4.2.2 Lake quality data

The lake water quality data used in this study comprised 18,612 observations at 22 monitoring sites/depths of the 13 variables. Some sites had two depths associated with their water quality sampling. The different depths were treated as independent sampling sites.

The ORC lake monitoring programme underwent major changes following the NIWA review in 2018. Several new sites were introduced, and older sites were phased out. Many of these older sites had long term records (starting in approximately 2000) but were ceased by mid-2018. Many of the water quality variables at the new sites were also monitored at these locations during an intensive investigation period between 2006-2009. These data were extracted from physical records for use in this study. The extracted data was not associated with censoring information. Observations were reinstated as censored values as part of the pre-processing based on the detection limits in operation for the same variables in other lakes over the same time-period.

4.2.3 Flow data

Many of the river water quality monitoring sites were associated with flow records, which were also obtained from the ORC database. Flows associated with the NIWA sites were a combination of measured and modelled flows. Water quality observations can be strongly associated with flow, and the effect of flow on water quality can be accounted for in analysis of trends. Mean daily flows were associated with 51 of the 115 monitoring sites (and, of these sites, approximately 87% of all sample occasions had an associated flow).

4.2.4 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 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, filtering rules applied by Larned et al. (2019) were used, 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 coarser (i.e., quarterly) seasons were retained for reporting. Bi-months were also included as an intermediate coarseness between months and quarters, as this sampling interval was historically used.

Using these filter rules, the number of site/variable combinations that would be included in the analysis under varying trend period end dates was explored. While the intention was to provide the most recent possible trend assessments (up to the end of the observations dataset, August 2020), the possibility of having an earlier end date was also considered, if that would significantly increase the number of sites that would comply with the filtering rules. End dates were considered at the end of months from December 2019 through to August 2020. The results of this analysis are not included in this report as generally, there was little variation in the number of sites that complied with the filtering rules for end dates between February 2020 and August 2020. The exception was for the macroinvertebrate metrics, which had a large reduction in the number of sites that complied with the filtering rules from the December 2019 cut-off point to all end dates in 2020 (generally a reduction from 26 to 13 sites). This arises due the cessation of several macroinvertebrate sites in 2018. In the interest of providing the most up to date trend assessments, the trends for rivers presented in this study were for 10 and 20-year periods ending at 31 August 2020.

A slightly different approach has been applied to the lake monitoring data in order to maximise the assessment of trends for these sites due the irregularity of the monitoring and changes in monitoring sites. The most recent end date to examine long term, fixed period, trends across all sites was identified. This date coincided with the termination of monitoring at a number of long term sites at the end of June 2018. We evaluated trends for 10- and 18-year periods up to the end of June 2018. The 18- year period was selected as there were no lake data available prior to 2000. For these fixed period trend assessments, the data were subjected to the same filtering rules as used for the river and groundwater sites.

Another deviation for the trend analysis at lake sites was for a group of sites that were monitored for a period between 2006-2009 after which there was no monitoring until the program was re-established in 2018. These sites have been analysed using alternative trend assessment procedures that evaluate the change between the two time-periods (see Section 4.2.11). However, it was important that the data still complied with the time-period requirements relating to representativeness of the time-periods, and that there was no bias toward any particular season in the records. Consequently, the two analysis time-periods for these site/variable combinations to be three complete years: 1 May 2006 to 30 April 2009, and 1 June 2017 to 31 May 2020 were set. It was also required that at least 80% of observations were available in each time-period.

4.2.5 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 (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 NH_4N 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.

A 'hi-censor' filter was applied in the trend assessments to minimise biases that might be introduced due to changes in detection limits through the trend assessment period. The hi-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).

4.2.6 Flow adjustment

Where water quality observations are made in a river and are associated with a solute or particulate matter (e.g., a concentration or an optical measure such as clarity or turbidity) some of the variation can be associated with the river flow (i.e., discharge) at the time the observation was made. The observed values can vary systematically with flow rate due to two kinds of physical processes. The water quality observations may decrease systematically with increasing flow due to the effect of dilution of the contaminant, or increase with increasing flow due to wash-off of the contaminant (Smith *et al.*, 1996). Different mechanisms may dominate at different sites so that the same water quality variable can exhibit positive or negative relationships with flow. Some water quality variables can be associated with a combination of dilution and wash off with increasing flow. For example, a portion of the *E. coli* load may come from point sources discharges such as sewage treatment plants (dilution effect), but another portion may be derived from surface wash-off. Increasing flow in this situation may result is an initial dilution at the low end of the discharge range, followed by an increase with discharge at higher values of discharge.

Trend analysis seeks to quantify the relationship between the water quality observations and time. In this context, flow can be considered as a covariate; a variable that is also related to the water quality observations but whose influence is confounding the water quality – time relationship of interest. Statistical analysis can be used to remove the influence of the covariate on the water quality observations. For river data, this statistical analysis is called flow adjustment. The same principle can be applied to other types of environment (e.g., lakes, groundwater) and other covariates (e.g., wind, precipitation) and so the more general term is covariate adjustment.

Covariate adjustment has two purposes. First, it can increase the statistical power of the trend assessment (i.e., increase the confidence in the estimate of direction and rate of the trend) by removing some of the variability that is associated with the covariate. Second, it removes any component of the trend that can be attributed to a trend in the covariate (e.g., a trend in the flow on sample occasions such as increasing or decreasing flow with time).

Covariate adjustment involves fitting a model that describes the relationship between the water quality observation and the covariate, and then using the residuals of the model instead of the original water quality observations in the subsequent trend assessment step. In the description of the covariate adjustment method below, flow adjustment was the focus (i.e., removing the influence of flow at from water quality observations made in a river). However, in principle, the method is the same for any other type of covariate adjustment.

Four alternative regression models were considered to describe the relationship between the water quality observations and flow: log-log regression, locally estimated scatterplot smoothing (LOESS, with spans of 0.7 and 0.9) and generalised additive models (GAM). Censored values were represented during model fitting by raw values (i.e., the numeric component of the censored values) multiplied by a 0.5 for detection limit censoring and 1.1 for reporting limit censoring.

The next step was to select the best model from the alternatives. Expert judgement was used to choose the most suitable model based at least three considerations: (1) the homoscedasticity (constant variance) of the regression residuals, (2) model goodness of fit measures and (3) plausibility of the shape of the fitted model. The model of goodness of fit measure alone should not be relied on because they can indicate good model performance but describe unrealistic relationships. This is particularly likely when more flexible models are used such as LOESS and GAM models and therefore these models should be used with caution.

When the relationship between flow and the water quality variable was poor, it was concluded that that there was not a systematic relationship between the observations and flow. In this case, no model was selected, no flow adjustment was performed and the trend assessment was performed on the raw data. Choosing not to flow adjust took into consideration the balance between the potential to reduce variance in the observations, and the risk of selecting an implausible/inappropriate model of the relationship between the observations and flow.

4.2.7 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.

Seasonality was evaluated 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), site/variable combinations were identified as being seasonal based on the *p*-value from the Kruskall-Wallis test with α=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).

4.2.8 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.

4.2.9 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 $\geq$ 8. Both the Mann Kendall and Seasonal Kendall assessments are based on calculating the Kendall *S* statistic, which is explained diagrammatically in Figure 2.

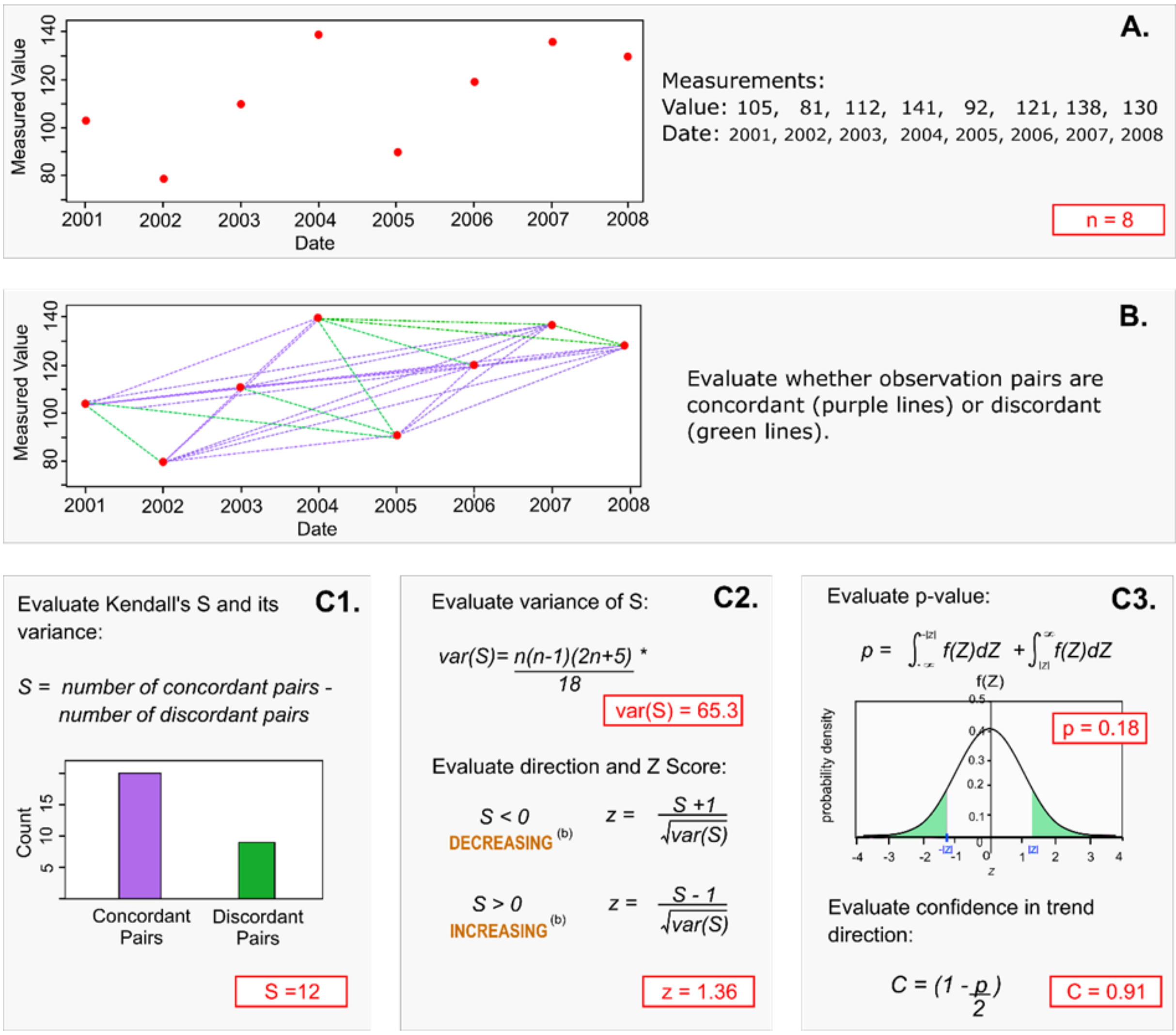


Figure 2.The Kendall S statistic is calculated by first evaluating the difference between all pairs of water quality observations (Figure 2, A and B). Positive differences are termed 'concordant' (i.e., the observations increased with increasing time) and negative differences are termed discordant (i.e., the observations decreased with increasing time). The Kendall S statistic is the number of concordant pairs minus the number of discordant pairs (Figure 2, C1). The sign of S indicates the water quality trend direction with a positive or negative sign indicating that observations increased or decreased through time respectively (Figure 2, C2). In the special case that the z score is equal to zero, the trend would be pronounced indeterminate, or equally likely to be increasing as decreasing.

4.2.10 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.

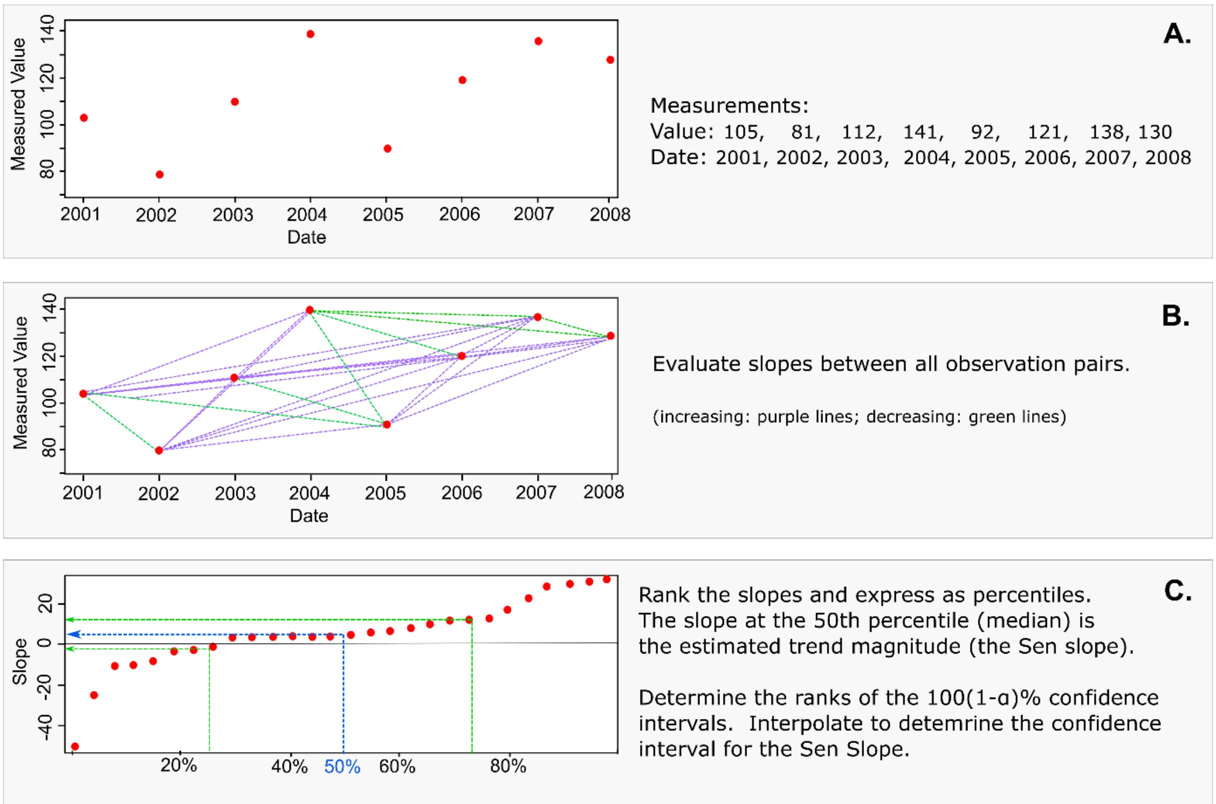


Figure 3 Pictogram of the calculation of the Sen slope, which is used to characterise trend rate.

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 3 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. 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 interobservation slope is censored.

4.2.11 Evaluating changes in discontinuous data

Some of the monitoring data for lake sites is broken into two distinct time-periods, with a moderate gap (~ 4 years) between these periods. Following the USGS guidelines (Helsel et al. 2020), these types of datasets have been analysed using a step change approach. The analysis procedure uses a rank-sum test (and seasonal variant where appropriate) to test whether there is a change in the observations between the two periods, and the Hodges-Lehman (H-L) estimator to evaluate the magnitude, and direction of the change.

The rank-sum test is implemented in R using the functions: twoSampleLinearRankTest and twoSampleLinearRankTestCensored (both part of the EnvStats package). The second function explicitly accounts for censored data in either or both of the time periods. A seasonal rank sum test is applied when the observations are determined to be seasonal. For the seasonal case, the rank sum statistic and variance are evaluated for each season and these are then individually summed to determine the overall test statistic. As for the Mann Kendall test, the *p*-value from the rank sum test was converted to a measure of the confidence in direction of change in water quality between the two time-periods.

The H-L estimator is evaluated in a similar manner as the Sen Slope, with the exception that rather than evaluating the rate of change between all pairs of observations, only the differences are evaluated, and only between pairs from different periods. The H-L estimator is the median of all possible differences between the data in the before and after periods. A seasonal H-L estimator is evaluated when the observations are determined to be seasonal.

We also provide an estimate of the rate of change that the difference represents, by dividing the H-L estimator by the difference between the mid times of each time period. This measure is indicative only and should only be used as an approximation of the relative magnitude of the rate of change at these sitesonly be used as an approximation of the relative magnitude of the rate of change at these sites.

4.2.12 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 $C_d = 1\text{-}C$. 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 trend for each site/variable combination was assigned a categorical level of confidence that the trend was improving according to its evaluated confidence, direction and the categories shown in Table 2. Improvement is indicated by decreasing trends for all the water quality variables in this study except for MCI, SQMCI, ASPM and dissolved oxygen (for which increasing trends indicate improvement).

Table 2. 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	*Descriptor 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

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 zeros. 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.

Changes for discontinuous data were classified as not analysed when there were less than 3 unique observations in the entire record, or if seasonal, within any season.

4.2.13 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 3. 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 in Figure 54 and Figure 55.

Table 3 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	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	114	50	32	34	18
ASPM	51	10	6	0	0
Chlorophyll a	44	0	0	0	0
Dissolved Inorganic Nitrogen	108	0	0	0	0
Dissolved Reactive Phosphorus	108	50	32	33	18
E.coli	114	50	27	28	13
MCI	54	13	7	0	0
Nitrite/Nitrate Nitrogen	114	50	32	34	18
SQMCI Score	53	13	7	0	0
Total Nitrogen	114	50	32	33	18
Total Phosphorus	114	50	32	32	18
Turbidity	114	50	32	32	18

5 Results Overview

In Otago five FMUs have been recognised: Clutha/Mata-Au, Taieri, North Otago, Dunedin Coastal and Catlins. The Clutha/Mata-Au FMU has been divided in to five sub-areas, or Rohe comprising the Upper Lakes Rohe, Dunstan Rohe, Manuherekia Rohe, Roxburgh Rohe and Lower Clutha Rohe. The results section is organised in FMU or Rohe chapters, each chapter follows the same format:

- Figure of the FMU/Rohe showing location of water quality monitoring sites
- State analysis results of grading of river/lake sites based on the NOF criteria. Including a comparison with the baseline state (2012-2017)
- State analysis maps showing results of river/lake sites coloured according to their state grading as indicated by NOF attribute bands.
- Trend analysis summary of sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement.
- At the end of each FMU/Rohe section a summary table is presented showing which sites and attributes fall below the national bottom line.

6 Upper Lakes Rohe (Clutha Matu/Au FMU)

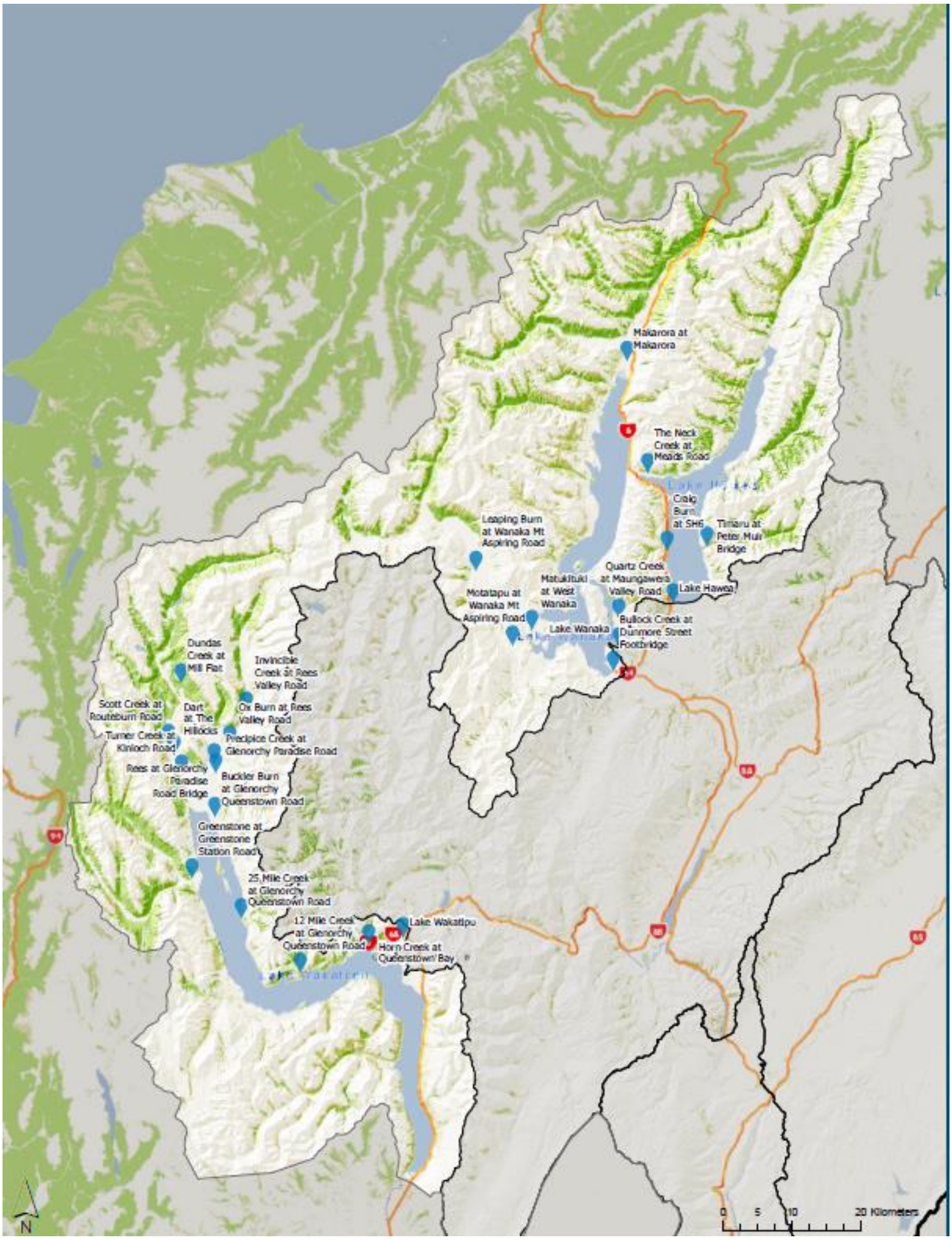


Figure 4 Location of water quality monitoring sites in the Upper Lakes Rohe

6.1 State Analysis Results

The results of grading the SoE sites in the Upper Lakes Rohe according to the NPSFM 2020 NOF criteria are summarised in Figure 5 and Figure 6 and mapped in Figure 7. Many sites in the Upper Lakes Rohe 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.

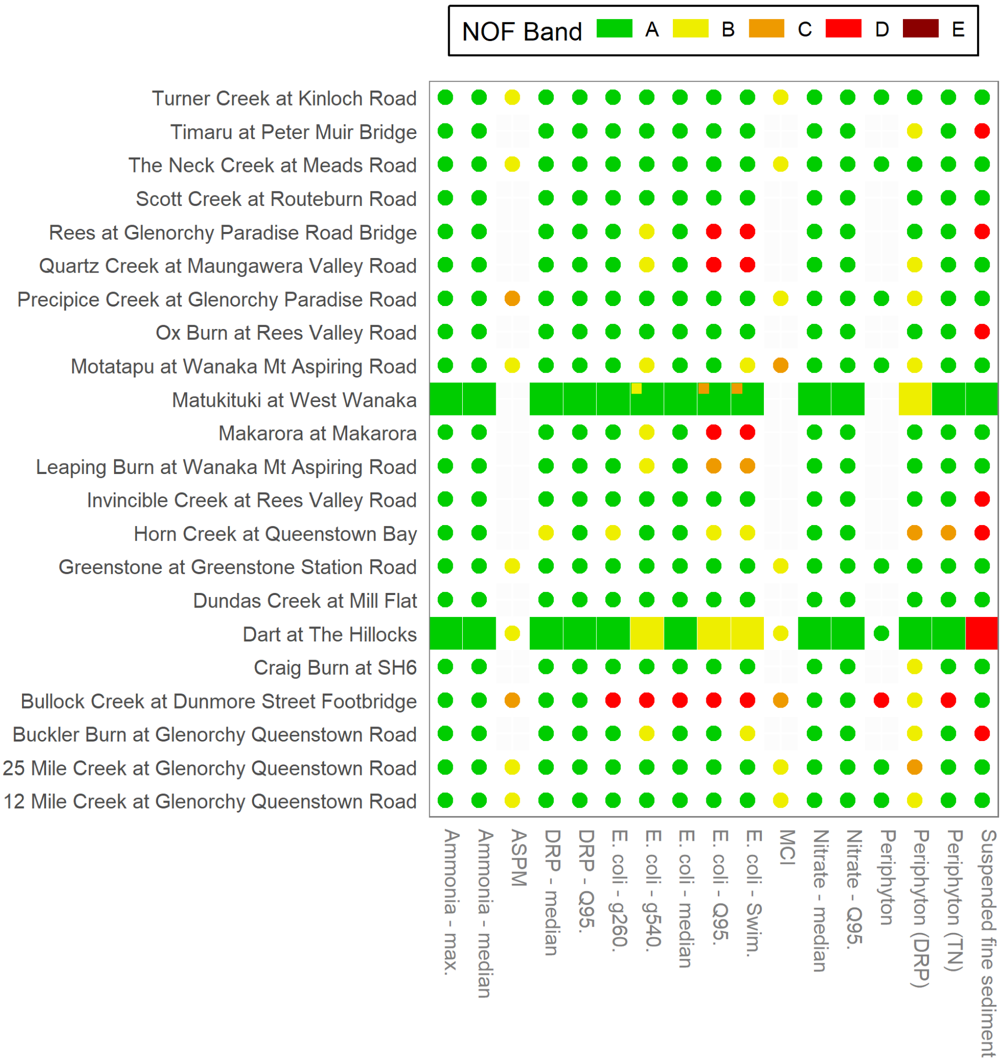


Figure 5 Grading of the river sites of the Upper Clutha Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

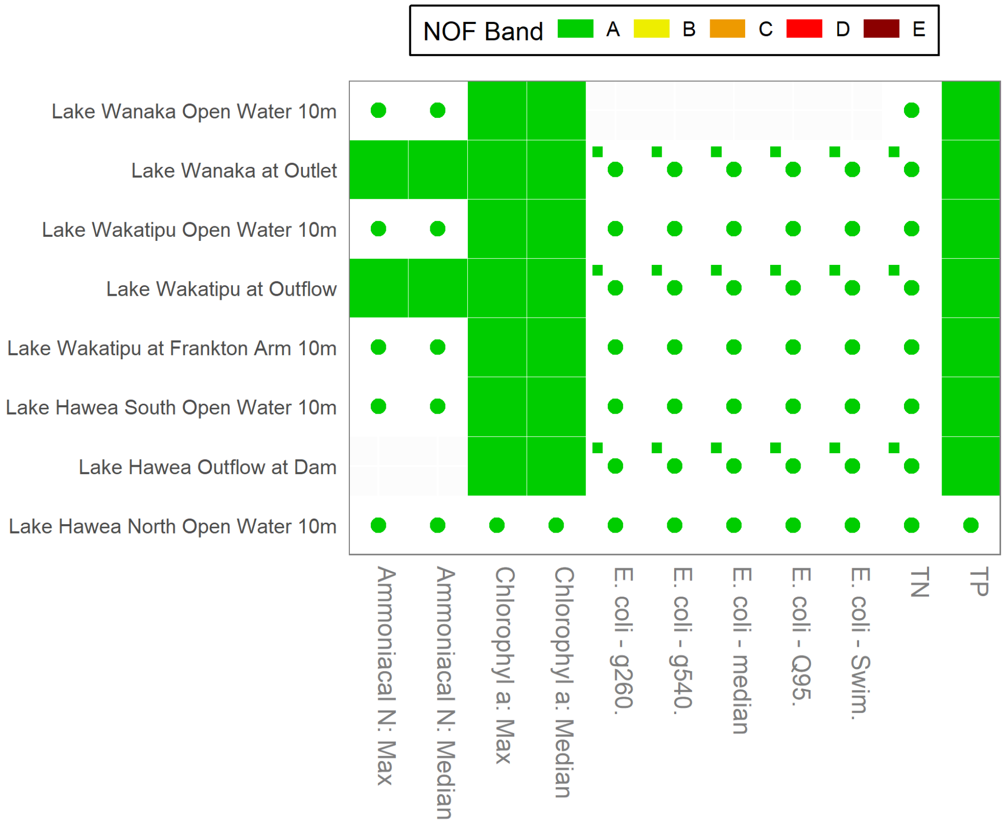


Figure 6 Grading of the lake sites of the Upper Clutha Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

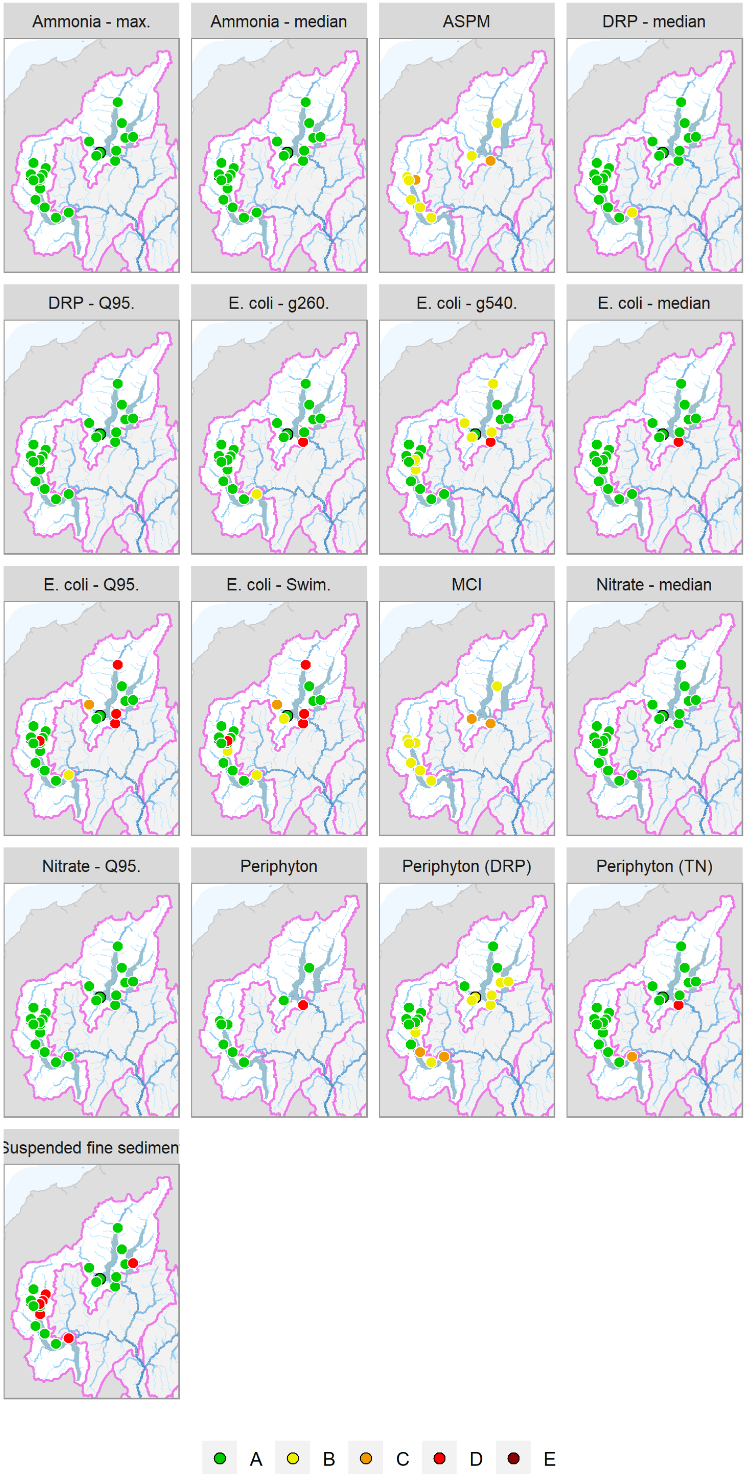


Figure 7 Maps showing Upper Clutha Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

6.1.1 Periphyton and Nutrients

Results for the river periphyton trophic state are shown in Figure 5 (periphyton). Most sites in the Upper Clutha are in attribute band 'A' for periphyton 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 an interim result of 'D' which places it below the national bottom line, this reflects a higher nutrient enrichment and the possibility of regular nuisance blooms.

Figure 5 shows the MfE (2020) DRP and TN concentrations to manage the NPSFM periphyton attribute state (periphyton DRP and periphyton TN). All sites have median DRP concentrations that place them in the 'A' or 'B' bands, however 12 Mile Creek and the Matukituki have median DRP concentrations that place them in the 'C' band. For TN median concentrations in the Upper Lakes Rohe are generally in the T50 mg chl-a/m2 band (or band 'A'), as would be expected in a low nutrient environment. The outliers are the urban stream Horn Creek, which has a median TN concentration of 0.27 mg/l placing it in band 'C' and 12 Mile Creek and Bullock Creek that have median TN concentrations placing them in band 'B'. Figure 5 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Upper Lakes Rohe show that every site achieves a band 'A', other than Horn Creek which achieves a band 'B' (median DRP). The NPSFM 2020 describes Band 'A' as *'Ecological communities and ecosystem processes are similar to those of natural reference conditions'.*

Results for the lakes are also shown in Figure 6. Trophic status is a common method for describing the health of lakes and an indicator of how much growth or productivity occurs in the lake, productivity being 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 NPSFM 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 5shows that this is the case for all the lake sites in the Upper Clutha 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.

6.1.2 Toxicants

NOF attribute bands for NH_4N and nitrate (measured as NNN) toxicity (Figure 5) 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 NH_4N; and all sites returning an 'A' band for NNN.

6.1.3 Suspended fine sediment (Rivers)

The clarity results for the Upper Lakes Rohe are shown in Figure 5. Sites that have a high degree of glacial flour present in the river, such as the Dart and Rees rivers return some very high turbidity (and suspended sediment) levels despite the rivers being close to natural state. The Buckler Burn (Glenorchy) Invincible Creek (Rees Valley), Ox Burn (Rees Valley) and Timaru Creek (Hawea) are not glacial fed, but have very steep catchments which would be prone to erosion. Horn Creek is the other stream to have turbidity below the national bottom line, this is an urban stream in the heart of Queenstown and is likely affected by stormwater as well as avian wildlife stirring up the creek bed.

6.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state of water quality and aquatic ecosystem health at a site. Figure 5 summarises MCI scores for sites monitored for aquatic macroinvertebrates throughout the Upper Lakes Rohe.

The MCI interim scores are somewhat comparable across sites with seven of the nine monitored sites returning comparable MCI scores above 120; reflecting a macroinvertebrate community in 'good' condition. The exceptions are Bullock Creek and Motatapu which return MCI scores between 100 and 110; reflecting moderate nutrient enrichment. In a regional context the Upper Clutha Rohe generally show overall water and habitat quality supports the existence of healthy invertebrate communities. The ASPM interim scores shown in Figure 5 reflect those of the MCI scores for Bullock Creek, but Precipice Creek, despite having a B grade for MCI, obtains a 'C' grade for ASPM, which the NPSFM describes as *'a community with moderate to severe loss of ecological integrity'*.

6.1.5 Human health for recreation

Figure 5 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, Makoroa, Quartz Creek and the Rees returning bacterial water quality above the national bottom line. Bullock Creek has high background bacteria concentrations which indicates an *E. coli* source that is affecting water quality even under low flow conditions, such as water fowl often being present in the stream above the sampling location.

For the lakes, compliance is excellent across in the Upper Lakes Rohe, with all sites at all statistical tests obtaining an 'A' band.

6.2 Trend Analysis

Trend analysis results for the Upper Lakes Rohe is shown in Figure 8.

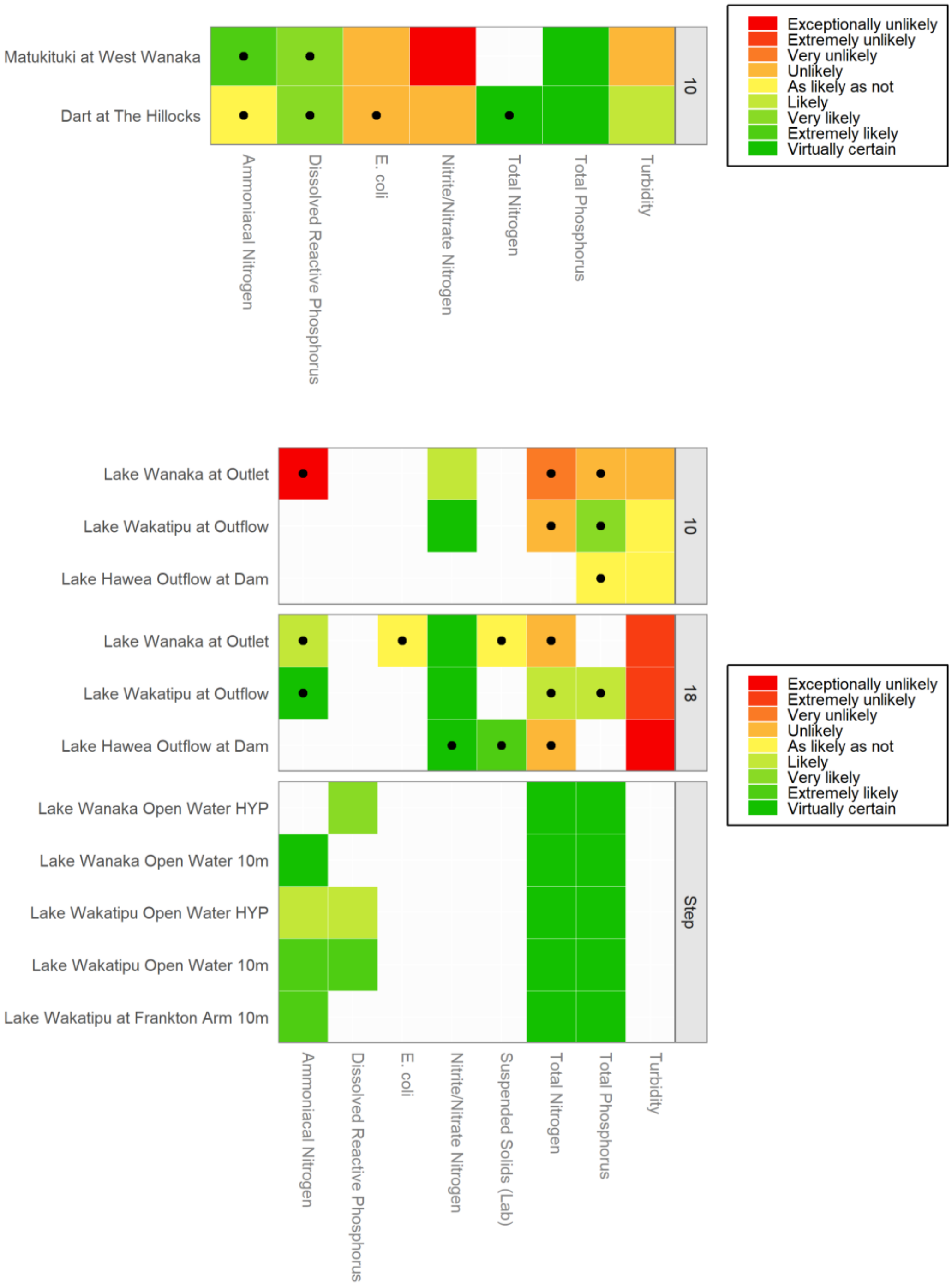


Figure 8 Summary of Upper Clutha sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2. Cells containing 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.

Results show that over a 10-year period the Dart at the Hillocks returned a 'virtually certain' (improving) trend for TP, but over the same period the Matukituki returned an 'exceptionally unlikely' improving trend for NNN.

Trend analysis for the Upper Lakes Rohe lakes is shown in Figure 8. NNN is 'virtually certain' to be improving from the outlets at Wakatipu, Wanaka and Hawea (over 18 years) and Wakatipu (over 10-years), turbidity is 'exceptionally unlikely' or 'extremely unlikely' to be improving at all three outflow sites (over 18 years).

For discontinuous data sets the two time-periods analysed were three complete years: 1 May 2006 to 30 April 2009, and 1 June 2017 to 31 May 2020. Most of the trends analysed were influenced by censored values (where true values are too low to be measured with precision) and have not been included. All sites had 'virtually certain' improving trends for TN as shown in Figure 8

6.3 Water quality summary and discussion: Upper lakes Rohe

The tables in this section summarise:

1) river and lake attribute states where the national bottom line is not met (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) all trends using raw data for rivers and continuous data for lakes over the two time-periods

Table 4 Summary of river state, where state does not meet the national bottom line cells are coloured red. No lake variables were below the national bottom line.

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Timaru Creek													
Rees River													
Quartz Creek													
Ox Burn													
Makarora River													
Invincible Creek													
Horn Creek													
Dart River													
Bullock Creek													
Buckler Burn													

Table 5 Summary of river sites (raw data) where trends are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
Dart at The Hillocks						
Total Nitrogen	57	BiMonth	10	0	Virtually certain	↑↑↑↑
Total Phosphorus	57	BiMonth	10	-0.0037	Virtually certain	↑↑↑↑
Matukituki at West Wanaka						
Ammoniacal Nitrogen	101	Month	10	0	Extremely likely	↑↑↑
Nitrite/Nitrate N	98	Month	10	0.0015	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	101	Month	10	-0.0008	Virtually certain	↑↑↑↑

Table 6 Summary lake sites where trends (continuous data) are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	Annual SenSlope	Trend Direction	Confidence	Descriptor
Lake Wakatipu at Outflow 10-year dataset							
Ammoniacal N	105	BiMonth	18	0	Decreasing	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	58	BiMonth	10	0.0008	Decreasing	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	105	BiMonth	18	0.0003	Decreasing	Virtually certain	↑↑↑↑
Turbidity	104	BiMonth	18	0.0106	Increasing	Extremely unlikely	↓↓↓
Lake Wanaka at Outlet 10-year dataset							
Ammoniacal N	60	BiMonth	10	0	Increasing	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	105	BiMonth	18	0.0008	Decreasing	Virtually certain	↑↑↑↑
Turbidity	105	BiMonth	18	0.0065	Increasing	Extremely unlikely	↓↓↓
Ammoniacal N	60	BiMonth	10	0	Increasing	Exceptionally unlikely	↓↓↓↓
Lake Hawea Outflow at Dam 10-year dataset							
Nitrite/Nitrate N	106	BiMonth	18	0	Decreasing	Virtually certain	↑↑↑↑
Turbidity	104	BiMonth	18	0.0120	Increasing	Exceptionally unlikely	↓↓↓↓
Lake Wakatipu at Outflow 18-year dataset							
Ammoniacal N	105	BiMonth	18	0	Decreasing	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	58	BiMonth	10	0.0008	Decreasing	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	105	BiMonth	18	0.0003	Decreasing	Virtually certain	↑↑↑↑
Turbidity	104	BiMonth	18	0.0106	Increasing	Extremely unlikely	↓↓↓
Lake Wanaka at Outlet 18-year dataset							
Ammoniacal N	60	BiMonth	10	0	Increasing	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	105	BiMonth	18	0.0008	Decreasing	Virtually certain	↑↑↑↑
Turbidity	105	BiMonth	18	0.0065	Increasing	Extremely unlikely	↓↓↓

Table 7 Summary of trends using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend	3	1	2	1					1
Rivers - 20-year trend									
Lakes – 10-year trend	1		1	1		3	1		1
Lakes – 18 year trend	4	1		3		2		2	1

Water quality is best at 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.

In the Upper Lakes Rohe water quality is generally very good, as it should be. Of the NOF attribute state, the Rees and Dart are below the national bottom line for turbidity, but this is a natural state due to glacial melt-water. Despite very good compliance with the *E.coli* attribute, four sites are below the national bottom line; Bullock Creek is an urban stream running through the Wanaka township with a large population of wildfowl, these and stormwater are likely to be the reason behind the poor grade. The Makarora and Rees are large rivers, with catchment areas largely in national parks. It is likely that the poor water quality is very localised, and possibly reflects the quality of tributaries running over the flats. The same can be said for Quartz Creek that runs over the flats before entering Lake Wanaka. The only other 'D' band was for periphyton in Bullock Creek. The lakes achieved attribute 'A' bands for all parameters assessed.

For trends, only the Dart and Matukituki have been monitored for a sufficiently long time-period for trend analysis to be undertaken. Perhaps the most worrying trend is NNN has shown an increase over the last 10-years in the Matukituki. Trend analysis in the lakes shows that TN has 'virtually certain' improving trends in the outlets of both Wakatipu and Wanaka, however turbidity is almost certainly degrading in Hawea and Wanaka.

Table 6 and Table 7 only show sites with 99%, 95% ,1% and 5% confidence levels. These equate to the 'virtually certain', 'extremely likely', 'exceptionally unlikely' and extremely unlikely' categories. It is important to note when sites have a zero sen slope alongside a reasonably high-level of confidence in trend direction, at these sites 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 Upper Lakes Rohe, there are a lot of sites with a zero sen slope, highlighting how low the concentrations of most analytes are in this region.

As stated previously, having accurate information on changes in land use and land management practice would help in identifying drivers of change evident with some water quality variables. The reasons for this are unclear as ORC do not collect any information on changes in land use or land management practices that would allow for confident assessment of drivers of turbidity or NNN in our waterways.

In summary; for the majority of sites across the Upper Clutha reporting region, water quality is excellent and the best in Otago;

- All sites return an 'A' band for the toxicity attribute states of ammonia and nitrate
- Nutrient concentrations stimulating algae growth low, other than in Bullock Creek where periphyton (chlorophyll *a*) is below the national bottom line.
- Bacterial water quality is excellent across all sites, with the exception of Bullock Creek, the Rees, the Makaroa and Quartz Creek; which are below the national bottom line.
- Clarity (suspended sediment) is only elevated in rivers fed by glaciers.
- Macroinvertebrate scores reflect the low nutrient and scarce food source (periphyton) content of rivers with scores in the 'B' or 'C' band.
- Trend analysis for rivers showed an 'exceptionally unlikely' improving for NNN in the Matukituki River and 'virtually certain' improving trend for TP in the Dart and Matukituki
- Trend analysis for lakes showed the outlets of Lakes Hawea, Wanaka and Wakatipu had 'exceptionally unlikely' or 'extremely unlikely' improving trends for turbidity, but 'virtually certa certain' improving trends for NNN.

7 Dunstan Rohe (Clutha Matu/Au FMU)

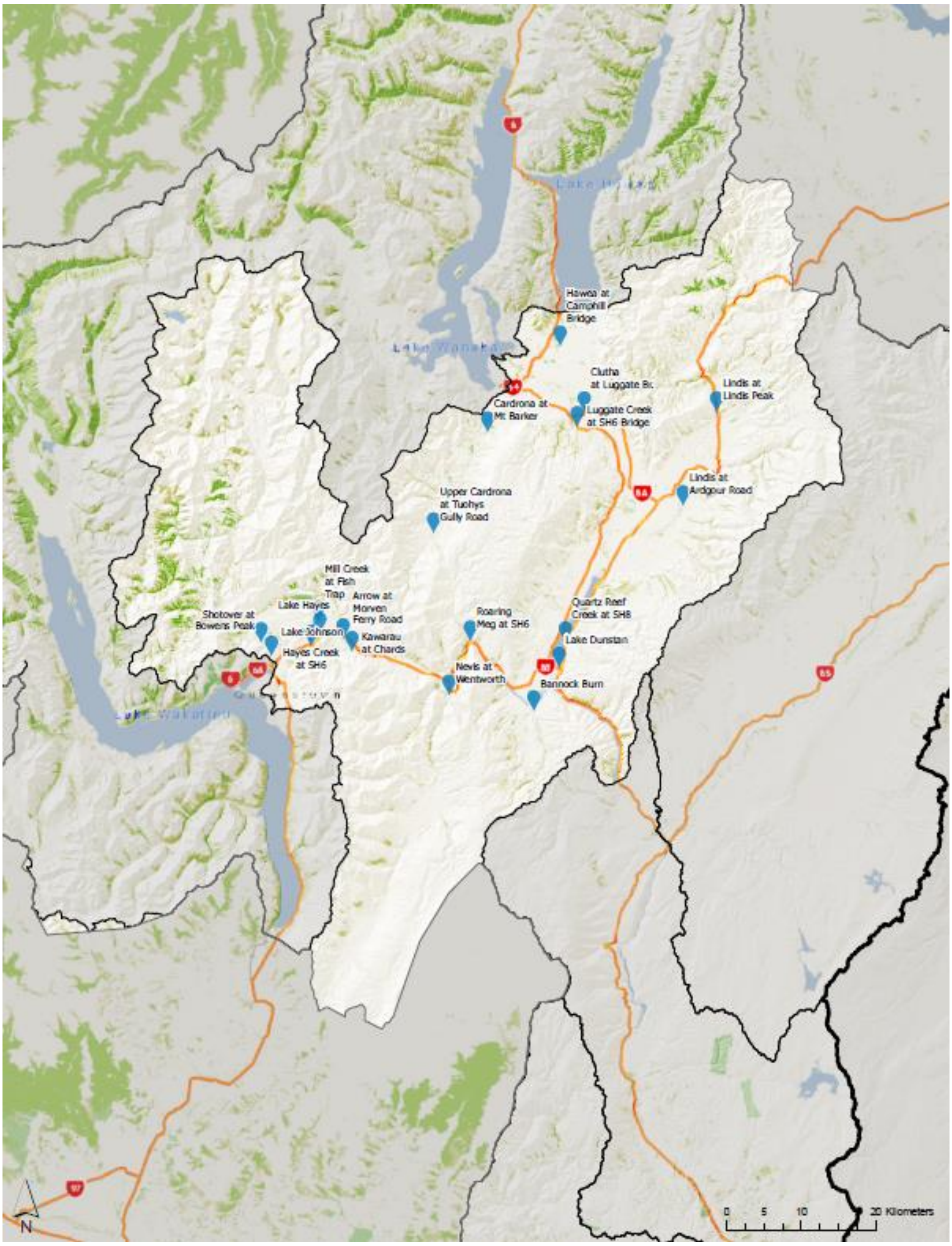


Figure 9 Location of water quality monitoring sites in the Dunstan Rohe

7.1 State Analysis Results

The results of grading the SoE sites in the Dunstan Rohe according to the NPSFM NOF criteria are summarised in Figure 10 and Figure 11 and mapped in Figure 12. Many sites in the Dusntan Rohe 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.

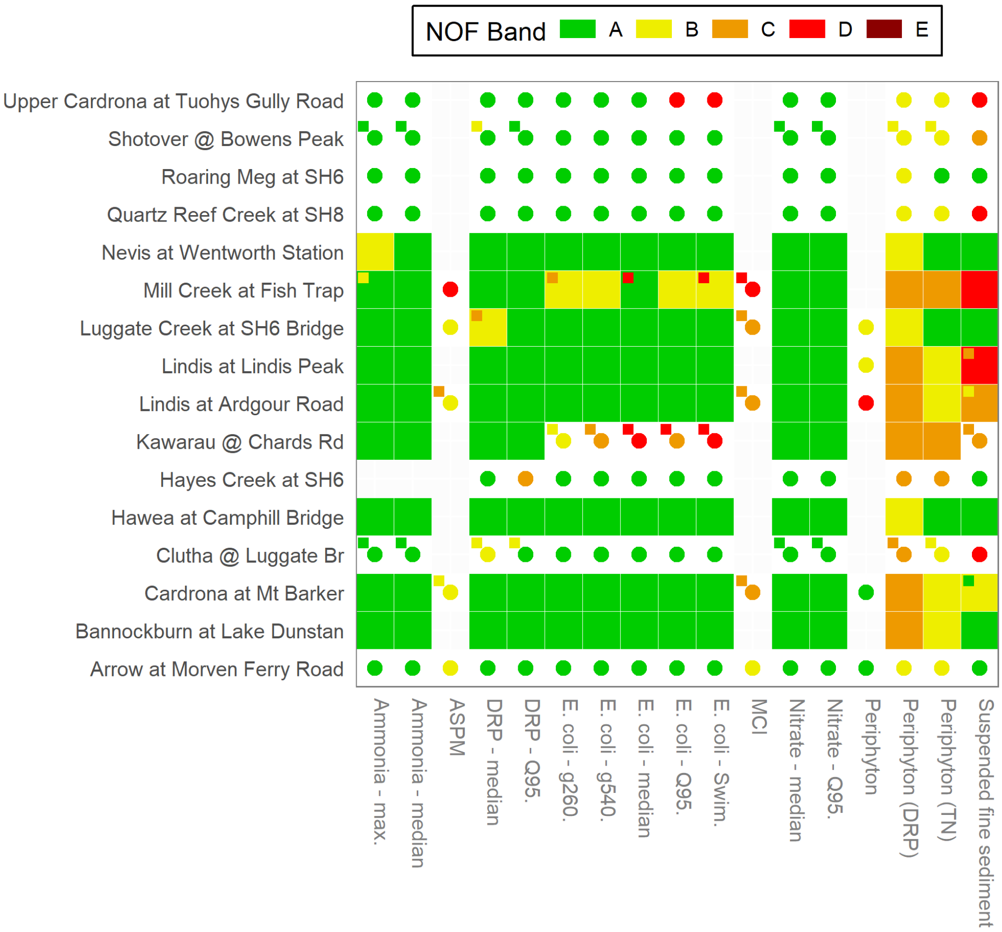


Figure 10 Grading of the river sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

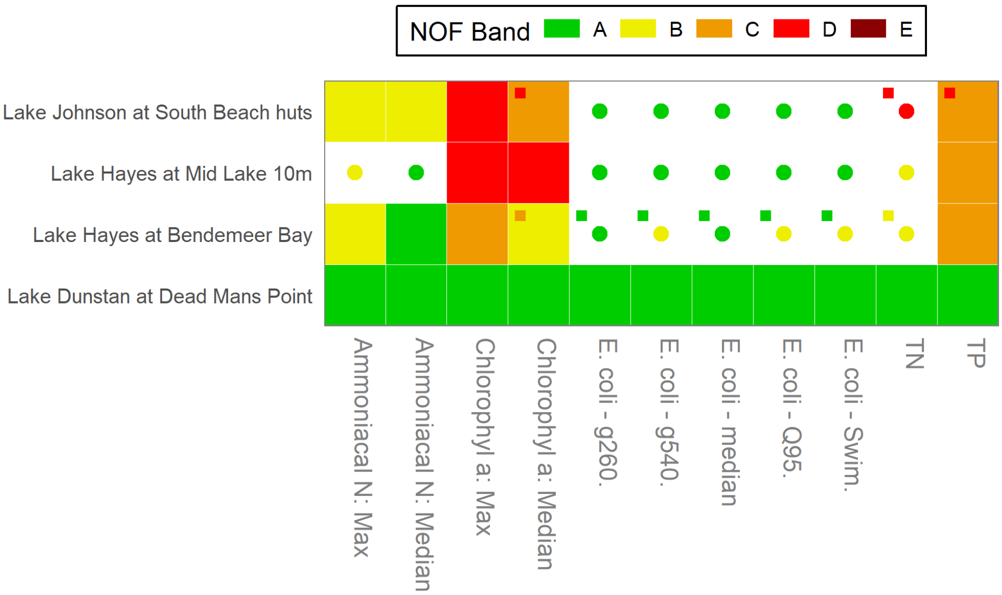


Figure 11 Grading of the lake sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

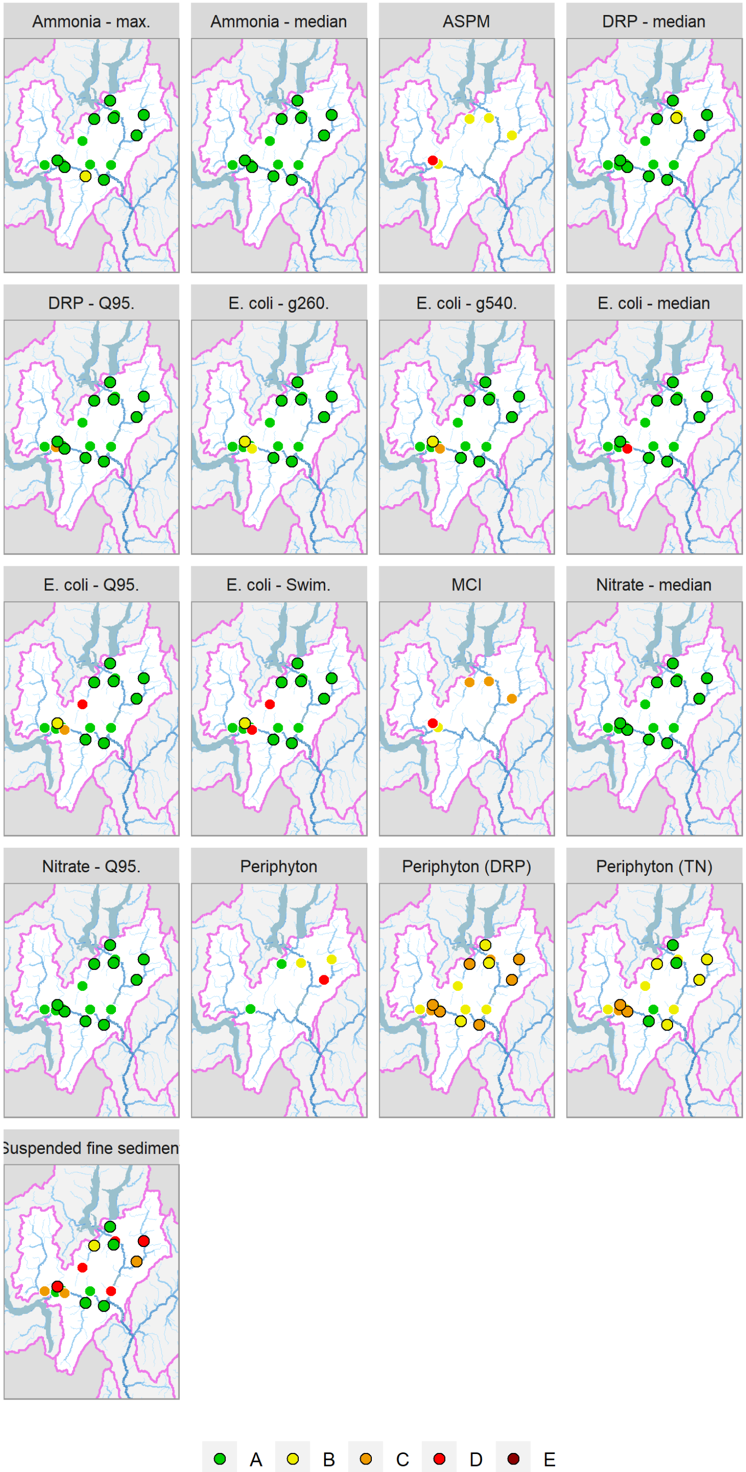


Figure 12 Maps showing Dunstan Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

7.1.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 12 (periphyton). The Dunstan Rohe returns a mixed bag of attribute bands for periphyton, the Arrow and Cardrona have an interim 'A' band as few results exceed 50 chl-*a*/m^2 meaning that blooms would be rare, reflecting negligible nutrient enrichment. The Lindis at Lindis Peak and Luggate Creek record interim 'B' bands and the Lindis at Ardgour Road, towards the bottom of the Lindis catchment has an interim result of 'D', below the national bottom line, this reflects a higher nutrient enrichment and the possibility of regular nuisance blooms

Figure 12 shows the MfE (2020) DRP and TN concentrations to manage the NPSFM periphyton attribute state (periphyton DRP and periphyton TN). Using the 20% exceedance criteria (mid-range), the TN median concentrations in the Dunstan Rohe are generally in the T120 mg chl-a/m2 band (or band 'B'), as would be expected in a low nutrient environment. The outliers are Hayes Creek, which is influenced by high nutrient concentrations in Lake Hayes, the Kawarau River and Mill Creek all of which are placed in band 'C'. The Hawea River, Nevis and Luggate Creek have low median TN concentrations and are graded as band 'B'. Median cocentrations of DRP place all sites in the 'B' or 'C' band.

Figure 12 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Dunstan Rohe show that every site achieves a band 'A', other than Luggate Creek and the Clutha at Luggate Bride which achieve a band 'B' and the noticeable outlier, Hayes Creek which achieves band 'C', due to receiving nutrient rich water from Lake Hayes. The NPSFM 2020 describes Band 'C' as *'Ecological ommunities are 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'.*

Results for the lakes are also shown in Figure 12. Trophic status is a common method for describing the health of lakes and an indicator of how much growth or productivity occurs in the lake, productivity being 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 NPSFM 2020 describes how phytoplankton affects lake ecological communities. If the chlorophyll a concentration are in the 'A' band, then '*Lake ecological communities are healthy and resilient, similar to natural reference conditions'*. Figure 12 shows that this is the case forLake Dunstan, but Lake Hayes (10m) and Lake Johnson achieve a 'D' band and Lake Hayes (Bendemeer Bay) achieves a 'C' band. The results for total nitrogen and total phosphorus are also shown in Figure 12, Lake Dunstan achieves 'A' bands reflecting low levels of total nutrients indicating that associated ecological communities are healthy and resilient, but Lake Johnson and Lake Hayes have higher concentrations of TN and TP. Lake Johnson falls below the national bottom line for TN achieving a 'D' band.

7.1.2 Toxicants

NOF attribute bands for NH_4N and nitrate (measured as NNN) toxicity are shown in Figure 12, the results for rivers show excellent protection levels against toxicity risk for nearly all Dunstan Rohe SoE monitoring sites, with all sites bar one (Nevis) returning an 'A' band for NH_4N and all sites returning an 'A' band (highest level of protection) for NNN. For lakes, Lake Johnson and Lake Hayes return 'C' bands and Lake Dunstan an 'A' band.

7.1.3 Suspended fine sediment (Rivers)

The clarity results for the Dunstan Rohe are shown in Figure 12. Six sites return an ‘A’ band which the NPSFM describes as having ‘*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions’* (NPSFM, 2020). Five sites return a ‘D’ band; the Upper Cardrona, Quartz Creek, Mill Creek, Lindis at Lindis Peak and the Clutha at Luggate.

7.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state of water quality and aquatic ecosystem health at a site. Figure 12 summarises MCI scores for sites monitored for aquatic macroinvertebrates throughout the Dunstan Rohe.

The MCI interim scores are somewhat comparable across sites with three of the five monitored sites returning MCI scores between 100 and 110; reflecting a macroinvertebrate community indicative of moderate organic pollution or nutrient enrichment. The exceptions are the Arrow River which returns a MCI score of 119 reflecting ‘good’ water quality and Mill Creek which returns an MCI score of 85, which is below the national bottom line. The poor score at Mill Creek would be indicative of severe organic pollution or nutrient enrichment as well as poor habitat quality.

The ASPM interim scores shown in Figure 12 reflect those of the MCI scores for the Arrow River and Mill Creek, but the other sites despite having a ‘C’ grade for MCI, obtain a ‘B’ grade for ASPM, which the NPSFM describes as ‘a community with mild to moderate loss of ecological integrity’.

7.1.5 Human health for recreation (Rivers)

Figure 12 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.

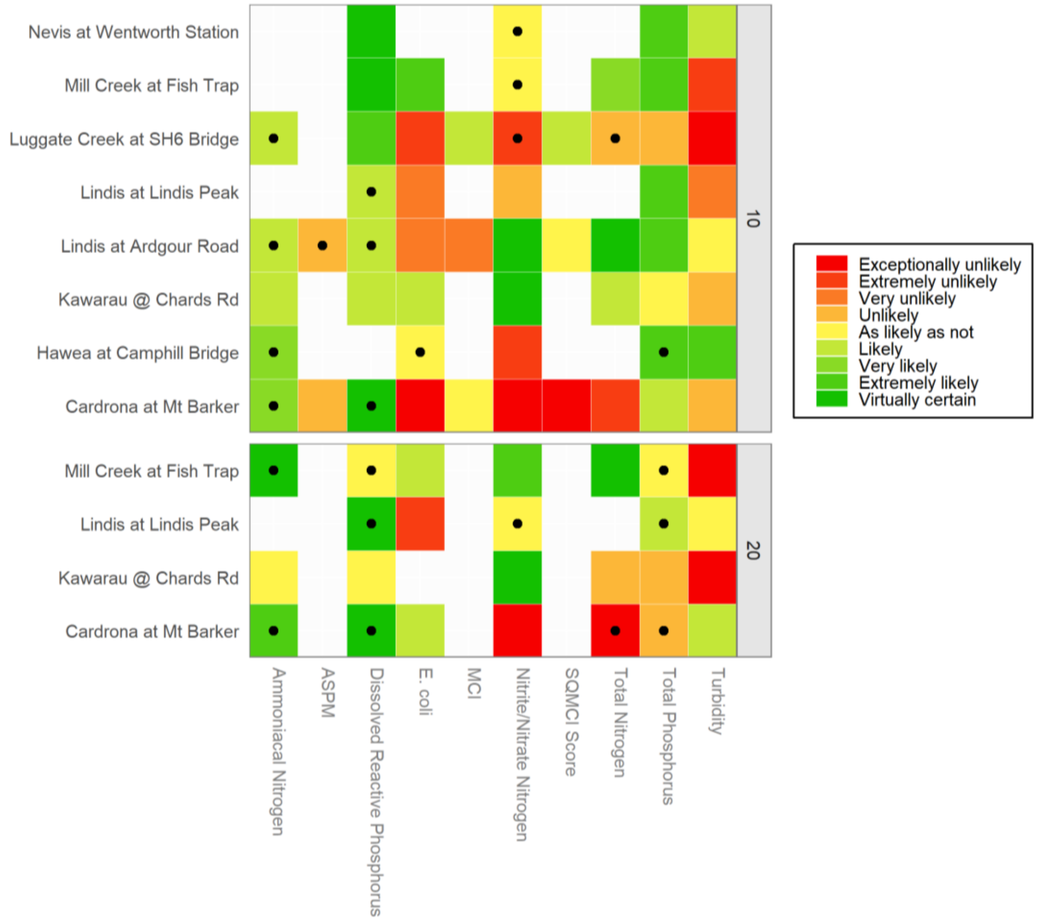
Compliance is generally excellent across in the Dunstan Rohe, with all sites other than the Kawarau and the Upper Cardrona having bacterial water quality above the national bottom line.

Figure 10 shows 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, as it only has 21 samples over 3 years. It is unknown what this upper catchment site would return as a 95th percentile over required the time-period. The Kawarau also does not meet minimum sample requirements, but does returns of the four statistical tests, two return a ‘C’ grade, one a ‘B’ grade and one a ‘D’ grade.

For lakes, Figure 11 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. Compliance is excellent across all lakes in the Dunstan Rohe, only Lake Hayes at Bendermeer Bay achieves a ‘B’ band, all other sites at all statistical tests obtain an ‘A’ grade.

7.2 Trend Analysis

Trend analysis results for the Dunstan Rohe is shown in Figure 13



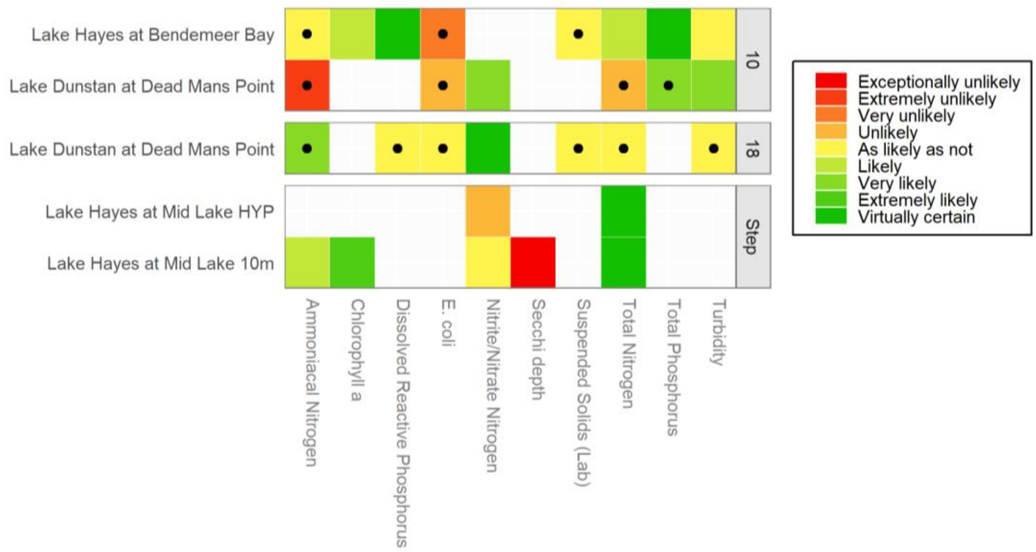


Figure 13 Summary of Dunstan Rohe sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2. Cells containing 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 most of the trends analysed were influenced by censored values, where true values are too low to be measured with precision, this is shown by the black dot in Figure 13. Over a 10-year time-period the Cardrona has the four variables (*E.coli*, NNN, TN and SQMCI) that shows 'exceptionally unlikely' or 'extremely unlikely' improving trends. Over the same time-period, Luggate Creek has five 'very unlikey' or 'extremely unlikely' improving trends and the Lindis at Ardgour Road has three 'unlikely' or 'very unlikey' improving trends. Over a 20-year time-period, the Cardrona shows the same 'exceptionally unlikely' or 'extremely unlikely' improving trends for TN and NNN, and Mill Creek and the Kawarau have an 'exceptionally unlikely' improving trend for turbidity.

Trends for the lake data ranged across the board from 'virtually certain' to 'exceptionally unlikely' improvements in most variables. The most notable trends are that over 10-years the lake data shows one 'exceptionally unlikely' improving trend for NH_4N at Lake Dunstan and that Lake Hayes has 'virtually certain' improving trends for DRP and TP. The step dataset shows that secchi depth was 'exceptionally unlikely' to be improving in Lake Hayes.

7.3 Water quality summary and discussion: Dunstan Rohe

The tables in this section summarise:

1) river and lake sites where attributes where the national bottom line is not met (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) all trends using raw data for rivers and continuous data for lakes over the two time-periods

Table 8 Summary of river and lake state, red cells show where state does not meet the national bottom line in one or more variable

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Upper Cardrona						■							■
Quartz Reef Creek													■
Mill Creek			■				■						■
Lindis at Peak													■
Kawarau at Chards						■							
Clutha at Luggate													■

	NH_4N - *max*	NH_4N - *median*	*Chlorophyll a -max*	*Chlorophyll a median*	*E.coli Overall*	*TN*	*TP*
Lake Johnson at South Beach huts			■				
Lake Hayes at Mid Lake 10m			■	■			

Table 9 Summary of river sites where trends are greater than 'likely' or 'unlikely' (raw data). Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	Annual SenSlope	Trend Direction	Confidence	Descriptor
Cardrona at Mt Barker							
Ammoniacal Nitrogen	119	BiMonth	20	0	Decreasing	Extremely likely	↑↑↑
Dissolved Reactive P	99	Month	10	0	Decreasing	Virtually certain	↑↑↑↑
Dissolved Reactive P	115	BiMonth	20	0	Decreasing	Virtually certain	↑↑↑↑
E. coli	100	Month	10	3.1637	Increasing	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	100	Month	10	0.0050	Increasing	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	118	BiMonth	20	0.0016	Increasing	Exceptionally unlikely	↓↓↓↓
SQMCI Score	9	Year	10	-0.4844	Decreasing	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	99	Month	10	0.0019	Increasing	Extremely unlikely	↓↓↓
Total Nitrogen	118	BiMonth	20	0	Increasing	Exceptionally unlikely	↓↓↓↓
Hawea at Camphill Bridge							
Nitrite/Nitrate N	100	Month	10	0.0002	Increasing	Extremely unlikely	↓↓↓
Total Phosphorus	99	Month	10	0	Decreasing	Extremely likely	↑↑↑
Turbidity	100	Month	10	-0.0122	Decreasing	Extremely likely	↑↑↑
Kawarau @ Chards Rd							
Nitrite/Nitrate N	98	Month	10	-0.0009	Decreasing	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	218	Month	20	-0.0004	Decreasing	Virtually certain	↑↑↑↑
Turbidity	218	Month	20	0.04331	Increasing	Exceptionally unlikely	↓↓↓↓
Lindis at Ardgour Road							
Nitrite/Nitrate N	105	Month	10	-0.0055	Decreasing	Virtually certain	↑↑↑↑
Total Nitrogen	104	Month	10	-0.0108	Decreasing	Virtually certain	↑↑↑↑
Total Phosphorus	103	Month	10	-0.0005	Decreasing	Extremely likely	↑↑↑
Lindis at Lindis Peak							
Dissolved Reactive P	98	BiMonth	20	0	Decreasing	Virtually certain	↑↑↑↑
E. coli	102	BiMonth	20	0.5339	Increasing	Extremely unlikely	↓↓↓
Total Phosphorus	58	BiMonth	10	-0.0006	Decreasing	Extremely likely	↑↑↑
Luggate Creek at SH6 Bridge							
Dissolved Reactive P	58	BiMonth	10	-0.0002	Decreasing	Extremely likely	↑↑↑
E. coli	100	Month	10	1.5020	Increasing	Extremely unlikely	↓↓↓
Nitrite/Nitrate N	41	Qtr	10	0	Increasing	Extremely unlikely	↓↓↓
Turbidity	100	Month	10	0.0429	Increasing	Exceptionally unlikely	↓↓↓↓
Mill Creek at Fish Trap							
Ammoniacal Nitrogen	79	Qtr	20	0	Decreasing	Virtually certain	↑↑↑↑
Dissolved Reactive P	98	Month	10	-0.0004	Decreasing	Virtually certain	↑↑↑↑
E. coli	98	Month	10	-3.7270	Decreasing	Extremely likely	↑↑↑
Nitrite/Nitrate N	116	BiMonth	20	-0.0028	Decreasing	Extremely likely	↑↑↑
Total Nitrogen	98	Month	10	-0.0034	Decreasing	Very likely	↑↑
Total Nitrogen	116	BiMonth	20	-0.0066	Decreasing	Virtually certain	↑↑↑↑
Total Phosphorus	99	Month	10	-0.0006	Decreasing	Extremely likely	↑↑↑
Turbidity	99	Month	10	0.1171	Increasing	Extremely unlikely	↓↓↓
Turbidity	115	BiMonth	20	0.0671	Increasing	Exceptionally unlikely	↓↓↓↓
Nevis at Wentworth Station							
Dissolved Reactive P	35	Qtr	10	-0.0005	Decreasing	Virtually certain	↑↑↑↑
Total Phosphorus	35	Qtr	10	-0.0004	Decreasing	Extremely likely	↑↑↑

Table 10 Summary lake sites where trends (continuous data) are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	Annual SenSlope	Trend Direction	Confidence	Descriptor
Lake Dunstan at Dead Mans Point							
Ammoniacal N	60	BiMonth	10	0	Increasin	Extremely unlikely	↓↓↓
Nitrite/Nitrate N	107	BiMonth	18	-0.0006	Decreasin	Virtually certain	↑↑↑↑
Lake Hayes at Bendemeer Bay							
Dissolved Reactive P	48	BiMonth	10	-0.0010	Decreasin	Virtually certain	↑↑↑↑
Total Phosphorus	48	BiMonth	10	-0.0018	Decreasin	Virtually certain	↑↑↑↑

Table 11 Overall summary of trends for the Dunstan Rohe using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2.

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descsriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend	6	8	3	12	7	7	4	5	4
Rivers - 20-year trend	5	2		4	6	3		1	4
Lakes – 10-year trend	1		3	2	3	2	1	3	
Lakes – 20-year trend	1		1		5				

In the Dunstan Rohe compliance with NPSFM NOF attribute states is generally very good. Table 8 shows that few sites have variables with NOF bands below the national bottom line.

In Table 9 and Table 10 only sites with 99%, 95% ,1% and 5% confidence levels are shown. These equate to the 'virtually certain', 'extremely likely', 'exceptionally unlikely' and extremely unlikely' categories. It is important to note when sites have a zero sen slope alongside a reasonably high-level of confidence in trend direction, at these sites 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 Dunstan Rohe, these sites include NH_4-N at Lake Dunstan, Cardrona and Mill Creek; DRP at Cardrona and Lindis at Peak; TN at Cardrona; TP at Hawea and NNN at Luggate Creek.

The Cardrona River had the most disturbing amount of 'exceptionally unlikely' or 'extremely unlikely' improving trends, including *E.coli*, TN, NNN and SQMCI. The NNN may be linked to slightly enriched groundwater contributing to surface flows in the lower reaches, possibly due to increasingly intensive land-use asociated with irrigation in the lower Cardrona. The SQMCI trend is based on fewer (i.e., only annual) observations, however confidence the Sen slope is quite large (-0.4 /yr). The other 'exceptionally unlikely' or 'extremely unlikely' improving trends include turbidity (Mill Creek, Luggate Creek and Kawarau) and NNN (Luggate Creek).

Mill Creek has improving trends in DRP, *E.coli*, NNN, TN and TP. This is good news for a catchment with increasing development pressure, however the degrading trend in turbidity suggests that land disturbance, either naturally from the Crown Range or from localised development is impacting on the Creek. The good news is that despite increasing turbidity in Mill Creek, TP (which is often bound to sediment) is 'virtually certain' to be improving in Lake Hayes.

It is difficult to assess why these trends have occurred, particularly as there is no accurate information on changes in land use and land management practice would help in identifying drivers of change evident with some water quality variables.

In summary; for the majority of sites across the Dunstan Rohe, water quality is excellent;

- All sites, other than the Nevis return an 'A' band for the toxicity attribute state of ammonia. All sites return an 'A' band for the toxicity attribute state of nitrate
- Periphyton (chlorophyll *a*) at the lower Lindis site achieves a 'D' band, despite achieving 'A' bands for NNN and DRP nutrient concentrations.
- Bacterial water quality is excellent across most sites, other than the Upper Cardrona and Kawarau which both achieve a 'D' band .
- ASPM scores were generally 'B' band, with Mill Creek a 'D' band. MCI scores were generally 'C' bands with Mill Creek a 'D' band.
- Trend analysis showed 'exceptionally unlikely' improving trends for the Cardrona River (*E.coli*, NNN, SQMCI) and Luggate Creek (*E.coli*, NNN, turbidity)
- 'Virtually certain' improving trends were seen in Mill Creek (DRP, TP)

8 Manuherekia Rohe (Clutha Matu/Au FMU)

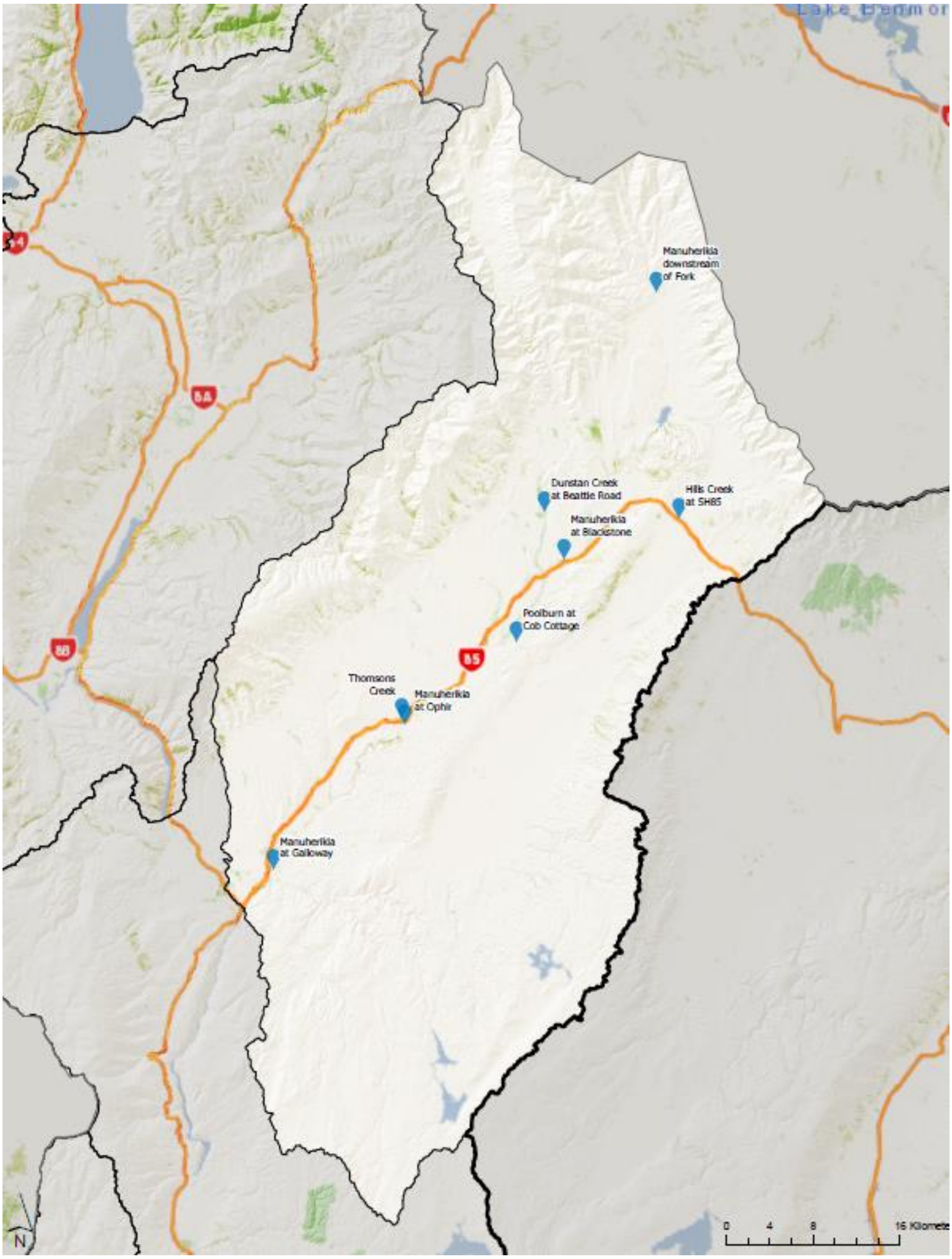


Figure 14 Location of water quality monitoring sites in the Manuherekia Rohe

8.1 State Analysis Results

The results of grading the SoE sites in the Manuherekia Rohe according to the NPSFM NOF criteria are summarised in Figure 15 and mapped in Figure 16. Many sites in the Manuherekia Rohe 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.

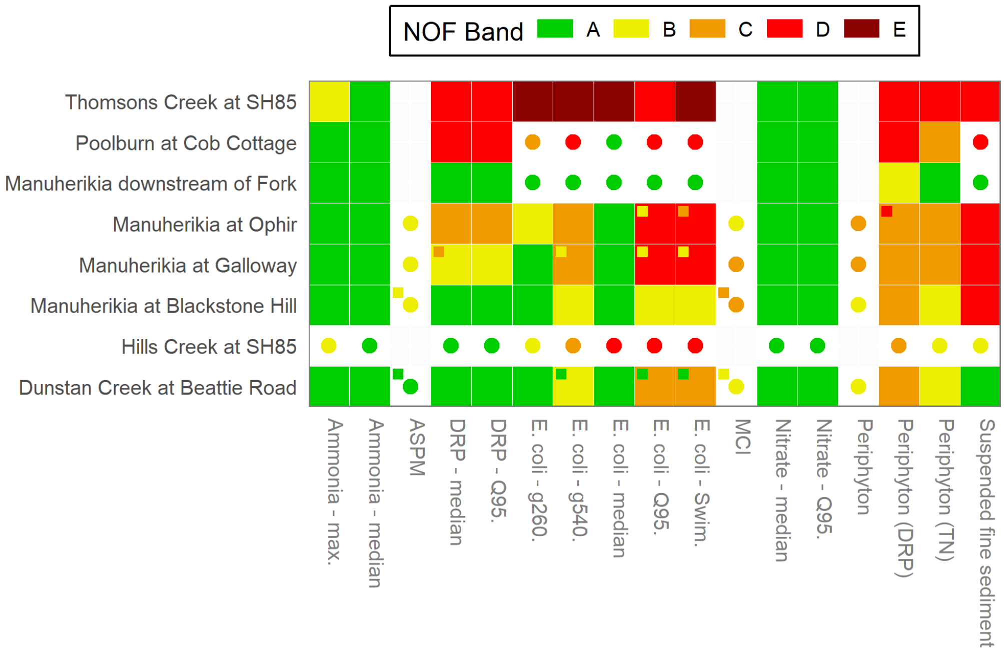


Figure 15 Grading of the river sites of the Manuherekia Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

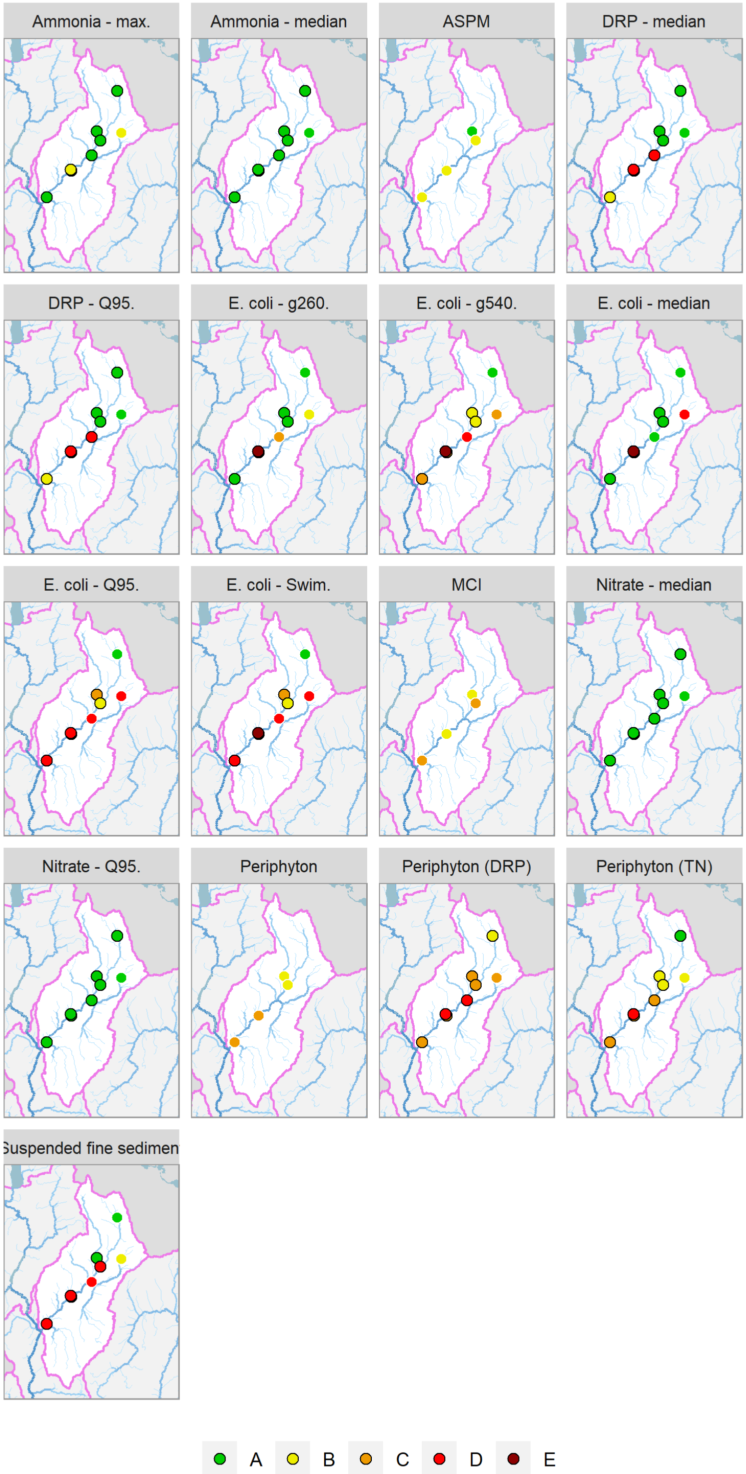


Figure 16 Maps showing Manuherekia Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

8.1.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 15 (periphyton). Dunstan Creek and Manuherekia at Blackstone Hill are likely to be in attribute band 'B' as few results exceed 120 chl-*a*/m2. Results from the Manuherika at Ophir and Galloway show that no results are >200 mg chl-*a*/m2, but many individual results have Chla > 120 chl-*a*/m2. It is likely that these sites will fall into attribute band 'C'. There is an increase in algae in the lower Manuherekia, compared to the two sites in the upper Manuherekia (Dunstan Creek and Blackstone Hill). Figure 15 shows the MfE (2020) DRP and TN concentrations to manage the NPSFM periphyton attribute state (periphyton DRP and periphyton TN). The upper catchment has lower median concentrations of TN placing Manuherekia d/s Forks in the 'A' band and Dunstan Creek, Hills Creek and Blackstone in the 'B' band. Ophir and Galloway have higher TN concentrations and fall into the 'C' band. The tributaries (Poolburn and Thomsons Creek) show a much higher median concentration, accordingly their TN band is 'D'.

The median concentration of DRP in Thomsons Creek and Poolburn is high, they have been allocated a 'D' band status. The Manuherekia d/s Fork and Hills Creek have the lowest DRP median concentration and fall in the 'B' band at 20% exceedance, all the other sites are allocated a 'C' band status for DRP at 20% exceedance.

Figure 16 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Dunstan Rohe show that Thomsons Creek and the Poolburn achieve a 'D' band which is below the national bottom line, the NPSFM 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'*.

All other sites other than the lower Manuherekia main-stem (Ophir and Galloway) achieve a band 'A'. The NPSFM 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'*

8.1.2 Toxicants

NOF attribute bands for N NH_4-N and nitrate (measured as NNN) toxicity are shown in Figure 16, the results show excellent protection levels against toxicity risk. All sites other than Hills Creek and Thomsons Creek return an 'A' band for NH_4-N and all sites returning an 'A' band (highest level of protection) for NNN.

8.1.3 Suspended fine sediment (Rivers)

The clarity results for the Manuherekia Rohe are shown in Figure 16. Five sites return a NOF band of 'D' which the NPSFM 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. Historical gold mining tailings in the area below Falls Dam are likely to elevate suspended solid concentrations in the main-stem Manuherekia during higher flows.

8.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state of water quality and aquatic ecosystem health at a site. Figure 16 summarises MCI scores for the Manuherekia. Dunstan Creek and Manuherekia at Ophir achieve a band 'B' for MCI whilst the Manuherekia at Blackstone and the Manuherekia at Galloway achieve a 'C' band, returning MCI scores between 100 and 110; this reflects a macroinvertebrate community indicative of moderate organic pollution or nutrient enrichment.

The ASPM interim NOF bands shown in Figure 15 reflect those of the MCI scores, Dunstan Creek and the Manuherekia at Blackstone obtain band 'B' for ASPM, which the NPSFM describes as 'a community with mild to moderate loss of ecological integrity' and the two other mainstem Manuherekia sites achieve a 'C' band.

8.1.5 Human health for recreation (Rivers)

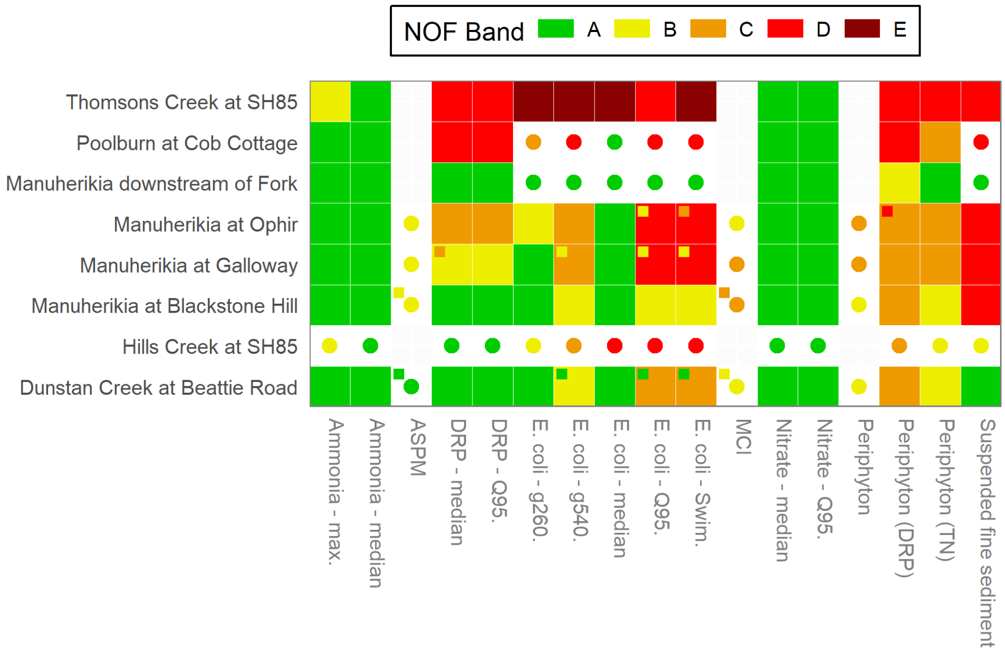


Figure 15 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading with the national bottom line being a 'D' band.

The *E.coli* grades 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 (NPSFM, 2020). Thomsons Creek, Hills Creek, the Poolburn and Ophir and Galloway in the lower Manuherekia fall below the national bottom line with the attribute band either a '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.

8.2 Trend Analysis

Trend analysis results for the Manuherekia Rohe is shown in Figure 17

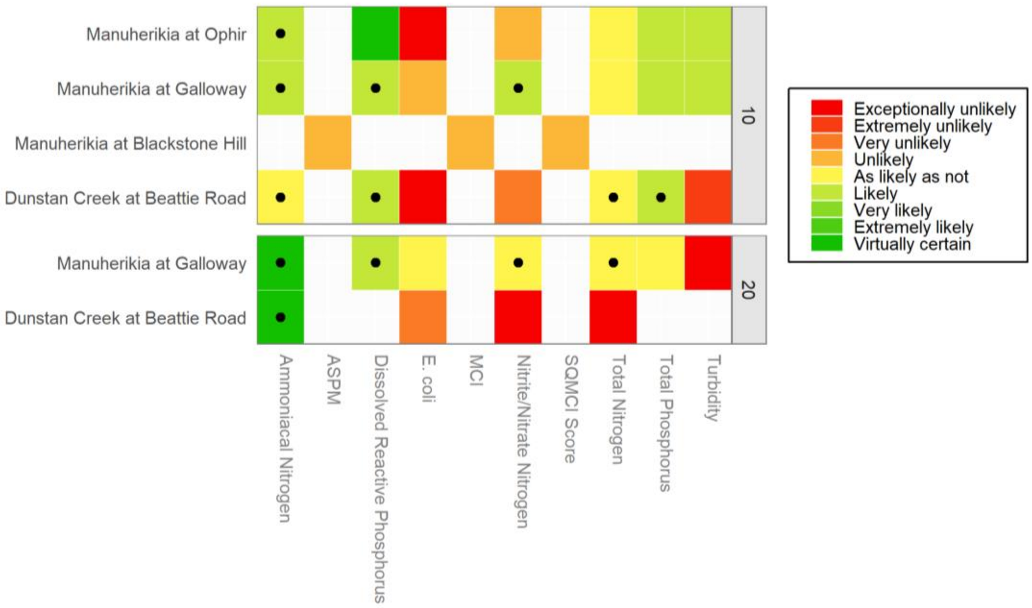


Figure 17 Summary of Upper Clutha sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined inTable 2. Cells containing 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.

Dunstan Creek has the largest number of trends showing 'exceptionally unlikely' or 'extremely unlikely' improvement. These include *E.coli* (Figure 18), NNN and turbidity over a 10-year period and *E.coli*, NNN and TN over a 20-year period. Other trends include an 'exceptionally unlikely' improving trend for *E.coli* at Ophir (over 10-years).

There are three sites with 'virtually certain' or 'extremely likely' improving trends, NH_4-N at Dunstan Creek and Galloway and DRP at Ophir.

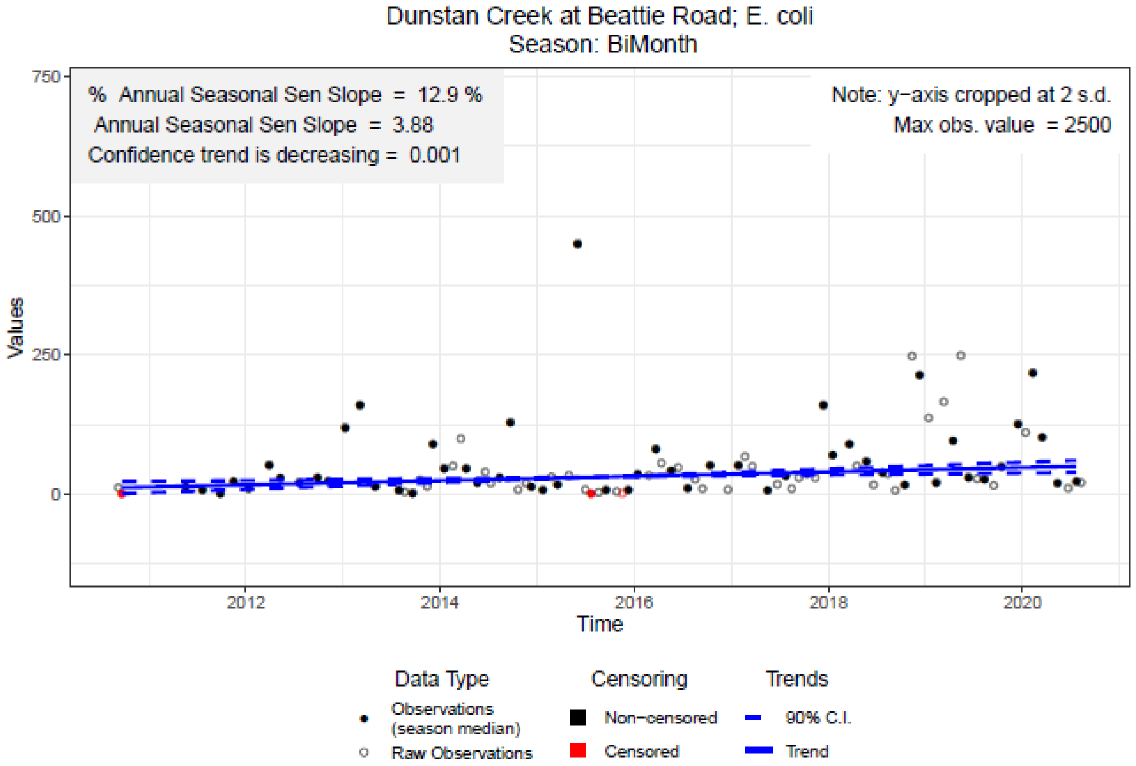


Figure 18 Dunstan Creek, E.coli is 'exceptionally unlikely' to be improving (over 10-years)

8.3 Water quality summary and discussion: Manuherekia Rohe

The tables in this section summarise:

1) river sites where the national bottom line is not met (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) all trends using raw data for rivers

Table 12 Summary of river, red cells show where state does not meet the national bottom line in one or more variable. There is no national bottom line for DRP, but DRP (median and Q95) have been included in the table when sites achieve a band 'D'.

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Thomsons Creek at SH85													
Poolburn at Cob Cottage													
Manuherekia d/s Fork													
Manuherekia at Ophir													
Manuherekia at Galloway													
Manuherekia at													
Hills Creek													
Dunstan Creek													

Table 13 Summary of river sites where trends are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
Dunstan Creek at Beattie Road						
Ammoniacal N	67	Qtr	20	0	Virtually certain	↑↑↑↑
E. coli	57	BiMonth	10	3.875332	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	67	Qtr	20	0.002833	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	67	Qtr	20	0.003444	Exceptionally unlikely	↓↓↓↓
Turbidity	56	BiMonth	10	0.036977	Extremely unlikely	↓↓↓
Manuherekia at Galloway						
Ammoniacal N	118	BiMonth	20	0	Virtually certain	↑↑↑↑
Turbidity	118	BiMonth	20	0.059861	Exceptionally unlikely	↓↓↓↓
Manuherekia at Ophir						
Dissolved Reactive P	101	Month	10	-0.00072	Virtually certain	↑↑↑↑
E. coli	101	Month	10	8.899505	Exceptionally unlikely	↓↓↓↓

Table 14 Overall summary of trends for the Manuherekia Rohe using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend	1			10	4	4	1	1	2
Rivers - 20-year trend	2			1	4	1		3	

In the Manuherekia Rohe state analysis identified that upstream of Falls Dam water quality was generally very good and achieved the NPSFM attribute band 'A' for all attributes measured. For periphyton the mainstem upper Manuherekia (Blackstone Hill) and Dunstan Creek achieved attribute band 'B', but in the lower Manuherekia (Galloway and Ophir) this dropped to attribute band 'C'. For *E.coli* the upper Manuherekia achieved attribute band 'B'/'C' but the lower Manuherekia main-stem and all tributaries achieved an attribute band 'D', placing them below the national bottom line.

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 run-off (from rainfall/irrigation) can transport soil and associated bacteria and nutrients to the nearest watercourse, contributing to poor water quality. The poor water quality in Thomsons Creek is likely replicated across all Creeks originating in the Dunstan Mountains, water quality becomes poorer as these tributaries flow over productive farmland towards the Manuherekia.

Across the Manuherekia Rohe there are a number of sites with degrading water quality trends, as shown in Table 13. Tributary sites which have 'state' below the national bottom line are likely contributing to the degrading trends in the main-stem. At Ophir an 'exceptionally unlikely' improving trend for *E.coli* was identified, but trends in Dunstan Creek were degrading for *E.coli*, NNN and turbidity (10-years) and *E.coli,* NNN and TN (over 20-years).

In Table 13 only sites with 99%, 95% ,1% and 5% confidence levels are shown. These equate to the 'virtually certain', 'extremely likely', 'exceptionally unlikely' and extremely unlikely' categories. It is important to note when sites have a zero sen slope alongside a reasonably high-level of confidence in trend direction, at these sites 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 Manuherekia Rohe, these sites include NH_4-N at Dunstan Creek and Manuherekia at Galloway.

In summary:

- Bacterial water quality is excellent in the Manuherekia above Falls Dam, concentrations increase downstream with both Ophir and Galloway achieving band 'D', below the national bottom line.
- Bacterial water quality is below the national bottom line at all tributary sites (Hills Creek, Thomsons Creek and the Poolburn)
- Nutrients increase in the main-stem between Blackstone and Ophir, then DRP improves downstream to achieve band 'B' at Galloway.
- The tributaries, Poolburn and Thomsons Creek, have poor water quality across all attribute states other than toxicity mainly achieving band 'D', below the NPSFM bottom line.
- Dunstan Creek has degrading trends for *E.coli*, NNN and turbidity (over 10-years)
- Ophir has an 'exceptionally unlikely' improving trend for *E.coli* (over 10-years).

9 Roxburgh Rohe (Clutha Matu/Au FMU)

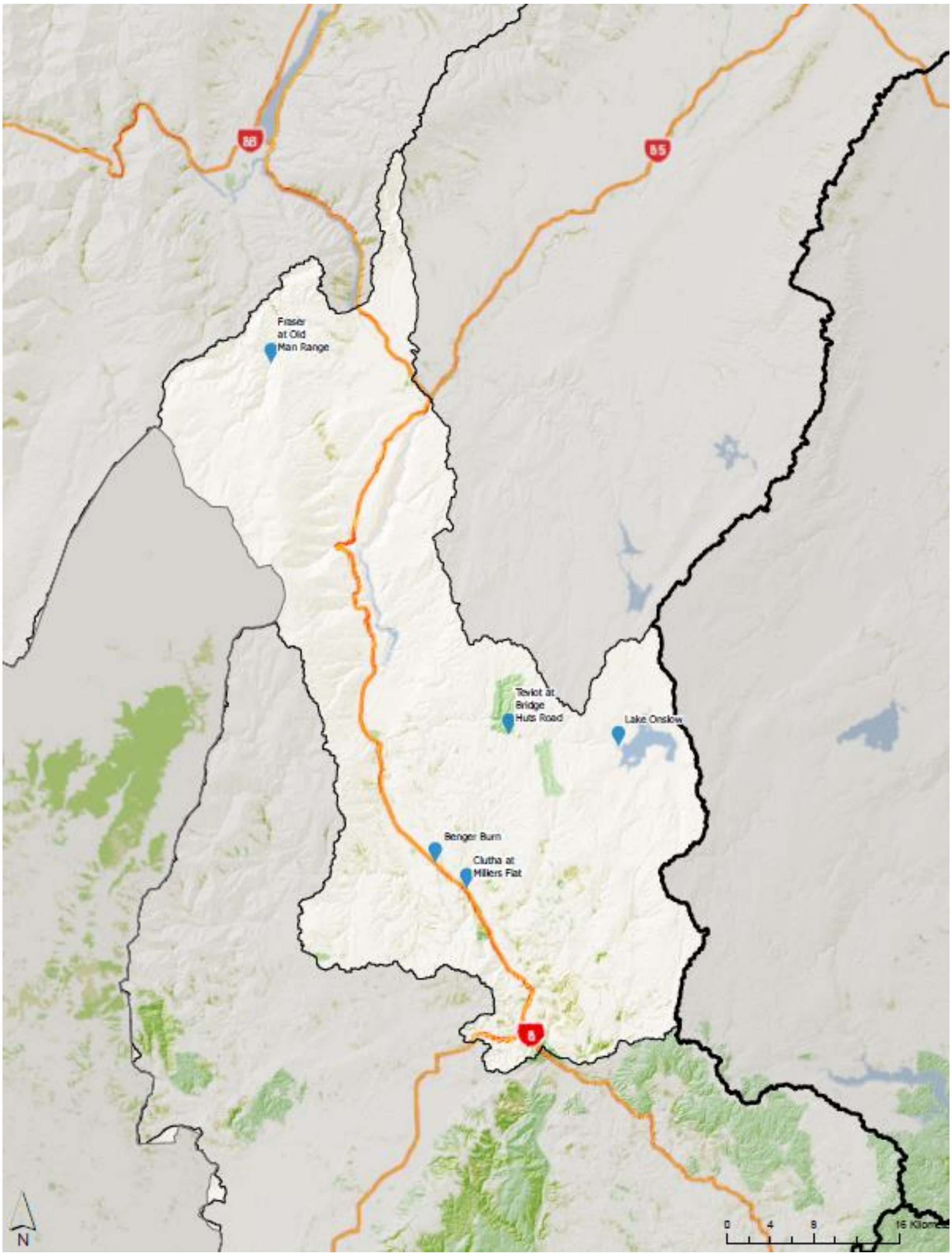
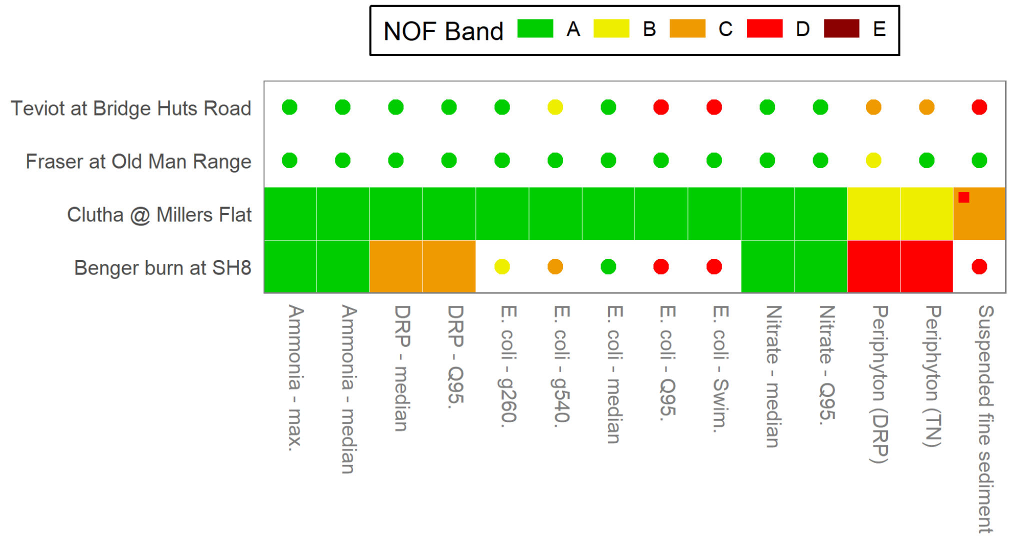


Figure 19 Location of water quality monitoring sites in the Roxburgh Rohe

9.1 State Analysis Results

The results of grading the SoE sites in the Roxburgh Rohe according to the NPSFM NOF criteria are summarised in Figure 20 and mapped Figure 21. Many sites in the Roxburgh Rohe did not meet the sample number requirements (shown in Table 1) 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.



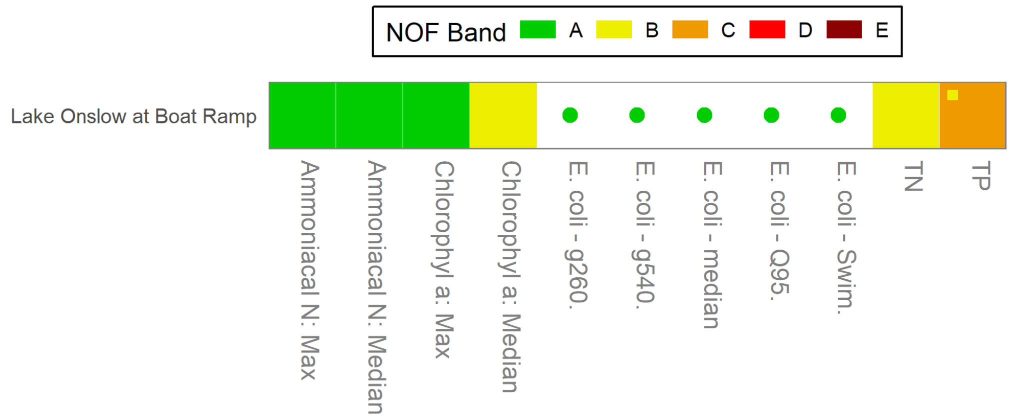


Figure 20 Grading of the river and lake sites in the Roxburgh based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

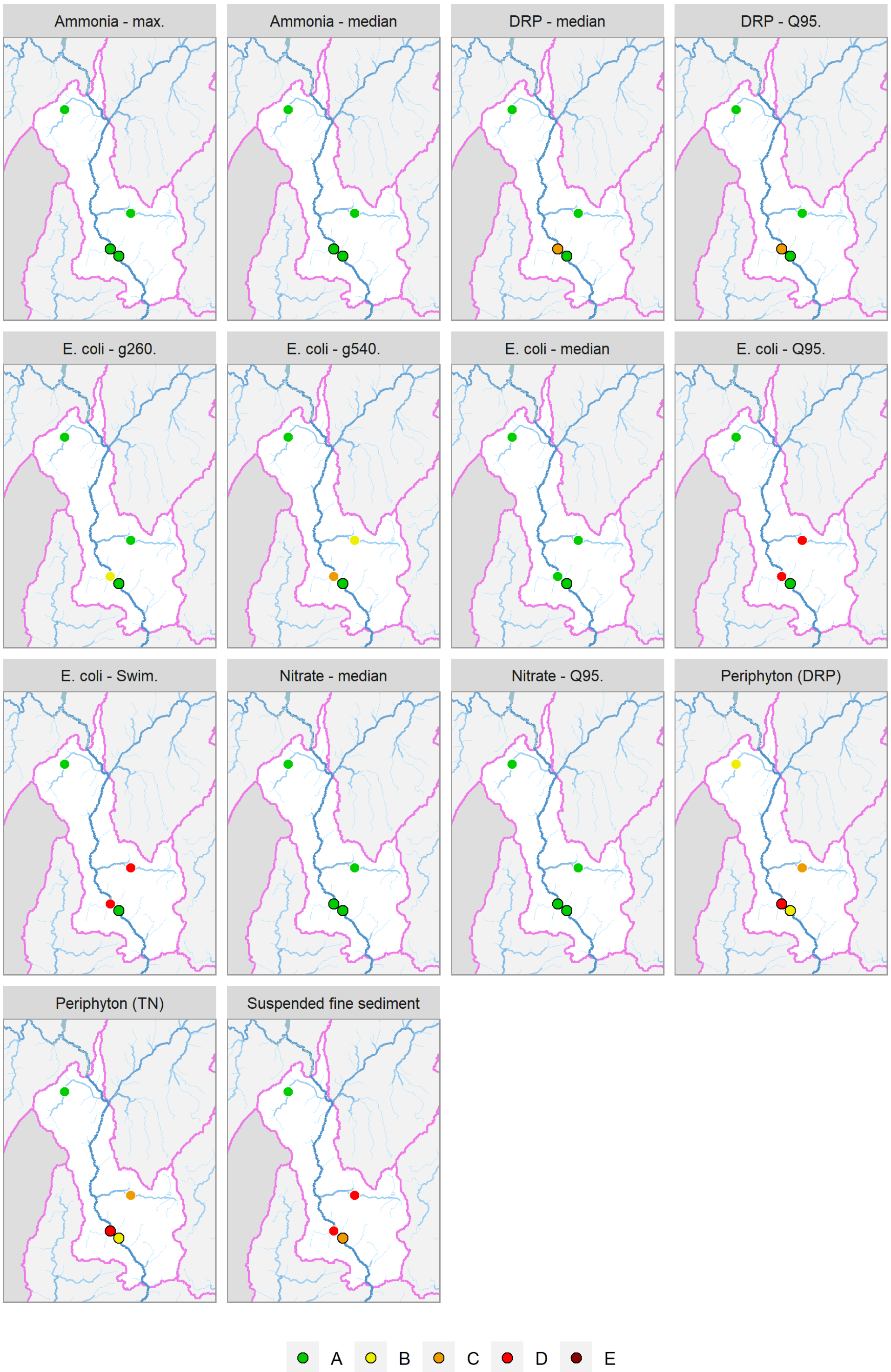


Figure 21 Maps showing Roxburgh Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

9.1.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 20 (periphyton). The Roxburgh Rohe does not have any sites that are monitored for chlorophyll a, but MfE (2020) TN concentrations to manage the NPSFM periphyton attribute states show that the Fraser River achieves a band 'A' as few results exceed 50 chl-*a*/m^2 meaning that blooms would be rare, reflecting negligible nutrient enrichment, the Clutha at Millers Flat a band 'B', the Teviot River a band 'C' and the Benger Burn achieves a band 'D'.

The MfE (2020) DRP concentrations to manage the NPSFM periphyton attribute states show the same pattern as the TN bands, other than the Fraser at Old Man Range which achieves a 'B' for DRP, when it achieved an 'A' band for TN.

Figure 21 also 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 'C'. The NPSFM 2020 describes band 'C' as *'Ecological communities are 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'*

The NPSFM 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 21, 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, which indicates that ecological communities are slightly-moderately impacted by additional algal and plant growth arising from nutrient levels above natural reference conditions.

9.1.2 Toxicants (Rivers)

In the Roxburgh Rohe the NOF attribute bands for NH_4-N and nitrate (measured as NNN) toxicity) show excellent protection levels against toxicity risk as all monitoring sites return an 'A' band for NH_4-N and NNN.

9.1.3 Suspended fine sediment

The clarity results for the Roxburgh Rohe are shown in Figure 20. 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'* (NPSFM, 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.

9.1.4 Human health for recreation

Figure 20 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.

Lake Onslow, the Fraser River and the Clutha at Millers Flat return 'A' bands across all four statistical tests, but the Teviot and Benger Burn achieve a 'D' band because their interim 95^{th} percentile is >1200 *E.coli*/100ml.

9.2 Trend Analysis

Results from trend analysis for the Roxburgh Rohe is shown in Figure 22.

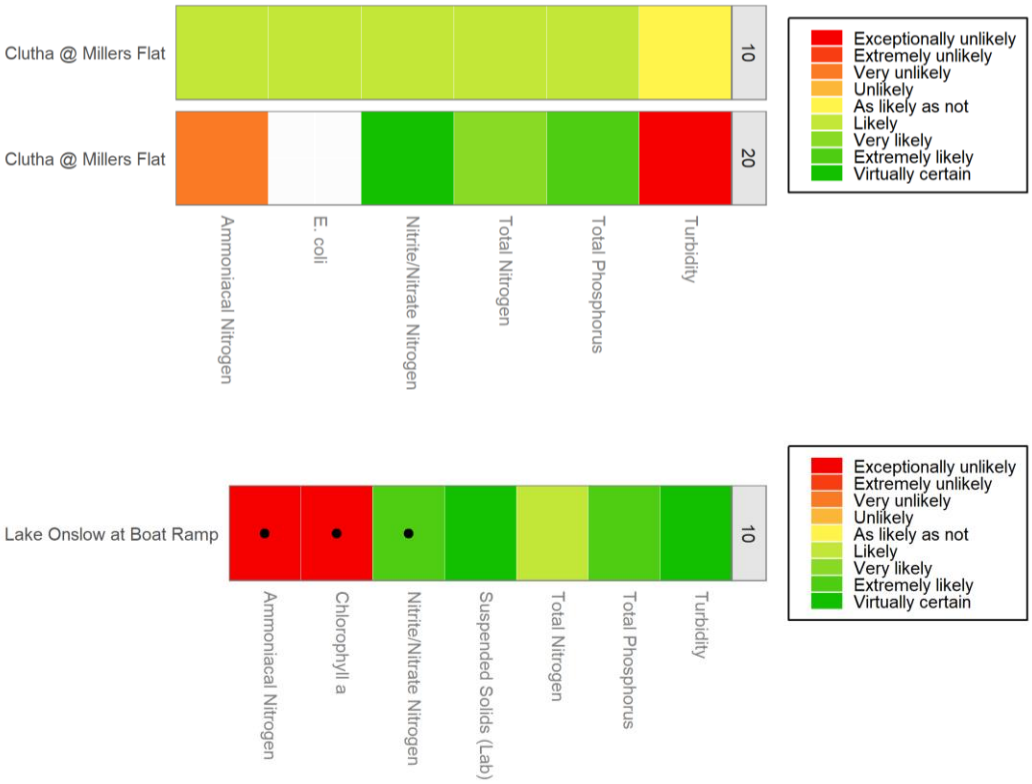


Figure 22 Summary of Roxburgh Rohe sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined inTable 2. Cells containing 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 22. In the 10-year time frame, Lake Onslow shows 'exceptionally unlikely' improving trends for NH_4-N and chlorophyll a, where most of the other variables show 'likely' to 'virtually certain' improving trends. For the Clutha River at Millers Flat, trend analysis shows a 20-year 'exceptionally unlikely' improvement in turbidity and an 'unlikely' improvement in NH_4-N, however nutrient concentrations have improving trends, NNN is 'virtually certain' to have improved over 20-years and TP is 'extremely likely' to have improved.

9.3 Water quality summary Roxburgh Rohe

The tables in this section summarise:

1) river and lake sites where attributes where the national bottom line is not met (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) all trends using raw data for rivers and continuous data for lakes over the two time-periods

Table 15 Summary of river state, red cells show where state does not meet the national bottom line in one or more variable.

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Teviot at Bridge Huts													
Fraser at Old Mans													
Clutha at Millers Flat													
Benger burn at SH8													

Table 16 Summary of river sites where trends are greater than 'likely' or 'unlikely' (raw data). Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
Clutha at Millers Flat						
Nitrite/Nitrate N	237	Month	20	-0.00034	Virtually certain	↑↑↑↑
Total Phosphorus	235	Month	20	-5.52417	Extremely likely	↑↑↑
Turbidity	237	Month	20	0.03662	Exceptionally unlikely	↓↓↓↓

Table 17 Summary of Lake Onslow trends when they are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	Confidence	AnnualSenSlope	Descriptor
Lake Onslow at Boat Ramp						
Ammoniacal N	49	BiMonth	10	Exceptionally unlikely	0	↓↓↓↓
Chlorophyll a	49	BiMonth	10	Exceptionally unlikely	0	↓↓↓↓
Nitrite/Nitrate N	49	BiMonth	10	Extremely likely	0	↑↑↑
Total Phosphorus	49	BiMonth	10	Extremely likely	-0.00096	↑↑↑
Turbidity	36	Qtr	10	Virtually certain	-0.36326	↑↑↑↑

Table 18 Overall summary of trends for Lake Onslow (continuous data). Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
River – 10-year trend				4	1				
River – 20-year trend	2	2	1						2
Lakes – 10-year trend									

The State analysis identified water quality in the Roxburgh Rohe rivers is generally good and the NPSFM band ‘A’ was achieved for most attributes. The only exceptions were for suspended fine sediment which was below the national bottom line in the Teviot and the Benger Burn. The suspended fine sediment in the Teviot is likely due to Lake Onslow, the main input to the river, as the lake is shallow and susceptible to sediment resuspension from wind-driven waves. *E.coli* was also below the national bottom line at these two sites.

In Table 16 and Table 17 only sites with 99%, 95% ,1% and 5% confidence levels are shown. These equate to the ‘virtually certain’, ‘extremely likely’, ‘exceptionally unlikely’ and extremely unlikely’ categories. 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 Roxburgh Rohe, Lake Onslow had three parametes with a zero Sen slope; NH_4-N, chlorophyll a and NNN. Lake Onslow, over 20-years had a ‘virtually certain’ improving trend for NNN and an ‘extremely likely’ improving trend for TP. In the same timeframe, turbidity showed an ‘exceptionally unlikely’ improving trend.

In summary:

- Water quality in the Clutha at Millers Flat and Fraser River generally achieve ‘A’ bands.
- The Teviot River does not meet the national bottom line for *E.coli* or suspended fine sediment.
- The Benger Burn does not meet the national bottom line for suspended fine sediment or *E.coli* and ‘D’ bands are achieved for periphyton DRP and periphyton TN
- The Clutha at Millers Flat has an ‘exceptionally unlikely’ improving trend for turbidity (over 20-years)

10 Lower Clutha Rohe (Clutha Matu/Au FMU)

Figure 23 Location of water quality monitoring sites in the Lower Clutha Rohe

10.1 State Analysis Results

The results of grading the SoE sites in the Lower Clutha Rohe according to the NPSFM NOF criteria are summarised in Figure 24 and mapped in Figure 25 . Many sites in the Lower Clutha Rohe 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 indicates the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

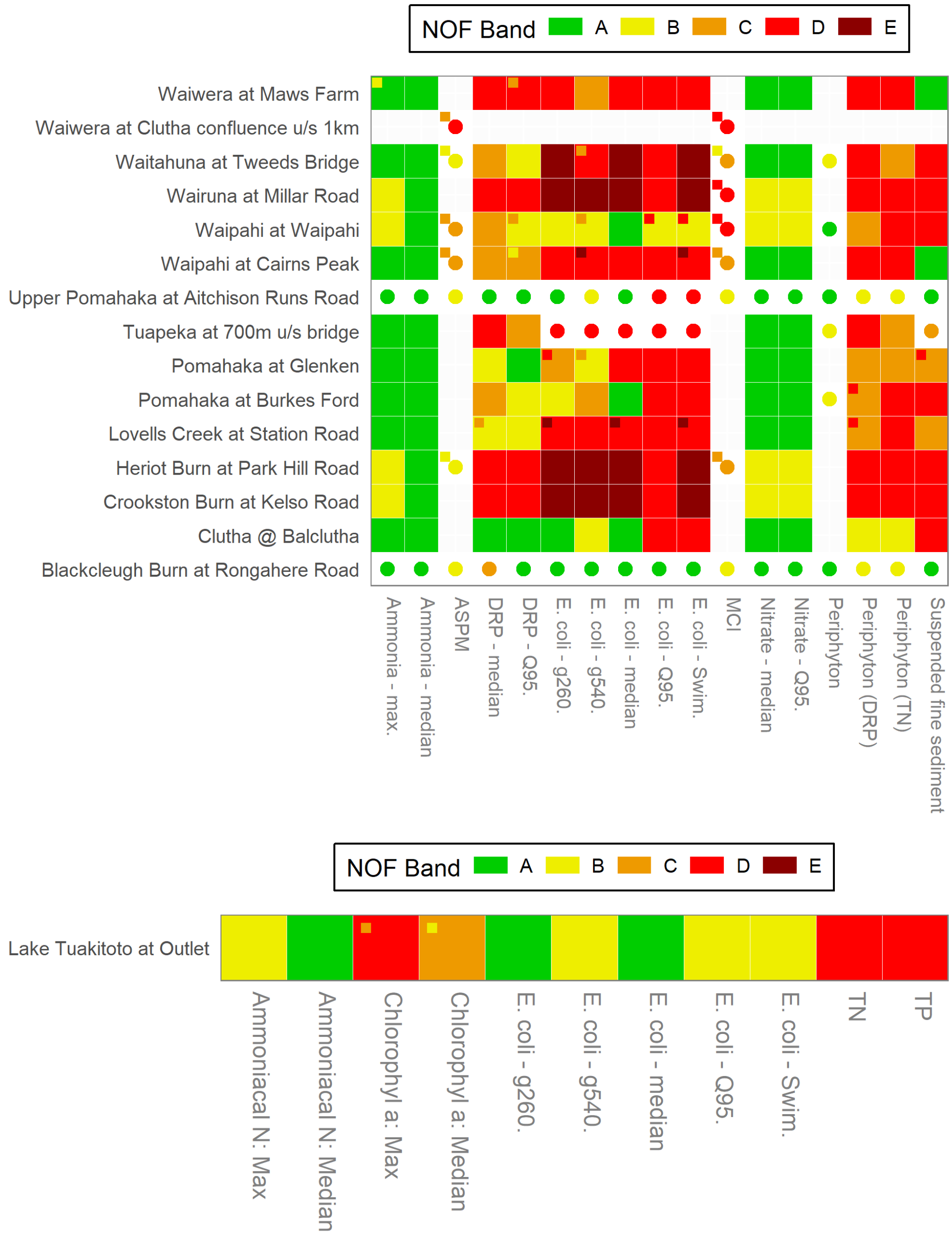


Figure 24 Grading of River and Lake sites in the Lower Clutha Rohe, based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

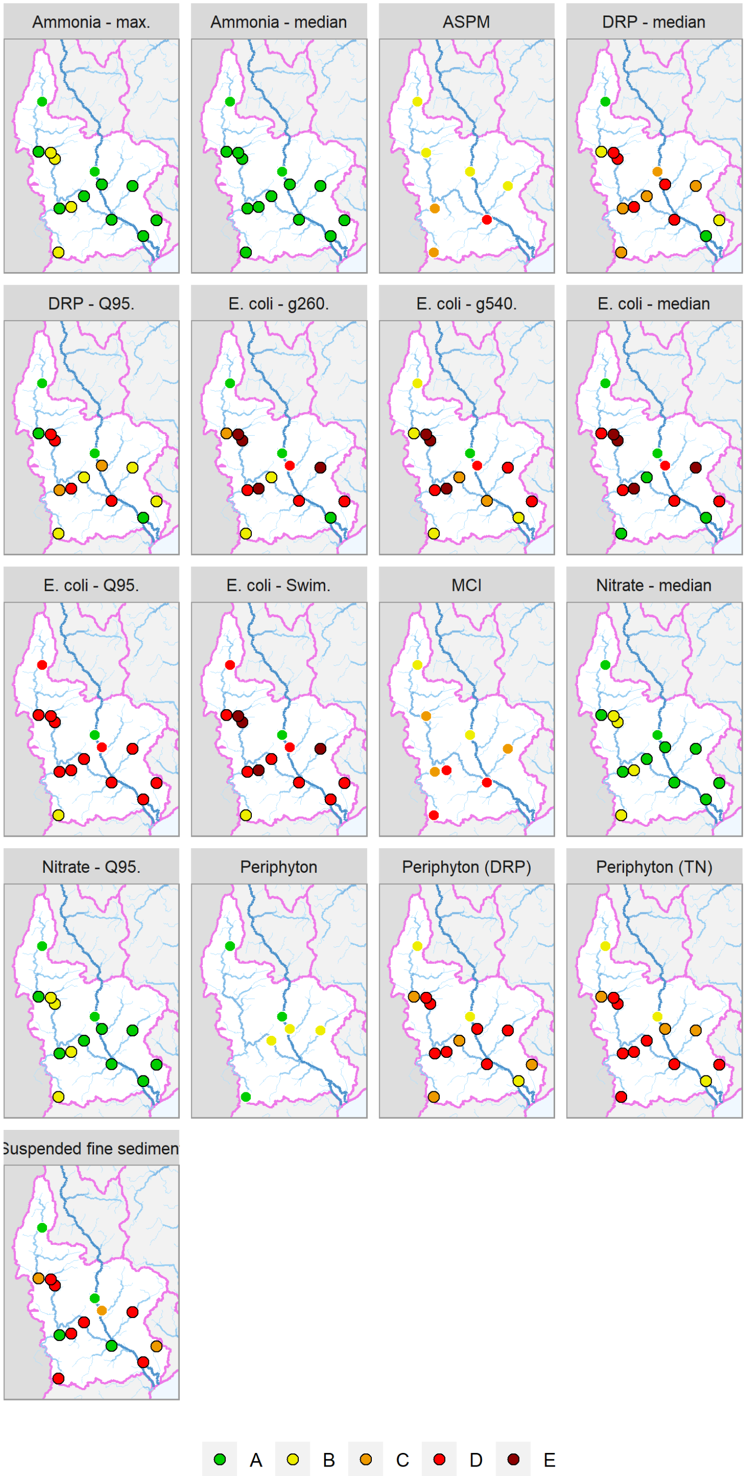


Figure 25 Maps showing Lower Clutha Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

10.1.1 Periphyton and Nutrients

Periphyton trophic state results to date are given in Figure 24 and show that the Lower Clutha Rohe returns either band 'A' or band 'B' for periphyton. The Blackcleugh Burn, Upper Pomahaka and Lower Waipahi have an interim 'A' band as few results exceed 50 chl-*a*/m^2, reflecting negligible nutrient enrichment. The Waitahuna records an interim band 'B'.

Figure 25 shows the MfE (2020) DRP and TN concentrations to manage the NPSFM periphyton attribute state (periphyton DRP and periphyton TN). Using the 20% exceedance criteria (mid-range), the DRP and TN median concentrations in the Lower Clutha Rohe generally exceed the T200 mg chl-a/m2 band and most sites achieve a band 'D', as would be expected in a high nutrient environment. The outliers are the Clutha at Balclutha, Upper Pomahaka and Blackcleugh Burn which achieve a band 'B'.

Figure 24 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Lower Clutha Rohe are varied, the sites with low nutrients achieve band 'A', the NPSFM 2020 describes this attribute state 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*'.

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'. The effect of the high DRP inputs is that the lower mainstem Pomahaka (Burkes Ford) achieves a 'B' band.

The NPSFM 2020 describes how phytoplankton (measured as chlorophyll 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 24 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 total nitrogen and total phosphorus, a 'D' band reflects high nutrient enrichment, which is consistent for a shallow (normal lake levels of about one metre) freshwater wetland (ORC, 2004).

10.1.2 Toxicants

NOF attribute bands for NH_4-N are given in Figure 24. The national bottom line for NH_4-N is below band 'B'. In the Lower Clutha all sites achieve band 'A' band other than four sites in the Pomahaka catchment (Crookston Burn, Heriot Burn and Wairuna and Waipahi) which achieve a band 'B', which affords a 95% species protection level.

NOF attribute bands for nitrate (measured as NNN) toxicity are given in Figure 24, 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 which achieves a 'C' band (annual 95^{th} percentile). The NPSFM 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 NH_4-N toxicity, showing good protection levels against toxicity risk.

10.1.3 Suspended fine sediment

The clarity results for Lower Clutha Rohe are shown in Figure 24. Most of the sites return a NOF band of 'D', which the NPSFM 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'.* Four sites; Waiwera, Waipahi at Cairns Peak, Upper Pomahaka and Blackcleugh Burn, return an 'A' band.

10.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state if water quality and aquatic ecosystem health at a site. Figure 24 summarises MCI scores for sites monitored for aquatic macroinvertebrates throughout the Lower Clutha Rohe.

Three of the monitored sites; Waipahi at Waipahi, Wairuna and Waiwera achieve an interim MCI score below the national bottom line (MCI 90). The NPSFM describes this state as *'reflecting a macroinvertebrate community indicative of sever organic pollution or nutrient enrichment. Communities are largely composed of taxa insensitive to inorganic pollution/nutrient enrichment'.* The Upper Pomahaka and Blackcleugh Burn achieve the highest MCI scores, achieving a 'B' band.

The ASPM interim scores shown in Figure 25 generally reflect those of the MCI scores, only the Waiwera falls below the national bottom line with a median score of 0.3 to achieve a 'D' grade. Four sites achieve a 'B' grade.

10.1.5 Human health for recreation (Rivers)

Figure 25 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 is generally poor across the Lower Rohe, with 12 of 15 sites returning bacterial water quality below the national bottom line. The NPSFM 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 Blackcleugh Burn achieved an 'A' band.

In the Pomahaka catchment, of the eight sites monitored three sites; the Crookston Burn, Heriot Burn and Wairuna achieved an 'E' band, three sites; Waipahi at Cairns Peak, Upper Pomahaka, Pomahaka at Burkes Ford and Pomahaka at Glenken achieved a 'D' band and one site; Waipahi at Waipahi achieved a 'B' band.

10.2 Trend Analysis

Trend analysis results for the Lower Clutha Rohe are shown in Figure 26 and Figure 27

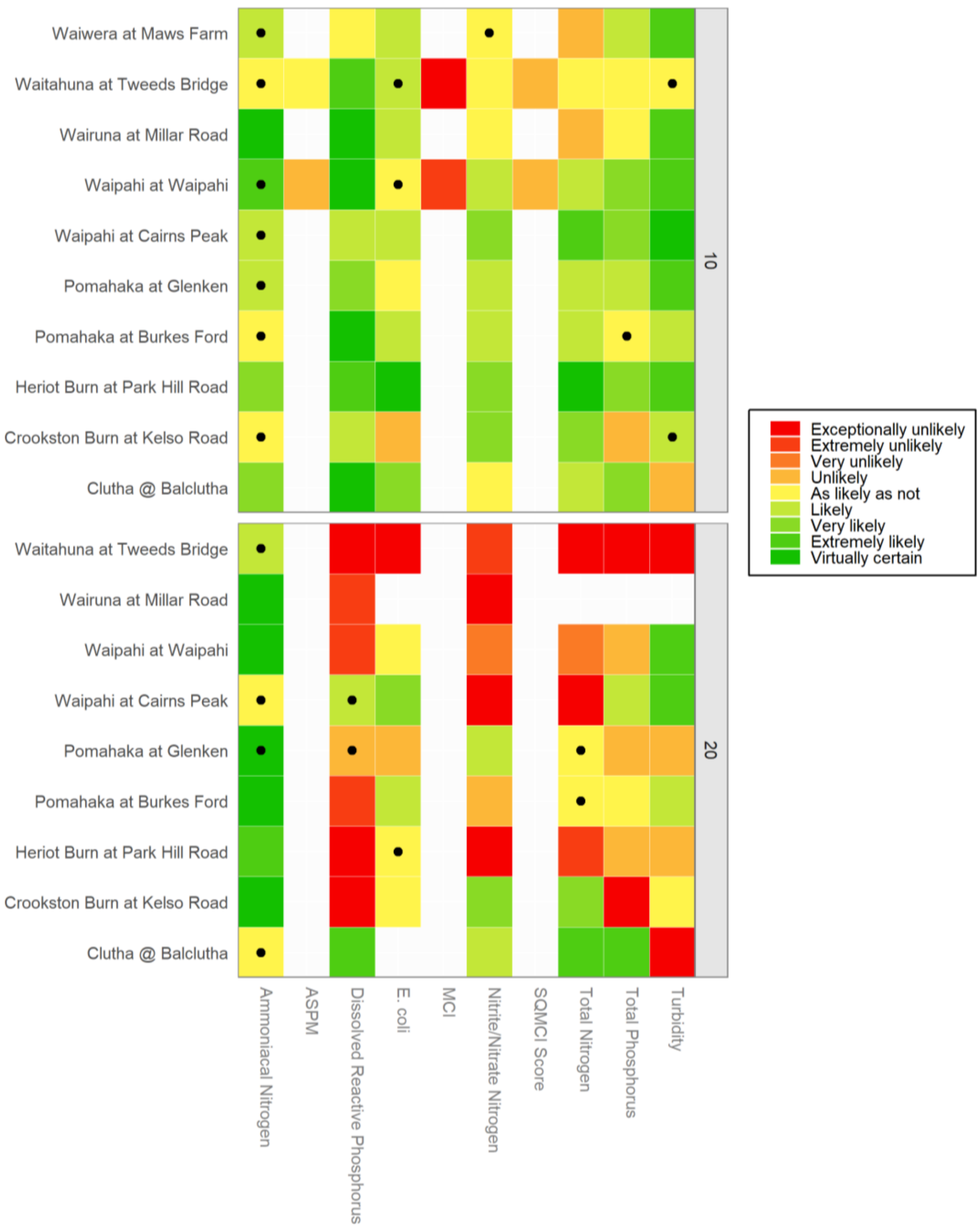


Figure 26 Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2Table 1. Cells 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.

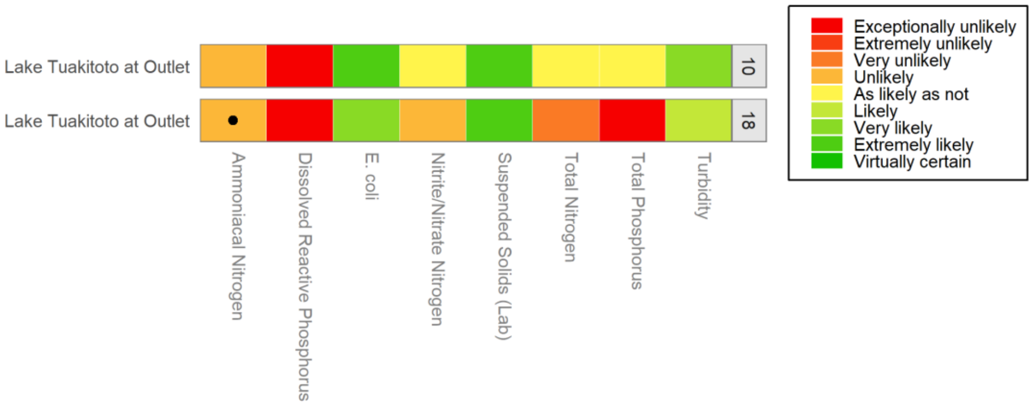


Figure 27 Summary of Lake Tuakitoto trends, categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2. Cells containing 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).

Trend analysis for the Lower Clutha Rohe rivers is shown in Figure 26. The Waitahuna returns 'exceptionally unlikely' improving trends over 20-years for DRP, *E.coli*, TN, TP and turbidity.

Over the 20-year period DRP and NNN were most likely to show 'exceptionally unlikely' improvement, and NH_4-N most likely to show 'virtually certain' improvement. Over the 10-year period most sites and most analytes are showing 'likely' to 'virtually certain' improvement, for example *E.coli* in the Heriot Burn (Figure 28)

Trend analysis for Lake Tuakitoto is shown in Figure 27, DRP over both 10-year and 18-year periods is 'exceptionally unlikely' to be improving.

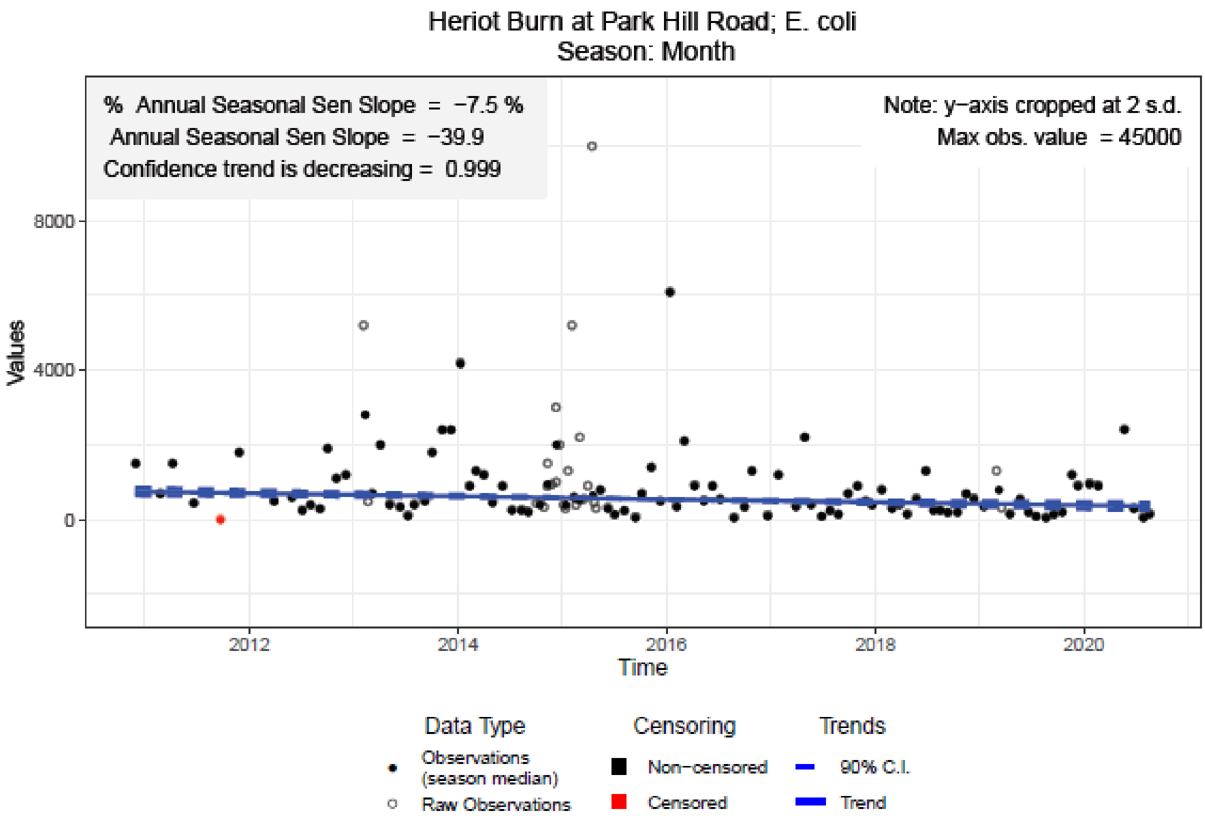


Figure 28 Heriot Burn. E.coli is 'virtually certain' to be improving (over 10-years)

10.3 Water quality summary and discussion: Lower Clutha Rohe

The tables in this section summarise:

1) river and lake sites where attributes where the national bottom line is not met (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) all trends using raw data for rivers and continuous data for lakes over the two time-periods

Table 19 Summary of river and lake state, red cells show where state does not meet the national bottom line in one or more variable. There is no national bottom line for DRP, but DRP (median and Q95) have been included in the table when sites achieve band 'D'.

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Waiwera at Maws Farm													
Waiwera at Confluence													
Waitahuna at Tweeds													
Wairuna at Millar Road													
Waipahi at Waipahi													
Waipahi at Cairns Peak													
Upper Pomahaka at													
Tuapeka at 700m u/s													
Pomahaka at Glenken													
Pomahaka at Burkes													
Lovells Creek at Station													
Heriot Burn at Park Hill													
Crookston Burn at Kelso													
Clutha at Balclutha													
Blackcleugh Burn at													

Table 20 Summary of Lake Tuakitoto State where attributes are graded D or below

	NH_4N - *max*	NH_4N - *median*	*Chlorophyll a -max*	*Chlorophyll a median*	*E.coli Overall*	*TN*	*TP*
Lake Tuakitoto at Outlet							

Table 21 Summary of river sites where trends are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
Clutha at Balclutha						
Dissolved Reactive P	119	Month	10	-9.6E-05	Virtually certain	↑↑↑↑
Dissolved Reactive P	239	Month	20	-1.8E-05	Extremely likely	↑↑↑
Total Nitrogen	239	Month	20	-0.00101	Extremely likely	↑↑↑
Total Phosphorus	119	Month	10	-0.00019	Very likely	↑↑
Total Phosphorus	239	Month	20	-9.4E-05	Extremely likely	↑↑↑
Turbidity	239	Month	20	0.050084	Exceptionally unlikely	↓↓↓↓
Crookston Burn at Kelso Road						
Ammoniacal N	99	BiMonth	20	-0.00117	Virtually certain	↑↑↑↑
Dissolved Reactive P	99	BiMonth	20	0.000914	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	99	BiMonth	20	0.000942	Exceptionally unlikely	↓↓↓↓
Heriot Burn at Park Hill Road						
Ammoniacal N	116	BiMonth	20	-0.00031	Extremely likely	↑↑↑
Dissolved Reactive P	103	Month	10	-0.00099	Extremely likely	↑↑↑
Dissolved Reactive P	116	BiMonth	20	0.000996	Exceptionally unlikely	↓↓↓↓
E. coli	103	Month	10	-39.9303	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	116	BiMonth	20	0.018769	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	104	Month	10	-0.03997	Virtually certain	↑↑↑↑
Total Nitrogen	116	BiMonth	20	0.015408	Extremely unlikely	↓↓↓
Turbidity	104	Month	10	-0.25686	Extremely likely	↑↑↑
Pomahaka at Burkes Ford						
Ammoniacal N	115	BiMonth	20	-0.00025	Virtually certain	↑↑↑↑
Dissolved Reactive P	102	Month	10	-0.0004	Virtually certain	↑↑↑↑
Dissolved Reactive P	115	BiMonth	20	0.000198	Extremely unlikely	↓↓↓
Pomahaka at Glenken						
Ammoniacal N	116	BiMonth	20	0	Virtually certain	↑↑↑↑
Turbidity	57	BiMonth	10	-0.10541	Extremely likely	↑↑↑
Waipahi at Cairns Peak						
Nitrite/Nitrate N	68	Qtr	20	0.015656	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	57	BiMonth	10	-0.02694	Extremely likely	↑↑↑
Total Nitrogen	68	Qtr	20	0.023244	Exceptionally unlikely	↓↓↓↓
Turbidity	57	BiMonth	10	-0.39658	Virtually certain	↑↑↑↑
Turbidity	66	Qtr	20	-0.1245	Extremely likely	↑↑↑
Waipahi at Waipahi						
Ammoniacal N	104	Month	10	0	Extremely likely	↑↑↑
Ammoniacal N	116	BiMonth	20	-0.00042	Virtually certain	↑↑↑↑
Dissolved Reactive P	104	Month	10	-0.00051	Virtually certain	↑↑↑↑
Dissolved Reactive P	116	BiMonth	20	0.000248	Extremely unlikely	↓↓↓
MCI	10	Year	10	-0.78438	Extremely unlikely	↓↓↓
Turbidity	104	Month	10	-0.1321	Extremely likely	↑↑↑
Turbidity	115	BiMonth	20	-0.05558	Extremely likely	↑↑↑
Wairuna at Millar Road						
Ammoniacal N	100	Month	10	-0.00233	Virtually certain	↑↑↑↑
Ammoniacal N	68	Qtr	20	-0.002	Virtually certain	↑↑↑↑
Dissolved Reactive P	100	Month	10	-0.001	Virtually certain	↑↑↑↑
Dissolved Reactive P	68	Qtr	20	0.000541	Extremely unlikely	↓↓↓
Nitrite/Nitrate N	68	Qtr	20	0.031128	Exceptionally unlikely	↓↓↓↓
Turbidity	100	Month	10	-0.37005	Extremely likely	↑↑↑
Waitahuna at Tweeds Bridge						
Dissolved Reactive P	105	Month	10	-0.00027	Extremely likely	↑↑↑
Dissolved Reactive P	117	BiMonth	20	0.000503	Exceptionally unlikely	↓↓↓↓
E. coli	117	BiMonth	20	8.810425	Exceptionally unlikely	↓↓↓↓
MCI	10	Year	10	-4.04643	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	117	BiMonth	20	0.002618	Extremely unlikely	↓↓↓
Total Nitrogen	116	BiMonth	20	0.006733	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	116	BiMonth	20	0.000817	Exceptionally unlikely	↓↓↓↓
Turbidity	117	BiMonth	20	0.072094	Exceptionally unlikely	↓↓↓↓
Waiwera at Maws Farm						
Turbidity	106	Month	10	-0.12939	Extremely likely	↑↑↑

Table 22 Summary lake sites where trends (continuous data) are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Ob	Frequenc	Period	TrendDirection	AnnualSenSlope	Descriptor
Lake Tuakitoto at Outlet						
Dissolved Reactive P	59	BiMonth	10	Increasing	0.001987755	↓↓↓↓
Dissolved Reactive P	104	BiMonth	18	Increasing	0.001845163	↓↓↓↓
E. coli	59	BiMonth	10	Decreasing	-5.947082768	↑↑↑
Total Phosphorus	104	BiMonth	18	Increasing	0.002423052	↓↓↓↓

Table 23 Overall summary of trends for the Lower Clutha Rohe using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend	8	9	12	21	16	8		1	1
Rivers - 20-year trend	5	6	3	7	9	8	2	5	13
Lakes – 10-year trend		2		1	3	1			1
Lakes – 18 year trend		1	1	1			2		2

In the Lower Clutha Rohe water quality generally has poor water clarity and high bacteria and nutrient concentrations. Of the NOF attribute states, *E.coli* was below the bottom line in 12 of the 15 sites monitored, suspended solids below the national bottom line in seven of the 15 sites and DRP in four of the monitored sites.

Lake Tuakitoto is a large freshwater wetland situated in the lower Clutha River catchment, Lovells Creek is the main inflow into the Lake. Lovells Creek scores poorly across all attribute states and is a reflection of the catchment, which largely consists of intensively grazed pasture with some scrub, and plantation forestry. Lake Tuakitoto scores 'D' bands for TP, TN and chlorophyll a (phytoplankton), this situation is unlikely to change, due to the shallow nature of the lake and poor flushing flows.

Alongside the poor state, trend analysis shows that water quality continues to degrade at some sites. The Waitahuna has degrading trends for DRP, *E.coli*, TN, TP and turbidity. The reason for this is unknown, as stated previously, having accurate information on changes in land use and land management practice will help in identifying drivers of change evident with some water quality variables.

In the case of the Pomahaka catchment, of the six monitoring sites which achieve a band 'D' or E' for *E.coli* most score poorly across all statistical tests with four of the six sites returning 'D' grades for the median *E.coli* statistic. It is thought that insufficient effluent storage and a prevalence of mole and tile drains through areas of the lower Pomahaka catchment result in these high *E. coli* concentrations. This is being addressed through Plan change 6AA, one of the aims of which is to strengthen provisions on farm effluent management. ORC is working throughout the Pomahaka catchment with groups such as the Pomahaka Watercare Group, the Landcare Trust and the Clutha Development Trust to address water quality issues. A large part of this effort is focused on improving bacterial water quality.

The Pomahaka catchment shows some positives, thre are far fewer degrading trends over the last 10-years than in the 20-year time-period. The Heriot Burn shows a 'virtually certain' improving trend for *E.coli* and TN, equally the Wairuna shows an 'virtually certain' improvement in NH_4-N and DRP. The lower Pomahaka site at Burkes Ford also shows encouraging results, with DRP showing 'virtually certain' improvement

In Table 21 and Table 22 only sites with 99%, 95% ,1% and 5% confidence levels are shown. These equate to the 'virtually certain', 'extremely likely', 'exceptionally unlikely' and extremely unlikely' categories. When sites have a zero sen slope alongside a reasonably high-level of confidence in trend direction, at these sites 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 Lower Clutha Rohe only NH_4-N at Waipahi was in this category.

In summary:

- Every site achieves 'A' or 'B' band for ammonia and nitrate toxicity
- Nutrient concentrations are generally high, other than in the main-stem Clutha, Blackcleugh Burn and Upper Pomahaka.
- No sites achieve 'A' bands in every NOF attribute state monitored. All sites have varying degrees of degraded water quality;
- In the Pomahaka catchment, bacterial water quality is severely degraded at all monitoring sites other than the lower Waipahi.
- The Heriot Burn, Crookston Burn, Waiwera River and Waipahi at Cairns Peak are the worst performing sites of the Lower Clutha/Pomahaka reporting region failing to meet the national bottom line for many attributes. The mainstem Pomahaka becomes degraded with distance downstream due to poor water quality inputs from these tributaries.
- The Waitahuna has degrading trends for DRP, *E.coli*, TN, TP and turbidity.

11 Taieri FMU

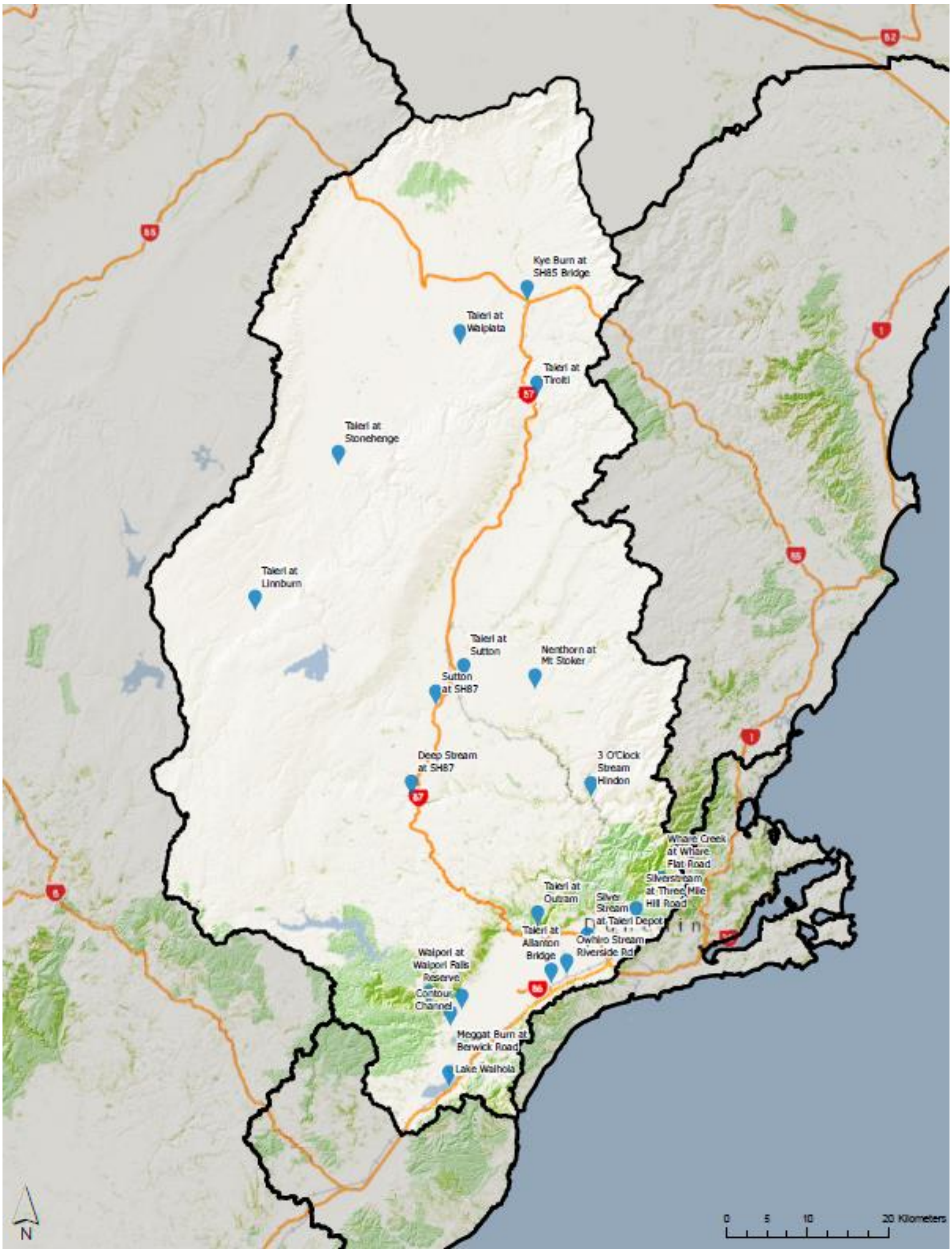


Figure 29 Location of water quality monitoring sites in the Taieri FMU

11.1 State Analysis Results

The results of grading the SoE sites in the Taieri FMU according to the NPSFM NOF criteria are summarised in Figure 30 and Figure 31 and mapped in Figure 32. Many sites in the Taieri 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.

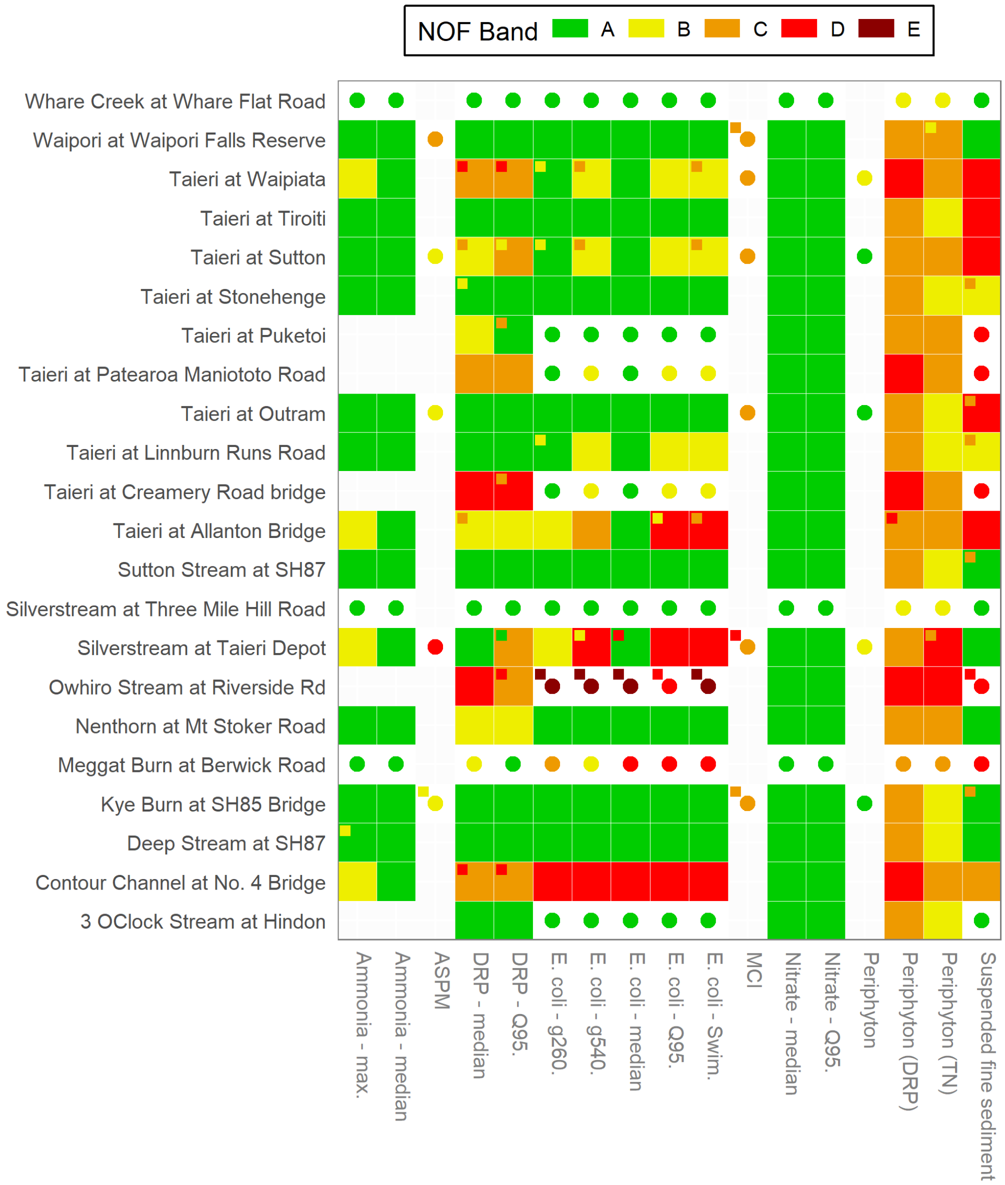


Figure 30 Grading of the river sites of the Taieri FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

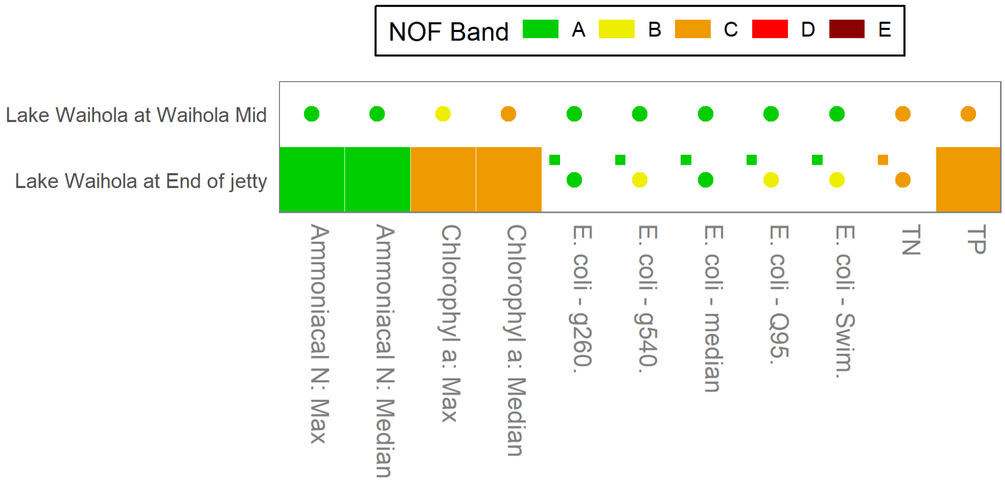


Figure 31 Grading of the lake sites of the Taieri FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

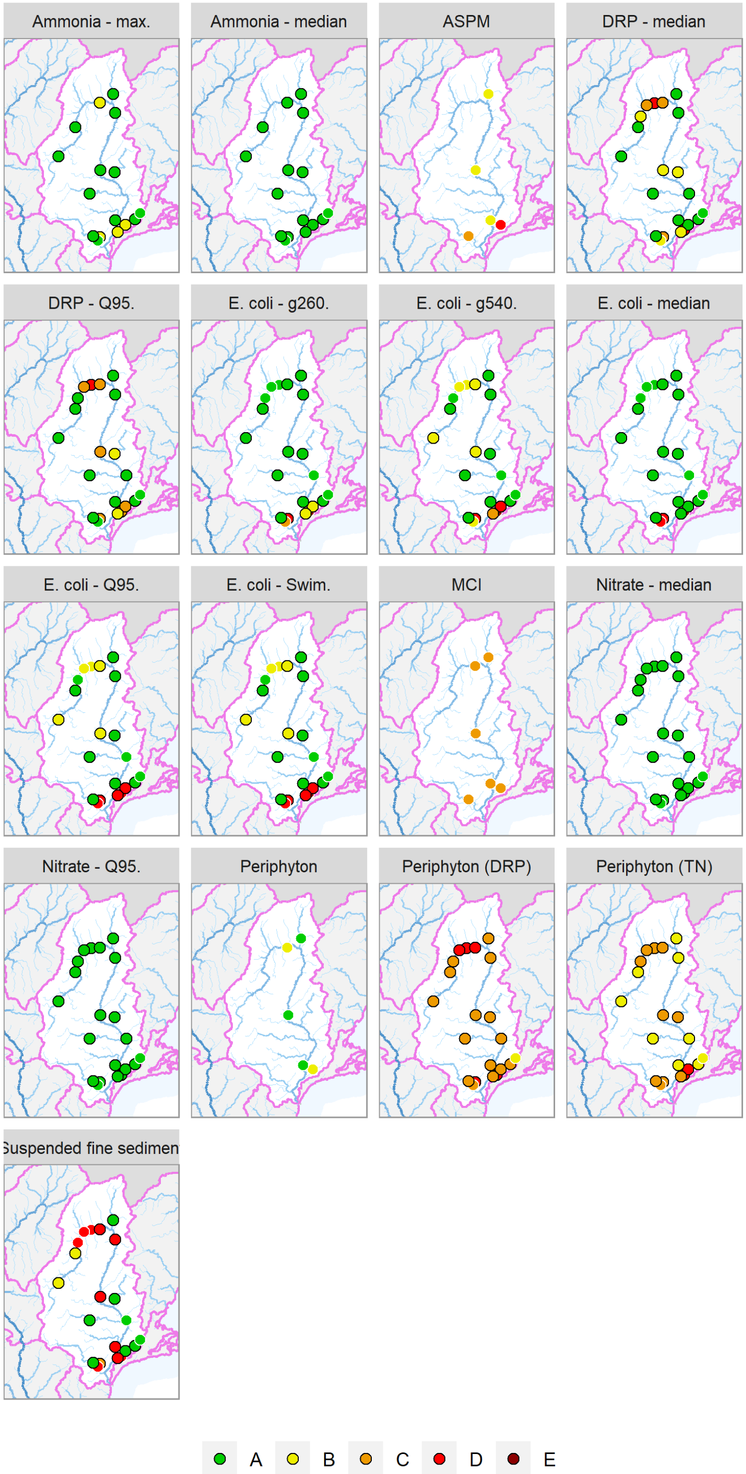


Figure 32 Maps showing Taieri FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines

11.1.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 32 (periphyton). Periphyton trophic state results to date show that the Taieri FMU achieves either 'A' or 'B' attribute bands for periphyton. The Kye Burn, Taieri at Outram and Taieri at Sutton achieve an interim 'A' band as few results exceed 50 chl-*a*/m^2, reflecting negligible nutrient enrichment. The Silverstream and Taieri at Waipiata record interim 'B' bands this reflects a low nutrient enrichment but the possibility of occassional blooms (NPSFM, 2020)

Figure 31 shows the MfE (2020) DRP and TN attribute bands to manage the NPSFM periphyton attribute state (periphyton DRP and periphyton TN). Using the 20% exceedance criteria (mid-range), the TN median concentrations in the Taieri FMU are generally in the T120 mg chl-a/m2 or T200 mg chl-a/m2 band ('B' or 'C'). The only outliers are the Owhiro Stream and the Silverstream which achieve band 'D', both are located on the Taieri Plain.

Using the 20% exceedance criteria (mid-range), the DRP median concentrations in the Taieri FMU are generally in the T200 mg chl-a/m2 band (or band 'C'), reflecting moderate nutrient enrichment. The Silverstream at Three Mile Road has a lower DRP median concentration and achieves band 'B'. Five sites achieve a band 'D', three mainstem sites (Waipiata, Patearoa Maniototo Road Bridge, Creamery Road Bridge), Owhiro Stream and the Contour Channel.

Figure 32 shows median DRP for an attribute state around wider ecological health, rather than just chlorophyll *a*. The results in the Taieri FMU show that most sites achieve either a band 'A' or band 'B', the NPSFM 2020 describes this as *'having ecological communities and ecosystem processes similar or slightly impacted by minor DRP elevation above natural reference condition'*. Three sites achieved a 'C' band, including two mainstem Taieri sites (Patearoa Road Bridge and Waipiata). Two sites achieved a band 'D' for the DRP median statistic, the Owhiro Stream and the Taieri at Creamery Road Bridge.

The NPSFM 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 31 shows that Lake Waihola is in the 'C' band, which the NPSFM 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 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).

11.1.2 Toxicants (Rivers)

The NOF attribute bands for NH_4-N are shown in Figure 32 and show excellent protection levels against toxicity risk. All sites return an 'A' band other than the Contour Channel, Silver Stream, Taieri at Allanton and Taieri at Waipiata which achieve a 'B' band. Lake Waihola returns an 'A' band for NH_4-N toxicity.

The NOF attribute band for nitrate toxicity (measured as NNN) are shown in Figure 32. All sites return an 'A' band. The NPSFM 2020 describes this state as '*high conservation value system. Unlikely to be effects even on sensitive species*'.

11.1.3 Suspended fine sediment

The suspended fine sediment results for the Taieri FMU are shown in Figure 32. Ten sites return a NOF band of 'D' which the NPSFM 2020 describes as 'high *impact of suspended sediment on instream biota'.* five of which are mainstem Taieri sites; Taieri at Waipiata, Taieri at Tiroiti, Taieri at Sutton, Taieri at Outram and Taieri at Allanton*. At the other end of the scale, nine sites returned 'A' band,* they are all tributary sites and include Whare Creek, Waipori, Sutton Stream, Silverstream, Nenthorn, Kyeburn, Deepstream and 3 O'Clock Stream. It should be noted that Sutton Stream, Taieri at Outram and the Taieri at Tiroiti were monitored by NIWA as part of the NRQWN, the results are not modelled.

11.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state of water quality and aquatic ecosystem health at a site. Figure 32 summarises MCI scores for the Taieri FMU. All sites achieve a 'C' band, returning MCI scores between 90 and 110; this reflects a macroinvertebrate community indicative of moderate organic pollution or nutrient enrichment. The ASPM interim scores shown in Figure 32 show that all sites achieve a 'B' band other than the Silverstream that obtains a band 'D' grade for ASPM, which the NPSFM describes as '*macroinvertebrate communities have severe loss loss of ecological integrity*'. It is likely that the substrate in the Silverstream is largely to blame for poorer macroinvertebrate scores.

11.1.5 Human health for recreation (Rivers)

Figure 31 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 is generally good across the Taieri FMU, of the 22 sites, 12 achieve an 'A' band, three a 'B' band (Taieri main-stem sites at Linnburn, Sutton and Waipiata), the other sites returned bacterial water quality below the national bottom line (four 'D' bands and one an 'E' band). Lake Waihola an 'A' band mid lake, and a 'B' band at the edge of lake site (jetty).

11.2 Trend Analysis

Trend analysis results for the Taieri FMU is shown in Figure 33 and Figure 34

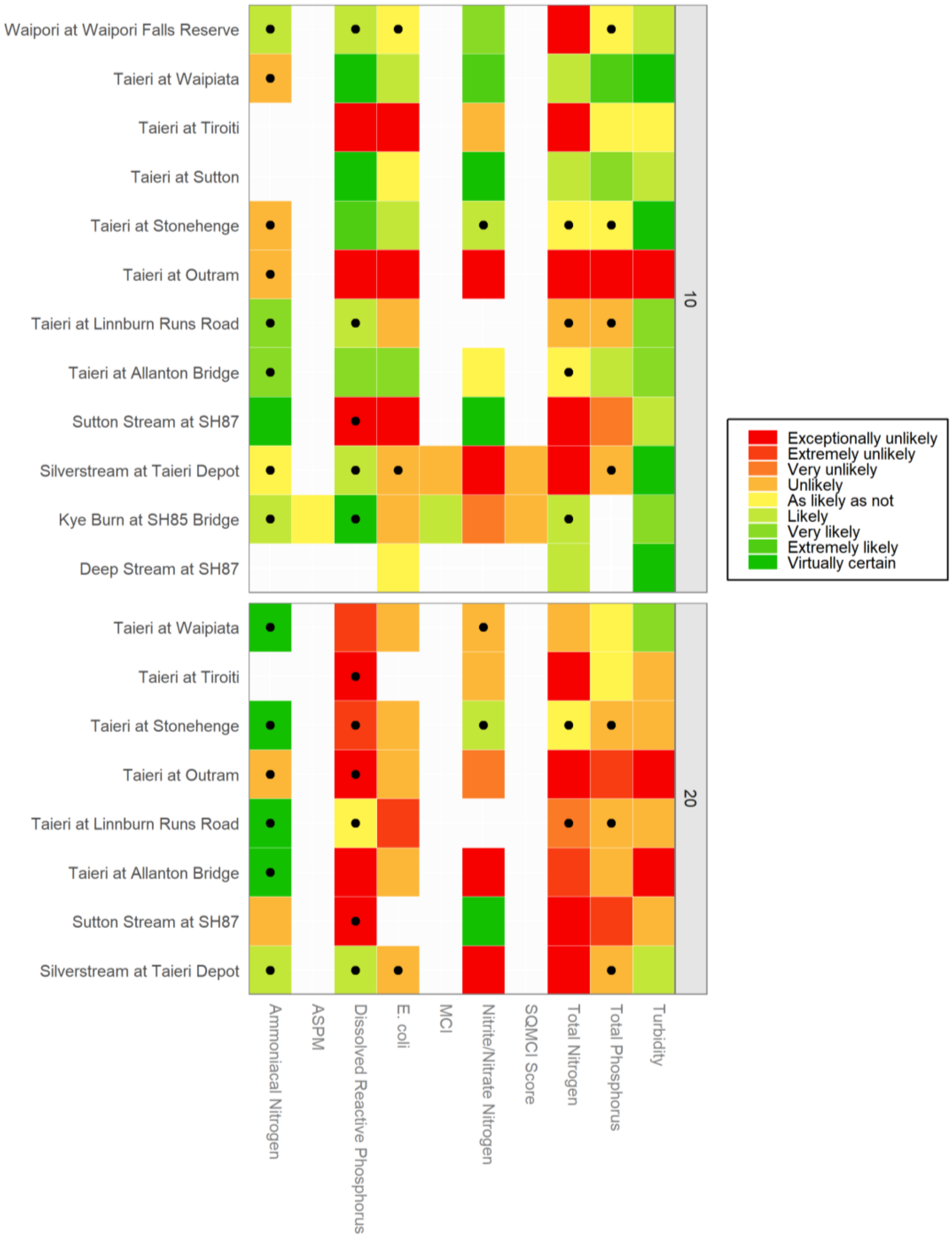


Figure 33 Summary of Taieri FMU river sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2. *Cells containing 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*

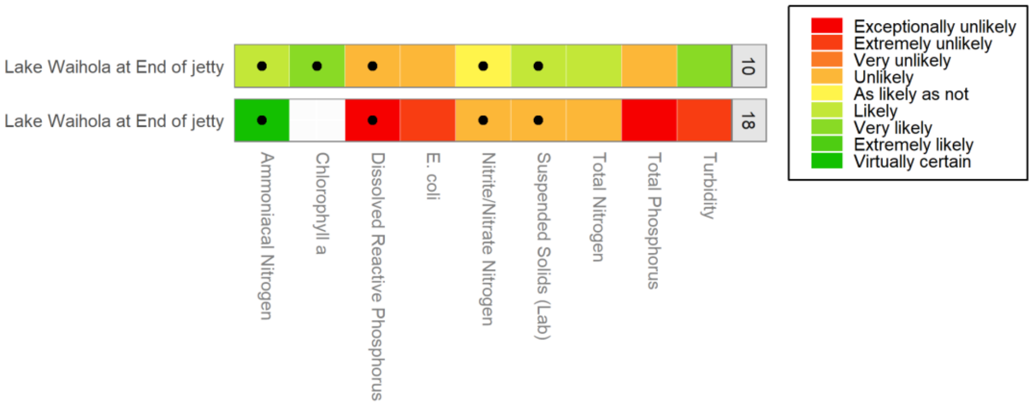


*Figure 34 Summary of Taieri FMU lake sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in*Table 2.. *Cells containing 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 FMU rivers is shown in Figure 33 and for Lake Waihola in Figure 34. Most sites have variables with 'exceptionally unlikely' or 'extremely unlikely' improving trends, these include:

- The Waipori River, TN (10-years)
- The Taieri at Waipiata, DRP (20-years)
- The Taieri at Tiroiti, DRP, *E.coli*, TN (10-years), DRP, TN (20-years)
- The Taieri at Stonehenge, DRP (20-years)
- The Taieri at Outram, DRP, *E.coli*, NNN, TN, TP, turbidity (10-years), DRP, TN, TP, turbidity (20-years)
- The Sutton Stream, DRP, *E.coli*, TN (10-years), DRP, TN TP (20-years)
- The Taieri at Linnburn, *E.coli* (20-years)
- The Taieri at Allanton, DRP, NNN, TN and turbidity (20-years)
- Sutton Stream, DRP, *E.coli*, TN (10-years), DRP, TN, TP (20-years)
- Silverstream at Taieri Depot, NNN, TN (20-years).
- Lake Waihola, DRP, *E.coli*, TP, turbidity (18 years)

Sites with 'virtually certain' or 'extremely likely' improving trends include:

- The Taieri at Waipiata, DRP, NNN, TP, turbidity (10-years), NH_4-N (20-years)
- Taieri at Sutton, DRP, NNN (10-years)
- Taieri at Stonehenge, DRP, turbidity (10-years), NH_4-N (20-years)
- Taieri at Linnburn and Allanton, NH4-N (20-years)
- Sutton Stream, NH_4-N, NNN (10-years), NNN (20-years)
- Silverstream at Taieri and Deep Stream, turbidity (10-years)
- Kye Burn, DRP (10-years)
- Lake Waihola, NH_4-N (20-years)

11.3 Water quality summary Taieri FMU

The tables in this section summarise:

1) river and lake sites where attributes where the national bottom line is not met (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) all trends using raw data for rivers and continuous data for lakes over the two time-periods

Figure 35 Summary of river state, red cells show where state does not meet the national bottom line in one or more variable. There is no national bottom line for DRP, but DRP (median and Q95) have been included in the table when sites achieve a band 'D'.

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Taieri at Waipiata											■		■
Taieri at Tiroiti													■
Taieri at Sutton													■
Taieri at Puketoi													■
Taieri at Patearoa											■		■
Taieri at Outram													■
Taieri at Creamery				■	■						■		■
Taieri at Allanton Bridge						■							■
Silverstream at Taieri						■						■	
Owhiro Stream				■		■					■	■	■
Meggat Burn						■							■
Contour Channel						■					■		

Figure 36 Summary of river sites where trends are greater than 'likely' or 'unlikely'.

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
Deep Stream at SH87						
Turbidity	35	Qtr	10	-0.05435	Virtually certain	↑↑↑↑
Kye Burn at SH85 Bridge						
Dissolved Reactive P	107	Month	10	0	Virtually certain	↑↑↑↑
Silverstream at Taieri Depot						
Nitrite/Nitrate N	101	Month	10	0.023347	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	106	BiMonth	20	0.016066	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	101	Month	10	0.025188	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	106	BiMonth	20	0.013899	Exceptionally unlikely	↓↓↓↓
Turbidity	101	Month	10	-0.08362	Virtually certain	↑↑↑↑
Sutton Stream at SH87						
Ammoniacal N	116	Month	10	-0.00103	Virtually certain	↑↑↑↑
Dissolved Reactive P	116	Month	10	0	Exceptionally unlikely	↓↓↓↓
Dissolved Reactive P	236	Month	20	0	Exceptionally unlikely	↓↓↓↓
E. coli	116	Month	10	5.941039	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	116	Month	10	-0.00103	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	236	Month	20	-0.00023	Virtually certain	↑↑↑↑
Total Nitrogen	116	Month	10	0.007475	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	234	Month	20	0.00167	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	235	Month	20	0.000161	Extremely unlikely	↓↓↓
Taieri at Allanton Bridge						
Ammoniacal N	113	BiMonth	20	0	Virtually certain	↑↑↑↑
Dissolved Reactive P	113	BiMonth	20	0.00024	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	113	BiMonth	20	0.002008	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	113	BiMonth	20	0.00453	Extremely unlikely	↓↓↓
Turbidity	113	BiMonth	20	0.134904	Exceptionally unlikely	↓↓↓↓
Taieri at Linnburn Runs Road						
Ammoniacal N	102	BiMonth	20	0	Virtually certain	↑↑↑↑
E. coli	102	BiMonth	20	0.980764	Extremely unlikely	↓↓↓
Taieri at Outram						
Dissolved Reactive P	119	Month	10	0.000155	Exceptionally unlikely	↓↓↓↓
Dissolved Reactive P	239	Month	20	0	Exceptionally unlikely	↓↓↓↓
E. coli	119	Month	10	2.165185	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	119	Month	10	0.001067	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	119	Month	10	0.019004	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	239	Month	20	0.002825	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	119	Month	10	0.001663	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	238	Month	20	0.000205	Extremely unlikely	↓↓↓
Turbidity	119	Month	10	0.150039	Exceptionally unlikely	↓↓↓↓
Turbidity	238	Month	20	0.051847	Exceptionally unlikely	↓↓↓↓
Taieri at Stonehenge						
Ammoniacal N	118	BiMonth	20	0	Virtually certain	↑↑↑↑
Dissolved Reactive P	114	Month	10	-5.5E-05	Extremely likely	↑↑↑
Dissolved Reactive P	118	BiMonth	20	0	Extremely unlikely	↓↓↓
Turbidity	102	Month	10	-0.05996	Virtually certain	↑↑↑↑
Taieri at Sutton						
Dissolved Reactive P	113	Month	10	-0.00042	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	113	Month	10	-0.00225	Virtually certain	↑↑↑↑
Taieri at Tiroiti						
Dissolved Reactive P	119	Month	10	0.000185	Exceptionally unlikely	↓↓↓↓
Dissolved Reactive P	239	Month	20	0	Exceptionally unlikely	↓↓↓↓
E. coli	119	Month	10	3.858275	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	119	Month	10	0.013466	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	239	Month	20	0.006387	Exceptionally unlikely	↓↓↓↓
Taieri at Waipiata						
Ammoniacal N	113	BiMonth	20	0	Virtually certain	↑↑↑↑
Dissolved Reactive P	114	Month	10	-0.0006	Virtually certain	↑↑↑↑
Dissolved Reactive P	113	BiMonth	20	0.000249	Extremely unlikely	↓↓↓
Nitrite/Nitrate N	114	Month	10	-0.00133	Extremely likely	↑↑↑
Total Phosphorus	114	Month	10	-0.001	Extremely likely	↑↑↑
Turbidity	102	Month	10	-0.20041	Virtually certain	↑↑↑↑
Waipori at Waipori Falls Reserve						
Total Nitrogen	101	Month	10	0.005418	Exceptionally unlikely	↓↓↓↓

Figure 37 Summary lake sites where trends (continuous data) are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	Trend Direction	AnnualSen Slope	Descriptor
Lake Waihola at End of jetty						
Ammoniacal N	105	BiMonth	18	Decreasing	0	↑↑↑↑
Dissolved Reactive P	105	BiMonth	18	Increasing	0	↓↓↓↓
E. coli	106	BiMonth	18	Increasing	1.000684932	↓↓↓
Total Phosphorus	104	BiMonth	18	Increasing	0.001271858	↓↓↓↓
Turbidity	104	BiMonth	18	Increasing	0.14570082	↓↓↓

Figure 38 Overall summary of trends for the Taieri FMU using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend	10	3	9	17	12	13	2		15
Rivers - 20-year trend	4		1	4	4	18	2	6	12
Lakes – 10-year trend			2	3	1	3			
Lakes – 18 year trend						3		2	2

In the Taieri FMU water quality is generally good with the majority of sites and attributes achieving 'A' and 'B' bands, as seen in Figure 31. The exception is for the DRP and TN (periphyton) attributes which achieved mainly 'C' bands.

Of the tributaries, the lower Taieri plain has some of the poorest water quality in the region. Three streams are monitored in the plain, the Contour Channel, the Silverstream and the Owhiro Stream. Although the Upper Silverstream has good water quality and generally meets NOF attribute 'A' bands, the lower Silverstream has a poorer outcome. At this stage it has been straightened and has little riparian vegetation (flood banks) it is also influenced to some extent by storm-water from Mosgiel township. The Silverstream returned 'D' bands for ASPM, *E.coli* and TN (periphyton). Although the Silverstream achieves an 'A' band for NNN and a 'C' band for DRP, the levels are not low enough to prevent cyanobacteria (phormidium) growth. Factors facilitating this are likely to be the lack of shade and few flushing flows which have proven to be ideal conditions for phormidium as this species of cyanobacteria tends to bloom most years.

The Contour Channel achieves a 'D' band for *E.coli* and DRP (periphyton), a 'C' band for DRP, TN (periphyton) and suspended fine sediment. The other stream that flows across the Taieri plain is the Owhiro Stream, this is a very small stream with areas of intensive agriculture in its catchment, it returns attribute bands below the national bottom line for DRP, *E.coli*, Periphyton (TN and DRP) and suspended fine sediment. Despite relatively good bacterial water quality throughout the reporting region, *E. coli* is the worst performing variable with five of 22 sites failing to meet the national bottom line, all of these sites are in the lower Taieri.

Lake Waihola shows nutrient and phytoplankton concentrations generally in the NOF 'C' bands, this is typical of a productive lake with increased levels of nutrients and algae over those that would be expected under natural or near natural conditions. Lake Waihola has episodic algal blooms typical of an eutrophic lake,

Trend analysis shows many degrading trends for the Taieri FMU. The Silverstream although returning band 'A's for NNN and DRP shows degrading trends for NNN. Of the main-stem Taieri sites, over the last 10-years, from the upper catchment to the lower catchment, Stonehenge a ‘virtually certain’ improving trend for turbidity, Waipiata has improving trends for DRP, NNN, TP and turbidity, Tiroiti has degrading trends for DRP, *E.coli* and TN, and Outram has degrading trends across most attribute states (*E.coli*, NN, TN, TP and turbidity).

In summary:

- Risk to ammonia and nitrate toxicity is negligible across the Taieri FMU
- The lower Taieri has high concentrations of *E. coli*. Five sites in the lower Taieri fail to meet the national bottom line for *E.coli* the attribute. The rest of the sites monitored had excellent bacterial compliance, achieving an ‘A’ or ‘B’ band.
- The Owhiro Stream in the lower Taieri catchment has the worst level of compliance against NOF attribute states of any site across the Taieri River FMU.
- TN is of moderate concentrations across the catchment, no sites returned an ‘A’ band, but 10 sites achieved a ‘B’ band, only the Silverstream and Owhiro achieved ‘D’ bands.
- DRP generally complies with the NOF ‘A’ or ‘B’ band.
- Where macroinvertebrate monitoring takes place, MCI is generally ‘fair’.
- Lake Waihola returns attribute bands consistent with those expected of an eutrophic lake
- Trend analysis shows many degrading trends across the FMU, particularly in the lower Taieri at Outram.

12 Dunedin Coast FMU

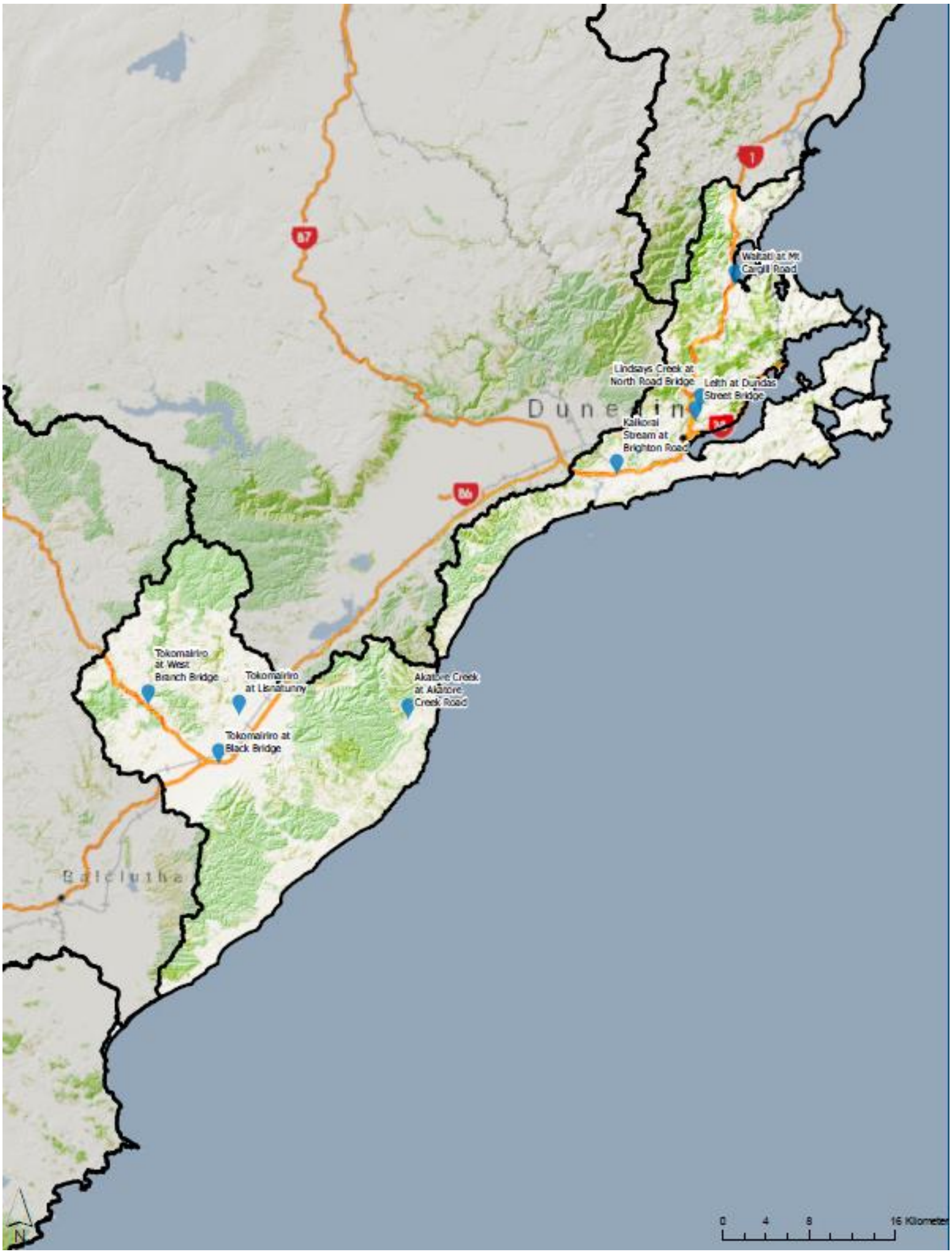


Figure 39 Location of water quality monitoring sites in the Dunedin Coast FMU

12.1 State Analysis Results

The results of grading the SoE sites in the Dunedin Coast FMU according to the NPSFM NOF criteria are summarised in Figure 40 and mapped in Figure 41. Many sites in the Dunedin Coast 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

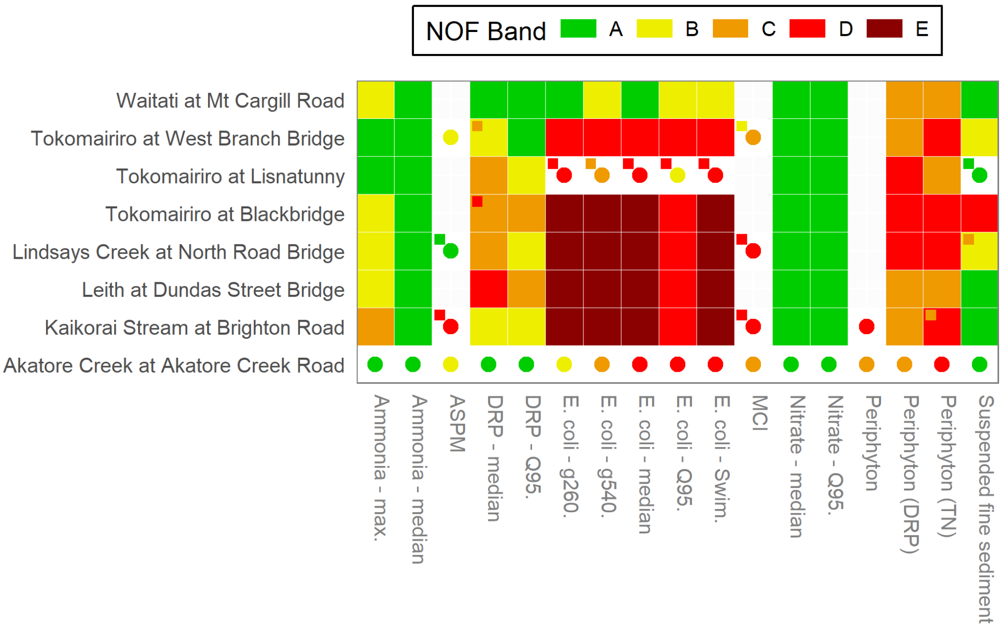


Figure 40 Grading of the river sites of the Dunedin Coast FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

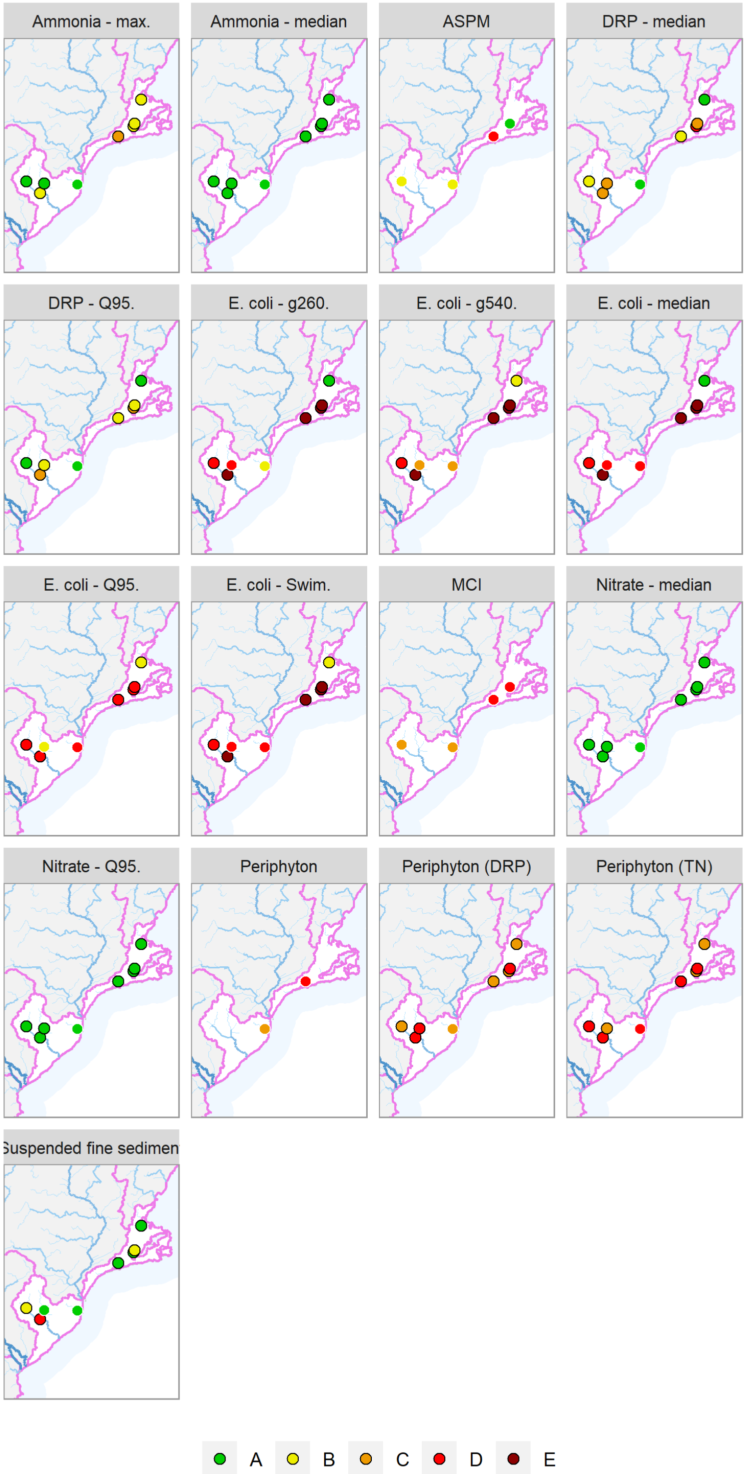


Figure 41 Maps showing Dunedin Coast FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

12.1.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 40 (periphyton). Periphyton trophic state results to date show that Akatore Creek is likely to be in attribute band 'C' for periphyton as results tend to be between >120 and $\leq$200 chl-*a*/m^2 meaning moderate nutrient enrichment. The Kaikorai Stream is likely be 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.

To manage the NPSFM periphyton attribute state (MfE, 2020) median concentrations of DRP and TN align to attribute bands (i.e., periphyton DRP and periphyton TN in Figure 41). Using the 20% exceedance criteria (mid-range), the TN median concentrations in the Dunedin Coast FMU are generally in or greater than the T200 mg chl-a/m2 band ('C' or 'D').

The DRP median concentrations in the Dunedin Coast FMU are generally in the T200 mg chl-a/m2 band or greater (band 'C' or 'D').

Figure 41 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Dunedin Coast Rohe show that two sites achieve an 'A' band (Waitati and Akatore), one site a 'B' band (Kaikorai) and three sites a 'C' band (Leith at Dundas Street and Tokomairiro at Lisnatunny and Blackbridge). The NPSFM 2020 describes band 'C' as *'Ecological communities impacted by moderate DRP elevation above natural reference conditions. If other coditions 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'*

The Leith achieves a 'D' band

12.1.2 Toxicants (Rivers)

NOF attribute bands for NH_4-N are shown in Figure 41 , it should be noted that the national bottom line is below band 'B'. In the Dunedin Coast Rohe three sites have excellent protection levels against ammonia toxicity (Akatore Creek, Tokomairio at Lisnatunny and Tokomairiro at West Branch Bridge) with all sites returning an 'A' band (highest level of protection) for NH_4-N. Of the remaining sites, the Kaikorai Stream returned a 'C' band for the annual maximum which is below the national bottom line. The NPSFM describes the 'C' band as *'ammonia starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)'.* The other three sites returned 'B' bands.

NOF attribute bands for nitrate (measured as NNN) toxicity are shown in Figure 41, again the national bottom line is below band 'B'. In the Dunedin Coast Rohe all sites achieve an 'A' band

12.1.3 Suspended fine sediment (Rivers)

The clarity results for the Dunedin Coast Rohe are shown in Figure 41. Most of the 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'* (NPSFM, 2020). The Tokomairio at West Branch Bridge and Lindsay's Creek return a NOF band of 'B' and the Tokomairio at Blackbridge achieves a 'D' band, which the NPSFM describes as *'moderate to high impact of suspended sediment on instream biota. Sensitive fish species may be lost'*

12.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state if water quality and aquatic ecosystem health at a site. Figure 40 summarises MCI scores for sites monitored for aquatic macroinvertebrates throughout the Dunedin Coast Rohe.

The MCI interim scores are somewhat comparable across sites with two of the four monitored sites returning MCI scores at or below the national bottom line (MCI 90). The NPSFM describes this state as *'reflecting a macroinvertebrate community indicative of sever organic pollution or nutrient enrichment.*

Communities are largely composed of taxa insensitive to inorganic pollution/nutrient enrichment'. Akatore Creek and the Tokomairiro at West Branch Bridge returned an MCI score above the national bottom line, achieving a 'C' grade.

The ASPM interim scores shown in Figure 40 generally reflect those of the MCI scores however Lindsay's Creek, despite having a 'D' grade for MCI, obtains an 'A' grade for ASPM, which the NPSFM describes as '*a community with mild to moderate loss of ecological integrity*'.

12.1.5 Human health for recreation (Rivers)

Figure 40 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 is generally poor across the Dunedin Coast Rohe, with all sites other than the Waitati River returning bacterial water quality below the national bottom line.

All sites have high background bacteria concentrations which may indicate an *E. coli* source that is affecting water quality even under low flow conditions, such as the presence of water fowl or stock, the urban streams may receive *E.coli* from urban infrastructure (drains).

12.2 Trend Analysis

Trend analysis results for the Dunedin Coast FMU is shown in Figure 42

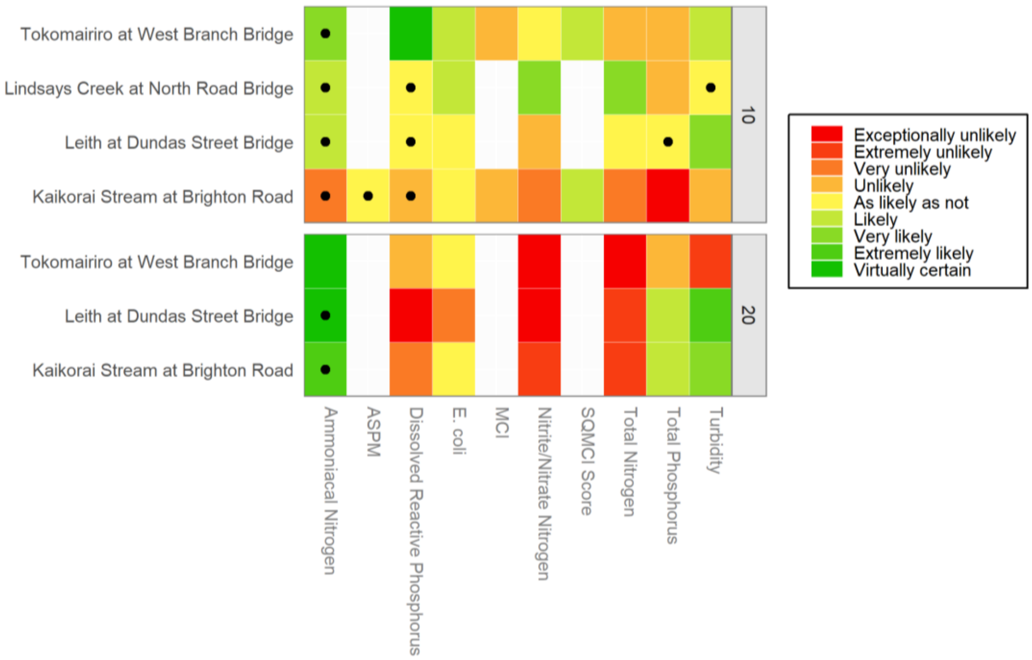


Figure 42 Summary of Upper Clutha sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2. Cells containing 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 Rohe rivers is shown in Figure 42, over a 10-year period the Kaikorai has an 'exceptionally unlikely' improving trend for TP and over a 20-year period an 'extremely unlikely' improving trend for NNN and TN.

In the Leith, over a 20-year period, there is an 'exceptionally unlikely' improving trend for DRP and NNN and in the Tokomairiro at West Branch Bridge, over a 10-year period there is a 'virtually certain' (improving) trend for DRP, but over the 20-year period there is an 'exceptionally unlikely' improving trend for NNN and TN.

12.3 Water quality summary Dunedin Coast FMU

The tables in this section summarise:

1) river and lake sites where attributes do not meet the national bottom line (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) summary of all trends using raw data for rivers and continuous data for lakes over the two time-periods

Table 24 Summary of river and lake state, red cells show where state does not meet the national bottom line in one or more variable. There is no national bottom line for DRP, but DRP (median and Q95) have been included in the table when sites achieve a band 'D'.

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Tokomairiro at W Br Br						■						■	
Tokomairiro at Lisnatunny						■					■		
Tokomairio at Blackbridge						■					■	■	■
Lindsay's Creek						■	■				■	■	
Leith at Dundas St				■		■							
Kaikorai at Brighton Rd						■	■			■		■	
Akatore Creek						■						■	

Table 25 Summary of river sites (not flow adjusted) where trends are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
Kaikorai Stream at Brighton Road						
Ammoniacal N	116	BiMonth	20	0	Extremely likely	↑↑↑
Nitrite/Nitrate N	116	BiMonth	20	0.008079	Extremely unlikely	↓↓↓
Total Nitrogen	116	BiMonth	20	0.007256	Extremely unlikely	↓↓↓
Total Phosphorus	56	BiMonth	10	0.000904	Exceptionally unlikely	↓↓↓↓
Leith at Dundas Street Bridge						
Ammoniacal N	115	BiMonth	20	0	Virtually certain	↑↑↑↑
Dissolved Reactive P	114	BiMonth	20	0.000377	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	115	BiMonth	20	0.012718	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	115	BiMonth	20	0.006574	Extremely unlikely	↓↓↓
Turbidity	115	BiMonth	20	-0.04083	Extremely likely	↑↑↑
Tokomairiro at West Branch Bridge						
Ammoniacal N	68	Qtr	20	-0.00038	Virtually certain	↑↑↑↑
Dissolved Reactive P	102	Month	10	-0.00038	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	68	Qtr	20	0.00677	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	68	Qtr	20	0.011153	Exceptionally unlikely	↓↓↓↓
Turbidity	68	Qtr	20	0.046185	Extremely unlikely	↓↓↓

Table 26 Overall summary of trends for the Dunedin Coast FMU using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend	1		4	7	9	8	3		1
Rivers - 20-year trend	2	2	1	2	2	2	2	4	4

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, the only site in Otago with this grade. *E.coli* was below the bottom line in seven of the eight sites monitored and TN returned a band 'D' in four of the eight sites monitored. The Kaikorai and Leith fail to meet the national bottom line for MCI.

These Dunedin City sites having a high degree of urbanisation with associated hardstanding requiring a stormwater network with point source discharges into the watercourses, these are likely to be conduits for contaminants during both wet and dry weather. Alongside the poor state, trend analysis shows that water quality in these urban streams continues to degrade. Over 20-years, the Kaikorai, Leith and Tokomairiro have degrading trends for TN and NNN, in addition the Kaikorai has a degrading trend for TP (10-years), the Leith for DRP (20-years) and the Tokomairio for turbidity (20-years)

There were three 'virtually certain' improving trends, two in the Tokomairiro at West Brach Bridge, and one in the Leith. 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 Dunedin Coast FMU, these sites include NH_4-N in the Tokomairo at West Branch Bridge (20-years) and NH_4-N in the Leith (10-years).

In summary:

- The Kaikorai has ammonia toxicity below the national bottom line
- Nutrient concentrations are generally high, four of eight sites achieve a 'D' band for total nitrogen, the other sites return a 'C' band
- Bacterial water quality is severely degraded at all monitoring sites other than the Waitati River.
- Trend analysis shows that in the Dunedin FMU there were more improving trends iIn the last 10-years than degrading trends.

13 North Otago FMU

Figure 43 Location of water quality monitoring sites in the North Otago FMU

13.1 State Analysis Results

The results of grading the SoE sites in the North Dunedin FMU according to the NPSFM NOF criteria are summarised in Figure 44 and mapped in Figure 45. Many sites in the North Otago 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.

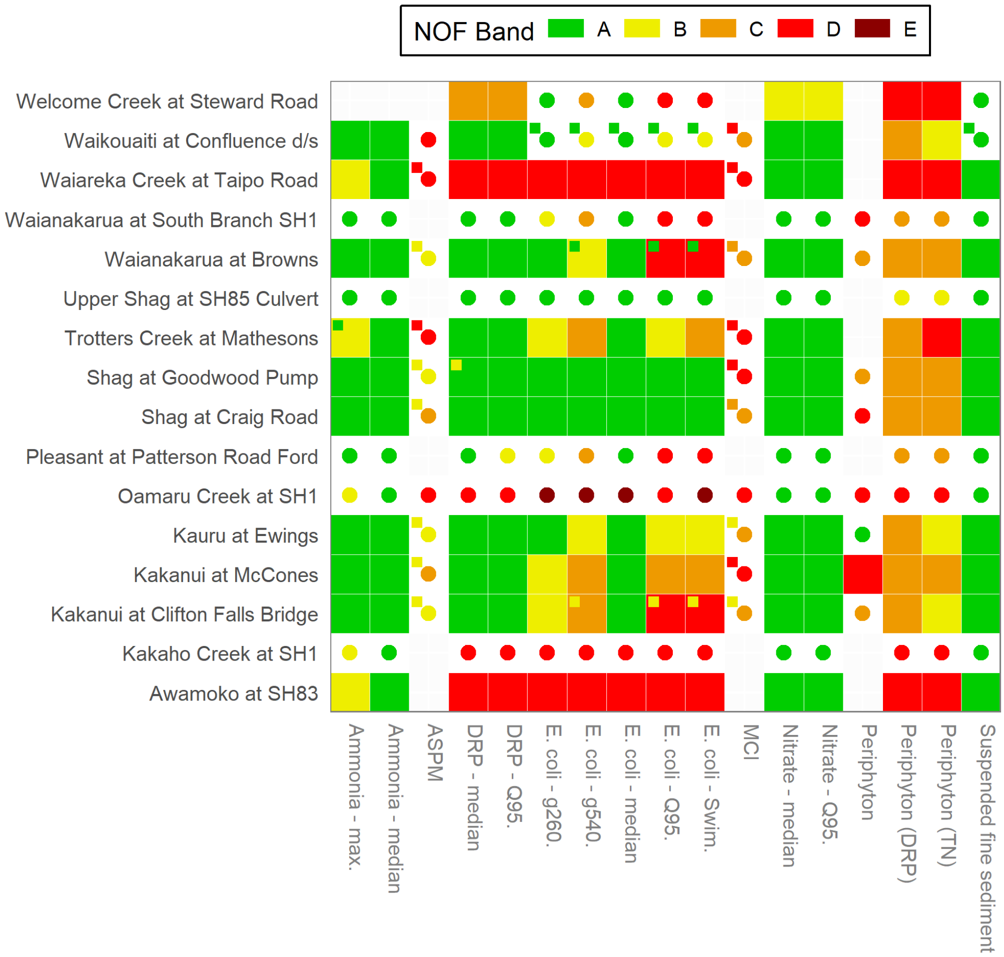


Figure 44 Grading of the river sites of the North Otago FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

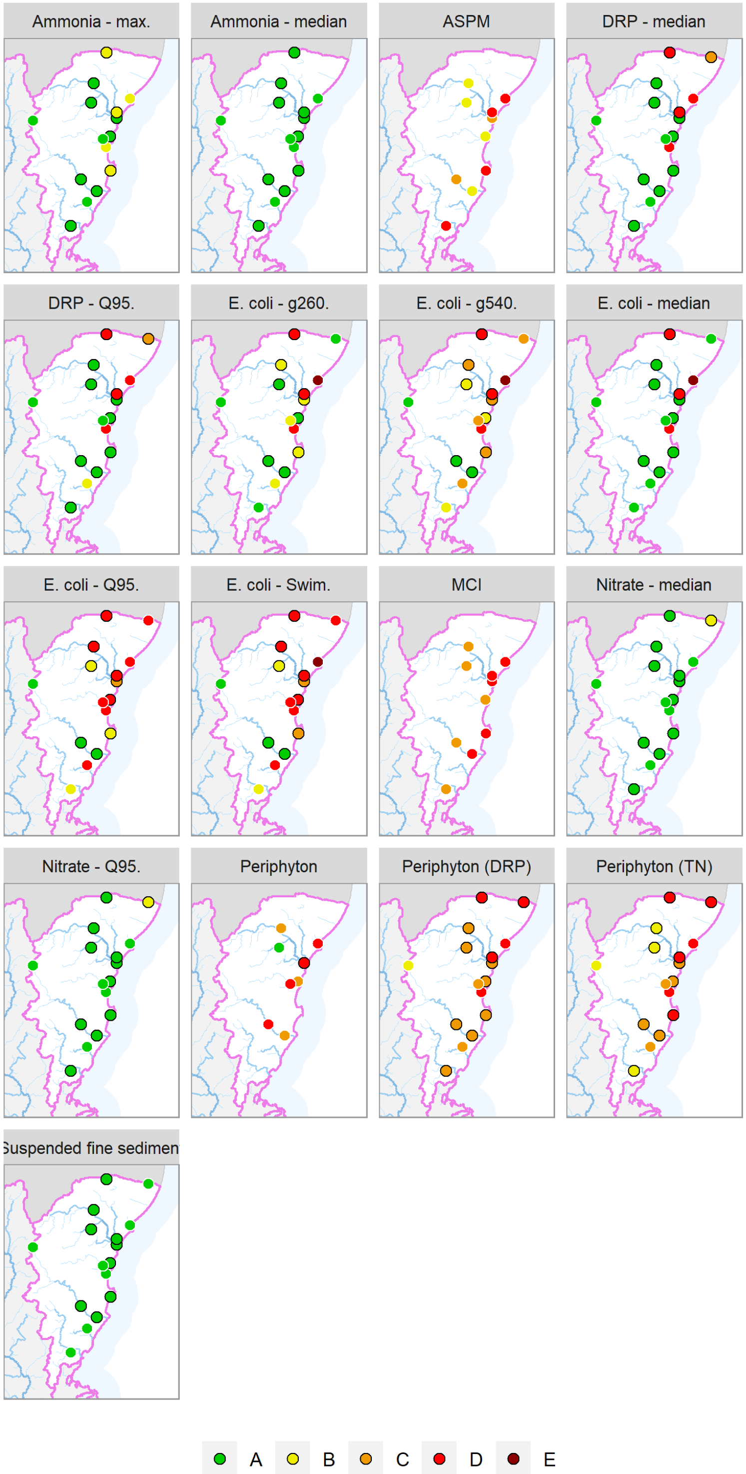


Figure 45 Maps showing North Otago FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines

13.1.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 44 (periphyton). Periphyton trophic state results to date show that the North Otago FMU returns mainly interim 'C' and 'D' bands. Kakanui at McCones, Oamaru Creek, Shag at Craig Road and the Waianakarua South Branch have interim results of 'D', below the national bottom line, this reflects an elevated nutrient enrichment and the possibility of regular nuisance blooms.

To manage the NPSFM periphyton attribute state (MfE, 2020) median concentrations of DRP and TN align to attribute bands (i.e., periphyton DRP and periphyton TN in Figure 44). Using the 20% exceedance criteria (mid-range), the TN median concentrations in the Dunedin Coast FMU are generally in or greater than the T200 mg chl-a/m2 band (band 'C' or 'D'). The DRP median concentrations in the Dunedin Coast FMU are also generally in the T200 mg chl-a/m2 band (equivalent to band 'C' or 'D'). The sites in band 'D' are the Awamoko, Kakaho Creek, Oamaru Creek and Waiareka Creek.

Figure 44 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the North Otago FMU show that most sites achieves band 'A'. Four sites, Awamoko, Kakaho Creek, Oamaru Creek, Waiareka Creek and Welcome Creek achieve a band 'D', which the NPSFM 2020 describes as '*ecological communities impacted by substantial DRP elevation above natural reference conditions*'.

13.1.2 Toxicants (Rivers)

NOF attribute bands for NH_4-N are shown for the North Otago sites in Figure 44, it should be noted that the national bottom line is below band 'B'. In the North Otago FMU 10 sites have excellent protection levels against ammonia toxicity with all sites returning an 'A' band (highest level of protection) for NH_4-N. The remaining sites, returned 'B' bands for the annual maximum. The NPSFM describes the 'B' band as *'ammonia starts impacting occasionally on the 5% most sensitive species'.*

NOF attribute bands for nitrate (measured as NNN) toxicity are given for North Otago sites in Figure 44, again the national bottom line is below band 'B'. In the North Otago FMU all sites achieve an 'A' band, other than Welcome Creek which achieves a 'B' band, the NPSFM describes 'B' band as NNN having *'some growth effect on up to 5% of species'*

13.1.3 Suspended fine sediment (Rivers)

The clarity results for the North Otago FMU are shown in Figure 44. 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'* (NPSFM, 2020).

13.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state of water quality and aquatic ecosystem health at a site. Figure 45 summarises MCI scores for sites monitored for aquatic macroinvertebrates throughout the North Otago FMU.

The MCI interim scores are low across all sites, five sites achieve a band 'C' and five are below the national bottom line, achieving a band 'D' which with NPSFM 2020 describes as a '*macroinvertebrate community indicative of severe organic pollution or nutrient enrichment*'.

The ASPM interim scores shown in Figure 44; four of the sites obtains a 'B' band however another four sites have MCI scores below the national bottom line. The Waikouaiti despite obtaining a 'C' grade for MCI, obtains a 'D' grade for ASPM.

13.1.5 Human health for recreation

Figure 44 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 is in the North Otago FMU is mixed, with eight of 16 sites returning bacterial water quality below the national bottom line. The NPSFM 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 three Shag River sites achieved an 'A' band.

13.2 Trend Analysis

Trend analysis results for the North Otago FMU is shown in Figure 46

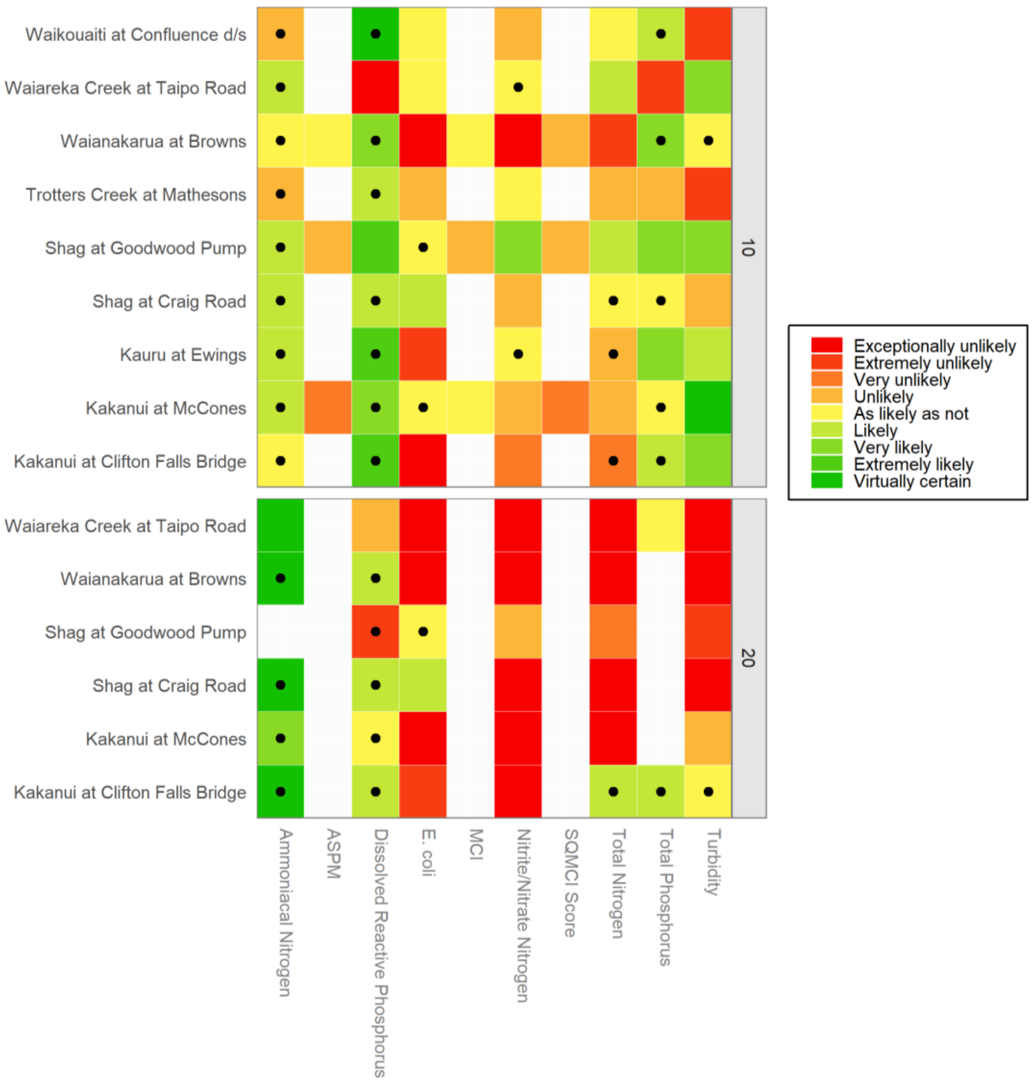


Figure 46 Summary of North Otago FMU sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2. *Cells containing 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 North Otago FMU rivers is shown in Figure 46. 'Virtually certain' or 'exceptionally unlikely' trends are indicated at most sites. Sites with 'exceptionally unlikely' or 'extremely unlikely' improving trends include:

- Waikouaiti at Confluence, turbidity (10-years)
- Waiareka Creek, *E.coli*, NNN, TN (10-years), *E.coli*, NNN, TN, turbidity (20-years)
- Waianakarua at Browns, NNN and over 20-years for *E.coli*, NNN (Figure 47), TN and turbidity Kakanui at Clifton over 10-years for *E.coli* and over 20-years for NNN.
- Trotters Creek, turbidity (10-years)
- Shag at Goodwood, DRP, turbidity (20-years), Shag at Craig Road, NNN, TN, turbidity (20-years)
- Kakanui at McCones, *E.coli*, NNN, TN (20-years)
- Kakanui at Clifton, *E.coli* (10-years), *E.coli*, NNN (20-years).

Sites with 'virtually certain' or 'extremely likely 'improving trends include:

- Waikouaiti at Conflucence, DRP (10-years)
- Kakanui at McCones, turbidity (10-years)
- NH_4-N (20-years) for Waiareka Creek, Waianakarua at Browns, Shag at Craig Road and Kakanui at Clifton Falls.

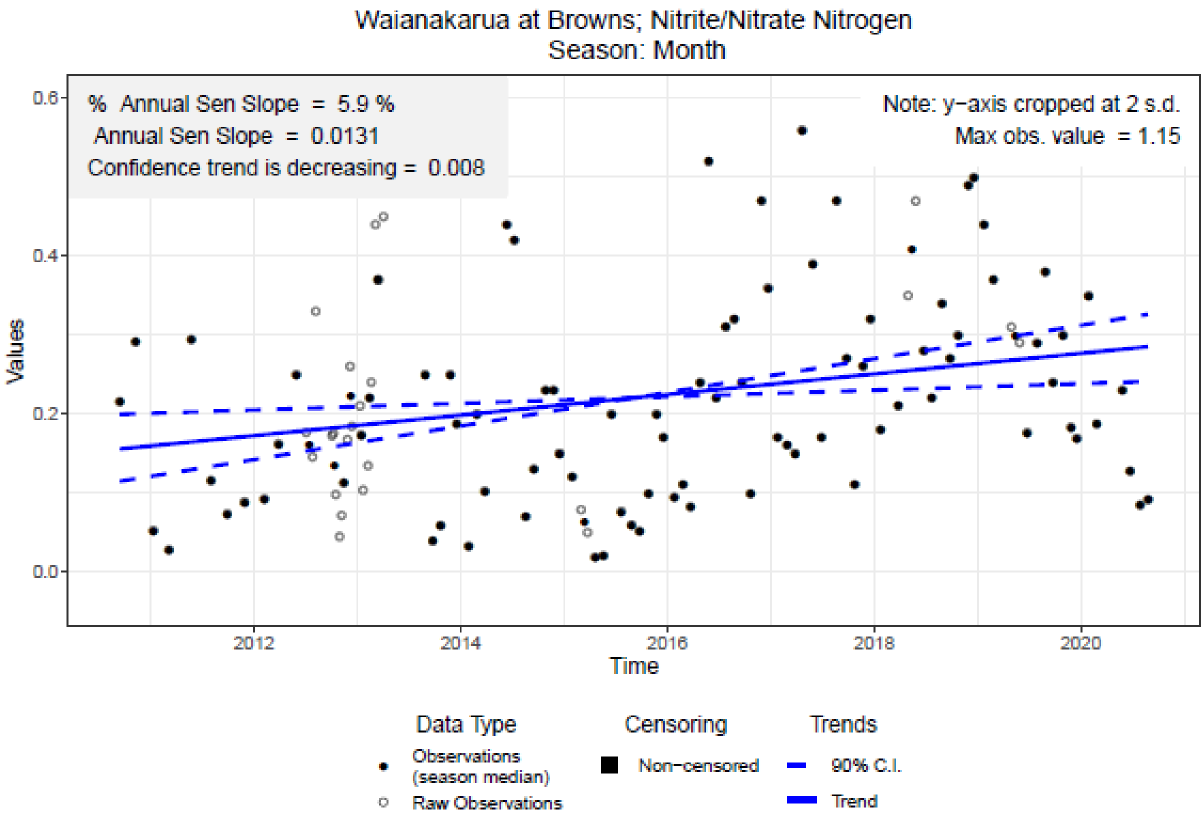


Figure 47 Waianakarua River, 10-year trend in Nitrite/Nitrate Nitrogen

13.3 Water quality summary North Otago FMU

The tables in this section summarise:

1) river and lake sites where attributes do not meet the national bottom line (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) summary of all trends using raw data for rivers and continuous data for lakes over the two time-periods

Table 27 Summary of river and lake state, red cells show where state does not meet the national bottom line in one or more variable . There is no national bottom line for DRP, but DRP (median and Q95) have been included in the table when sites achieve a band 'D'.

Site Name	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Welcome Creek						■					■	■	
Waikouaiti			■										
Waiareka Creek				■	■	■	■				■	■	
Waianakarua						■							
Trotters Creek			■				■					■	
Shag at Goodwood							■						
Shag at Craig Road										■			
Pleasant River							■						
Oamaru Creek			■	■	■	■	■			■	■	■	
Kakanui at McCones							■			■			
Kakanui at Clifton						■	■						
Kakaho Creek				■	■	■					■	■	
Awamoko				■	■	■					■	■	

Table 28 Summary of river sites where trends are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined Table 2

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
Kakanui at Clifton Falls Bridge						
Ammoniacal N	111	BiMonth	20	0	Virtually certain	↑↑↑↑
Dissolved Reactive P	104	Month	10	0	Extremely likely	↑↑↑
E. coli	109	Month	10	5.728637	Exceptionally unlikely	↓↓↓↓
E. coli	110	BiMonth	20	1.839	Extremely unlikely	↓↓↓
Nitrite/Nitrate N	111	BiMonth	20	0.00064	Exceptionally unlikely	↓↓↓↓
Kakanui at McCones						
E. coli	114	BiMonth	20	2.005766	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	114	BiMonth	20	0.013947	Exceptionally unlikely	↓↓↓↓
SQMCI Score	10	Year	10	-0.1021	Very unlikely	↓↓
Total Nitrogen	113	BiMonth	20	0.016878	Exceptionally unlikely	↓↓↓↓
Turbidity	102	Month	10	-0.03946	Virtually certain	↑↑↑↑
Kauru at Ewings						
Dissolved Reactive P	57	BiMonth	10	0	Extremely likely	↑↑↑
E. coli	102	Month	10	2.461253	Extremely unlikely	↓↓↓
Shag at Craig Road						
Ammoniacal N	110	BiMonth	20	0	Virtually certain	↑↑↑↑
Nitrite/Nitrate N	110	BiMonth	20	0.005144	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	110	BiMonth	20	0.008768	Exceptionally unlikely	↓↓↓↓
Turbidity	110	BiMonth	20	0.020714	Exceptionally unlikely	↓↓↓↓
Shag at Goodwood Pump						
Dissolved Reactive P	103	Month	10	-0.00024	Extremely likely	↑↑↑
Dissolved Reactive P	111	BiMonth	20	0	Extremely unlikely	↓↓↓
Turbidity	114	BiMonth	20	0.012219	Extremely unlikely	↓↓↓
Trotters Creek at Mathesons						
Turbidity	58	BiMonth	10	0.066027	Extremely unlikely	↓↓↓
Waianakarua at Browns						
Ammoniacal N	114	BiMonth	20	0	Virtually certain	↑↑↑↑
E. coli	100	Month	10	8.860577	Exceptionally unlikely	↓↓↓↓
E. coli	113	BiMonth	20	1.501027	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	102	Month	10	0.013059	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	111	BiMonth	20	0.007787	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	102	Month	10	0.013379	Extremely unlikely	↓↓↓
Total Nitrogen	111	BiMonth	20	0.007521	Exceptionally unlikely	↓↓↓↓
Turbidity	114	BiMonth	20	0.012135	Exceptionally unlikely	↓↓↓↓
Waiareka Creek at Taipo Road						
Ammoniacal N	114	BiMonth	20	-0.00079	Virtually certain	↑↑↑↑
Dissolved Reactive P	105	Month	10	0.008087	Exceptionally unlikely	↓↓↓↓
E. coli	114	BiMonth	20	6.725544	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	114	BiMonth	20	0.022186	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	114	BiMonth	20	0.03203	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	106	Month	10	0.00644	Extremely unlikely	↓↓↓
Turbidity	114	BiMonth	20	0.037376	Exceptionally unlikely	↓↓↓↓
Waikouaiti at Confluence d/s						
Dissolved Reactive P	32	Qtr	10	0	Virtually certain	↑↑↑↑
Turbidity	48	BiMonth	10	0.04634	Extremely unlikely	↓↓↓

Table 29 Overall summary of trends for the North Otago FMU using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend	2	3	9	13	17	15	4	5	4
Rivers - 20-year trend	4		1	6	4	3	1	3	15

In the North Otago FMU all sites other than the Kauru and Upper Shag return at least one attribute band below the national bottom line. All sites return 'A' or 'B' bands for ammonia and nitrate toxicity, and all sites return 'A' bands for suspended fine sediment. 'D' bands are returned for DRP in four of the 16 sites, for *E.coli* in eight of the 16 sites and for periphyton in four of the eight sites monitored. Macroinvertebrate metrics were generally in the 'C' or 'D' bands.

The urban stream, Oamaru Creek returns the most 'D' bands, likely due to the influence or urban run-off on the Creek, Waiareka Creek and the Awamoko also return mostly 'D' bands but these sites are in a rural setting.

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 'exceptionally unlikely' improving trends, Clifton Falls (*E.coli*), Waianakarua (*E.coli*, NNN, TN) and Waiareka Creek (DRP, TP). 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 NH_4-N and DRP at the Kakanui at Clifton site, DRP at Ewings, NH_4-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.

In summary:

- All sites are in the 'A' or 'B' band for ammonia and nitrate toxicity
- TN concentrations are generally low enough to meet the 20% spatial exceedance criteria for periphyton growth. DRP does not meet this criteria at four sites (Awamoko, Kakaho, Oamaru Creek and Waiareka Creek).
- Bacterial water quality is severely degraded at eight of the 15 monitoring sites. The three Shag River sites attain an 'A' grade for E. coli.
- Trend analysis shows that in the North Otago there were fewer degrading trends over the last 10-years compared to the last 20-years. In the last 10-years there are also more improving trends than degrading trends.
- Over the last 10-years, the Waianakarua has three 'extremely likely' or 'exceptionally unlikely' improving trends, more than any of the other North Otago sites.

14 Catlins FMU

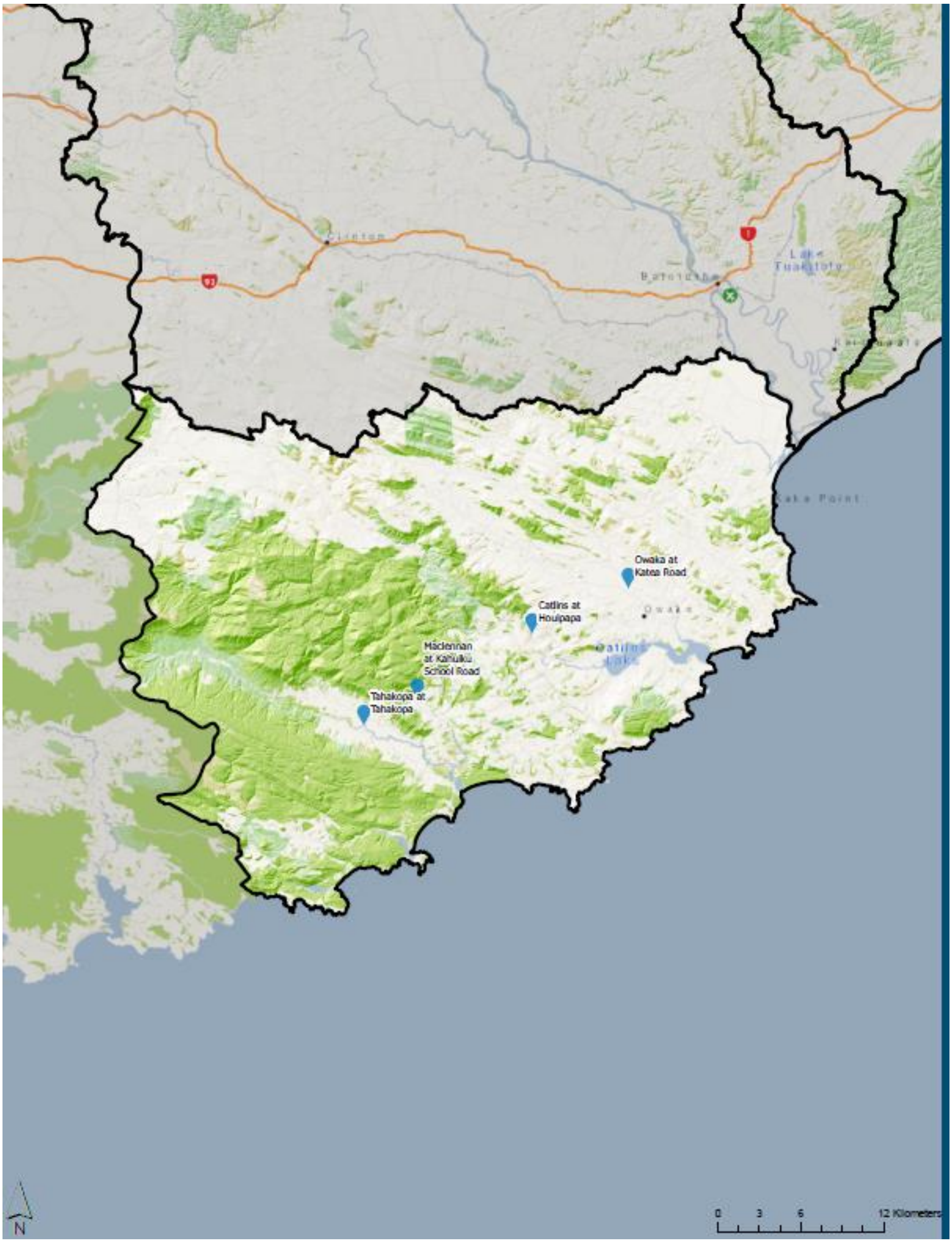


Figure 48 Location of water quality monitoring sites in the Catlins FMU

14.1 State Analysis Results

The results of grading the SoE sites in the Catlins FMU based on the NPSFM NOF criteria are summarised in Figure 49 and mapped in Figure 50. 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

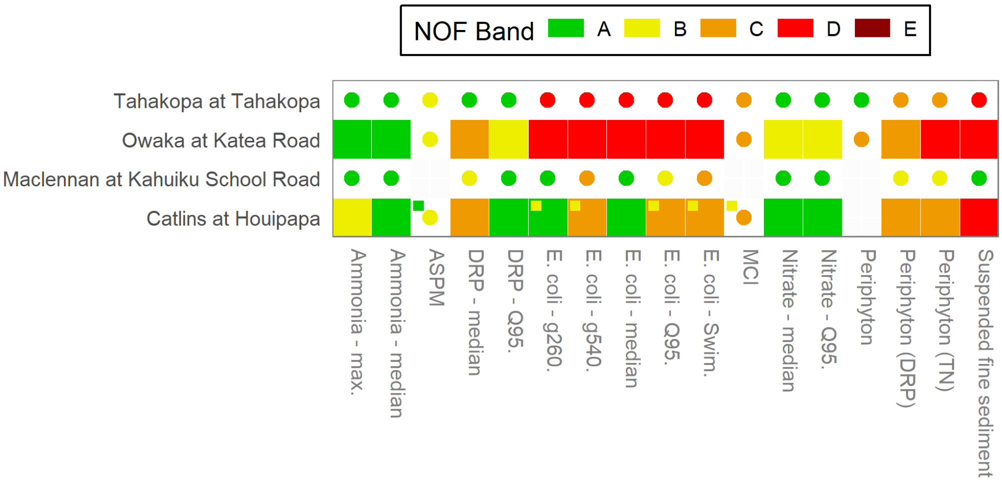


Figure 49 Grading of the river sites of the Catlins FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

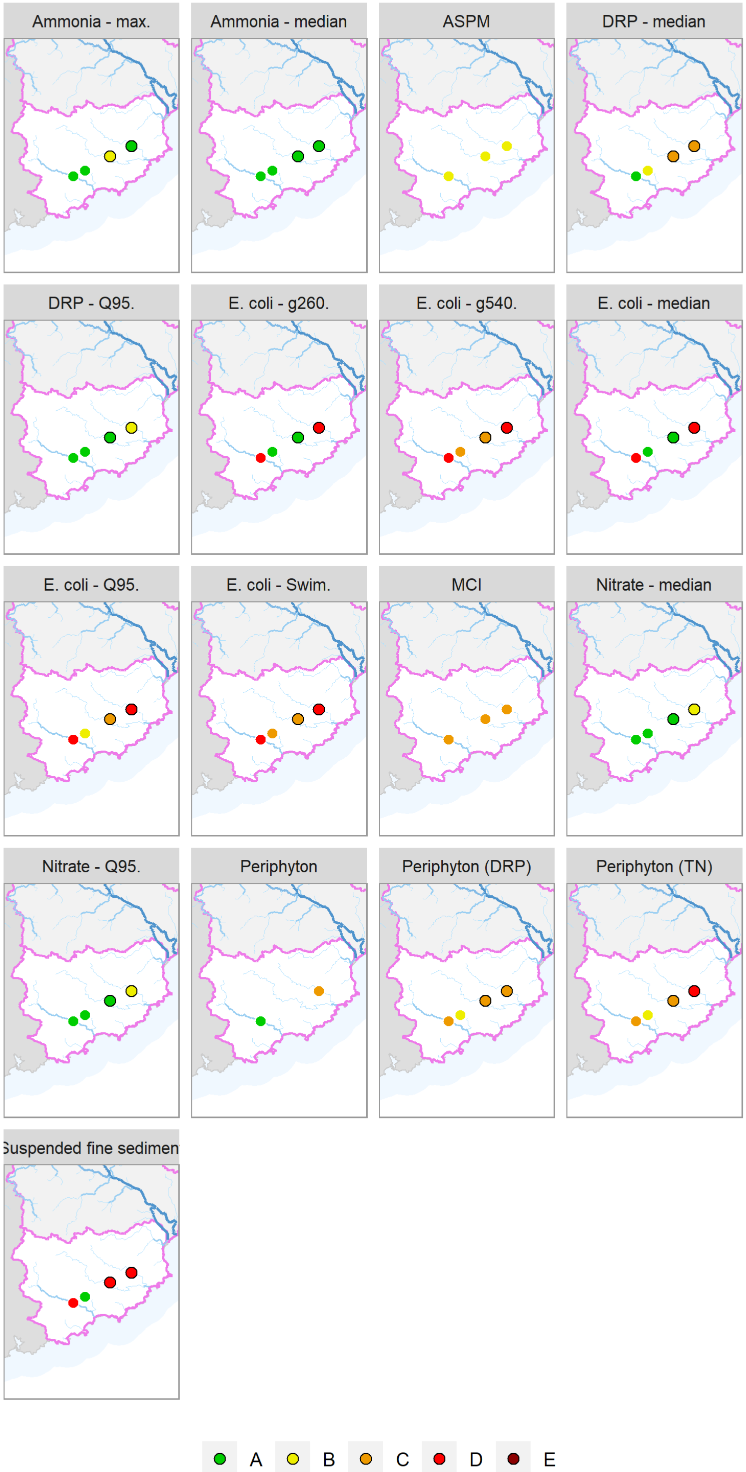


Figure 50 Maps showing Catlins FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

14.1.1 Periphyton and Nutrients

Periphyton trophic state results to date are given in Figure 49 and show that of the two sites monitored in the Catlins FMU, the Tahakopa returns an interim 'A' band as few results exceed 50 chl-*a*/m^2 reflecting low nutrient enrichment and the Owaka returned a 'C' band reflecting a more nutrient rich environment.

To manage the NPSFM periphyton attribute state (MfE, 2020) median concentrations of DRP and TN align to attribute bands (i.e., periphyton DRP and periphyton TN in Figure 49). Using the 20% exceedance criteria (mid-range), the TN median concentrations in the Catlins FMU are generally in or greater than the T200 mg chl-a/m2 band ('C' or 'D'). The DRP median concentrations in the Dunedin Coast FMU are generally in the T200 mg chl-a/m2 band (band 'C').

Figure 49 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Catlins Rohe show that one site achieves an 'A' band (Tahakopa), one site a 'B' band (Maclennan) and two sites a 'C' band (Catlins and Owaka). The NPSFM 2020 describes band 'C' as *'Ecological communities impacted by moderate DRP elevation above natural reference conditions. If other coditions 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'*

14.1.2 Toxicants (Rivers)

NOF attribute bands for NH_4-N are given in Figure 49, the national bottom line for toxicants is below band 'B'. The Catlins FMU has three sites returning an 'A' band (highest level of protection) for NH_4-N. The remaining site (the Catlins) returned a 'B' band for the annual maximum. The NPSFM describes the 'B' band as *'ammonia starts impacting occasionally on the 5% most sensitive species'.*

NOF attribute bands for nitrate (measured as NNN) toxicity are given in Figure 49. In the Catlins FMU all sites achieve an 'A' band, other than the Owaka which achieves a 'B' band across both statistical metrics, the NPSFM describes 'B' band as NNN having *'some growth effect on up to 5% of species'*

14.1.3 Suspended fine sediment (Rivers)

The suspended fine sediment results for the Catlins FMU are shown in Figure 49. Most sites return a NOF band of 'D' which denotes '*high limpact 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*' (NPSFM, 2020). The Maclennan returns a band of 'B'.

14.1.4 Aquatic Life (Rivers)

Macroinvertebrate Community Index (MCI) scores provide an integrated indicator of the general state of water quality and aquatic ecosystem health at a site. Figure 49 summarises MCI scores for sites monitored for aquatic macroinvertebrates throughout the Catlins FMU.

All sites return an MCI score between 90 and 110, or a band 'C' reflecting a macroinvertebrate community indicative of moderate organic pollution or nutrient enrichment. Figure 49 also summarises ASPM scores for sites monitored for aquatic macroinvertebrates throughout the Catlins FMU. All sites return an ASPM score between 0.4 and 0.6, or a band 'B' reflecting a macroinvertebrate community indicative of mild to moderate loss of ecological integrity.

14.1.5 Human health for recreation (Rivers)

Figure 49 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 is quite poor across the Catlins FMU, with two sites; Owaka and Tahakopa, returning bacterial water quality below the national bottom line on all four statistical metrics. The other two sites return an overall 'C' band despite returning 'A' band median scores.

14.2 Trend Analysis

Trend analysis results for the Catlins River is shown in Figure 51. Over a 20-year period the Catlins has 'exceptionally unlikely' improving trends for *E.coli*, NNN and TN, with an 'extremely unlikely' improving trend for TP. In the shorter timefrme there are three 'extremely likely' or 'virtually certain' improving trends for NH_4-N, DRP and turbidity. There are no degrading trends in the last 10-years.

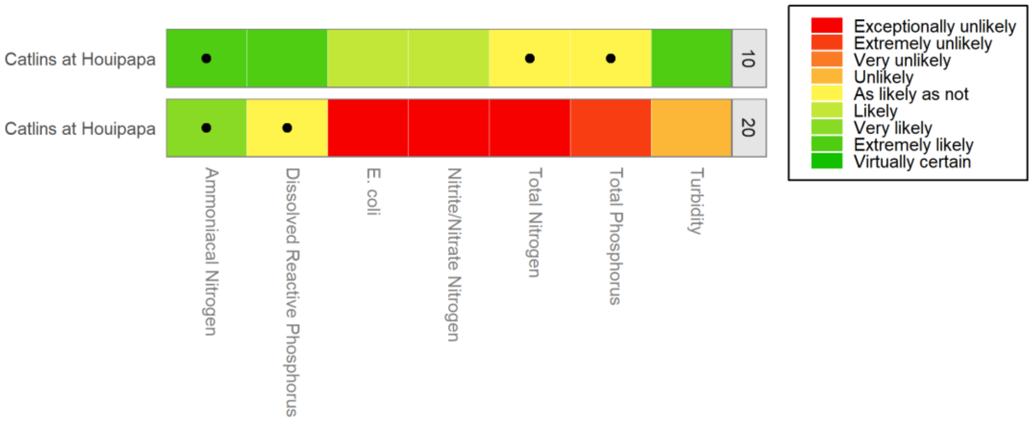


Figure 51 Summary of Upper Clutha sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 2. *Cells containing 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*

14.3 Water quality summary Catlins FMU

The tables in this section summarise:

1) river and lake sites where attributes where the national bottom line is not met (NPSFM, 2020)
2) trends in river and lake sites when the trends are greater than 'likely' or 'unlikely'
3) all trends using raw data for rivers and continuous data for lakes over the two time-periods

Table 30 Summary of river and lake state, red cells show where state does not meet the national bottom line in one or more variable

sID	NH_4N - *max*	NH_4N - *median*	ASPM	DRP - median	DRP – Q95	*E.coli*	MCI	NNN - median	NNN – Q95	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Tahakopa at Tahakopa													
Owaka at Katea Road													
Catlins at Houipapa													

Table 31 Summary of river sites where trends (raw data) are greater than 'likely' or 'unlikely'. Confidence is expressed categorically based on the levels defined in Table 2

Analyte	#Obs	Frequency	Period	AnnualSenSlope	Confidence	Descriptor
			Catlins at Houipapa			
Ammoniacal N	102	Month	10	0	Extremely likely	↑↑↑
Dissolved Reactive P	101	Month	10	-0.00032	Extremely likely	↑↑↑
E. coli	114	BiMonth	20	3.066082	Exceptionally unlikely	↓↓↓↓
Nitrite/Nitrate N	114	BiMonth	20	0.007367	Exceptionally unlikely	↓↓↓↓
Total Nitrogen	114	BiMonth	20	0.007508	Exceptionally unlikely	↓↓↓↓
Total Phosphorus	113	BiMonth	20	0.000292	Extremely unlikely	↓↓↓
Turbidity	101	Month	10	-0.14904	Extremely likely	↑↑↑

Table 32 Overall summary of trends for the Catlins FMU using raw data for rivers and continuous data for lakes. Confidence is expressed categorically based on the levels defined in Table 2

	Virtually certain	Extremely likely	Very likely	Likely	As likely as not	Unlikely	Very unlikely	Extremely unlikely	Exceptionally unlikely
Descriptor	↑↑↑↑	↑↑↑	↑↑	↑	↔	↓	↓↓	↓↓↓	↓↓↓↓
Rivers - 10-year trend		3	2		2				
Rivers - 20-year trend					1	1	1		3

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 toxicity. The Owaka and Tahakopa return 'D' bands for *E.coli* and 'C' bands are returned for MCI at all sites. Suspended fine sediment returns 'D' bands at all sites other than the Maclennan, which achieves an 'A' band.

There were three 'extremely likely' or 'very likely' improving trends in the Catlins in the last 10-years (NH_4N, DRP and turbidity). 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 Catlins River, this was true for NH_4N, (Table 31).

In summary:

- All sites are in the 'A' or 'B' band for ammonia and nitrate toxicity
- TN and DRP concentrations are low enough to meet the 20% spatial exceedance criteria for periphyton growth, other than TN at Owaka.
- Bacterial water quality is degraded in the Owaka and Tahakopa.
- Trend analysis for the Catlins shows four 'extremely, or exceptionally unlikely' improving trends over 20-years for *E.coli*, NNN, TP and TN.
- There were no degrading trends over the last 10-years.

15 **Otago Summary**

This section gives an overview of water quality state and water quality trends across Otago.

15.1 Otago Overview: Water Quality State

Table 33 shows a summary of lake sites where attributes fall below the national bottom line. All lakes do not meet the NPSFM national bottom line for chlorophyll a and Lake Tuakitoto does not meet the NPSFM national bottom line for TN and TP.

Table 33 Summary of lake sites where attributes fall below the NPSFM national bottom line

FMU/Rohe	*Site Name*	*Chlorophyll a max*	*Chlorophyll a median*	*TN*	*TP*
Dunstan Rohe	Lake Johnson at South Beach				
	Lake Hayes at Mid Lake 10m				
Dunedin Coast FMU	Lake Tuakitoto at Outlet				

Table 34 details all river sites where attributes do not meet the NPSFM bottom line. The table shows that 46 sites do not meet the NPSFM bottom line for *E.coli* and 40 sites did not meet the NPSFM bottom line for suspended fine sediment and for DRP 14 sites were in band 'D' (ecosystem health) attribute.

The Ministry for the Environment produced guidance (MfE, 2020) for defining nutrient concentrations to manage the NPSFM periphyton attribute states in rivers. The guidance is centered around spatial exceedances for TN and DRP. TN and DRP median concentrations are compared to the spatial exceedance criteria of 20%. At this level there is some risk (ie, 20%) that the chlorophyll *a* response at some sites will exceed the desired chlorophyll *a* threshold, even if the DRP or TN concentration targets are achieved. Results in Table 34 show that 25 sites for TN and 23 sites for DRP were elevated above the the 20% exceedance criteria.

Table 34 Summary of river sites where attributes fall below the NPSFM national bottom line. There is no national bottom line for DRP, but DRP (median and Q95) have been included in the table when sites achieve band 'D'.

FMU/Rohe	sID	ASPM	DRP - median	DRP – Q95	E.coli	MCI	Periphyton	Periphyton (DRP)	Periphyton (TN)	Suspended fine sediment
Upper Lakes Rohe	Timaru Creek									■
	Rees River				■					■
	Quartz Creek				■					
	Ox Burn									■
	Makarora River				■					■
	Invincible Creek									■
	Horn Creek									
	Dart River									■
	Bullock Creek				■		■		■	
	Buckler Burn									■
Dunstan Rohe	Upper Cardrona				■					■
	Quartz Reef Creek									■
	Mill Creek	■				■				■
	Lindis at Peak									■
	Kawarau at Chards				■					
	Clutha at Luggate									■
Manuherekia Rohe	Thomsons Creek at SH85		■	■	■			■	■	■
	Poolburn at Cob Cottage		■	■				■		■
	Manuherikia d/s Fork									
	Manuherikia at Ophir				■					■
	Manuherikia at Galloway				■					■
	Manuherikia at Blackstone									■
	Hills Creek				■					
	Dunstan Creek									
Roxburgh	Teviot at Bridge Huts				■					■
	Fraser at Old Mans Range									
	Clutha at Millers Flat									
	Benger burn at SH8				■			■	■	■
Lower Clutha Rohe	Waiwera at Maws Farm		■	■	■			■	■	
	Waiwera at Confluence	■				■				
	Waitahuna at Tweeds Bridge				■			■		■
	Wairuna at Millar Road		■	■	■	■		■	■	■
	Waipahi at Waipahi					■			■	■
	Waipahi at Cairns Peak				■			■	■	
	Upper Pomahaka at Aitchison Runs Road				■					
	Tuapeka at 700m u/s bridge		■		■			■		
	Pomahaka at Glenken				■					
	Pomahaka at Burkes Ford				■				■	■
	Lovells Creek at Station Road				■				■	
	Heriot Burn at Park Hill Road		■	■	■			■	■	■
	Crookston Burn at Kelso Road		■	■	■			■	■	■
	Clutha at Balclutha				■					■
	Blackcleugh Burn at Rongahere Road				■					
Taieri FMU	Taieri at Waipiata							■		■
	Taieri at Tiroiti									■
	Taieri at Sutton									■
	Taieri at Puketoi									■
	Taieri at Patearoa							■		■
	Taieri at Outram									■
	Taieri at Creamery		■	■				■		■
	Taieri at Allanton Bridge				■					■
	Silverstream at Taieri Depot				■				■	
	Owhiro Stream		■		■			■	■	■
	Meggat Burn				■					■
	Contour Channel				■			■		
Dunedin Coast	Tokomairiro at W Br Br				■				■	
	Tokomairiro at Lisnatunny				■			■		
	Tokomairio at Blackbridge				■			■	■	■
	Lindsay's Creek				■	■		■	■	
	Leith at Dundas St		■		■					
	Kaikorai at Brighton Rd				■	■	■		■	
North Otago FMU	Akatore Creek				■				■	
	Welcome Creek				■			■	■	
	Waikouaiti	■								
	Waiareka Creek		■	■	■	■		■	■	
	Waianakarua				■					
	Trotters Creek	■				■			■	
	Shag at Goodwood					■				
	Shag at Craig Road						■			
	Pleasant River					■				
	Oamaru Creek	■	■	■	■	■	■	■	■	
	Kakanui at McCones					■	■			
	Kakanui at Clifton				■	■				
	Kakaho Creek		■	■	■			■	■	
	Awamoko		■	■	■			■	■	
Catlins	Tahakopa at Tahakopa				■					■
	Owaka at Katea Road				■				■	■
	Catlins at Houipapa									■

15.2 Otago Overview: Water Quality Trends

Figure 52 and Figure 53 show colour coded bar charts representing the proportions of sites with trends indicating improving and degrading water quality based on the categories defined in Table 2 for the 10- and 20-year trend periods, respectively. These plots show that 20-year trends were predominantly degrading for all variables apart from ammoniacal nitrogen and for the 10-year trend period the predominant trend direction was variable by water quality variable. Interpretation of these plots should also take into account that there were variable nmbers of sites included in the different time-periods (Table 3)

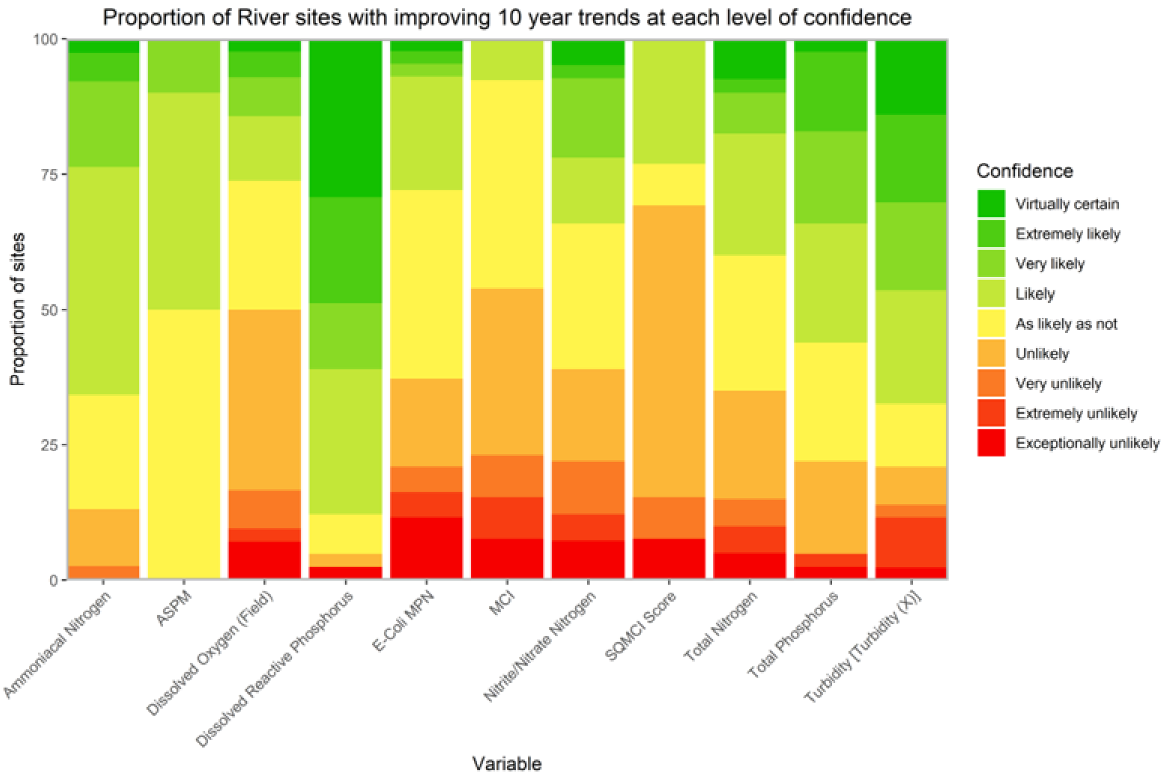


Figure 52 Summary plot representing the proportion of river sites with improving 10-year time-period trends at each categorical level of confidence. The plot shows the proportion of sites for which the trend indicated improving water quality at levels of confidence defined in Table 2. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends. Trends used in this graph are not flow-adjusted, and have a hi-censor filter applied.

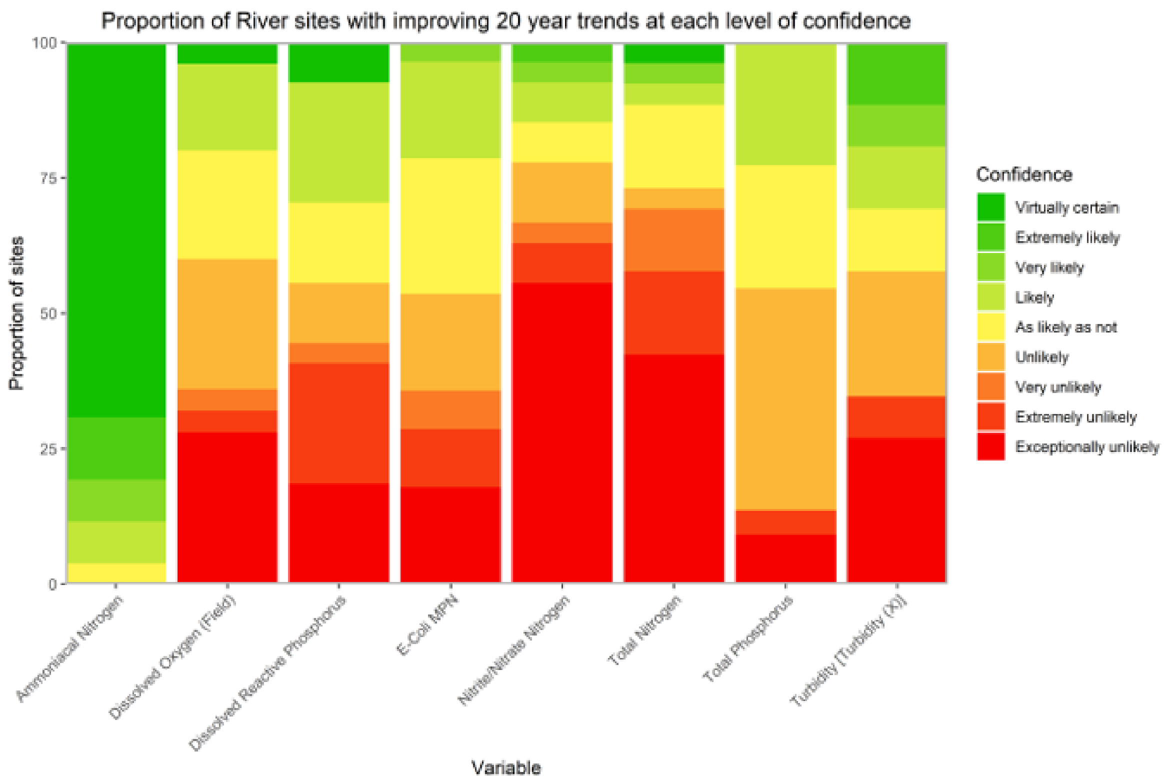


Figure 53 Summary plot representing the proportion of river sites with improving 20-year time-period trends at each categorical level of confidence. The plot shows the proportion of sites for which the trend indicated improving water quality at levels of confidence defined inTable 2.. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends. Trends used in this graph are not flow-adjusted, and have a hi-censor filter applied.

LWP (2020b) provides maps showing trend direction for rivers across Otago, the 10-year raw water quality trend direction is shown in Figure 54 and the 20-year raw water quality trend direction in Figure 55

Figure 54 Map of river sites classified by confidence that their 10-year raw water quality trend direction indicated improving water quality. Confidence is expressed categorically based on the levels defined in Table 2. LWP (2020b)

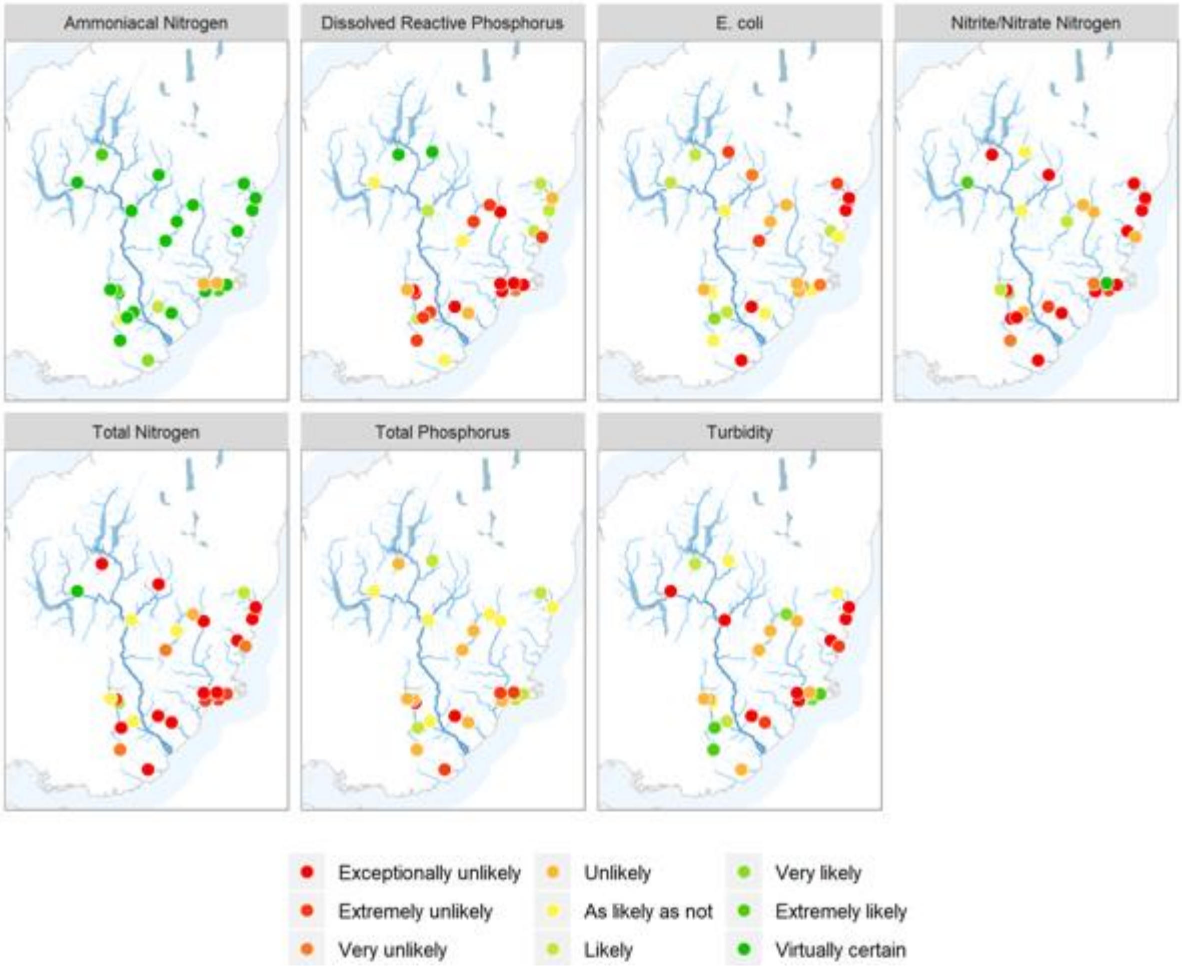


Figure 55 Map of river sites classified by confidence that their 20-year raw water quality trend direction indicated improving water quality. Confidence is expressed categorically based on the levels defined in Table 2 LWP. (2020b)

LWP (2020b) also provide maps for lake trend direction, these are shown in Figure 56 and Figure 57Figure 56 *Map of lake sites classified by confidence that their 10-year water quality trend direction indicated improving water quality.* Confidence is expressed categorically based on the levels defined inTable 2. LWP (2020b)

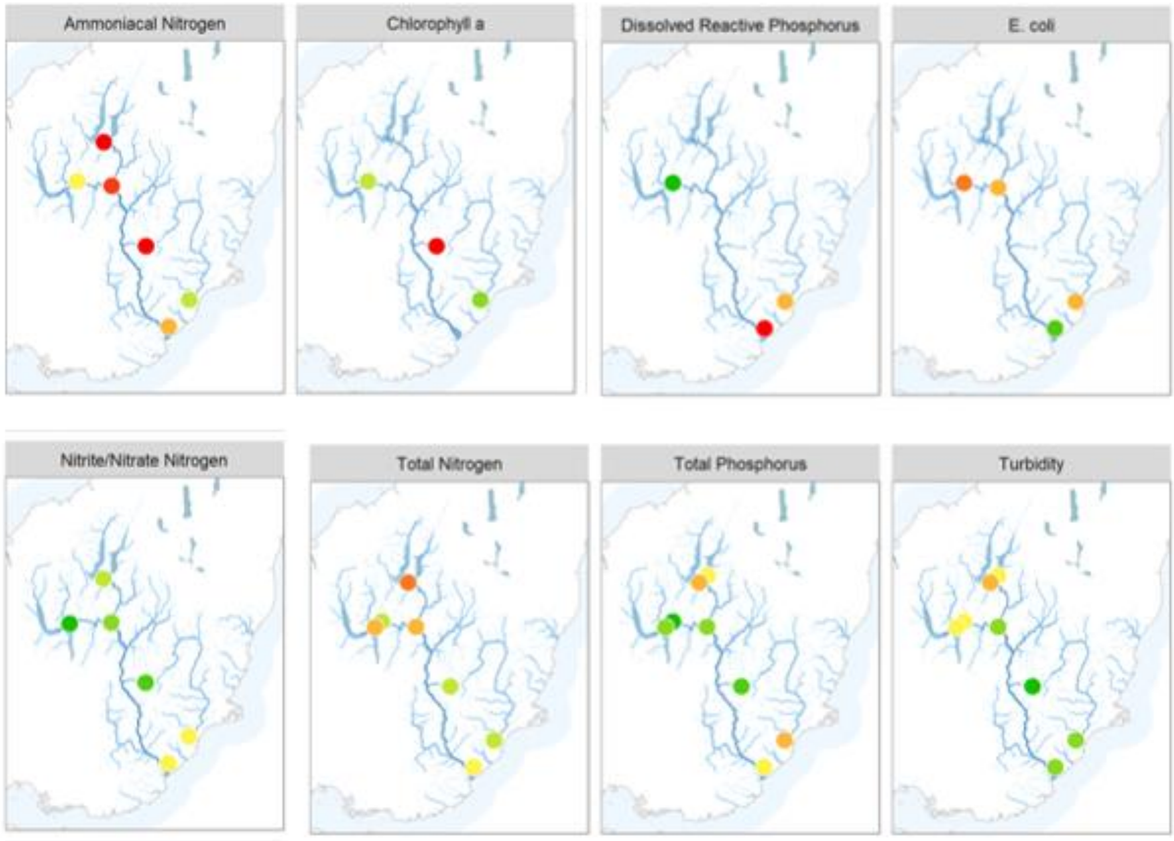


Figure 56 Map of lake sites classified by confidence that their 10-year water quality trend direction indicated improving water quality. Confidence is expressed categorically based on the levels defined inTable 2. LWP (2020b)

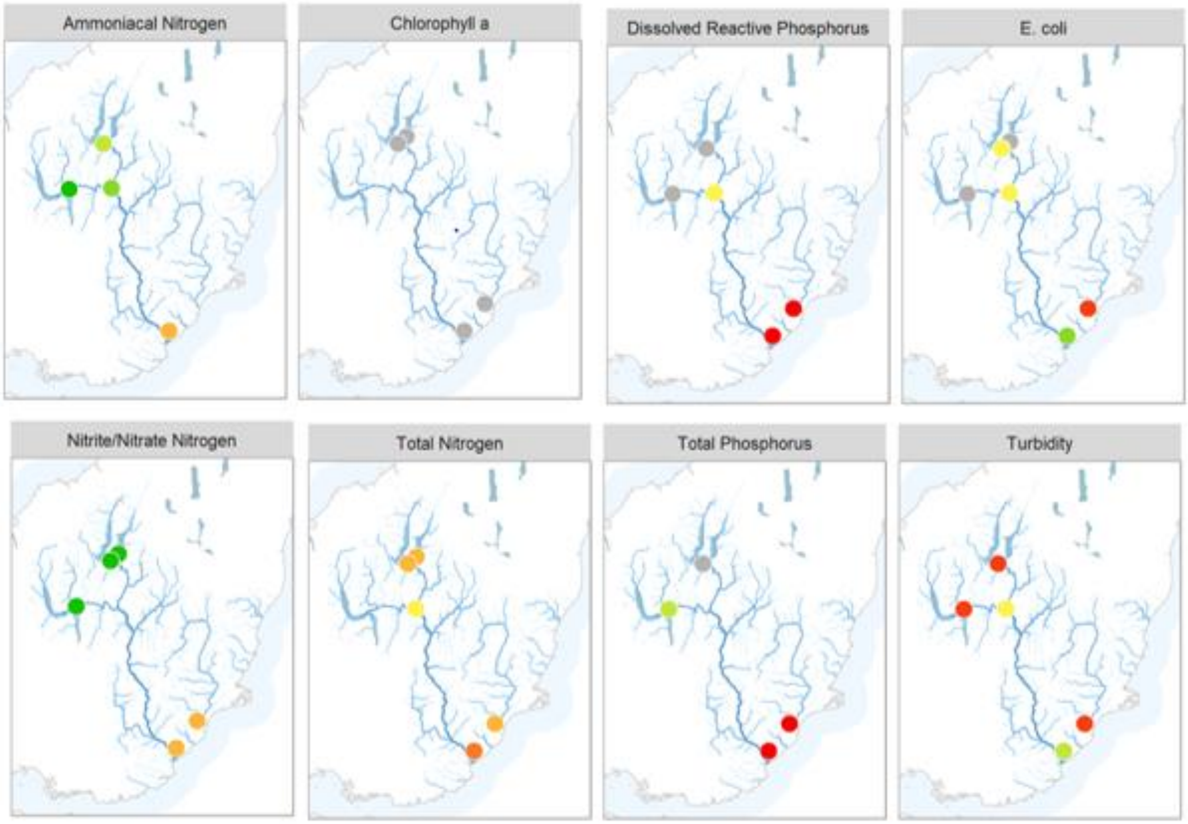


Figure 57 Map of lake sites classified by confidence that their 18-year water quality trend direction indicated improving water quality. Confidence is expressed categorically based on the levels defined inTable 2. LWP (2020b)

Acknowledgements

Thanks to LWP Ltd for calculation of state and trend metrics, provision of the summary maps and matrices and for assistance and support. Thanks also to ORC's Environmental Monitoring team for their collection of surface water samples, there would be no report without them. Finally, thanks to Jason Augspurger and Hugo Borges for overall helpfulness.

References

ANZECC, A., 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra:1–103.

Biggs, B. (2000) New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams. NIWA Client Report. Report no., 116 pp.

Burdon, F.J.; McIntosh, A.R.; Harding, J.S. Habitat loss drives threshold response of benthic invertebrate communities to deposited sediment in agricultural streams. Ecol. Appl. 2013, 23, 1036–1047

Clapcott J, Young R, Sinner J, Wilcox M, Storey R, Quinn J, Daughney C, Canning A, 2018. Freshwater biophysical ecosystem health framework. Prepared for Ministry for the Environment. Cawthron Report No. 3194. 89 p. plus appendices.

Choquette, A.F., R.M. Hirsch, J.C. Murphy, L.T. Johnson, and R.B. Confesor Jr, 2019. Tracking Changes in Nutrient Delivery to Western Lake Erie: Approaches to Compensate for Variability and Trends in Streamflow. Journal of Great Lakes Research 45:21–39.

LWP Ltd., 2020a. State of Lake and River Wate Quality in the Otago Region. For records up to 30 June 2020, prepared for Otago Regional Council.

LWP Ltd., 2020b. ORC River, Groundwater and Lake water quality Trend analysis. For 10 and 20-year periods up to September 2020, prepared for Otago Regional Council.

Franklin, P., D. Booker, and R. Stoffels, 2020. Contract 23184: Task 2 - Turbidity and Visual Clarity Threshold Conversion. NIWA.

Greenland, S., S.J. Senn, K.J. Rothman, J.B. Carlin, C. Poole, S.N. Goodman, and D.G. Altman, 2016. Statistical Tests, P Values, Confidence Intervals, and Power: A Guide to Misinterpretations. European Journal of Epidemiology 31:337–350.

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 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.NZ Government, 2020. National Policy Statement for Freshwater Management 2020.

NIWA 2017.Review of Otago Regional Council's State of the environment Monitoring Programme, Rier and lake water quality and ecology. Report prepared for Otago Regional Council.

Otago Regional Council, 2004. Regional Plan: Water for Otago

Otago Regional Council, 2004. Regional Plan: Water for Otago. Dunedin: Otago Regional Council.

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

Smith, D.G., G.B. McBride, G.G. Bryers, J. Wisse, and D.F. Mink, 1996. Trends in New Zealand's National River Water Quality Network. New Zealand Journal of Marine and Freshwater Research 30:485–500.

Snelder, T.H. and B.J.F. Biggs, 2002. Multi-Scale River Environment Classification for Water Resources Management. Journal of the American Water Resources Association 38:1225–1240.

Stark JD, Maxted JR, 2007. A user guide for the Macroinvertebrate Community Index. Prepared for the Ministry for the Environment. Cawthron Report No.1166. 58 p.

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

Whitehead, A.L., Booker, D.J. 2020. NZ River Maps: An interactive online tool for mapping predicted freshwater variables across New Zealand. NIWA, Christchurch. https://shiny.niwa.co.nz/nzrivermaps/

Wasserstein, R.L. and N.A. Lazar, 2016. The ASA Statement on P-Values: Context, Process, and Purpose. Taylor & Francis.

Appendix 1. River Environment Classification System (REC)

The Ministry for the Environment, in conjunction with NIWA developed the New Zealand River Environment Classification (REC) system (Snelder et al., 2004). The REC system characterises river environments at six hierarchical levels, according to their climate (1), source of flow (2), geology (3), land cover (4), network position (5) and valley landform (6), and within each level are a series of categories that are used to describe reaches of rivers throughout New Zealand.

Table 35 REC classification levels, classes and criteria used to assign river segments to REC classes (from Snelder, 2004).

Factor	Climate	Code	Criteria
1. Climate	Warm extremely wet Warm wet Warm dry Cool extremely wet Cool wet Cool dry	WX WW WD CX CW CD	*Mean annual temperature:* Warm: >12ºC Cool: >12ºC *Mean annual effective precipitation:* Extremely wet: >1500mm Wet: 500 to 1500 mm, Dry: < 500mm
2. Source of Flow	Glacial mountain Mountain Hill Low elevation Lake Spring Regulated Wetland	GM M H L Lk Sp R W	*% permanent ice:* Glacial Mountain: >1.5% *Rainfall volume in elevation categories:* Mountain: >50% above 1000 m Hill: 50% between 400 to 1000 m Low elevation: 50% below 400 m *Lake influence index* *Others manually assigned*
3. Geology	Alluvium Hard sedimentary Soft sedimentary Volcanic basic Volcanic acidic Plutonic Miscellaneous	Al HS SS VB VA Pl M	*Spatially dominant geology category, unless:* Soft sedimentary >25%, then classified as sedimentary
4. Land cover	Bare Native forest Pastoral Tussock Scrub Exotic forest Wetland Urban	B IF P T S EF W U	*Spatially dominant land cover class, unless:* Pasture: >25%, then classified as pasture Urban: >15% then classified as urban
5. Network position	Low order Middle order High order	L M H	*Stream Order:* Low: 1 and 2 Medium: 3 and 4 High: >5
6. Valley landform	High gradient Medium gradient Low gradient	H M L	Valley slope: High: >0.04 Medium: 0.02 to 0.04 Low: <0.02