Environmental Science and Policy Committee

Meeting will be held at Phillip Laing House, Council Chambers, Level 2, 144 Rattray Street, Central Dunedin,

ORC Official YouTube Livestream

Members:

Cr Lloyd McCall (Co-Chair)	Cr Andrew Noone
Cr Alexa Forbes	Cr Gretchen Robertson
Cr Gary Kelliher	Cr Bryan Scott
Cr Michael Laws	Cr Alan Somerville
Cr Kevin Malcolm	Cr Elliot Weir
Cr Tim Mepham	Cr Kate Wilson

Senior Officer: Richard Saunders, Chief Executive

Meeting Support: Kylie Darragh, Governance Support Officer

29 June 2023 02:00 PM

Agenda Topic **Page**

1. WELCOME

2. APOLOGIES

Cr Bryan Scott is a tentative apology for this meeting

3. PUBLIC FORUM

Requests to speak should be made to the Governance Support team on 0800 474 082 or to governance@orc.govt.nz at least 24 hours prior to the meeting, however, this requirement may be waived by the Chairperson at the time of the meeting. No requests to speak were made prior to publication of the agenda.

4. CONFIRMATION OF AGENDA

Note: Any additions must be approved by resolution with an explanation as to why they cannot be delayed until a future meeting.

5. DECLARATION OF INTERESTS

Members are reminded of the need to stand aside from decision-making when a conflict arises between their role as an elected representative and any private or other external interest they might have. Councillor interests are published on the ORC website.

That the minutes of the Environmental Science and Policy Meeting of 26 April 2023 be received and confirmed as a true and accurate record.

Otago Regional Council

Environmental Science and Policy Committee
MINUTES

Minutes of an ordinary meeting of the Environmental Policy and Science Committee held in the Council Chamber, Level 2 Philip Laing House, 144 Rattray Street, Dunedin on Wednesday 26 April 2023, commencing at 10:04 AM.

PRESENT

Cr Lloyd McCall	*(Co-Chairperson)*
Cr Alexa Forbes	
Cr Gary Kelliher	
Cr Michael Laws	
Cr Kevin Malcolm	
Cr Tim Mepham	
Cr Andrew Noone	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Alan Somerville	
Cr Elliot Weir	
Cr Kate Wilson	

1. WELCOME

Chairperson McCall welcomed Councillors, members of the public and staff to the meeting at 10:04 am. Staff present included Pim Borren, (interim Chief Executive), Anita Dawe (GM Policy and Science), Nick Donnelly (General Manager Corporate Services & CFO), Gavin Palmer (GM Operations), Richard Saunders (GM Communications), Tom Dyer (Science Manager), Ben Mackey (Land Team), Erik Button (Scientist, Land and Soil) Sam Thomas (Scientist, Coast), Scott Jarvie (Scientist, Biodiversity), Liz Spector (Governance Support - online), Trudi McLaren (Governance Support).

2. APOLOGIES

There were no apologies.

3. PUBLIC FORUM

No public forum was held.

4. CONFIRMATION OF AGENDA

The agenda was confirmed as published.

5. DECLARATIONS OF INTERESTS

No changes were made to Councillor declarations of interest.

6. MATTERS FOR CONSIDERATION

6.1. Land Science Update

This paper provided an update of the major land and soil science mapping and monitoring programmes currently underway. Anita Dawe (GM Policy and Science), Tom Dyer (Manager, Science) Dr Erik Button and Dr Ben Mackey (Team Leader Land) were present to respond to questions about the report.

Cr McCall commented that this was an excellent paper which provided a base to inform decision and policy making for the future.

Resolution ESP23-101: Cr Robertson Moved, Cr Wilson Seconded

That the Committee:

*1) **Notes** this report.*

MOTION CARRIED

6.2. 2022 Air Quality SOE Report

Chairperson McCall advised that the 2022 Air Quality SOE Report (6.2) and 2022 Air Quality Projects - NO2 & SO2 Monitoring and ULEB testing (6.3) would be considered concurrently. 6.2 2022 Air Quality SOE Report presented the results of the State of the Environment (SoE) monitoring for air quality for the calendar year 2022 and 6.3 2022 Air Quality Projects - NO_2 & SO_2 Monitoring and ULEB testing presented the results of the two air quality projects undertaken during 2022.

Anita Dawe (GM Policy and Science), Tom Dyer (Manager, Science) and Ben Mackey (Team Leader Land) were present to respond to questions about the report.

Cr Kelliher noted the positive trend and said it was good to see. He said that the report will allow people in urban areas to make decisions when they are looking at moving to different areas, and they will be able to select areas within towns that would be better suited to them or be able to go out of town for certain periods because of health.

Cr Laws said that these results were important for the community, and that they deserve recognition for the work they have done to address air quality issues, especially given the growth in population.

Resolution ESP23-102: Cr Malcolm Moved, Cr Kelliher Seconded

That the Committee:

1) ***Notes*** *the 2022 Air Quality SOE Report.*
2) ***Notes*** *the 2022 Air Quality Projects - NO2 & SO2 Monitoring and ULEB testing*

MOTION CARRIED

6.4. Kelp Forest Phase Monitoring Project

This report is Phase 1 of a multi-year programme developed to provide baseline knowledge and guidance for ongoing monitoring of Otago's coastal marine ecosystems.

Anita Dawe (GM Policy and Science), Tom Dyer (Manager, Science), and Sam Thomas were present to respond to questions about the report. They advised that this report was a summary of the last 10 years to set the groundwork for more significant and detailed findings over the next 5 years.

Chairperson McCall commented that this report was extremely informative and thanked the presenters/authors.

Resolution ESP23-103: Cr Weir Moved, Cr Wilson Seconded

That the Committee:

1) ***Receives*** *this report.*
2) ***Notes*** *that phase 1 of the kelp forest monitoring programme "*Giant Macrocystis forests; Distribution and trends for the Otago region*" has been completed.*
3) ***Notes*** *that phase 1 is part of a broader five-year programme that will produce a passive monitoring platform online combined with in-situ long term monitoring.*

MOTION CARRIED

6.5. Regional Threat Lists for Reptile Species in Otago

This paper was provided to detail development of regional threat classifications, provide examples from other regions where regional conservation statuses have added values to national assessments, and detail the first regional conservation status undertaken for a species group (reptiles) in the Otago region.

Anita Dawe (GM Policy and Science), Tom Dyer (Manager, Science) and Scott Jarvie were present to respond to questions about the report. Tom advised that this type of technical paper will be available to experts who are considering any land use changes in the future. He noted the work is in the early stages, but it will enable those working in this area to take better and more effective steps in future. He stated staff are working on this with a wide range of organisations, including the Department of Conservation.

Resolution ESP23-104: Cr Wilson Moved, Cr Noone Seconded

That the Environmental Science and Policy committee:

1) ***Notes** this report.*

MOTION CARRIED

6.6. Marine Significant Ecological Areas Spatial Mapping Project

This report provided the Committee with information on the mapping project completed by NIWA to map the marine significant ecological areas within Otago's coastal marine area and surrounding adjoining coastal space. The mapping will be used to inform the review of the Regional Plan: Coast for Otago, and to assist in developing the coastal monitoring programme. The mapping identifies the marine ecological significant areas and key habitats/ecosystems in Otago.

Anita Dawe (GM Policy and Science), Tom Dyer (Manager, Science) and Sam Thomas (Scientist, Coast) were present to respond to questions about the report. Mr Dyer stated the report was undertaken by NIWA and included data from many different areas and sources.

Cr Weir left the meeting at 11.50am and returned at 11.55am

Resolution ESP23-105: Cr Forbes Moved, Cr Mepham Seconded

That the Committee:

1) ***Receives** this report.*
2) ***Notes** that the marine significant ecological area spatial mapping has been completed.*
3) ***Notes** that next steps include a management framework for marine significant ecological areas, and a more detailed monitoring programme for the coastal area.*

MOTION CARRIED

6.7. Key messages from the Ministry for the Environment and Stats NZ report Our Freshwater 2023 released on 12 April 2023

This report was provided to updated Councillors on findings of the Ministry's report, *Our freshwater 2023* and to make some observations regarding the implications of those findings for the Council. Anita Dawe (GM Policy and Science), and Peter Constantine (Acting Principal Planner) were present to respond to questions about the report.

Cr Weir thanked everyone involved for the report and noted that it contained a lot of very useful information. Following Councillor questions and discussion of the report, it was moved:

Resolution ESP23-106: Cr Weir Moved, Cr Somerville Seconded

That the Council:

1) ***Notes*** *this report.*
2) ***Notes*** *the key findings from* Our freshwater 2023*.*
3) ***Notes*** *the observations regarding the implications of the key findings for the ongoing work of the Otago Regional Council.*

MOTION CARRIED

7. CLOSURE

There was no further business and Chairperson Lloyd McCall declared the meeting closed at 12:12 pm.

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Chairperson Date

7.1. Contact recreation Report 2022/2023

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2219
Activity:	Governance Report
Author:	Markus Dengg, Freshwater Scientist
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	29 June 2023

PURPOSE

1. This report summarises contact recreation programme ('the programme') undertaken at 31 sites in Otago's rivers, lakes, and coastal waters at weekly intervals between December 2022 and 31 March 2023 which is ORC's defined bathing season. Monitoring focuses on human health risks of faecal contamination and/or potentially toxic cyanobacteria.

EXECUTIVE SUMMARY

2. The programme follows the national microbiological water quality guidelines for marine and freshwater recreational areas (Ministry for the Environment & Ministry of Health, 2003[1]), the National Policy Statement for Freshwater Management 2020 (NPSFM,2020[2]) and The New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters: Interim Guidelines[3] (MfE & MoH, 2009).
3. Weekly monitoring results and any temporary health warnings are reported on the Land Air Water Aotearoa (LAWA) website[4]. LAWA also states a 'long term grade' [5]for each recreational site, alongside the weekly sampling result.
4. In the 2022-2023 season, across both coastal (16) and freshwater (15) sites, 378 routine microbiological samples were taken. Elevated concentrations of *E. coli* (fresh water*)* or enterococci (marine water) in samples meant that the 'unsuitable for swimming' category was met on 20 occasions, and the 'caution advised' category was met on 12 occasions (categories shown in Figure 3).
5. Six lakes (Butchers Dam, Falls Dam, Lake Hayes, Lake Waihola, Pinders Pond and Tomahawk Lagoon) were monitored weekly for cyanobacteria. Both Butchers Dam and Lake Waihola had planktonic algae blooms exceeding the 'action' red mode which initiates further testing and public notification. This is consistent with the recommended actions outlined in the cyanobacteria guidelines(Table 5).
6. Benthic cyanobacteria cover was monitored at five river sites - Waikouaiti at Bucklands, Taieri at Outram, Taieri at Waipiata, Manuherekia at Shaky Bridge, and Waianakarua at

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[1] https://environment.govt.nz/assets/Publications/Files/microbiological-quality-jun03.pdf

[2] https://environment.govt.nz/assets/Publications/Files/national-policy-statement-for-freshwater-management-2020.pdf

[3] http://www.mfe.govt.nz/sites/default/files/nz-guidelines-cyanobacteria-recreationalfresh-waters.pdf

[4] https://www.lawa.org.nz/

[5] Long term is defined as weekly monitoring results for faecal bacteria monitoring over the previous 5 years

Graves Dam. These sites did not exceed the 'action' red mode for benthic cyanobacteria (>50% surface cover).

7. Faecal source tracking (FST) was undertaken on seventeen occasions. FST in the Waianakarua catchment showed avian and ruminant sources on nine occasions out of 11 samples. Sources of *E. coli* in the Waikouaiti Estuary and Otokia Creek were identified as avian (all results are set out in Table 3). The Manuherekia at Shaky Bridge, Taieri at Waipiata and Lake Dunstan at Clyde Rowing Club had one instance each of elevated *E. coli* due to ruminant sources (determined by faecal source tracking). The two occasions where *E. coli* concentrations triggered the red alert level at the Taieri at Outram were linked to ruminant sources.

RECOMMENDATION

That the Committee:

1. ***Notes** this report.*

LEGISLATIVE REQUIREMENTS

8. Two main sources of legislation define the monitoring required to assess the water quality of areas used for contact recreation - the Resource Management Act (1991) and the Health Act (1956). The responsibility for overseeing these Acts is shared between Regional Councils, Territorial Authorities (TAs) and the National Public Health Service, Southern.
9. The National Policy Statement for Freshwater Management 2020 (NPSFM, 2020) provides national direction on how local and regional authorities should carry out their responsibilities under the Resource Management Act 1991 for managing freshwater.
10. Human health for recreation is a compulsory freshwater value under the NPSFM, 2020. This value refers to the extent to which Freshwater Management Units (FMU) or part of an FMU supports people being able to connect with the water through a range of activities such as swimming, waka, boating, fishing, mahinga kai, and water skiing, in a range of different flows or levels.
11. The NPSFM 2020 contains two attributes for human health for recreation. The first is aimed at the State of Environment reporting and is based on 60 samples over a maximum of 5 years (Appendix 2A, Table 11). The second is a separate framework for assessing human health for recreation, specifically for primary contact sites in lakes and rivers during the bathing season; as described in NPSFM 2020 Appendix 2B, Table 22 (Figure 1).
12. Otago's recreational water quality monitoring programme follows the national microbiological water quality guidelines for marine and freshwater recreational areas (MfE/MoH 2003). The guidelines provide monitoring protocols and public health notification protocols to use when health risks at primary contact sites are detected.

Table 22 – *Escherichia coli* (*E. coli*) (primary contact sites)

Value	Human contact
Freshwater body Type	Primary contact sites in lakes and rivers (during the bathing season)
Attribute unit	95th percentile of *E. coli*/100 mL (number of *E. coli* per hundred millilitres)
Attribute band and description	**Numeric attribute state**
Excellent Estimated risk of *Campylobacter* infection has a < 0.1% occurrence, 95% of the time.	≤ 130
Good Estimated risk of *Campylobacter* infection has a 0.1 – 1.0% occurrence, 95% of the time.	> 130 and ≤ 260
Fair Estimated risk of *Campylobacter* infection has a 1 – 5% occurrence, 95% of the time.	> 260 and ≤ 540
National bottom line	**540**
Poor Estimated risk of *Campylobacter* infection has a > 5% occurrence, at least 5% of the time.	> 540
The narrative attribute state description assumes "% of time" equals "% of samples".	

Figure 1: NPSFM (2020) Appendix 2B, Table 22. Escherichia coli (E. coli) at primary contact sites.

13. In Otago, the Central Otago District Council (CODC), Dunedin City Council (DCC), Waitaki District Council (WDC) and Clutha District Council (CDC), rely on the ORC (Otago Region Council) to provide follow up sampling if the 'action' level is reached, and to provide public information through sign installation and media. The Queenstown Lakes District Council (QLDC) provides follow up monitoring and communication for sites monitored in their district.

SAMPLING SITES

14. Bacteria concentrations, used as indicators for faecal contamination, are monitored at 15 fresh water and eight coastal sites throughout Otago (as shown in Figure 2). The DCC samples eight additional coastal sites between Sandfly Bay and St Clair Beach, and these results are added to ORC's summer recreational water quality monitoring as reported on LAWA. The sampling by the DCC is a requirement of consents for Dunedin City's wastewater discharges.
15. There are only 4 freshwater river sites in the contact recreation programme and benthic cyanobacteria cover is regularly monitored at those river sites - the Manuherekia River at Shaky Bridge, Waikouaiti River at Bucklands, Taieri at Waipiata and Taieri at Outram. (Figure 2).
16. Planktonic cyanobacteria were monitored at six lake sites - Lake Waihola, Lake Hayes, Falls Dam, Pinders Pond, Tomahawk Lagoon and Butchers Dam (Figure 2). These sites have all had cyanobacteria blooms in the past hence the inclusion in the monitoring programme.
17. Duplicate samples were taken for faecal source tracking (FST) at all freshwater and estuarine sites. FST uses DNA and Polymerase Chain Reaction (PCR) analyses to identify

the animal source of the bacteria found in the samples (*E. coli*). Tests are available that can identify bacteria from humans, ruminants, dogs, gulls and avian.

Figure 2: Map of contact recreation sites monitored for microbiological water quality (E. coli and Enterococci) and cyanobacteria in Otago.

MICROBIOLOGICAL MONITORING

18. Weekly water quality sampling of recreational sites in the 2022/23 season began on 5 December 2022 and continued until 27 March 2023. Thirty-one sites were monitored for indicator bacteria.
19. The water samples taken at Otago's contact recreation sites are tested for *Escherichia coli (E. coli)* in freshwaters and enterococci in marine waters. These bacteria are used as indicators for other harmful pathogens. *E. coli is* a type of bacteria commonly found in the gut of warm-blooded mammals (including people) and birds. *E. coli* can survive for up to four to six weeks outside the body in fresh water, making it a useful indicator of faecal contamination and the presence of disease-causing organisms.
20. Results from sampling were compared against the National Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE/MoH, 2003) to assess the health risk of swimming. If faecal indicator bacteria concentrations exceeded the human health guidelines (Figure 3, Figure 4, MfE/MoH, 2023), results were shared with the Public Health Service, Southern (PHS) and Territorial Authorities (TAs) and communicated to the public. This follows a well-defined process that is in place for when these situations occur.
21. LAWA reports the water quality results on their website, which is updated daily during summer with the latest risk assessment and test data for swimming spots across New Zealand.
22. The LAWA website shows weekly risk results (Figure 3) and a long-term grade for each swimming site (Figure 4). The weekly 'risk' categories are: 'generally suitable for swimming' (green - low infection risk); 'caution advised' (amber - moderate infection risk); and 'not suitable for swimming' (red - high infection risk). The four long term 'risk' grades are calculated using 95th percentile *E. coli* and enterococci values obtained over the last five years of monitoring.

Mode	Trigger level		Management response
	Beach: Enterococci / 100mL	**River/Lake: *E. coli*/100 mL**	
Surveillance	Equal to or less than 140 Enterococci / 100 mL	Equal to or less than 260 *E. coli* / 100 mL	Routine monitoring.
Alert	More than 140 Enterococci / 100 mL	More than 260 *E. coli* / 100 mL	Increase monitoring and investigate source.
Action	More than 280 Enterococci / 100 mL	More than 550 *E. coli* / 100 mL	Public warnings if required, increased monitoring and investigation of contaminant source.

Figure 3 Water quality guideline values and indicator organisms used to assess marine and freshwater recreational areas (MfE and MoH, 2003).

Long-term grade	Coastal beach sites	River and Lake sites
Excellent	95th percentile value of Enterococci / 100ml: 0 – 40 Description of risk: Risk of illness is less than 1% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: 0 – 130 Description of risk: Estimated risk of *Campylobacter* infection has a < 0.1% occurrence, 95% of the time.
Good	95th percentile value of Enterococci / 100ml: >40 – 200 Description of risk: Risk of illness is less than 5% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: >130 – 260 Description of risk: Estimated risk of *Campylobacter* infection has a 0.1 – 1.0% occurrence, 95% of the time.
Fair	95th percentile value of Enterococci / 100ml: >200-500 Description of risk: Risk of illness is between 5 and 10% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: >260 – 540 Description of risk: Estimated risk of *Campylobacter* infection has a 1 - 5% occurrence, 95% of the time.
Poor	95th percentile value of Enterococci / 100ml: > 500 Description of risk: Risk of illness is more than 10% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: > 540 Description of risk: Estimated risk of *Campylobacter* infection has >5% occurrence, at least 5% of the time

Figure 4 The long-term grade determines whether a site overall is excellent, good, fair, or poor for swimming over the recreational bathing season

CYANOBACTERIA MONITORING

23. Cyanobacteria in rivers and lakes can pose a risk to human and animal health because they can produce cyanotoxins. In lakes, cyanobacterial species tend to float in the water (planktonic)compared to rivers where they form dense mats on the beds of rivers (benthic).
24. ORC has developed a method for Otago – the Cyanobacteria Monitoring and Response Method - which follow the MfE/MoH (2009) guidelines (Figure 5 and Figure 6) and were developed in a collaboration between ORC, Public Health Service,Southern, and Territorial Authorities.
25. The New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters: Interim Guidelines[6] (MfE & MoH, 2009) contain suggested methods for monitoring and responding to benthic and planktonic cyanobacteria in streams, rivers, and lakes. The guidelines cover the health risks of swimming in recreational waters containing cyanobacteria, but not the risks for drinking water. The guidelines also do not address cyanobacteria's health risks for animals (i.e., dogs or livestock) that come into contact with or ingest water containing cyanobacteria.
26. The ORC undertook weekly visual surveillance for potentially toxic benthic cyanobacteria growth at the four freshwater contact recreation sites (Figure 1). Planktonic cyanobacteria were routinely monitored at six lake sites; Lake Waihola, Lake Hayes, Falls Dam, Pinders Pond, Tomahawk Lagoon and Butchers Dam (Figure 1).
27. The above 4 sites are chosen as regular testing because cyanobacteria have been observed there in the past. Additionally, other sites were also tested for cyanobacteria

[6] https://environment.govt.nz/publications/new-zealand-guidelines-for-cyanobacteria-in-recreational-fresh-waters-interim-guidelines/

when unexpected seasonal blooms occurred, or when ORC staff became aware of potential blooms through public notification or visual surveillance.

Alert level	Actions (See section 2.4 for the recommended framework for roles and responsibilities relating to actions, and the text box at the beginning of Section 3 for advice on interpreting the guidance in this table.)
Surveillance (green mode) *Situation 1:* The cell concentration of total cyanobacteria does not exceed 500 cells/mL.[a] *Situation 2:* The biovolume equivalent for the combined total of all cyanobacteria does not exceed 0.5 mm^3/L.	• Undertake weekly or fortnightly visual inspection[b] and sampling of water bodies where cyanobacteria are known to proliferate between spring and autumn.
Alert (amber mode) *Situation 1:* Biovolume equivalent of 0.5 to < 1.8 mm^3/L of potentially toxic cyanobacteria (see Tables 1 and 2); **or** *Situation 2*[c]: 0.5 to < 10 mm^3/L total biovolume of all cyanobacterial material.	• Increase sampling frequency to at least weekly.[d] • Notify the public health unit. • Multiple sites should be inspected and sampled.
Action (red mode) *Situation 1:* ≥ 12 µg/L total microcystins; **or** biovolume equivalent of ≥ 1.8 mm^3/L of potentially toxic cyanobacteria (see Tables 1 and 2); **or** *Situation 2*[c]: ≥ 10 mm^3/L total biovolume of all cyanobacterial material; **or** *Situation 3*[e]: cyanobacterial scums consistently present.	• Continue monitoring as for alert (amber mode).[d] • If potentially toxic taxa are present (see Table 1), then consider testing samples for cyanotoxins.[f] • Notify the public of a potential risk to health.

Figure 5 Alert-level framework for planktonic cyanobacteria (MfE, 2009)

Alert level[a]	Actions (See section 2.4 for the recommended framework for roles and responsibilities relating to actions, and the text box at the beginning of Section 3 for advice on interpreting the guidance in this table.)
Surveillance (green mode) Up to 20% coverage[b] of potentially toxigenic cyanobacteria (see Table 1) attached to substrate.	• Undertake fortnightly surveys between spring and autumn at representative locations in the water body where known mat proliferations occur and where there is recreational use.
Alert (amber mode) 20–50% coverage of potentially toxigenic cyanobacteria (see Table 1) attached to substrate.	• Notify the public health unit. • Increase sampling to weekly. • Recommend erecting an information sign that provides the public with information on the appearance of mats and the potential risks. • Consider increasing the number of survey sites to enable risks to recreational users to be more accurately assessed. • If toxigenic cyanobacteria (see Table 2) dominate the samples, testing for cyanotoxins is advised. If cyanotoxins are detected in mats or water samples, consult the testing laboratory to determine if levels are hazardous.
Action (red mode) *Situation 1:* Greater than 50% coverage of potentially toxigenic cyanobacteria (see Table 1) attached to substrate; **or** *Situation 2:* up to 50% where potentially toxigenic cyanobacteria are visibly detaching from the substrate, accumulating as scums along the river's edge or becoming exposed on the river's edge as the river level drops.	• Immediately notify the public health unit. • If potentially toxic taxa are present (see Table 2) then consider testing samples for cyanotoxins.. • Notify the public of the potential risk to health.

Figure 6 Alert-level framework for benthic cyanobacteria (MfE, 2009)

WATER QUALITY MONITORING RESULTS

28. Table 1 and Table 2 show the LAWA results for ORC's recreational monitoring sites. Results are displayed as the percentage of the time results comply with each category for the weekly results (2021/22) and the long-term grade (2016-2021).Eight of the 23 sites monitored have a 'poor' long-term grade. Lake Hawea, Lake Wanaka, and Lake Dunstan have an 'excellent' long-term grade, Lake Waihola at Jetty has a 'good' long-term grade, and Lake Wakatipu at Frankton Bay has a 'fair' long-term grade. Three sites, Clutha at Dunorling Street, Waianakarua at Graves Dam and Pinders Pond, have not been monitored long enough to have a long-term grade (Table 1). The criterium for awarding a 'poor' long term grade is based on the 95th percentile of *E. coli*/100mL >540 (over a 5 year monitoring period). Only a few elevated samples will place the site into the 'poor' long term grade category. An example is Lake Wakatipu at Queenstown Bay (Figure 7) which has a 'poor' long term grade despite in the last five years only 5% (four of 80 samples) of samples exceeded 540 *E. coli*/100mL. Otokia Creek at Brighton is placed in the same category although has had a lot more samples exceed the threshold - 21% or (24 of the 108 samples) exceeded 540 *E. coli*/100mL.

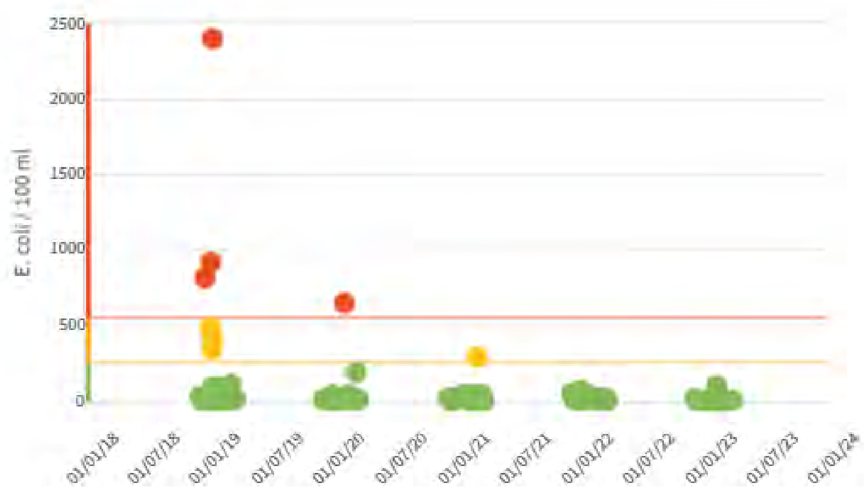


Figure 7 Lake Wakatipu at Queenstown Bay. Sample results from last five years.

29. During the 2022-2023 season, eight sites had an 'unsuitable for swimming' status on at least one occasion. They were - Kakanui Estuary at Kakanui Bridge, Waianakarua at Graves Dam, Taieri River at Outram, Otokia Creek at Brighton, Waikouaiti Estuary at the Wharf, Taieri at Waipiata, Manuherekia at Shaky Bridge and Clutha at Dunorling Street (Table 1).
30. In order to understand the data in relation to the NPSFM, 2020, Table 1 compares each site to Table 22 of the NPSFM, 2020which compares samples to the estimated risk of Campylobacter infection. If the site is classified as 'excellent', the risk of campylobacter infection is <0.1% occurrence, 95% of the time. Nine of the sampled sites were classified as 'excellent.'
31. Three sites were classified as 'fair' (1-5% occurrence, 95% of the time), and three sites were classified as being below the national bottom line or 'poor' (> 5% occurrence, at least 5% of the time).

Table 1: Results from freshwater contact recreation sampling December 2022 to March 2023. 'Suitable for swimming' shows water quality is good and risk to health is low (E. coli <260 cfu/100ml), 'caution advised' indicates the health risk has increased (E. coli 260-550 cfu/100ml) and 'unsuitable for swimming' indicates an unacceptable health risk (E. coli >550cfu/100ml). The long-term grade is taken from five years of results and reported on LAWA. The NPSFM grade is the 95th percentile of results taken over the contact recreation season.

Site	2022-2023			NPSFM Grade (2022-2023)	5-year results (2018/2019-2022/2023)			LAWA long term grade
	% suitable	% caution	% unsuitable		% suitable	% caution	% unsuitable	
Waianakarua at Graves Dam	6	38	56	Poor	73	12	13	None
Taieri River at Outram Glen	75	13	13	Poor	90	3	7	Poor
Waikouaiti at Bucklands	100	0	0	Excellent	97	2	0	Poor
Lake Waihola at Jetty	100	0	0	Excellent	62	17	19	Good
Taieri River at Waipiata	67	20	7	Poor	98	0	0	Poor
Lake Dunstan at Alpha Street	100	0	0	Excellent	100	0	0	Excellent
Lake Dunstan at Clyde Rowing Club	94	0	0	Excellent	71	21	8	Excellent
Manuherekia River at Shaky Bridge	88	6	6	Fair	96	0	4	Poor
Clutha at Dunorling Street	94	0	6	Fair	NA	NA	NA	None
Pinders Pond	100	0	0	Excellent	94	2	5	None
Lake Hayes (Shallows)	100	0	0	Excellent	95	2	3	Poor
Lake Wanaka at Roys Bay	94	0	6	Fair	98	0	2	Excellent
Lake Hawea at Holiday Park	100	0	0	Excellent	88	5	6	Excellent
Lake Wakatipu at Queenstown Bay	100	0	0	Excellent	95	2	2	Poor
Lake Wakatipu at Frankton Bay	100	0	0	Excellent	0	0	0	Fair

Table 2: Results from coastal contact recreation sampling December 2022 to March 2023. 'Suitable for swimming' shows water quality is good and risk to health is low (Enterococci <140 cfu/100ml), 'caution advised' indicates the health risk has increased (Enterococci 140-280 cfu/100ml) and 'unsuitable for swimming' indicates an unacceptable health risk (Enterococci >280 cfu/100ml).

Site	2022-2023			5-year results (2018/2019-2022/2023)			LAWA long term grade
	% suitable	% caution	% unsuitable	% suitable	% caution	% unsuitable	
Kakanui Estuary at Kakanui Bridge	94	0	6	85	5	10	Poor
Hampden Beach	100	0	0	94	4	2	Good
Oamaru Harbour at Friendly Bay	100	0	0	97	2	2	Fair
Otokia Creek at Brighton	83	0	17	74	5	21	Poor
Otago Harbour at Macandrew Bay	100	0	0	93	3	4	Fair
Waikouaiti Estuary at the Wharf	94	0	6	95	2	3	Fair
Kaka Point	100	0	0	99	0	1	Excellent
Catlins at Pounawea	100	0	0	96	2	2	Fair

32. Three coastal sites had an 'unsuitable for swimming' status on at least one occasion during the 2022/23 season - Kakanui Estuary at Kakanui Bridge, Otokia Creek at Brighton, and Waikouaiti Estuary at the Wharf. Most of Otago's coastal sites have a 'fair' long-term

grade, with only Kaka Point and Hampden Beach having an 'excellent' long-term grade. Otokia Creek and Kakanui Estuary have a 'poor' grade (Table 2).

FAECAL SOURCE TRACKING

33. Faecal source tracking (FST) is used to identify the source of bacterial contamination and was used on samples that showed an 'unsuitable for swimming' result after weekly testing. Contact recreation sites that had FST analysis were Waianakarua at Graves Dam, Kakanui Estuary at Kakanui Bridge, Otokia Creek at Brighton, Waikouaiti Estuary at the Wharf and Manuherekia at Shaky Bridge (Table 3). The main faecal bacteria sources for all sites were ruminant (cow), avian or gull (Red-billed Gull).
34. The results from FST are shown in Table 3, with many of the results below the detection limit (<180 copies/100mL).

Table 3: Results from faecal source tracking undertaken between December 2022 and March 2023.

Date	Site	Avian GFD	Avian Gull4	Canine DG72	General GenBac3	Human HF183	Human HumM2	Ruminant BacR
		copies/100 ml						
12/6/2022	Wainakarua at Graves Dam	<180	71000	<180	100000	610	<180	21000
12/20/2022	Manuherekia at Shaky Bridge	810	<180	<180	430000	430	<180	22000
19/12/2022	Taieri at Waipiata	<180	<180	<180	2700000	<180	<180	650000
12/20/2022	Wainakarua at Graves Dam	<180	<180	<180	60000	210	<180	2300
12/21/2022	Wainakarua at Graves Dam	<180	8100	<180	25000	730	<180	4200
12/21/2022	Wainakarua at Graves Dam	760	33000	<180	68000	380	<180	5100
12/21/2022	Wainakarua Upstream Ford Cosy Dell Road	300	72000	<180	85000	1100	<180	12000
12/21/2022	Wainakarua Upstream Glencoe Campsite	480	47000	<180	18000	290	<180	<180
12/29/2022	Wainakarua at Graves Dam	<180	7100	<180	15000	<180	<180	1800
1/5/2023	Wainakarua at Graves Dam	<900	9100	<900	28000	<900	<900	1800
1/24/2023	Waikouaiti Estuary at the Wharf	1200	270	<180	87000	<180	<180	<180
1/24/2023	Wainakarua at Graves Dam	<180	3000	<180	15000	<180	<180	640
1/23/2023	Otokia Creek at Brighton Road	7500	75000	<900	490000	<900	<900	<900
3/7/2023	Clutha at Dunorling Street	<180	<180	<180	740000	51000	3700	<180
3/7/2023	Manuherekia at Shaky Bridge	1100	<180	<180	540000	780	<180	56000
3/7/2023	Wainakarua at Graves Dam	<180	<180	<180	11000	<180	<180	2100
3/13/2023	Kakanui Estuary at Kakanui Bridge	6500	620	<180	160000	<180	<180	<180
3/13/2023	Otokia Creek at Brighton Road	4800	6300	<180	440000	<180	<180	<180
3/13/2023	Wainakarua at Graves Dam	210	<180	<180	54000	560	<180	1700

35. The Waianakarua at Graves Dam was added as a contact recreation site in the 2022/23 season after cyanobacteria complaints in the 2021/22 season. The site returned elevated *E. coli,* and further FST analysis in the catchment (21.12.2022, Table 3) indicated that in most instances, the source was gull and ruminant (Table 3). In 2019, a red-billed gull colony in the neighbouring Kakanui River catchment was identified as the primary source of faecal bacterial input.

CYANOBACTERIA RESULTS

36. Results from planktonic cyanobacteria tests in lakes during the 2022-2023 summer show that Lake Hayes, Tomahawk Lagoon, Pinders Pond and Falls Dam did not have a cyanobacteria bloom.
37. At Lake Waihola, the cyanobacteria *Anabaena lemmermanii* was present on two occasions. The action (red) mode was reached on 12 December with a biovolume of 6.725 mm^3/L. The second time the action (red) mode was triggered was on 16 January, with a biovolume of 11.81 mm^3/L. Warning signs were put up every time the lake reached the red mode and taken down when the lake was placed in the green mode again (Figure 8).
38. At Butchers Dam, a bloom of *Anabaena lemmermanii* with a biovolume of 2.442 mm^3/L appeared on 11 November which is early in the season. This bloom was the only occurrence of potentially toxic cyanobacteria at Butchers Dam this season.

39. This season, there were 6 reports from the public to ORC of potentially toxic algae. In two instances, site visits and laboratory results confirmed the presence of *Phormidium* at >50% benthic cover triggering the action (red) mode. These were Hanley's Creek on 17 January this year, and Cardrona upstream of the Clutha Confluence on 7 March this year. In both instances, signs were erected, and the public was informed via e-mails and social media.
40. ORC was made aware of the death of a dog after the potential ingestion of toxic algae (28 December 2022). The incident happened at a swimming spot in the Clutha River near the Roxburgh Golf Course. Follow-up sampling and site inspections did not yield any conclusive results.
41. The four regularly tested river contact recreation sites did not show benthic algae blooms.

Figure 8: Benthic cyanobacteria warning sign on left, planktonic cyanobacteria warning sign on right

DISCUSSION

42. Two new monitoring sites were introduced in the 2022/2023 season. Pinders Pond near Roxburgh had a cyanobacteria bloom in the 2021/2022 season, and therefore it was added to the programme to be monitored closely this season, and Waianakarua at Graves Dam was added to the programme because of benthic cyanobacteria concerns.
43. In terms of elevated results occurring through the season, Otago experienced heavy rainfall which can impact monitoring results. The rainfall occurred before samples were taken on 12 and 19 December, which elevated bacteria concentrations at many sites along the Taieri River (Table 3). A rainfall event on 12 January can also be linked with high *E. coli* levels observed in the Taieri at Outram.
44. The standard of 540 *E. coli*/100mL is often exceeded in rivers after moderate rainfall. In some cases, a poor long-term grade may indicate how many samples were taken when flows were high rather than show consistently poor water quality. Six freshwater sites were awarded a ‘poor’ long term grade.

45. When compared to Table 22 of the NPSFM, 2020, seven of the 13 freshwater sites monitored were classified as ‘Excellent’, two sites were ‘Fair’, and three were below the national bottom line or ‘Poor’.
46. FST indicated that the main faecal bacteria sources were ruminant, avian or gull. The Waianakarua River’s water quality is compromised during the period red-billed gulls roost in the gorge upstream. Any resolution would require action on the roosting area however the birds are legally protected and a taonga for Ngai Tahu.
47. At the sites monitored for planktonic cyanobacteria, Lake Waihola and Butchers Dam had *Anabaena lemmermanii* present for short periods during summer. Cyanobacteria blooms in rivers and lakes cannot be predicted easily, but they are more likely after long stable spells of weather in nutrient-rich waterbodies

CONSIDERATIONS

Strategic Framework and Policy Considerations

48. This programme supports the healthy water strategic priority through monitoring and publishing of information to support public decision making around how the interact with water at popular sites in Otago.

Financial Considerations

49. This work is funded and planned as part of the annual work programmes.

Legislative and Risk Considerations

50. The contact recreation programme ensures compliance with the National Policy Statement Freshwater Management, 2020.

Climate Change Considerations

51. In the future, sites, and monitoring periods may need review and amendment to consider climate change.

NEXT STEPS

52. The contact recreation programme will recommence in December 2023.

ATTACHMENTS

Nil

7.2. Estuary SOE Programme Update 2023

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2314
Activity:	Governance Report
Author:	Sam Thomas, Coastal Scientist
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	29 June 2023

PURPOSE

[1] To provide the Committee with an update on the progress of the State of the Environment (SoE) Estuary Monitoring Programme. The report outlines what monitoring has been completed in the past two financial years and outlines the next steps in the monitoring programme.

EXECUTIVE SUMMARY

[2] The SoE estuary monitoring programme was reviewed and expanded in 2020. Data from the monitoring programme will be used to inform both regulatory plans, and non-regulatory work such as integrated catchment management planning. The revised programme uses a combination of monitoring techniques to provide information on estuary health. This report outlines the interim monitoring results/progress of the SoE estuary programme for the 2021/22 field season and the 2022/23 season.

RECOMMENDATION

That the Council:

1) ***Notes** this report.*
2) ***Notes** that the estuary monitoring programme is being implemented according to the estuary monitoring programme plan that was updated in 2020.*
3) ***Notes** that next steps include an estuary monitoring programme review to ensure the programme is delivering maximum value and to start prioritising areas for investigations and targeted management/restoration where needed.*

BACKGROUND

[3] Until 2020, only five estuaries in Otago had some kind of monitoring occurring. The estuary monitoring programme was updated in 2020 to build a resilient monitoring network that can provide data and information needed to manage Otago’s estuaries. The programmes aim was to gain an understanding of each estuarine environment within the Otago region and to then determine monitoring priorities once a current state was determined.

[4] The updated estuary monitoring programme has been designed to provide useful data for both regulatory and non-regulatory programmes that in turn manage Otago’s estuaries.

[5] To date, the monitoring is a mixture of broad scale, fine scale monitoring and sediment plate monitoring. Broad scale habitat monitoring maps the current estuarine state based

on habitats within the estuary such as areal extent of nuisance algae, seagrass, mud extent and salt marsh. This provides a baseline of habitat condition within the estuary and its surrounding margins (out to 200m). Broad scale mapping is the first monitoring undertaken on an estuary to provide a current state and to determine if further monitoring such as fine scale monitoring is required. Once an initial baseline state for the estuary has been established, broad scale mapping occurs every five years in estuaries that are under more stress for example with large areas of nuisance macroalgae. If an estuary is in a healthier state mapping is every 10 years. This monitoring is undertaken to assess long term trends in habitat condition.

[6] Fine scale monitoring establishes monitoring sites in the intertidal areas of the estuary to monitor long terms trends in macrofauna and physical parameters such as mud content and heavy metals. Fine scale monitoring is undertaken for three years to create a baseline dataset for the estuary and then every five years after that period unless conditions change. Fine scale monitoring is undertaken in estuaries under greater stress and also in a number of other sentinel/reference sites. Sediment plate monitoring is established to monitor erosion/deposition trends in the long term and occurs annually in all estuaries with fine scale sites or with sediment issues. Monitoring schedules in estuaries change dependent on where in the monitoring cycle they sit.

DISCUSSION

2021/24 Field Season Update

[7] During the 2021/22 field monitoring season the Pleasant River, Papanui Inlet, Akatore and Tautuku Estuary were added to the estuary monitoring programme. Broad scale mapping occurred in these estuaries (reports attached) providing a current state based on habitat mapping. Pleasant River, Blueskin Bay and Tautuku Estuary all had fine scale monitoring occurring to gather data as part of the 3-year baseline monitoring. Sediment plate monitoring occurred in the Shag, Waikouaiti and Pleasant River, as well as Blueskin Bay, Kaikorai, Tokomairiro, and the Catlins and Tautuku estuary (see attached sediment plate summary reports). A new piece of monitoring occurred in the Catlins estuary with macroalgae mapping undertaken to map the extent of nuisance macroalgae and the extent of change. This was undertaken in the Catlins Estuary due to an increase in the extent of Gracilaria since first monitoring in 2016 (please find report attached).

[8] At the completion of the 2022/23 field season all the estuaries in Otago have a current state for estuarine health, the new estuaries added to the programme were Tahakopa, Waipati/Chaslands estuaries and Hoopers and Papanui Inlet. Hoopers Inlet currently only has salt marsh mapped as the tide did not drain sufficiently for intertidal mapping to be undertaken. The lack of receding tide also meant that the sediment plate monitoring for Kaikorai Estuary could not be completed during the 2022/23 season. The lack of tide draining to this extent is an exception to the normal tidal processes for these systems. The Hoopers Inlet mapping will be completed during the 2023/24 field season along with the sediment plate monitoring in the Kaikorai Estuary and other planned estuary monitoring. Fine scale data was gathered for the Pleasant River, Tautuku and Blueskin bay Estuaries, with a 3- year baseline report due for Blueskin Bay in the next few weeks. Sediment plate monitoring continued in all estuaries with the outputs/reports for the above work all due in the next few weeks.

[9] When conditions do not allow for monitoring work to be completed, work is reprioritised to ensure an efficient overall programme. A report on the predicted change

in estuarine habitat based on potential sea level rise scenarios will be completed instead of the remaining Hoopers Inlet mapping. This report will highlight the current salt marsh extent, the potential loss of salt marsh and areas where salt marsh could migrate to under different sea level rise situations. This report will provide an important information for estuarine management in areas surrounding estuaries.

2023/24 Field season work plan:

[10] The field work monitoring for the 2023/24 season is as follows: Fine scale mapping will occur in the Shag and Pleasant Rivers, and Waikouaiti, Catlins and Tautuku estuary. The Shag, Catlins and Waikouaiti estuaries will be 5-year reports which will be the first trend reports for estuaries in Otago for five years of fine scale monitoring. Tautuku and Pleasant River estuary monitoring will be the completion of the 3-year baseline monitoring.

[11] Broad scale mapping during the 2023/24 field season will occur in the Shag, Waikouaiti and Catlins estuary, as it is five years since monitoring began and therefore will provide trend reports for these estuaries.

[12] Sediment plate monitoring will occur in the Shag, Pleasant River, Waikouaiti, Blueskin bay, Akatore, Kaikorai, Tokomairiro, Catlins and Tautuku estuaries.

[13] An estuary monitoring programme review will occur in 2024. This review will go through the programme to determine its suitability to inform regulatory plans and to make sure it is providing useful data to make management decisions. A focus of the programme review will be to look at both the future monitoring needed, but also to look at estuaries to focus on for targeted investigations for management needs, targeted monitoring, and restoration potential within estuaries.

OPTIONS

[14] The purpose of this report it to provide an update. No options are presented.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[15] The state of the environment estuary monitoring programme will provide information and data needed for both regulatory and non-regulatory management needs.

[16] The estuarine programme review will look to optimise the estuary monitoring programme and provide refined guidance on restoration potential and areas requiring targeted investigations for management.

Financial Considerations

[17] Within the current long-term plan, budget is allocated to undertake this work. However, the amount of work and monitoring will be determined by allocation of funding during future long-term planning process.

Significance and Engagement

[18] Engagement will be ongoing between stakeholders and iwi that operate in the estuarine space.

Legislative and Risk Considerations

[19] ORC needs to gather appropriate data to inform regulatory plans such as the land and water plan and regional plan: coast to meet its obligations.

Climate Change Considerations

[20] Understanding the potential change in salt marsh habitat is important to manage challenges facing these ecosystems from sea level rise.

Communications Considerations

[21] Communication between iwi and key stakeholders will occur on a project-by-project basis.

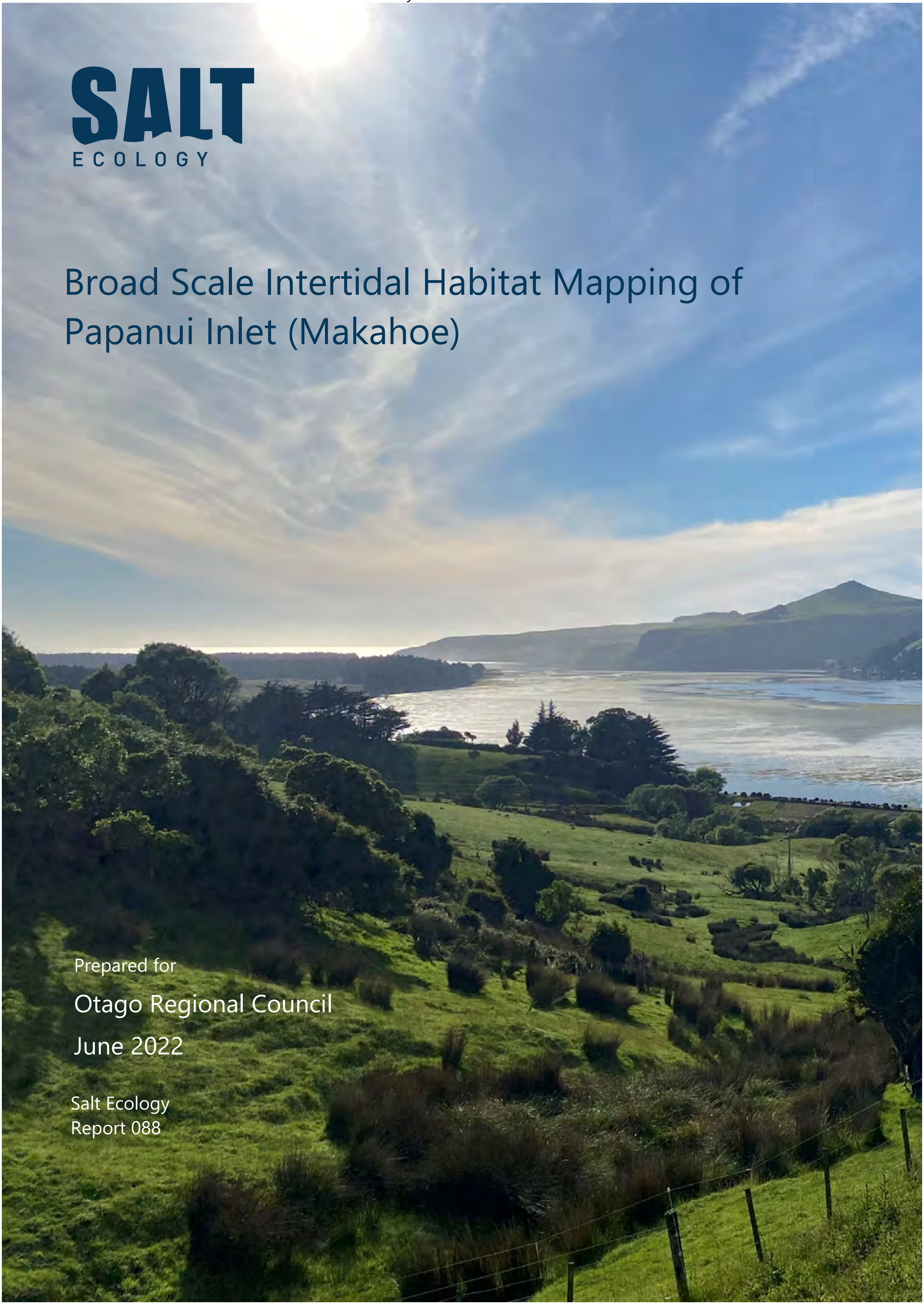
NEXT STEPS

[22] To continue the current monitoring programme for the 2023/24 field season as planned.

[23] To review the current monitoring programme in 2024 to make sure that it is fit for purpose to gather data needed to make informed management decisions and that monitoring network is optimised and targeted investigations/monitoring and restoration are prioritised.

ATTACHMENTS

1. Papanui BS 2022 FINAL [**7.2.1** - 65 pages]
2. Pleasant River BS 2022 FINAL [**7.2.2** - 66 pages]
3. Pleasant River 2022 FS FINAL [**7.2.3** - 38 pages]
4. Shag sedplate report 2021-22 FINAL [**7.2.4** - 2 pages]
5. Toko sedplate report 2021-22 FINAL [**7.2.5** - 2 pages]
6. Waik sedplate report 2021-22 FINAL [**7.2.6** - 2 pages]
7. Akatore BS 2022 FINAL reduced [**7.2.7** - 58 pages]
8. Blueskin sedplate report 2021-22 FINAL [**7.2.8** - 2 pages]
9. Catlins sedplate report 2021-22 FINAL [**7.2.9** - 2 pages]
10. Catlins Macroalgae 2022 clientdraft-1 [**7.2.10** - 36 pages]
11. Kaik sedplate report 2021-22 FINAL [**7.2.11** - 2 pages]



SALT ECOLOGY

Broad Scale Intertidal Habitat Mapping of Papanui Inlet (Makahoe)

Prepared for

Otago Regional Council

June 2022

Salt Ecology
Report 088

Cover photo: Looking down at Papanui Inlet (Makahoe) in the direction of the entrance showing extensive seagrass beds, November 2021.

RECOMMENDED CITATION

Roberts KL, Scott-Simmonds T, Southwick M, Stevens LM. 2022. Broad Scale Intertidal Habitat Mapping of Papanui Inlet (Makahoe). Salt Ecology Report 088, prepared for Otago Regional Council, June 2022. 55p.

SALT ECOLOGY

For the People
Mō ngā tāngata

Broad Scale Intertidal Habitat Mapping of Papanui Inlet (Makahoe)

Prepared by

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for

Otago Regional Council

June 2022

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For the environment
Mō te taiao

SALT ECOLOGY

GLOSSARY

AA	Affected Area (OMBT metric)
AIH	Available Intertidal Habitat (OMBT metric)
aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
HEC	High Enrichment Conditions
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for reviewing the draft report. The tools used to produce GIS summaries and maps were developed by Megan Southwick (Salt Ecology). The macrofauna data analysis was carried out by Barrie Forrest (Salt Ecology). ORC provided the rectified aerial imagery used in the mapping. Thanks to Rebecca McGrouther (Port Otago) for providing consent monitoring reports.

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SUMMARY

Papanui Inlet (Makahoe) is a medium sized (378ha) shallow, intertidally dominated, tidal lagoon type estuary (SIDE) located on the Otago Peninsula on New Zealand's southeast coast. The estuary is a monitored by Otago Regional Council (ORC) as part of its State of the Environment programme using methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). This report describes a survey conducted in November 2021 which assessed the dominant substrate and vegetation features present including seagrass, salt marsh and macroalgae.

KEY FINDINGS

- Intertidal substrate was dominated by sand (263.7ha, 90.8% of the intertidal area), with virtually no mud-dominated (>50% mud) substrate (0.07ha, 0.02%).
- There was no evidence of nuisance macroalgae or excessive sedimentation indicating current nutrient and fine sediment inputs are below thresholds of concern.
- Intertidal seagrass beds were extensive (111.1ha, 38.3%) reflecting suitable growing conditions comprising low sediment mud content, high water clarity and low nutrient inputs. However, extensive grazing damage from waterfowl was evident.
- Salt marsh (12.9ha, 4.4% of the intertidal area) was dominated by herbfield (81.0%), estuarine shrub (8.4%), grassland (4.8%) and rushland (3.9%). It was most extensive on the northern margin of the Inlet. Localised grazing pressures were present.
- The estuary margin was heavily modified due to historic reclamation and drainage of salt marsh, and shoreline hardening to protect roading.
- The 200m terrestrial margin was 26.4% densely vegetated (mainly exotic forest) otherwise dominated by low producing grassland (66%).
- The dominant catchment land uses were high-producing (59%) and low-producing (18%) grassland, mixed exotic shrubland (9%), exotic forest (7%) and indigenous scrub/forest (6%).
- The Estuary Trophic Index (ETI) score (0.227) indicated nutrient enrichment (eutrophication) was very low.

Despite the grazing pressure on seagrass beds, Papanui Inlet (Makahoe) was in 'very good' condition, with expansive beds of high value seagrass, very little mud-dominated sediment and a diverse range of other habitat types including salt marsh, sandflats and cockle beds. The high ecological quality of the estuary can be attributed to small freshwater inflows, low nutrient and sediment inputs and well flushed tidal flats.

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) Score	No unit	0.227	Very Good
Mud-dominated substrate	% of intertidal area >50% mud	0.02	Very Good
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.945	Very Good
Seagrass	% decrease from baseline	nd	November 2021 - baseline
Salt marsh extent (current)	% of intertidal area	4.4	Poor
Historical salt marsh extent*	% of historical remaining	70%	Good
200m terrestrial margin	% densely vegetated	25.4	Fair
High Enrichment Conditions	ha	0	Very Good
High Enrichment Conditions	% of estuary	0	Very Good
Sedimentation rate*	CSR:NSR ratio**	1.7	Good
Sedimentation rate*	mm/yr	0.06	Very Good

Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. *Estimated. **CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

RECOMMENDATIONS

- Repeat the broad scale habitat mapping at 5-10 yearly intervals to track long term changes in estuary condition.
- Protect important habitats such as seagrass, cockle beds and salt marsh (e.g. vehicle exclusion, reconnect areas of remnant salt marsh to the estuary, reduce grazing pressures).
- Include Papanui Inlet (Makahoe) in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will maintain the high ecological quality of the estuary.

1. INTRODUCTION

1.1 BACKGROUND

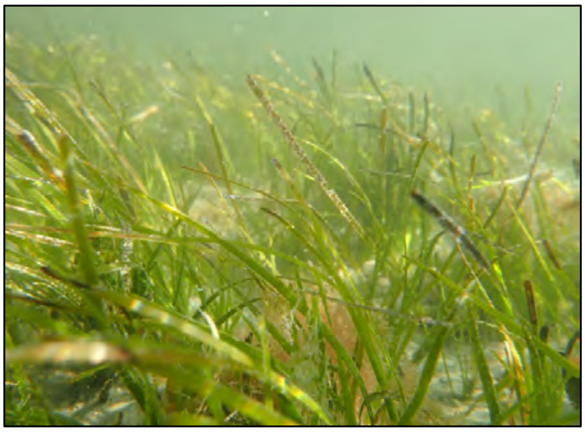
Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 based on the methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c), or extensions of that approach.

NEMP monitoring is primarily designed to detect and understand changes in estuaries over time and determine the effect of catchment influences, especially those contributing to the input of nutrients and muddy sediments. Excessive nutrient and fine sediment inputs are a primary driver of estuary eutrophication symptoms such as prolific macroalgal (seaweed) growth, and poor sediment condition.

The NEMP (Robertson et al. 2002a-c) is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results provide a valuable basis for establishing a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

The current report describes the methods and results of broad scale monitoring undertaken in Papanui Inlet (Makahoe) on the 26 and 29 November 2021 (Fig. 1). The primary purpose of the current work was to characterise substrate and the presence and extent of seagrass, macroalgae and salt marsh.



Seagrass in Papanui Inlet (Makahoe)

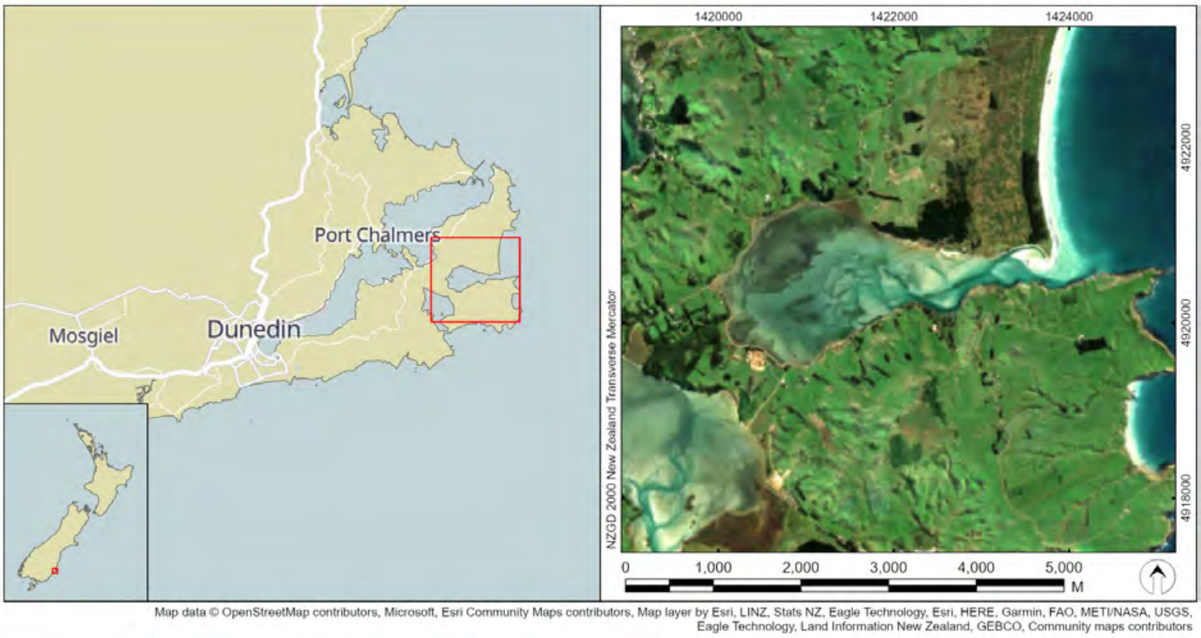


Fig. 1. Location of Papanui Inlet (Makahoe), Otago.

1.2 OVERVIEW OF PAPANUI INLET (MAKAHOE)

Papanui Inlet (Makahoe) is a medium sized (378ha) estuarine system located on the Otago Peninsula on New Zealand's southeast coast. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary (SIDE) that is well flushed. Freshwater inputs represent ~1% of the total estuary volume (Plew et al. 2018). The combined flushing potential and low freshwater inputs mean the estuary is unlikely to experience nutrient driven water column problems, e.g. phytoplankton blooms. However, the estuary has the capacity to retain fine sediments and sediment-bound nutrients in deposition areas making it moderately susceptible to nutrient enrichment and fine sediment impacts.

The estuary drains almost completely at low tide exposing ~77% of the estuary area. The lower estuary is protected from the ocean by a sand spit dominated by lupin and marram grass dunes. The Okia Flats on the northern side of the estuary is classified as a regionally significant wetland in the Regional Plan: Water for Otago because it represents the best regional example of dune hollow vegetation and provides habitat for nationally or internationally rare or threatened species. The salt marsh present on the northern edge of the estuary is classified as a regionally significant wetland because it is habitat for the declining *Carex litorosa* (sea sedge) and the naturally uncommon *Stenostachys laevis* (wheatgrass; Regional Plan: Water for Otago).

Drained (top) and eroding (bottom) salt marsh on the northern estuary margin

Entrance of Papanui Inlet (Makahoe), looking over the Okia Flats

The estuary drains a 1,248ha catchment comprising ~58.8% intensive pasture, ~17.8% low producing pasture, 8.9% mixed exotic shrubland and 7.0% exotic forest. Only, 23.1% of the catchment is densely vegetated and mostly comprises exotic vegetation (Table 1; Fig. 2). The estuary margin is modified with a road around much of the estuary edge and a rock wall preventing landward migration of the estuary in response to sea level rise.

Road and artificial rock wall bordering the estuary

Table 1. Summary of catchment land cover (LCDB5 2017/18) Papanui Inlet (Makahoe).

LCDB5 (2017/2018) Catchment Land Cover		Ha	%
6	Surface Mine or Dump	4.3	0.3
40	High Producing Exotic Grassland	733.4	58.8
41	Low Producing Grassland	222.4	17.8
45	Herbaceous Freshwater Vegetation	3.7	0.3
46	Herbaceous Saline Vegetation[1]	10.3	0.8
52	Manuka and/or Kanuka	5.4	0.4
54	Broadleaved Indigenous Hardwoods	33.0	2.6
56	Mixed Exotic Shrubland	111.3	8.9
64	Forest - Harvested	1.8	0.1
69	Indigenous Forest	34.4	2.8
71	Exotic Forest	87.8	7.0
Grand Total		1248	100
Total densely vegetated area (LCDB classes 45-71)		287.8	23.1

[1]Herbaceous Saline Vegetation includes dunes

Papanui Inlet (Makahoe) was an early Māori settlement, providing shelter, kaimoana, including shellfish, seals and penguins along the coast, and access to the fishery offshore. Several important archeological sites exist including middens and the second oldest waka (canoe) ever found in New Zealand.

Cockles (*Austrovenus stutchburyi*) remain abundant and an important source of kaimoana for Ngāi Tahu (James et al. 2010; Kainamu 2010). Southern Clams Ltd commercially harvest cockles in Papanui Inlet, although harvesting temporarily ceased between 2006 and 2017 because water quality did not meet shellfish quality assurance standards. Some water quality degradation has been attributed to nutrient run off from land and contamination by waterfowl (Moore et al. 2015). The estuary comprises both terrestrial and marine sediments, with terrestrial inputs likely enhanced during forest clearance (Moore et al. 2015).

Cockle beds in the mid estuary

The estuary is an important habitat for waders including the eastern bar-tailed godwit, white-faced heron, pied oystercatcher, variable oyster catcher, pied stilt and spur winged plover (ORC Regional Plan: Coast; 2016 Wader Count). Other habitats include extensive seagrass beds and sandflats that are an important nursery for pātiki (flatfish; ORC Regional Plan: Coast). The estuary retains high cultural and ecological values and is therefore classified as a coastal protection area in the Otago Regional Plan: Coast.

Seagrass beds in Papanui Inlet (Makahoe)

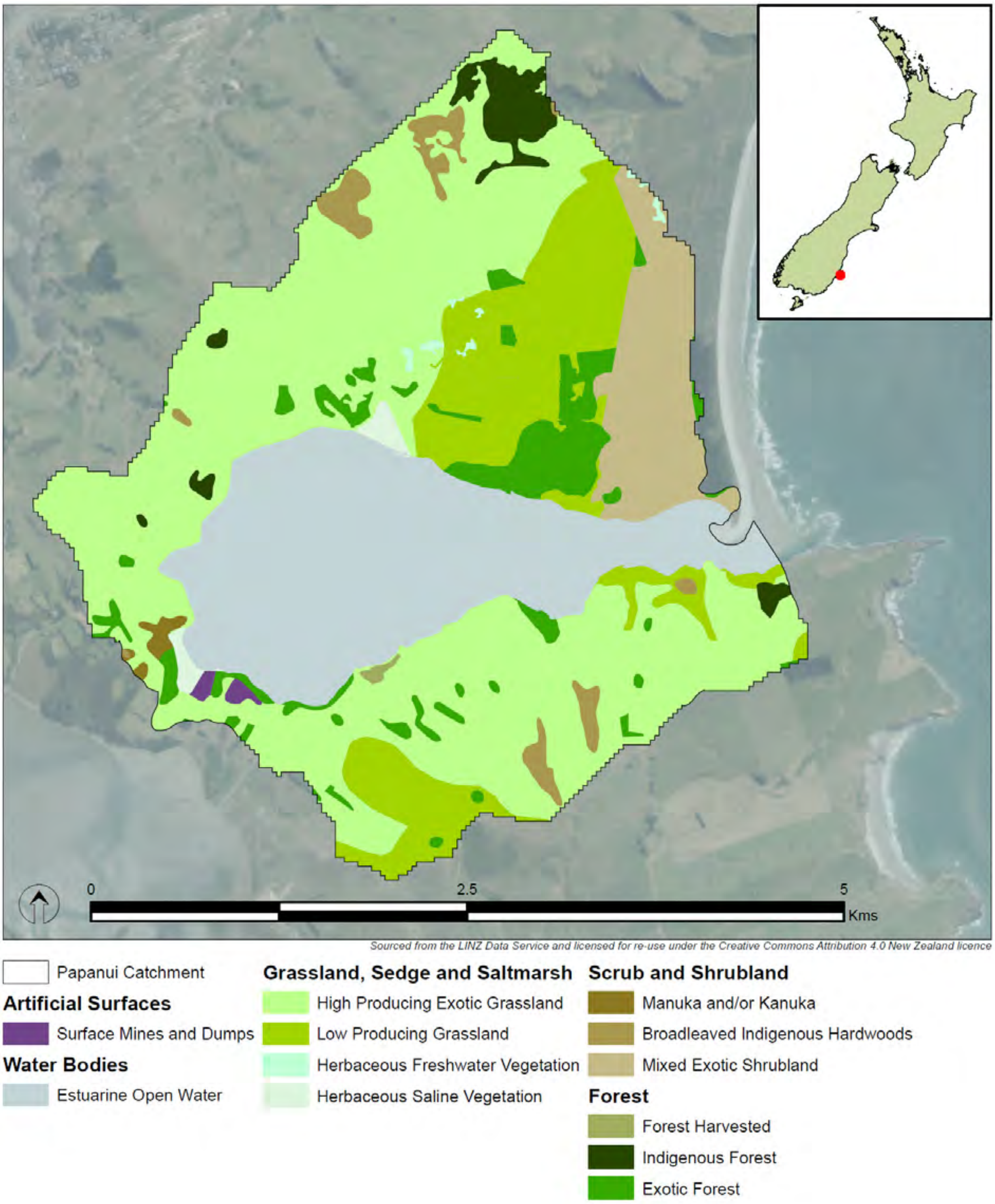


Fig. 2. Papanui Inlet (Makahoe) catchment land use classifications from LCDB5 (2017/2018) database.

2. METHODS

2.1 OVERVIEW

Broad scale habitat mapping of Papanui Inlet (Makahoe) was carried out on 26 and 29 November 2021. The focus of the study was to characterise substrate and the presence and extent of seagrass, macroalgae and salt marsh.

2.2 BROAD SCALE MAPPING METHODS

Broad scale surveys involve describing and mapping estuaries according to dominant surface habitat features (substrate and vegetation). The type, presence and extent of substrate, salt marsh, macroalgae or seagrass reflects multiple factors, for example the combined influence of sediment deposition, nutrient availability, salinity, water quality, clarity and hydrology. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to small scale temporal variation associated with instantaneous water quality measures.

NEMP methods (Appendix 1) were used to map and categorise intertidal estuary substrate and vegetation. The mapping procedure combines aerial photography, detailed ground-truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats can be monitored by repeating the mapping exercise. Broad scale mapping is typically carried out during September to May when most plants are still visible and seasonal vegetation has not died back. Aerial photographs are ideally assessed at a scale of less than 1:5000, as at a broader scale it becomes difficult to accurately determine changes over time.

In 2021, imagery was supplied by ORC (1:3000 colour aerial imagery captured between January and April 2019). Ground-truthing was undertaken on 26 and 29 November 2021 by experienced scientists who assessed the estuary on foot to map spatial extent of dominant vegetation and substrate. A particular focus was to characterise the spatial extent of muddy sediment (as a key stressor), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats. The latter were estuarine seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the terrestrial margin bordering the estuary. Background information on the ecological significance of opportunistic macroalgae and the different vegetation features is provided in Table 2.

In the field, features were drawn directly onto laminated aerial photographs. The broad scale features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features, e.g. salt marsh, and its underlying substrate type.

For broad scale mapping purposes, an estuary is defined as a partly enclosed body of water, where freshwater inputs (i.e. rivers, streams) mix with seawater. The estuary entrance (i.e seaward boundary) was defined as a straight line between the seaward-most points of land that enclose the estuary, and the upper estuary boundary (i.e. riverine boundary) was based on the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For further detail see FGDC (2012).

Assessment criteria, developed largely from previous broad scale mapping assessments, apply thresholds for helping to assess estuary condition. Additional details on specific broad scale measures are provided in Sections 2.3-2.8.

Seagrass in Papanui Inlet (Makahoe), looking toward the entrance

Salt marsh on the margin of Papanui Inlet (Makahoe)

Table 2. Overview of the ecological significance of various vegetation types.

Habitat	Description
Terrestrial margin vegetation	A densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important food source and habitat for a variety of species and, in waterway riparian zones, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity.
Salt marsh	Salt marsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important in estuaries as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds and provides an important habitat for a variety of species including fish and birds.
Seagrass	Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

2.3 SUBSTRATE CLASSIFICATION AND MAPPING

Salt Ecology has extended the NEMP approach to include substrate beneath vegetation to create a continuous substrate layer for the estuary. Furthermore, a revision of the NEMP substrate classifications is summarised in Appendix 1.

Substrate classification is based on the dominant surface substrate features present, e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories based on sediment 'muddiness', assessed according to an expert field-based assessment of textural and firmness characteristics. In November 2021, 6 sediment grainsize samples were collected to validate field classifications of substrate type, with 4 additional validation samples sourced from consent monitoring results (Appendix 2).

The area (horizontal extent) of mud-dominated sediment is used as a primary indicator of sediment mud impacts and in assessing susceptibility to nutrient enrichment impacts (trophic state).

Mobile sands near the estuary entrance

Causeway and drain input to Papanui Inlet (Makahoe)

2.4 SEDIMENT OXYGENATION

The apparent Redox Potential Discontinuity (aRPD) depth was used to assess the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment. The aRPD depth is the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). aRPD provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions. Sediments were considered to have poor oxygenation if the aRPD was consistently <10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. As significant sampling effort is required to map sub-surface conditions accurately, the approach is intended as a preliminary screening tool to determine the need for additional sampling effort. The aRPD depth was recorded at all grain size locations collected from representative substrate types (Appendix 2).

Example of distinct colour change with depth, brown oxygenated sediments are on the surface down to ~30mm

2.5 MACROALGAE ASSESSMENT

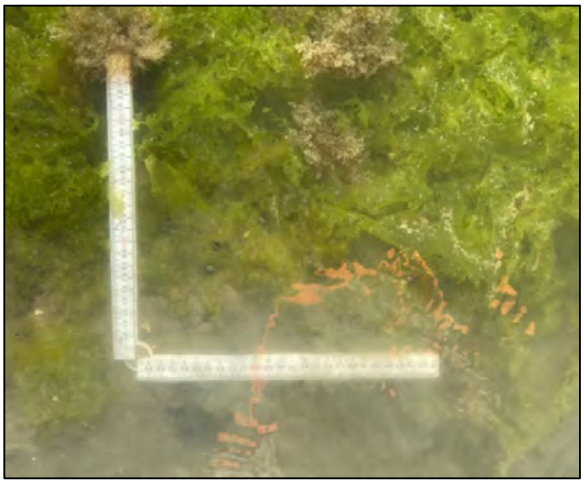
The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature.

The ETI (Robertson et al. 2016b) adopted the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach. The OMBT, described in detail in Appendix 3, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within five overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- *Percentage cover of opportunistic macroalgae:* The spatial extent and surface cover of algae present in intertidal soft sediment habitat in an estuary provides an early warning of potential eutrophication issues.
- *Macroalgal biomass:* Biomass provides a direct measure of macroalgal growth (wet weight biomass). Measurements and estimates of mean biomass are made within areas affected by macroalgal growth, as well as across the total estuary intertidal area.
- *Extent of algal entrainment into the sediment matrix:* Macroalgae is defined as entrained when growing in stable beds or with roots deep (e.g. >30mm) within the sediments, which indicates that persistent macroalgal growths have established.

If an estuary supports <5% opportunistic macroalgal cover in total within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' (EQR score ≥ 0.8 to 1.0) with no further sampling required. A numeric EQR score is calculated for the 'high' band using the approach described in Stevens et al. (2022).

Using this approach, opportunistic macroalgae patches were mapped during field ground-truthing using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (Fig. 3). Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the extent of macroalgal entrainment were measured.



Assessing macroalgal cover in Papanui Inlet (Makahoe)

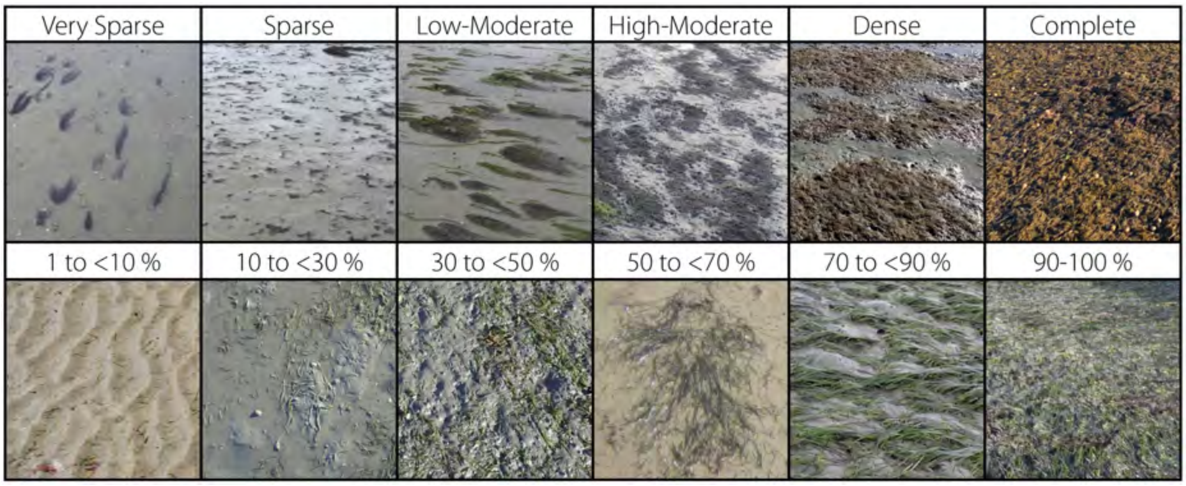


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algal material was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale. When sufficient representative patches had been measured to enable biomass to be reliably estimated, biomass estimates were made following the OMBT method. Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on the five-point scale adopted by the method as noted above.

Ulva spp. present on the southern side of the estuary

2.6 SEAGRASS ASSESSMENT

As for macroalgae, the percent cover of seagrass patches was visually estimated through ground-truthing, based on the 6-category percent cover scale in Fig. 3.

To assess change in seagrass extent over time, aerial imagery from 1958, 1970, 1985 and 2000 (retrolens.co.nz) was georeferenced in ArcMap 10.6 and visible seagrass was digitised. Because it was difficult to distinguish boundaries between subtidal and intertidal areas on the historic imagery, the total area of seagrass (>50% cover) across the whole estuary has been compared across years. For comparison with November 2021, both intertidal and subtidal seagrass were mapped. Because the estuary nearly completely drained at low tide, and the remaining subtidal areas were shallow with high water clarity, subtidal areas were mapped based on the aerial imagery. As discussed in Section 2.10, it is difficult to reliably map seagrass areas of <50% cover solely from aerial imagery (i.e., no ground-truthing), therefore comparisons with November 2021 are made with the percent cover categories >50% cover.

2.7 SALT MARSH

NEMP methods were used to map and categorise salt marsh with dominant estuarine plant species used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock; Robertson et al. 2002a-c; Appendix 1). Two measures were used to assess salt marsh condition: i) intertidal extent (percent cover) and ii) current extent compared to estimated historical extent.

LiDAR and historic aerial imagery were used to estimate historic salt marsh extent. LiDAR data was supplied by ORC as a terrain dataset of the coastal margin. All LiDAR geoprocessing was performed using ArcGIS Pro 2.9.3. The terrain dataset was converted to raster using the Terrain to Raster (3D Analyst) tool. Contour lines were created using the Contour List (Spatial Analyst) tool. The 1.6m contour was selected to represent the upper estuary boundary elevation based on a comparison with existing estuary mapping and a visual assessment of aerial imagery.

2.8 TERRESTRIAL MARGIN

Broad scale NEMP methods were used to map and categorise the 200m terrestrial margin using the dominant land cover classification codes described in the Landcare Research Land Cover Data Base (LCDB) detailed in Appendix 1.

Terrestrial margin in the lower estuary, mix of exotic vegetation

Road and artifical rock wall on edge of estuary

Fenced and grazed salt marsh adjacent to estuary

2.9 SEDIMENT QUALITY & MACROFAUNA

Sediment quality and macrofauna samples were collected from three sites and used as supporting indicators to calculate an Estuary Trophic Index (ETI) score for the estuary (Robertson et al (2016b). The ETI requires supporting indicators represent the 10% of the estuary most susceptible to eutrophication (Zeldis et al. 2017).

At each of the three locations, a surface (~20mm) sediment sample was collected, stored on ice, and sent to RJ Hill Laboratories for analysis of the following: particle grain size in three categories (%mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP) and total sulfur (TS). Details of laboratory methods and detection limits are provided in Appendix 2.

At each site one sample for macrofauna was collected using a large sediment core (130mm diameter, 150mm deep). The core was extruded into a 0.5mm mesh sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a mixture of 75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification by NIWA. The types of animals present in each sample, as well as the range of different species (i.e. richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments (see Forrest et al. 2022).

Sediment sampling on the incoming tide – note the high water clarity

2.10 DATA RECORDING AND QA/QC

Broad scale mapping provides a rapid overview of estuary substrate, macroalgae, seagrass and salt marsh condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial imagery, the extent of ground-truthing undertaken to validate features visible on photographs, and the experience of those undertaking the mapping. In most instances features with readily defined edges can be mapped at a scale of ~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse seagrass or macroalgal beds. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed, but when relying on photographs alone, accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

In November 2021, following digitising of habitat features, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables.

As well as annotation of field information onto aerial photographs during the field ground-truthing, point estimate macroalgal data (i.e. biomass and cover measurements, entrainment), along with supporting measures of sediment aRPD, texture and sediment type were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMap 10.6.

2.11 ASSESSMENT OF ESTUARY CONDITION

In addition to the authors' expert interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 3). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3. The condition ratings are primarily sourced from the NZ ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 4. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores (i.e. which range from 'high' to 'bad'). The thresholds used to place biomass into OMBT bands

Table 3. Indicators used to assess results in the current report.

Indicator	Unit	Very good	Good	Fair	Poor
Broad scale Indicators					
ETI score[1]	No unit	≤ 0.25	>0.25 to 0.5	>0.5 to 0.75	>0.75 to 1.0
Mud-dominated substrate[2]	% of intertidal area >50% mud	< 1	1 to 5	> 5 to 15	> 15
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥0.8 to 1.0	≥0.6 to <0.8	≥0.4 to <0.6	0.0 to <0.4
Seagrass[2]	% decrease from baseline	< 5	≥ 5 to 10	≥ 10 to 20	≥ 20
Salt marsh extent (current)[2]	% of intertidal area	> 20	> 10 to 20	> 5 to 10	0 to 5
Historical salt marsh extent[2]	% of historical remaining	≥ 80 to 100	≥ 60 to 80	≥ 40 to 60	< 40
200m terrestrial margin[2]	% densely vegetated	≥ 80 to 100	≥ 50 to 80	≥ 25 to 50	< 25
High Enrichment Conditions[1]	ha	< 0.5	≥ 0.5 to 5	≥ 5 to 20	≥ 20
High Enrichment Conditions[1]	% of estuary	< 1	≥ 1 to 5	≥ 5 to 10	≥ 10
Sedimentation rate[1]*	CSR:NSR ratio	1 to 1.1 xNSR	1.1 to 2	2 to 5	> 5
Sedimentation rate[3]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Sediment quality					
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to ≤ 20	≤ 10

[1] General indicator thresholds derived from a New Zealand Estuary Tropic Index (Robertson et al. 2016b), with adjustments for aRPD (FGDC 2012). See text and Appendix 4 for further explanation of the origin or derivation of the different metrics.

[2] Subjective indicator thresholds derived from previous broad scale mapping assessments.

[3] Ratings derived or modified from Townsend and Lohrer (2015).

*CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling) have been recently revised for use in New Zealand (Plew et al. 2020a) and are included in Appendix 3.

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HECs) was evaluated. For our purposes, HECs are defined as mud-dominated sediments (≥50% mud content) with >50% macroalgal cover and with macroalgae entrained and growing as stable beds rooted within the sediment. These areas typically also have an aRPD depth shallower than 10mm due to sediment anoxia.

As many of the scoring categories in Table 3 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Cockles beds, Papanui Inlet (Makahoe)

Herbfield adjacent to dune vegetation in Papanui Inlet (Makahoe)

3. RESULTS

A summary of the November 2021 survey in Papanui Inlet (Makahoe) is provided below and in the appendices. Supporting GIS files (supplied to ORC as a separate electronic output) provide a more detailed dataset designed for easy interrogation and to address specific monitoring and management questions.

3.1 SUBSTRATE

Table 4 and Fig. 4 show intertidal substrate was dominated by firm sand (182.0ha, 62.7%) in the main body of the estuary, and mobile sand (81.6ha, 28.1%) in the lower estuary. Rockfield (1.8ha or 0.6%) was present on the southern margin of the estuary toward the entrance. Artificial boulder field (0.2%) was localised along the estuary margin to protect the road from erosion. Mud-dominated sediments were scarce (0.07ha, 0.02%) and associated with salt marsh habitat or localised stream inputs where fine sediments naturally accumulate. While large cockle (*Austrovenus stutchburyi)* beds exist, only a small area was dominated by shellbank (1.1ha), with cockles otherwise growing in the dominant substrate types (firm or mobile sand). There was good agreement between the subjective sediment classifications applied during mapping and the sediment grainsize validation measures (see Appendix 2).

Table 4. Summary of dominant intertidal substrate, Papanui Inlet (Makahoe), November 2021.

Substrate Class	Feature	Ha	%
Artificial	Boulder field	0.7	0.2
	Gravel field	0.8	0.3
Bedrock	Rock field	1.8	0.6
Boulder/ Cobble/ Gravel	Cobble field	0.2	0.1
	Gravel field	1.0	0.3
Sand (0-10% mud)	Mobile sand	81.6	28.1
	Firm sand	182.0	62.7
Muddy Sand (>10-25% mud)	Firm muddy sand	5.0	1.7
	Soft muddy sand	8.3	2.9
Muddy Sand (>25-50% mud)	Firm muddy sand	7.5	2.6
	Soft muddy sand	0.01	0.004
Sandy Mud (>50-90% mud)	Firm sandy mud	0.04	0.01
	Soft sandy mud	0.03	0.01
Zootic	Shell bank	1.1	0.4
Total		290.2	100

Shellbank on mobile sand (top) and sand with sparse cockles (bottom)

Artificial boulder field and gravel field on road margin (top) and eroding artificial boulder field (bottom)

Muddy sands associated with a freshwater input (top) and drainage channels through salt marsh (bottom)

Seagrass growing on firms sands

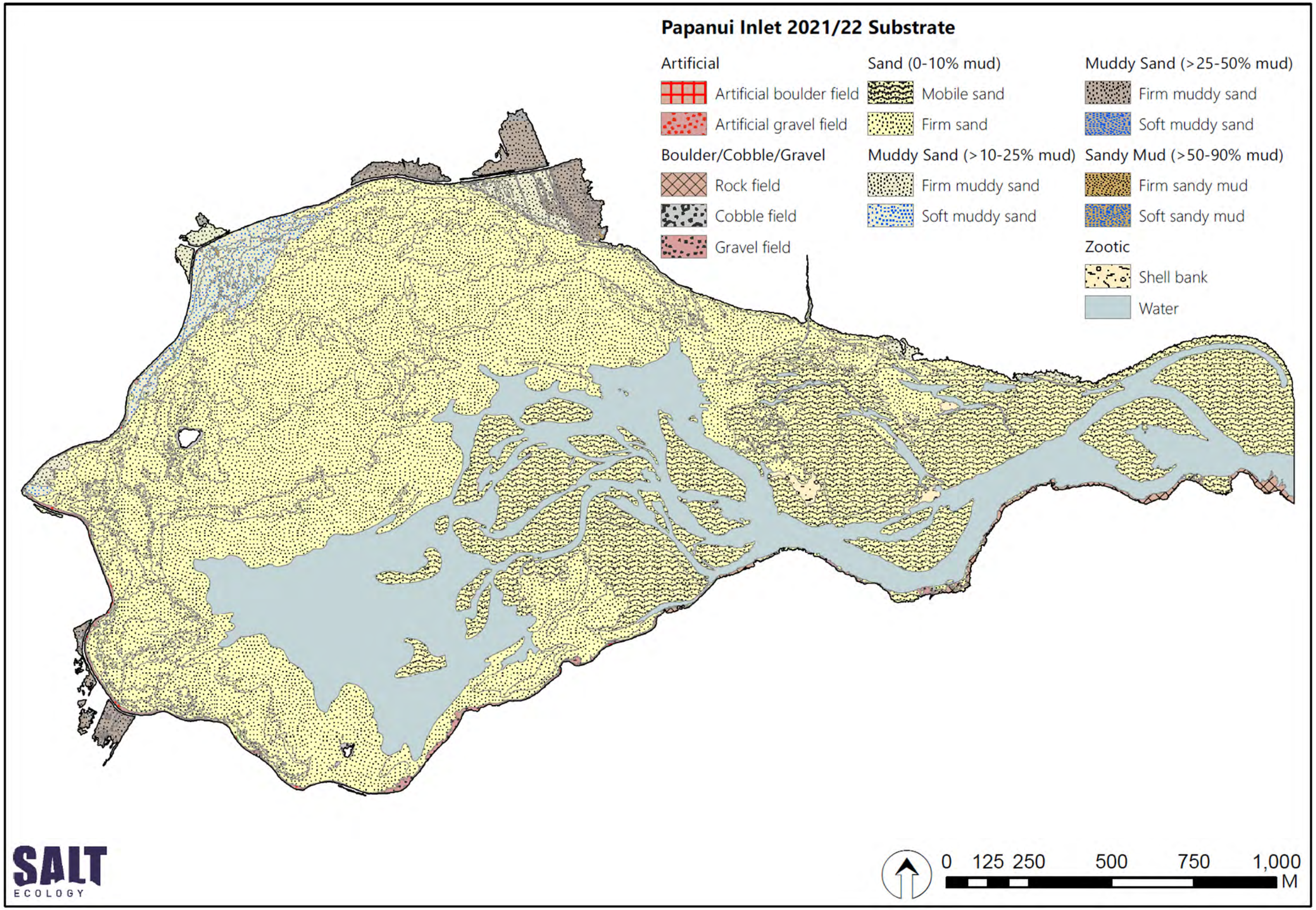


Fig. 4. Dominant substrate types in the intertidal zone, Papanui Inlet (Makahoe), November 2021.

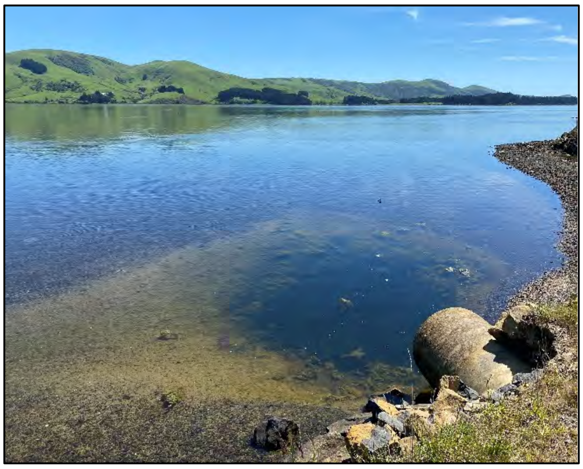
3.2 SEDIMENT OXYGENATION

In November 2021, spot measurements of aRPD showed that sand-dominated sediments were well oxygenated (see photo). In areas of high macroalgal cover there were no visible signs of poor sediment oxygenation suggesting that intermittent blooms of macroalgae observed in the estuary are not significantly impacting the benthic habitat. Firm sands supporting seagrass were generally well oxygenated with seagrass roots extending deep into the sediment. In contrast, the aRPD was shallow (<10mm) in seagrass growing in soft muddy-sands on the northwest margin.

In general, the shallowest aRPD depths occurred in sediments with increasing mud content and/or organic material. For example, near stream inputs, soft muddy-sands or in areas where drift seagrass had accumulated and was decomposing. Areas of poor sediment oxygenation were uncommon in the estuary.

Firm sand (left) aRPD ~30mm and Ulva spp. (right) aRPD ~40mm

Low oxygen (black) sediments were present in crab burrowing deposits in soft muddy-sands (top), and beneath decaying seagrass washed ashore (bottom)



Low oxygen sediment directly below drain outlet

3.3 OPPORTUNISTIC MACROALGAE

Table 5 summarises macroalgae percentage cover and biomass classes for Papanui Inlet (Makahoe) in November 2021, with the mapped cover and biomass shown in Fig. 5 and Fig. 6 respectively. Macroalgal sampling stations and data are provided in Appendix 5. Marine species and drift macroalgae were not recorded as part of the nuisance macroalgae assessment.

Table 5. Summary of intertidal macroalgal cover (A) and biomass (B), Papanui Inlet (Makahoe), November 2021.

A. Cover

Percent cover category	Ha	%
Absent or trace (<1%)	275.4	94.9
Very sparse (1 to <10%)	6.8	2.3
Sparse (10 to <30%)	1.5	0.5
Low-Moderate (30 to <50%)	5.6	1.9
High-Moderate (50 to <70%)	0.6	0.2
Dense (70 to <90%)	0.4	0.1
Complete (≥90%)	0.02	0.01
Total	290.2	100.0

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	275.4	94.9
Very low (1 - 100)	8.3	2.8
Low (101 - 200)	0.0	0.0
Moderate (201 - 500)	0.0	0.0
High (501 - 1450)	6.2	2.1
Very high (>1450)	0.4	0.1
Total	290.2	100.0

Key macroalgae results were as follows:

- Macroalgae were scarce in the Available Intertidal Habitat (AIH). Cover was classified as trace (<1%) or very sparse (1 to <10%) across 97.2% of the intertidal area, and sparse (10 to <30%) or low-moderate (30 to <50%) across 2.4% (Table 5). Overall, the Affected Area (AA) where macroalgae were growing was small (14.8ha, 5.3%; Fig. 5; Table 6).
- Macroalgae cover >50% only comprised 1.0ha (0.3%) of the intertidal area, and were predominantly growing on firm sands or near channel margins.
- When present, the dominant macroalgae was the green seaweed *Ulva* spp. with the red seaweed *Agarophyton* spp. (previously known as *Gracilaria* spp.) and the red seaweed *Ceramium* spp. only present in small amounts (see photos).
- Mean wet weight biomass was low across the AIH (23.3 g/m^2), and moderate in the AA (436.5 g/m^2; Table 6).
- Areas of high *Ulva* spp. biomass (i.e., >501g/m^2) were recorded on the northern and southern flats (Fig. 6), although underlying sediments appeared healthy.
- No High Enrichment Condition (HEC) areas (mud-dominated sediments with >50% macroalgal cover entrained in stable beds) were recorded.

Because the estuary had <5% opportunistic macroalgal cover across the AIH (1.4%; Table 6), the OMBT method rates overall quality status as 'high', equivalent to the condition rating of 'very good' (Table 3). In order to provide a more nuanced assessment of state, a numeric OMBT EQR score was calculated using only the % cover AIH sub-metric as described in Stevens et al. (2022). The numeric EQR score (0.945) highlights that macroalgae were not a dominant vegetation type in the estuary, and did not appear to be causing any significant adverse effects on the benthic community or seagrass.

Ulva spp. northern Papanui Inlet

Localised macroalgal growths on stream margin

Mix of *Ulva* spp. and *Agarophyton* spp. on firm sands

Table 6. Summary of OMBT input metrics, overall Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 3). Condition rating is based on criteria in Table 3.

2021 Metric	Face value	FEDS	Environmental Quality Class
%cover in AIH	1.4	0.945	High
Average biomass (g/m^2) in AIH	23.3	0.953	High
Average biomass (g/m^2) in AA	436.5	0.442	Moderate
%entrained in AA	0	1.0	High
Worst of AA (ha) and AA (% of AIH)		0.776	Good
AA (ha)	14.8	0.776	Good
AA (% of AIH)	5.3	0.793	Good
Survey EQR		0.945*	'Very Good'

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating
*Because <5% cover in the AIH, score calculated from % cover AIH sub-metric only using method in Stevens et al. (2022).

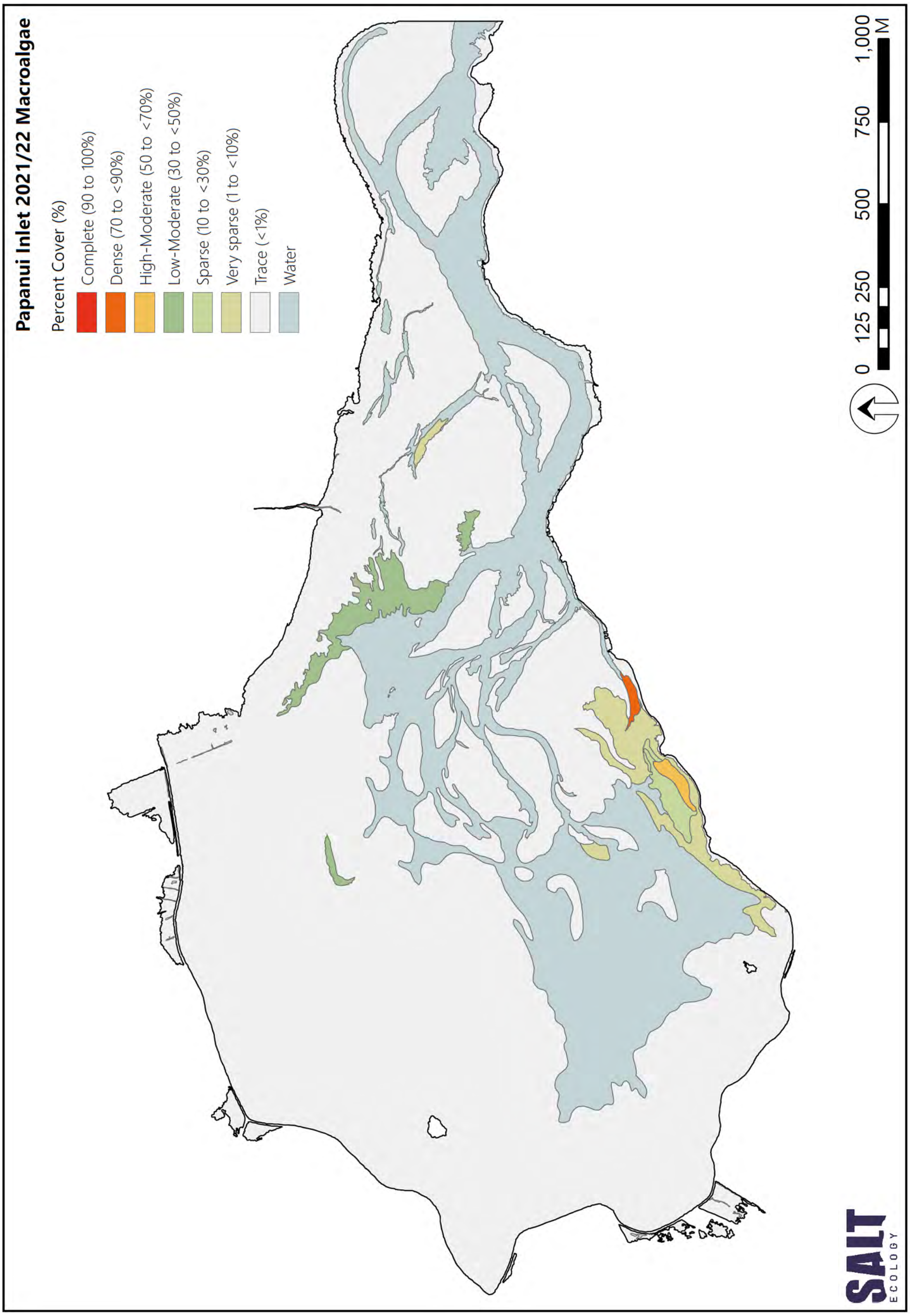


Fig. 5. Distribution and percent cover classes of macroalgae, Papanui Inlet (Makahoe), November 2021.

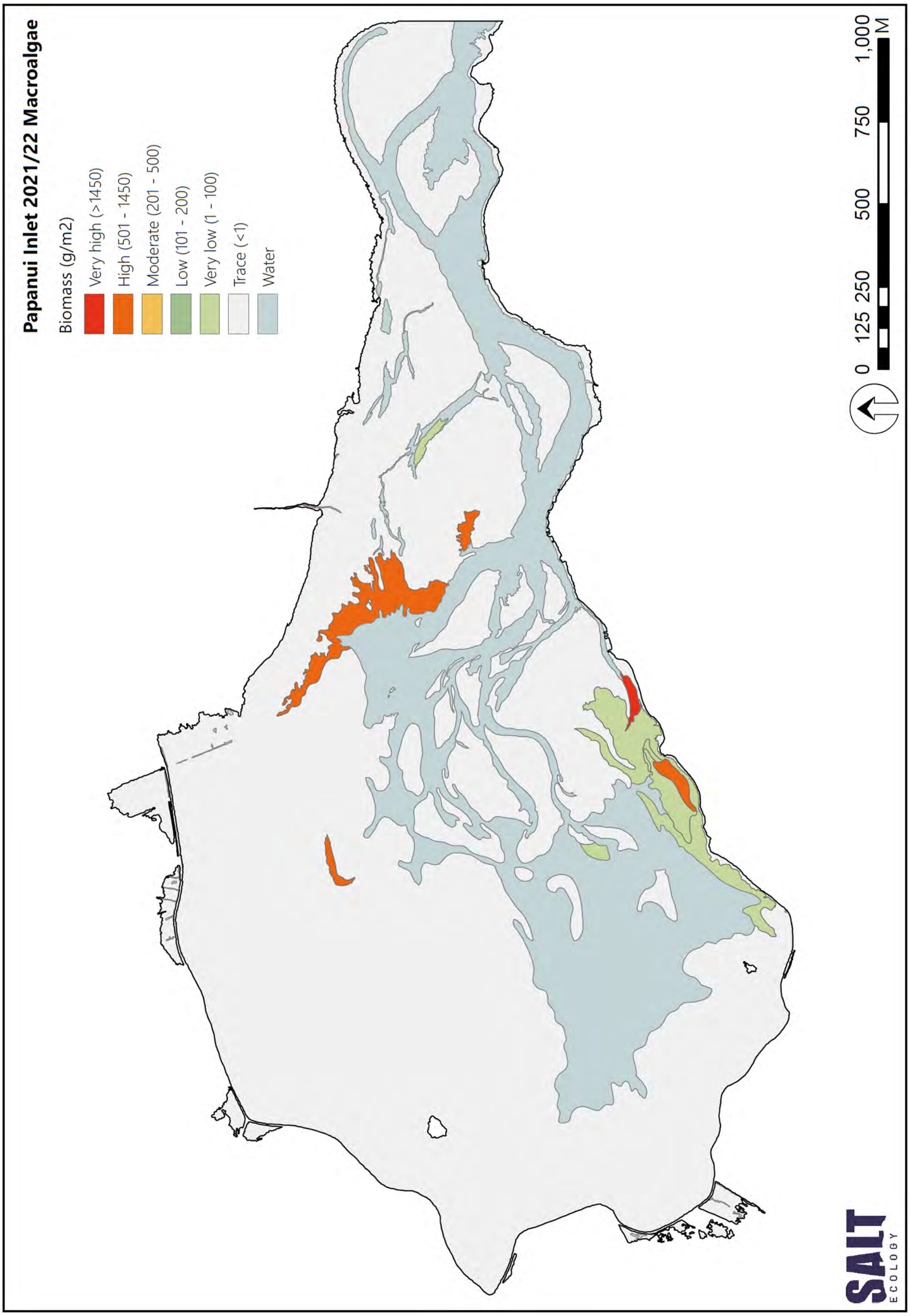


Fig. 6. Biomass (wet weight; g/m^2) classes of macroalgae, Papanui Inlet (Makahoe), November 2021.

3.4 SEAGRASS

Table 7 and Fig. 7 summarise seagrass (*Zostera muelleri*) percent cover. Seagrass was extensive, comprising 38.3% of the intertidal area with cover >50% across 84.0ha (28.9%). The largest expanse of seagrass was recorded in the northwest, with luxuriant beds of >70% cover common near the estuary margin. Overall seagrass appeared healthy, however there was extensive grazing damage by waterfowl (e.g. black swans and Canadian geese), and vehicle damage in the northern estuary (see photos). Dead seagrass was observed in beds and as accumulations on the southwest margin, however aside from grazing there were no other obvious stressors to explain the seagrass dieback.

Swan guano across the seagrass beds

Table 7. Summary of seagrass percent cover categories, Papanui Inlet (Makahoe), November 2021.

Percent cover category	Ha	%
Absent or trace (<1%)	179.0	61.7
Very sparse (1 to <10%)	0.1	0.0
Sparse (10 to <30%)	7.2	2.5
Low-Moderate (30 to <50%)	19.8	6.8
High-Moderate (50 to <70%)	60.6	20.9
Dense (70 to <90%)	21.2	7.3
Complete (≥90%)	2.1	0.7
Total	290.2	100

Dead seagrass (brown) in beds and washed ashore in background

Seagrass beds in Papanui Inlet (Makahoe)

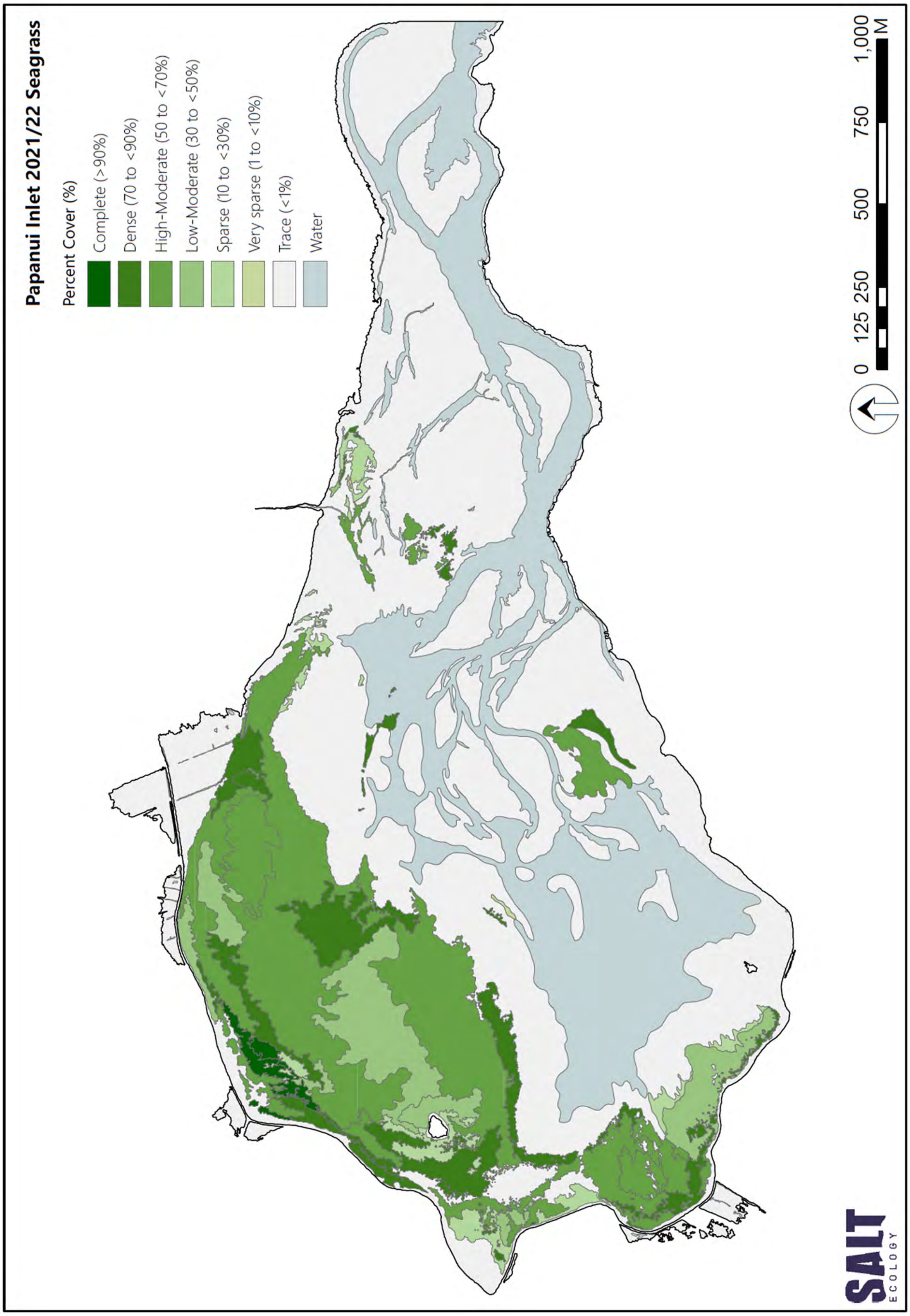


Fig. 7. Distribution and percent cover classes of seagrass, Papanui Inlet (Makahoe), November 2021.

Vehicle damage across seagrass beds, Papanui Inlet (Makahoe)

November 2021 represents the first baseline broad scale survey undertaken by ORC. Anecdotal reports from landowners in the area suggest areas of current seagrass extent in the northwest of the estuary were historically unvegetated sandflats. To explore this further, seagrass visible on aerial images taken in 1958, 1970, 1985, 2000 was digitised and compared to present day (see Section 2.6). For the purposes of comparison across years cover is assumed to be >50% and there is no distinction between intertidal and subtidal seagrass as the boundaries were difficult to distinguish from historic imagery. Table 8 and Fig. 8 represent seagrass extent between 1958 and present day. These should be treated as best estimates because image quality, time of image capture (i.e. month) and tide height varied between dates, and the images were not ground-truthed.

Table 8. Estimated historic seagrass extent for the whole estuary.

Year	ha	% Estuary
Feb-1958	62.0	16.4
Feb-1970	59.9	15.8
Feb-1985	70.6	18.7
Mar-2000	135.3	35.8
Nov-2021*	92.8	24.6

*Includes subtidal seagrass beds not included in Table 6 and Fig. 7.

In 1958 seagrass was localised in the central tidal flats and, over time, has migrated north (1985) and northwest (2000) with extent variable over time (Table 8; Fig. 8; Appendix 6). Seagrass has expanded over time and has remained the dominant vegetation type in the estuary ranging from 15.8% in 1970 to a peak of 35.8% in 2000 (Table 8).

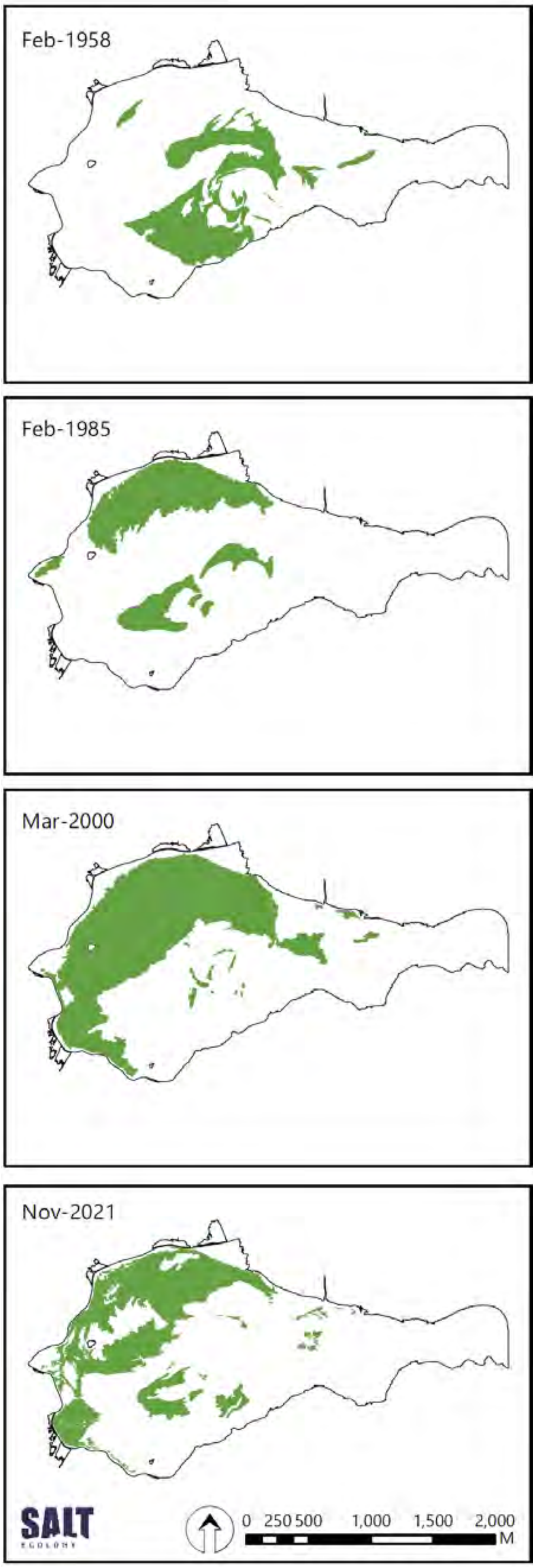


Fig. 8. Historic seagrass extent for the whole estuary. See Appendix 6 for larger images and 1970 map.

3.5 SALT MARSH

Table 9 summarises intertidal salt marsh with the distribution mapped in November 2021 presented in Fig. 9. Dominant and subdominant species are recorded in Appendix 7. The area of salt marsh recorded in November 2021 was 12.9ha (4.4% of the intertidal area) (Table 9), with the most extensive area on the northern margin.

Table 9. Summary of salt marsh area (ha and %) in Papanui Inlet (Makahoe), November 2021.

Subclass	Ha	%
Estuarine Shrub	1.1	8.4
Sedgeland	0.2	1.8
Tussockland	0.003	0.02
Grassland	0.6	4.8
Rushland	0.5	3.9
Herbfield	10.4	81.0
Total	**12.9**	**100**

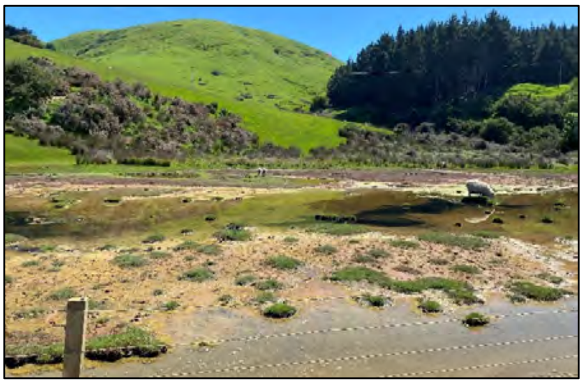
Herbfield was the dominant class (10.4ha or 81% of total salt marsh). The dominant species were *Sarcocornia quinqueflora* (Glasswort; see photo), *Selliera radicans* (Remuremu), and *Samolus repens* (Primrose). Other common species included *Disphyma australe* (NZ ice plant) and *Cotula coronopifolia* (Bachelor's button). Estuarine shrub comprised 1.1ha or 8.4% of the salt marsh. The dominant species was *Plagianthus divaricatus* (Salt marsh ribbonwood). Rushland comprised only a small area (0.5ha) and was dominated by *Apodasmia similis* (Jointed wirerush) and *Ficinia (Isolepis) nodosa* (Knobby clubrush). Other common salt marsh species included *Puccinella pungens* (salt grass) and *Poa cita* (silver tussock). Introduced weeds and the grass *Festuca arundinacea* (tall fescue) were present in some areas, particularly on the margin near the road or adjacent grassland. Several patches of salt marsh are within fenced areas that are grazed by sheep.

In Papanui Inlet (Makahoe), salt marsh extent is limited by the steep topography of the adjacent land. Historical losses are evident with reclamation for roading on the margin, and drainage and conversion to pasture also common in the low-lying areas. The historic margin, estimated from LiDAR data (Fig. 9; Appendix 8), indicates there has been ~6ha or 30% loss of salt marsh when compared to the predicted historic extent (i.e., 70% of the natural cover remains), a condition rating of 'good' (Table 3). There is localised erosion of some herbfields at the seaward edge of the salt marsh (see photo).

Sarcocornia quinqueflora (Glasswort) eroding

Schoenoplectus pungens (Three square)

Rushland and sedgeland



Sheep grazing an area that contains herbfield species

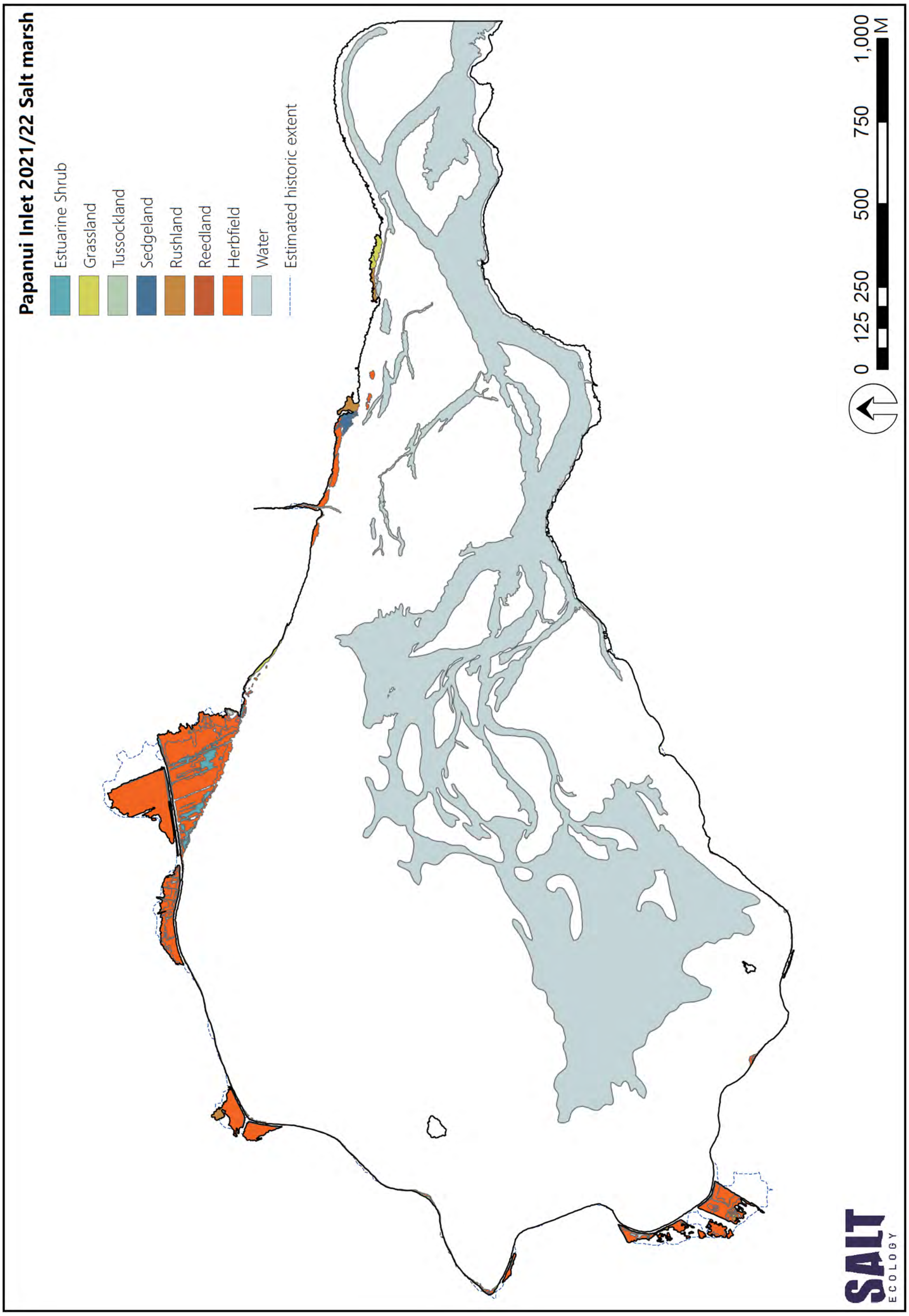


Fig. 9. Distribution and vegetation subclasses of salt marsh habitat, Papanui Inlet (Makahoe), November 2021.

3.6 TERRESTRIAL MARGIN

Table 10 and Fig. 10 summarise the land cover of the 200m terrestrial margin which has been extensively modified and is dominated by low producing grassland (66.0%) and exotic forest (17.1%). There are a few remnant patches of native vegetation scattered around the estuary (<7% of the margin). Gorse and/or broom comprised 0.9%.

Built-up areas comprised 5.4% and were mainly toward the south. While transport infrastructure comprises only a small portion (1.9%), its relative impact on the estuary is significant with most of the fringing margin modified for roading and protected from the sea by artificial rock wall which prevents any landward migration of the estuary in response to sea level rise (see photos on following page).

Of the terrestrial margin, 26.4% was densely vegetated (Table 10), including large areas of exotic forest (17.1%) and smaller areas of manuka and/or kanuka (2.3%) and broadleaved indigenous hardwoods (3.9%). Herbaceous saline vegetation (2.0%) represents the dune area near the entrance which was dominated by exotic species, namely *Lupinus arboreus* (tree lupin) and *Ammophilia arenaria* (marram grass).

As discussed in Section 1.1 the estuary drains a 1,248ha catchment comprising ~58.8% intensive pasture, ~17.8% low producing pasture, 8.9% mixed exotic shrubland and 7.0% exotic forest. Only, 23.1% of the catchment remains densely vegetated and mostly comprises exotic vegetation (Table 1; Fig. 2).

Table 10. Summary of 200m terrestrial margin land cover, Papanui Inlet (Makahoe), November 2021.

LCDB Class	Ha	%
1 Built-up Area (settlement)	12.4	5.4
5 Transport Infrastructure	4.4	1.9
16 Gravel and Rock	0.5	0.2
20 Lake or Pond	0.2	0.1
41 Low Producing Grassland	151.0	66.0
46 Herbaceous Saline Vegetation	4.6	2.0
47 Flaxland	0.1	0.0
51 Gorse and/or Broom	2.0	0.9
52 Manuka and/or Kanuka	5.3	2.3
54 Broadleaved Indigenous Hardwoods	9.0	3.9
56 Mixed Exotic Shrubland	0.3	0.1
71 Exotic Forest	39.2	17.1
Grand Total	228.8	100
Total dense vegetated margin (LCDB classes 45-71)	60.4	26.4

Low producing grassland and exotic forest on the northern margin of Papanui Inlet

Road and artificial rock wall on the estuary margin

Naturally steep topography on the estuary margin

Herbfield in paddock and exotic forest in background

Manuka and/or Kanuka and exotic eucalypt forest

Tree lupin and exotic forest on estuary margin

Gorse and grassland on the estuary margin

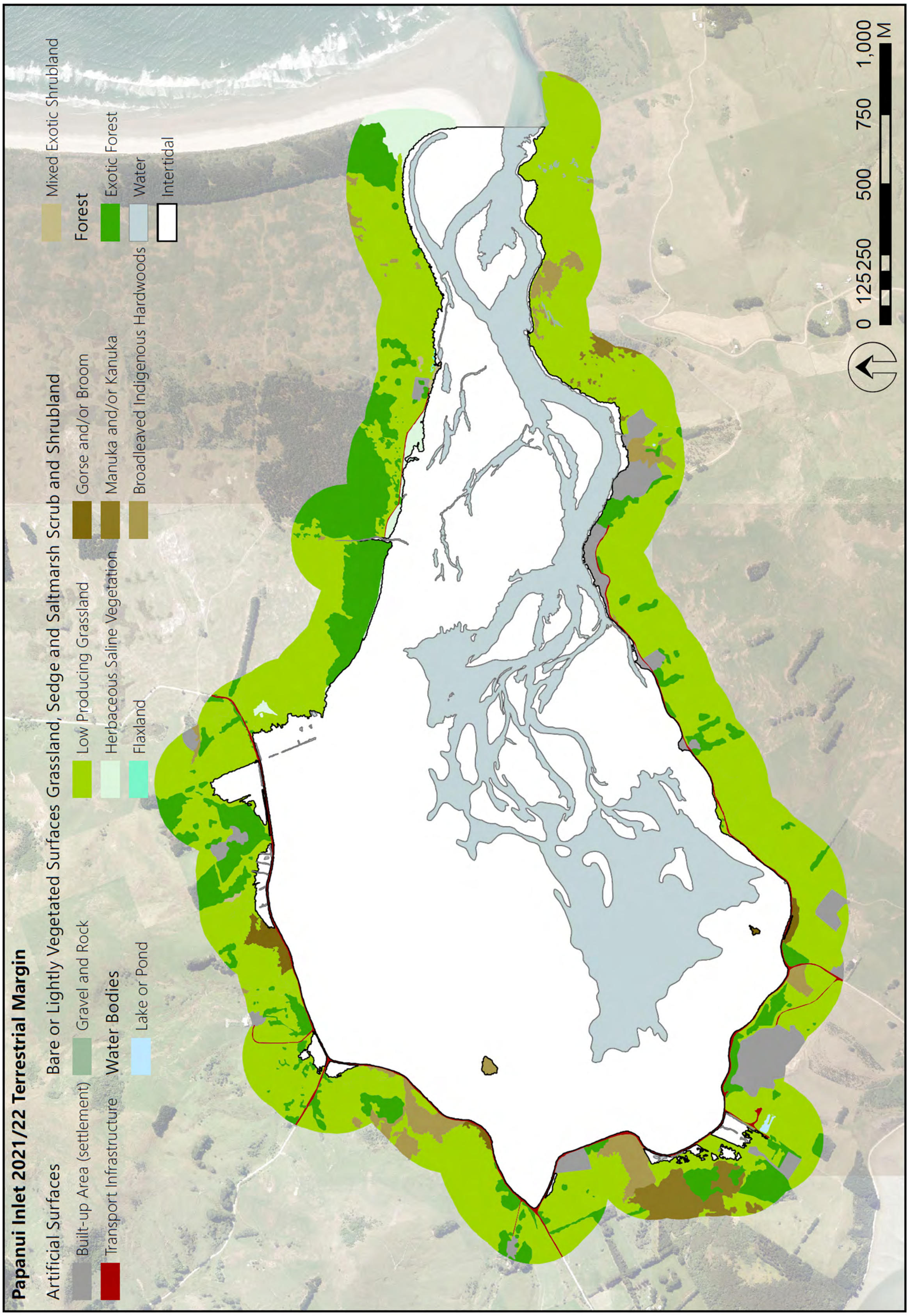


Fig. 10. Map of 200m terrestrial margin land cover, Papanui Inlet (Makahoe), November 2021.

3.7 ESTUARY TROPHIC INDEX (ETI)

Table 11 summarises the indicators used to calculate an overall ETI score for Papanui Inlet (Makahoe). Raw data are presented in Appendix 9. The primary indicator of eutrophication response in SIDE type estuaries, like Papanui/Makahoe, is macroalgae (OMBT EQR), with supporting sediment indicators of macrofauna (AMBI), total nitrogen (TN), total organic carbon (TOC) and oxygenation (aRPD). The overall ETI score of 0.227 was rated 'very good' in terms of eutrophication which is reflected in other metrics such as the high EQR, good sediment oxygenation and the absence of high enrichment conditions.

Table 11. Primary and supporting indicators used to calculate the ETI for Papanui Inlet (Makahoe).

Indicator	Raw Value	Equivalent ETI Score
Primary indicator		
Macroalgae (EQR)	0.945	0.125
Supporting Indicator		
AMBI	1.56	0.313
TN (mg/kg)	<500	0.375
TOC (%)	0.12	0.125
aRPD (mm)	20	0.500
Final ETI Score		0.227 "Very Good"

Seagrass on firm sand

Expansive intertidal flats with segarass beds on firms sands in Papanui Inlet (Makahoe)

4. KEY FINDINGS

Key broad scale indicator results and ratings are summarised in Tables 12 and 13, with additional supporting data used to assess estuary condition presented in Table 14.

Overall, Papanui Inlet (Makahoe) was in 'very good' condition with well flushed tidal flats dominated by clean firm sands or mobile sands supporting a variety of high value features including seagrass, cockle beds and salt marsh. Of the most common stressors evident in New Zealand estuaries, mud-dominated (>50% mud) sediments comprised just 0.02% of the intertidal area and were confined to areas near stream and drain inputs where localised deterioration in water quality was also evident. There was no evidence of nuisance macroalgae or excessive sedimentation indicating current nutrient and fine sediment inputs are below thresholds of concern. The high overall ecological quality of the estuary likely reflects low freshwater inputs (~1% of the estuary volume; Plew et al. 2018) and well-flushed intertidal flats (77% intertidal; Table 12).

The extensive sandflats in the well-flushed central basin supported large cockle beds. Cockles (*Austrovenus stutchburyi)* are an important food source for birds and smaller infauna, they also oxygenate sediments, and filter phytoplankton and sediment from the water column. Cockles are also an important source of kaimoana (seafood), although as filter feeders they are susceptible to contaminants in the water, with poor water quality causing the closure of the commercial cockle fishery between 2006 and 2017, likely due to run-off from the heavily developed catchment (77% pastoral farming).

Table 13. Summary of key broad scale features as a percentage of total estuary, intertidal or margin area, Papanui Inlet (Makahoe), November 2021.

a. Area summary	ha	% Estuary
Intertidal area	290.2	76.8
Subtidal area	87.8	23.2
Total estuary area	378.0	100

b. Key fine sediment features	ha	% Intertidal
Mud-enriched (25 to <50%)	7.5	2.6
Mud-dominated (≥50%)	0.1	0.02

c. Key vegetation features	ha	% Intertidal
Salt marsh	12.9	4.4
Seagrass (≥50% cover)	83.1	28.6
Macroalgal beds (≥50% cover)	1.0	0.3

d. Terrestrial margin (200m)	ha	% Margin
200m densely vegetated margin	60.4	26.4

Localised freshwater input from an under-road culvert

Table 12. Summary of key broad scale indicator results and ratings.

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) score	No unit	0.227	Very Good
Mud-dominated substrate	% of intertidal area >50% mud	0.02	Very Good
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.945	Very Good
Seagrass	% decrease from baseline	nd	November 2021 - baseline
Salt marsh extent (current)	% of intertidal area	4.4	Poor
Historical salt marsh extent*	% of historical remaining	70%	Good
200m terrestrial margin	% densely vegetated	25.4	Fair
High Enrichment Conditions	ha	0	Very Good
High Enrichment Conditions	% of estuary	0	Very Good
Sedimentation rate*	CSR:NSR ratio**	1.7	Good
Sedimentation rate*	mm/yr	0.06	Very Good

Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. *Estimated. **CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

The dominant vegetation type in the estuary was extensive beds of seagrass (*Zostera muelleri*) growing in in firm sands and a small area of soft muddy-sand on the northwest margin. Seagrass is a key feature in estuaries because it is a food source and habitat for fish, birds and macroinvertebrates. Seagrass can also influence water quality by trapping fine sediments, stabilising substrate, and assimilating nutrients. Seagrass is common in other Otago estuaries with large well-flushed intertidal areas and low freshwater inputs, for example, Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea.

The review of historic imagery highlights that seagrass has been an important habitat in Papanui Inlet since at least the 1950s, but has been variable over time and appears to be migrating from the centre of the estuary toward the north and west. This change is supported by anecdotal reports from landowners in the catchment, and consent monitoring which has shown seagrass cover and extent is variable at both the annual and seasonal temporal scales, with an overall reduction in seagrass extent observed between 2013 and 2021 (e3 scientific, 2022).

While seagrass remained extensive, stressors were present in November 2021 including grazing from waterfowl (e.g. black swans and Canadian geese) and vehicle tracks traversing the northern seagrass beds. In 2017, a large decrease in seagrass cover was attributed to drift algae deposited in the estuary over the summer period (Ryder Consulting 2017), however, there were no signs of excess drift algae in the estuary during the November 2021 sampling. Other common catchment driven stressors known to impact seagrass (i.e. fine sediment deposition, poor water clarity, excess nutrient inputs causing nuisance macroalgae blooms) were not evident in November 2021.

Shellbank and mobile sands

Seagrass on firm sands

Large cockle in Papanui Inlet

Salt marsh is an important feature of estuaries because it traps sediments and assimilates nutrients in addition to providing habitat for birds and insects. Salt marsh (12.9ha, 4.4% of the intertidal area) was a relatively small portion of the estuary, but is naturally limited in extent due to the steep topography of the margin. An estimated ~70% of the historic salt marsh extent remains in the estuary (a condition rating of 'good'), with losses primarily due to historical drainage and reclamation.

The largest remaining area of salt marsh on the northern margin of Papanui Inlet is classified as a regionally significant wetland in the Regional Plan: Water for Otago. While this area is largely protected, smaller remnant patches of salt marsh are under ongoing pressure due to drainage and grazing. Salt marsh is also under pressure from the extensively modified margin with shoreline hardening greatly limiting the scope for managed retreat in response to sea level rise.

Channel through salt marsh adjacent to the road, Papanui Inlet

Salt marsh and freshwater input in the southwest corner

Rock wall armoured road and adjacent grazed salt marsh

The ETI score was 0.227, a condition rating of 'very good' indicating few eutrophication impacts in the estuary. This is supported by the absence of High Enrichment Conditions (HEC) and low macroalgae cover. These results are consistent with modelled nitrogen loads of just 2.1mgN/m^2/d, well below the ~100mgN/m^2/d threshold at which nuisance macroalgae problems are predicted occur (Robertson et al. 2017; Table 14).

Table 14. Supporting data used to assess estuary ecological condition in Papanui Inlet (Makahoe).

Supporting Condition Measure	Papanui Inlet
Mean freshwater flow (m^3/s)[1]	0.9
Catchment Area (Ha)[1]	1248
Catchment nitrogen load (TN/yr)[2]	3.1
Catchment phosphorus load (TP/yr)[2]	0.2
Catchment sediment load (KT/yr)[1]	0.3
Estimated N areal load in estuary (mg/m^2/d)[2]	2.1
Estimated P areal load in estuary (mg/m^2/d)[2]	0.1
CSR:NSR ratio[1]	1.7
Trap efficiency (sediment retained in estuary)[1]	98%
Estimated rate of sed. trapped in estuary (mm/yr)[1]	0.06

[1]Hicks et al. 2019.

[2]CLUES version 10.3, Run date: March 2021

Furthermore, NIWA's national estuary sediment load estimator (Hicks et al., 2019) predicts sediment input and retention, and was used to calculate a net deposition rate for the estuary. The estuary is predicted to be highly efficient at trapping sediment (98% retention). Spreading all of the retained sediment evenly throughout the estuary would result in average estuary infilling of ~0.06mm/yr (Table 14), a condition rating of 'very good' (Table 13).

Based on the relative difference in estimated yields from an undisturbed catchment, the current sedimentation rate (CSR) is estimated to be 1.7 times the natural sedimentation rate (NSR; Table 14). The condition rating for the CSR:NSR ratio is rated 'good' (Table 12). These sedimentation rate results, the very small extent of mud-dominated sediments (0.02%), and the widespread dominance (90.8%) of sandy sediments with <10% mud content in the estuary, indicate fine sediment issues are not currently a concern.

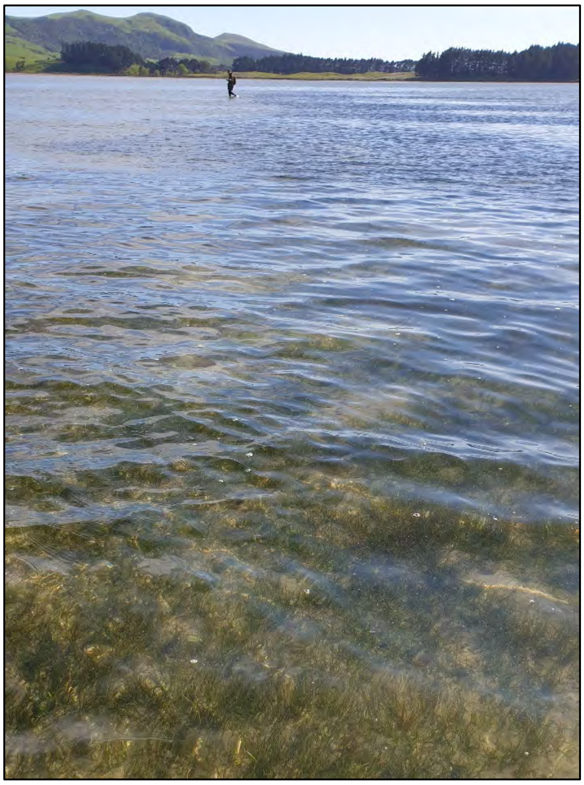
The most significant current issues identified were extensive waterfowl grazing of seagrass beds, localised water quality issues at point source discharges (e.g. drains, culverts), grazing of salt marsh, and shoreline hardening. The latter has disrupted the natural connectivity between the land and estuary and greatly limits the capacity of the estuary to adapt to predicted sea level rise.

5. RECOMMENDATIONS

Despite the grazing pressure on seagrass beds, Papanui Inlet (Makahoe) was in 'very good' condition, with expansive beds of high value seagrass, very little mud-dominated sediment and a diverse range of other habitat types including salt marsh, sandflats and cockle beds. The high ecological quality of the estuary can be attributed to small freshwater inflows, low sediment and nutrient inputs and well flushed tidal flats.

Based on the findings of the current survey it is recommended that ORC consider the following:

- Repeat the broad scale habitat mapping at 5-10 yearly intervals to track long term changes in estuary condition.
- Protect important habitats such as seagrass, cockle beds and salt marsh (e.g. vehicle exclusion, reconnect areas of remnant salt marsh to the estuary, reduce grazing pressures).
- Include Papanui Inlet (Makahoe) in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will maintain the high ecological quality of the estuary.



Broad scale mapping seagrass beds on incoming tide

Seagrass growing on firm sands, Papanui Inlet (Makahoe)

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP (Robertson et al. 2002) with minor modifications as listed. Revised substrate classes were developed by Salt Ecology to more accurately classify fine unconsolidated substrate. Terrestrial margin vegetation was classified using the field codes included in the Landcare Research Land Cover Database (LCDB5) - see following page.

VEGETATION (mapped separately to the substrates they overlie and ordered where commonly found from the upper to lower tidal range).

Estuarine shrubland: Cover of estuarine shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh (density at breast height).
Tussockland: Tussock cover is 20-100% and exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples occur in all species of *Cortaderia*, *Gahnia*, and *Phormium*, and in some species of *Chionochloa*, *Poa*, *Festuca*, *Rytidosperma*, *Cyperus*, *Carex*, *Uncinia*, *Juncus*, *Astelia*, *Aciphylla*, and *Celmisia*.
Sedgeland: Sedge cover (excluding tussock-sedges and reed-forming sedges) is 20-100% and exceeds that of any other growth form or bare ground. "Sedges have edges". If the stem is clearly triangular, it's a sedge. If the stem is flat or rounded, it's probably a grass or a reed. Sedges include many species of *Carex*, *Uncinia*, and *Scirpus*.
Grassland[1]: Grass cover (excluding tussock-grasses) is 20-100% and exceeds that of any other growth form or bare ground.
Introduced weeds[1]: Introduced weed cover is 20-100% and exceeds that of any other growth form or bare ground.
Reedland: Reed cover is 20-100% and exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha*, *Bolboschoenus*, *Scirpus lacutris*, *Eleocharis sphacelata*, and *Baumea articulata*.
Lichenfield: Lichen cover is 20-100% and exceeds that of any other growth form or bare ground.
Cushionfield: Cushion plant cover is 20-100% and exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.
Rushland: Rush cover (excluding tussock-rushes) is 20-100% and exceeds that of any other growth form or bare ground. A tall, grass-like, often hollow-stemmed plant. Includes some species of *Juncus* and all species of *Apodasmia (Leptocarpus)*.
Herbfield: Herb cover is 20-100% and exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.
Seagrass meadows: Seagrasses are the sole marine representatives of Angiospermae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and are mapped.
Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain chlorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope. Macroalgal density, biomass and entrainment are classified and mapped.
Note NEMP classes of Forest and Scrub are considered terrestrial and have been included in the terrestrial Land Cover Data Base (LCDB) classifications.

[1]*Additions to the NEMP classification.*

SUBSTRATE (physical and zoogenic habitat)
Sediment texture is subjectively classified as: firm if you sink 0-2 cm, soft if you sink 2-5cm, very soft if you sink >5cm, or mobile - characterised by a rippled surface layer.

Artificial substrate: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates. Commonly sub-grouped into artificial: substrates (seawalls, bunds etc), boulder, cobble, gravel, or sand.
Rock field: Land in which the area of basement rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Cobble field: Land in which the area of unconsolidated cobbles (>20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Sand: Granular beach sand with a low mud content 0-10%. No conspicuous fines evident when sediment is disturbed.
Sand/Shell: Granular beach sand and shell with a low mud content 0-10%. No conspicuous fines evident.
Muddy sand (Moderate mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >10-25%). Granular when rubbed between the fingers, but with a smoother consistency than sand with a low mud fraction. Generally firm to walk on.
Muddy sand (HIgh mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >25-50%). Granular when rubbed between the fingers, but with a much smoother consistency than muddy sand with a moderate mud fraction. Often soft to walk on.
Sandy mud (Very high mud content): Mud/sand mixture dominated by mud (i.e. >50%-90% mud). Sediment rubbed between the fingers is primarily smooth/silken but retains a granular component. Sediments generally very soft and only firm if dried out or another component, e.g. gravel, prevents sinking.
Mud (>90% mud content): Mud dominated substrate (i.e. >90% mud). Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out or another component, e.g. gravel, prevents sinking.
Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.
Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.
Shell bank: Area that is dominated by dead shells

Table of modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.1m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Mobile sand	mS
		Firm shell/sand	fSS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Mobile muddy sand	mMS10
		Firm muddy shell/sand	fSS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Mobile muddy sand	mMS25
		Firm muddy shell/sand	fMSS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Tubeworm reef	TUBE
Artificial Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aS BF
		Cobble field	aS CF
		Gravel field	aS GF
		Sand field	aS SF

Artificial Surfaces
- 1 Built-up Area (settlement)
- 2 Urban ParklandOpen Space
- 5 Transport Infrastructure
- 6 Surface Mines and Dumps

Bare or Lightly Vegetated Surfaces
- 10 Sand and Gravel
- 12 Landslide
- 16 Gravel and Rock

Water Bodies
- 20 Lake or Pond
- 21 River

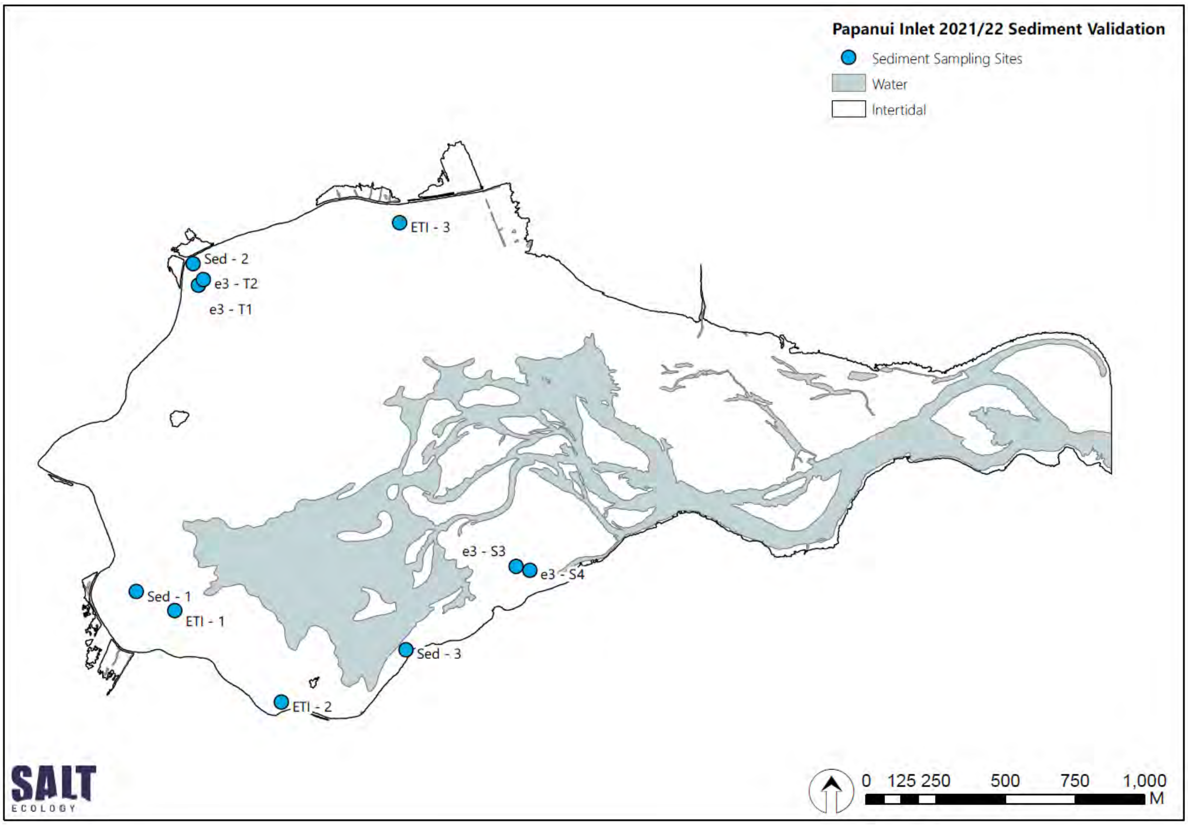
Cropland
- 30 Short-rotation Cropland
- 33 Orchard Vineyard & Other Perennial Crops

Grassland, Sedge and Saltmarsh
- 40 High Producing Exotic Grassland
- 41 Low Producing Grassland
- 45 Herbaceous Freshwater Vegetation
- 46 Herbaceous Saline Vegetation

Scrub and Shrubland
- 47 Flaxland
- 50 Fernland
- 51 Gorse and/or Broom
- 52 Manuka and/or Kanuka
- 54 Broadleaved Indigenous Hardwoods
- 56 Mixed Exotic Shrubland
- 58 Matagouri or Grey Scrub

Forest
- 64 Forest - Harvested
- 68 Deciduous Hardwoods
- 69 Indigenous Forest
- 71 Exotic Forest

APPENDIX 2. SEDIMENT SAMPLING STATIONS PAPANUI INLET (MAKAHOE), NOVEMBER 2021



Sediment validation samples matched 6 of 6 % mud content bands assessed in the field. Additional data for 4 composite sediment samples collected on 26 Nov 2021 were obtained from an e3 Scientific report (e3 Scientific, 2022) and are also included in the table below. The % mud content bands were accurate for fs0-10 and ±2% mud content for the sms10_25 bands assessed in the field.

Source	NZTM_E	NZTM_N	Field code	Subjective % mud	% mud	% sand	% gravel
ETI - 1	1420377	4919891	fs0_10	<10%	5.8	94.2	< 0.1
ETI - 2	1420760	4919562	fs0_10	<10%	2.4	97.4	0.2
ETI - 3	1421185	4921285	fs0_10	<10%	2.8	97.2	< 0.1
Sediment - 1	1420238	4919959	fs0_10	<10%	2.8	97.1	< 0.1
Sediment - 2	1420443	4921137	sms10_25	10 to 25%	14.8	85.2	< 0.1
Sediment - 3	1421208	4919750	fs0_10	<10%	7.2	90.1	2.7
e3 Scientific data collected 26 November 2021 (e3 Scientific, 2022)							
Transect 1 (T1)	1420462	4921060	sms10_25	10 to 25%	26	nd.	nd.
Transect 2 (T2)	1420480	4921080	sms10_25	10 to 25%	27	nd.	nd.
Site 3 (S3)	1421604	4920050	fs0_10	<10%	4.2	nd.	nd.
Site 4 (S4)	1421653	4920036	fs0_10	<10%	5.2	nd.	nd.

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	2783394 SPv1
Contact:	Keryn Roberts	**Date Received:**	30-Nov-2021
	C/- Salt Ecology Limited	**Date Reported:**	25-Jan-2022
	21 Mount Vernon Place	**Quote No:**	114525
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Broadscale- Papanui Inlet
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Papa-Otag-1 26-Nov-2021 2:30 pm	Papa-Otag-2 26-Nov-2021 5:00 pm	Papa-Otag-3 29-Nov-2021 9:00 am	Papa-Otag-ETI-1 29-Nov-2021 11:00 am	Papa-Otag-ETI-2 29-Nov-2021 11:30 am
Lab Number:		2783394.1	2783394.2	2783394.3	2783394.4	2783394.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	80	75	75	79	78
Total Recoverable Phosphorus	mg/kg dry wt	-	-	-	198	280
Total Sulphur*‡	g/100g dry wt	-	-	-	0.040	0.040
Total Nitrogen*	g/100g dry wt	-	-	-	< 0.05	< 0.05
Total Organic Carbon*	g/100g dry wt	-	-	-	0.12	0.10
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	< 0.1	2.7	< 0.1	0.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	97.1	85.2	90.1	94.2	97.4
Fraction < 63 µm*	g/100g dry wt	2.8	14.8	7.2	5.8	2.4

Sample Name:		Papa-Otag-ETI-3 29-Nov-2021 12:00 pm				
Lab Number:		2783394.6				
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	76	-	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	133	-	-	-	-
Total Sulphur*‡	g/100g dry wt	0.030	-	-	-	-
Total Nitrogen*	g/100g dry wt	< 0.05	-	-	-	-
Total Organic Carbon*	g/100g dry wt	0.13	-	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	-	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	97.2	-	-	-	-
Fraction < 63 µm*	g/100g dry wt	2.8	-	-	-	-

Analyst's Comments

‡ Analysis subcontracted to an external provider. Refer to the Summary of Methods section for more details.

Appendix No.1 - SGS Report

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked * or any comments and interpretations, which are not accredited.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	4-6
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	4-6
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	4-6
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	4-6
Total Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g dry wt	4-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	4-6
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	4-6
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-6
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 07-Dec-2021 and 25-Jan-2022. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 3. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multi-metric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5-part multi-metric OMBT, modified for NZ estuary types, is presented in the WFD-UKTAG (2014) with additions described in Plew et al. (2020), and is paraphrased below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of *mud, muddy sand, sandy mud, sand, stony mud and mussel beds*. Areas which are judged unsuitable for algal blooms, e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. PERCENTAGE COVER OF THE AVAILABLE INTERTIDAL HABITAT (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. TOTAL EXTENT OF AREA COVERED BY ALGAL MATS (AFFECTED AREA (AA)) OR AFFECTED AREA AS A PERCENTAGE OF THE AIH (AA/AIH, %).

The affected area represents the total area of macroalgal cover in hectares. In large water bodies, small patches of macroalgal coverage relative to the estuary size would result in the total percent cover across the AIH remaining within the 'high' or 'good' status. While the affected area may be relatively small when compared to estuary size the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities (WFD-UKTAG 2014). In order to account for this, the OMBT included an additional metric; the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse-case scenario.

3. BIOMASS OF AIH (G.M^{-2}).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within ±5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. BIOMASS OF AA (G.M^{-2}).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. PRESENCE OF ENTRAINED ALGAE (% OF QUADRATS).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool. All the metrics are equally weighted and combined within the multi-metric, in order to best describe the changes in the nature and degree of opportunistic macroalgae growth on sedimentary shores due to nutrient pressure.

TIMING

The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March). However, peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification, e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

SUITABLE LOCATIONS

The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing intermittently closed and open estuaries (ICOEs) due to the particular challenges in setting suitable reference conditions for these water bodies.

DERIVATION OF THRESHOLD VALUES

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

REFERENCE THRESHOLDS

A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g/m^2 wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

CLASS THRESHOLDS FOR PERCENT COVER

High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

Table A1. The final face value thresholds and metrics for levels of the ecological quality status. These thresholds have been recently revised for New Zealand (see Table A3).

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^{-2}) of AIH[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).
Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

CLASS THRESHOLDS FOR BIOMASS

Class boundaries for biomass values were derived from DETR (2001) recommendations that <500g.m^{-2} wet weight was an acceptable level above the reference level of <100g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500g.m^{-2} represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500gm^{-2} but less than 1,000g.m^{-2} would lead to a classification of Moderate quality status at best but would depend on the percentage of the AIH covered. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003). **Thresholds applied in the current study are described and presented in Table A3.**

THRESHOLDS FOR ENTRAINED ALGAE

Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently, the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

EQR CALCULATION

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Rating** score (EQR).
The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the categories in Table A1. The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 - where Total % cover = Sum of [(patch size) / 100] x average % cover for patch
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH (g.m^{-2}) = Total biomass / AIH - where Total biomass = Sum of (patch size x average biomass for the patch)
- Biomass of Affected Area (g.m^{-2}) = Total biomass / AA - where Total biomass = Sum of (patch size x average biomass for the patch)
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A2).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

*Final Equidistant Index score = Upper Equidistant range value – ([Face Value - Upper Face value range] * (Equidistant class range / Face Value Class Range)).*

Table A2 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range. Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.

Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

Metric	Quality status	Face value ranges			Equidistant class range values		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g.m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g.m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

The final EQR score is calculated as the average of equidistant metric scores.

A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

Biomass thresholds included in the OMBT were lowered for use in NZ by Plew et al. (2020) based on unpublished data from >25 shallow well-flushed intertidal NZ estuaries (Robertson et al. 2016b) and the results from similar estuaries in California. Sutula et al. (2014) reported that in eight Californian estuaries, macroalgal biomass of 1450g.m^{-2} wet weight, total organic carbon of 1.1% and sediment total nitrogen of 0.1% were thresholds associated with anoxic conditions near the surface (aRPD < 10 mm). Green et al. (2014) reported significant and rapid negative effects on benthic invertebrate abundance and species richness at macroalgal abundances as low as 840–930g.m^{-2} wet weight in two Californian estuaries. McLaughlin et al. (2014) reviewed Californian biomass thresholds and found the elimination of surface deposit feeders in the range of 700–800g.m^{-2}. As the Californian results were consistent with NZ findings, the latter thresholds were used to lower the OMBT good/moderate threshold from ≤500 to ≤200g.m^{-2}, the moderate/poor threshold from ≤1000 to ≤500gm^{-2} and the poor/bad threshold from >3000 to >1450g.m^{-2}. These thresholds are considered to provide an early warning of nutrient related impacts in NZ prior to the establishment of adverse enrichment conditions that are likely difficult to reverse.

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Table A3. Revised final face value thresholds and metrics for levels of the ecological quality status used in the current assessment.

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^{-2}) of AIH[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

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APPENDIX 4. INFORMATION SUPPORTING RATINGS IN THE REPORT

SEDIMENT MUD CONTENT

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more sticky and cohesive, and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon, and sediment-bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations and, on intertidal flats of estuaries, can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

APPARENT REDOX POTENTIAL DISCONTINUITY (ARPD)

aRPD depth, the visually apparent transition between oxygenated sediments near the surface and deeper more anoxic sediments, is a primary estuary condition indicator as it is a direct measure of time integrated sediment oxygenation. Knowing if the aRPD is close to the surface is important for three main reasons:

The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species. The tendency for sediments to become anoxic is much greater if the sediments are muddy. Anoxic sediments contain toxic sulphides and support very little aquatic life. As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, become released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (i.e. >3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

OPPORTUNISTIC MACROALGAE

The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with high mud and low oxygen conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014; Robertson et al 2016a,b; Zeldis et al. 2017), with results combined with those of other indicators to determine overall condition.

SEAGRASS

Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column. It is also susceptible to degraded sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent are likely to indicate an increase in these types of pressures. The assessment metric used is the percent change from baseline measurements.

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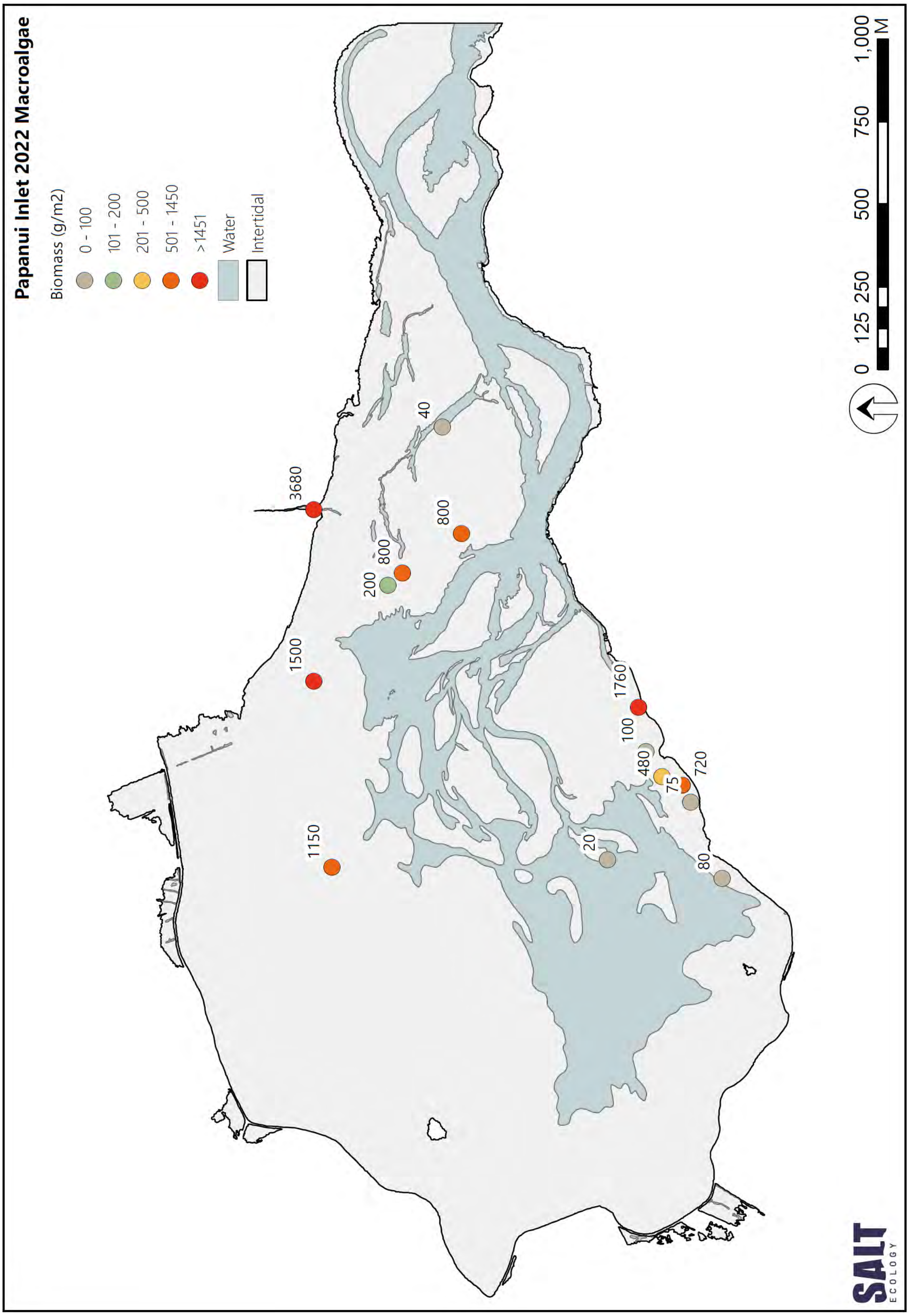
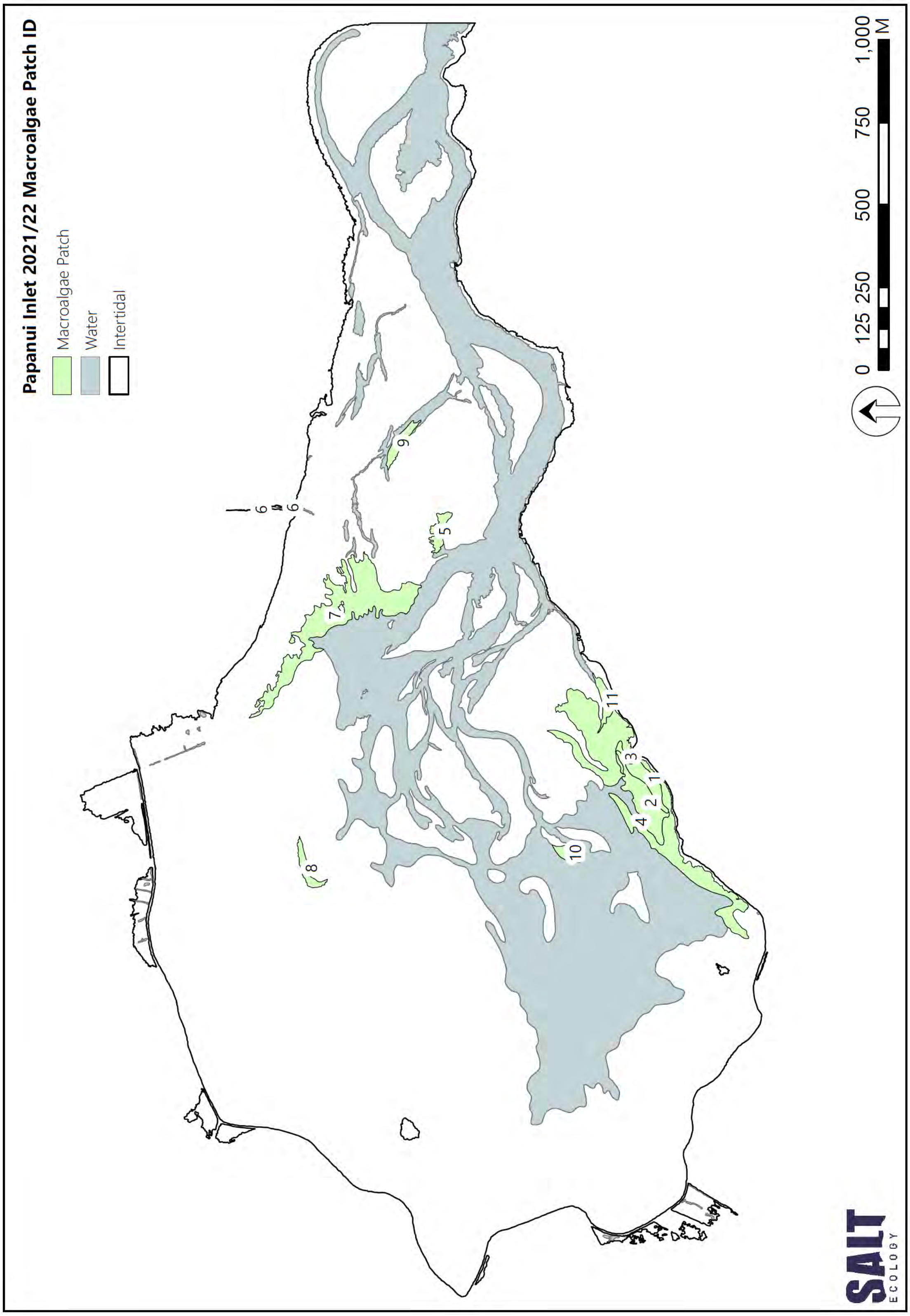
APPENDIX 5: MACROALGAL BIOMASS STATIONS & OMBT, PAPANUI INLET (MAKAHOE)



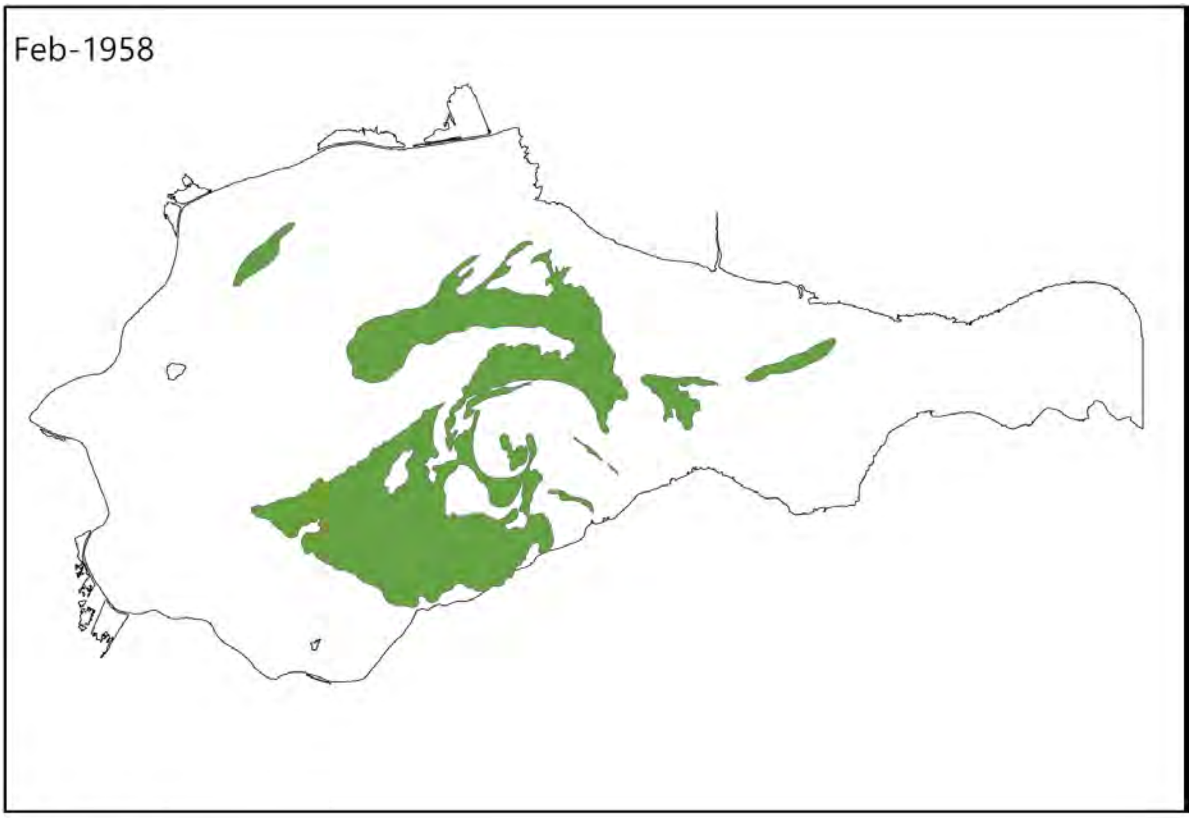
Macroalgal patch ID used in the OMBT-EQR

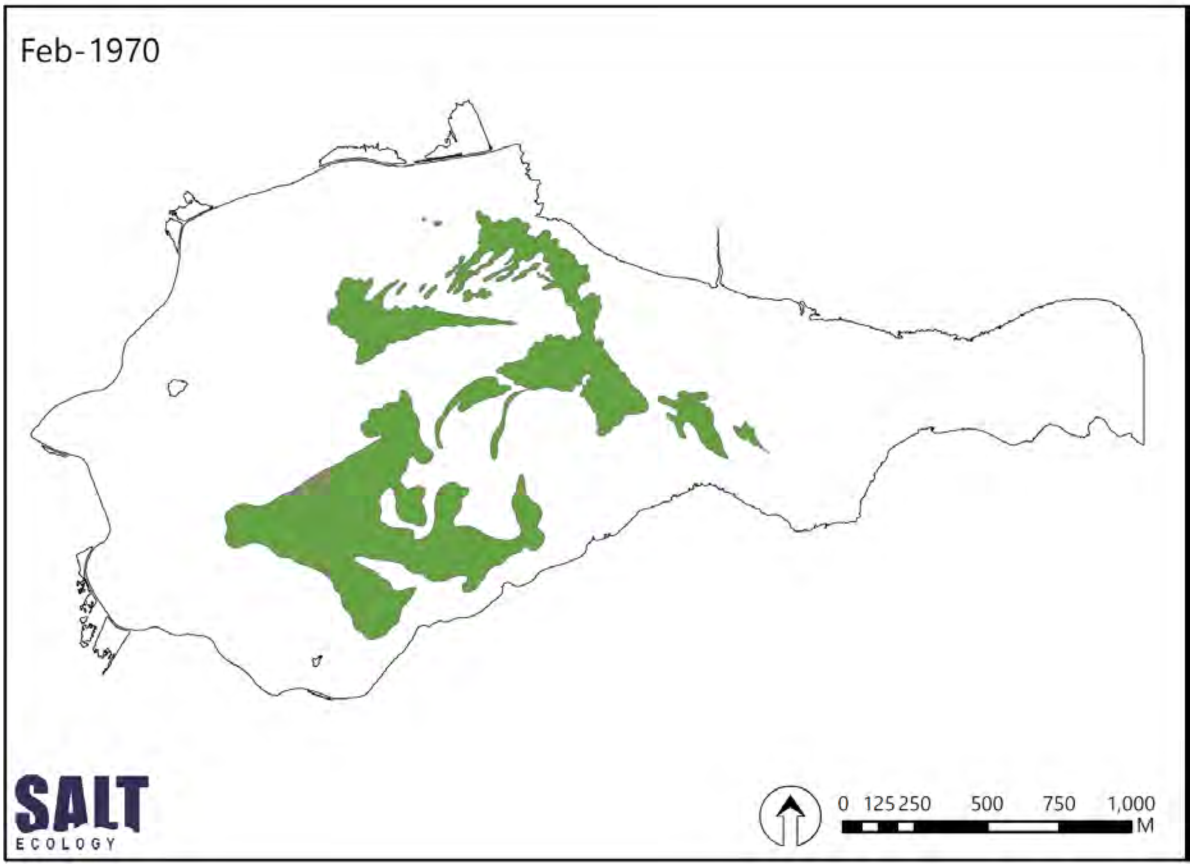


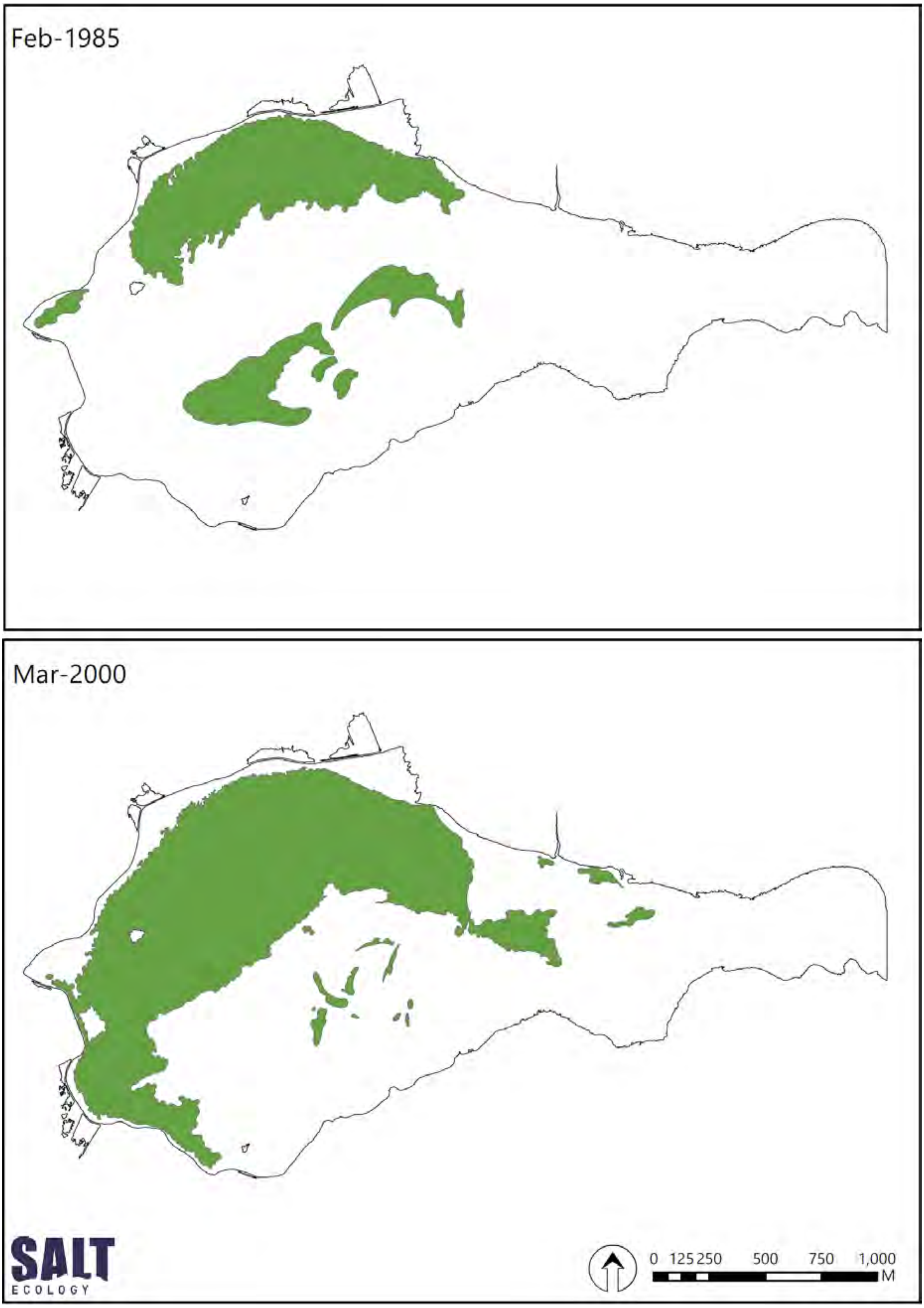
Macroalgal patch information used in the calculation of the OMBT-EQR

PatchID	Dominant Species	Sub-dominant spcies	% Cover	Percent Cover Category	Biomass (g/m^2)	CrsBiomass	Entrained	Substrate	Area (ha)
1	*Ulva* spp.	Unspecified Macroalgae	62	High-Moderate (50 to <70%)	600	High (501 - 1450)	0	firm sand	0.6
2	*Agarophyton* spp.	*Ulva* spp.	15	Sparse (10 to <30%)	100	Very low (1 - 100)	0	firm sand	0.2
3	*Agarophyton* spp.	*Ulva* spp.	16	Sparse (10 to <30%)	100	Very low (1 - 100)	0	firm sand	1.3
4	*Ulva* spp.	Unspecified Macroalgae	9	Very sparse (1 to <10%)	78	Very low (1 - 100)	0	firm sand	6.1
5	*Ulva* spp.		40	Low-Moderate (30 to <50%)	800	High (501 - 1450)	0	firm sand	0.4
6	*Ulva* spp.		90	Complete (>90%)	3680	Very high (>1450)	0	firm sand	0.0
7	*Ulva* spp.		43	Low-Moderate (30 to <50%)	833	High (501 - 1450)	0	firm sand	4.8
8	*Ulva* spp.		30	Low-Moderate (30 to <50%)	1150	High (501 - 1450)	0	firm sand	0.3
9	*Ulva* spp.		5	Very sparse (1 to <10%)	40	Very low (1 - 100)	0	firm sand	0.4
10	Unspecified Macroalgae	*Ulva* spp.	6	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	mobile sand	0.3
11	*Ulva* spp.	Unspecified Macroalgae	80	Dense (70 to <90%)	1760	Very high (>1450)	0	firm sand/shell	0.4

APPENDIX 6. TIME SERIES OF SEAGRASS CHANGE IN PAPANUI INLET



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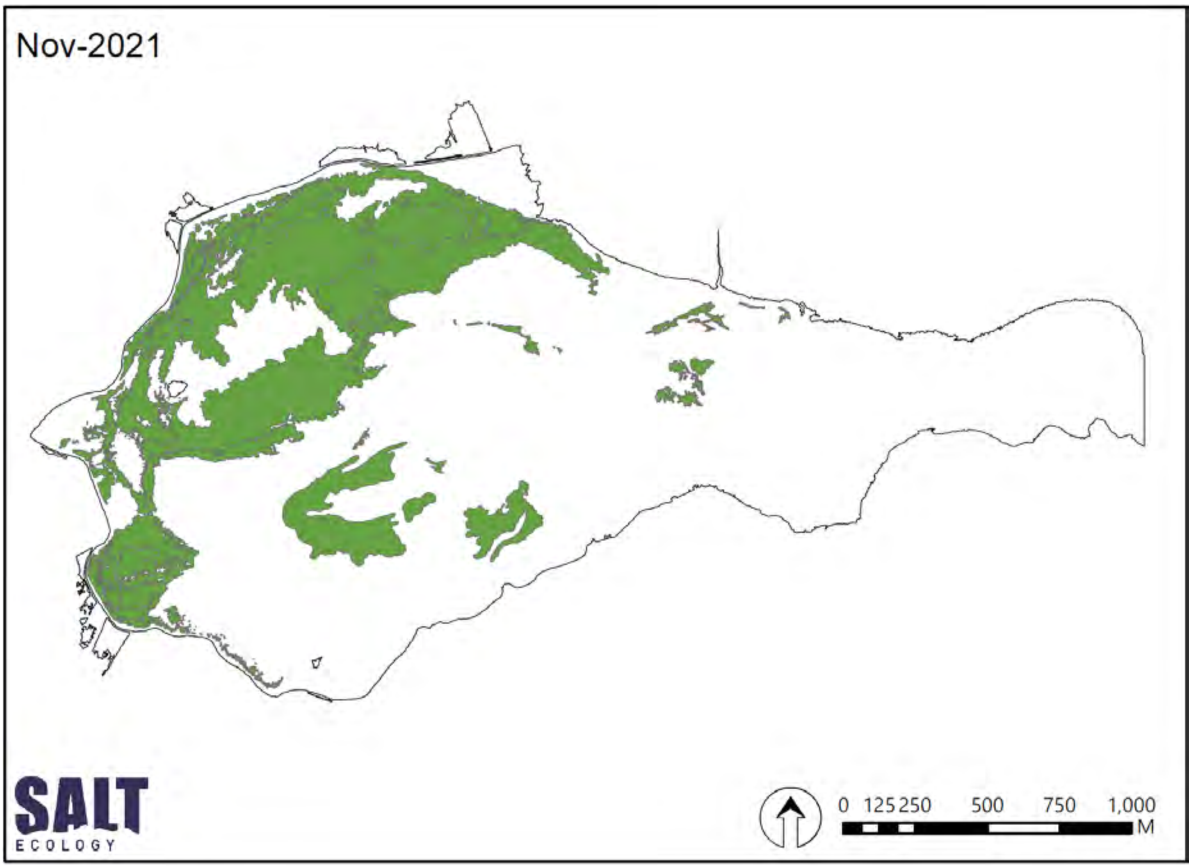
Mar-2000
SALT
ECOLOGY
0 125 250 500 750 1,000
M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SALT
ECOLOGY
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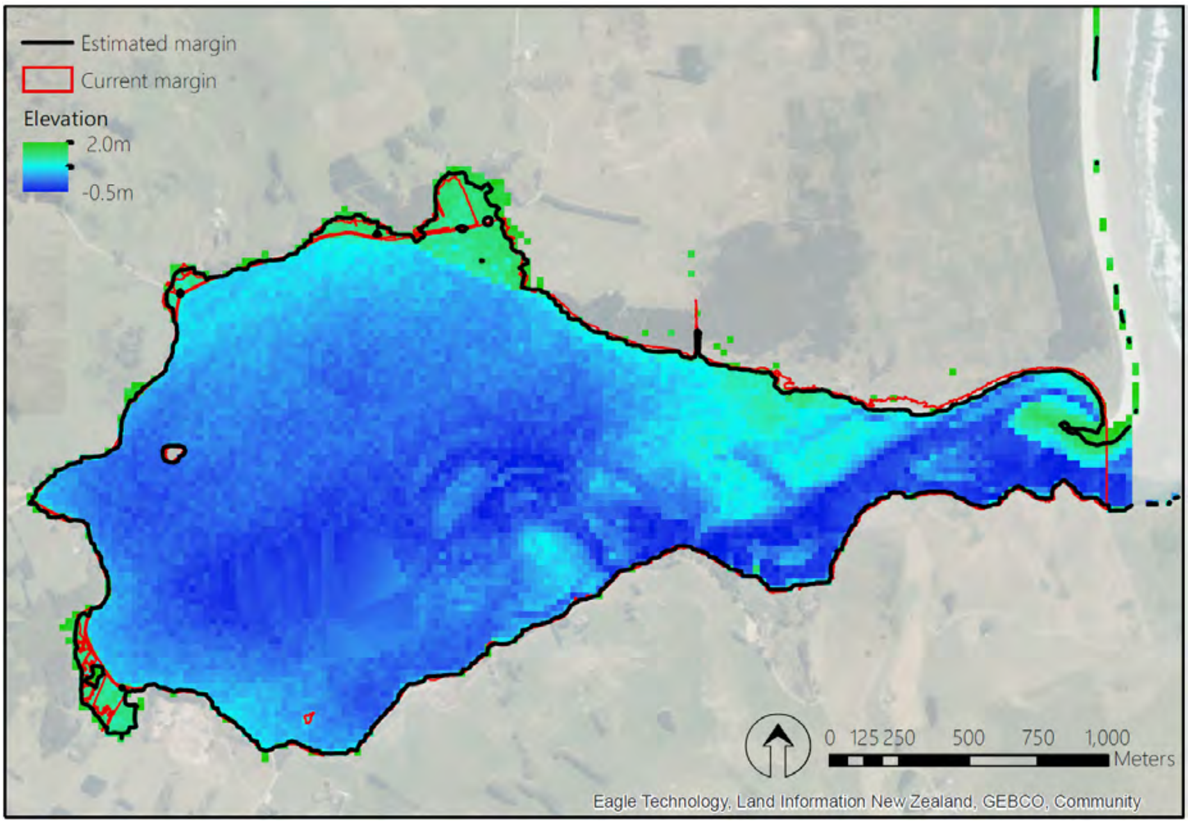
M

APPENDIX 7: DOMINANT SALT MARSH SPECIES IN PAPANUI INLET (MAKAHOE)

SubClass	Dominant species	Subdominant Species 1	Subdominant Species 2	Ha	%
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Apodasmia similis (Jointed wirerush)		0.02	0.15
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Carpobrotus edulis (Ice Plant)		0.04	0.31
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Festuca arundinacea (Tall fescue)		0.14	1.07
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Ficinia (Isolepis) nodosa (Knobby clubrush)		0.01	0.06
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Ficinia (Isolepis) nodosa (Knobby clubrush)	Schoenoplectus pungens (Three square)	0.02	0.13
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)			0.83	6.42
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Sarcocornia quinqueflora (Glasswort)		0.01	0.09
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Sarcocornia quinqueflora (Glasswort)	Poa cita (Silver tussock)	0.03	0.20
Tussockland	Puccinella stricta (Salt grass)			0.00	0.02
Sedgeland	Schoenoplectus pungens (Three square)	Ficinia (Isolepis) nodosa (Knobby clubrush)	Selliera radicans (Remuremu)	0.00	0.02
Sedgeland	Schoenoplectus pungens (Three square)			0.21	1.66
Sedgeland	Schoenoplectus pungens (Three square)	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	0.02	0.13
Grassland	Festuca arundinacea (Tall fescue)	Ficinia (Isolepis) nodosa (Knobby clubrush)		0.06	0.45
Grassland	Festuca arundinacea (Tall fescue)	Introduced weeds		0.01	0.11
Grassland	Festuca arundinacea (Tall fescue)	Lupinus arboreus (Tree lupin)		0.10	0.78
Grassland	Festuca arundinacea (Tall fescue)			0.08	0.65
Grassland	Festuca arundinacea (Tall fescue)	Plagianthus divaricatus (Salt marsh ribbonwood)		0.20	1.54
Grassland	Festuca arundinacea (Tall fescue)	Pteridium esculentum (Bracken fern)	Ficinia (Isolepis) nodosa (Knobby clubrush)	0.13	1.05
Grassland	Festuca arundinacea (Tall fescue)	Ulex europaeus (Gorse)		0.03	0.26
Rushland	Apodasmia similis (Jointed wirerush)			0.02	0.17
Rushland	Apodasmia similis (Jointed wirerush)	Plagianthus divaricatus (Salt marsh ribbonwood)	Sarcocornia quinqueflora (Glasswort)	0.01	0.11
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Festuca arundinacea (Tall fescue)		0.05	0.35
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Festuca arundinacea (Tall fescue)	Plagianthus divaricatus (Salt marsh ribbonwood)	0.02	0.16
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Lupinus arboreus (Tree lupin)	Festuca arundinacea (Tall fescue)	0.16	1.24
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)			0.22	1.72
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Plagianthus divaricatus (Salt marsh ribbonwood)		0.02	0.14
Herbfield	Disphyma australe (NZ Ice Plant, Horokaka)			0.01	0.11
Herbfield	Samolus repens (Primrose)	Apium prostratum (Native celery)	Isolepis cernua (Slender clubrush)	0.01	0.05
Herbfield	Samolus repens (Primrose)			0.01	0.11
Herbfield	Samolus repens (Primrose)	Sarcocornia quinqueflora (Glasswort)	Suaeda novaezelandiae (Sea blite)	0.22	1.70
Herbfield	Samolus repens (Primrose)	Selliera radicans (Remuremu)		0.53	4.13
Herbfield	Sarcocornia quinqueflora (Glasswort)	Cotula coronopifolia (Bachelor's button)	Selliera radicans (Remuremu)	0.01	0.09
Herbfield	Sarcocornia quinqueflora (Glasswort)	Isolepis cernua (Slender clubrush)		0.01	0.07
Herbfield	Sarcocornia quinqueflora (Glasswort)			0.14	1.08
Herbfield	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)		0.02	0.17
Herbfield	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	Selliera radicans (Remuremu)	0.04	0.30
Herbfield	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	Suaeda novaezelandiae (Sea blite)	0.11	0.87
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	Isolepis cernua (Slender clubrush)	0.58	4.53
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)		2.11	16.43
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	Samolus repens (Primrose)	3.79	29.50
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	Suaeda novaezelandiae (Sea blite)	0.02	0.18
Herbfield	Sarcocornia quinqueflora (Glasswort)	Suaeda novaezelandiae (Sea blite)		0.29	2.22
Herbfield	Selliera radicans (Remuremu)			0.85	6.61
Herbfield	Selliera radicans (Remuremu)	Samolus repens (Primrose)		0.33	2.53
Herbfield	Selliera radicans (Remuremu)	Sarcocornia quinqueflora (Glasswort)		0.35	2.71
Herbfield	Selliera radicans (Remuremu)	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	0.96	7.48
Herbfield	Selliera radicans (Remuremu)	Schoenoplectus pungens (Three square)	Samolus repens (Primrose)	0.02	0.14
Grand Total				12.86	100.0

APPENDIX 8: HISTORIC MARGIN ESTIMATED FROM LIDAR DATA



The black line represents the estimated margin derived from the 1.6m contour extracted from the LiDAR data. The area historical salt marsh was estimated to be ~16.4ha.

APPENDIX 9: RAW SEDIMENT AND MACROFAUNA DATA

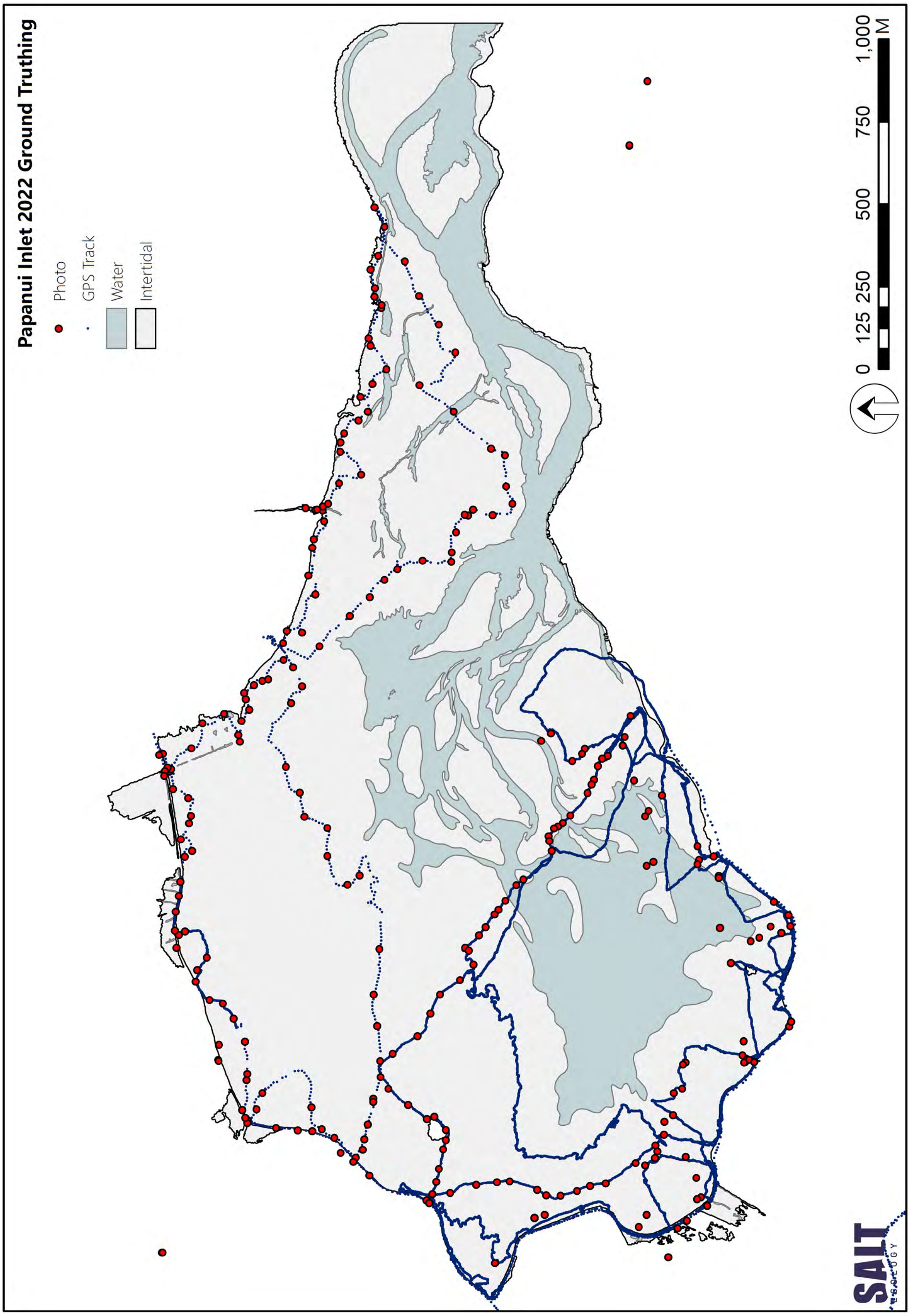
Sediment data and macrofauna indices

Parameter	Unit	PAPA-OTAG ETI - 1	PAPA-OTAG ETI - 2	PAPA-OTAG ETI - 3
Sediment Chemistry				
Total Phosphorus (TP)	mg/kg dry wt	198	280	133
Total Sulfur (TS)	g/100g dry wt	0.04	0.04	0.03
Total Nitrogen (TN)	g/100g dry wt	< 0.05	< 0.05	< 0.05
Total Organic Carbon (TOC)	g/100g dry wt	0.12	0.1	0.13
Gravel (≥2mm)	g/100g dry wt	< 0.1	0.2	< 0.1
Sand (≥63mm to <2mm)	g/100g dry wt	94.2	97.4	97.2
Mud (≤63mm)	g/100g dry wt	5.8	2.4	2.8
aRPD	mm	20	20	20
Macrofauna indices				
AMBI	no unit	0.49	0.85	3.32
Overall Abundance	no unit	329	137	693
Overall Diversity	no unit	17	14	12

Raw macrofauna data. EG refers to ecological sensitivity group used to calculate the AMBI.

Main group	Taxa	Habitat	EG	PAPA ETI 1	PAPA ETI 2	PAPA ETI 3
Amphipoda	*Paracalliope novizealandiae*	Infauna	I	5	24	16
Amphipoda	*Paracorophium excavatum*	Infauna	IV	1	8	236
Amphipoda	*Proharpinia sp.*	Infauna	I	2		
Amphipoda	*Torridoharpinia hurleyi*	Infauna	I	50	33	29
Amphipoda	*Urothoe sp. 1*	Infauna	II	1	2	
Anthozoa	*Edwardsia sp.*	Epibiota	II	14	5	34
Bivalvia	*Arthritica sp. 5*	Infauna	III	2	4	151
Bivalvia	*Austrovenus stutchburyi*	Infauna	II		1	
Bivalvia	*Lasaea parengaensis*	Infauna	II	13		49
Bivalvia	*Legrandina turneri*	Infauna	NA	113	46	159
Bivalvia	*Nucula nitidula*	Infauna	I	98	2	
Gastropoda	*Cominella glandiformis*	Epibiota	III	1	2	
Gastropoda	*Notoacmea scapha*	Epibiota	II		1	
Polychaeta	*Leodamas sp.*	Infauna	III			1
Polychaeta	*Boccardia syrtis*	Infauna	II	1	1	
Polychaeta	*Capitella cf. capitata*	Infauna	V		1	1
Polychaeta	*Macroclymenella stewartensis*	Infauna	II	9	7	
Polychaeta	*Nereididae (juv)*	Infauna (juvenile)	NA			8
Polychaeta	*Paradoneis lyra*	Infauna	III	13		
Polychaeta	*Perinereis vallata*	Infauna	III	2		2
Polychaeta	*Protocirrineris nuchalis*	Infauna	III	1		
Polychaeta	*Scolecolepides benhami*	Infauna	IV			7
Tanaidacea	*Tanaidacea*	Infauna	II	3		

APPENDIX 10. GROUND-TRUTHING IN PAPANUI INLET (MAKAHOE), NOV. 2021




SALT
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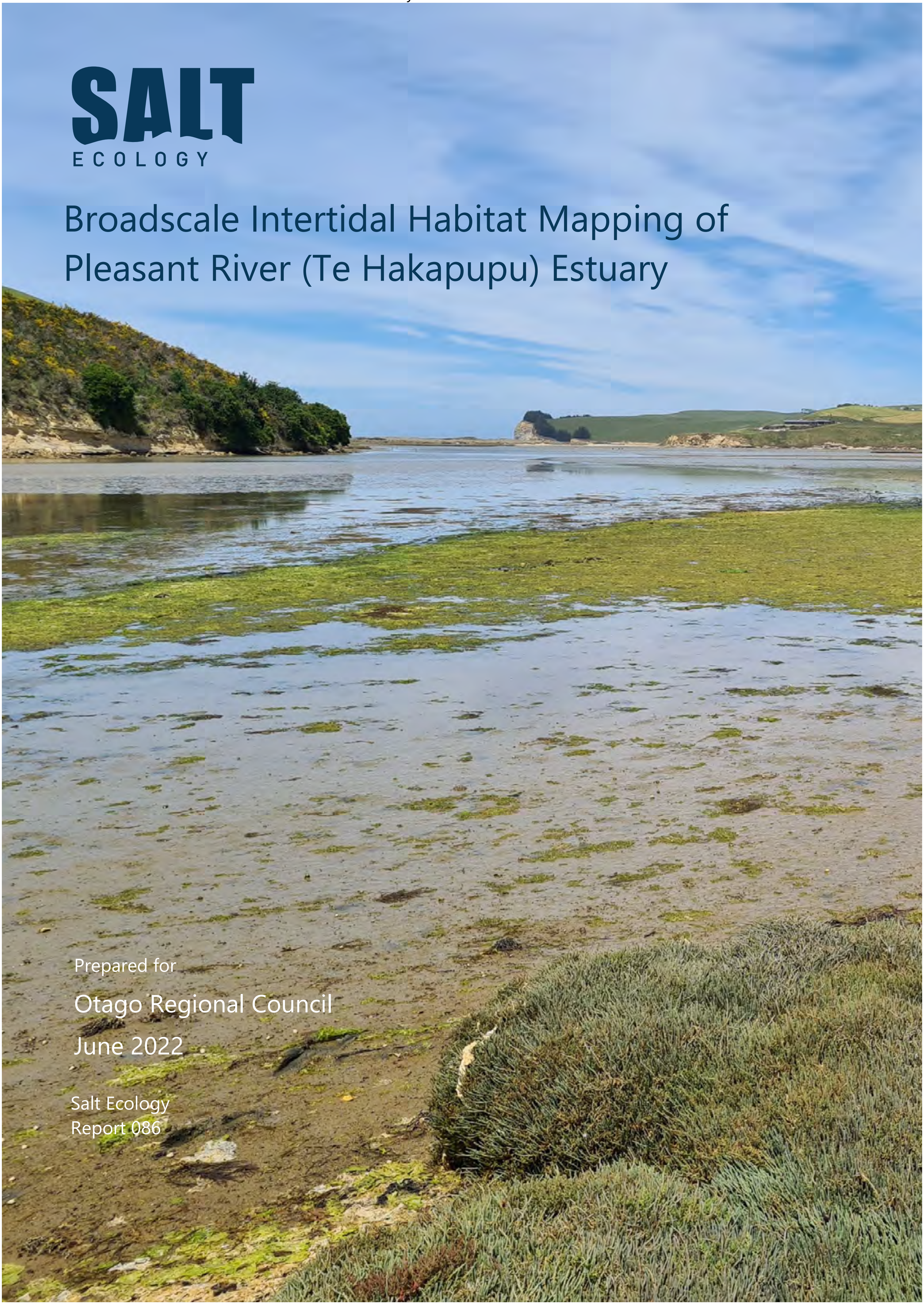

SALT ECOLOGY

Broadscale Intertidal Habitat Mapping of Pleasant River (Te Hakapupu) Estuary

Prepared for

Otago Regional Council

June 2022

Salt Ecology
Report 086

Cover photo: Pleasant River (Te Hakapupu) Estuary looking toward the estuary entrance, November 2021, showing herb field and *Ulva* spp.

RECOMMENDED CITATION

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SALT ECOLOGY

For the People
Mō ngā tāngata

Broadscale Intertidal Habitat Mapping of Pleasant River (Te Hakapupu) Estuary

Prepared by

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and Barrie Forrest

for

Otago Regional Council

June 2022

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For the environment
Mō te taiao

GLOSSARY

AMBI	AZTI Marine Biotic Index
AA	Affected Area (OMBT metric)
AIH	Available Intertidal Habitat (OMBT metric)
aRPD	Apparent Redox Potential Discontinuity
DO	Dissolved Oxygen
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
HEC	High Enrichment Conditions
LiDAR	Light Detection and Ranging
NEMP	National Estuary Monitoring Protocol
NIWA	National Institute of Water and Atmospheric Research
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
QA/QC	Quality Assurance/Quality Control
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TS	Total sulfur

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SUMMARY

Pleasant River (Te Hakapupu) Estuary is a medium sized (216ha) estuarine system located ~50km north of Dunedin. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary monitored by Otago Regional Council (ORC) as part of its State of the Environment programme, using methodologies described in New Zealand's National Estuary Monitoring Protocol. This report describes a survey conducted in November 2021, which assessed the dominant substrate and vegetation features present in the estuary, including seagrass, salt marsh and macroalgae.

KEY FINDINGS

- Mud-dominated sediments (>50% mud) comprised 16.7% of the intertidal area and were localised to the estuary side arms or salt marsh habitat where fine sediments tend to accumulate.
- Eutrophic conditions, especially in side arms and parts of the mid estuary, were evident in the form of:
  - Extensive growths of nuisance opportunistic macroalgae and other filamentous algae, often accompanied by poorly-oxygenated or anoxic muddy sediments (see photo).
  - A large area (8% of the total estuary) classified as exhibiting 'High Enrichment Conditions' (>50% algal growth in poorly oxygenated sediments with high mud content)
  - An Estuary Trophic Index score of 0.766, which is representative of 'poor' conditions.

- No intertidal seagrass was recorded, with salt marsh (mainly herbfield) being the dominant vegetation type (80.4ha or 42.8% of the intertidal area). Approximately 37% (48ha) of historic salt marsh has been lost to reclamation, drainage and conversion to pasture.
- The catchment has been extensively developed with pasture (61.9%) and exotic forest (31.1%) being the dominant land use types. Only 6.6% of the 200m terrestrial margin was densely vegetated.

Overall, with the exception of salt marsh, the other broad scale indicators in Pleasant River Estuary were rated 'fair' to 'poor'. The results suggest that the estuary's capacity to assimilate nutrient and sediment inputs is currently being exceeded.

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) score	No unit	0.766	Poor
Mud-dominated substrate	% of intertidal area >50% mud	16.7	Poor
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.445	Fair
Seagrass	% decrease from baseline	0.0	na (no data before Nov-2021)
Salt marsh extent (current)	% of intertidal area	42.8	Very Good
Historical salt marsh extent*	% of historical remaining	63	Good
200m terrestrial margin	% densely vegetated	6.6	Poor
High Enrichment Conditions	ha	17.2[1]	Fair
High Enrichment Conditions	% of estuary	8.0	Fair
Sedimentation rate[2]	CSR:NSR ratio[3]	3.4	Fair
Sedimentation rate[2]	mm/yr	3.8	Poor

Colour bandings are reported in Table 3. OMBT=Opportunistic Macroalgal Blooming Tool. [1]Includes intertidal and ponded areas [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

RECOMMENDATIONS

- Repeat the broad scale habitat mapping at 5 yearly intervals to track long term changes in estuary condition. Consider more frequent targeted nuisance macroalgae and filamentous algae monitoring (e.g. every 1-2 years), especially if conditions are observed to deteriorate.
- Protect and enhance existing salt marsh to prevent further losses and consider restoration in suitable areas.
- Include Pleasant River Estuary in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will improve the ecological quality of the estuary.

1. INTRODUCTION

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 based on the methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c), or extensions of that approach.

NEMP monitoring is primarily designed to detect and understand changes in estuaries over time and determine the effect of catchment influences, especially those contributing to the input of nutrients and muddy sediments. Excessive nutrient and fine sediment inputs are a primary driver of estuary eutrophication symptoms such as prolific macroalgal (seaweed) growth, and poor sediment condition.

The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results provide a baseline assessment of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

The current report describes the methods and results of broad scale monitoring undertaken in Pleasant River (Te Hakapupu) Estuary between 25-27 November 2021 (Fig. 1). The primary purpose of the current work was to characterise substrate types and the presence and extent of seagrass, macroalgae and salt marsh. Fine scale monitoring, undertaken at the time of sampling, is reported in Forrest et al. (2022).

Map data © OpenStreetMap contributors, Microsoft, Esri Community Maps contributors, Map layer by Esri, LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Fig. 1. Location of Pleasant River (Te Hakapupu) Estuary, Otago.

Salt marsh herbfield in the foreground and steep grass-dominated margin in the background, Pleasant River Estuary

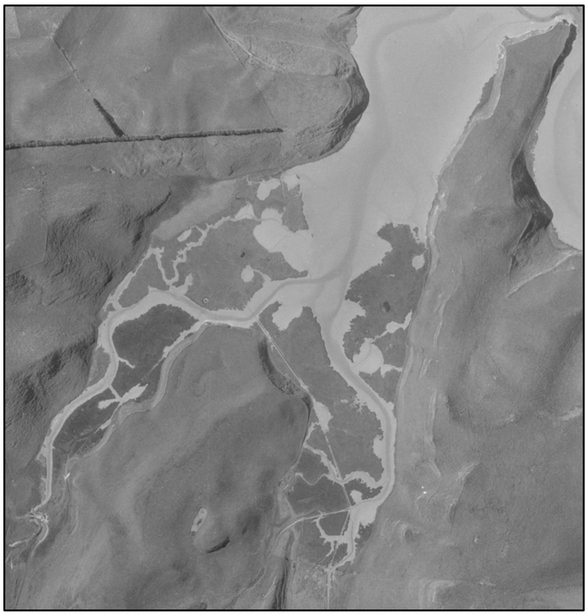
2. BACKGROUND TO PLEASANT RIVER ESTUARY

Pleasant River Estuary is a medium sized (216ha) estuarine system located ~50km north of Dunedin on New Zealand's southeast coast. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary (SIDE) with a flushing time of ~5 days (Plew et al. 2018). Unlike the well-flushed mid to lower estuary, the narrow channels in the upper estuary are susceptible to stratification and water column nutrient problems. The estuary also has the capacity to retain fine sediments and sediment bound nutrients in deposition areas (e.g. side arms) making it moderately susceptible to nutrient enrichment impacts.

The main freshwater inflow to the estuary is Pleasant River along with several smaller tributaries. Freshwater inputs represent ~30% of the total estuary volume (Plew et al. 2018). The estuary drains almost completely at low tide exposing ~86% of the estuary area. The lower estuary is protected from the ocean by a sand spit dominated by marram grass dunes.

The extensive areas of salt marsh herbfield (mainly glasswort; *Sarcocornia quinqueflora*) and rushland are recognised as a regionally significant wetland in the Otago Regional Plan: Water. However, historic drainage and reclamation of salt marsh for pasture is a common feature of the estuary, particularly in the side arms (see photo). Fencing of herbfield for grazing continues and flapgates and causeways restrict saltwater inundation of salt marsh habitat. A causeway that blocked the entrance of the southern arm was removed in 2009 to reinstate tidal flushing (Moller & Moller 2012; southern arm shown in photo). Despite this, previous salt marsh habitat has not re-established.

Remnants of the causeway removed in 2009



Salt marsh in the southwest side arm 1958 (top; source Retrolens) and 2019 (bottom; source ORC)

Pleasant River Estuary was traditionally utilised by Māori as an important kāinga mahinga kai (food gathering settlement). A significant archeological site at the Pleasant River mouth has identified early hunting of moa and seals before a transition to kaimoana (seafood). The estuary provides extensive spawning and nursery habitat for marine and freshwater fish species including patiki (flatfish), inanga (whitebait) and tuna (long-finned eel and short-finned eel; Ngāi Tahu Atlas). The establishment of a marine reserve that would extend from Pleasant River to Stony Creek has been proposed to protect important reef, estuary, and kelp forest habitats (SMPF 2018).

The estuary is a coastal protection area in the Otago Regional Plan: Coast for its cultural and ecological values. The estuary is particularly important for waders and waterfowl including godwits, South Island pied oystercatcher, variable oystercatcher, pied stilt, banded dotterel white-faced heron, gulls, shags and ducks (WDC 2004).

The estuary drains a 12,747ha catchment comprising ~38.1% intensive pasture, ~23.8% low producing pasture and ~31.1% exotic forest. 37.7% of the catchment is densely vegetated (Table 1; Fig. 2). The immediate terrestrial margin of Pleasant River Estuary is dominated by pasture on gently sloping hill country that falls steeply to the estuary (Moore 2015). The bedrock is sedimentary, meaning there is moderate to high susceptibility of overland flow, and sediment and particulate phosphorus issues (LandscapeDNA.org).

Recently, the Tūmai Beach Development on the southern margin of the estuary has prepared an environmental enhancement plan as part of their consent conditions. The long-term restoration plan aims to integrate ecosystem restoration and sustainable pasture production by planting natives on the terrestrial margin, salt marsh plantings, stock exclusion and reducing vehicle use in the estuary (TBEEG 2021).

While there has been extensive reclamation and modification to the estuary margin, the estuary retains high ecological, cultural and human use values.

Table 1. Summary of catchment land cover (LCDB5 2017/18) Pleasant River Estuary.

LCDB5 (2017/2018) Catchment Land Cover		Ha	%
1	Built-up Area (settlement)	0.5	0.00
6	Surface Mine or Dump	3.4	0.03
10	Sand or Gravel	7.2	0.06
12	Landslide	2.9	0.02
20	Lake or Pond	3.5	0.03
30	Short-rotation Cropland	21.2	0.2
40	High Producing Exotic Grassland	4860	38.1
41	Low Producing Grassland	3037	23.8
46	Herbaceous Saline Vegetation	116.1	0.9
51	Gorse and/or Broom	419.7	3.3
52	Manuka and/or Kanuka	56.6	0.4
54	Broadleaved Indigenous Hardwoods	64.2	0.5
56	Mixed Exotic Shrubland	54.4	0.4
58	Matagouri or Grey Scrub	33.2	0.3
64	Forest - Harvested	80.5	0.6
68	Deciduous Hardwoods	13.2	0.1
69	Indigenous Forest	6.8	0.05
71	Exotic Forest	3967	31.1
Grand Total		12747	100
Total densely vegetated area (LCDB classes 45-71)		4812	37.7

Native plantings on the terrestrial margin

Native plantings on the terrestrial margin adjacent to salt marsh

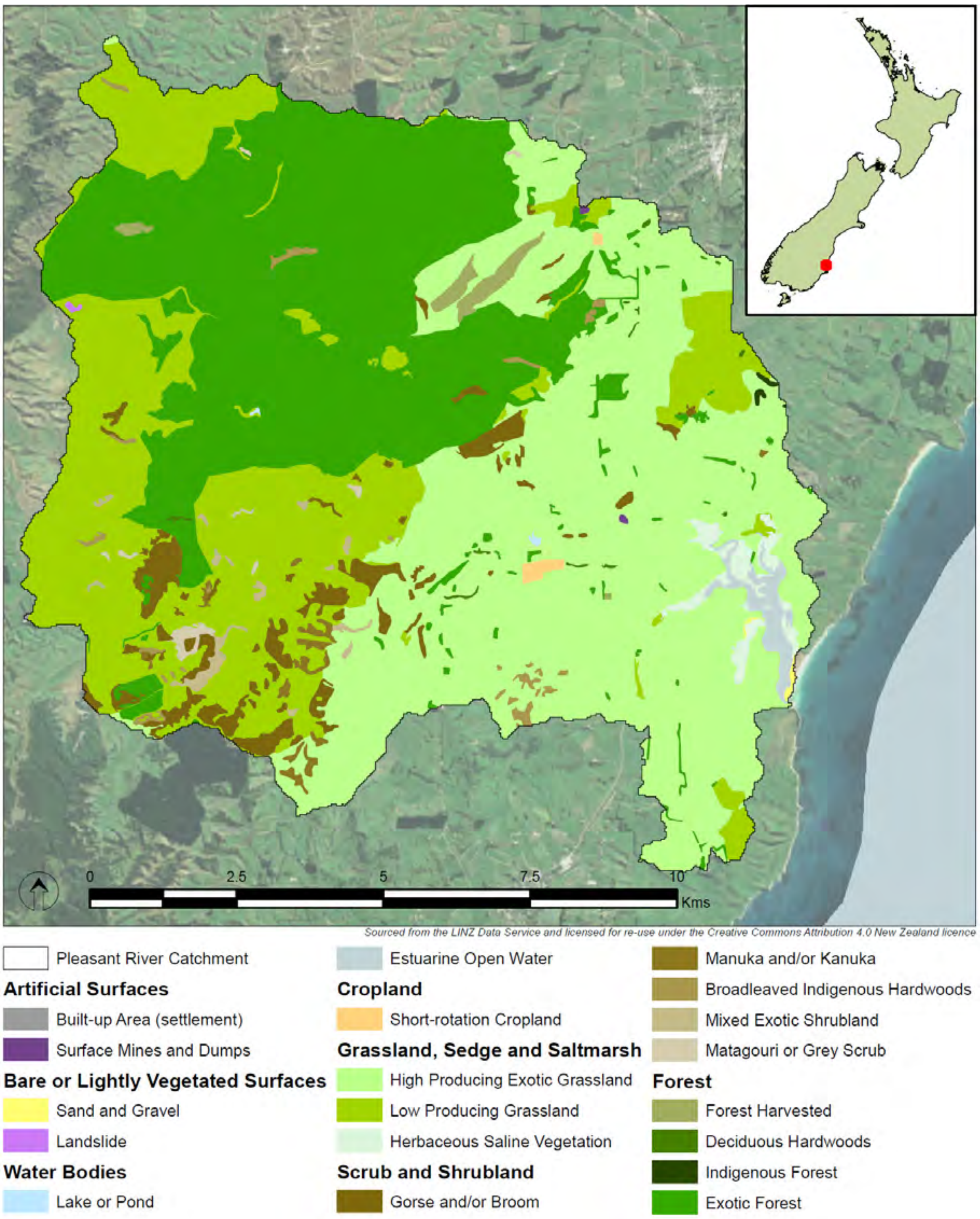


Fig. 2. Pleasant River Estuary catchment land use classifications from LCDB5 (2017/2018) database.

3. METHODS

3.1 BROAD SCALE MAPPING METHODS

Broad scale surveys involve describing and mapping estuaries according to dominant surface habitat features (substrate and vegetation). The type, presence and extent of substrate, salt marsh, macroalgae or seagrass reflects multiple factors, for example the combined influence of sediment deposition, nutrient availability, salinity, water quality, clarity and hydrology. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to small scale temporal variation associated with instantaneous water quality measures.

NEMP methods (Appendix 1) were used to map and categorise intertidal estuary substrate and vegetation. The mapping procedure combines aerial photography, detailed ground-truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats can be monitored by repeating the mapping exercise. Broad scale mapping is typically carried out during September to May when most plants are still visible and seasonal vegetation has not died back. Aerial photographs are ideally assessed at a scale of less than 1:5000, as at a broader scale it becomes difficult to accurately determine changes over time.

Imagery for the present study was supplied by ORC (1:3000 colour aerial imagery captured between February to March 2021). Ground-truthing was undertaken between 25-27 November 2021 by experienced scientists, who assessed the estuary on foot to map the spatial extent of dominant vegetation and substrate. A particular focus was to characterise the spatial extent of muddy sediment (as a key stressor), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats. The latter were estuarine seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the terrestrial margin bordering the estuary. Background information on the ecological significance of opportunistic macroalgae and the different vegetation features is provided in Table 2.

In the field, features were drawn directly onto laminated aerial photographs. The broad scale features were subsequently digitised into ArcMap 10.8 shapefiles using a Huion Kamvas 22 drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features, e.g. salt marsh, and its underlying substrate type.

For broad scale mapping purposes, an estuary is defined as a partly enclosed body of water, where freshwater inputs (i.e. rivers, streams) mix with seawater. The estuary entrance (i.e. seaward boundary) was defined as a straight line between the seaward-most points of land that enclosed the estuary, and the upper estuary boundary (i.e. riverine boundary) was based on the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For further detail see FGDC (2012).

Assessment criteria, developed largely from previous broad scale mapping assessments, apply thresholds for helping to assess estuary condition. Additional details on specific broad scale measures are provided in Sections 3.3-3.8.

Mapping salt marsh vegetation in Pleasant River Estuary

Table 2. Overview of the ecological significance of vegetation types.

Habitat	Description
Terrestrial margin vegetation	A densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important food source and habitat for a variety of species and, in waterway riparian zones, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity.
Salt marsh	Salt marsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important in estuaries as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds and provides an important habitat for a variety of species including fish and birds.
Seagrass	Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (mainly via secondary impacts from macroalgal smothering), and sediment quality (e.g. low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae (e.g. *Agarophyton* spp. & *Ulva* spp.) are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at using excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

3.2 SUBSTRATE CLASSIFICATION AND MAPPING

Salt Ecology has extended the NEMP approach to include substrate beneath vegetation to create a continuous substrate layer for the estuary. Furthermore, a revision of the NEMP substrate classifications is summarised in Appendix 1.

Substrate classification is based on the dominant surface substrate features present, e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories relating to 'muddiness' and 'firmness' characteristics, which were assessed in the field. In November 2021, 12 samples for sediment grainsize were collected to validate field classifications of substrate type (Appendix 2).

The area (horizontal extent) of mud-dominated sediment is used as a primary indicator of sediment mud impacts and in assessing susceptibility to nutrient enrichment impacts (trophic state).

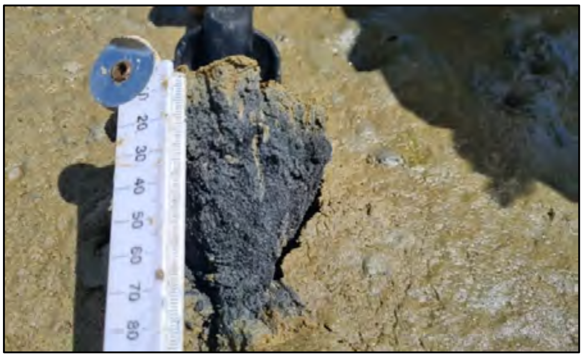
Mobile sands near the estuary entrance

Gravel field in the mid estuary

Very soft sandy mud in the estuary arm adjacent to salt marsh

3.3 SEDIMENT OXYGENATION

The apparent Redox Potential Discontinuity (aRPD) depth was used to assess the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment. The aRPD depth is the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). aRPD provides an easily-measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions. Sediments were considered to have poor oxygenation if the aRPD was consistently <10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. As significant sampling effort is required to map sub-surface conditions accurately, the approach was intended as a preliminary screening tool to determine the need for additional sampling effort. The aRPD depth was recorded at all grain size locations collected from representative substrate types (Appendix 2).



Example of distinct colour change with depth, showing brown oxygenated sediments on the surface down to ~10mm

3.4 MACROALGAE ASSESSMENT

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature. To improve the macroalgal assessment, the ETI (Robertson et al. 2016b) adopted the United Kingdom Water Framework Directive (WFD-UKTAG 2014; Appendix 3) Opportunistic Macroalgal Blooming Tool (OMBT) approach. The OMBT, described in detail in Appendix 2, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within five overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- *Percentage cover of opportunistic macroalgae:* The spatial extent and surface cover of algae present in intertidal soft sediment habitat in an estuary provides an early warning of potential eutrophication issues.
- *Macroalgal biomass:* Biomass provides a direct measure of macroalgal growth (wet weight biomass). Measurements and estimates of mean biomass are made within areas affected by macroalgal growth, as well as across the total estuary intertidal area.
- *Extent of algal entrainment into the sediment matrix:* Macroalgae is defined as entrained when growing in stable beds or with roots deep (e.g. >30mm) within the sediments, which indicates that persistent macroalgal growths have established.

If an estuary supports <5% opportunistic macroalgal cover in total within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' (EQR score ≥ 0.8 to 1.0) with no further sampling required. A numeric EQR score is calculated for the 'high' band using the approach described in Stevens et al. (2022).

Using the above methods, opportunistic macroalgae patches were mapped during field ground-truthing, using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (Fig. 3). Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the extent of macroalgal entrainment were measured.

Sampling macroalgal biomass in Pleasant River Estuary

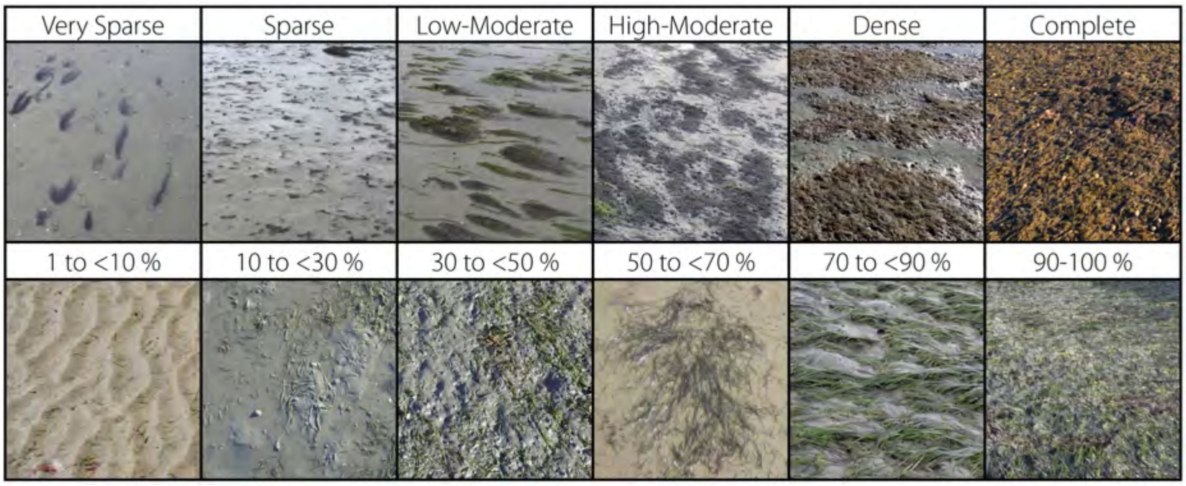


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algal material was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale. When sufficient representative patches had been measured to enable biomass to be reliably estimated, biomass estimates were made following the OMBT method. Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on the five-point scale adopted by the method as noted above.

3.5 SEAGRASS ASSESSMENT

As for macroalgae, the percent cover of seagrass patches was visually estimated through ground-truthing, based on the percent cover scale in Fig. 3.

3.6 SALT MARSH

NEMP methods were used to map and categorise salt marsh, with dominant estuarine plant species used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock; Robertson et al. 2002a-c; Appendix 1). Two measures were used to assess salt marsh condition: i) intertidal extent (percent cover) and ii) current extent compared to estimated historical extent.

LiDAR and historic aerial imagery were used to estimate historic salt marsh extent. The earliest available aerial image from 1958 (retrolens.co.nz) was georeferenced in ArcMap and visible saltmarsh was digitised in ArcMap 10.8 as described in Section 3.1. LiDAR data were supplied by ORC as an elevation raster of the Pleasant River Estuary area and as a terrain dataset of the coastal margin. All geoprocessing was performed using ArcGIS Pro 2.9.3. The terrain dataset was converted to raster using the Terrain to Raster (3D Analyst) tool. Both raster datasets were converted to simplified elevation polygons using the Raster to Polygon tool. The upper estuary boundary elevation was determined using existing estuary mapping and a visual assessment of aerial imagery. Elevation polygons at and below the upper estuary boundary elevation were combined using the Merge tool. A combination of buffering (Pairwise Buffer tool) and smoothing (Smooth Polygon tool) were used to simplify the resulting estuary boundary polygon. For estuary areas not covered by either of the raster layers, the upper estuary boundary was digitised based on aerial imagery interpretation.

Weighing macroalgae in a sample rinse bag

3.7 TERRESTRIAL MARGIN

Broadscale NEMP methods were used to map and categorise the 200m terrestrial margin using the dominant land cover classification codes described in the Landcare Research Land Cover Data Base (LCDB) detailed in Appendix 1.

Native plantings on the terrestrial margin adjacent to salt marsh

Pasture adjacent to the estuary

3.8 WATER QUALITY

At three sampling locations, water quality measures were taken from ~20cm below the water surface and 5cm from the bottom to assess whether there was any salinity or temperature stratification. Water column measures of pH, salinity, dissolved oxygen (DO), temperature and chlorophyll-a (as an indicator of phytoplankton presence) were made using a YSI Pro10 meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Care was taken not to disturb bottom sediments before sampling. Stratification, where present, was recorded along with water depth and clarity (Secchi depth).

3.9 SEDIMENT QUALITY & MACROFAUNA

Sediment quality and macrofauna samples were collected from three sites and used as supporting indicators to calculate an Estuary Trophic Index (ETI) score for the estuary (Robertson et al (2016b). The ETI requires supporting indicators to represent the 10% of the estuary most susceptible to eutrophication (Zeldis et al. 2017).

At each of the three locations, a surface (~20mm) sediment sample was collected, stored on ice, and sent to RJ Hill Laboratories for analysis of the following: particle grain size in three categories (%mud <63μm, sand <2mm to ≥63μm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP) and total sulfur (TS). Details of laboratory methods and detection limits are provided in Appendix 2.

At each site, one sample for macrofauna was collected using a large sediment core (130mm diameter, 150mm deep). The core was extruded into a 0.5mm mesh sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a mixture of 75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification by NIWA. The types of animals present in each sample, as well as the range of different species (i.e. richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments (see Forrest et al. 2022).

3.10 DATA RECORDING AND QA/QC

Broad scale mapping provides a rapid overview of estuary substrate, macroalgae, seagrass and salt marsh condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial imagery, the extent of ground-truthing undertaken to validate features visible on photographs, and the experience of those undertaking the mapping. In most instances features with readily defined edges can be mapped at a scale of ~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse seagrass or macroalgal beds. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed, but when relying on photographs alone, accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

In November 2021, following digitising of habitat features, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables.

As well as annotation of field information onto aerial photographs during the field ground-truthing, point estimate macroalgal data (i.e. biomass and cover measurements, entrainment), along with supporting measures of sediment aRPD, texture and sediment type were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP 10.8.

3.11 ASSESSMENT OF ESTUARY CONDITION

In addition to the authors' expert interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 3). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3. The condition ratings are primarily sourced from the ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 4. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores (i.e. which range from 'high' to 'bad'). The thresholds used to place biomass into OMBT bands have been recently revised for use in New Zealand (Plew et al. 2020a) and are included in Appendix 3.

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HECs) was evaluated. For our purposes, HECs are defined as mud-dominated (≥50% mud content) soft-sediments with >50% macroalgal cover (often with macroalgae entrained and growing as stable beds 'rooted' within the sediment), which typically also have a sediment aRPD depth shallower than 10mm due to sediment anoxia.

As many of the scoring categories in Table 3 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Table 3. Indicators used to assess results in the current report.

Indicator	Unit	Very good	Good	Fair	Poor
Broad scale Indicators					
ETI score[1]	No unit	≤ 0.25	>0.25 to 0.5	>0.5 to 0.75	>0.75 to 1.0
Mud-dominated substrate[2]	% of intertidal area >50% mud	< 1	1 to 5	> 5 to 15	> 15
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥0.8 to 1.0	≥0.6 to <0.8	≥0.4 to <0.6	0.0 to <0.4
Seagrass[2]	% decrease from baseline	< 5	≥ 5 to 10	≥ 10 to 20	≥ 20
Salt marsh extent (current)[2]	% of intertidal area	> 20	> 10 to 20	> 5 to 10	0 to 5
Historical salt marsh extent[2]	% of historical remaining	≥ 80 to 100	≥ 60 to 80	≥ 40 to 60	< 40
200m terrestrial margin[2]	% densely vegetated	≥ 80 to 100	≥ 50 to 80	≥ 25 to 50	< 25
High Enrichment Conditions[1]	ha	< 0.5	≥ 0.5 to 5	≥ 5 to 20	≥ 20
High Enrichment Conditions[1]	% of estuary	< 1	≥ 1 to 5	≥ 5 to 10	≥ 10
Sedimentation rate[1]*	CSR:NSR ratio	1 to 1.1 xNSR	1.1 to 2	2 to 5	> 5
Sedimentation rate[3]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Sediment quality					
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to ≤ 20	≤ 10

[1] General indicator thresholds derived from a New Zealand Estuary Tropic Index (Robertson et al. 2016b), with adjustments for aRPD (FGDC 2012). See text and Appendix 4 for further explanation of the origin or derivation of the different metrics.

[2] Subjective indicator thresholds derived from previous broad scale mapping assessments.

[3] Ratings derived or modified from Townsend and Lohrer (2015).

*CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling).

4. RESULTS

A summary of the November 2021 survey in Pleasant River Estuary is provided below and in the appendices. Supporting GIS files (supplied to ORC as a separate electronic output) provide a more detailed dataset designed for easy interrogation and to address specific monitoring and management questions.

4.1 SUBSTRATE

Table 4 and Fig. 4 show intertidal substrate was dominated by firm muddy sand (117.9ha, 62.8%) in the upper estuary and side arms. Substrate within salt marsh habitat also comprised firm muddy sand in the range of >25 to 50% mud. Rock fields were a prominent feature near the estuary entrance (see photo; Table 4). Small areas of gravel field (2.5ha, 1.3%) were located on the mid estuary flats. Mud-dominated sediments (>50% mud) were localised to the large side arms or salt marsh habitat where fine sediments tend to naturally accumulate (see photos & Fig. 4). Zootic habitat (shellbank) was only a small feature of the estuary comprising 0.02% of the intertidal area. In general, there was good agreement between the subjective assessment of substrate class and the laboratory-analysed sediment validation samples (Appendix 2).

Table 4. Summary of dominant intertidal substrate, Pleasant River Estuary, November 2021.

Substrate Class	Features	Ha	%
Artificial	Boulder field	0.2	0.1
	Cobble field	0.03	0.01
Bedrock	Rock field	0.5	0.3
Boulder/Cobble/ Gravel	Boulder field	0.2	0.1
	Cobble field	0.08	0.04
	Gravel field	2.5	1.3
Sand (0-10% mud)	Mobile sand	7.5	4.0
	Firm sand	12.5	6.7
Muddy Sand (>10-25% mud)	Firm muddy sand	33.4	17.8
	Soft muddy sand	3.2	1.7
Muddy Sand (>25-50% mud)	Firm muddy sand	84.6	45.0
	Soft muddy sand	11.9	6.3
Sandy Mud (>50-90% mud)	Firm sandy mud	4.4	2.3
	Soft sandy mud	15.2	8.1
	Very soft sandy mud	10.5	5.6
Mud (>90% mud)	Firm mud	1.0	0.5
	Soft mud	0.3	0.2
Zootic	Shell bank	0.03	0.02
Total		**187.9**	**100**


Rock field (top) and mobile sand (bottom) in the lower estuary near the entrance


Dried mud and filamentous algae (top) and very soft sandy mud (bottom) in the mid estuary

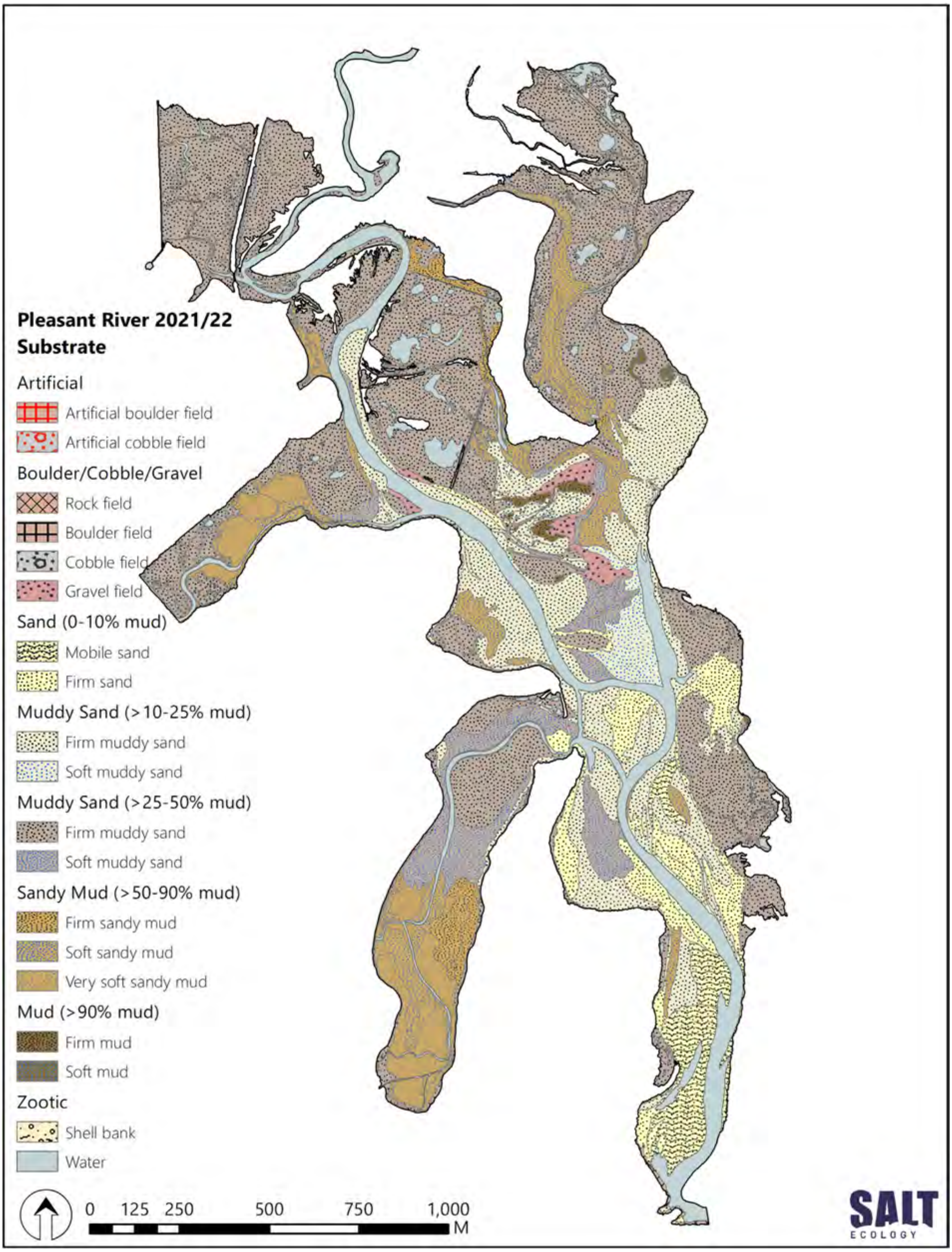


Fig. 4. Distribution of type of substrate recorded in Pleasant River Estuary, November 2021.

4.2 SEDIMENT OXYGENATION

Sediment oxygenation (aRPD) was measured within representative substrate types to assess the trophic state of the sediment. Spot measurements of aRPD showed that sand-dominated sediments in the lower estuary were well-oxygenated, particularly areas of mobile sand. While there were no obvious signs of oxygen depletion on the surface of unvegetated soft, muddy-sands in the upper estuary, in these areas aRPD depths were close to the sediment surface (see photo).

In general, the shallowest aRPD depths occurred in sediments with increasing mud content or organic content. For example, near stream inputs, deposition areas, or in the presence of macroalgae (see photos).

Soft, muddy sand (top), opportunistic macroalgae growing on top of very soft sandy mud (middle) and filamentous macoalgae growing on top of soft, sandy mud (bottom)

4.3 MACROALGAE

4.3.1 Opportunistic macroalgae

Table 5 summarises percentage cover and biomass classes for opportunistic macroalgae (*Agarophyton* spp. & *Ulva* spp.), with the mapped cover and biomass shown in Fig. 5 and Fig. 6 respectively. Macroalgal sampling stations and data are provided in Appendix 5. Non-opportunistic marine species and drift macroalgae were not recorded as part of the nuisance macroalgae assessment.

Table 5. Summary of intertidal cover (A) and biomass (B) of opportunistic macroalgae.

A. Percent Cover

Percent cover category	Ha	%
Absent or trace (<1%)	162.3	86.4
Very sparse (1 to <10%)	5.1	2.7
Sparse (10 to <30%)	6.3	3.4
Low-Moderate (30 to <50%)	2.4	1.3
High-Moderate (50 to <70%)	0.8	0.4
Dense (70 to >90%)	6.8	3.6
Complete (>90%)	4.0	2.1
Total	187.9*	100

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	162.3	86.4
Very low (1 - 100)	7.5	4.0
Low (101 - 200)	1.7	0.9
Moderate (201 - 500)	4.1	2.2
High (501 - 1450)	4.5	2.4
Very high (>1450)	7.7	4.1
Total	187.9*	100

* Total intertidal area including salt marsh

Measuring macroalgae biomass

Key opportunistic macroalgae results were as follows:

- A cover exceeding 50% was recorded across 11.6ha of the intertidal habitat, with the highest cover recorded in the mid estuary and side arms (Table 5A; Fig. 5). Overall, the Affected Area (AA), where opportunistic macroalgae was growing, was 23.8% (25.4ha) of the available intertidal habitat (AIH; Fig. 5; Table 6).
- Macroalgal patches exceeding 90% cover (4.0ha) were a mix of the green seaweed *Ulva* spp. and red seaweed *Agarophyton* spp. growing on soft sediments (see photos). Underlying sediments had a shallow aRPD, indicating organic enrichment.
- In the lower estuary, opportunistic cover was generally <50%. In these areas, wave fetch and channel scouring likely limit excess macroalgal growth. However, entrained *Agarophyton* spp. was common on the channel margins (see photo pg. 17).
- Mean wet weight biomass was rated 'moderate' across the AIH (321g/m^2), and 'poor' in the AA (1348g/m^2; Table 6).
- Marine macroalgal species were common in the deep channel near the estuary entrance (see photo pg. 17), and other estuarine macroalgae were prolific in some areas, as described in the next section.

The overall quality status using the OMBT method was reported as 'moderate', equivalent to an ETI condition rating of 'fair' (Table 3). The numeric OMBT EQR score (0.445), reflects that opportunistic macroalgae were present across large areas of the estuary and were generally associated with areas of fine sediment deposition.

Mixed *Ulva* spp. and *Agarophyton* spp. on soft sediments

Table 6. Summary of OMBT input metrics, overall Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 3) for opportunistic macroalgae. The survey EQR score has an ETI rating of 'fair' based on criteria in Table 3.

Nov-2021 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	10.5	0.690	Good
Average biomass (g/m^2) in AIH	320.6	0.520	Moderate
Average biomass (g/m^2) in AA	1348.0	0.221	Poor
% entrained in AA	43.1	0.246	Poor
Worst of AA (ha) and AA (% of AIH)		0.550	Moderate
AA (ha)	25.6	0.722	Good
AA (% of AIH)	23.8	0.550	Moderate
Survey EQR		0.445	Fair

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating,

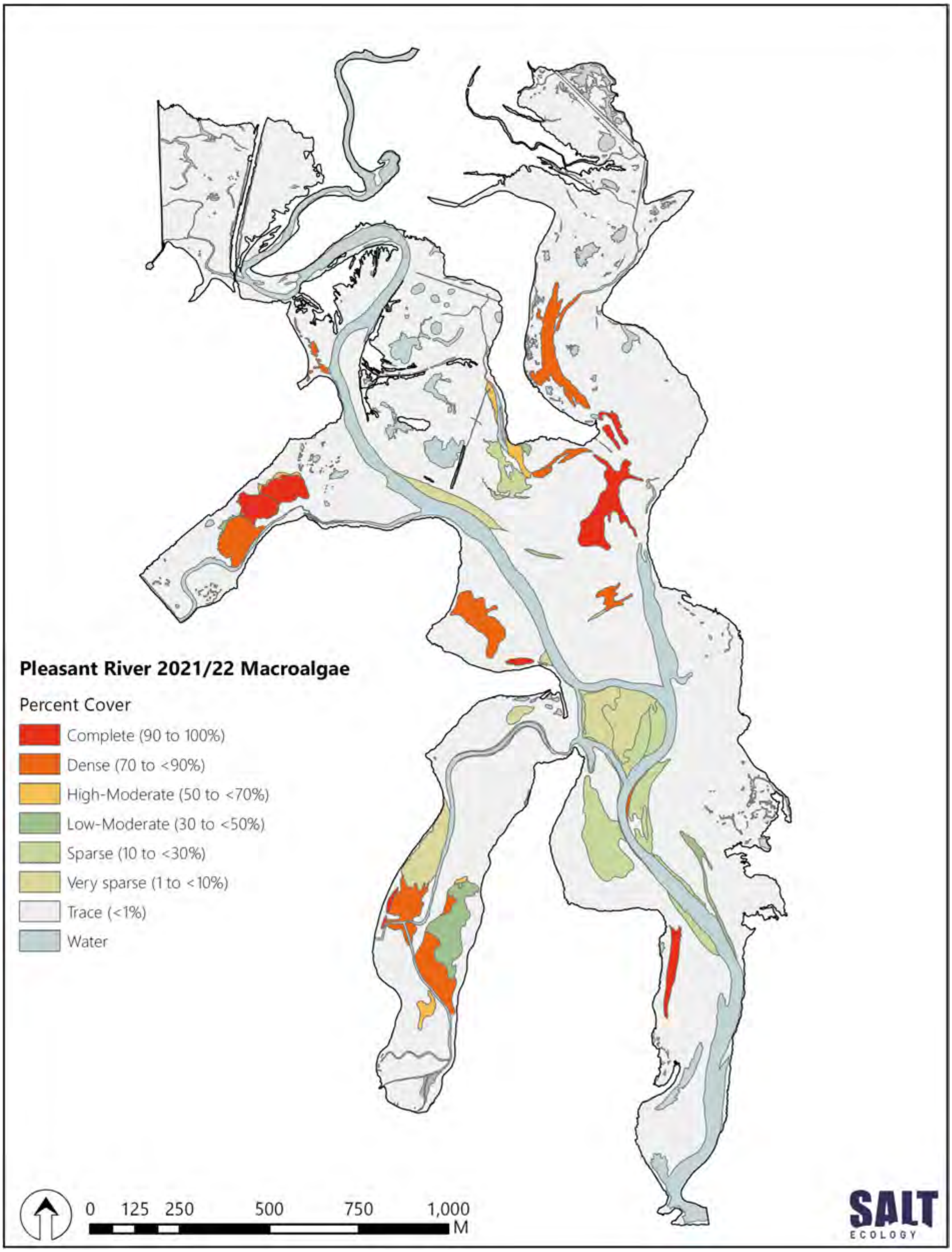


Fig. 5. Distribution and percent cover classes of opportunistic macroalgae in Pleasant River Estuary, November 2021.

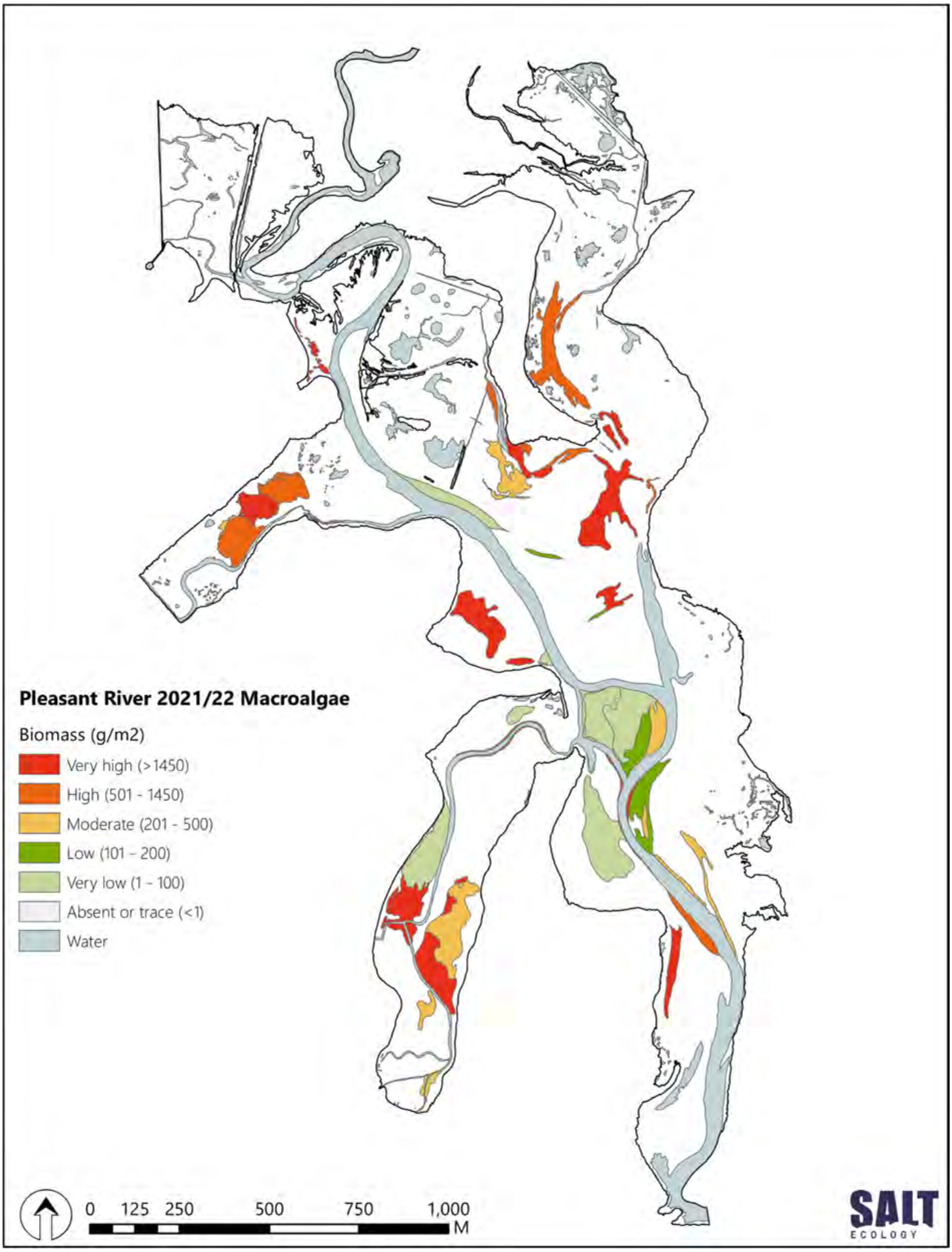
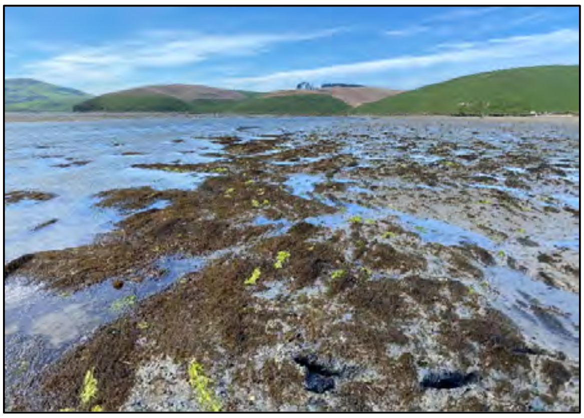


Fig. 6. Distribution and biomass classes of opportunistic macroalgae in Pleasant River Estuary, November 2021.

Mixed *Ulva* spp. and *Agarophyton* spp. on soft muddy sands

Ulva spp. growing on soft muddy sands



Entrained *Agarophyton* spp. on the channel margin

Scouring on channel margin, *Agarophyton* spp. and *Ulva* spp.

Marine algae attached to rock substrate at the estuary entrance

Entrained *Agarophyton* spp. mixed with *Ulva* spp.

4.3.2 Other macroalgae

In addition to opportunistic macroalgal species, other filamentous algae were also prolific in parts of the estuary (Fig. 7). These species included the following:

- A mat-forming macroalga (identified by NIWA as *Vaucheria* sp.), was relatively abundant across 8.3ha or 7.7% of the available intertidal habitat (i.e. excluding salt marsh). In general, this species was associated with very soft (4.4ha) and soft (2.6ha) sandy-mud. Below the thick mats (and often in adjacent bare areas), underlying sediments were enriched and anoxic and had a strong sulfide odour, (Fig. 7; see photo adjacent and below).
- Other long-stranded filamentous green algae, which superficially appeared to comprise more than one species, were prolific in areas of ponded water within herbfields. Sediments were similar, enriched and anoxic in these areas (Fig. 7; see photo adjacent).

4.3.3 High Enrichment Conditions

High Enrichment Condition areas (HECs) are generally defined in relation to the proliferation of opportunistic macroalgae. However, due to the extensive areas of other algae species in Pleasant River Estuary, the definition was broadened to include areas with >50% cover filamentous algal cover (i.e. of *Vaucheria* sp. and ponded filamentous species) because of the contribution made by these species to sediment degradation. Based on this broader definition, HEC areas covered a total of 17.2ha (Fig. 8), comprising:

- 11.8ha (6.3% of the intertidal) consisting of intertidal *Agarophyton* spp., *Ulva* spp. and *Vaucheria* sp. in deposition zones (e.g. south-west & west arms, mid estuary).
- 5.4ha of filamentous algae within herbfield ponds.

Low oxygen sediments below mat-forming patches of a filamentous algae, identified as *Vaucheria* sp. Below the thick mats, underlying sediments were enriched, anoxic and had a strong sulfide odour. This photo illustrated black, anoxic surface sediments between the *Vaucheria* sp. patches. This species was particularly extensive in the south-west arm of the estuary (see photo at bottom).

Filamentous green algae growing in ponds within salt marsh. Like the areas of *Vaucheria* sp., sediments were also strongly enriched and anoxic in these ponded areas.

Filamentous green algae *Vaucheria* sp. growing prolifically at the head of the south-west arm

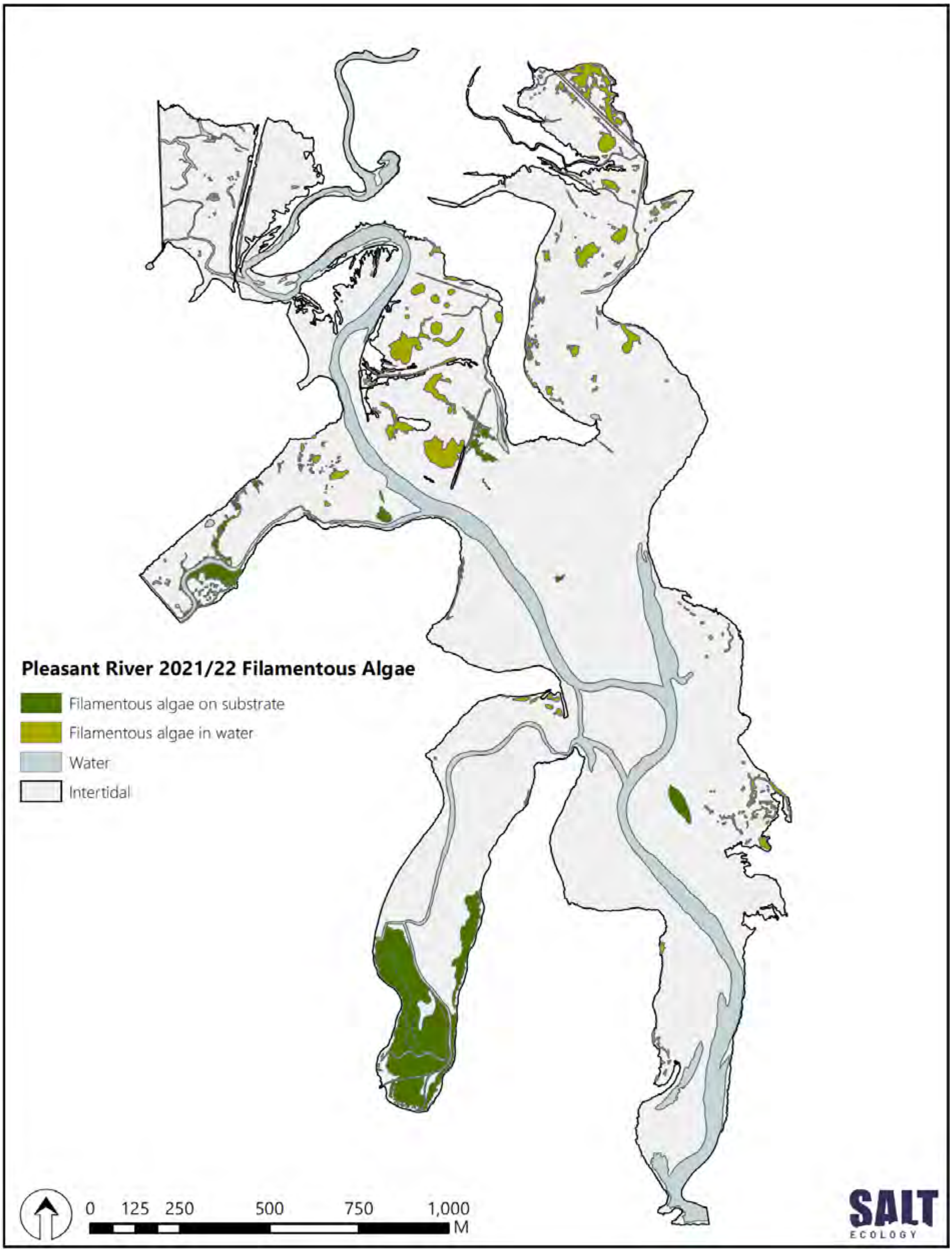


Fig. 7. Distribution of filamentous algae (presence/absence) in Pleasant River Estuary, November 2021. Filamentous algae in water refers to areas of green filamentous algae in ponds within salt marsh herbfields.

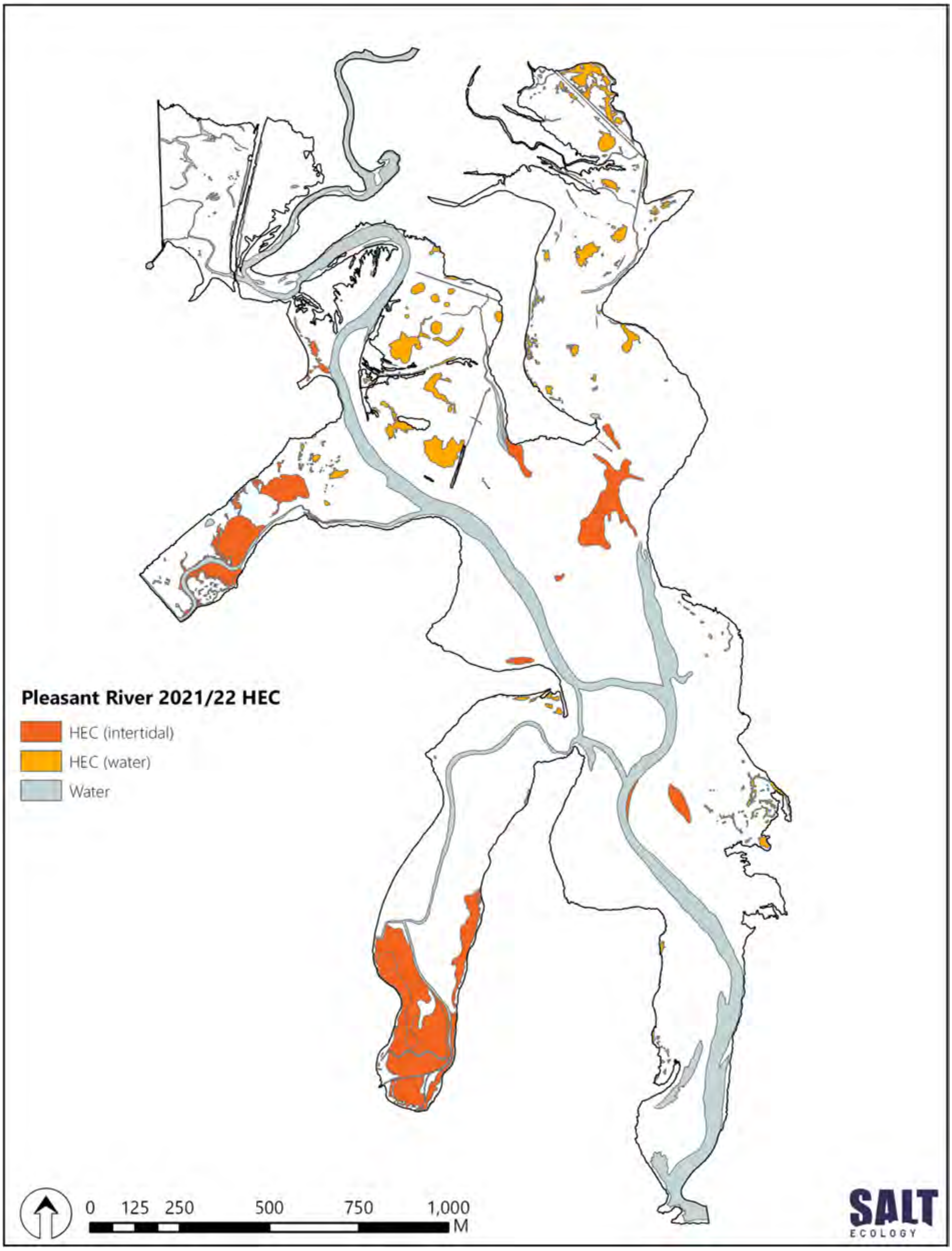


Fig. 8. Areas of High Enrichment Conditions (HEC) in Pleasant River Estuary, November 2021, including opportunistic macroalgae and other areas where filamentous algal species were prolific. HEC (water) refers to areas of green filamentous algae in ponds within salt marsh herbfields.

4.4 SEAGRASS

No seagrass was recorded in Pleasant River Estuary in November 2021.

4.5 SALT MARSH

Table 7 summarises intertidal salt marsh, with the distribution mapped in November 2021 presented in Fig. 9. Dominant and subdominant species are recorded in Appendix 6. Salt marsh covered 80.4ha (42.8%) of the intertidal area and was most extensive in the upper estuary and on the eastern margin (Fig. 9).

Table 7. Summary of salt marsh area (ha and %) in Pleasant River Estuary, November 2021.

Subclass	Ha	%
Estuarine Shrub	0.8	0.9
Grassland	0.3	0.4
Tussockland	0.1	0.1
Sedgeland	0.2	0.3
Rushland	1.1	1.4
Herbfield	77.9	96.9
Total	80.4	100.0

The dominant class was herbfield, comprising 77.9ha (96.9% of total salt marsh), with the main species being *Sarcocornia quinqueflora* (glasswort; see photo) and *Selliera radicans* (remuremu; see photo). Other herbfield species included *Samolus repens* (primrose), *Suaeda novaezelandiae* (sea blite) and *Thyridia repens* (New Zealand musk).

Nest in *Sarcocornia quinqueflora* (glasswort) herbfield

Selliera radicans (Remuremu)

Rushland comprised 1.1ha (1.4% of total salt marsh), with the dominant species being *Apodasmia similis* (jointed wirerush; see photo) and *Ficinia (Isolepis) nodosa* (knobby clubrush). Estuarine shrubs comprised 0.8ha (0.9% of total salt marsh), with the dominant species being *Plagianthus divaricatus* (salt marsh ribbonwood). Sedgeland (*Schoenoplectus pungens*; three square) comprised only a small area of the estuary 0.2ha (0.3% total salt marsh; see photo). Introduced weeds and the grass *Festuca arundinacea* (tall fescue) were present in some areas.

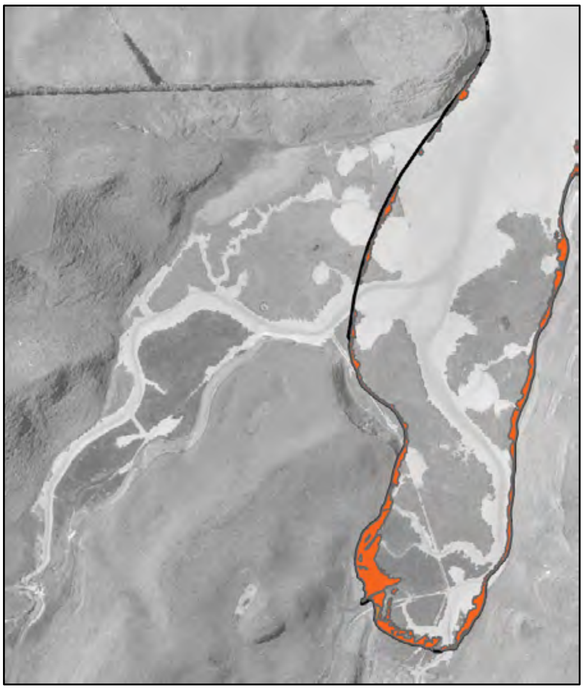
Apodasmia similis (jointed wirerush) and herbfield foreground, with *Plagianthus divaricatus* (salt marsh ribbonwood) in the background

Schoenoplectus pungens (three square sedge)

Fig. 9. Distribution and type of salt marsh in Pleasant River Estuary, November 2021.

LiDAR data (Appendix 7) and historic aerial imagery (Appendix 8) were used to estimate the extent of salt marsh prior to estuary drainage and reclamation. It was estimated that salt marsh historically covered ~128ha of the intertidal area (Fig. 10) and the dominant class was herbfield. Compared with the current salt marsh extent described in this report, we therefore estimate that there has been a loss of 47.6ha (or 37% of salt marsh) when compared to the historic extent (i.e. 63% of natural cover remains). Despite the magnitude of the loss, the percentage of salt marsh remaining equates to a condition rating of 'good' (see Table 3).

The largest losses have occurred in the north of the estuary and south-west and west arms, where salt marsh has been drained and reclaimed for pasture. Drainage channels remain common, particularly in the north (see photo). In the south-west arm there has been >90% loss of salt marsh, particularly herbfield, through reclamation (see photos adjacent; Fig. 10). Flapgates are common in the side arms and upper estuary, preventing inundation of remaining herbfield. While some herbfield species persist, these areas were freshwater dominated. Fencing and grazing of herbfield continues in most areas.



Current estuary boundary and salt marsh extent overlaid on the 1958 aerial image of the south-west arm prior to reclamation. The black outline is the current mapped estuary, illustrating former salt marsh along the left half of the image that has been lost (now farmland).

Causeway across the west arm, with water flow into the upper arm restricted by a flapgate (left farmland and right salt marsh)

Fencing through salt marsh habitat, with many areas still grazed

Drainage channels through *Sarcocornia quinqueflora* (glasswort) herbfield

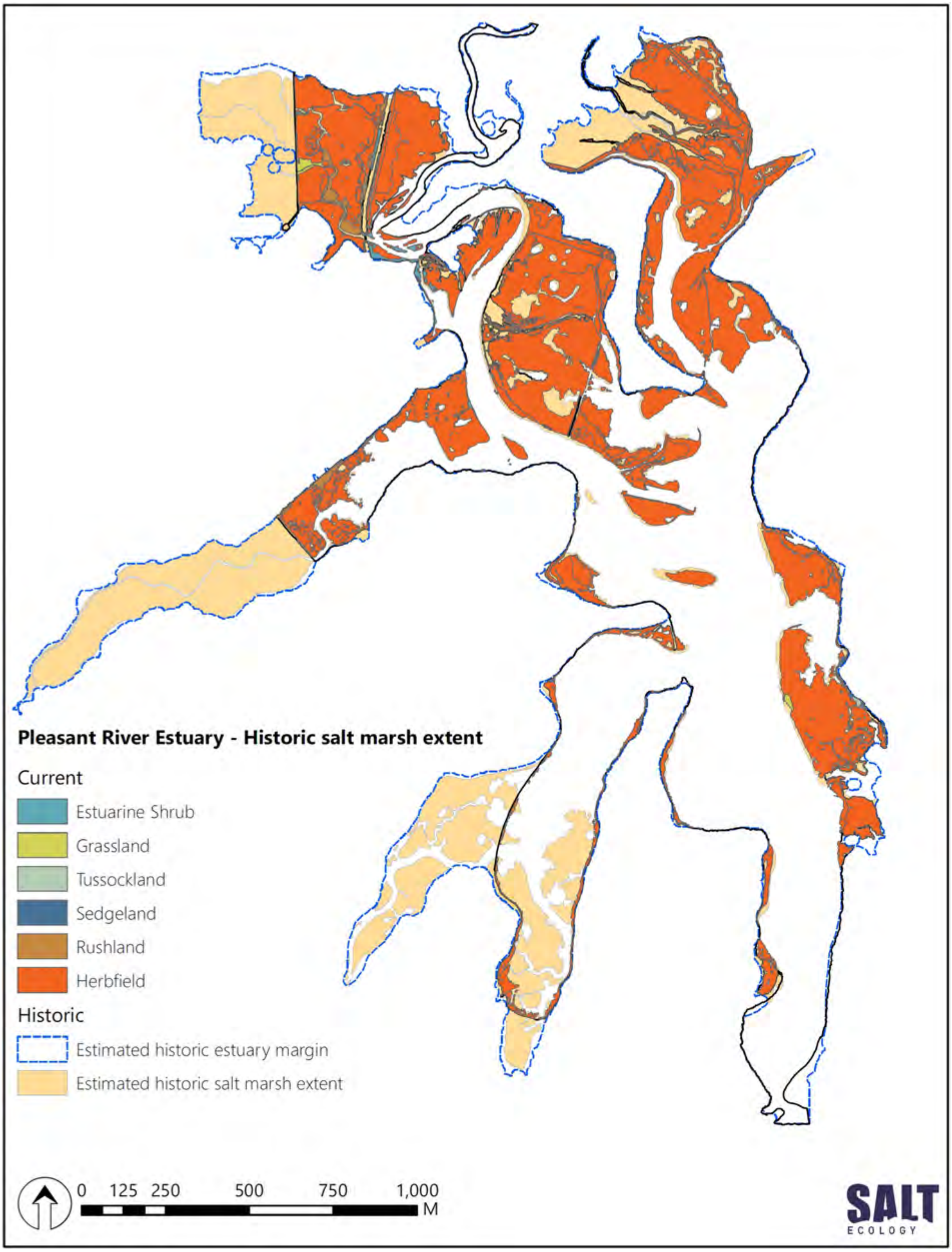


Fig. 10. Estimated distribution of historic salt marsh in Pleasant River Estuary. Estimated using LiDAR and aerial imagery from 1958 (source: retrolens.co.nz). The current mapped area (black line) and salt marsh extent is overlaid onto the historic salt marsh extent (yellow) and historic estuary margin (blue dashed line). See Appendix 8.

4.6 TERRESTRIAL MARGIN

Table 8 and Fig. 11 summarises the land cover of the 200m terrestrial margin, which was 59.3% high producing grassland and 28.4% low producing grassland. Only 6.6% of the terrestrial margin was densely vegetated and mostly comprised exotic vegetation (e.g. exotic forest, mixed exotic shrubland and gorse).

Gorse growing on the estuary margin (top) and the dominant land use, grassland, on sloping hill country (bottom)

Rail infrastructure transects herbfield in the upper estuary and traverses the margin of the north-west and western arms. While transport infrastructure was only a small portion (1.3%) of the terrestrial margin, its relative impact is significant with both reclamation and shoreline hardening having been undertaken to accommodate rail infrastructure. The built-up area within the terrestrial margin comprised 0.9% of the margin area.

Rail infrastructure transecting herbfield in the upper estuary

The herbaceous saline vegetation described in Fig. 11 is 3% of the terrestrial margin, and represents the dune area near the estuary entrance, which was dominated by exotic marram grass (*Ammophilia arenaria*). Historically dunes in this area were likely active and dominated by the native sand binder pīngao (*Ficinia spiralis*).

Aerial image of marram (*Ammophila arenaria*) dune system in 1958 (left) and 2018 (right)

Table 8. Summary of 200m terrestrial margin land cover, Pleasant River Estuary, November 2021.

LCDB5 Class	Ha	%
1 Built-up Area (settlement)	2.9	0.9
5 Transport Infrastructure	4.0	1.3
10 Sand and Gravel	8.0	2.6
20 Lake or Pond	1.1	0.4
21 River	1.4	0.5
40 High Producing Grassland	183.4	59.3
41 Low Producing Grassland	88.0	28.4
46 Herbaceous Saline Vegetation	9.3	3.0
51 Gorse and/or Broom	5.9	1.9
54 Broadleaved Indigenous Hardwoods	0.4	0.1
56 Mixed Exotic Shrubland	0.9	0.3
58 Matagouri or Grey Scrub	0.4	0.1
71 Exotic Forest	3.7	1.2
Grand Total	309.3	100
Total dense vegetated margin (LCDB5 classes 45-71)	20.5	6.6

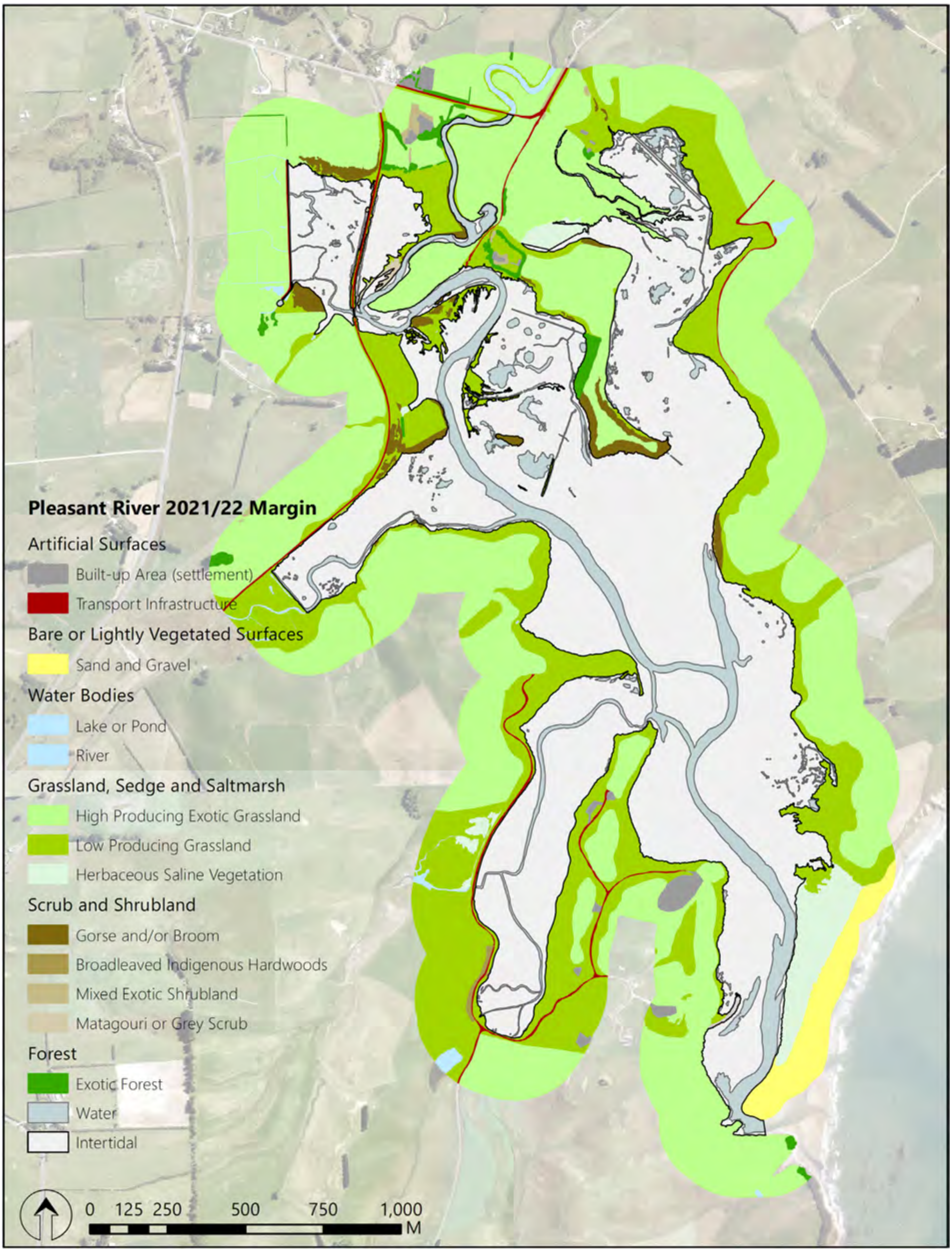


Fig. 11. Map of 200m terrestrial margin land cover, Pleasant River Estuary, November 2021. Dunes, near the entrance, were categorised as 'herbaceous saline vegetation' to maintain consistency with LCDB5.

4.7 WATER QUALITY

Water quality data presented in Table 9 provide ancillary information to support the broad scale mapping survey. Site locations are presented in Appendix 2.

Table 9. Water quality for Pleasant River Estuary, November 2021.

Station	WQ 1	WQ 2	WQ 3
NZTM East	1422378	1421814	1421720
NZTM North	4952499	4951544	4951616
Distance from mouth (m)	1200	3000	3000
Stratified	No	No	Yes
Surface measurements			
Measurement depth (m)	0.2	0.1	0.1
Temperature (°C)	14.4	15.6	13.0
DO saturation (%)	133.1	154.3	35.3
DO concentration (g/m^3)	10.9	15.0	3.7
Salinity	34.1	3.9	0.6
pH	7.85	8.49	8.60
Chlorophyll-*a* (mg/m^3)	1.3	12.5	3.6
Bottom measurements			
Measurement depth (m)	0.7	0.25	0.2
Temperature (°C)	14.4	15.6	14.5
DO saturation (%)	133.1	154.3	132.6
DO concentration (g/m^3)	10.9	15.0	11.7
Salinity	34.1	3.9	18.5
pH	7.85	8.49	7.85
Chlorophyll-*a* (mg/m^3)	1.3	12.5	7.5
Secchi depth (m)	>0.75	>0.3	>0.25
Max depth (m)	0.75	0.30	0.3
Channel width (m)[1]	35	1	0.5
Sediment texture	firm	soft	very soft
Sediment type	s	sm	sm

[1] Estimated at the time of sampling.

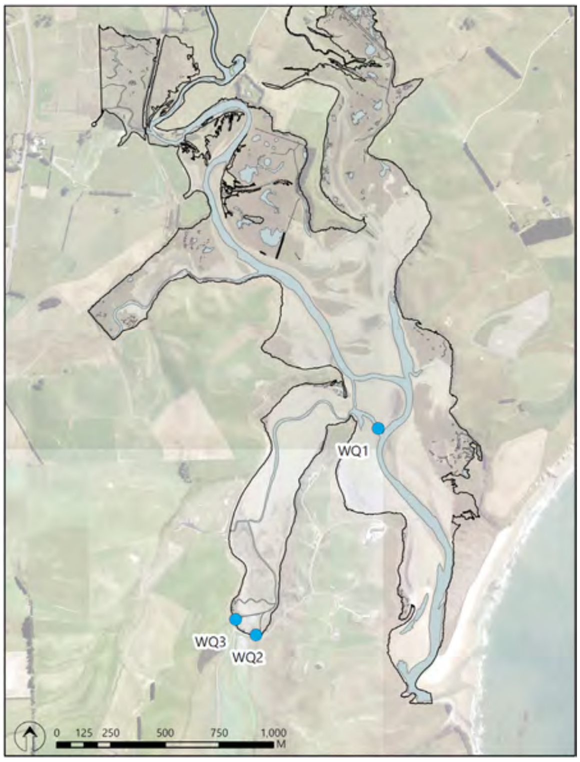
As expected, the site closest to the estuary entrance (WQ1) exhibited higher salinity and lower chlorophyll-*a* owing to the marine influence in this area. The water column at site WQ1 was well oxygenated (>100% dissolved oxygen saturation) at the time of sampling.

Smaller streams in the south-west arm were shallow (~0.3m) and water quality was variable. At site WQ2 the water column was well mixed, salinity low, oxygen was over-saturated and chlorophyll-*a* was elevated at 12.5mg/m^3. Site WQ3 was shallow and stratified with low oxygen recorded at the surface, possibly due to the source (i.e. the reservoir) of the input stream. These results suggest that the smaller input streams were enriched with elevated chlorophyll-*a* and low oxygen conditions at the time of sampling.

Furthermore, drainage channels and ponds in salt marsh habitat were highly enriched and expressing signs of eutrophication with excess filamentous algal growth and low oxygen.

Stream input, with seawater incursion restricted by flapgates

Drainage channel with a dark organic substrate



Location of water quality sites in Pleasant River Estuary

4.8 ESTUARY TROPHIC INDEX (ETI)

Table 10 summarises the indicators used to calculate an overall ETI score for the estuary. Raw data are presented in Appendix 9. The primary indicator of eutrophication response in SIDE type estuaries, like Pleasant River Estuary, is macroalgae (OMBT EQR), with supporting sediment indicators of macrofauna (AZTI Marine Biotic Index; AMBI), total nitrogen (TN), total organic carbon (TOC) and sediment oxygenation (aRPD). The overall ETI score of 0.776 was rated 'poor' in terms of eutrophication, which is reflected in constituent metrics such as the low macroalgal EQR and poor sediment oxygenation and other broad scale indicators such as the presence of HEC areas.

Table 10. Primary and supporting indicators used to calculate the ETI for Pleasant River Estuary.

Indicator	Raw Value	Equivalent ETI Score[1]
Primary indicator		
Macroalgae (EQR)	0.445[2]	0.688
Supporting Indicator		
AMBI	4.89	0.875
TN (mg/kg)	2470	0.813
TOC (%)	1.80	0.688
aRPD (mm)	1.7	1.00
Final ETI Score	0.766	Poor

[1]Zeldis et al. 2017, [2]EQR from Table 6

Dry filamentous algae, likely only indundated on spring tides, in the foreground and macroalgae in the background (top), and very soft sand muds devoid of oxygen (bottom)

Dense *Ulva* spp. and *Agarophyton* spp. on anoxic and very soft sandy-muds

5. SYNTHESIS OF KEY FINDINGS

Key broad scale indicator results and ratings are summarised in Tables 11 and 12, with additional supporting data used to assess estuary condition presented in Table 13.

Pleasant River Estuary was intertidally dominated (187.9ha or 87% of the estuary area) with the subtidal areas restricted to relatively narrow river channels. Overall, the estuary was in 'fair' to 'poor' condition with highly eutrophic side arms expressing excess algal growth on soft, muddy sediments with low sediment oxygen. The compromised ecological quality of the estuary likely reflects high freshwater inputs (~30% of the estuary volume; Plew et al. 2018) from a developed catchment, extensive estuary reclamation, and restricted flushing of side arms.

Mud-dominated sediments, a common stressor in New Zealand estuaries, comprised 31.3ha or 16.7% of the intertidal area and were common in side arms and in the mid-estuary. Deposition of fine sediments is promoted in the side arms due to a combination of direct freshwater inputs from developed hill country, and reduced flushing. A partial causeway in the north-east arm and the natural geology of the north-west arm minimise flushing in those areas. In the south-west arm, tidal inundation was impeded by a causeway that was installed across the entrance in the 1960's, with the area used for cattle grazing up until the causeway was removed in 2009, reflooding some of the tidal flats (Moller and Moller 2012). The mid estuary comprised muddy sands (>10 to 50% mud) that were exhibiting symptoms of mild stress in terms of biota living in the sediment (Forrest et al. 2022). The lower estuary flats were marine influenced and dominated by clean firm or mobile sands.

Table 12. Summary of key broad scale features as a percentage of total estuary, intertidal or margin area, Pleasant River Estuary, November 2021.

a. Area summary	ha	% Estuary
Intertidal area	187.9	86.8
Subtidal area	28.5	13.2
Total estuary area	216.3	100

b. Key fine sediment features	ha	% Intertidal
Mud-enriched (25 to <50% mud)	96.4	51.3
Mud-dominated (≥50% mud)	31.3	16.7

c. Key vegetation features	ha	% Intertidal
Salt marsh	80.4	42.8
Seagrass (≥50% cover)	0.0	0.0
Opportunistic macroalgal (≥50% cover)	11.6	6.2
Filamentous algae (≥50% cover)	7.9	4.2

d. Terrestrial margin (200m)	ha	% Margin
200m densely vegetated margin	20.5	6.6

Mud dominated sediments in the north-west arm

Table 11. Summary of key broad scale indicator results and ratings.

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) score	No unit	0.766	Poor
Mud-dominated substrate	% of intertidal area >50% mud	16.7	Poor
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.445	Fair
Seagrass	% decrease from baseline	0.0	na (no data before Nov-2021)
Salt marsh extent (current)	% of intertidal area	42.8	Very Good
Historical salt marsh extent*	% of historical remaining	63	Good
200m terrestrial margin	% densely vegetated	6.6	Poor
High Enrichment Conditions	ha	17.2[1]	Fair
High Enrichment Conditions	% of estuary	8.0	Fair
Sedimentation rate[2]	CSR:NSR ratio[3]	3.4[4]	Fair
Sedimentation rate[2]	mm/yr	3.8	Poor

Colour bandings are reported in Table 3. OMBT=Opportunistic Macroalgal Blooming Tool. [1]Includes intertidal and ponded areas [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted), [4]Assumes 50% wetland attenuation under natural conditions

The observations of soft, muddy sediment accumulation are consistent with NIWA's national estuary sediment load estimator (Hicks et al., 2019), which is designed to predict sediment input and retention. This tool indicated that Pleasant River Estuary is predicted to be highly efficient at trapping sediment (91% retention). Spreading all of the retained sediment evenly throughout the estuary would result in average estuary infilling of ~3.8mm/yr (Table 13), which equates to a condition rating of 'poor' (Table 12). Based on the relative difference in estimated yields from an undisturbed catchment, and assuming a further 50% attenuation from the historical presence of wetlands, the current sedimentation rate (CSR) is estimated to be 3.4 times the natural sedimentation rate (NSR; Table 13). The condition rating for the CSR:NSR ratio is rated 'fair' (Table 12). These sedimentation rate results and the large area of mud-dominated sediments (16.7%), reinforce that fine sediment issues are a cause for concern.

Table 13. Supporting data used to assess estuary ecological condition in Pleasant River Estuary.

Supporting Condition Measure	Pleasant River
Mean freshwater flow (m^3/s)[1]	0.98
Catchment Area (Ha)	12847
Catchment nitrogen load (TN/yr)[2]	17.0
Catchment phosphorus load (TP/yr)[2]	2.9
Catchment sediment load (KT/yr)[1]	9.8
Estimated N areal load in estuary ($mg/m^2/d$)[2]	47.7
Estimated P areal load in estuary ($mg/m^2/d$)[2]	8.2
CSR:NSR ratio[1]	3.4
Trap efficiency (sediment retained in estuary)[1]	91%
Estimated rate of sed. trapped in estuary (mm/yr)[1]	3.8

[1]Hicks et al. 2019.

[2]CLUES version 10.3, Run date: March 2021

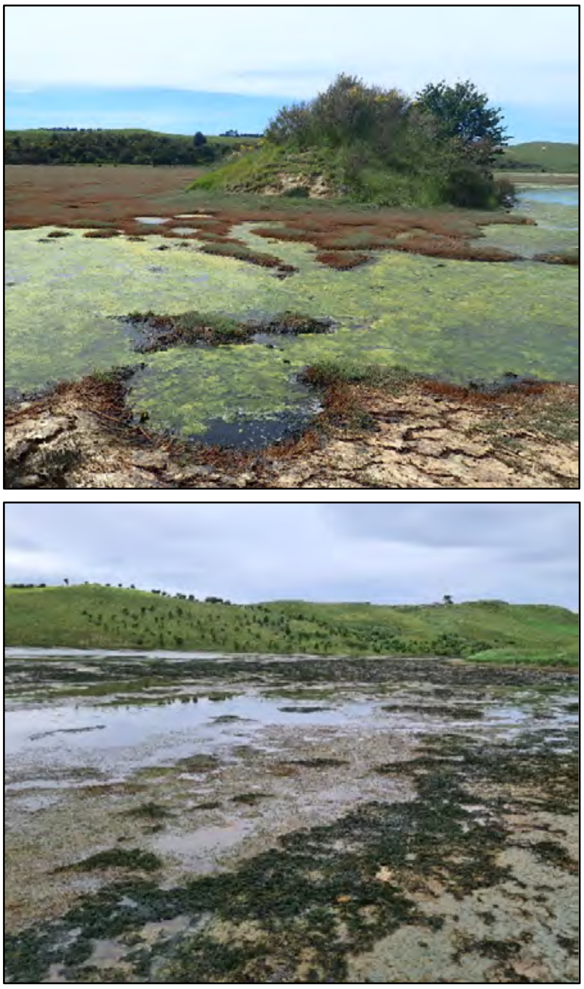
Algae is an important natural feature in estuaries and contributes to their high productivity and biodiversity. However, when nutrients are in excess and growing conditions are suitable, nuisance blooms of algae can have detrimental effects on estuary health (e.g. seagrass smothering, trapping fine sediments, increasing the organic loading, and causing low oxygen conditions). In Pleasant River Estuary prolific growths of opportunistic macroalgae and filamentous algae were present in the side arms, mid estuary, and ponds within herbfields.

The macroalgae OMBT-EQR score (0.445) was rated 'fair', with an ETI score of 0.776 (rated 'poor'), indicating that the estuary is expressing significant signs of eutrophication. As the EQR does not include the large areas of filamentous algal growth, it under-states the current degradation of the estuary. It is assumed that the proliferation of filamentous species is in part a trophic response, although the drivers of prolific *Vaucheria* sp. growth are unclear. This species is rare in South Island estuaries, and appears more common in the North Island, although is poorly understood in New Zealand (Wilcox 2012; Muralidhar 2014). Of interest from overseas studies is that extensive mats of *Vaucheria* sp., with enriched anoxic and sulfidic sediments beneath, have been described in estuarine systems (e.g. Simons 1974; Reise et al. 2022). These effects, and the mechanisms that are thought to contribute to proliferation, have similarities to that described for the opportunistic *Agarophyton* spp. (see Table 2 & Section 3). The mechanisms include rapid growth and spread via asexual reproduction, and the infiltration of rhizoids into the sediment matrix, which lead to the formation of stable beds and enhance the trapping of muddy sediments. For example, Reise et al. (2022) described an increase in sediment level of 20cm over three years that was attributed to the establishment of one particular *Vaucheria* species.

Accordingly, to better characterise the extent of eutrophic conditions, *Vaucheria* and other filamentous algae were included in the assessment of high enrichment conditions (HEC). A total of 17.2ha, or 8% of the estuary area, was expressing HEC, with high biomass algal growths associated with muddy sediments and severe sediment anoxia. This situation suggests that catchment sediment and nutrient loads currently exceed the estuary's assimilative capacity and problems can be expected to persist and worsen without management intervention. In relation to nutrients, of interest is that the modelled nitrogen load ($47.7mgN/m^2/d$) is below the ~$100mgN/m^2/d$ threshold at which nuisance macroalgae problems are predicted to occur (Robertson et al. 2017; Table 13). This apparent contradiction is likely due to the cumulative effects of nitrogen loads and other pressures, including extensive reclamation, poor flushing and altered hydrology (i.e. flapgates, causeways) in the estuary.

While poor water quality (Table 9) is the largest contributor to excess algal growth in estuaries, sediments that retain a eutrophic legacy (i.e. sediments rich in nutrients) can lead to a lag in the recovery response to management interventions. For example, the largest area of *Vaucheria* sp. in the south-west arm was growing on previously grazed and eroded herbfield sediments that were rich in organic matter, sulfur, and nutrients (Appendix 9). It is likely that, in these areas, any recovery response (i.e. decrease in algal blooms) will be delayed until other internal nutrient sources are depleted.

Ulva spp. and *Agarophyton* spp. in the north-west arm



Unidentified filamentous algae growing in shallow anoxic ponds within salt marsh (top) and *Vaucheria* sp. growing on eroded herbfield in the south-west arm (bottom)

Seagrass is a key feature in estuaries, providing food and habitat for fish, birds and macroinvertebrates. Seagrass can also influence water quality by trapping fine sediments, stabilising substrate, and assimilating nutrients. Unlike other Otago estuaries (Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea) where seagrass is a prominent vegetation type, no seagrass was recorded in Pleasant River Estuary. A review of the aerial imagery from 1958 confirms the absence of seagrass, although by this time the estuary was already heavily modified, therefore it is uncertain whether seagrass would have grown in the estuary historically. The lack of seagrass potentially reflects the large-scale estuary modification and/or other conditions that would limit seagrass growth, in particular, a strong freshwater influence (low salinity), high sediment deposition, macroalgal growth in the likely areas seagrass would grow (i.e. side arms), and wave fetch and substrate mobility in the mid to lower estuary that could prevent establishment.

Salt marsh (mainly herbfield) was the dominant vegetation type in the estuary (80.4ha or 42.8% of the intertidal area). Salt marsh is an important feature of estuaries because it traps sediments and assimilates nutrients, in addition to providing habitat for birds and insects. An estimated ~63% of the historic salt marsh extent remains, equating to a condition rating of 'good'; however, the relative area of salt marsh lost, compared to the historic extent, is large (47.6ha loss). The greatest losses are due to reclamation, with salt marsh historically drained and converted to pasture (Fig. 10). Despite the salt marsh in Pleasant River Estuary being classified as a regionally significant wetland in the Regional Plan: Water for Otago, drainage and grazing are still occurring, particularly in the upper estuary and side arms. Smaller losses are attributed to erosion on channel margins and die-off of herbfield vegetation around ponds that have prolific filamentous algal growth and severe anoxia. Without active management, ongoing losses of salt marsh habitat can be expected.

Reclamation, drainage and structures that impede salt marsh growth are common in the estuary (i.e. causeways, flapgates, shoreline hardening for rail infrastructure). These modifications have significantly altered estuary hydrology and disrupted the natural connectivity between the land and the sea, compromising overall ecological health. There is significant scope for salt marsh protection and restoration, with the largest gains likely achieved through restoring the natural connectivity (i.e. removal of flapgates, causeways), and re-flooding areas of existing or previous estuary habitat, particularly in the upper estuary where herbfield vegetation persists. In the south-west arm, tidal inundation was restored to part of the arm when the causeway was removed in 2009. While some salt marsh has re-established, the legacy of almost 50 years of pasture and grazing remains.

In conclusion, the most significant issues identified in Pleasant River Estuary were large scale estuary reclamation (~20% loss), altered hydrology and ongoing drainage and grazing of salt marsh habitat, and excessive growths of opportunistic macroalgae and filamentous algal species. Coupled with current elevated catchment nutrient and sediment loads, the estuary's assimilative capacity has been greatly reduced resulting in large areas of eutrophic conditions (i.e. excess algal growth coupled with poor sediment oxygen and muddy sediments), particularly in the side arms.

Fenced and grazed herbfield with drainage channel in foreground

Filamentous algae growing on substrate that used to be herbfield habitat

Bird nest in herbfield habitat

Artificial boulder field restricting water movement through the channel

Highly enriched drainage channels with profilic filamentous algae growth and low oxygen

Ulva spp. in the mid estuary

6. RECOMMENDATIONS

Overall, the November 2021 monitoring results highlight that Pleasant River Estuary is under stress, and is expressing signs of excess sedimentation and eutrophication. These features are evident as prolific growths of opportunistic macroalgae and filamentous algae, in addition to muddy sediments with poor sediment oxygenation in the affected areas. Coupled with historic losses of salt marsh habitat, the estuary is in 'fair'' to 'poor' condition. Without active management to reduce catchment nutrient and sediment loads, and to prevent further salt marsh losses and enhance existing habitat, these symptoms can be expected to persist and worsen. Based on the findings of the current survey it is recommended that ORC consider the following:

- Repeat the broad scale habitat mapping at 5-yearly intervals to track long term changes in estuary condition.
- Consider more frequent targeted nuisance macroalgae and filamentous algae monitoring (e.g. every 1-2 years), especially if conditions are observed to deteriorate.
- Protect existing salt marsh from further losses and consider restoration in suitable areas (i.e. re-connecting salt marsh to the estuary) to enhance and expand existing habitat.
- Include Pleasant River Estuary in the ORC limit-setting programme and establish limits for catchment sediment and nutrient inputs that will improve the ecological quality of the estuary.

Ulva spp. growing on very soft sandy-muds

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP (Robertson et al. 2002) with minor modifications as listed. Revised substrate classes were developed by Salt Ecology to more accurately classify fine unconsolidated substrate. Terrestrial margin vegetation was classified using the field codes included in the Landcare Research Land Cover Database (LCDB5) - see following page.

VEGETATION (mapped separately to the substrates they overlie and ordered where commonly found from the upper to lower tidal range).

Estuarine shrubland: Cover of estuarine shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh (density at breast height).

Tussockland: Tussock cover is 20-100% and exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples occur in all species of *Cortaderia*, *Gahnia*, and *Phormium*, and in some species of *Chionochloa*, *Poa*, *Festuca*, *Rytidosperma*, *Cyperus*, *Carex*, *Uncinia*, *Juncus*, *Astelia*, *Aciphylla*, and *Celmisia*.

Sedgeland: Sedge cover (excluding tussock-sedges and reed-forming sedges) is 20-100% and exceeds that of any other growth form or bare ground. "Sedges have edges". If the stem is clearly triangular, it's a sedge. If the stem is flat or rounded, it's probably a grass or a reed. Sedges include many species of *Carex*, *Uncinia*, and *Scirpus*.

Grassland[1]: Grass cover (excluding tussock-grasses) is 20-100% and exceeds that of any other growth form or bare ground.

Introduced weeds[1]: Introduced weed cover is 20-100% and exceeds that of any other growth form or bare ground.

Reedland: Reed cover is 20-100% and exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha*, *Bolboschoenus*, *Scirpus lacutris*, *Eleocharis sphacelata*, and *Baumea articulata*.

Lichenfield: Lichen cover is 20-100% and exceeds that of any other growth form or bare ground.

Cushionfield: Cushion plant cover is 20-100% and exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.

Rushland: Rush cover (excluding tussock-rushes) is 20-100% and exceeds that of any other growth form or bare ground. A tall, grass-like, often hollow-stemmed plant. Includes some species of *Juncus* and all species of *Apodasmia (Leptocarpus)*.

Herbfield: Herb cover is 20-100% and exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.

Seagrass meadows: Seagrasses are the sole marine representatives of Angiospermae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and are mapped.

Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain chlorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope. Macroalgal density, biomass and entrainment are classified and mapped.

Note NEMP classes of Forest and Scrub are considered terrestrial and have been included in the terrestrial Land Cover Data Base (LCDB) classifications.

[1]Additions to the NEMP classification.

SUBSTRATE (physical and zoogenic habitat)

Sediment texture is subjectively classified as: firm if you sink 0-2 cm, soft if you sink 2-5cm, very soft if you sink >5cm, or mobile - characterised by a rippled surface layer.

Artificial substrate: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates. Commonly sub-grouped into artificial: substrates (seawalls, bunds etc), boulder, cobble, gravel, or sand.

Rock field: Land in which the area of basement rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Cobble field: Land in which the area of unconsolidated cobbles (>20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Sand: Granular beach sand with a low mud content 0-10%. No conspicuous fines evident when sediment is disturbed.

Sand/Shell: Granular beach sand and shell with a low mud content 0-10%. No conspicuous fines evident.

Muddy sand (Moderate mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >10-25%). Granular when rubbed between the fingers, but with a smoother consistency than sand with a low mud fraction. Generally firm to walk on.

Muddy sand (HIgh mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >25-50%). Granular when rubbed between the fingers, but with a much smoother consistency than muddy sand with a moderate mud fraction. Often soft to walk on.

Sandy mud (Very high mud content): Mud/sand mixture dominated by mud (i.e. >50%-90% mud). Sediment rubbed between the fingers is primarily smooth/silken but retains a granular component. Sediments generally very soft and only firm if dried out or another component, e.g. gravel, prevents sinking.

Mud (>90% mud content): Mud dominated substrate (i.e. >90% mud). Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out or another component, e.g. gravel, prevents sinking.

Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.

Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.

Shell bank: Area that is dominated by dead shells

Table of modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.1m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Mobile sand	mS
		Firm shell/sand	fSS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Mobile muddy sand	mMS10
		Firm muddy shell/sand	fSS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Mobile muddy sand	mMS25
		Firm muddy shell/sand	fMSS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Mud (M)	Very high mud (>90%)	Firm mud	fM90
		Soft mud	sM90
		Very soft mud	vsM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Tubeworm reef	TUBE
Artificial Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aS BF
		Cobble field	aS CF
		Gravel field	aS GF
		Sand field	aS SF

Artificial Surfaces
- 1 Built-up Area (settlement)
- 2 Urban ParklandOpen Space
- 5 Transport Infrastructure
- 6 Surface Mines and Dumps

Bare or Lightly Vegetated Surfaces
- 10 Sand and Gravel
- 12 Landslide
- 16 Gravel and Rock

Water Bodies
- 20 Lake or Pond
- 21 River

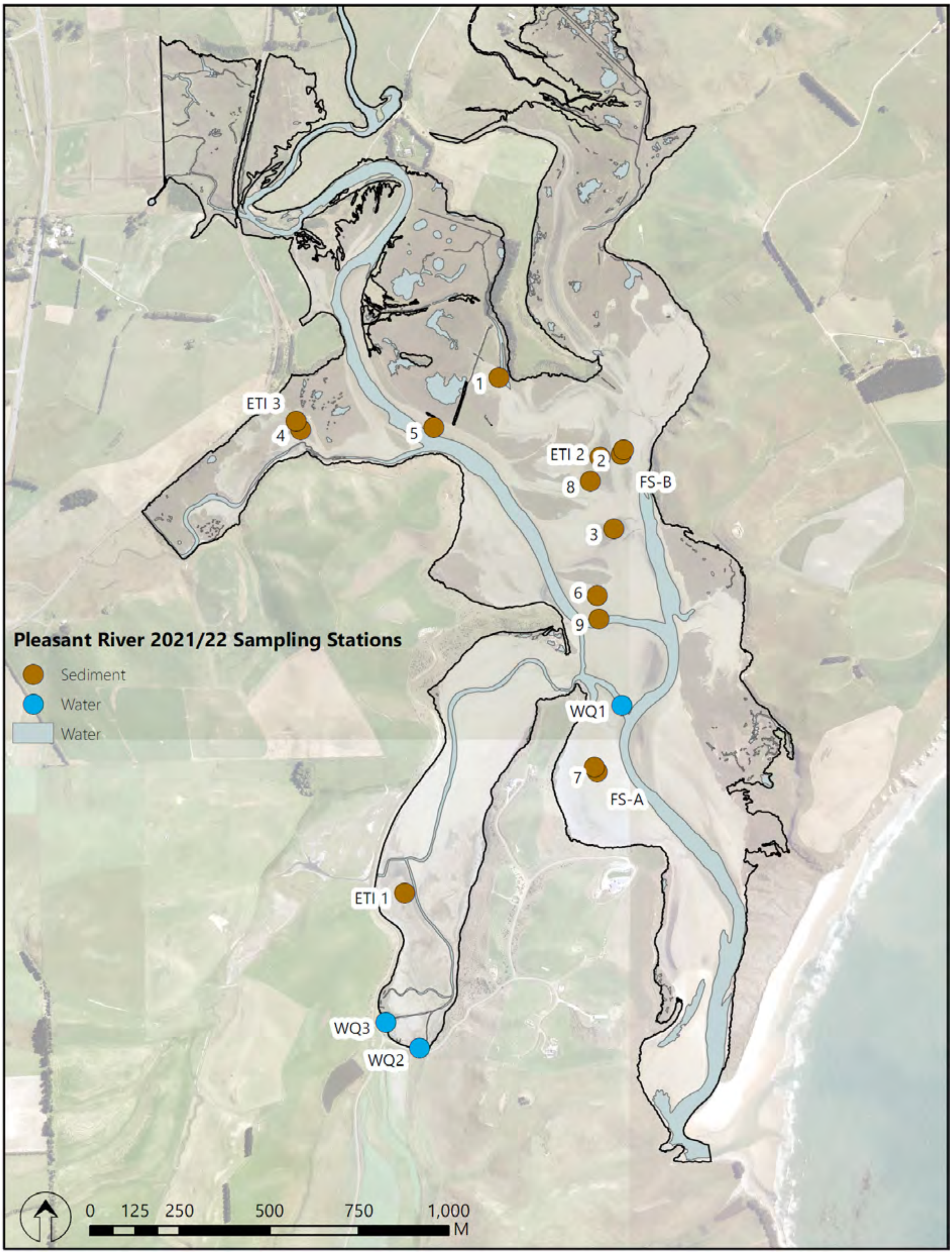
Cropland
- 30 Short-rotation Cropland
- 33 Orchard Vineyard & Other Perennial Crops

Grassland, Sedge and Saltmarsh
- 40 High Producing Exotic Grassland
- 41 Low Producing Grassland
- 45 Herbaceous Freshwater Vegetation
- 46 Herbaceous Saline Vegetation

Scrub and Shrubland
- 47 Flaxland
- 50 Fernland
- 51 Gorse and/or Broom
- 52 Manuka and/or Kanuka
- 54 Broadleaved Indigenous Hardwoods
- 56 Mixed Exotic Shrubland
- 58 Matagouri or Grey Scrub

Forest
- 64 Forest - Harvested
- 68 Deciduous Hardwoods
- 69 Indigenous Forest
- 71 Exotic Forest

APPENDIX 2. SEDIMENT SAMPLING STATIONS PLEASANT RIVER ESTUARY, NOVEMBER 2021



Station	Easting	Northing	Field Code	Subjective % mud	% mud	% sand	% gravel	aRPD (mm)
Sediment - 1	1422035.8	4953411.8	vssm50_90	50 to 90%	74.0	25.0	1.0	1
Sediment - 2	1422375.4	4953197.5	sms10_25	10 to 25%	45.6	53.8	0.5	3
Sediment - 3	1422355.7	4952990.3	fs0_10	<10%	12.3	87.3	0.4	10
Sediment - 4	1421481.4	4953267.2	vssm50_90	50 to 90%	72.8	27.1	< 0.1	1
Sediment - 5	1421853.2	4953273.5	sms10_25	10 to 25%	26.5	73.3	0.2	30
Sediment - 6	1422310.7	4952803.9	sms25_50	25 to 50%	68.5	30.9	0.6	5
Sediment - 7	1422309.7	4952313.7	sms25_50	25 to 50%	46.5	53.4	< 0.1	2
Sediment - 8	1422290.2	4953124	sms50_90	50 to 90%	41.9	57.7	0.4	nd.
Sediment - 9	1422315.2	4952740	sms25_50	25 to 50%	61.2	38.5	0.3	nd.
ETI 1	1421772	4951977	sms50_90	50 to 90%	81.1	17.9	1.1	1
ETI 2	1422317	4953190	vssm50_90	50 to 90%	63.0	36.6	0.4	0
ETI 3	1421470	4953291	sms50_90	50 to 90%	75.2	24.4	0.4	2
FS-A	1422302	4952327	sms25_50	25 to 50%	38.5	61.5	0.1	3
FS-B	1422384	4953211	sms25_50	25 to 50%	41.7	57.5	0.8	3

In general, there was good agreement between the subjective % mud content and measured % mud content, except for four samples, particularly around the 50% mud range. Sediment samples are collected from a surface scraping down to 20mm in some instances a fine layer of mud is observed on the sediment surface and could contribute to the higher mud contents observed in the laboratory analysed samples (see photos).

Sediment – 2

Sediment – 6

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	2783401 SPv1
Contact:	Keryn Roberts C/- Salt Ecology Limited 21 Mount Vernon Place Washington Valley Nelson 7010	**Date Received:**	30-Nov-2021
		Date Reported:	25-Jan-2022
		Quote No:	114513
		Order No:	
		Client Reference:	Broadscale- Pleasant River
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Ples-Otag-1 25-Nov-2021 12:50 pm	Ples-Otag-2 25-Nov-2021 1:30 pm	Ples-Otag-3 25-Nov-2021 2:30 pm	Ples-Otag-4 25-Nov-2021 6:00 pm	Ples-Otag-5 25-Nov-2021 12:40 pm
Lab Number:		2783401.1	2783401.2	2783401.3	2783401.4	2783401.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	54	72	81	68	69
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	1.0	0.5	0.4	< 0.1	0.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	25.0	53.8	87.3	27.1	73.3
Fraction < 63 µm*	g/100g dry wt	74.0	45.6	12.3	72.8	26.5

Sample Name:		Ples-Otag-6 25-Nov-2021 3:30 pm	Ples-Otag-7 25-Nov-2021 4:30 pm	Ples-Otag-8 25-Nov-2021 9:10 am	Ples-Otag-9 25-Nov-2021 3:00 pm	Ples-Otag-ETI-1 26-Nov-2021 6:30 pm
Lab Number:		2783401.6	2783401.7	2783401.8	2783401.9	2783401.10
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	57	66	63	63	44
Total Recoverable Phosphorus	mg/kg dry wt	-	-	-	-	780
Total Sulphur*‡	g/100g dry wt	-	-	-	-	0.83
Total Nitrogen*	g/100g dry wt	-	-	-	-	0.46
Total Organic Carbon*	g/100g dry wt	-	-	-	-	3.5
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.6	< 0.1	0.4	0.3	1.1
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	30.9	53.4	57.7	38.5	17.9
Fraction < 63 µm*	g/100g dry wt	68.5	46.5	41.9	61.2	81.1

Sample Name:		Ples-Otag-ETI-2 26-Nov-2021 5:00 pm	Ples-Otag-ETI-3 26-Nov-2021 6:00 pm			
Lab Number:		2783401.11	2783401.12			
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	62	67	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	530	550	-	-	-
Total Sulphur*‡	g/100g dry wt	0.42	0.29	-	-	-
Total Nitrogen*	g/100g dry wt	0.18	0.10	-	-	-
Total Organic Carbon*	g/100g dry wt	1.17	0.72	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.4	0.4	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	36.6	24.4	-	-	-
Fraction < 63 µm*	g/100g dry wt	63.0	75.2	-	-	-

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked * or any comments and interpretations, which are not accredited.

Analyst's Comments

‡ Analysis subcontracted to an external provider. Refer to the Summary of Methods section for more details.

Appendix No.1 - SGS Report

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	10-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	10-12
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-12
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	10-12
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	10-12
Total Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g dry wt	10-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	10-12
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	10-12
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-12
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 08-Dec-2021 and 25-Jan-2022. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 3. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multi-metric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5-part multi-metric OMBT, modified for NZ estuary types, is presented in the WFD-UKTAG (2014) with additions described in Plew et al. (2020), and is paraphrased below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of *mud, muddy sand, sandy mud, sand, stony mud and mussel beds*. Areas which are judged unsuitable for algal blooms, e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. PERCENTAGE COVER OF THE AVAILABLE INTERTIDAL HABITAT (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. TOTAL EXTENT OF AREA COVERED BY ALGAL MATS (AFFECTED AREA (AA)) OR AFFECTED AREA AS A PERCENTAGE OF THE AIH (AA/AIH, %).

The affected area represents the total area of macroalgal cover in hectares. In large water bodies, small patches of macroalgal coverage relative to the estuary size would result in the total percent cover across the AIH remaining within the 'high' or 'good' status. While the affected area may be relatively small when compared to estuary size the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities (WFD-UKTAG 2014). In order to account for this, the OMBT included an additional metric; the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse-case scenario.

3. BIOMASS OF AIH ($G.M^{-2}$).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within ±5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. BIOMASS OF AA ($G.M^{-2}$).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. PRESENCE OF ENTRAINED ALGAE (% OF QUADRATS).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool. All the metrics are equally weighted and combined within the multi-metric, in order to best describe the changes in the nature and degree of opportunistic macroalgae growth on sedimentary shores due to nutrient pressure.

TIMING

The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March). However, peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification, e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

SUITABLE LOCATIONS

The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing intermittently closed and open estuaries (ICOEs) due to the particular challenges in setting suitable reference conditions for these water bodies.

DERIVATION OF THRESHOLD VALUES

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

REFERENCE THRESHOLDS

A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g/m^2 wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

CLASS THRESHOLDS FOR PERCENT COVER

High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

Table A1. The final face value thresholds and metrics for levels of the ecological quality status. These thresholds have been recently revised for New Zealand (see Table A3).

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^{-2}) of AIH[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).
Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

CLASS THRESHOLDS FOR BIOMASS

Class boundaries for biomass values were derived from DETR (2001) recommendations that <500g.m^{-2} wet weight was an acceptable level above the reference level of <100g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500g.m^{-2} represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500gm^{-2} but less than 1,000g.m^{-2} would lead to a classification of Moderate quality status at best but would depend on the percentage of the AIH covered. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003). **Thresholds applied in the current study are described and presented in Table A3.**

THRESHOLDS FOR ENTRAINED ALGAE

Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently, the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

EQR CALCULATION

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Rating** score (EQR).
The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the categories in Table A1. The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 - where Total % cover = Sum of [(patch size) / 100] x average % cover for patch
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH (g.m^{-2}) = Total biomass / AIH - where Total biomass = Sum of (patch size x average biomass for the patch)
- Biomass of Affected Area (g.m^{-2}) = Total biomass / AA - where Total biomass = Sum of (patch size x average biomass for the patch)
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A2).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

*Final Equidistant Index score = Upper Equidistant range value – ([Face Value - Upper Face value range] * (Equidistant class range / Face Value Class Range)).*

Table A2 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range. Note: the table is “simplified” with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999’.

Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

Metric	Quality status	Face value ranges			Equidistant class range values		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g.m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g.m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

The final EQR score is calculated as the average of equidistant metric scores.

A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

Biomass thresholds included in the OMBT were lowered for use in NZ by Plew et al. (2020) based on unpublished data from >25 shallow well-flushed intertidal NZ estuaries (Robertson et al. 2016b) and the results from similar estuaries in California. Sutula et al. (2014) reported that in eight Californian estuaries, macroalgal biomass of 1450g.m^{-2} wet weight, total organic carbon of 1.1% and sediment total nitrogen of 0.1% were thresholds associated with anoxic conditions near the surface (aRPD < 10 mm). Green et al. (2014) reported significant and rapid negative effects on benthic invertebrate abundance and species richness at macroalgal abundances as low as 840–930g.m^{-2} wet weight in two Californian estuaries. McLaughlin et al. (2014) reviewed Californian biomass thresholds and found the elimination of surface deposit feeders in the range of 700–800g.m^{-2}. As the Californian results were consistent with NZ findings, the latter thresholds were used to lower the OMBT good/moderate threshold from ≤500 to ≤200g.m^{-2}, the moderate/poor threshold from ≤1000 to ≤500gm^{-2} and the poor/bad threshold from >3000 to >1450g.m^{-2}. These thresholds are considered to provide an early warning of nutrient related impacts in NZ prior to the establishment of adverse enrichment conditions that are likely difficult to reverse.

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Table A3. Revised final face value thresholds and metrics for levels of the ecological quality status used in the current assessment.

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^{-2}) of AIH[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

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APPENDIX 4. INFORMATION SUPPORTING RATINGS IN THE REPORT

SEDIMENT MUD CONTENT

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more sticky and cohesive, and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon, and sediment-bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations and, on intertidal flats of estuaries, can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

APPARENT REDOX POTENTIAL DISCONTINUITY (ARPD)

aRPD depth, the visually apparent transition between oxygenated sediments near the surface and deeper more anoxic sediments, is a primary estuary condition indicator as it is a direct measure of time integrated sediment oxygenation. Knowing if the aRPD is close to the surface is important for three main reasons:

The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species. The tendency for sediments to become anoxic is much greater if the sediments are muddy. Anoxic sediments contain toxic sulphides and support very little aquatic life. As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, become released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (i.e. >3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

OPPORTUNISTIC MACROALGAE

The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with high mud and low oxygen conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014; Robertson et al 2016a,b; Zeldis et al. 2017), with results combined with those of other indicators to determine overall condition.

SEAGRASS

Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column. It is also susceptible to degraded sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent are likely to indicate an increase in these types of pressures. The assessment metric used is the percent change from baseline measurements.

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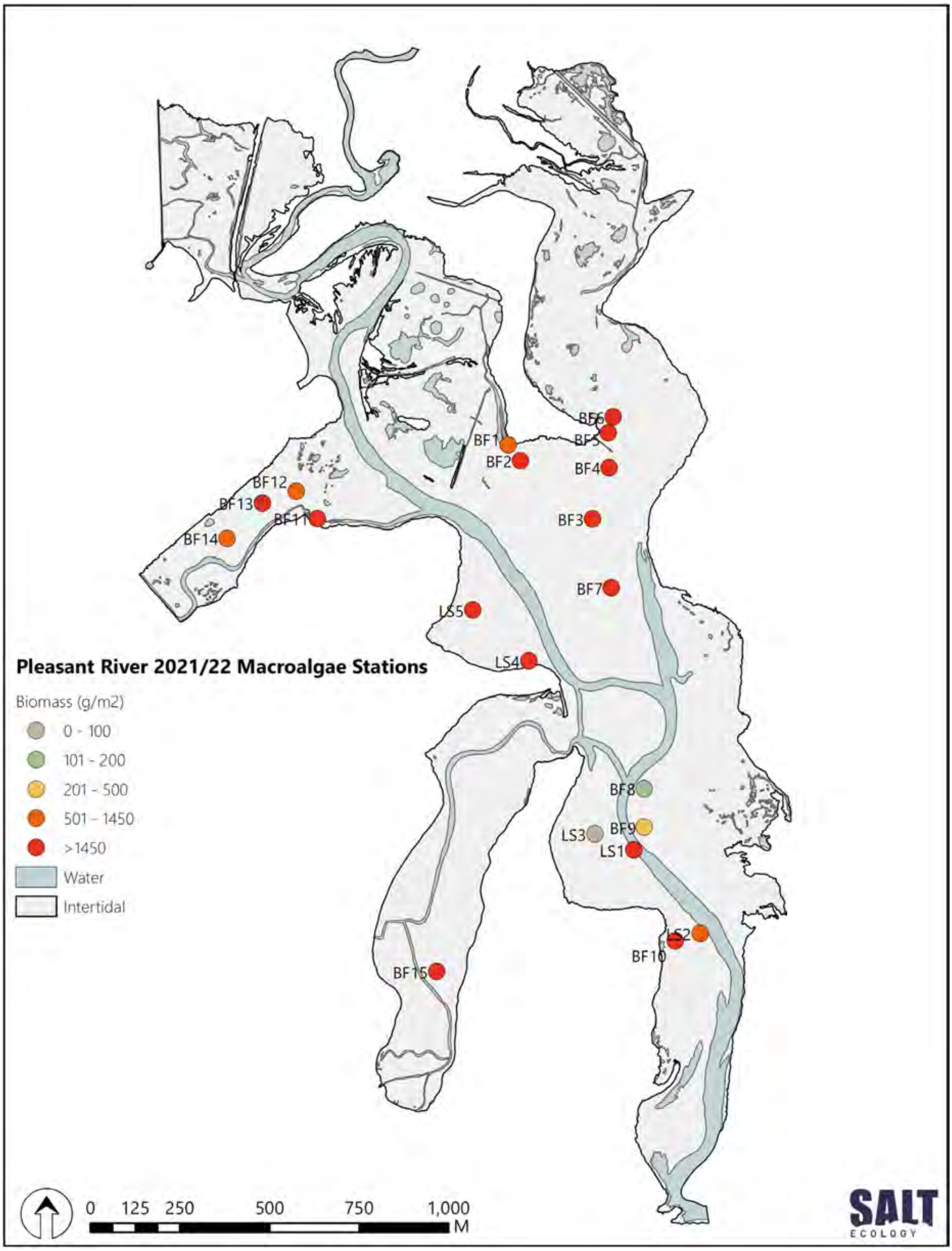
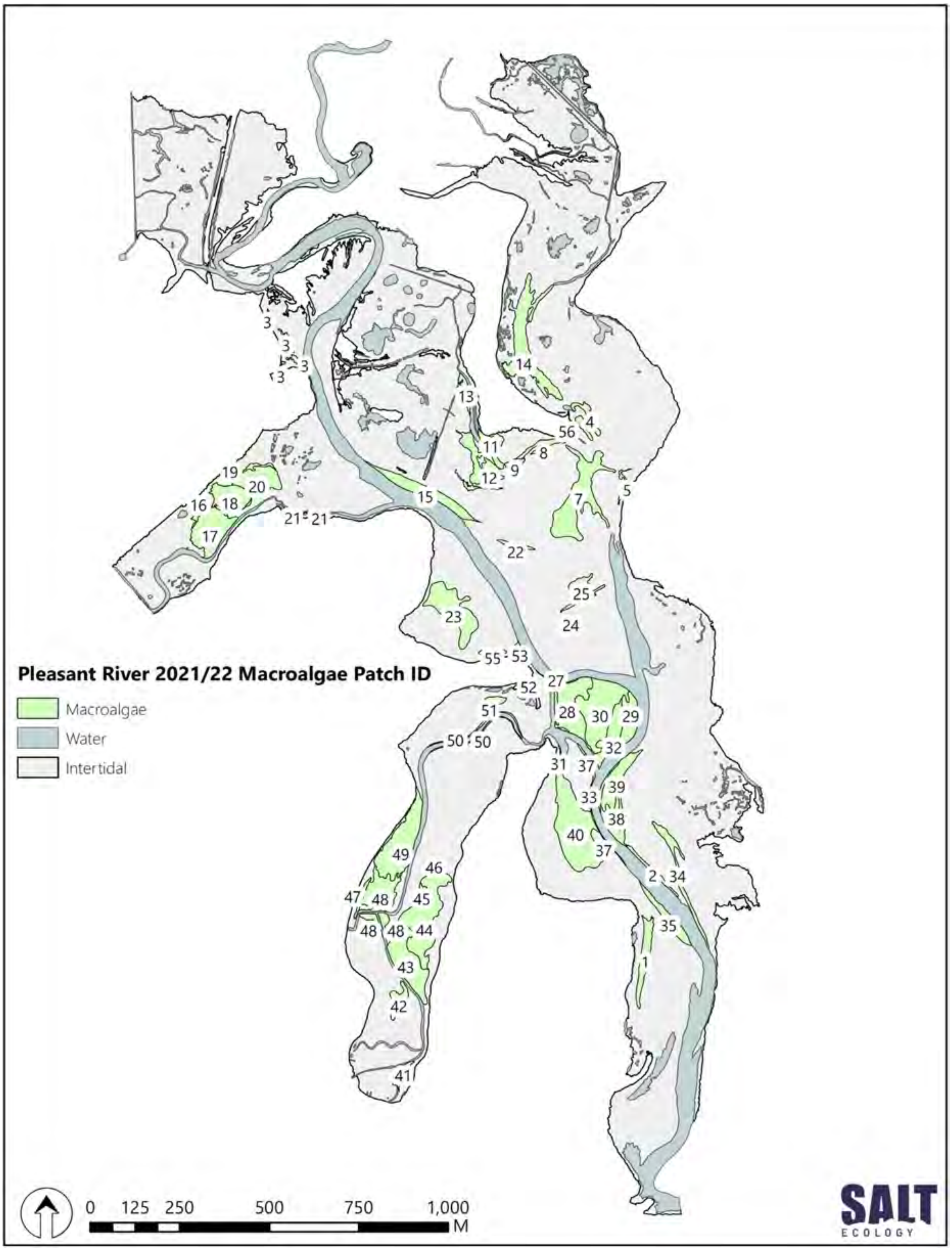
APPENDIX 5: MACROALGAL BIOMASS STATIONS & OMBT, PLEASANT RIVER ESTUARY



Macroalgal patch ID for the OMBT-EQR



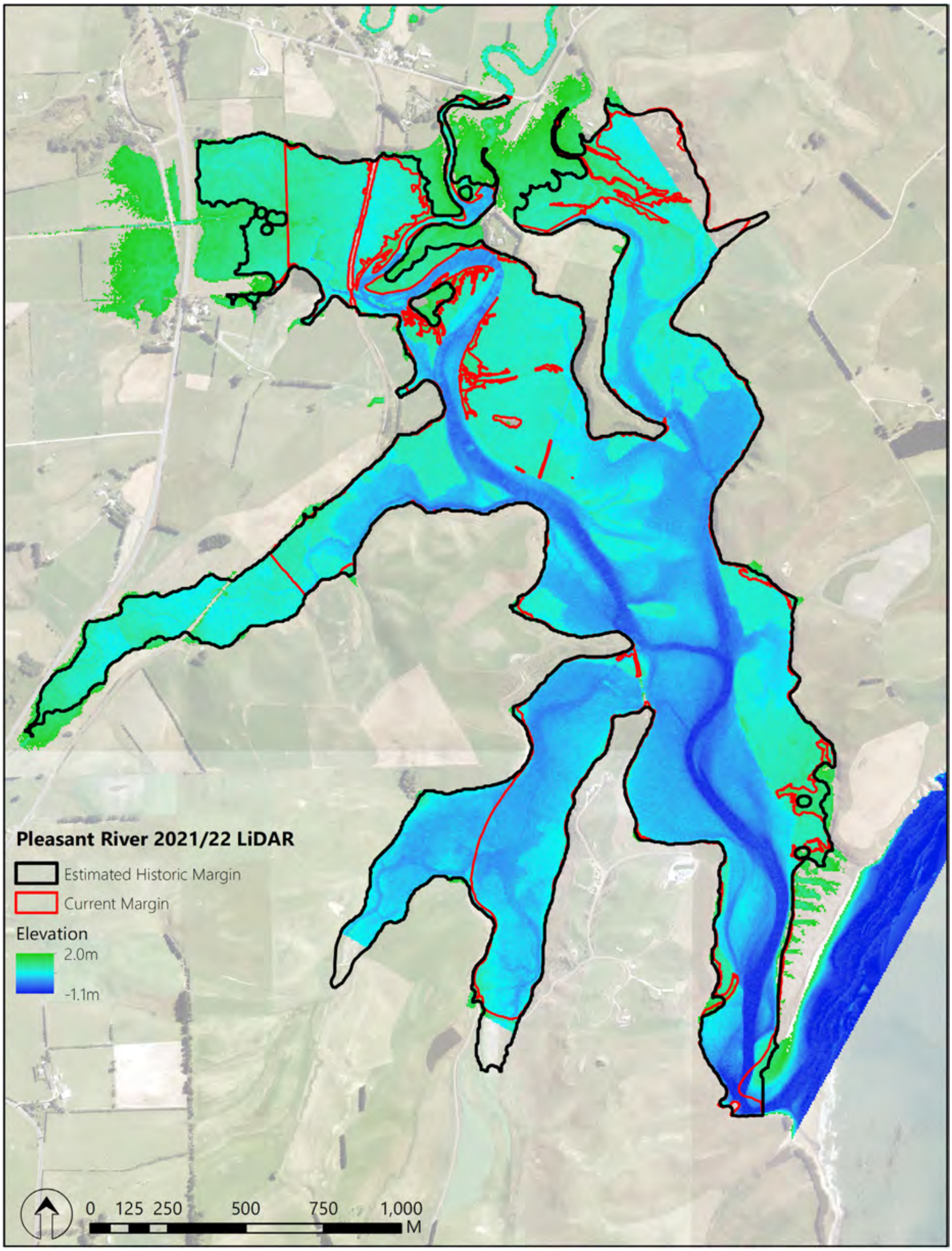
Macroalgal patch information used in the calculation of the OMBT-EQR

PatchID	Dominant Species	Sub-dominant spcies	% Cover	Percent Cover Category	Biomass (g/m^2)	Biomass Category	Entrained	Substrate	Area (ha)
1	*Agarophyton* spp.	*Ulva* spp.	95	Complete (>90%)	3400	Very high (>1450)	0	sSM	0.50
2	*Agarophyton* spp.		10	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fS	0.16
3	*Agarophyton* spp.	*Ulva* spp.	80	Dense (70 to <90%)	2500	Very high (>1450)	1	vsSM	0.16
4	*Ulva* spp.	*Agarophyton* spp.	90	Complete (>90%)	3000	Very high (>1450)	0	sSM	0.18
5	*Agarophyton* spp.		25	Sparse (10 to <30%)	1000	High (501 - 1450)	1	fMS10	0.07
6	*Ulva* spp.	*Agarophyton* spp.	25	Sparse (10 to <30%)	100	Very low (1 - 100)	0	sSM	0.01
7	*Ulva* spp.	*Agarophyton* spp.	100	Complete (>90%)	7560	Very high (>1450)	1	sSM	1.59
8	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1000	High (501 - 1450)	0	sSM	0.20
9	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1500	Very high (>1450)	0	sMS25	0.10
10	*Ulva* spp.		40	Low-Moderate (30 to <50%)	600	High (501 - 1450)	0	sSM	0.07
11	*Agarophyton* spp.	*Ulva* spp.	69	High-Moderate (50 to <70%)	1480	Very high (>1450)	1	sSM	0.26
12	*Ulva* spp.	*Agarophyton* spp.	20	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fMS10	0.78
13	*Agarophyton* spp.	*Ulva* spp.	50	High-Moderate (50 to <70%)	1000	High (501 - 1450)	1	sSM	0.14
14	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1300	High (501 - 1450)	1	sSM	1.52
15	*Agarophyton* spp.		1	Very sparse (1 to <10%)	10	Very low (1 - 100)	0	fMS10	0.76
16	*Ulva* spp.	*Agarophyton* spp.	35	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	1	vsSM	0.06
17	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1000	High (501 - 1450)	1	vsSM	1.04
18	*Ulva* spp.	*Agarophyton* spp.	90	Complete (>90%)	1600	Very high (>1450)	1	vsSM	0.67
19	*Ulva* spp.	*Agarophyton* spp.	50	High-Moderate (50 to <70%)	700	High (501 - 1450)	1	vsSM	0.11
20	*Ulva* spp.	*Agarophyton* spp.	100	Complete (>90%)	1200	High (501 - 1450)	1	vsSM	0.75
21	*Agarophyton* spp.		85	Dense (70 to <90%)	5680	Very high (>1450)	1	vsSM	0.03
22	*Agarophyton* spp.	*Ulva* spp.	30	Low-Moderate (30 to <50%)	200	Low (101 - 200)	0	sMS25	0.09
23	*Ulva* spp.	*Agarophyton* spp.	80	Dense (70 to <90%)	2240	Very high (>1450)	1	sSM	1.17
24	*Agarophyton* spp.		10	Sparse (10 to <30%)	200	Low (101 - 200)	0	sSM	0.04
25	*Ulva* spp.	*Agarophyton* spp.	75	Dense (70 to <90%)	2000	Very high (>1450)	0	sMS25	0.28
26	*Ulva* spp.		5	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	fMS10	0.02
27	*Ulva* spp.	*Agarophyton* spp.	11	Sparse (10 to <30%)	80	Very low (1 - 100)	0	fMS10	0.12
28	*Agarophyton* spp.		1	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	fMS10	1.13
29	*Agarophyton* spp.	*Ulva* spp.	20	Sparse (10 to <30%)	350	Moderate (201 - 500)	1	fMS10	0.55
30	*Agarophyton* spp.		1	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	fS	1.54
31	*Ulva* spp.		10	Sparse (10 to <30%)	40	Very low (1 - 100)	0	fMS10	0.03
32	*Agarophyton* spp.		10	Sparse (10 to <30%)	200	Low (101 - 200)	1	fMS10	0.61
33	*Agarophyton* spp.	*Ulva* spp.	80	Dense (70 to <90%)	2500	Very high (>1450)	1	sSM	0.07
34	*Agarophyton* spp.		30	Low-Moderate (30 to <50%)	350	Moderate (201 - 500)	0	fMS10	0.42
35	*Agarophyton* spp.	*Ulva* spp.	12	Sparse (10 to <30%)	1280	High (501 - 1450)	1	fS	0.40
36	*Agarophyton* spp.		10	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fMS10	0.01
37	*Agarophyton* spp.		20	Sparse (10 to <30%)	1840	Very high (>1450)	0	fMS10	0.05
37	*Agarophyton* spp.		20	Sparse (10 to <30%)	1840	Very high (>1450)	0	fS	0.04
38	*Agarophyton* spp.	*Ulva* spp.	26	Sparse (10 to <30%)	250	Moderate (201 - 500)	0	fMS10	0.11
39	*Agarophyton* spp.	*Ulva* spp.	12	Sparse (10 to <30%)	110	Low (101 - 200)	0	fMS10	0.91
40	*Agarophyton* spp.		10	Sparse (10 to <30%)	90	Very low (1 - 100)	1	sMS25	2.17
41	*Ulva* spp.		30	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	0	vsSM	0.15
42	*Ulva* spp.		50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	vsSM	0.24
43	*Ulva* spp.	*Agarophyton* spp.	80	Dense (70 to <90%)	4240	Very high (>1450)	0	vsSM	1.17
44	*Ulva* spp.	*Agarophyton* spp.	35	Low-Moderate (30 to <50%)	300	Moderate (201 - 500)	0	fSM	1.61
44	*Ulva* spp.	*Agarophyton* spp.	35	Low-Moderate (30 to <50%)	300	Moderate (201 - 500)	0	fSM	0.01
45	*Ulva* spp.	*Agarophyton* spp.	80	Dense (70 to <90%)	3000	Very high (>1450)	0	vsSM	0.11
46	*Agarophyton* spp.	*Ulva* spp.	50	High-Moderate (50 to <70%)	3000	Very high (>1450)	0	fSM	0.04
47	*Ulva* spp.		90	Complete (>90%)	1500	Very high (>1450)	0	sSM	0.09
48	*Ulva* spp.	*Agarophyton* spp.	85	Dense (70 to <90%)	1500	Very high (>1450)	0	vsSM	1.00
49	Unspecified Macroalgae	*Agarophyton* spp.	2	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	sMS25	1.46
50	*Agarophyton* spp.		10	Sparse (10 to <30%)	1000	High (501 - 1450)	1	sMS25	0.20
51	*Agarophyton* spp.		5	Very sparse (1 to <10%)	40	Very low (1 - 100)	0	sMS25	0.22
52	*Agarophyton* spp.	*Ulva* spp.	11	Sparse (10 to <30%)	80	Very low (1 - 100)	0	fMS10	0.01
53	*Agarophyton* spp.		10	Sparse (10 to <30%)	100	Very low (1 - 100)	0	fMS10 shel	0.08
54	*Agarophyton* spp.		40	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	1	sSM	0.01
55	*Agarophyton* spp.		100	Complete (>90%)	1680	Very high (>1450)	1	sSM	0.12
56	*Ulva* spp.	*Agarophyton* spp.	95	Complete (>90%)	1840	Very high (>1450)	1	fMS10	0.00
56	*Ulva* spp.	*Agarophyton* spp.	95	Complete (>90%)	1840	Very high (>1450)	1	sSM	0.10

APPENDIX 6: DOMINANT SALT MARSH SPECIES IN PLEASANT RIVER ESTUARY

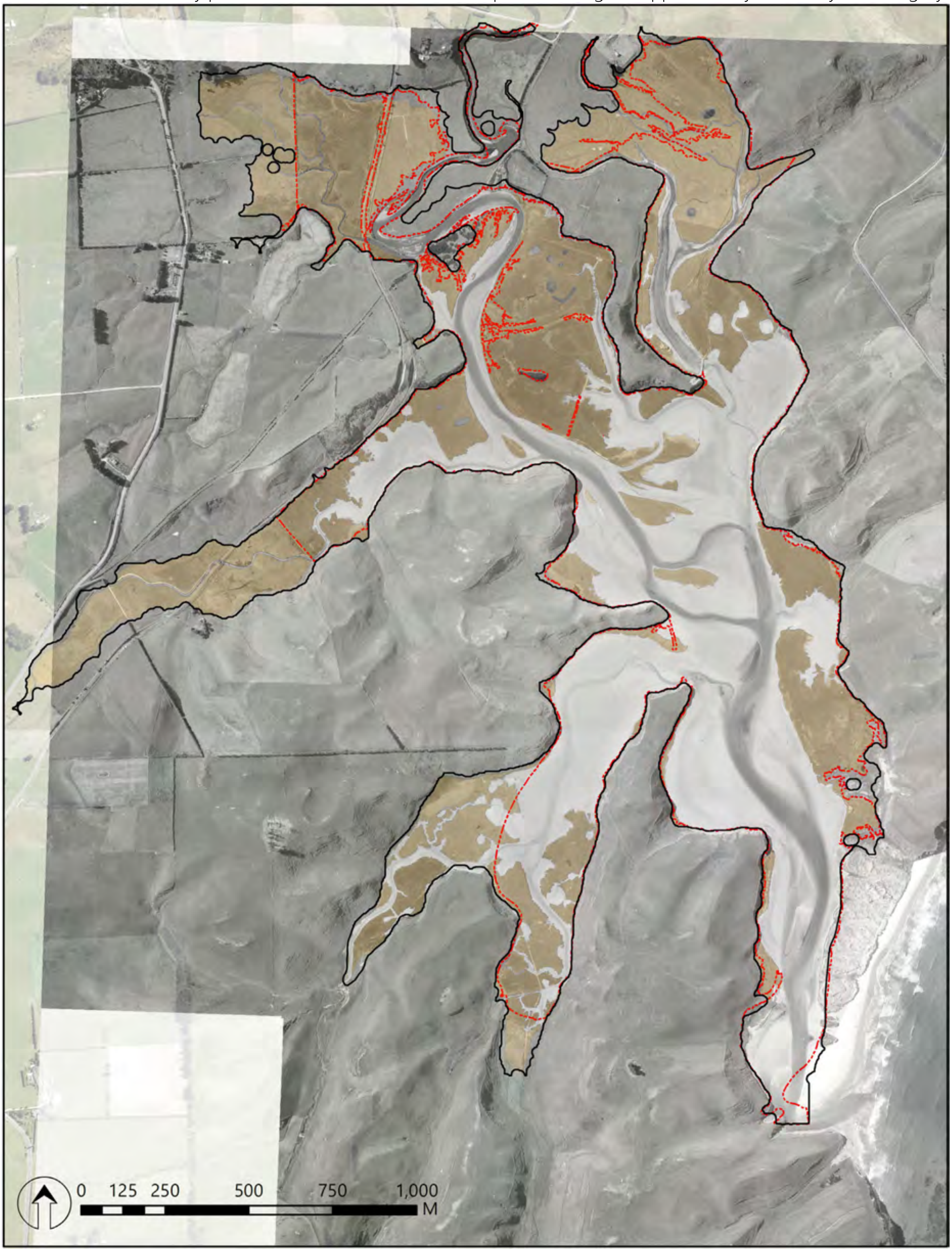
SubClass	Dominant species	Sub-dominant species 1	Sub-dominant species 2	Area (Ha)	% Salt marsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	0.07	0.08
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)		0.02	0.03
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)		0.05	0.06
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	*Ulex europaeus* (Gorse)	0.01	0.01
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)			0.12	0.14
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Poa cita* (Silver tussock)	*Apodasmia similis* (Jointed wirerush)	0.02	0.03
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)	*Apodasmia similis* (Jointed wirerush)	0.17	0.21
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)		0.05	0.06
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.18	0.22
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	0.01	0.01
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Stipa stipoides*	*Festuca arundinacea* (Tall fescue)	0.04	0.05
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Ulex europaeus* (Gorse)		0.03	0.04
Tussockland	*Poa cita* (Silver tussock)	*Sarcocornia quinqueflora* (Glasswort)		0.00	0.00
Tussockland	*Poa cita* (Silver tussock)	*Selliera radicans* (Remuremu)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.05	0.06
Sedgeland	*Schoenoplectus pungens* (Three square)			0.19	0.24
Sedgeland	*Schoenoplectus pungens* (Three square)	*Samolus repens* (Primrose)	*Apodasmia similis* (Jointed wirerush)	0.01	0.01
Sedgeland	*Schoenoplectus pungens* (Three square)	*Samolus repens* (Primrose)		0.01	0.01
Sedgeland	*Schoenoplectus pungens* (Three square)	*Sarcocornia quinqueflora* (Glasswort)		0.02	0.02
Grassland	*Festuca arundinacea* (Tall fescue)	*Atriplex prostrata* (Orache, Creeping saltbush)		0.01	0.02
Grassland	*Festuca arundinacea* (Tall fescue)	*Ficinia nodosa* (Knobby clubrush)	*Poa cita* (Silver tussock)	0.07	0.08
Grassland	*Festuca arundinacea* (Tall fescue)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	0.20	0.25
Grassland	*Festuca arundinacea* (Tall fescue)	*Ulex europaeus* (Gorse)		0.04	0.05
Rushland	*Apodasmia similis* (Jointed wirerush)			0.53	0.65
Rushland	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		0.60	0.75
Rushland	*Ficinia nodosa* (Knobby clubrush)			0.00	0.00
Rushland	*Ficinia nodosa* (Knobby clubrush)	*Thyridia repens* (New Zealand musk)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.01	0.02
Herbfield	*Cotula coronopifolia* (Bachelor's button)			0.08	0.10
Herbfield	*Leptinella dioica*			0.01	0.01
Herbfield	*Leptinella dioica*	*Selliera radicans* (Remuremu)		0.02	0.03
Herbfield	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)		0.10	0.13
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.10	0.12
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	*Selliera radicans* (Remuremu)	0.06	0.07
Herbfield	*Sarcocornia quinqueflora* (Glasswort)			14.09	17.52
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)		0.01	0.02
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Suaeda novaezelandiae* (Sea blite)	0.00	0.00
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.76	0.94
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)		0.67	0.83
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	0.44	0.55
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Atriplex prostrata* (Orache, Creeping saltbush)	6.15	7.65
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Leptinella dioica*	0.30	0.37
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Lycium ferocissimum* (Boxthorn)	0.07	0.09
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)		36.23	45.06
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	0.11	0.14
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	5.88	7.31
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Suaeda novaezelandiae* (Sea blite)	2.24	2.79
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.24	0.30
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Disphyma australe* (NZ Ice Plant, Horokaka)	0.00	0.00
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)		2.74	3.41
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Selliera radicans* (Remuremu)	0.67	0.84
Herbfield	*Selliera radicans* (Remuremu)	*Atriplex prostrata* (Orache, Creeping saltbush)	*Sarcocornia quinqueflora* (Glasswort)	0.04	0.05
Herbfield	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Samolus repens* (Primrose)	0.07	0.09
Herbfield	*Selliera radicans* (Remuremu)	*Leptinella dioica*	*Sarcocornia quinqueflora* (Glasswort)	0.22	0.27
Herbfield	*Selliera radicans* (Remuremu)			0.86	1.07
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.25	0.32
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)		3.48	4.33
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	0.79	0.99
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.31	0.39
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	0.85	1.06
Herbfield	*Suaeda novaezelandiae* (Sea blite)			0.00	0.01
Herbfield	*Suaeda novaezelandiae* (Sea blite)	*Sarcocornia quinqueflora* (Glasswort)		0.00	0.00
Herbfield	*Thyridia repens* (New Zealand musk)			0.04	0.05
Grand Total				**80.4**	**100**

APPENDIX 7: HISTORIC MARGIN ESTIMATED FROM LIDAR AND AERIAL IMAGERY



APPENDIX 8: HISTORIC SALT MARSH EXTENT ESTIMATED FROM LIDAR AND AERIAL IMAGERY

Historic salt marsh digitised from 1958 aerial image (source: retrolens.co.nz). Where reclamation or margin modification was already present salt marsh extent was extrapolated using the upper estuary boundary and imagery.



APPENDIX 9: RAW SEDIMENT AND MACROFAUNA DATA

Sediment data and macrofauna indices used for ETI calculation.

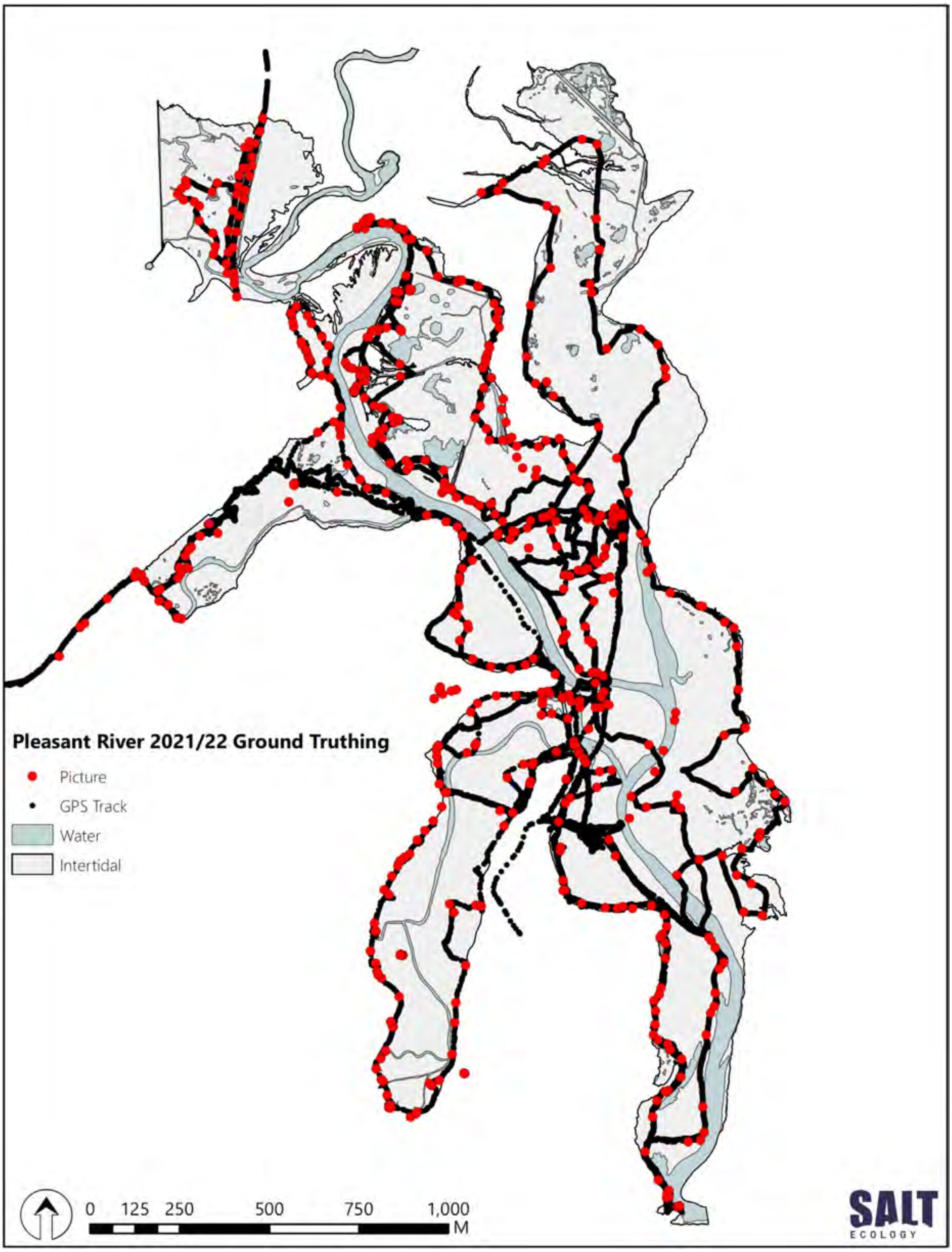
Parameter	Unit	PLES-OTAG ETI - 1	PLES-OTAG ETI - 2	PLES-OTAG ETI - 3
Sediment Chemistry				
Total Phosphorus (TP)	mg/kg dry wt	780	530	550
Total Sulfur (TS)	g/100g dry wt	0.83	0.42	0.29
Total Nitrogen (TN)	g/100g dry wt	0.46	0.18	0.10
Total Organic Carbon (TOC)	g/100g dry wt	3.50	1.17	0.72
Gravel (≥2mm)	g/100g dry wt	1.1	0.4	0.4
Sand (≥63mm to <2mm)	g/100g dry wt	17.9	36.6	24.4
Mud (≤63mm)	g/100g dry wt	81.1	63.0	75.2
aRPD	mm	1	0	2
Macrofauna indices				
AZTI Marine Biotic index	no unit	4.50	5.29	nd.
Overall Abundance	no unit	279	1462	nd.
Overall Diversity	no unit	7	17	nd.

*nd. = no data

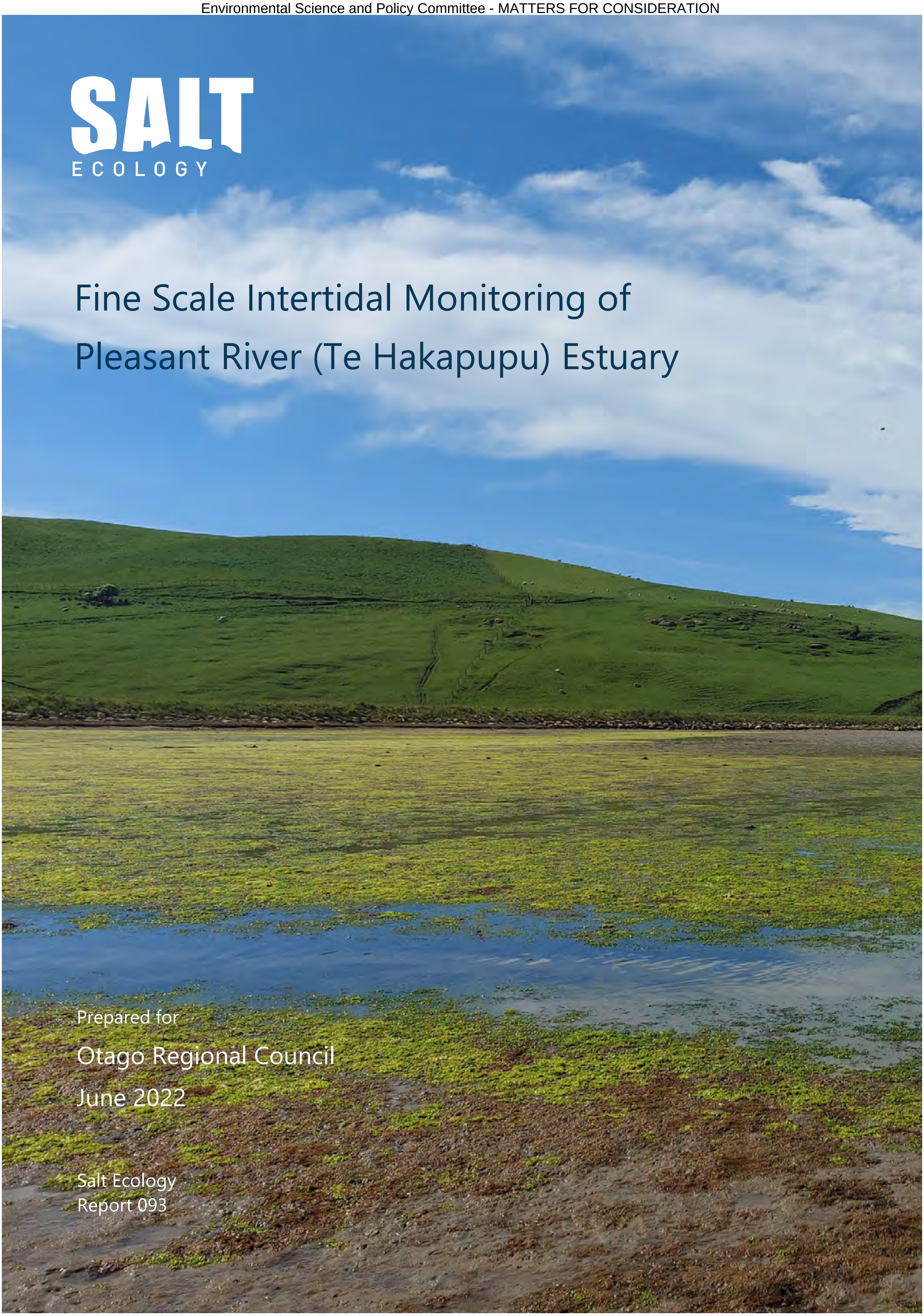
Raw macrofauna data. EG refers to ecological sensitivity group used to calculate the AZTI Marine Biotic index.

Main group	Taxa	Habitat	EG	PLES-OTAG ETI-1	PLES-OTAG ETI-2
Amphipoda	*Paracalliope novizealandiae*	Infauna	I	42	26
Amphipoda	*Paracorophium excavatum*	Infauna	IV	2	
Amphipoda	*Paramoera chevreuxi*	Infauna	II		2
Amphipoda	*Parawaldeckia kidderi*	Infauna	II		10
Bivalvia	*Arthritica* sp. 5	Infauna	III	4	99
Decapoda	*Hemiplax hirtipes*	Infauna	III		1
Gastropoda	*Cominella glandiformis*	Epibiota	III		1
Gastropoda	*Micrelenchus huttonii*	Epibiota	NA		1
Gastropoda	*Notoacmea scapha*	Epibiota	II		1
Gastropoda	*Zeacumantus subcarinatus*	Epibiota	II	100	411
Nemertea	*Nemertea*	Infauna	III		3
Oligochaeta	*Naididae*	Infauna	V	56	
Polychaeta	*Boccardia syrtis*	Infauna	II		32
Polychaeta	*Capitella cf. capitata*	Infauna	V	74	841
Polychaeta	*Paradoneis lyra*	Infauna	III		2
Polychaeta	*Perinereis vallata*	Infauna	III		1
Polychaeta	*Platynereis sp.*	Infauna	III		3
Polychaeta	*Scolecolepides benhami*	Infauna	IV	1	23
Polychaeta	*Scoloplos cylindrifer*	Infauna	I		5

APPENDIX 10: GROUND-TRUTHING IN PLEASANT RIVER ESTUARY




SALT
ECOLOGY



SALT
ECOLOGY

Fine Scale Intertidal Monitoring of Pleasant River (Te Hakapupu) Estuary

Prepared for

Otago Regional Council

June 2022

Salt Ecology
Report 093

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Fine Scale Intertidal Monitoring of Pleasant River (Te Hakapupu) Estuary

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for

Otago Regional Council
June 2022

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For the environment
Mō te taiao

GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value (for ANZG sediment quality)
ETI	Estuary Trophic Index
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of Environment (Monitoring)
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
Zn	Zinc

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SUMMARY

As part of its State of the Environment programme, Otago Regional Council (ORC) monitors the ecological condition of significant estuaries in its region. This report describes the first of three planned annual baseline ecological monitoring and sedimentation surveys in Pleasant River (Te Hakapupu) Estuary, which was conducted in November 2021. The estuary is of particular interest to the local community and ORC due to concerns regarding a deterioration in its condition in recent years. The survey followed the 'fine scale' approach described in New Zealand's National Estuary Monitoring Protocol, with 'sediment plates' installed at the time of the survey to enable future sedimentation monitoring. Monitoring was conducted at two sites, and results assessed against condition rating criteria for estuary health, as per the Table below.

KEY FINDINGS

- Both sites had a moderate to high sediment mud content and showed mild to moderate symptoms of enrichment in terms of three trophic state indicators (aRPD, %TOC and TN in the Table below). These attributes are consistent with catchment run-off, in part reflecting catchment land uses dominated by pasture and exotic forestry.
- An analysis of trace contaminants (mainly trace metals) provided no evidence of any significant anthropogenic contaminant sources in the catchment.
- The estuary has a diverse mix of macrofauna species that is greater than most other estuaries in the Otago region, and stands out as having particularly high organism abundances. The most abundant organisms included some relatively hardy taxa that can thrive in enriched or disturbed conditions, which contributed to moderately-elevated values of the ecological health index AMBI.

Considering the sediment quality and biological assessment collectively, the fine scale survey results suggest that the two monitored sites in Pleasant River Estuary are exhibiting symptoms of mild stress, although have not reached a 'tipping' point whereby multiple indicators are showing signs of degradation. By contrast, the results of the broad scale habitat mapping survey, which was undertaken concurrent with the fine scale assessment, revealed that some areas of the upper estuary, as well as side arms, are exhibiting symptoms of excess nutrient enrichment; i.e. eutrophication. Although not being situated in the worst-affected parts of the estuary, the fine scale sites are representative of the main tidal flats, and are suitable for long-term monitoring.

Summary of estuary condition based on key indicators

Site	Mud %	aRPD mm	TN mg/kg	TP mg/kg	TOC %	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Hg mg/kg	Ni mg/kg	Zn mg/kg	AMBI na
A	38.5	3	900	483	0.69	4.5	0.040	8.7	2.8	3.7	< 0.02	5.1	22.3	3.6
B	41.7	3	450*	440	0.40	4.3	0.039	7.7	2.4	3.2	< 0.02	4.5	23.3	3.5

** Sample mean includes values below lab detection limits*
< All values below lab detection limit

Condition rating key:

Very Good	Good	Fair	Poor

RECOMMENDATIONS

- Complete two additional annual surveys as planned in the summers of 2022/23 and 2023/24. Together with data gathered from changes in sediment plate depth, the work will provide a comprehensive baseline for the long-term monitoring of ecological health in Pleasant River Estuary.
- Compile data summaries after the second survey, but defer the next comprehensive analysis and reporting until completion of the 3-year baseline, at which time the management implications of the survey findings should be considered.

1. INTRODUCTION

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). The NEMP is intended to provide resource managers nationally with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results establish a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

One of the key additional methods that has been put in place subsequent to the NEMP being developed is 'sediment plate' monitoring. This component typically involves an annual assessment of patterns of sediment accretion and erosion in estuaries, based on changes in sediment depth over buried concrete pavers. Sediment plate monitoring stations are often established at NEMP fine scale sites, or nearby. In addition to providing information on patterns of sediment accretion and erosion, sediment plate monitoring aids interpretation of physical and biological changes at fine scale sites.

Monitoring of selected estuaries in the Otago region has been undertaken using the above methods for several years, with key locations being Shag River, Waikouaiti, Kaikorai, Tokomairiro, Blueskin Bay and Catlins estuaries. ORC has recently expanded its SOE monitoring programme and in the summer of 2021/2022 added several other estuaries, one of which was Pleasant River (Te Hakapupu) Estuary in North Otago (Fig. 1). Pleasant River Estuary is of particular interest to the local community and ORC due to concerns regarding a deterioration in its condition in recent years.

In November 2021, Salt Ecology undertook a NEMP broad scale and fine scale survey in Pleasant River Estuary, and installed sediment plates for future sedimentation monitoring. This report describes the methods and results of the fine scale and sediment plate components, with the broad scale work described by Roberts et al. (2022). Results of the present survey are discussed in the context of existing knowledge and historical influences on Pleasant River Estuary and in relation to various criteria for assessing estuary health. The survey is intended as the first of three consecutive annual baseline surveys using the fine scale and sediment plate approach.

Fig. 1. Location of Pleasant River (Te Hakapupu) Estuary.

2. BACKGROUND TO PLEASANT RIVER ESTUARY

The following background information on Pleasant River Estuary has been adapted from Roberts et al. (2022) and incorporates the findings of the broad scale habitat mapping survey described in that report.

Pleasant River Estuary is a medium sized (216ha) estuarine system, defined as a shallow, intertidally dominated, tidal lagoon type estuary (SIDE). The estuary has a flushing time of ~5 days (Plew et al. 2018); however, whereas, the mid to lower estuary is relatively well-flushed, the narrow channels in the upper estuary are susceptible to stratification and water column nutrient problems. The estuary has the capacity to retain fine sediments and sediment bound nutrients in deposition areas (e.g. side arms) making it moderately susceptible to nutrient enrichment impacts.

The main freshwater inflow to the estuary is Pleasant River, along with several smaller tributaries. Freshwater inputs represent ~30% of the total estuary volume (Plew et al. 2018). The estuary drains almost completely at low tide exposing ~86% of the estuary area (Roberts et al. 2022). The lower estuary is protected from the ocean by a sand spit dominated by marram grass dunes. The catchment area is 12,747ha, comprising ~38.1% intensive pasture, ~23.8% low producing pasture and ~31.1% exotic forest. In total, 37.7% of the catchment is densely vegetated (Fig. 2).

The immediate terrestrial margin of Pleasant River Estuary is dominated by pasture on gently sloping hill country that falls steeply to the estuary (Moore 2015). The bedrock is sedimentary, meaning there is moderate to high susceptibility of overland flow and sediment and particulate phosphorus issues (LandscapeDNA.org).

The broadscale survey highlighted that the estuary is expressing signs of eutrophication (i.e. nutrient enrichment), with nuisance macroalgae and filamentous algae common in the side arms and mid estuary and often associated with muddy sediments and anoxia (i.e. no oxygen). Mud-dominated (>50% mud) sediments were common and comprised 16.7% of the intertidal area, and were generally found in the estuary side arms or within salt marsh habitat where fine sediments tend to accumulate.

Ulva spp. and *Agarophyton* spp. growing in muddy anoxic sediments in the north-west arm

Salt marsh herbfield (mainly glasswort, *Sarcocornia quinqueflora*), is the dominant vegetation type in the estuary (42.8% of the intertidal area) and is recognised as a regionally significant wetland in the Regional Plan: Water for Otago (Roberts et al. 2022). However, historic drainage and reclamation of salt marsh for pasture is a common feature of the estuary, particularly in the side arms (see photos next page). Fencing of herbfield for grazing continues to occur, and flap gates restrict saltwater inundation of salt marsh habitat. A causeway that blocked the entrance of the southern arm to allow for cattle grazing was removed in 2009 to reinstate tidal flushing (Moller & Moller 2012). However, the area of previous salt marsh habitat has not recovered.

Middle section of Pleasant River Estuary

Remnants of the causeway removed in 2009

Pleasant River Estuary was traditionally utilised by Māori as an important kāinga mahinga kai (food gathering settlement). A significant archeological site at the estuary mouth has identified early hunting of moa and seals before a transition to kaimoana (seafood). The estuary provides extensive spawning and nursery habitat for marine and freshwater fish species including patiki (flatfish), inanga (whitebait) and tuna (long-finned eel and short-finned eel; Ngāi Tahu Atlas). The establishment of a marine reserve that would extend from Pleasant River Estuary to Stony Creek has been proposed to protect important coastal reef, estuary, and kelp forest habitats (SMPF 2018).

The estuary is a coastal protection area in the Otago Regional Plan: Coast, based on its cultural and ecological values. The estuary is particularly important for waders and waterfowl including godwits, South Island pied oystercatcher, variable oystercatcher, pied stilt, banded dotterel white-faced heron, gulls, shags and ducks (WDC 2004).

The Tūmai Beach Development on the southern margin of the estuary has recently prepared an environmental enhancement plan as part of their consent conditions. The long-term restoration plan aims to integrate ecosystem restoration and sustainable pasture production by planting natives on the terrestrial margin, salt marsh plantings, and through exclusion of stock and reducing vehicle use in the estuary (TBEEG 2021).

While there has been extensive reclamation and modification to the estuary margin, the estuary retains high ecological, cultural and human use values.

Salt marsh in the southwest side arm 1958 (top; source Retrolens) and 2019 (bottom; source ORC)

Lower estuary flats

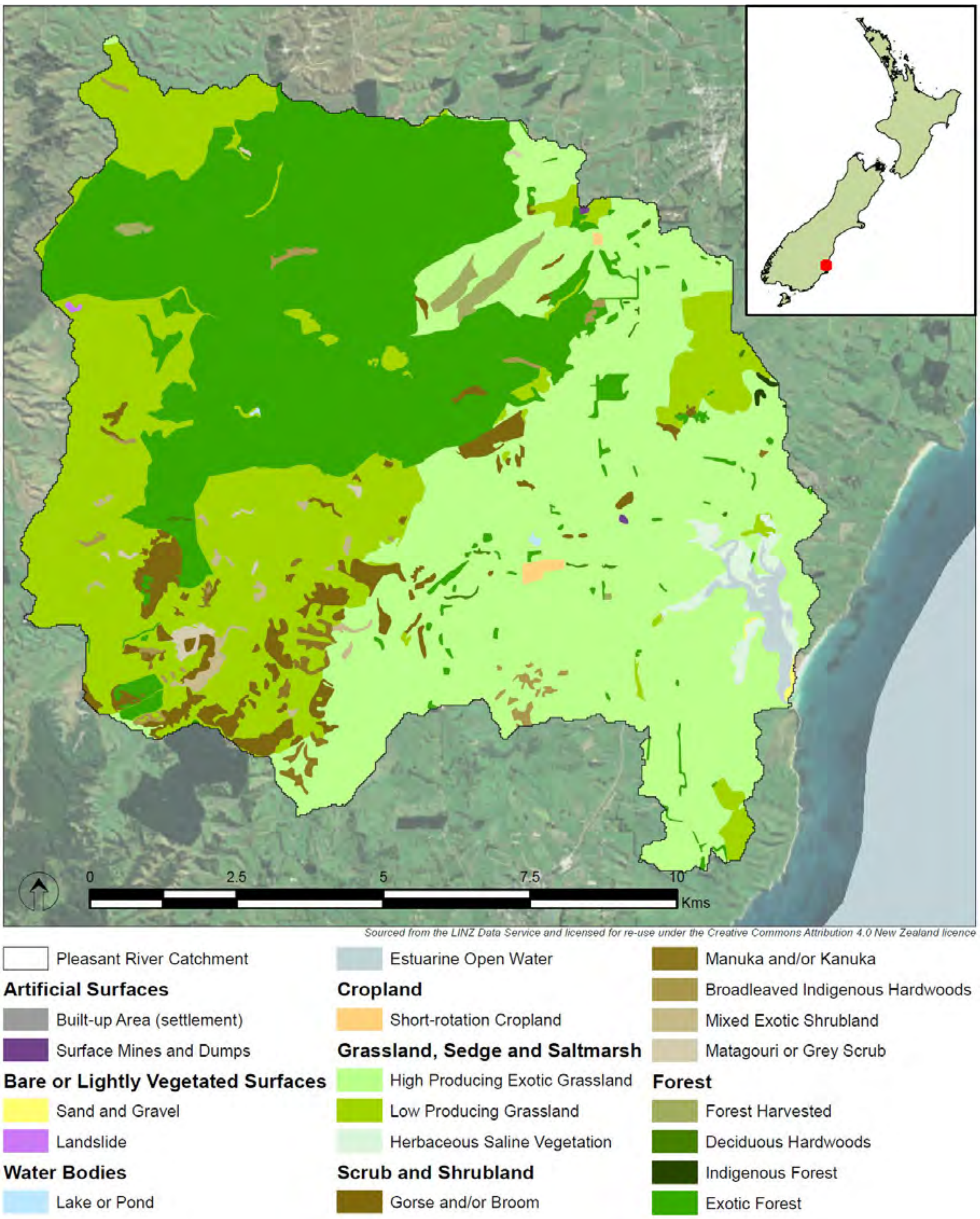


Fig. 2. Pleasant River Estuary and surrounding catchment land use classifications from LCDB5 (2017/18) database.

3. FINE SCALE METHODS

3.1 OVERVIEW OF NEMP FINE SCALE APPROACH

Mapping the main habitats in an estuary using the NEMP broad scale approach provides a good basis for identifying representative areas to establish fine scale and sediment plate sites. The NEMP advocates that fine scale monitoring is undertaken in soft sediment (sand/mud) habitat in the mid to low tidal range of priority estuaries. The actual tidal elevation is often determined by the location of suitable, stable soft-sediment habitat.

The environmental characteristics assessed in fine scale surveys incorporate a suite of common benthic indicators, including biological attributes such as the 'macrofaunal' assemblage and various physico-chemical characteristics; e.g. sediment mud content, trace metals, nutrients (Table 1).

Extensions to the NEMP methodology that support the fine scale approach include the development of various metrics for assessing ecological condition according to prescribed criteria, and inclusion of sediment plate monitoring as noted in Section 1. These additional components are included in the present report and are described in the subsections below.

3.2 PLEASANT RIVER ESTUARY FINE SCALE AND SEDIMENT PLATE SITES

The broad scale survey revealed extensive mud/sand flats across much of Pleasant River Estuary, providing a choice of locations for fine scale sites. The selected placement of the sites was in muddy-sand habitats of the middle and upper estuary (Fig. 3), at approximately mid-tide level.

A schematic of the sampling approach is provided on the site overview map in Fig. 3, with details described below. Site A was positioned on the true right side of Pleasant River in an embayment off the main river channel, with Site B placed in an upper estuary side arm off the true left of the main channel. Each fine scale site was set up as a 30 x 60m rectangle according to NEMP recommendations.

Sediment plates were installed along the upstream 30m margin of each site (Fig. 3). To assist relocation, fine scale site corners and the locations of sediment plates were marked with wooden pegs. Coordinates for each of these features are provided in Appendix 1. Site set-up, sediment installation and sampling were undertaken on 26 Nov 2021, with the support of the local community. On the day of sampling, the predicted low tide at Pleasant River entrance was 0.66m occurring at ~15:16 (tides.niwa.co.nz), with a lag of ~2 hours observed at the sampling sites.

Overview of fine scale site B, 26 November 2021

3.3 SEDIMENT PLATES

Four concrete 'plates' (pavers, 19cm x 23cm) for sediment plate monitoring were installed at each of the two fine scale sites, positioned at 5, 10, 20 and 25m along the upstream site boundary (see Fig. 3).

Plates were buried between 50-100mm depth in the sediment. After leveling, baseline depths (from the sediment surface to each buried plate) were measured. For this purpose, a 2m straight edge was placed over each plate position to average out any small-scale irregularities in surface topography. The depth to each plate was measured in triplicate by vertically inserting a probe into the sediment until the plate was located. Depth was measured to the nearest millimeter.

At each site, a single sediment sample (composited from sub-samples 20mm deep taken next to each plate) was collected and retained for laboratory analysis of grain size, using the methods described for fine scale monitoring (see Section 3.4). As the sediment plate measurements are expected to be undertaken annually, the grain size data can be used to assess any changes in sediment muddiness.

Installing sediment plates at Pleasant River Site B, 26 November 2021

Fig. 3. Location of sites in Pleasant River Estuary, and schematics illustrating fine scale and sediment plate methods.

3.4 FINE SCALE SAMPLING AND BENTHIC INDICATORS

Each fine scale site was divided into a 3 x 3 grid of nine plots (Fig. 3). Fine scale sampling for sediment indicators was conducted in each plot, with Fig. 3 showing the standard numbering sequence for replicates 1-9 at both sites, and the designation of zones X, Y and Z (for compositing sediment samples; Fig. 3). A summary of the benthic indicators, the rationale for their inclusion, and the field sampling methods, is provided in Table 1. Although the baseline sampling approach generally adhered to the NEMP, additions to early NEMP methods that have been introduced in most surveys conducted over the last 10 or more years. For present purposes we adopted these modifications as indicated in Table 1.

3.4.1 Sediment quality assessment

At each fine scale site, three composite sediment samples (each ~250g) were pooled from sub-samples collected (to 20mm depth) across each of zones X, Y and Z (replicates 1-3, 4-6 and 7-9, respectively; see Fig. 3). Samples were stored on ice and sent to RJ Hill Laboratories for analysis of the following constituents: particle grain size in three categories (%mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP); and trace contaminants (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; nickel, Ni; zinc, Zn). Details of laboratory methods and detection limits are in Appendix 2.

3.4.2 Field sediment oxygenation assessment

To assess sediment oxygenation, the apparent redox potential discontinuity (aRPD) depth (Table 1) was measured. The aRPD is a subjective measure of the enrichment state of sediments according to the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). The aRPD depth in all surveys was measured (to the nearest mm) after extracting a large sediment core (130mm diameter, 150mm deep) from each of the nine plots, placing it on a tray, and splitting it vertically. Representative split cores (X1, Y4 and Z7) were also photographed.

3.4.3 Biological sampling

Sediment-dwelling macrofauna

To sample sediment-dwelling macrofauna, each of the large sediment cores used for assessment of aRPD was placed in a separate 0.5mm sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a mixture of 75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification by NIWA. The types of animals present in each sample, as well as the range of different species (i.e. richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments.

Laying sediment plates and placing pegs at Site B

Collecting sediment cores from Site A

Table 1. Summary of NEMP fine scale benthic indicators, rationale for their use, and sampling method. Any meaningful departures from NEMP are described in footnotes.

NEMP benthic indicators	General rationale	Sampling method
Physical and chemical		
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across 9 plots (see note 1).
Nutrients (nitrogen and phosphorus) and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across 9 plots (see note 1).
Trace metals (copper, chromium, cadmium, lead, nickel, zinc)	Common toxic contaminants generally associated with human activities.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across 9 plots (see notes 1, 2).
Depth of apparent redox potential discontinuity layer (aRPD)	Subjective time-integrated measure of the enrichment state of sediments according to the visual transition between oxygenated surface sediments and deeper deoxygenated black sediments. The aRPD can occur closer to the sediment surface as organic matter loading increases.	1 x 130mm diameter sediment core to 150mm deep for each of 9 plots, split vertically, with depth of aRPD recorded in the field where visible.
Biological		
Macrofauna	The abundance, composition and diversity of macrofauna, especially the infauna living with the sediment, are commonly-used indicators of estuarine health.	1 x 130mm diameter sediment core to 150mm deep (0.013m^2 sample area, 2L core volume) for each of 9 plots, sieved to 0.5mm to retain macrofauna (see note 1).
Epibiota (epifauna)	Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health.	Abundance score based on ordinal SACFOR scale in Table 2 (see note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover score based on ordinal SACFOR scale in Table 2 (see note 3).
Epibiota (microalgae)	The composition and prevalence of microalgae are indicators of nutrient enrichment.	Visual assessment of conspicuous growths based on ordinal SACFOR scale in Table 2 (see notes 3, 4).

Notes:

[1] For cost reasons, and to provide a balanced sampling grid, macrofauna was assessed in 9 discrete samples (one per plot) and sediment quality assessed in 3 composite samples, rather than 10 discrete samples as specified in the NEMP.

[2] Arsenic and mercury are not required by NEMP, but were included in the trace element suite.

[3] Assessment of epifauna, macroalgae and microalgae used SACFOR in favour of quadrat sampling outlined in NEMP. Quadrat sampling is subject to considerable within-site variation for epibiota that have clumped or patchy distributions.

[4] NEMP recommends taxonomic composition assessment for microalgae but this is not typically undertaken due to unavailability of expertise nationally, and lack of demonstrated utility of microalgae as a routine indicator.

Surface-dwelling epibiota

In addition to macrofaunal core sampling, epibiota (macroalgae, and conspicuous surface-dwelling animals nominally >5mm body size) visible on the sediment surface at each site were semi-quantitatively categorised using 'SACFOR' abundance (animals) or percentage cover (macroalgae) ratings shown in Table 2. These ratings represent a scoring scheme simplified from established monitoring methods (MNCR 1990; Blyth-Skyrme et al. 2008).

The SACFOR method is ideally suited to characterise intertidal epibiota with patchy or clumped distributions. It was conducted as an alternative to the quantitative quadrat sampling specified in the NEMP, which is known to poorly characterise scarce or clumped species. Note that our epibiota assessment did not include infaunal species that may be visible on the sediment surface, but whose abundance cannot be reliably determined from surface observation (e.g. cockles).

Table 2. SACFOR ratings for site-scale abundance, and percent cover of epibiota and algae, respectively.

SACFOR category	Code	Density per m^2	Percent cover
Super abundant	S	> 1000	> 50
Abundant	A	100 - 999	20 - 50
Common	C	10 - 99	10 - 19
Frequent	F	2 - 9	5 - 9
Occasional	O	0.1 - 1	1 - 4
Rare	R	< 0.1	< 1

3.5 DATA RECORDING, QA/QC AND ANALYSIS

All sediment and macrofaunal samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. Field measurements from the fine scale and sediment plate surveys were recorded electronically in templates that were custom-built using software available at www.fulcrumapp.com. Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position for that record (e.g. a sediment core). Field data were exported to Excel, together with data from the sediment and macrofaunal analyses.

The Excel sheets were imported into the software R 4.0.5 (R Core Team 2021) and merged by common sample identification codes. All summaries of univariate responses (e.g. totals, means ± 1 standard error) were produced in R, including tabulated or graphical representations of data from sediment plates, laboratory sediment quality analyses, and macrofauna. Where results for sediment quality parameters were below analytical detection limits, averaging (if undertaken) used half of the detection limit value, according to convention.

Before macrofaunal analyses, the data were screened to remove species that were not regarded as a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g. terrestrial beetles). To facilitate comparisons with future surveys, and other Otago estuaries, cross-checks were made to ensure consistent naming of species and higher taxa. For this purpose, the adopted name was that accepted by the World Register of Marine Species (WoRMS, www.marinespecies.org/).

Macrofaunal response variables included richness and abundance by species and higher taxonomic groupings. In addition, scores for the biotic health index AMBI (Borja et al. 2000) were derived. AMBI scores reflect the proportion of taxa falling into one of five eco-groups (EG) that reflect sensitivity to pollution (in particular eutrophication), ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

To meet the criteria for AMBI calculation, macrofauna data were reduced to a subset that included only adult 'infauna' (those organisms living within the sediment matrix), which involved removing surface dwelling epibiota and any juvenile organisms. AMBI scores were calculated based on standard international eco-group classifications where possible (http://ambi.azti.es), with the most recent eco-group list developed in December 2020.

To reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand (e.g. Cawthron EGs used by Berthelsen et al. 2018). Note that AMBI scores were not calculated for macrofaunal cores that did not meet operational limits defined by Borja et al. (2012), in terms of the percentage of unassigned taxa (>20%), or low sample richness (<3 taxa) or abundances (<6 individuals).

Multivariate representation of the macrofaunal community data used the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in site similarity as a function of macrofaunal composition and abundance were assessed using an 'unconstrained' non-metric multidimensional scaling (nMDS) ordination plot, based on pairwise Bray-Curtis similarity index scores among samples aggregated within each site and zone (see Fig. 3). The purpose of aggregation was to smooth over the 'noise' associated with a core-level analysis and enable the relationship to patterns in sediment quality variables (which were composited within zones) to be determined.

Prior to the multivariate analysis, macrofaunal abundance data were fourth-root or presence-absence transformed to down-weight the influence on the ordination pattern of the dominant species or higher taxa. The purpose of the presence-absence transformation was to explore site differences that were attributable to species occurrences irrespective of their relative abundances. The procedure PERMANOVA was used to test for compositional differences among sites, based on both types of transformed data.

Overlay vectors and bubble plots on the nMDS were used to visualise relationships between multivariate biological patterns and sediment quality data. Additionally, the Primer procedure Bio-Env was used to evaluate the suite of sediment quality variables that best explained the biological ordination pattern.

3.6 ASSESSMENT OF ESTUARY CONDITION

To supplement our analyses and interpretation of the data, results were assessed within the context of various estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas. These metrics assign different indicators to one of four rating bands, colour-coded as shown in Table 3. Most of the condition ratings in Table 3 were derived from those described in a New Zealand Estuary Trophic Index (Robertson et al. 2016a, b), which includes purpose-developed criteria for eutrophication, and also draws on wider national and international environmental quality guidelines. Key elements of this approach are as follows:

- *New Zealand Estuary Trophic Index (ETI):* The ETI provides screening guidance for assessing where an estuary is positioned on a eutrophication gradient. While many of the constituent metrics are intended to be applied to the estuary as a whole (i.e. in a broad scale context), site-specific thresholds for %mud, TOC, TN, aRPD and AMBI are described by Robertson et al. (2016b). We adopted those thresholds for present purposes, except: (i) for %mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016c); and (ii) for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012).
- *ANZG (2018) sediment quality guidelines*: The condition rating categories for trace contaminants were benchmarked to ANZG (2018) sediment quality guidelines as described in Table 3. The Default Guideline Value (DGV) and Guideline Value-High (GV-high) specified in ANZG are thresholds that can be interpreted as reflecting the potential for 'possible' or 'probable' ecological effects, respectively. Until recently, these thresholds were referred to as ANZECC (2000) Interim Sediment Quality Guideline low (ISQG-low) and Interim Sediment Quality Guideline high (ISQG-high) values, respectively.
- A sedimentation guideline of 2mm of sediment accumulation per year above natural deposition rates, proposed by Townsend and Lohrer (2015), will be relevant to subsequent surveys in Pleasant River Estuary.

Note that the scoring categories described above and in Table 3 should be regarded only as a general guide to assist with interpretation of estuary condition. Accordingly, it is major spatio-temporal changes in the categories that are of most interest, rather than their subjective condition descriptors; i.e. descriptors such as 'poor' condition should be regarded more as a relative rather than absolute rating.

Walking to the fine scale site in the mid to lower estuary

Table 3. Condition ratings used to characterise estuarine health for key indicators. See footnotes and main text for explanation of the origin or derivation of the different metrics. Note that sediment plates were installed in November 2021, hence the sedimentation rate indicator will be relevant to future surveys.

Indicator	Unit	Very good	Good	Fair	Poor
General indicators [1]					
Sedimentation rate[a]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[b]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[c]	mm	≥ 50	20 to < 50	10 to < 20	< 10
TN[b]	mg/kg	< 250	250 to < 1000	1000 to < 2000	≥ 2000
TOC[b]	%	< 0.5	0.5 to < 1	1 to < 2	≥ 2
AMBI[b]	na	0 to 1.2	> 1.2 to 3.3	> 3.3 to 4.3	≥ 4.3
Trace elements [2]					
As	mg/kg	< 10	10 to < 20	20 to < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 to <1.5	1.5 to < 10	≥ 10
Cr	mg/kg	< 40	40 to <80	80 to < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 to <65	65 to < 270	≥ 270
Hg	mg/kg	< 0.075	0.075 to <0.15	0.15 to < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 to <21	21 to < 52	≥ 52
Pb	mg/kg	< 25	25 to <50	50 to < 220	≥ 220
Zn	mg/kg	< 100	100 to <200	200 to < 410	≥ 410

1. Ratings derived or modified from: [a]Townsend and Lohrer (2015), [b]Robertson et al. (2016) with modification for mud content described in text, [c]FGDC (2012).

2. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good = < 0.5 x DGV; Good = 0.5 x DGV to < DGV; Fair = DGV to < GV-high; Poor = > GV-high. DGV = Default Guideline Value, GV-high = Guideline Value-high. These were formerly the ANZECC (2000) sediment quality guidelines whose exceedance roughly equates to the occurrence of 'possible' and 'probable' ecological effects, respectively.

Macroalgae (*Agarophyton* spp. and *Ulva* spp.) in Pleasant River Estuary

4. KEY FINDINGS

4.1 GENERAL FEATURES OF FINE SCALE SITES

The selected sites were typical of the intertidal flats across the main estuary. Within each site the sediment textural characteristics were uniform, being sands with a substantial mud component that made conditions soft to walk on. The photos below show the similarity in the general appearance of the two sites, with both having a conspicuous cover of macroalgae, in particular *Agarophyton* spp.

Soft muddy-sand sediments at Site A (top) and Site B (bottom)

4.2 SEDIMENT PLATES

Sediment plate data are provided in Appendix 3. These data provide baseline measurements against which future changes in plate depth can be determined, and annual or longer-term sediment accrual or erosion evaluated.

4.3 SEDIMENT QUALITY

4.3.1 Sediment grain size, TOC and nutrients

Composite sediment sample raw data are tabulated in Appendix 4. Laboratory analyses of sediment grain size confirmed the field observations of muddy-sand sediments at both site with a mean mud content of 38% at Site A and 42% at Site B (Fig. 4).

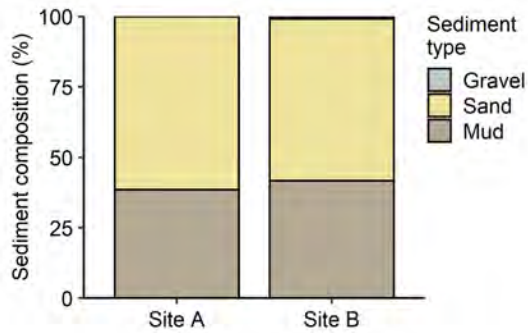


Fig. 4. Mean (n=3) sediment grain size in composite samples. Size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

To provide a visual impression of sediment quality relative to the Table 3 condition ratings, Fig. 5 compares the mean percentage mud, total organic carbon (TOC) and total nitrogen (TN) from composite samples against the rating thresholds. Both sites are rated 'poor' for their mud content, reflecting exceedance of the biologically relevant threshold of 25%.

Levels of organic matter (TOC) and nutrients (TN and TP) were elevated at Site A relative to Site B (Fig. 5, Appendix 4). Condition ratings for TOC and TN were 'good' or 'very good' (TP has no rating criteria), although TN at Site A was approaching the 'fair' threshold of 1,000mg/kg.

4.3.2 Sediment oxygenation

Despite the 'good' rating for two of the trophic state indicators (TOC and TN), the sediment profile showed signs of moderate enrichment (Fig. 6, see also photos in Fig. 7). Mean aRPD values were around 3mm, which is rated as 'poor', with a dark grey/black sediment profile evident.

The shallow aRPD will to a certain extent reflect the moderate mud content of the sediment, which acts as a barrier to oxygenation. Importantly, there were no symptoms of excessive enrichment, which usually manifests as black anoxic sediment near the surface and a strong 'rotten egg' smell of hydrogen sulphide.

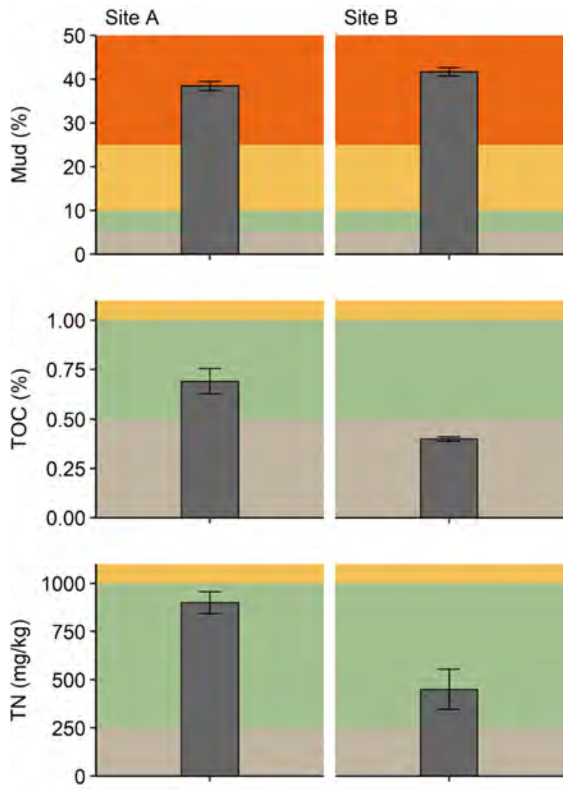


Fig. 5. Mean (±SE, n=3) sediment %mud, total organic carbon, and total nitrogen relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

Note also, that although the aRPD was shallow on average, there was evidence of brown oxygenated surface sediments being mixed into deeper sediment layers by the action of the burrowing organisms (a process known as 'bioturbation'; see photos in Fig. 7).

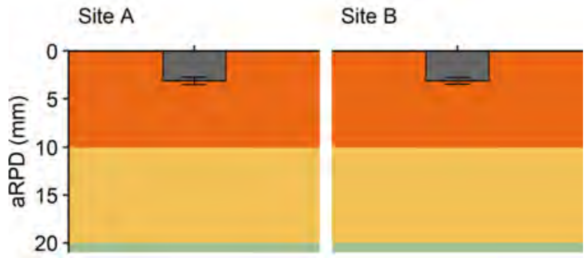


Fig. 7. Mean (±SE, n=3) aRPD relative to condition ratings. Rating key as per Fig. 5.

4.3.3 Trace contaminants

Plots of trace contaminants in relation to condition ratings are provided in Fig. 8 (see also Appendix 4). Trace contaminant levels were very low, and all rated as 'very good', reflecting that the concentrations were less than half of the ANZG (2018) Default Guideline Value (DGV) for 'possible' ecological effects. These results suggest that there are no significant anthropogenic sources of trace contaminants in the catchment.

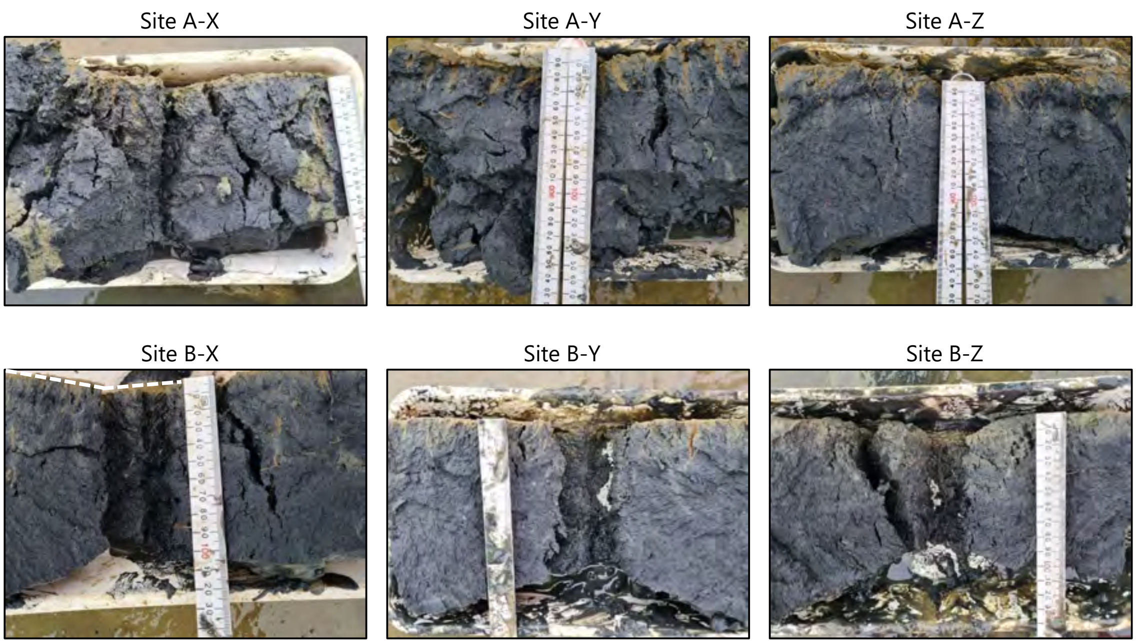


Fig. 6. Example sediment cores from the fine scale sites A and B. To illustrate the approximate depth of the aRPD, a dashed white line is shown on the zone X core from Site B.

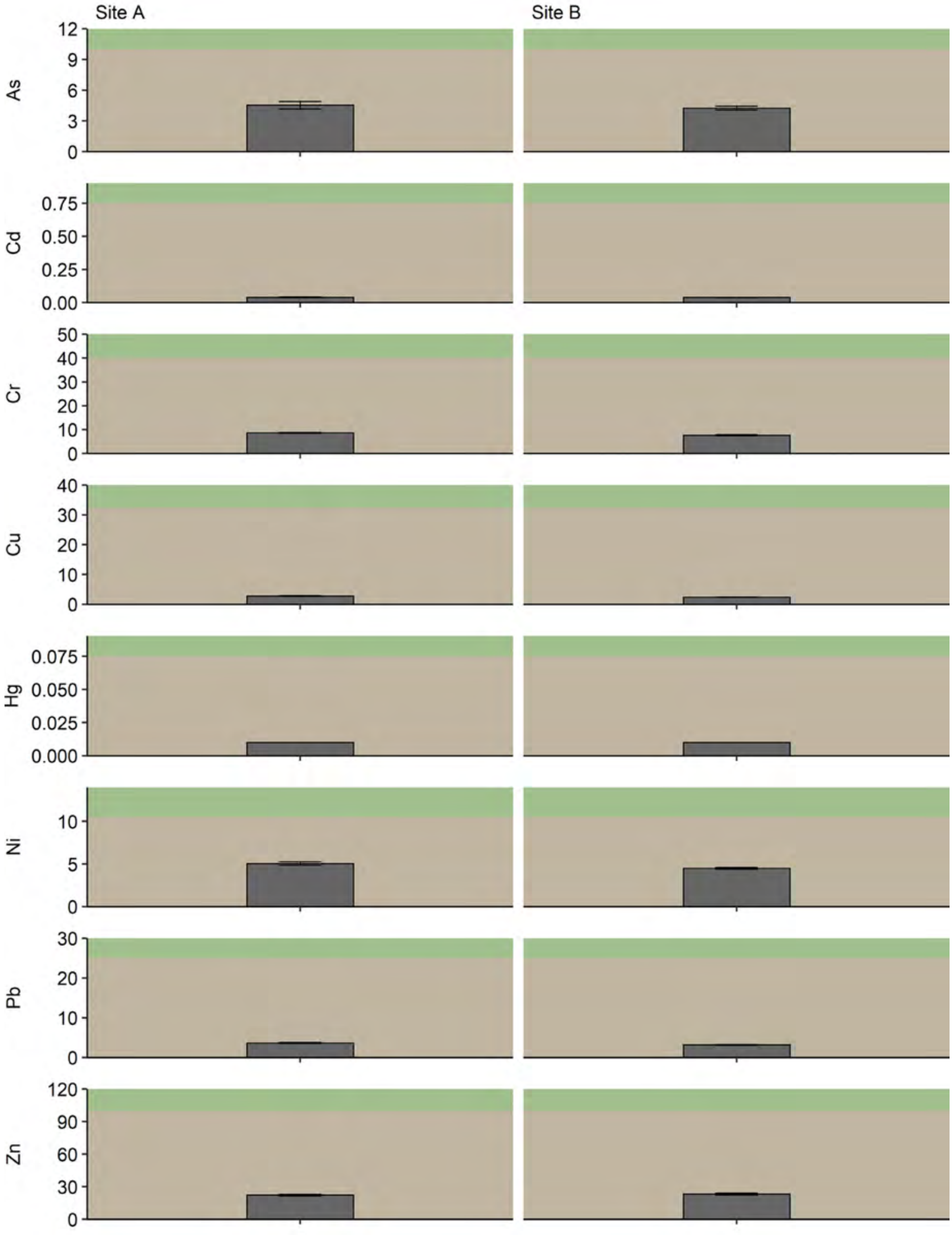


Fig. 8. Mean (±SE, n=3) trace contaminant concentrations relative to condition ratings. The boundary between grey ('very good' condition) and green ('good' condition) corresponds to half of the ANZG (2018) sediment quality Default Guideline Value for 'possible' ecological effects.

Condition rating key:

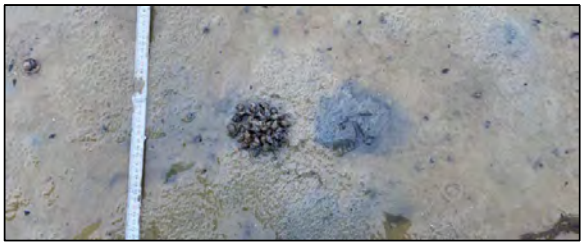
Very Good	Good	Fair	Poor

4.4 MACROFAUNA

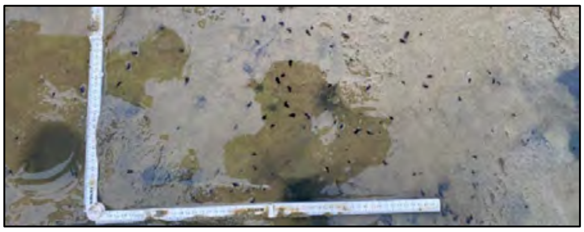
4.4.1 Conspicuous surface epibiota

Results from the site-level assessment of surface-dwelling invertebrates and macroalgae are shown in Table 4. Conspicuous at both sites was the mud whelk *Cominella glandiformis*, rated as common, and the mudflat topshell *Diloma subrostratum*. At Site B the horn snail *Zeacumantus subcarinatus* was particularly abundant (~250/m^2), but this species was not observed at Site A.

In terms of macroalgae, the red seaweed *Agarophyton* spp. was common (~15% cover) at Site A, but rated as rare at Site B. Trace amounts of sea lettuce *Ulva* spp. were present at both sites, but not to the extent observed in some other parts of the estuary (Roberts et al. 2022; see also report cover photo).

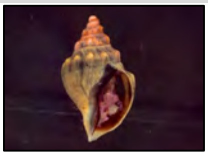
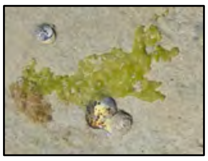


Clumps of mud whelks *Cominella glandiformis* were common at both sites



The horn snail (aka black spire snail) *Zeacumantus subcarinatus* was abundant at Site B

Table 4. SACFOR scores for epibiota based on the scale in Table 2. Invertebrate specimen photos provided by NIWA.

Species	Common name	Functional description	Image	Site A	Site B
Invertebrates					
Cominella glandiformis	Mud whelk	Carnivore and scavenger		C (21)	C (21)
Diloma subrostratum	Mudflat topshell	Grazer and deposit feeder		F (3)	O (1)
Zeacumantus subcarinatus	Horn snail	Microalgal and seaweed grazer		Absent	A (250)
Macroalgae					
Agarophyton spp.*	Red seaweed	Primary producer		C (15%)	R (0.5%)
Ulva spp.	Green seaweed/ Sea lettuce	Primary producer		R (0.1%)	R (0.05%)

* *Agarophyton* spp. is the revised name for *Gracilaria* spp.

4.4.2 Macrofauna cores

Raw data for sediment-dwelling macrofauna are provided in Appendix 5, and the most commonly-occurring taxa are described in Table 5.

Macrofaunal taxa and abundances

Both sampling sites were species-rich, but Site A in particular. A total of 12 main taxonomic groups was present, with 46 macrofaunal taxa sampled in total. Of these, 41 taxa were present at Site A and 30 at Site B (see Appendix 5). Mean species richness values were 22 taxa at Site A and 16 taxa at Site B. Organism abundances were very high, being 960/core at Site A and less than half that number (435/core) at Site B (Fig. 9b).

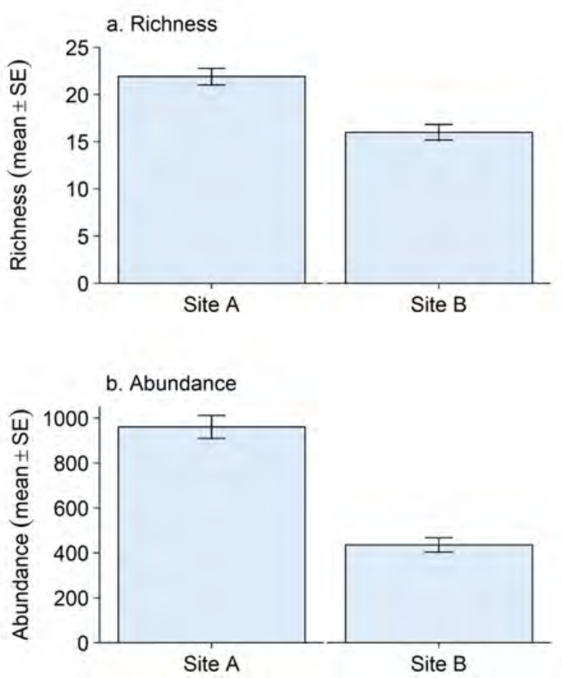


Fig. 9. Mean (± SE, n=10) taxon richness and abundance per core sample.

The representation of organisms in terms of the five AMBI eco-groups is shown in Fig. 10. All EGs were represented across the species mix, but especially EGs II and III. Although the range of hardy taxa (EGs IV and V) was relatively low, those present were quite abundant. As such, mean values of the biological index AMBI were moderately elevated, with an index value at both sites of ~3.5 out of a maximum score of 7 (Fig. 11). This value corresponds to a 'fair' condition rating against the New Zealand ETI criteria (Table 3).

Organism abundances were dominated by various polychaete worms, notably *Capitella* cf. *capitata*, which is a tolerant EG V organism that can thrive in disturbed or enriched environments. Also abundant were nationally cosmopolitan polychaete species that spanned relative hardy to more sensitive EGs, including *Scolecolepides benhami* (EG IV), *Paradoneis lyra* (EG III) and *Boccardia syrtis* (EG II).

Among the sub-dominant non-polychaete taxa were species that are common in estuaries nationally, including the small bivalve *Arthritica* sp. 5 (EG III; referred to in other ORC reports as Arthritica sp. 1 or Arthritica cf bifurca, with the sp. 5 designation being based on the voucher specimens held by NIWA), the small anemone *Edwardsia* sp. (EG II) and the amphipod *Paracalliope novizelandiae* (EG I).

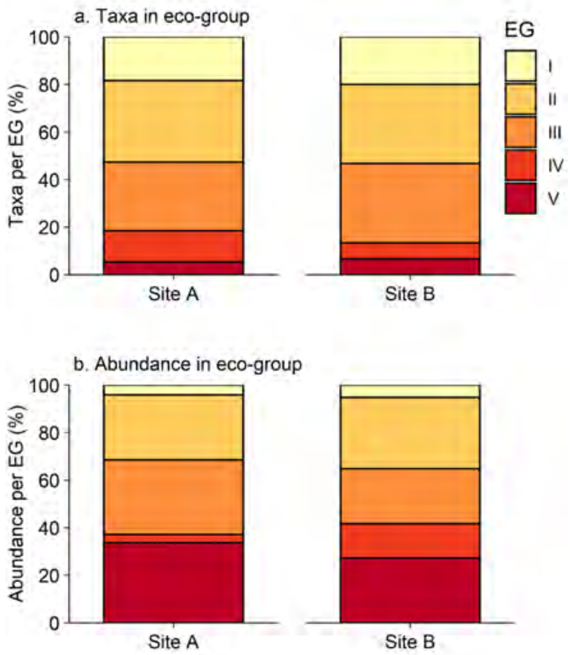


Fig. 10. Site-level data showing the number of taxa and organisms within eco-groups ranging from sensitive (EG-I) to tolerant (EG-V).

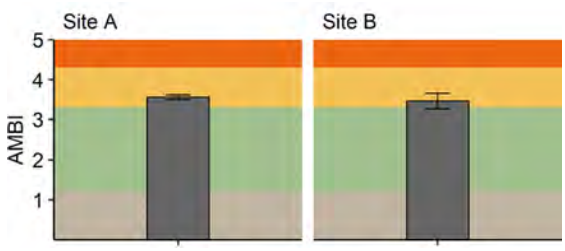
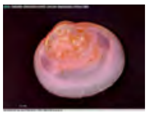


Fig. 11. Mean (± SE, n=10) AMBI scores compared with condition rating criteria.

Condition rating key:

Very Good	Good	Fair	Poor

Table 5. Description and site-aggregated abundances of the most commonly occurring sediment-dwelling macrofauna.

Main group, species & eco-group	Site A	Site B	Description	Image
Amphipoda, *Paracalliope novizelandiae* EG I	156	2	Amphipods are shrimp-like crustaceans. This species is common in New Zealand estuaries. It is considered to be able to tolerate muddy habitats to some extent, despite the EG I designation.	
Anthozoa, *Edwardsia* sp. EG II	73	126	A tiny elongate anemone adapted for burrowing. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Considered intolerant of anoxic conditions.	
Bivalvia, *Arthritica* sp. 5 EG III	26	61	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.	
Polychaeta, *Boccardia syrtis* EG II	1825	927	A small surface deposit-feeding spionid. Found in a wide range of sand/mud habitats. Lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Sensitive to organic enrichment.	
Polychaeta, *Capitella* cf. *capitata* EG V	2894	1063	Subsurface deposit feeding worm that is highly tolerant of disturbed or harsh conditions.	
Polychaeta, *Microphthalmus riseri* EG II	324	61	A little-known worm in family Hesionidae, which is a family of phyllodocid 'bristle worms'.	
Polychaeta, *Paradoneis lyra* EG III	2413	778	Common deposit feeding paraonid worm considered to be reasonably tolerant of muddy sediment and organic enrichment.	
Polychaeta, *Prionospio aucklandica* EG III	182	40	A surface deposit-feeding spionid common in harbours and estuaries. Associated mainly with muddy habitats. Considered tolerant to organic enrichment.	
Polychaeta, *Scolecolepides benhami* EG IV	261	564	A spionid, surface deposit feeder that is common in estuaries and coastal areas throughout New Zealand.	
Polychaeta, *Scoloplos cylindrifer* EG I	180	185	Common in estuaries. Long, slender, sand-dwelling unselective deposit feeder. Although designated EG I, can inhabit relatively muddy and organic-rich sediments.	

EG=Eco-Group, ranging from sensitive (EG-I) to tolerant (EG-V) to enrichment and other types of environmental pollution

Multivariate patterns and association with sediment quality variables

The nMDS ordination in Fig. 13 shows zone-aggregated samples of similar composition close to each other in a 2-dimensional plot, with less similar samples being further apart. This plot illustrates that macrofaunal composition among sampling zones within sites was more similar than between the two sites, which is fairly typical in estuarine environments where strong gradients can occur over scales of hundreds of metres.

However, tests based on the PERMANOVA procedure indicated that compositional differences between sites were not significant, irrespective of whether the comparison was based on relative abundance (i.e. fourth-root transformed) data (Pseudo-F=5.65, p= 0.11) or species presence-absence (Pseudo-F=6.03, p=0.003). In fact, SIMPER analysis revealed that, despite spatial separation in the MDS, the compositional similarity between the two sites (measured by the Bray-Curtis index) was quite high (~71%), while within each site the similarity among zones was ~85%.

Hence, the differences in macrofauna composition among the sites are reasonably subtle, and reflect both shifts in dominance (e.g. see Table 5) and differences in the actual species present (see Fig. 13a). There were 16 species or higher taxa at Site A that were not recorded at the relatively species-poor Site B, but only 5 taxa present at Site B that were not recorded at Site A (Appendix 5). Some of these were organisms that occurred in low abundance, for which chance plays a role in determining whether they are detected by core sampling (i.e. they could be present at a site but missed during sampling due to their low abundances). However, some of the differences were attributable to more abundant taxa that were present at one site but not the other, and conceivably represent true differences. For example, the Site B taxa included the gastropod *Zeacumantus subcarinatus*, amphipod *Torridoharpinia hurleyi* and copepods, which were absent at Site A.

Analysis of associations between macrofauna and sediment quality revealed that organic matter (%TOC) and nutrient content (TN) were both highly correlated with composition patterns (Spearman rank correlation, ρ=0.80). By contrast, there was no correlation with the other trophic state variable aRPD (ρ=-0.01), and a poor correlation with sediment mud content (ρ=0.28).

Sediment mud content and organic/nutrient enrichment are among the strongest drivers of macrofaunal composition in New Zealand estuaries (Cummings et al. 2003; Robertson et al. 2015; Berthelsen et al. 2018; Clark et al. 2020; Clark et al. 2021). In the case of Pleasant River Estuary, as the fine scale sites have a similar grain size composition (see Fig. 4), the mild levels of TOC and TN enrichment at Site A relative to Site B appear to be the more important of the factors that influence site macrofaunal differences.

Whelks clumped on the sediment surface

Core sampling at site B

Sand flats in the mid estuary

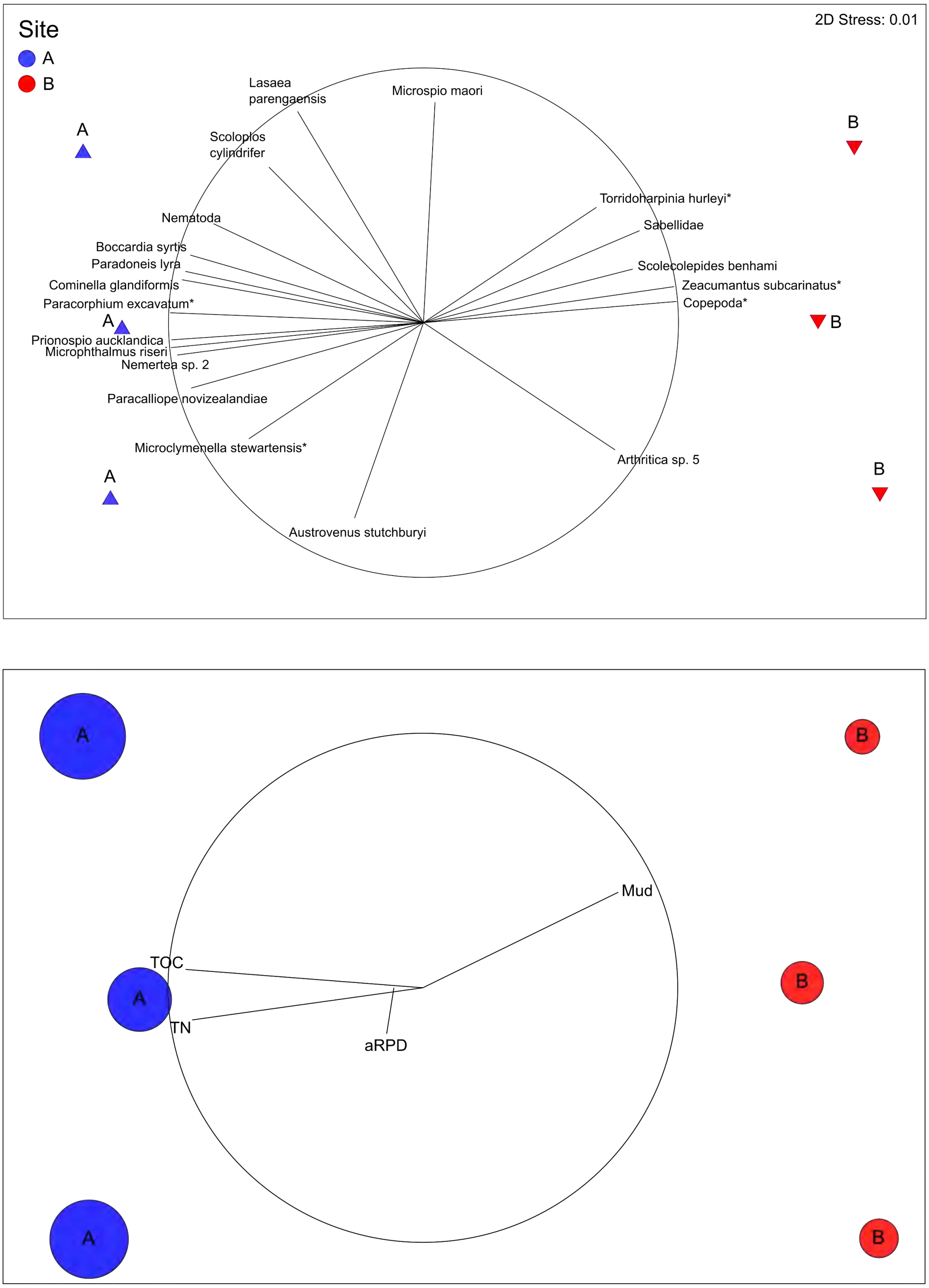


Fig. 12. Non-metric MDS ordination of macrofaunal core samples aggregated within sampling zones at each site.

The three zones at each site are placed such that closer ones are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of near-zero for the nMDS indicates that a 2-dimensional plot provides an accurate representation of differences. Samples aggregated within zone and site were ~85% similar in terms of the Bray-Curtis macrofaunal index, with a between site similarity of ~71%. Vector overlays indicate the direction and strength of association (length of line relative to circle) of grouping patterns in terms of: a) the most correlated macrofauna species (an asterisk denotes those present at one site but not the other), and b) key sediment quality variables. Bubble sizes in the bottom pane are scaled to sediment %TOC; TOC and TN were the sediment quality variables most closely correlated with macrofaunal composition differences.

5. SYNTHESIS AND RECOMMENDATIONS

5.1 SYNTHESIS OF KEY FINDINGS

This report has described the findings of an ecological monitoring survey conducted at two sites in Pleasant River Estuary, largely following the fine scale methods described in New Zealand's National Estuary Monitoring Protocol (NEMP), with method extensions described in Table 1. Sediment plates installed at the time of the survey will be monitored in the future to determine sedimentation rates.

A summary of key environmental quality indicators relative to condition ratings (Table 6) highlights that both sites were relatively muddy and showed moderate symptoms of enrichment (i.e. a shallow aRPD). Quantitative indicators of trophic state (%TOC & TN) were elevated at Site A relative to Site B, with nutrient-enrichment levels (i.e. TN) being close to the 'fair' threshold of 1000mg/kg.

Table 6. Summary of scores of estuary condition based on mean values of key indicators, compared to rating criteria in Table 3. Note that TP has no rating criteria.

Metric	Units	A	B
Mud	%	38.5	41.7
aRPD	mm	3	3
TN	mg/kg	900	450*
TP	mg/kg	483	440
TOC	%	0.69	0.40
As	mg/kg	4.5	4.3
Cd	mg/kg	0.040	0.039
Cr	mg/kg	8.7	7.7
Cu	mg/kg	2.8	2.4
Pb	mg/kg	3.7	3.2
Hg	mg/kg	< 0.02	< 0.02
Ni	mg/kg	5.1	4.5
Zn	mg/kg	22.3	23.3
AMBI	na	3.6	3.5

** Sample mean includes values below lab detection limits*
< All values below lab detection limit

The enriched, muddy nature of the estuary sediments is consistent with catchment run-off, in part reflecting the high proportion of land use consisting of pasture and exotic forestry (Fig. 2). A NIWA study currently being undertaken in the estuary is investigating sediment sources in relation to these types of land uses. As well as generating muddy sediments, land uses such as agriculture can lead to soil contamination with trace metals and other pollutants, which are associated with practices such as fertiliser application (Gaw et al. 2006; Lebrun et al. 2019). In turn, muddy sediments can carry a high load of anthropogenic contaminants, due to the surface area they provide for contaminant adsorption. However, in the case of Pleasant River Estuary the analysis of trace elements provided no evidence of any significant contaminant sources in the catchment, with concentrations of all analytes being less than half of the ANZG (2018) sediment quality guideline value associated with the potential for adverse ecological effects.

Looking toward the estuary entrance

Pleasant River channel in the upper estuary

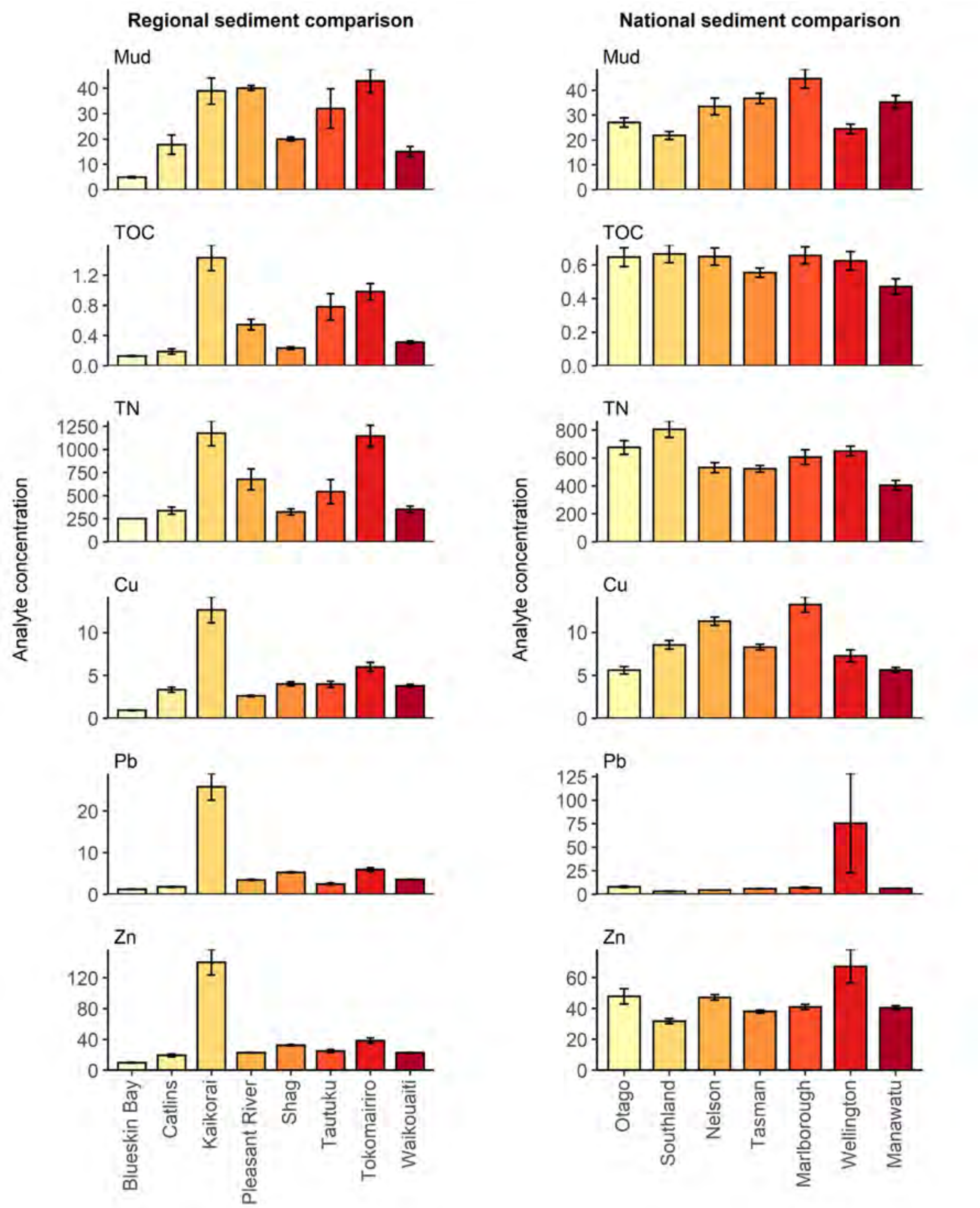


Fig. 13. Broad patterns in key sediment quality indicators, comparing Pleasant River Estuary with other estuaries in the Otago region (mean ± SE for surveys pooled within estuary), and Otago estuaries collectively against other regions of New Zealand (mean ± SE for estuary surveys pooled within region). Analyte concentrations for mud and TOC are percentages, otherwise they are mg/kg.

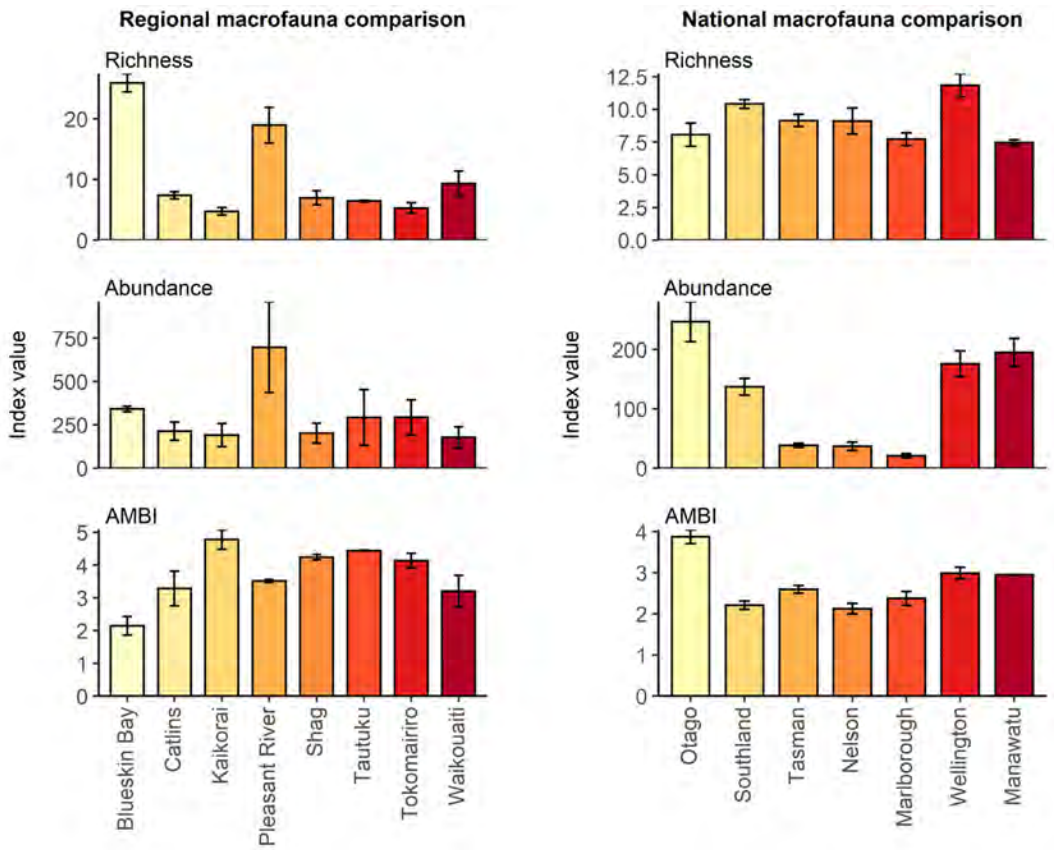


Fig. 14. Broad patterns in key macrofaunal indicators, comparing Pleasant River Estuary with other estuaries in the Otago region (mean ± SE for surveys pooled within estuary), and Otago estuaries collectively against other regions of New Zealand (mean ± SE for estuary surveys pooled within region).

Compared with other estuaries that are monitored as part of ORC's programme, Pleasant River Estuary is relatively muddy, shows intermediate levels of enrichment, and has low levels of key trace contaminants especially when compared against Kaikorai Estuary and its urbanised catchment (Fig. 13). In terms of macrofauna, Pleasant River Estuary had a diverse mix of species that is greater than most other estuaries in the region, and stands out as having particularly high organism abundances (Fig. 14). The abundant organisms included some relatively hardy taxa that can thrive in enriched or disturbed conditions. As such, the AMBI index was elevated outside of a healthy range and rated as 'fair' against ETI criteria (see Table 3), although mean values were within the range evident in other Otago estuaries (Fig. 13).

Considering the sediment quality and biological assessment collectively, the fine scale survey results suggest that the two monitored sites in Pleasant River Estuary are exhibiting symptoms of mild stress, although have not reached a 'tipping' point whereby multiple indicators are showing signs of degradation. By contrast, the results of the broad scale survey revealed that some areas of the upper estuary, as well as side arms, are exhibiting symptoms of excess nutrient enrichment; i.e. eutrophication (Roberts et al. 2022). Although not being situated in the worst-affected parts of the estuary, the fine scale sites are representative of the main tidal flats, and are suitable for long-term monitoring.

5.2 RECOMMENDATIONS

- Complete two additional annual surveys as planned in the summers of 2022/23 and 2023/24. Together with data gathered from changes in sediment plate depth, the work will provide a comprehensive baseline for the long-term monitoring of ecological health in Pleasant River Estuary.
- Compile data summaries after the second survey, but defer the next comprehensive analysis and reporting until completion of the 3-year baseline, at which time the management implications of the survey findings should be considered.

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APPENDIX 1. GPS COORDINATES FOR FINE SCALE SITES (CORNERS) AND SEDIMENT PLATES

FINE SCALE SITES

Estuary	Site	Peg	NZTM_E	NZTM_N
Ples-Otag	A	C1	1422303	4952329
Ples-Otag	A	C2	1422330	4952280
Ples-Otag	A	C3	1422301	4952268
Ples-Otag	A	C4	1422275	4952396
Ples-Otag	B	C1	1422383	4953211
Ples-Otag	B	C2	1422391	4953154
Ples-Otag	B	C3	1422361	4953516
Ples-Otag	B	C4	1422351	4953209

SEDIMENT PLATES

Site	Site	Peg/Plate	NZTM_E	NZTM_N
Ples-Otag	A	Peg1 (C1)	1422303	4952329
Ples-Otag	A	Plate 1	1422297	4952326
Ples-Otag	A	Plate 2	1422293	4952326
Ples-Otag	A	Peg2	1422289	4952324
Ples-Otag	A	Plate 3	1422284	4952322
Ples-Otag	A	Plate 4	1422279	4952319
Ples-Otag	A	Peg3 (C4)	1422275	4952316
Ples-Otag	B	Peg1 (C1)	1422383	4953211
Ples-Otag	B	Plate 1	1422378	4953213
Ples-Otag	B	Plate 2	1422374	4953211
Ples-Otag	B	Peg2	1422369	4953211
Ples-Otag	B	Plate 3	1422364	4953210
Ples-Otag	B	Plate 4	1422359	4953210
Ples-Otag	B	Peg3 (C4)	1422351	4953209

APPENDIX 2. RJ HILL ANALYTICAL METHODS FOR SEDIMENTS

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-6
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	1-6
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-6
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.8 mg/kg dry wt	1-6
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-6
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

APPENDIX 3. SEDIMENT PLATE RAW BASELINE DATA

Date	Site	Sediment Texture	Sediment Type	Mud (%)	Sand (%)	Gravel (%)	aRPD (mm)	Plate	Depth (mm)
26/11/2021	A	soft	MS25_50	42.6	57.4	<0.1	4	p1	54
26/11/2021	A	soft	MS25_50					p2	53
26/11/2021	A	soft	MS25_50					p3	61
26/11/2021	A	soft	MS25_50					p4	50
26/11/2021	B	soft	MS25_50	46.1	51.6	2.3	2	p1	60
26/11/2021	B	soft	MS25_50					p2	55
26/11/2021	B	soft	MS25_50					p3	54
26/11/2021	B	soft	MS25_50					p4	83

* MS25_50 = muddy sand with >25-50% mud

APPENDIX 4. SEDIMENT QUALITY RAW DATA

Value for aRPD show zone mean and range. Data are otherwise based on composite samples in each zone.

Site	Zone	Gravel	Sand	Mud	TOC	TN	TP	aRPD	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
		%	%	%	%	mg/kg	mg/kg	mm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
A	X	0.2	59.4	40.5	0.79	1000	500	2.7 (2 to 4)	4.8	0.044	9	2.9	<0.02	5.4	3.8	23
	Y	<0.1	62.9	37.1	0.71	900	500	3.7 (2 to 5)	5	0.036	8.8	2.9	<0.02	5.1	3.8	23
	Z	<0.1	62.1	37.8	0.57	800	450	3.0 (2 to 4)	3.8	0.04	8.3	2.6	<0.02	4.7	3.4	21
B	X	0.3	59.9	39.8	0.42	600	460	3.3 (2 to 4)	4.4	0.039	7.6	2.5	<0.02	4.5	3.2	23
	Y	1.6	55.6	42.8	0.38	<500	400	3.3 (2 to 5)	3.9	0.037	7.3	2.3	<0.02	4.3	3	22
	Z	0.5	57.1	42.4	0.4	500	460	2.7 (2 to 3)	4.5	0.041	8.1	2.5	<0.02	4.7	3.3	25
								DGV	20	1.5	80	65	0.15	21	50	200
								GV-high	70	10	370	270	1	52	220	410

APPENDIX 5. MACROFAUNA CORE RAW DATA

Raw data are for 9 replicate cores at each of Sites A and B.

Main group	Taxa	Habitat	EG	A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	B9
Amphipoda	Aoridae	Infauna	I													1					
Amphipoda	Paracalliope novizealandiae	Infauna	I	27	12	21	15	46	19	2	4	10	1								1
Amphipoda	Paracorophium excavatum	Infauna	IV	1		1		1		1		1									
Amphipoda	Parawaldeckia kidderi	Infauna	II	2	3	6	2	3	10	8	6	8						1			
Amphipoda	Proharpinia sp.	Infauna	I					1													
Amphipoda	Protorchestia sp.	Infauna	II							1											
Amphipoda	Torridoharpinia hurleyi	Infauna	I										1			1					
Anthozoa	Edwardsia sp.	Epibiota	II	10	4	6	4	6	8	16	11	8	23	16	20	5	16	20	3	15	8
Bivalvia	Arthritica sp. 5	Infauna	III	6		2	1	7	5	2	2	1	5	9	5	4	3	5	5	15	10
Bivalvia	Austrovenus stutchburyi	Infauna	II						1	1	2									1	1
Bivalvia	Lasaea parengaensis	Infauna	II	6		4			2	3			1		1		3	1			1
Bivalvia	Linucula hartvigiana	Infauna	II	1				2													
Copepoda	Copepoda	Infauna	II												2		5				3
Cumacea	Colurostylis lemurum	Infauna	II	2	1	1						1									
Decapoda	Hemiplax hirtipes	Infauna	III	2																1	1
Gastropoda	Cominella glandiformis	Epibiota	III	1	3		1		2	4				1	1		2		1		1
Gastropoda	Dotidae	Epibiota	NA									2									
Gastropoda	Notoacmea scapha	Epibiota	II				1														
Gastropoda	Potamopyrgus estuarinus	Epibiota	IV				1														
Gastropoda	Zeacumantus subcarinatus	Epibiota	II										8		1	12	4	5	3		4
Nematoda	Nematoda	Infauna	III	6	1			5		2		4	1					1			
Nemertea	Nemertea	Infauna	III		1				1	2		2		3	1	1	2		2		1
Nemertea	Nemertea sp. 2	Infauna	III	1	4	2	3	5	2	3		3	1	1			1		1		
Oligochaeta	Naididae	Infauna	V	2	1		1							1				1			1
Polychaeta	?Orbiniidae	Infauna	NA						1												
Polychaeta	Boccardia proboscidea	Infauna	IV	2	1																
Polychaeta	Boccardia syrtis	Infauna	II	196	222	187	155	240	192	214	195	224	72	80	199	101	121	148	31	72	103
Polychaeta	Capitella cf. capitata	Infauna	V	317	256	400	340	382	314	238	306	341	214	184	55	210	108	113	127	16	36
Polychaeta	Glycera sp.	Infauna	II				1														
Polychaeta	Heteromastus filiformis	Infauna	IV	9	2	2	5	4		3	2	4		1	3		1				
Polychaeta	Macroclymenella stewartensis	Infauna	II				1					1									
Polychaeta	Maldanidae (juv)	Infauna	I		1																
Polychaeta	Microphthalmus riseri	Infauna	II	39	14	54	19	65	25	17	35	56	12	11	5	4	9	2	15	1	2
Polychaeta	Microspio maori	Infauna	I			1											2				
Polychaeta	Naineris naineris-A	Infauna	I		1	1		1			1	1									
Polychaeta	Nereididae (juv)	Infauna (juvenile)	NA		4	2		8	4	5	1	5									
Polychaeta	Paradoneis lyra	Infauna	III	483	378	241	189	147	260	223	90	402	115	80	137	81	64	74	92	84	51
Polychaeta	Perinereis vallata	Infauna	III							2			1								
Polychaeta	Pettiboneia sp.	Infauna	II	6	26	6	3	5	2	3		5	1								1
Polychaeta	Platynereis sp.	Infauna	III	1																	
Polychaeta	Prionospio aucklandica	Infauna	III	23	14	36	23	20	15	14	18	19	7	11	3	1	4	2	6	2	4
Polychaeta	Protocirrineris nuchalis	Infauna	III	1			2	2			4	1		1							
Polychaeta	Sabellidae	Infauna	I	2		2		2	1	1	3	3	3	1	12	2	35	22	2	4	12
Polychaeta	Scolecolepides benhami	Infauna	IV	28	25	31	15	5	22	44	55	36	67	63	46	61	74	51	91	59	52
Polychaeta	Scoloplos cylindrifer	Infauna	I	15	28	32	15	4	15	35	15	21	20	16	16	13	10	14	4	4	8
Tanaidacea	Tanaidacea	Infauna	II															1			


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SHAG ESTUARY: 2021/2022 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 008. Prepared by Barrie Forrest for Otago Regional Council, March 2022

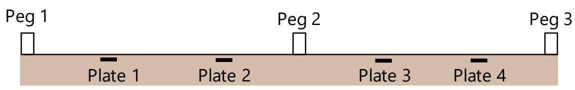
OVERVIEW

Since Dec-2016, Otago Regional Council has undertaken annual State of the Environment monitoring in Shag Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 24 November 2021.

Fig. 1. Location of Shag Estuary monitoring sites.

METHODS

Estuary sedimentation is measured using the 'sediment plate' method (e.g. Forrest et al. 2021). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate (n=3) and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories). This approach allows changes in sediment muddiness to be determined even where there are no changes in sediment depth. Sediment oxygenation is an ancillary biological health variable that is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings corresponding to the colours in Table 1.

Table 2. Indicator values and condition ratings from the Nov-2021 survey.

Indicator	A	B
Sedimentation (mm/yr)*	0.72	-0.59
Mud content (%)	27.6	25.7
aRPD (mm)	30	30

*Sedimentation is the mean annual sedimentation rate since the baseline (n=5 yrs).

Sedimentation rate

The cumulative change in sediment depth over plates at each site is shown in Fig. 2. The mean sedimentation rate over the past 5 years has been low, corresponding to condition ratings of 'good' and 'very good' at Sites A and B, respectively (Table 1). Sedimentation has been highly variable across surveys. At Site A, a significant deposition event in Jan-2021 was followed by subsequent erosion in the period preceding the latest survey. The temporal variance in erosion and accretion at both sites likely reflects the river-dominated hydrological setting, periodic restriction of the estuary entrance, and

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012).

catchment disturbance from land use activities (e.g. 71% pasture and 11% forestry; Stevens & Robertson 2017).

Sediment mud content and oxygenation

Sediment mud content was rated as 'poor' at both sites in Nov-2021 as it exceeded the biologically relevant threshold of 25%. At Site A, mud content has nonetheless declined since the Jan-2021 deposition event referred to above (Fig. 3).

The average aRPD depth was 30mm at both sites in Nov-2021 reflecting well-oxygenated conditions (a rating of 'good'). This level of oxygenation is partially maintained by the presence of crabs, shellfish (e.g. cockles) and other organisms, which turn over surface sediments and create voids that allow air and water to transfer oxygen to underlying layers.

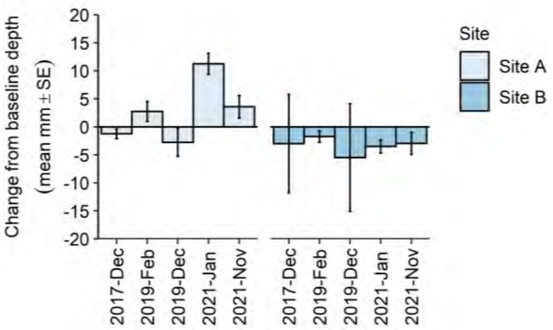


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to the baseline.

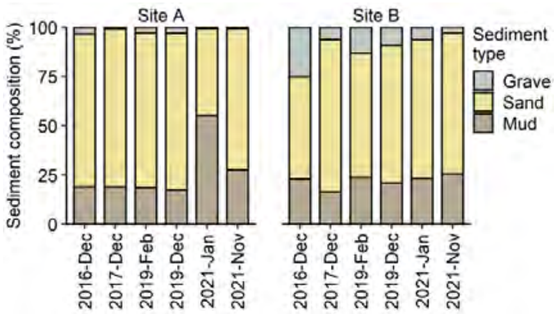


Fig. 3. Sediment particle grain size at each site. The baseline result for each site (Dec-2016) is also shown.

CONCLUSIONS

The sedimentation rate over the past 5 years has been highly variable, but less than the 2mm/yr national guideline value. The Nov-2021 results nonetheless show that the estuary flats remain under pressure from muddy sediments and reinforce previous recommendations (e.g. Robertson et al. 2017) to monitor and manage catchment sediment sources.

Muddy surface sediments at Site A in Nov-2021

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Comprehensive reporting should be undertaken 5-yearly as part of 'fine scale' ecological and sediment monitoring (next due in the summer of 2023/24).

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TOKOMAIRIRO ESTUARY: 2021/2022 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 006. Prepared by Barrie Forrest for Otago Regional Council, March 2022

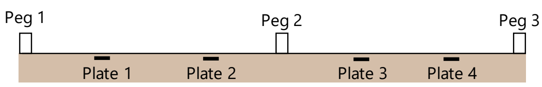
OVERVIEW

Since Dec-2017, Otago Regional Council has undertaken annual State of the Environment monitoring in Tokomairiro Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring was initially undertaken at three sites, with ongoing monitoring at Sites B and C only (Fig. 1). The latest survey was carried out on 23 November 2021.

Fig. 1. Location of Tokomairiro Estuary monitoring sites. Site A has been discontinued as measurement plates could not be found at the time of the Jan-2021 survey.

METHODS

Estuary sedimentation is measured using the 'sediment plate' method (e.g. Forrest et al. 2021). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers.



Measurements are averaged across each plate (n=3) and used to calculate a mean annual sedimentation rate for each site. A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories). This approach allows changes in sediment muddiness to be determined even where there are no changes in sediment depth.

Sediment oxygenation is an ancillary biological health variable that is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings corresponding to the colours in Table 1.

Table 2. Indicator values and condition ratings from the Nov-2021 survey.

Indicator	A**	B	C
Sedimentation (mm/yr)*	-6.69	3.17	0.80
Mud content (%)	11.1	63.2	57.0
aRPD (mm)	>50	17	8

* Mean annual sedimentation rate relative to the baseline (n=1-4 years). Five years of data are required to assess a meaningful trend.
** The Site A data are from the last monitored date, Dec-2019.

Sedimentation rate

The cumulative change in sediment depth over plates at each site is shown in Fig. 2. The greatest accumulation was at Site B, where the mean annual sedimentation was rated 'poor' due to exceedance of

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012).

the 2mm/yr guideline value (Table 1). The sedimentation between Jan-2021 and Nov-2021 equated to almost 10mm/yr. By contrast, sedimentation was low at Site C (rated 'good'). The erosion in Dec-2019 at Site A (where monitoring has been discontinued) reflects the dynamic hydrological environment and movement of mobile sands in the lower estuary.

Sediment mud content and oxygenation

Sediment mud content was rated as 'poor' at mid- and upper estuary Sites B and C, where it exceeded the biologically relevant threshold of 25%. Mud content has been consistently high across all monitoring years at these sites (Fig. 3). Tokomairiro Estuary drains a large catchment whose land uses are predominantly agriculture (54%) and forestry (35%), which are known sources of muddy sediment (Forrest et al. 2020).

The average aRPD depth was shallow at Sites B and C, corresponding to condition ratings of 'poor' and 'fair', respectively. The elevated mud content in the sediment acts as a barrier to oxygenation. Macroalgae and/or microalgae at these sites was suggestive of excess nutrient enrichment (see photos). By contrast, the aRPD is quite deep in the porous sandy sediments of the lower estuary around Site A where there is no evidence of excessive algal growths.

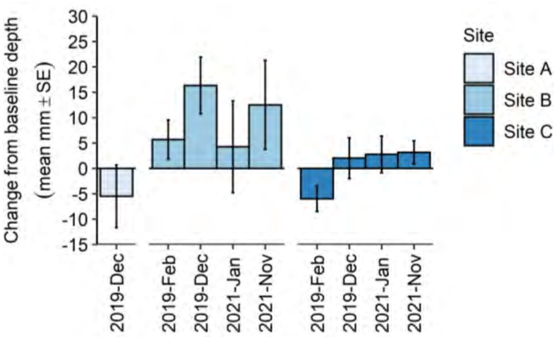


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to the baseline.

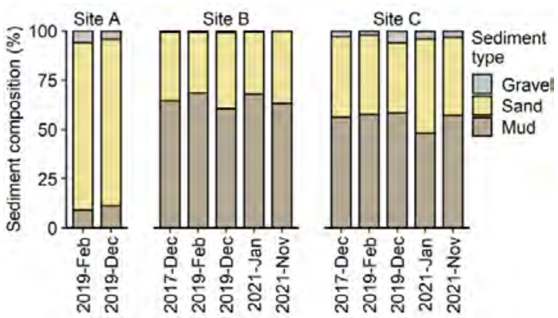


Fig. 3. Sediment particle grain size at each site. The baseline result for each site is also shown.

CONCLUSIONS

The sedimentation rate since Dec-2017 has been greatest at Site B, where it has exceeded the 2mm/yr national guideline value. The Nov-2021 results overall show that the mid and upper river margins at Sites B and C remain under pressure from fine sediment and organic/nutrient enrichment impacts, and further reinforce previous recommendations (e.g. Forrest et al. 2020) to manage catchment inputs to the estuary.

In Nov-2021 benthic microalgae were conspicuous at Site B (left), with filamentous macroalgae conspicuous at Site C (right).

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Comprehensive reporting should be undertaken 5-yearly as part of 'fine scale' ecological and sediment monitoring (next due in the summer of 2024/25).

REFERENCES

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Townsend M, Lohrer D. 2015. ANZECC Guidance for Estuary Sedimentation. NIWA client report number HAM2015-096, prepared for Ministry for the Environment 45p.

SALT ECOLOGY

WAIKOUAITI ESTUARY: 2021/2022 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 005. Prepared by Barrie Forrest for Otago Regional Council, March 2022

OVERVIEW

Since Dec-2016, Otago Regional Council has undertaken annual State of the Environment (SOE) monitoring in Waikouaiti Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at three sites (Fig. 1), with the latest survey carried out on 24 November 2021.

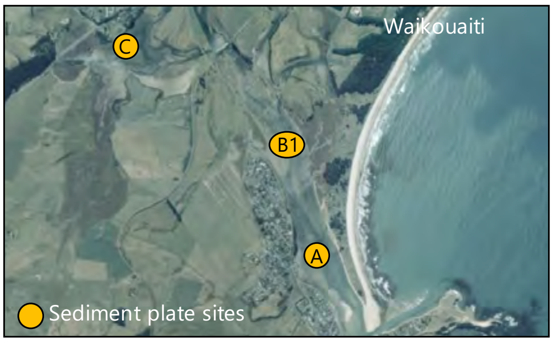
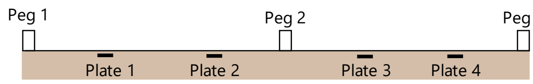


Fig. 1. Location of Waikouaiti Estuary monitoring sites. Site B1 replaced nearby Site B, which was washed away.

METHODS

Estuary sedimentation is measured using the 'sediment plate' method (e.g. Forrest et al. 2021). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate (n=3) and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories). This approach allows changes in sediment muddiness to be determined even where there are no changes in sediment depth. Sediment oxygenation is an ancillary biological health variable that is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings corresponding to the colours in Table 1.

Table 2. Indicator values and condition ratings from the Nov-2021 survey.

Indicator	A	B1	C
Sedimentation (mm/yr)*	1.29	-7.15	-3.93
Mud content (%)	6.6	4.6	26.5
aRPD (mm)	50	8	12

* Mean annual sedimentation rate relative to the baseline (n=2 yrs for Sites A & B1, n=5 yrs for Site C). Five years of data are required to assess a meaningful trend.

Sedimentation rate

The cumulative change in sediment depth over plates at each site is shown in Fig. 2. There has been a low level of annual sedimentation at Site A (rated 'fair'), with high variability between plates likely owing to the dynamic hydrological environment near the estuary entrance, and the presence of shell hash.

Sites B1 and C have shown consistent erosion since monitoring began. In Waikouaiti Estuary high river flows can cause scouring of the tidal flats, which at former Site B led to the sediment above installed

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012).

plates being eroded away. Site C in the upper estuary comprises fine muddy sediments and is located near two small stream inputs that could have a localised influence on sediment movement and erosion.

Sediment mud content and oxygenation

Mud content was low at Sites A and B1, where sand and gravel (>2mm particle diameter) fractions were dominant. By contrast, at upper estuary Site C the sediment condition was rated as 'poor' due to the mud content exceeding the biologically relevant threshold of 25% (Fig. 3). Sediment mud content has remained at a consistent level within each site across each monitoring survey to date.

The relatively deep aRPD depth of 50mm at Site A (condition rating 'very good', Table 2) likely reflects the sandy sediment at this site, with oxygenation also maintained by the presence of crabs, numerous cockles and other organisms, which turn over surface sediments and create voids that allow air and water to transfer oxygen to underlying layers. The relatively shallow aRPD at Sites B1 and C is indicative of moderate organic enrichment, with condition ratings of 'poor' and 'fair', respectively. At Site C there were also moderate growths of filamentous algae (see photo) that had not been recorded previously.

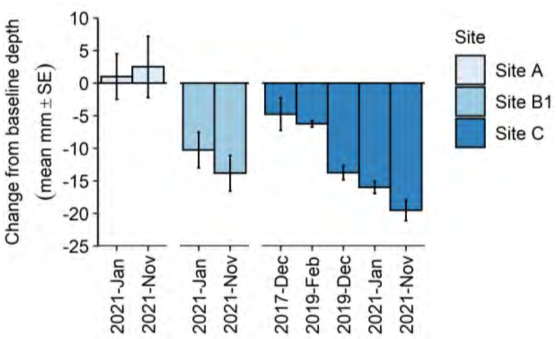


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to the baseline.

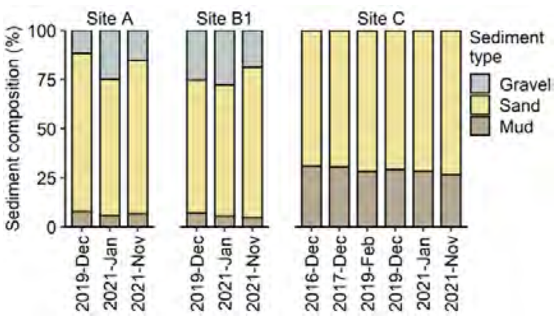


Fig. 3. Sediment particle grain size at each site. The baseline result for each site is also shown.

CONCLUSIONS

There has been no significant sedimentation at the Waikouaiti Estuary monitoring sites, with scouring and erosion due to hydrodyamic processes appearing to override any depositional pressure of sediment from the catchment. Nonetheless, the Nov-2021 results show that upper estuary Site C is consistently muddy. Additionally, Sites B1 and C are both expressing moderate enrichment effects. As such, the results reinforce previous recommendations (e.g. Robertson et al. 2017) to manage catchment influences on the estuary.

Algal growth at Site C (left) and firm sand with cockles at Site A (right) in Nov-2021.

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Comprehensive reporting should be undertaken 5-yearly as part of 'fine scale' ecological and sediment monitoring (next due in the summer of 2023/24).

REFERENCES

Federal Geographic Data Committee (FGDC). 2012. Coastal and Marine Ecological Classification Standard Catalog of Units, Federal Geographic Data Committee FGDC-STD-018-2012. 343p.

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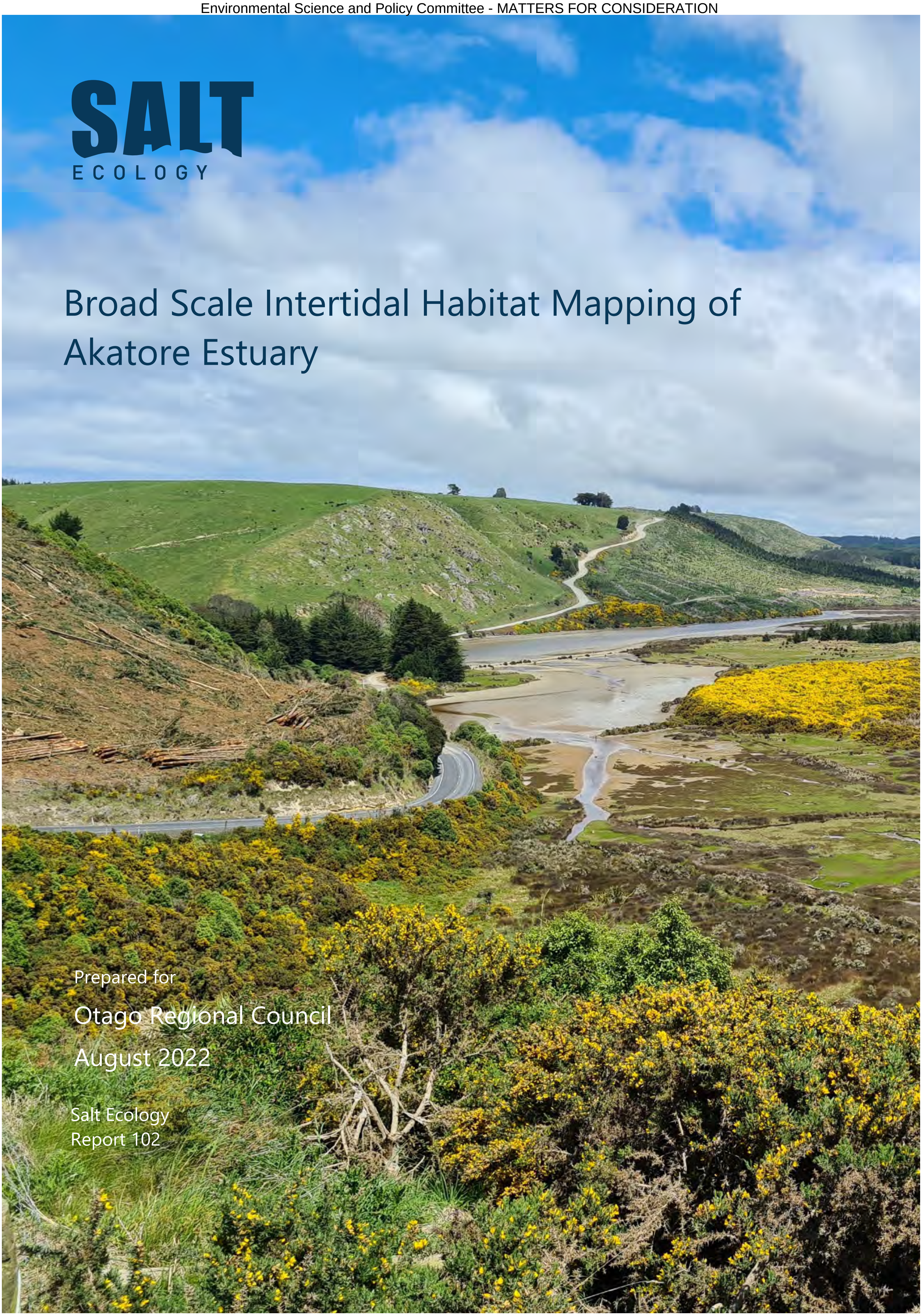

SALT ECOLOGY

Broad Scale Intertidal Habitat Mapping of Akatore Estuary

Prepared for

Otago Regional Council

August 2022

Salt Ecology
Report 102

Cover photo: Akatore Estuary, November 2021, view to the southwest, over the northern arm

RECOMMENDED CITATION

Roberts KL, Stevens LM, Forrest BM. 2022. Broad Scale Intertidal Habitat Mapping of Akatore Estuary. Salt Ecology Report 102, prepared for Otago Regional Council, August 2022. 49p.

SALT ECOLOGY

For the People
Mō ngā tāngata

Broad Scale Intertidal Habitat Mapping of Akatore Estuary

Prepared by

Keryn Roberts,

Leigh Stevens

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for

Otago Regional Council

August 2022

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For the environment
Mō te taiao

SALT
ECOLOGY

GLOSSARY

AA	Affected Area (OMBT metric)
AIH	Available Intertidal Habitat (OMBT metric)
aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
HEC	High Enrichment Conditions
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
SIDE	Shallow, Intertidally Dominated Estuary
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

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SUMMARY

Akatore Estuary is a medium sized (69ha) shallow, intertidally dominated, tidal lagoon type estuary located ~50km south of Dunedin on New Zealand's south coast. The estuary is monitored by Otago Regional Council (ORC) as part of its State of the Environment programme using methodologies described in New Zealand's National Estuary Monitoring Protocol. This report describes a survey conducted in November 2021 which assessed the dominant substrate and vegetation features present including seagrass, salt marsh and macroalgae.

KEY FINDINGS

- Unvegetated intertidal flats were dominated by sandy mud (>50-90% mud) in the upper estuary, muddy sand (25-50% mud) in the mid estuary and sands (<10% mud) in the lower estuary. The substrate within most salt marsh areas comprised firm muddy sand (25-50% mud).
- Mud extent (13.7% of the intertidal area) was rated 'fair', and sedimentation rate 'poor', indicating fine sediments are a cause for concern.
- Nuisance macroalgae was a minor feature in the estuary (1.3ha or 3% of the available intertidal habitat) and localised to channel margins and within depositional areas of salt marsh. Subtidal growths were also evident.
- Salt marsh, mainly rushland, was the dominant vegetation type (26.9ha 44.3% of the intertidal area). Historic drainage and reclamation of salt marsh has been extensive. No intertidal seagrass was recorded.
- The 200m terrestrial margin was 42.5% densely vegetated and dominated by exotic forest and gorse/ broom.
- The catchment is highly modified with 77.2% exotic forest, and 12% high-producing grassland.
- The Estuary Trophic Index (ETI) score (0.523) indicated moderate nutrient enrichment (eutrophication).

The broad scale indicators, summarised in the table below, show Akatore Estuary was in 'good' to 'very good' condition with respect to salt marsh, macroalgae and high enrichment conditions. Mud extent and sedimentation rate were rated 'fair' to 'poor' indicating that fine sediment is the primary issue in the estuary.

Broad Scale Indicators	Unit	2021 Value	November 2021
Estuary Trophic Index (ETI) Score	No unit	0.523	Fair
Mud-dominated substrate	% of intertidal area >50% mud	13.7 (13.7)[1]	Fair
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.881	Very Good
Seagrass	% decrease from baseline	-	*baseline year*
Salt marsh extent (current)	% of intertidal area	44.3	Very Good
Historical salt marsh extent[2]	% of historical remaining	70[2]	Good
200m terrestrial margin	% densely vegetated	42.5	Fair
High Enrichment Conditions	ha	0.2	Very Good
High Enrichment Conditions	% of estuary	0.3	Very Good
Sedimentation rate[2]	CSR:NSR ratio[3]	2.2	Fair
Sedimentation rate[2]	mm/yr	3.2	Poor

Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. [1]In brackets mud-dominated sediment outside salt marsh [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

RECOMMENDATIONS

- Repeat the broad scale habitat mapping at 5-10 yearly intervals to track long term changes in estuary condition.
- Explore options to further protect and enhance existing salt marsh and wetland habitat
- Assess contemporary and historic sediment sources, and management options of major inputs.
- Establish sediment plate monitoring sites to measure temporal changes in sedimentation and mud content.
- Include Akatore Estuary in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will continue to protect the high ecological quality of the estuary and its catchment.

1. INTRODUCTION

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 based on the methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c), or extensions of that approach.

NEMP monitoring is primarily designed to detect and understand changes in estuaries over time and determine the effect of catchment influences, especially those contributing to the input of nutrients and muddy sediments. Excessive nutrient and fine sediment inputs are a primary driver of estuary eutrophication symptoms such as prolific macroalgal (seaweed) growth, and poor sediment condition.

The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results provide a valuable basis for establishing a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

The current report describes the methods and results of broad scale monitoring undertaken in Akatore Estuary on 28 November 2021 (Fig. 1). The primary purpose of the current work was to characterise substrate and the presence and extent of seagrass, macroalgae and salt marsh.

Akatore Estuary, salt marsh in the northern arm

Map data © OpenStreetMap contributors, Microsoft, Esri Community Maps contributors, Map layer by Esri, LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Fig. 1. Location of Akatore Estuary, Otago.

2. BACKGROUND TO AKATORE ESTUARY

Akatore Estuary is a medium sized (69ha) estuarine system located ~50km south of Dunedin on New Zealand's south coast. The estuary is a shallow, intertidally dominated (~88%) estuary (SIDE) with a flushing time of ~5 days (Plew et al. 2018). The residence time, particularly in the upper tidal reaches, means the estuary is susceptible to nutrient driven water column problems on occasion (e.g. phytoplankton blooms; Plew et al. 2018). The estuary also has the capacity to retain fine sediments and sediment-bound nutrients in deposition areas making it susceptible to both nutrient enrichment and fine sediment impacts.

The main freshwater inflows are Akatore Creek (Whakatōrea) to the northwest and Stoneygrove Creek to the west, along with several other smaller streams. The mean freshwater inflow of 0.69m^3/s represents ~31% of the total estuary volume (Plew et al. 2018). Hydrology has been significantly modified with roads constructed through the estuary, culverts and a causeway in the northern arm, and drainage channels through wetland and salt marsh areas (see photos on following page).

The estuary drains a 6,945ha catchment that has been significantly modified with only small areas (6.7%) of indigenous vegetation remaining (Table 1; Fig. 2). While the catchment is 87.9% densely vegetated, this is dominated by 68.8% exotic forest, 8.4% harvested exotic forest and 3.9% gorse and/or broom (Table 1; Fig. 2). High producing exotic grassland comprises 12.0% of the catchment area, approximately half of it located in the upper catchment and half directly adjacent to the estuary.

While large areas of salt marsh and freshwater wetland have been lost due to historic burning, drainage and land-use change, extensive areas remain and are recognised as regionally significant in the ORC Regional Plan: Water for Otago. The area is an important habitat for the at risk (declining) South Island fernbird (mātātā) and the at risk (naturally uncommon) herbfield species *Thyridia (Mimulus) repens* - New Zealand musk (ORC Regional Plan: Water 2004).

Birdlife are abundant both on the intertidal flats and within salt marsh, with spur-winged plover, yellowhammer, redpoll, Australasian harrier, pied stilt, variable oystercatcher, and South Island fernbird (mātātā) recorded previously (Rate & Lloyd 2012). In 2016, a marine protected area with fishery restrictions was proposed for Akatore Estuary to prevent overfishing of shellfish and other fish species including flounder (pātiki) and eels (tuna) (SEMPF, 2016). Cockles (tuaki) in Akatore Estuary are a customary mahinga kai resource for Kāi Tahu and are also collected recreationally (SEMPF, 2016).

Despite significant catchment modification the estuary retains high ecological, cultural and social values in addition to areas of protected salt marsh and wetland habitat.

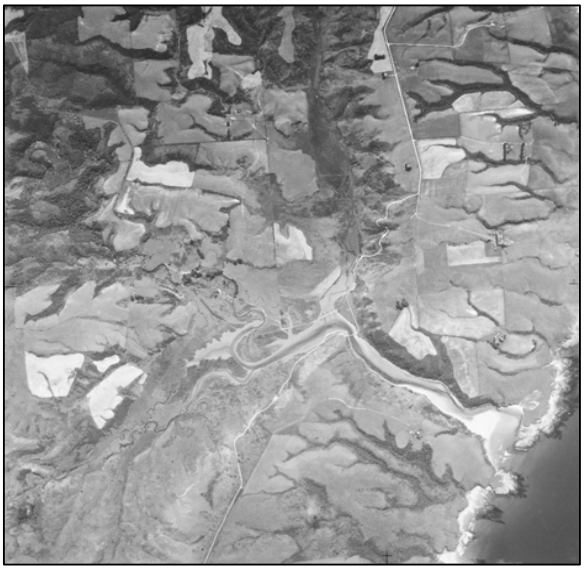
Table 1. Summary of catchment land cover (LCDB5 2017/18) Akatore Estuary.

LCDB5 (2017/2018) Catchment Land Cover	Ha	%
10 Sand or Gravel	4.6	0.1
21 River	1.7	0.02
40 High Producing Exotic Grassland	831.1	12.0
41 Low Producing Grassland	4.8	0.1
46 Herbaceous Saline Vegetation	79.0	1.1
51 Gorse and/or Broom	271.1	3.9
52 Manuka and/or Kanuka	103.1	1.5
54 Broadleaved Indigenous Hardwoods	251.5	3.6
64 Forest - Harvested	584.9	8.4
68 Deciduous Hardwoods	2.3	0.03
69 Indigenous Forest	33.0	0.5
71 Exotic Forest	4777.9	68.8
Grand Total	6944.8	100
Total densely vegetated area (LCDB classes 45-71)	6102.6	87.9

Akatore Estuary, pasture and wetland in the background and forestry (recently harvested and replanted) in the foreground

Aerial photo showing altered hydrology in the northern arm (top) and close up of road and culverts (bottom)

Drainage channel through salt marsh (top) and remnants of an old bridge causeway in the northern arm (bottom)



Akatore Estuary in 1946, hydrology was already modified and land mostly cleared

Aerial imagery showing dark green exotic forest along the east of the estuary in 2006 (top) and in 2019 (bottom) after harvesting

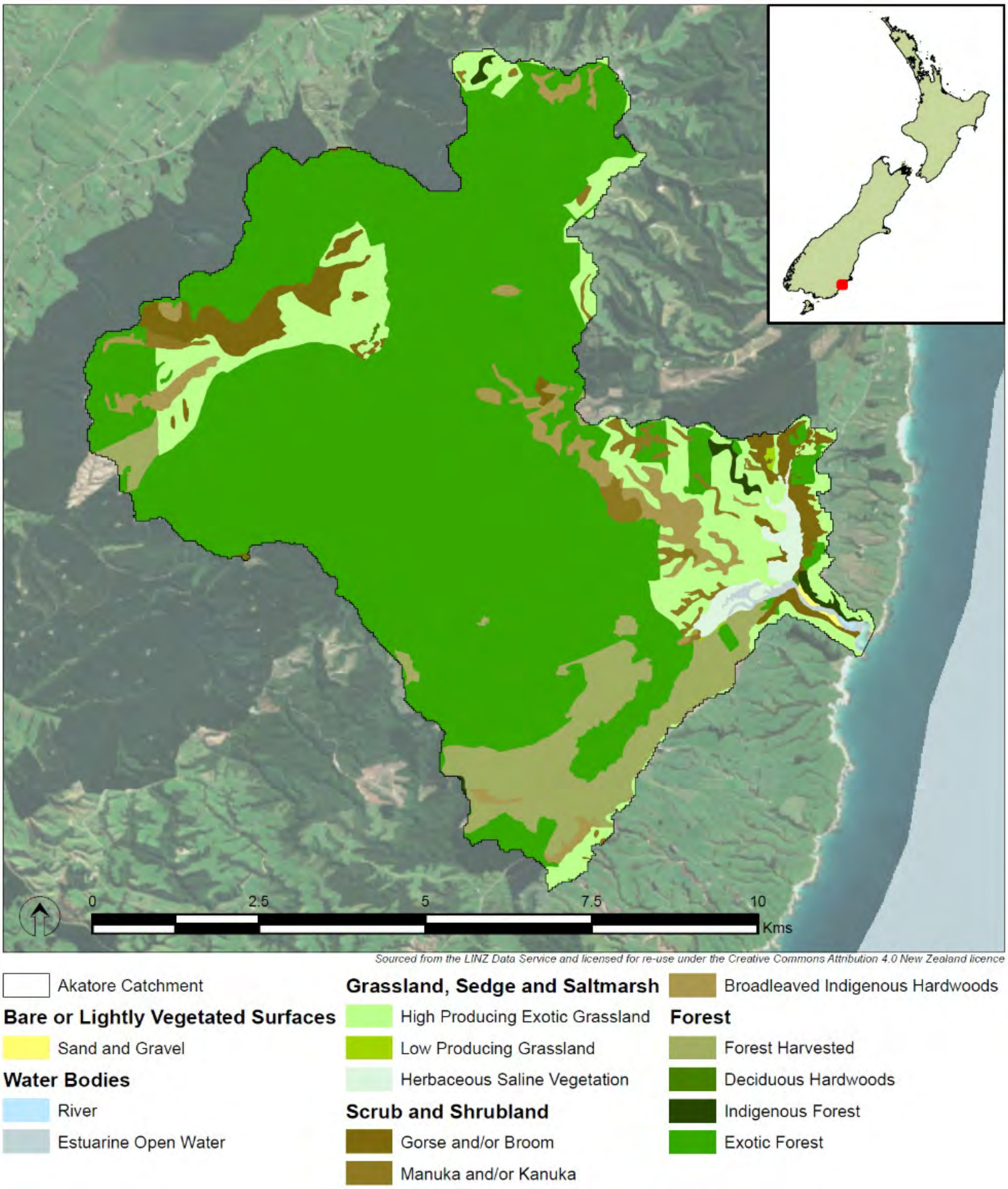


Fig. 2. Akatore Estuary catchment land use classifications from LCDB5 (2017/2018) database.

Salt marsh and gorse/broom on the margin of the northeast arm of Akatore Estuary

3. METHODS

3.1 BROAD SCALE MAPPING METHODS

Broad scale surveys involve describing and mapping estuaries according to dominant surface habitat features (substrate and vegetation). The type, presence and extent of substrate, salt marsh, macroalgae or seagrass reflects multiple factors, for example the combined influence of sediment deposition, nutrient availability, salinity, water quality, clarity and hydrology. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to small scale temporal variation associated with instantaneous water quality measures.

NEMP methods (Appendix 1) were used to map and categorise intertidal estuary substrate and vegetation. The mapping procedure combines aerial photography, detailed ground-truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats can be monitored by repeating the mapping exercise. Broad scale mapping is typically carried out during September to May when most plants are still visible and seasonal vegetation has not died back. Aerial photographs are ideally assessed at a scale of less than 1:5000, as at a broader scale it becomes difficult to accurately determine changes over time.

In 2021, imagery was supplied by ORC (0.3m/pixel colour aerial imagery captured in the summer of 2018-2019). Ground-truthing was undertaken on 28 November 2021 by experienced scientists who assessed the estuary on foot to map the spatial extent of dominant vegetation and substrate. A particular focus was to characterise muddy sediment (as a key stressor), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats. The latter were estuarine seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the 200m terrestrial margin bordering the estuary. Background information on the ecological significance of opportunistic macroalgae and the different vegetation features is provided in Table 2.

In the field, features were drawn directly onto 1:3000 scale laminated aerial photographs. The broad scale features were subsequently digitised into ArcMap 10.6 shapefiles using a Huion Kamvas 22 drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features, e.g. salt marsh, and its underlying substrate type.

For broad scale mapping purposes, an estuary is defined as a partly enclosed body of water, where freshwater inputs (i.e. rivers, streams) mix with seawater. The estuary entrance (i.e seaward boundary) was defined as a straight line between the seaward-most points of land that enclose the estuary, and the upper estuary boundary (i.e. riverine boundary) was based on the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For further detail see FGDC (2012).

Assessment criteria, developed largely from previous broad scale mapping assessments, apply thresholds for helping to assess estuary condition. Additional details on specific broad scale measures are provided in Sections 3.2-3.7 and are summarised in Table 3.

Channel through rushland in Akatore Estuary

Gorse growing on the estuary margin of Akatore Estuary

Table 2. Overview of the ecological significance of various vegetation types.

Habitat	Description
Terrestrial margin vegetation	A densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important food source and habitat for a variety of species and, in waterway riparian zones, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity.
Salt marsh	Salt marsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important in estuaries as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds and provides an important habitat for a variety of species including fish and birds.
Seagrass	Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

3.2 SUBSTRATE CLASSIFICATION AND MAPPING

Substrate classification in the NEMP is based on the dominant surface features present, e.g. rock, boulder, cobble, gravel, sand, mud. Salt Ecology has revised the NEMP substrate classifications for sand and mud (summarised in Appendix 1) by dividing previously merged categories of 'firmness' and 'muddiness' into independent categories. For 'muddiness', categories were defined relative to sediment mud content, which can be subjectively assessed in the field and validated using laboratory analyses. In 2021, 9 sediment grain size samples were collected to validate field classifications of substrate type (Appendix 2).

Salt Ecology has also extended the NEMP methodology to record the substrate present beneath vegetation. These extensions enable a continuous substrate layer for the estuary to be produced. Improved characterisation of sediment muddiness facilitates its assessment as a potential determinant of habitat condition and a driver of ecological change.

The area (horizontal extent) of mud-dominated sediment is used as a primary indicator of sediment mud impacts and in assessing susceptibility to nutrient enrichment impacts (trophic state).

Mobile sands near the estuary entrance

Soft muddy-sand in the mid estuary

3.3 SEDIMENT OXYGENATION

The apparent Redox Potential Discontinuity (aRPD) depth was used to assess the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment. The aRPD depth is the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). aRPD depth provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions. Sediments were considered to have poor oxygenation if the aRPD was consistently <10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. As significant sampling effort is required to map sub-surface conditions accurately, the approach is intended as a preliminary screening tool to determine the need for additional sampling effort. The aRPD depth was recorded at all grain size locations collected from representative substrate types (Appendix 2).

Example of distinct colour change with depth, brown oxygenated sediments are on the surface down to ~10mm

3.4 MACROALGAE ASSESSMENT

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature. To address this the ETI (Robertson et al. 2016b) adopted the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach. The OMBT, described in detail in Appendix 3, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within five overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- *Percentage cover of opportunistic macroalgae:* The spatial extent and surface cover of algae present in intertidal soft sediment habitat in an estuary provides an early warning of potential eutrophication issues.
- *Macroalgal biomass:* Biomass provides a direct measure of macroalgal growth (wet weight biomass). Measurements and estimates of mean biomass are made within areas affected by macroalgal growth, as well as across the total estuary intertidal area.
- *Extent of algal entrainment into the sediment matrix:* Macroalgae is defined as entrained when growing in stable beds or with roots deep (e.g. >30mm) within the sediments, which indicates that persistent macroalgal growths have established.

If an estuary supports <5% opportunistic macroalgal cover in total within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' (EQR score ≥ 0.8 to 1.0) with no further sampling required. A numeric EQR score is calculated for the 'high' band using the approach described in Stevens et al. (2022).

Using the OMBT approach, opportunistic macroalgae patches were mapped during field ground-truthing using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (Fig. 3). Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the extent of macroalgal entrainment were measured.

Sampling macroalgal biomass in Akatore Estuary

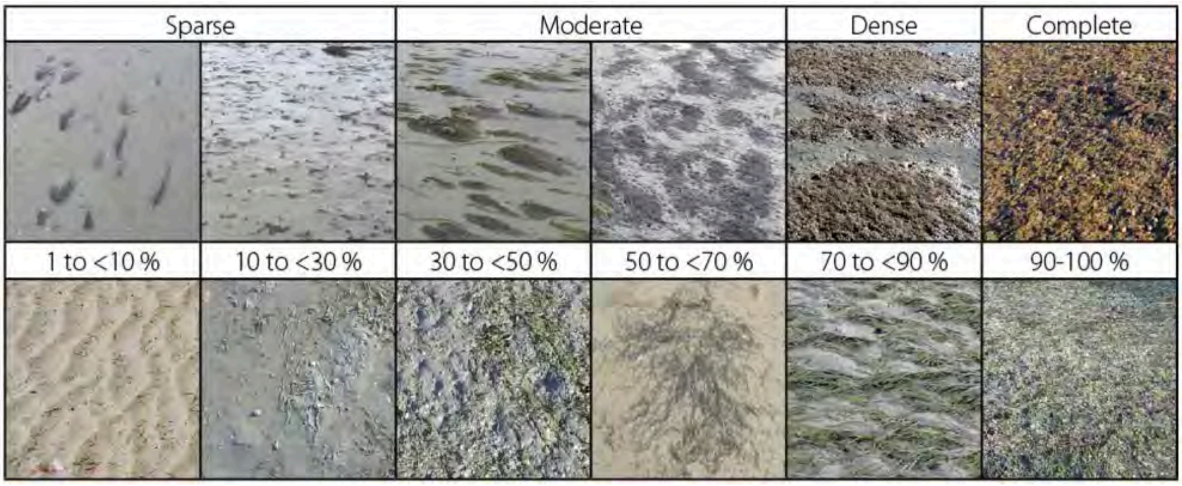


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

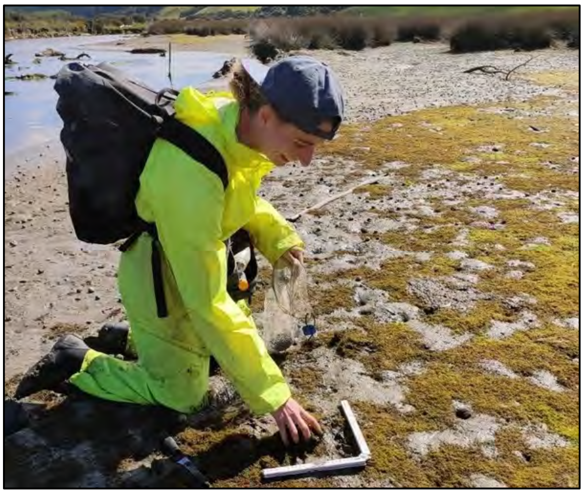
Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algal material was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale. When sufficient representative patches had been measured to enable biomass to be reliably estimated, biomass estimates were made following the OMBT method. Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on the five-point scale adopted by the method as noted above.

3.5 SEAGRASS ASSESSMENT

As for macroalgae, the percent cover of seagrass patches was visually estimated through ground-truthing, based on the 6-category percent cover scale in Fig. 3.

3.6 SALT MARSH

NEMP methods were used to map and categorise salt marsh, with dominant estuarine plant species used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock; Robertson et al. 2002a-c; Appendix 1). Two measures were used to assess salt marsh condition: i) intertidal extent (percent cover) and ii) current extent compared to estimated historical extent. Historic aerial imagery was used to estimate historical extent.



Sampling biomass in Aaktore Estuary at ETI Site 1

Herbfield and rushland in Akatore Estuary

3.7 TERRESTRIAL MARGIN

Broad scale NEMP methods were used to map and categorise the 200m terrestrial margin using the dominant land cover classification codes described in the Landcare Research Land Cover Data Base (LCDB) detailed in Appendix 1.

Newly planted forestry on estuary margin, Akatore Estuary

Gorse and mixed exotic forest on the margin, Akatore Estuary

Pasture on the estuary margin, Akatore Estuary

3.8 WATER QUALITY

At three sampling locations, water quality measures were taken from ~20cm below the water surface and 5cm from the bottom to assess whether there was any salinity or temperature stratification. Water column measures of pH, salinity, dissolved oxygen (DO), temperature and chlorophyll-a (as an indicator of phytoplankton presence) were made using a YSI Pro10 meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Care was taken not to disturb bottom sediments before sampling. Stratification, where present, was recorded along with water depth and clarity (Secchi depth).

Measuring water quality in the mid estuary

3.9 SEDIMENT QUALITY & MACROFAUNA

Sediment quality and macrofauna samples were collected from three sites and used as supporting indicators to calculate an ETI score for the estuary (Robertson et al. 2016b). The ETI requires supporting indicators represent the 10% of the estuary most susceptible to eutrophication (Zeldis et al. 2017).

At each of the three locations, a surface (~20mm) sediment sample was collected, stored on ice, and sent to RJ Hill Laboratories for analysis of the following: particle grain size in three categories (%mud <63μm, sand <2mm to ≥63μm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP) and total sulfur (TS). Details of laboratory methods and detection limits are provided in Appendix 2.

At each site, one sample for macrofauna was collected using a large sediment core (130mm diameter, 150mm deep). The core was extruded into a 0.5mm mesh sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a mixture of 75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification by NIWA. The types of animals present in each sample, as well as the range of different species (i.e. richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments (see Forrest et al. 2022).

Eutrophic ETI Site 2 (top) and Site 3 (bottom)

3.10 DATA RECORDING AND QA/QC

Broad scale mapping provides a rapid overview of estuary substrate, macroalgae, seagrass and salt marsh condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial imagery, the extent of ground-truthing undertaken to validate features visible on photographs, and the experience of those undertaking the mapping. In most instances features with readily defined edges can be mapped at a scale of ~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse seagrass or macroalgal beds. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed, but when relying on photographs alone, accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

In November 2021, following digitising of habitat features, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables.

As well as annotation of field information onto aerial photographs during the field ground-truthing, point estimate macroalgal data (i.e. biomass and cover measurements, entrainment), along with supporting measures of sediment aRPD, texture and sediment type were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP.

3.11 ASSESSMENT OF ESTUARY CONDITION

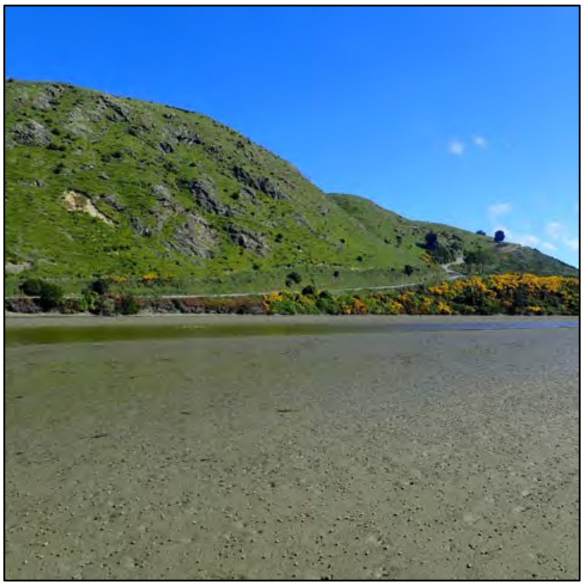
In addition to the authors' expert interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 3). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3. The condition ratings are primarily sourced from the ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 4. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores (i.e. which range from 'high' to 'bad').

The thresholds used to place biomass into OMBT bands have been recently revised for use in New Zealand (Plew et al. 2020) and are included in Appendix 3.

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HECs) was evaluated. For our purposes, HECs are defined as mud-dominated sediments (≥50% mud content) with >50% macroalgal cover and with macroalgae entrained and growing as stable beds rooted within the sediment. These areas typically also have an aRPD depth shallower than 10mm due to sediment anoxia.

Looking down on salt marsh in the southeast arm, forestry in the foreground

As many of the scoring categories in Table 3 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).



Mudflats in lower estuary

Table 3. Indicators used to assess results in the current report.

Indicator	Unit	Very good	Good	Fair	Poor
Broad scale Indicators					
ETI score[1]	No unit	≤ 0.25	>0.25 to 0.5	>0.5 to 0.75	>0.75 to 1.0
Mud-dominated substrate[2]	% of intertidal area >50% mud	< 1	1 to 5	> 5 to 15	> 15
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥0.8 to 1.0	≥0.6 to <0.8	≥0.4 to <0.6	0.0 to <0.4
Seagrass[2]	% decrease from baseline	< 5	≥ 5 to 10	≥ 10 to 20	≥ 20
Salt marsh extent (current)[2]	% of intertidal area	> 20	> 10 to 20	> 5 to 10	0 to 5
Historical salt marsh extent[2]	% of historical remaining	≥ 80 to 100	≥ 60 to 80	≥ 40 to 60	< 40
200m terrestrial margin[2]	% densely vegetated	≥ 80 to 100	≥ 50 to 80	≥ 25 to 50	< 25
High Enrichment Conditions[1]	ha	< 0.5	≥ 0.5 to 5	≥ 5 to 20	≥ 20
High Enrichment Conditions[1]	% of estuary	< 1	≥ 1 to 5	≥ 5 to 10	≥ 10
Sedimentation rate[1]	CSR:NSR ratio*	1 to 1.1 xNSR	1.1 to 2	2 to 5	> 5
Sedimentation rate[3]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Sediment quality					
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to ≤ 20	≤ 10

[1] General indicator thresholds derived from a New Zealand Estuary Tropic Index (Robertson et al. 2016b), with adjustments for aRPD (FGDC 2012). See text and Appendix 4 for further explanation of the origin or derivation of the different metrics.

[2] Subjective indicator thresholds derived from previous broad scale mapping assessments.

[3] Ratings derived or modified from Townsend and Lohrer (2015).

*CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

4. RESULTS

A summary of the 28 November 2021 survey in Akatore Estuary is provided below, with additional information in the appendices. Supporting GIS files (supplied to ORC as a separate electronic output) provide a more detailed dataset designed for easy interrogation and to address specific monitoring and management questions.

4.1 SUBSTRATE

Table 4 and Fig. 4 show the dominant substrates were firm muddy sand (>25-50% mud; 45% of the estuary), predominantly located among salt marsh in the upper tidal range, and mobile sand (8.8ha, 14.6%) and firm sand (6.9ha, 11.4%) in the lower estuary. Elsewhere, unvegetated intertidal flats in the upper estuary were dominated by soft sandy mud, with areas of very soft sandy mud localised to channel margins and around the fringes of salt marsh. Soft muddy sand (>25-50% mud) was the dominant substrate type In the mid estuary (5.3ha, 8.7%). Rock field was most prominent toward the estuary entrance (Fig. 4) along with small areas of gravel, while zootic habitat (shellbank) comprised only (0.02%) in the lower estuary intertidal area. There was very good agreement between the subjective assessment of substrate class and the laboratory analysed sediment validation samples (Appendix 2).

Upper estuary intertidal flats (top) and near the channel margin (bottom) comprising sandy mud

Table 4. Summary of dominant intertidal substrate, Akatore Estuary, November 2021.

Substrate Class	Features	Ha	%
Artificial	Boulder field	0.02	0.04
	Gravel field	0.01	0.01
Bedrock	Rock field	1.6	2.6
Boulder/Cobble/ Gravel	Boulder field	0.1	0.1
	Cobble field	0.1	0.2
	Gravel field	0.9	1.5
Sand (0-10% mud)	Mobile sand	8.8	14.6
	Firm sand	6.9	11.4
Muddy Sand (>10-25% mud)	Firm muddy sand	1.5	2.4
Muddy Sand (>25-50% mud)	Firm muddy sand	27.2	44.8
	Soft muddy sand	5.3	8.7
Sandy Mud (>50-90% mud)	Firm sandy mud	0.7	1.2
	Soft sandy mud	5.6	9.2
	Very soft sandy mud	2.0	3.4
Zootic	Shell bank	0.01	0.02
Total		**60.7**	**100**

Gravel in the lower estuary

Shellbank on firm sands in the lower estuary

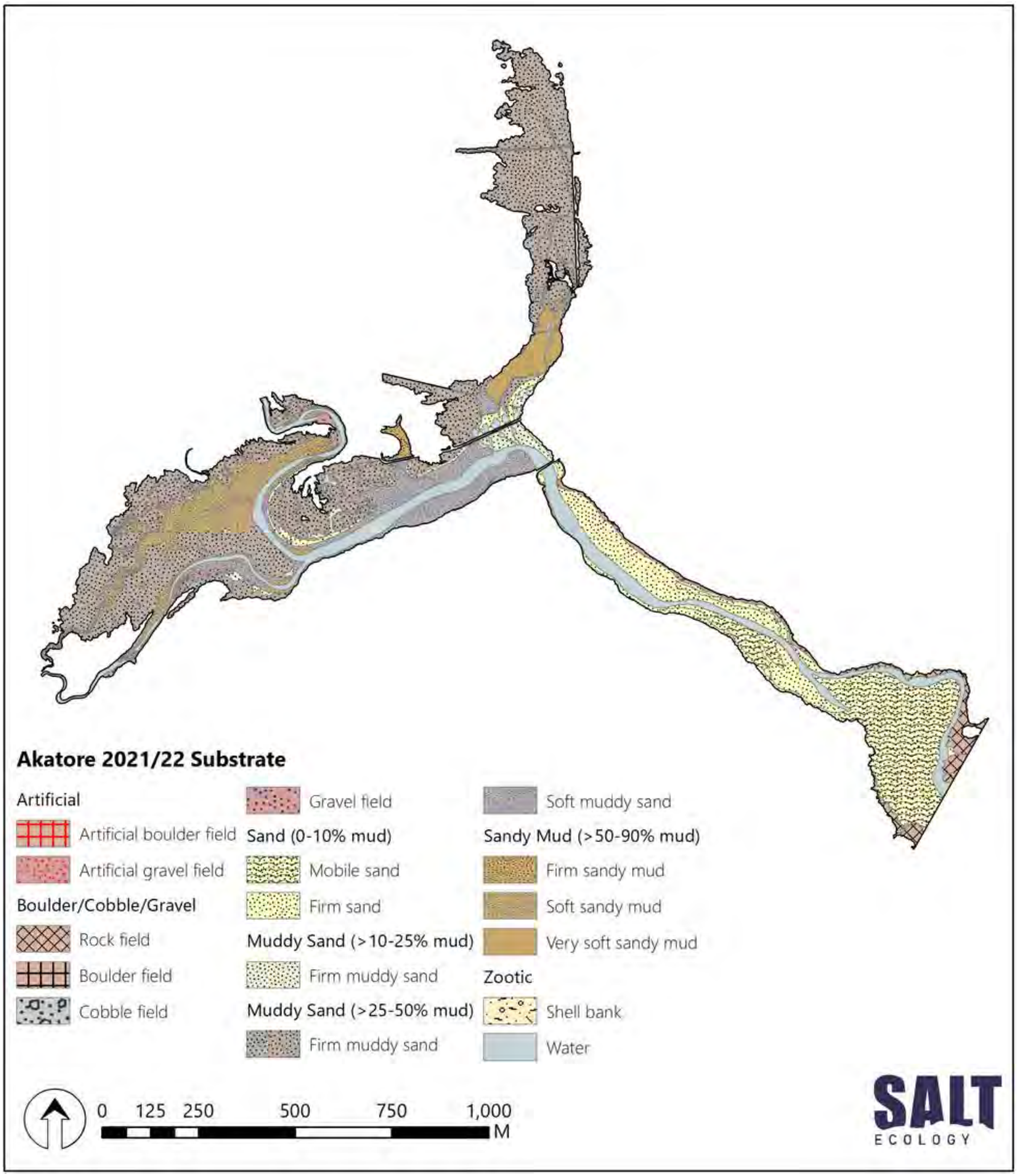


Fig. 4. Distribution of dominant surface substrate types recorded in Akatore Estuary, November 2021.

Rock field and mobile sands at the estuary entrance

4.2 SEDIMENT OXYGENATION

Sediment oxygenation was measured within representative substrate types to assess the trophic state of the sediment. In November 2021, spot measurements of aRPD showed that sand-dominated sediments were well oxygenated, while firm muddy sands in the mid to upper estuary generally had a relatively shallow aRPD (<10mm - see photo) indicating organic enrichment.

The shallowest aRPD depths occurred in sediments with elevated mud or organic content. For example, near stream inputs, deposition areas or in the presence of macroalgae. Areas of poor sediment oxygenation were most common in the upper estuary.

Shallow aRPD in firm muddy sand (10-25% mud)

Soft sandy mud (left) and mud (right) with shallow aRPD

4.3 MACROALGAE

4.3.1 Opportunistic macroalgae

Table 5 summarises macroalgae percentage cover and biomass classes, with the mapped cover and biomass shown in Figs 5 and 6 respectively. Macroalgal sampling stations and data are provided in Appendix 5. Marine species and drift macroalgae were not recorded as part of the nuisance macroalgae assessment.

Table 5. Summary of intertidal macroalgal cover (A) and biomass (B), Akatore Estuary, November 2021.

A. Percent Cover

Percent cover category	Ha	%
Absent or trace (<1%)	59.4	97.8
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	0.1	0.2
Low-Moderate (30 to <50%)	0.0	0.0
High-Moderate (50 to <70%)	0.2	0.3
Dense (70 to >90%)	1.0	1.7
Complete (>90%)	0.03	0.1
Total	60.7*	100.0

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	59.4	97.8
Very low (1 - 100)	0.0	0.0
Low (101 - 200)	0.1	0.2
Moderate (201 - 500)	0.0	0.0
High (501 - 1450)	0.5	0.8
Very high (>1450)	0.8	1.3
Total	60.7*	100.0

* Total intertidal area including salt marsh

Shallow aRPD in soft sandy mud with complete macroalgae cover

Agarophtyon spp. growing on soft sandy muds in the mid estuary

Key macroalgae results were as follows:

- Very little macroalgae was present in the estuary. Cover was classified as absent or trace (<1%) across 97.8% of the intertidal area (Table 5A). Within the Available Intertidal Habitat (AIH) the Affected Area (AA), where macroalgae were growing, was small (1.3ha, 3.9%; Fig. 5; Table 6).
- When present, macroalgal patches generally exceeded 50% cover (1.2ha) and were located in the upper western arm of the estuary. They were dominated by the green seaweed *Ulva* spp. growing on soft and very soft sandy muds (see photos). Underlying sediments had a shallow aRPD indicating organic enrichment and sediment degradation.
- Mean wet weight biomass was low across the AIH (65.6g/m^2), but high in the very localised AA (1669g/m^2; Table 6), and at a level above which adverse ecological impacts are expected to occur.
- Subtidal macroalgae was common in the shallow channels in the upper estuary and near the estuary entrance and comprised both *Ulva* spp. and *Agarophyton* spp (see photos opposite).

Because the estuary had <5% opportunistic macroalgal cover across the AIH (3.0%; Table 6), the overall quality status using the OMBT method is reported as 'high' equivalent to the condition rating of 'very good' (Table 3). A numeric OMBT EQR score was calculated using only the % cover AIH sub-metric as described in Stevens et al. (2022). The numeric OMBT EQR score (0.881), reflects that macroalgae was not a dominant feature in the estuary and was largely confined to the channels and channel margins of the upper estuary.

Ulva spp. growing on soft sandy mud, near the channel

Agarophtyon spp. growing in the channel and on the margin

Ulva spp. and filamentous green algae on soft sandy muds

Table 6. Summary of OMBT input metrics, overall Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 3). ETI rating is based on criteria in Table 3.

Nov-2021 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	3.0*	0.881	High
Average biomass (g/m^2) in AIH	65.6	0.869	High
Average biomass (g/m^2) in AA	1669.0	0.197	Bad
% entrained in AA	26.4	0.357	Poor
Worst of AA (ha) and AA (% of AIH)		0.843	High
AA (ha)	*1.3*	*0.973*	*High*
AA (% of AIH)	*3.9*	*0.843*	*High*
Survey EQR		0.881*	'Very Good'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating
*Because there was <5% cover in the AIH, EQR score calculated from % cover AIH sub-metric only using the method in Stevens et al. (2022).

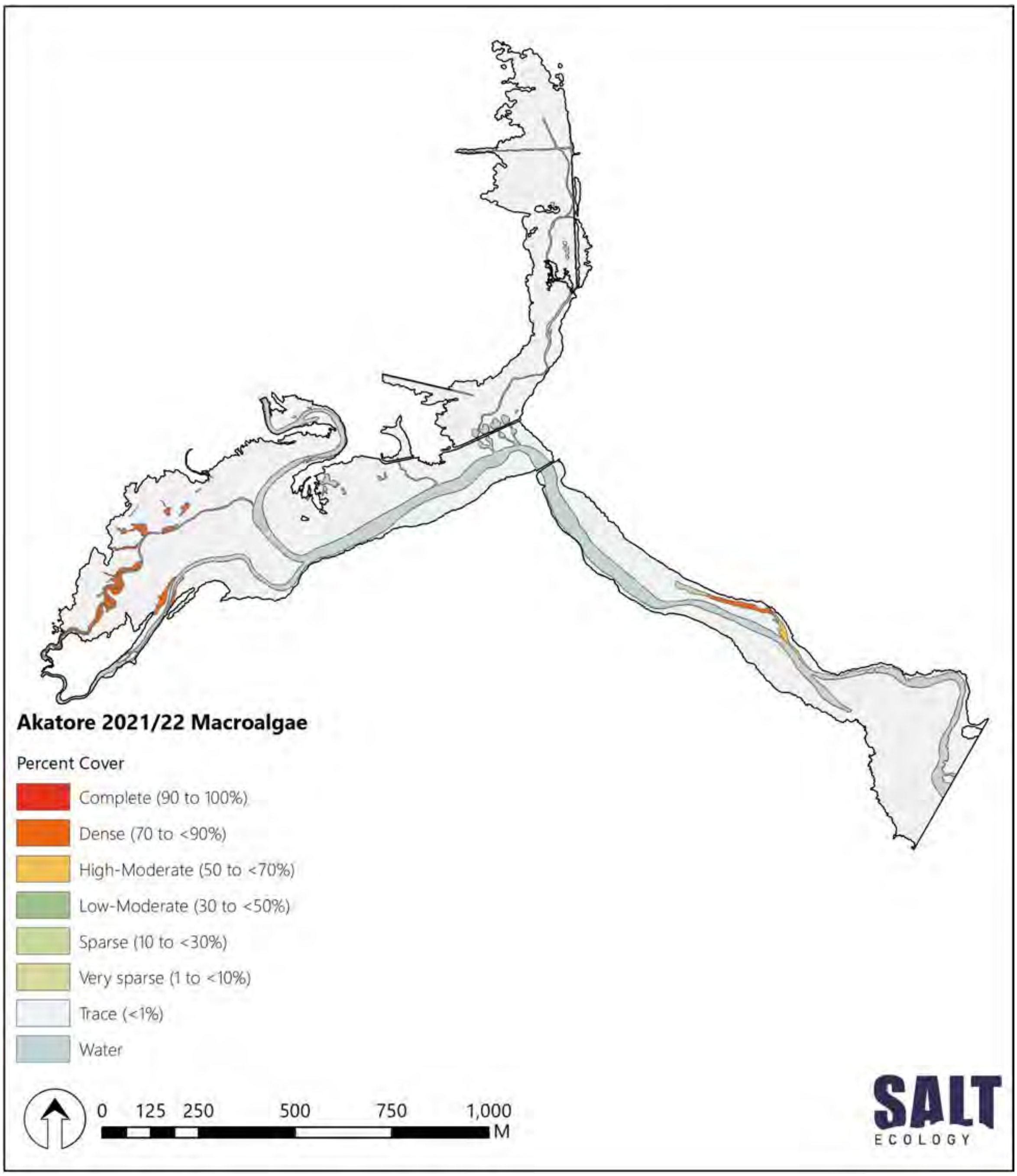


Fig. 5. Distribution and percent cover classes of macroalgae in Akatore Estuary, November 2021.

Ulva spp. and filamentous green algae growing on soft sandy mud on the channel margin in the western arm

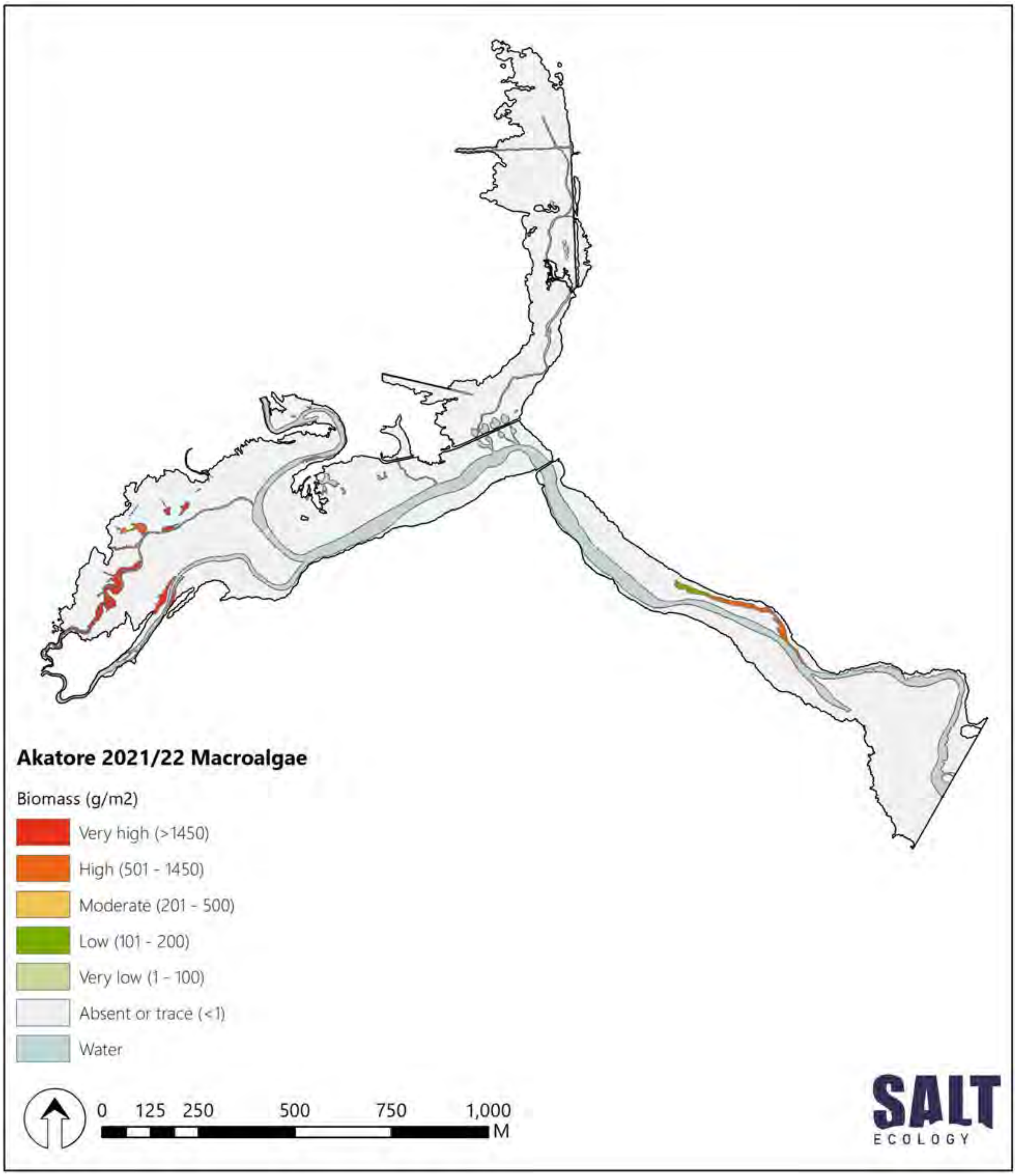


Fig. 6. Distribution and biomass classes of macroalgae in Akatore Estuary, November 2021.

Ulva spp. on the channel margin in the lower estuary associated with firm sands and gravel

4.3.2 Other macroalgae

In addition to opportunistic macroalgal species, a dark green filamentous mat-forming macroalga (identified by NIWA as *Vaucheria* sp.; Roberts et al. 2022) was growing in localised parts of the estuary. Because of the small extent present and overlap with opportunistic macroalgae, these growths were not mapped separately or characterised in detail.

Vaucheria sp. was present in the western arm on the channel margins and growing on eroding herbfield in the northern arm (see photos below). *Vaucheria* sp. was typically associated with soft sandy-mud growing as a smothering layer on the sediment surface. The underlying sediment was generally organically enriched and poorly oxygenated.

Mat of *Vaucheria* sp. growing in a bed of *Ulva* spp. on the channel margin in the western arm

Vaucheria sp. growing on eroding herbfield

4.3.3 High Enrichment Conditions

High Enrichment Condition (HEC) areas (mud-dominated sediments with >50% macroalgal cover entrained in stable beds) comprised 0.2ha (0.3% of the intertidal area). These areas were limited to small deposition zones in the upper estuary, particularly around channels and freshwater inputs (Appendix 6).

Areas of high enrichment conditions comrpising high macroalgal cover growing in very soft sandy mud

High enrichment conditions, thick macroalgal cover and anoxic muddy sediments above knee height

4.4 SEAGRASS

No intertidal seagrass was recorded in Akatore Estuary in November 2021.

4.5 SALT MARSH

Table 7 summarises intertidal salt marsh with the distribution mapped in November 2021 presented in Fig. 7. Dominant and subdominant species are recorded in Appendix 7. Salt marsh covered 26.9ha (44.3%) of the intertidal area and was most extensive in the upper estuary arms.

Table 7. Summary of salt marsh area (ha and %) in Akatore Estuary, November 2021.

Class	Ha	%
Estuarine Shrub	2.2	8.2
Sedgeland	0.1	0.4
Rushland	19.3	71.6
Herbfield	5.3	19.9
Total	26.9	100

The dominant class was rushland comprising 19.3ha (71.6% of total salt marsh). The dominant species was *Apodasmia similis* (Jointed wirerush). Estuarine shrubs comprised 2.2ha (8.2% of total salt marsh) and the dominant species was *Plagianthus divaricatus* (Salt marsh ribbonwood). Herbfield was present across 5.3ha (19.9% of total salt marsh) and the dominant species were *Selliera radicans* (Remuremu) and *Samolus repens* (Primrose). Other salt marsh species included *Sarcocornia quinqueflora* (Glasswort), *Thyridia repens* (New Zealand musk), *Cyperus ustulatus* (Giant umbrella sedge), *Coprosma propinqua subsp. propinqua* (Mingi mingi) and the rush *Isolepis cernua* (Slender clubrush). Introduced weeds and the grass *Festuca arundinacea* (tall fescue) were present in some areas. Vehicle damage was evident in the northwest of the estuary (see top photo opposite) and natural erosion of the herbfield margin was relatively common along seaward or channel margins.

Large areas of salt marsh have been historically drained with long straight channels remaining today, particularly in the northern arm. This has compromised much of the remaining salt marsh by limiting tidal inundation and allowing terrestrial weeds to become widely established. Many of these drained areas are grazed resulting in additional impacts from pugging and trampling.

Vehicle tracks through herbfield in the western arm

Apodasmia similis (Jointed wirerush) and *Plagianthus divaricatus* (Salt marsh ribbonwood)

Selliera radicans (Remuremu)

Eroding edge of *Samolus repens* (Primrose) herbfield

Historic drainage channels carved through rushland

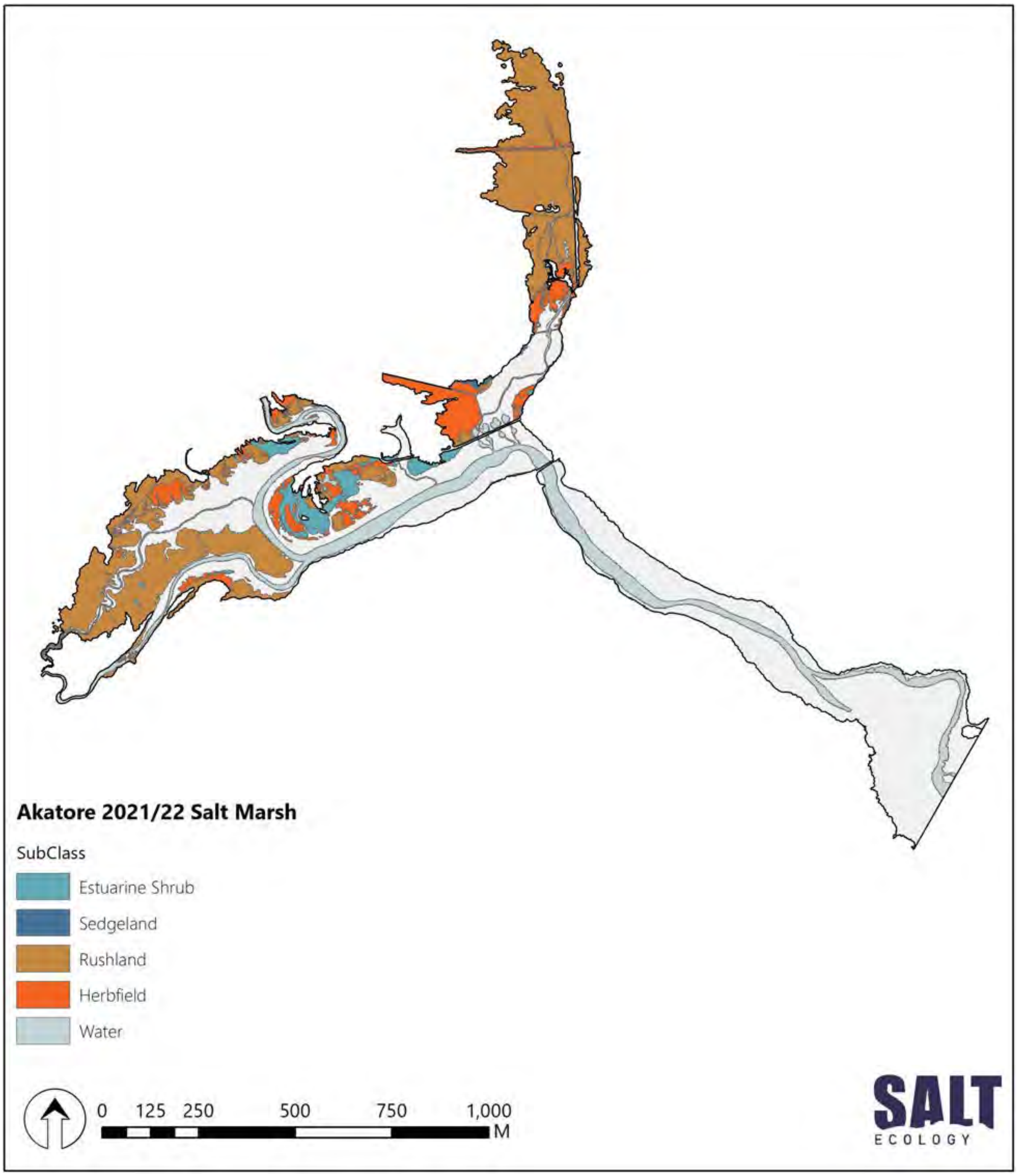


Fig. 7. Distribution of salt marsh in Akatore Estuary, November 2021.

Extensive areas of *Apodasmia similis* (Jointed wirerush) in the mid to upper estuary

Extensive areas of *Apodasmia similis* (Jointed wirerush) in the western arm, planted pine trees in the foreground

Salt marsh in the northern arm comprising herbfield, rushland and estuarine shrubs. Yellow flowers are gorse and broom.

4.6 TERRESTRIAL MARGIN

Table 8 and Fig. 8 summarise the land cover of the 200m terrestrial margin which was 42.5% densely vegetated, including extensive areas of gorse and/or broom (13.1%), exotic forest (13.5%) and small areas of native vegetation, i.e. broadleaved indigenous hardwoods (9.5%) and manuka and/or kanuka (2.6%). Both high-producing (27.3%) and low-producing (25.3%) grassland were a common feature in the terrestrial margin.

Gorse and pine near the estuary margin

Broadleaved indigenous hardwoods with small areas of exotic forest near the estuary entrance

Transition from herbfield, rushland, estuarine shrub through to native scrub

In areas of previously drained salt marsh, particularly in the northern arm, herbaceous freshwater vegetation (1.1%) was present. Both the salt marsh and freshwater wetland are classified as regionally significant in the Otago Regional Plan: Water for Otago (2004).

Upper boundary of the salt marsh habitat in the northern arm

Table 8. Summary of 200m terrestrial margin land cover, Akatore Estuary, November 2021.

LCDB5 Class		%
1	Built-up Area (settlement)	0.01
5	Transport Infrastructure	1.4
10	Sand and Gravel	0.4
16	Gravel and Rock	2.8
20	Lake or Pond	0.1
21	River	0.3
40	High Producing Exotic Grassland	27.3
41	Low Producing Grassland	25.2
45	Herbaceous Freshwater Vegetation	1.1
46	Herbaceous Saline Vegetation	0.5
47	Flaxland	1.1
50	Fernland	0.5
51	Gorse and/or Broom	13.1
52	Manuka and/or Kanuka	2.6
54	Broadleaved Indigenous Hardwoods	9.5
56	Mixed Exotic Shrubland	0.4
58	Matagouri or Grey Scrub	0.1
71	Exotic Forest	13.5
Total		100
Total dense vegetated margin (LCDB classes 45-71)		42.5

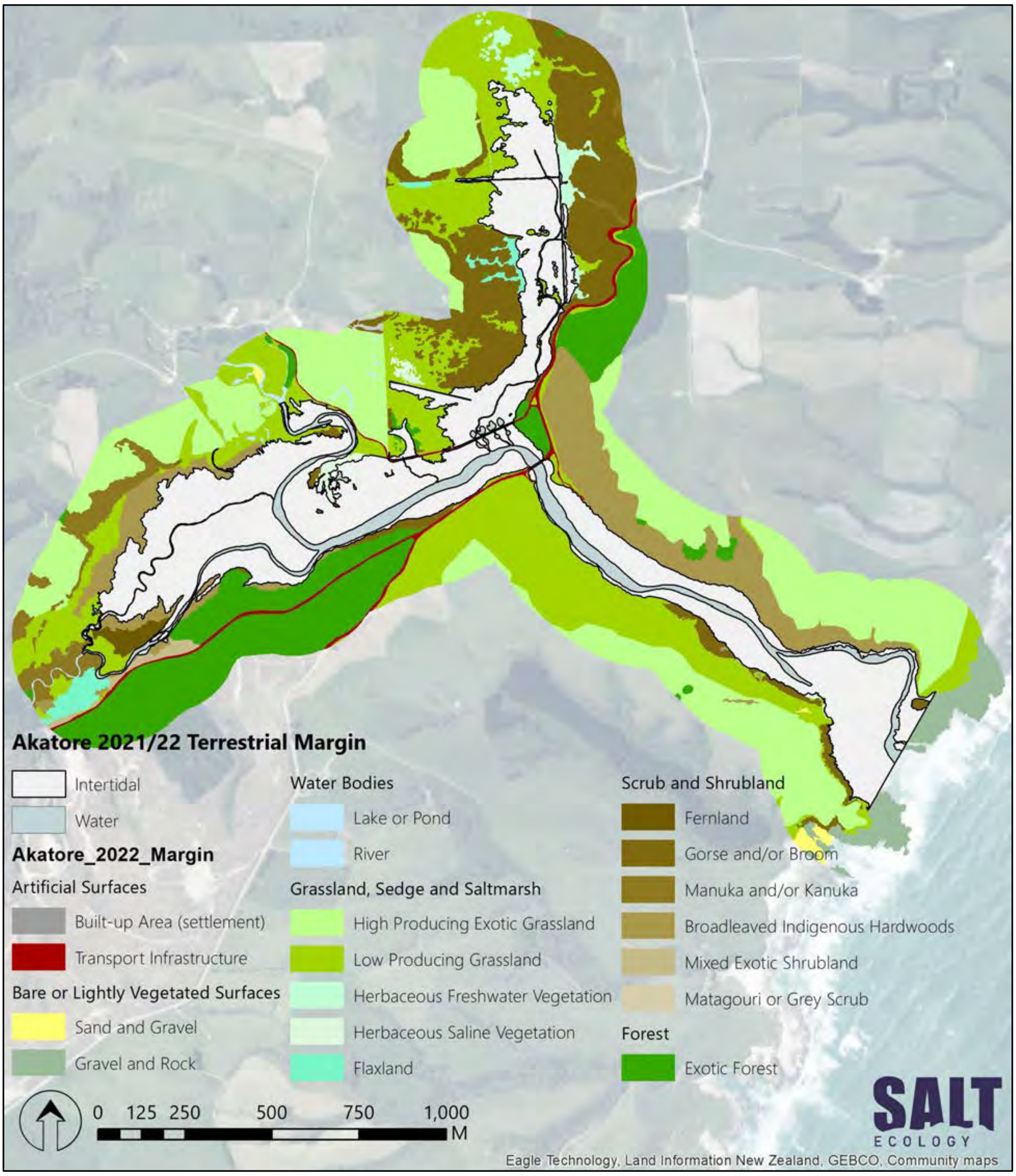


Fig. 8. Map of 200m terrestrial margin land cover, Akatore Estuary, November 2021.

Low producing pasture and exotic forest on the estuary margin

4.7 WATER QUALITY

Water quality data presented in Table 9 provides ancillary information to support the broad scale mapping survey. Three measurements were taken, one from Akatore bridge in the mid-lower estuary, and from two sites where water pools above the culverts under Akatore Creek Road (see map in Appendix 2).

Table 9. Water quality for Akatore Estuary, November 2021.

Station	Site 1 Pool	Site 2 Pool	Site 3 Bridge
NZTM East	1381661	1381714	1381844
NZTM North	4890390	4890412	4890305
Distance from mouth (m)	1500	1500	1350
Stratified	yes	no	yes
Surface measurements			
Measurement depth (m)	0.2	0.2	0.2
Temperature (°C)	24.8	16.3	20.5
DO saturation (%)	102.0	163.0	114.0
DO concentration (g/m^3)	8.4	12.0	10.0
Salinity	2.7	12.0	3.8
pH	8.7	8.4	8.5
Chlorophyll-a (mg/m^3)	9.4	2.2	4.5
Bottom measurements			
Measurement depth (m)	0.5	0.5	1.0
Temperature (°C)	16.2	16.3	16.1
DO saturation (%)	132.0	163.0	156.0
DO concentration (g/m^3)	10.9	12.0	12.5
Salinity	32.3	12.0	34.3
pH	8.2	8.4	8.2
Chlorophyll-a (mg/m^3)	4.5	2.2	11.5
Secchi depth (m)	>0.7	>0.7	>1.5
Max depth (m)	0.70	0.70	1.5
Channel width (m)[1]	15	15	40
Sediment texture	firm	firm	firm
Sediment type	sand	sand	sand

[1]Estimated at the time of sampling.

The poorly-flushed pool above the culvert at Site 1 was stratified and had high surface water temperatures and elevated chlorophyll-*a* relative to the other surface water sites. The pool at Site 2 was well mixed with no stratification observed. At all sites the water column was well oxygenated (>100% dissolved oxygen saturation) at the time of sampling.

As expected, the site closest to the estuary entrance (Site 3) exhibited higher salinity in the bottom water than the sites further upstream (Site 1 and 2). The main channel through the estuary was shallow (<1.5m) and stratified at the time of sampling with a freshwater layer overlying salt water (Site 3; Table 9). Chlorophyll-*a* was elevated in the bottom waters of the main channel, and appeared to reflect a marine source of phytoplankton.

While nutrients were not directly measured, observations of excess macroalgae growing in the subtidal channels throughout the estuary suggest there are sufficient nutrients to support excessive algal growths under suitable growing conditions.

Site 1, stratified water upstream of the road culvert near margin

Site 2, well mixed water upstream of the road culvert in centre

Site 3, Akatore bridge

4.8 ESTUARY TROPHIC INDEX (ETI)

Table 10 summarises the indicators used to calculate an overall ETI score for Akatore Estuary. Raw data for sediment metrics are presented in Appendix 8. The primary indicator of eutrophication response in SIDE type estuaries, like Akatore, is macroalgae (OMBT-EQR) with ETI supporting sediment indicators of macrofauna (AMBI), total nitrogen (TN), total organic carbon (TOC) and sediment oxygenation (aRPD) used to assess trophic state. The overall ETI score of 0.523 was rated 'fair' in terms of eutrophication, driven largely by sediment enrichment indicators. Areas of enrichment were localised to the upper estuary channels, channel margins and deposition areas within salt marsh habitat.

Table 10. Primary and supporting indicators used to calculate the ETI for Akatore Estuary.

Indicator	Raw Value	Equivalent ETI Score
Primary indicator		
Macroalgae (EQR)	0.881	0.188
Supporting Indicator		
AMBI	4.79	0.875
TN (mg/kg)	2700	0.813
TOC (%)	2.62	0.813
aRPD (mm)	4	0.934
Final ETI Score		0.523 "Fair"

High macroalgae cover in very soft sandy muds with shallow aRPD

Salt marsh (rushland) and unvegetated mud flats

5. SYNTHESIS OF KEY FINDINGS

Key broad scale indicator results and ratings are summarised in Table 11 and Table 12, and additional supporting data used to assess estuary condition are presented in Table 13.

Akatore Estuary was intertidally dominated (60.7ha or 87.5% of the estuary area) with subtidal areas comprising low tide channels and pools behind the road causeway. The estuary supported a variety of habitats including salt marsh, mudflats, rock field and firm and mobile sands. Large parts of the western arm are protected within the Department of Conservation Akatore Wildlife Management Area and the estuary salt marsh and adjacent freshwater wetland are classified as regionally significant in the Otago Regional Plan: Water for Otago (2004). While the estuary retains high ecological values (e.g. extensive salt marsh habitat), the catchment is extensively modified, salt marsh has been historically reclaimed and/or drained, there are localised areas of excess macroalgal growth, and muddy sediments are common.

Table 11. Summary of key broad scale features as a percentage of total estuary, intertidal or margin area, Akatore Estuary, November 2021.

a. Area summary	Ha	% Estuary
Intertidal area	60.7	87.5
Subtidal area	8.7	12.5
Total estuary area	**69.4**	**100**
b. Key substrate features	**Ha**	**% Intertidal**
Mud-enriched (25 to <50%)	32.5	53.4
Mud-dominated (≥50%)	8.3	13.7
c. Key habitat features	**Ha**	**% Intertidal**
Salt marsh	26.9	44.3
Seagrass (≥50% cover)	0.0	0.0
Macroalgal beds (≥50% cover)	1.2	2.0
d. Terrestrial margin (200m)		**% Margin**
200m densely vegetated margin		82.2

Mud-dominated sediments, a common stressor in New Zealand estuaries, comprised 8.3ha or 13.7% of the intertidal area and were common in the upper estuary intertidal flats and on the channel margins within salt marsh habitat (see photos). Deposition of fine sediments is promoted in the upper estuary because of salinity driven flocculation, low wave energy, altered hydrology (i.e. low flushing in the northern arm) and their close proximity to freshwater inputs. While estuaries naturally accumulate sediments, catchment land uses and modification to the estuary (e.g. salt marsh drainage, altered hydrology) can accelerate fine sediment deposition.

Mud-dominated anoxic sediments in the upper estuary

NIWA's national estuary sediment load estimator (Hicks et al. 2019) estimates sediment inputs and retention. This information can be used to calculate a net deposition rate in the estuary. The estuary is predicted to be highly efficient at trapping sediment (82% retention) and, if all of the retained sediment was spread evenly throughout the estuary, it would result in an overall average of ~3.2mm/yr of estuary infilling (Table 13), a condition rating of 'poor' (Table 12). Based on the relative difference in estimated yields from an undisturbed catchment, and assuming a further 50% attenuation from the historical presence of wetlands, the current sedimentation rate (CSR) based on land cover is estimated to be 2.2 times the natural sedimentation rate (NSR; Table 13). The condition rating for the CSR:NSR ratio is rated 'fair' (Table 12), but does not account for additional inputs expected from recent disturbance activities like forest harvesting.

The fine sediment deposition evident in Akatore Estuary is likely attributable to a combination of historic land clearance and salt marsh drainage, and more contemporary inputs, particularly from exotic forestry, the dominant land use type in the catchment (77.2%, Fig. 2). In 2018, there was extensive harvesting in the lower catchment and on the estuary margin (see photos pg. 3). It is well known that land disturbance activities associated with exotic forestry can cause high sediment inputs, particularly during harvest and in the post-harvest period before replanted forest reaches a closed canopy state (Green et al. 2014; Gibbs & Swales 2019). Known catchment sediment sources coupled with the sedimentation results and the large area of mud-dominated sediments (13.7%), reinforce that fine sediment issues are a cause for concern and should be carefully managed.

Recently re-planted pine on the estuary margin and plantation forestry in the background

Table 12. Summary of key broad scale indicator results and ratings.

Broad Scale Indicators	Unit	2021 Value	November 2021
Estuary Trophic Index (ETI) Score	No unit	0.523	Fair
Mud-dominated substrate	% of intertidal area >50% mud	13.7 (13.7)[1]	Fair
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.881	Very Good
Seagrass	% decrease from baseline	-	*baseline year*
Salt marsh extent (current)	% of intertidal area	44.3	Very Good
Historical salt marsh extent[2]	% of historical remaining	70[2]	Good
200m terrestrial margin	% densely vegetated	42.5	Fair
High Enrichment Conditions	ha	0.2	Very Good
High Enrichment Conditions	% of estuary	0.3	Very Good
Sedimentation rate[2]	CSR:NSR ratio[3]	2.2	Fair
Sedimentation rate[2]	mm/yr	3.2	Poor

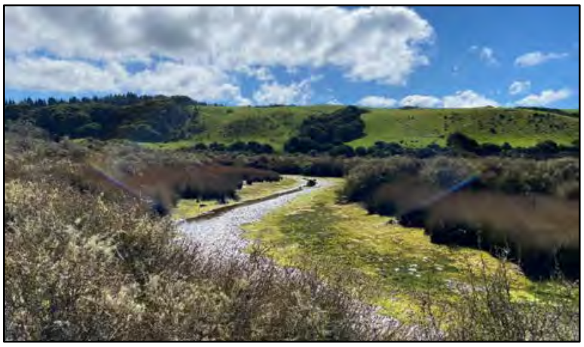
Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. [1]In brackets mud-dominated sediment outside salt marsh [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

Table 13. Supporting data used to assess ecological condition in Akatore Estuary.

Supporting Condition Measure	Akatore Estuary
Mean freshwater flow (m^3/s)[1]	0.44
Catchment Area (Ha)[1]	6945
Catchment nitrogen load (TN/yr)[2]	15.0
Catchment phosphorus load (TP/yr)[2]	1.5
Catchment sediment load (KT/yr)[1]	2.3
Estimated N areal load in estuary (mg/m^2/d)[2]	59.1
Estimated P areal load in estuary (mg/m^2/d)[2]	6.0
CSR:NSR ratio[1]	1.1
CSR:NSR ratio (50% natural wetland attenuation)	2.2
Trap efficiency (sediment retained in estuary; %)[1]	81.7
Estimated rate of sedimentation (mm/yr)[1]	3.2

[1] Hicks et al. 2019.

[2] CLUES version 10.6 (LCBD5), Run date: August 2022



Ulva spp. and *Vaucheria* sp. on channel margin

Ulva spp. and *Agarophyton* spp. growing around salt marsh

The macroalgae OMBT-EQR score (0.881) was rated 'very good', with an ETI score of 0.523 (rated 'fair'), indicating that while macroalgae was a minor feature in the estuary, comprising only 3.9% of the available intertidal habitat, affected sediments were showing signs of enrichment (e.g. low sediment oxygen, impoverished macrofauna community). Macroalgae was dominated by the green seaweed *Ulva* spp. and to a lesser extent *Agarophyton* spp. (previously known as *Gracilaria* spp.). Localised areas of *Vaucheria* sp., also recorded in Pleasant River Estuary (Roberts et al. 2022), were associated with areas of very soft muds and low sediment oxygen. Dense areas of macroalgae with very high biomass (>1450g/m^2) were confined to channel margins or in deposition zones around salt marsh habitat (see photos). A small (0.3%) area of high enrichment conditions (i.e. high macroalgal cover, mud-dominated sediments with low sediment oxygen) was located in the western arm. The absence of widespread nuisance macroalgae is consistent with a modelled nitrogen load of 59mgN/m^2/d, which is below the ~100mgN/m^2/d threshold at which nuisance macroalgae problems are predicted occur (Robertson et al. 2017; Table 13). However, localised areas of nuisance macroalgae, the presence of subtidal macroalgal growths particularly around freshwater inputs, and phytoplankton growths in pooled subtidal areas, all suggest nutrient loads should be managed to prevent any further expansion of macroalgae.

Salt marsh, mainly rushland, was the dominant vegetated habitat (Table 11). Salt marsh is an important feature of estuaries because it traps sediments and filters nutrients and also provides an important habitat for birds (e.g. South Island fernbird) and insects. While the salt marsh is extensive (a condition rating of 'very good'), large areas of salt marsh and the adjacent freshwater wetland have been reclaimed and/or drained (see photos). In the northern arm, drained areas have become more terrestrially dominated with introduced species including gorse and tall fescue now the dominant vegetation type in parts. Elsewhere, salt marsh has been converted to pasture which is the dominant land use type in the 200m terrestrial margin of the estuary (Table 8). In addition to the relatively large losses from historical drainage, smaller recent losses were due to localised vehicle damage near the road edge and the erosion of herbfield near river channels.

Drainage channel through *Apodasmia similis* (Jointed wirerush)

Drainage channel through transitional saline and freshwater wetland

In terms of historical losses, the estuary is rated 'good' with an estimated >70% of the natural salt marsh cover remaining (Table 12). As discussed above, drainage, reclamation and altered estuary hydrology have contributed to the losses over time, and an increase in terrestrial freshwater vegetation in areas previously dominated by salt marsh. While the salt marsh and freshwater wetland areas are protected from development under the Otago Regional Plan: Water for Otago, there is still significant scope for salt marsh and wetland restoration in Akatore Estuary. The largest gains are likely achieved through stock exclusion and from restoring the natural connectivity (i.e. upgrading culverts in the northern arm to improve estuary flushing), and re-flooding areas of existing or previous estuary habitat, particularly in areas where herbfield vegetation persists.

Herbfield growing areas reclaimed for pasture

Eroding herbfield on the channel edge

Seagrass is a common feature in many of the larger lagoon type Otago estuaries (e.g. Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea). However, seagrass was not recorded from Akatore Estuary, a result consistent with findings from similar SIDE estuaries across the region that have extensive areas of salt marsh habitat (e.g. Tautuku and Pleasant River), but a strong freshwater influence. It is uncertain whether seagrass would have grown in the estuary prior to human modification because of naturally limiting conditions to seagrass growth, in particular, a strong freshwater influence (low salinity) and/or high wave fetch and substrate mobility in the mid to lower estuary. A review of aerial imagery indicates that there was no seagrass present in 1946. However, the estuary was already heavily modified at that time and the lack of seagrass may reflect modified hydrology and/or high sediment deposition in the estuary.

In conclusion, historic modification of hydrology and salt marsh habitat have substantially altered Akatore Estuary with the most significant current issue identified as fine sediment deposition. The sedimentation rate and mud extent, coupled with localised areas of nuisance macroalgae around stream inputs, suggest that both sediment loads, and to a lesser extent nutrient loads, need to be managed.

6. RECOMMENDATIONS

Based on the findings of the current survey it is recommended that ORC consider the following:

- Repeat the broad scale habitat mapping at 5-10 yearly intervals to track long term changes in estuary condition.
- Explore options to further protect and enhance existing salt marsh and wetland habitat, e.g. stock exclusion, tidal reconnection, weed control, management of fine sediment.
- Assess contemporary and historic sediment sources via a desktop review, and management options of major inputs.
- Establish sediment plate monitoring sites in the western arm to measure temporal changes in sedimentation and mud content.
- Include Akatore Estuary in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will continue to protect the high ecological quality of the estuary and its catchment.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP (Robertson et al. 2002) with minor modifications as listed. Revised substrate classes were developed by Salt Ecology to more accurately classify fine unconsolidated substrate. Terrestrial margin vegetation was classified using the field codes included in the Landcare Research Land Cover Database (LCDB5) - see following page.

VEGETATION (mapped separately to the substrates they overlie and ordered where commonly found from the upper to lower tidal range).

Estuarine shrubland: Cover of estuarine shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh (density at breast height).
Tussockland: Tussock cover is 20-100% and exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples occur in all species of *Cortaderia*, *Gahnia*, and *Phormium*, and in some species of *Chionochloa*, *Poa*, *Festuca*, *Rytidosperma*, *Cyperus*, *Carex*, *Uncinia*, *Juncus*, *Astelia*, *Aciphylla*, and *Celmisia*.
Sedgeland: Sedge cover (excluding tussock-sedges and reed-forming sedges) is 20-100% and exceeds that of any other growth form or bare ground. "Sedges have edges". If the stem is clearly triangular, it's a sedge. If the stem is flat or rounded, it's probably a grass or a reed. Sedges include many species of *Carex*, *Uncinia*, and *Scirpus*.
Grassland[1]: Grass cover (excluding tussock-grasses) is 20-100% and exceeds that of any other growth form or bare ground.
Introduced weeds[1]: Introduced weed cover is 20-100% and exceeds that of any other growth form or bare ground.
Reedland: Reed cover is 20-100% and exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha*, *Bolboschoenus*, *Scirpus lacutris*, *Eleocharis sphacelata*, and *Baumea articulata*.
Lichenfield: Lichen cover is 20-100% and exceeds that of any other growth form or bare ground.
Cushionfield: Cushion plant cover is 20-100% and exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.
Rushland: Rush cover (excluding tussock-rushes) is 20-100% and exceeds that of any other growth form or bare ground. A tall, grass-like, often hollow-stemmed plant. Includes some species of *Juncus* and all species of *Apodasmia (Leptocarpus)*.
Herbfield: Herb cover is 20-100% and exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.
Seagrass meadows: Seagrasses are the sole marine representatives of Angiospermae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and are mapped.
Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain chlorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope. Macroalgal density, biomass and entrainment are classified and mapped.
Note NEMP classes of Forest and Scrub are considered terrestrial and have been included in the terrestrial Land Cover Data Base (LCDB) classifications.

[1]Additions to the NEMP classification.

SUBSTRATE (physical and zoogenic habitat)
Sediment texture is subjectively classified as: firm if you sink 0-2 cm, soft if you sink 2-5cm, very soft if you sink >5cm, or mobile - characterised by a rippled surface layer.

Artificial substrate: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates. Commonly sub-grouped into artificial: substrates (seawalls, bunds etc), boulder, cobble, gravel, or sand.
Rock field: Land in which the area of basement rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Cobble field: Land in which the area of unconsolidated cobbles (>20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Sand: Granular beach sand with a low mud content 0-10%. No conspicuous fines evident when sediment is disturbed.
Sand/Shell: Granular beach sand and shell with a low mud content 0-10%. No conspicuous fines evident.
Muddy sand (Moderate mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >10-25%). Granular when rubbed between the fingers, but with a smoother consistency than sand with a low mud fraction. Generally firm to walk on.
Muddy sand (HIgh mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >25-50%). Granular when rubbed between the fingers, but with a much smoother consistency than muddy sand with a moderate mud fraction. Often soft to walk on.
Sandy mud (Very high mud content): Mud/sand mixture dominated by mud (i.e. >50%-90% mud). Sediment rubbed between the fingers is primarily smooth/silken but retains a granular component. Sediments generally very soft and only firm if dried out or another component, e.g. gravel, prevents sinking.
Mud (>90% mud content): Mud dominated substrate (i.e. >90% mud). Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out or another component, e.g. gravel, prevents sinking.
Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.
Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.
Shell bank: Area that is dominated by dead shells

Table of modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.1m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Mobile sand	mS
		Firm shell/sand	fSS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Mobile muddy sand	mMS10
		Firm muddy shell/sand	fSS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Mobile muddy sand	mMS25
		Firm muddy shell/sand	fMSS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Mud (M)	Very high mud (>90%)	Firm mud	fM90
		Soft mud	sM90
		Very soft mud	vsM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Tubeworm reef	TUBE
Artificial Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aS BF
		Cobble field	aS CF
		Gravel field	aS GF
		Sand field	aS SF

Artificial Surfaces

1 Built-up Area (settlement)
2 Urban Parkland/Open Space
5 Transport Infrastructure
6 Surface Mines and Dumps

Bare or Lightly Vegetated Surfaces

10 Sand and Gravel
12 Landslide
16 Gravel and Rock

Water Bodies

20 Lake or Pond
21 River

Cropland

30 Short-rotation Cropland
33 Orchard Vineyard & Other Perennial Crops

Grassland, Sedge and Saltmarsh

40 High Producing Exotic Grassland
41 Low Producing Grassland
45 Herbaceous Freshwater Vegetation
46 Herbaceous Saline Vegetation

Scrub and Shrubland

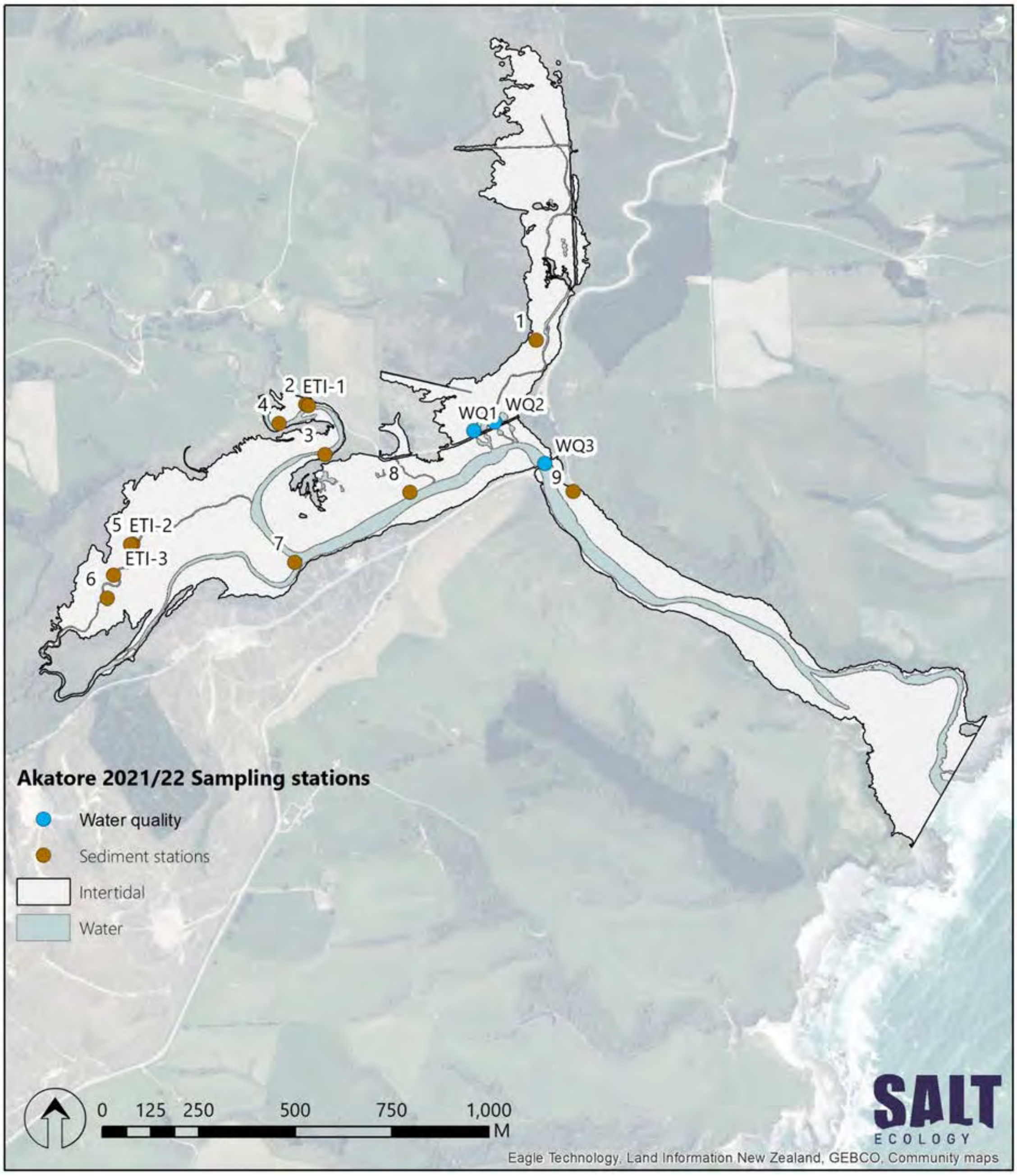
47 Flaxland
50 Fernland
51 Gorse and/or Broom
52 Manuka and/or Kanuka
54 Broadleaved Indigenous Hardwoods
56 Mixed Exotic Shrubland
58 Matagouri or Grey Scrub

Forest

64 Forest - Harvested
68 Deciduous Hardwoods
69 Indigenous Forest
71 Exotic Forest

APPENDIX 2. SAMPLING STATIONS IN AKATORE ESTUARY, NOVEMBER 2021

Sampling stations for sediment validation and water quality



Site	NZTM_E	NZTM_N	Field code	Subjective % mud	Measured % mud	Measured % sand	Measured % gravel
Akat-Otag - 1	1381823	4890624	vsSM	50 - 90%	61.5	38.4	0.1
Akat-Otag - 2	1381227	4890458	vsSM	50 - 90%	53.9	45	1.1
Akat-Otag - 3	1381276	4890328	vsSM	50 - 90%	78.0	19.6	2.3
Akat-Otag - 4	1381157	4890408	fMS10	10 - 25%	21.3	78.5	0.2
Akat-Otag - 5	1380778	4890096	vsM90	90 - 100%	92.4	4.1	3.5
Akat-Otag - 6	1380712	4889956	vsSM	50 - 90%	95.4	4.5	< 0.1
Akat-Otag - 7	1381198	4890048	sMS25	25 - 50%	43.2	54.7	2.1
Akat-Otag – 8*	1381496	4890229	sMS25	25 - 50%	37.6	58.7	3.7
Akat-Otag – 9*	1381918	4890232	fS	0 - 10%	< 0.1	100.8	7.9
Akat-Otag - ETI-1	1381232	4890453	vsSM	50 - 90%	49.9	48.6	1.5
Akat-Otag - ETI-2	1380774	4890096	vsM90	90 - 100%	93.8	5.4	0.7
Akat-Otag - ETI-3	1380729	4890015	vsSM	50 - 90%	87.6	12.2	0.3

*Samples Akat-Otag-8 and Akat-Otag-9 were mis-labelled when sent to the lab. In the raw data sheet from Hills laboratories Akat-Otag-8 refers to Akat-Otag-9 (vice versa).

In general, there was very good agreement between the subjective %mud field estimates and the validation sample mud contents measured in the laboratory. Akat-Otag-6 showed the largest variation with a difference of ±5.4% mud when compared to the subjective assessment.

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	2783276 SPv1
Contact:	Keryn Roberts	**Date Received:**	30-Nov-2021
	C/- Salt Ecology Limited	**Date Reported:**	27-Jan-2022
	21 Mount Vernon Place	**Quote No:**	114524
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Broadscale - Akatore Esturary
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Akat-Otag-1 28-Nov-2021 2:00 pm	Akat-Otag-2 28-Nov-2021 2:30 pm	Akat-Otag-3 28-Nov-2021 3:00 pm	Akat-Otag-4 28-Nov-2021 3:30 pm	Akat-Otag-5 28-Nov-2021 4:00 pm
Lab Number:		2783276.1	2783276.2	2783276.3	2783276.4	2783276.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	62	57	47	73	30
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.1	1.1	2.3	0.2	3.5
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	38.4	45.0	19.6	78.5	4.1
Fraction < 63 µm*	g/100g dry wt	61.5	53.9	78.0	21.3	92.4

Sample Name:		Akat-Otag-6 28-Nov-2021 4:30 pm	Akat-Otag-7 28-Nov-2021 5:00 pm	Akat-Otag-8 28-Nov-2021 5:30 pm	Akat-Otag-9 28-Nov-2021 6:30 pm	Akat-Otag-ETI-1 28-Nov-2021 4:35 pm
Lab Number:		2783276.6	2783276.7	2783276.8	2783276.9	2783276.10
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	48	68	70	82	55
Total Recoverable Phosphorus	mg/kg dry wt	-	-	-	-	490
Total Sulphur*‡	g/100g dry wt	-	-	-	-	0.23
Total Nitrogen*	g/100g dry wt	-	-	-	-	0.18
Total Organic Carbon*	g/100g dry wt	-	-	-	-	1.97
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	2.1	7.9	3.7	1.5
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	4.5	54.7	100.8	58.7	48.6
Fraction < 63 µm*	g/100g dry wt	95.4	43.2	< 0.1	37.6	49.9

Sample Name:		Akat-Otag-ETI-2 28-Nov-2021 5:40 pm	Akat-Otag-ETI-3 28-Nov-2021 6:10 pm			
Lab Number:		2783276.11	2783276.12			
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	39	46	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	740	660	-	-	-
Total Sulphur*‡	g/100g dry wt	0.59	0.62	-	-	-
Total Nitrogen*	g/100g dry wt	0.36	0.27	-	-	-
Total Organic Carbon*	g/100g dry wt	3.2	2.7	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.7	0.3	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	5.4	12.2	-	-	-
Fraction < 63 µm*	g/100g dry wt	93.8	87.6	-	-	-

Analyst's Comments

ǂ Analysis subcontracted to an external provider. Refer to the Summary of Methods section for more details.

Appendix No.1 - SGS Report

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	10-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	10-12
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-12
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	10-12
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	10-12
Total Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g dry wt	10-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	10-12
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	10-12
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-12
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 07-Dec-2021 and 27-Jan-2022. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 3. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multi-metric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5-part multi-metric OMBT, modified for NZ estuary types, is presented in the WFD-UKTAG (2014) with additions described in Plew et al. (2020), and is paraphrased below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of *mud, muddy sand, sandy mud, sand, stony mud and mussel beds.* Areas which are judged unsuitable for algal blooms, e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. PERCENTAGE COVER OF THE AVAILABLE INTERTIDAL HABITAT (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. TOTAL EXTENT OF AREA COVERED BY ALGAL MATS (AFFECTED AREA (AA)) OR AFFECTED AREA AS A PERCENTAGE OF THE AIH (AA/AIH, %).

The affected area represents the total area of macroalgal cover in hectares. In large water bodies, small patches of macroalgal coverage relative to the estuary size would result in the total percent cover across the AIH remaining within the 'high' or 'good' status. While the affected area may be relatively small when compared to estuary size the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities (WFD-UKTAG 2014). In order to account for this, the OMBT included an additional metric; the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse-case scenario.

3. BIOMASS OF AIH ($g.m^{-2}$).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within ±5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. BIOMASS OF AA ($g.m^{-2}$).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. PRESENCE OF ENTRAINED ALGAE (% OF QUADRATS).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool. All the metrics are equally weighted and combined within the multi-metric, in order to best describe the changes in the nature and degree of opportunistic macroalgae growth on sedimentary shores due to nutrient pressure.

TIMING

The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March). However, peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification, e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

SUITABLE LOCATIONS

The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing intermittently closed and open estuaries (ICOEs) due to the particular challenges in setting suitable reference conditions for these water bodies.

DERIVATION OF THRESHOLD VALUES

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

REFERENCE THRESHOLDS

A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g/m^2 wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

CLASS THRESHOLDS FOR PERCENT COVER

High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to

Table A1. The final face value thresholds and metrics for levels of the ecological quality status. These thresholds have been recently revised for New Zealand (see Table A3).

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^{-2}) of AIH[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).

Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

CLASS THRESHOLDS FOR BIOMASS

Class boundaries for biomass values were derived from DETR (2001) recommendations that <500g.m^{-2} wet weight was an acceptable level above the reference level of <100g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500g.m^{-2} represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500gm^{-2} but less than 1,000g.m^{-2} would lead to a classification of Moderate quality status at best but would depend on the percentage of the AIH covered. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003). Thresholds applied in the current study are described and presented in Table A3.

THRESHOLDS FOR ENTRAINED ALGAE

Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently, the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

EQR CALCULATION

Each metric in the OMBT has equal weighting and is combined to produce the Ecological Quality Rating score (EQR).

The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the categories in Table A1. The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 - where Total % cover = Sum of [(patch size) / 100] x average % cover for patch
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH (g.m^{-2}) = Total biomass / AIH - where Total biomass = Sum of (patch size x average biomass for the patch)
- Biomass of Affected Area (g.m^{-2}) = Total biomass / AA - where Total biomass = Sum of (patch size x average biomass for the patch)
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A2).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

*Final Equidistant Index score = Upper Equidistant range value – ([Face Value - Upper Face value range] * (Equidistant class range / Face Value Class Range)).*

Table A2 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range. Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.

The final EQR score is calculated as the average of equidistant metric scores.

A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

Metric	Quality status	Face value ranges			Equidistant class range values		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH ($g.m^{-2}$)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) ($g.m^{-2}$)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

Biomass thresholds included in the OMBT were lowered for use in NZ by Plew et al. (2020) based on unpublished data from >25 shallow well-flushed intertidal NZ estuaries (Robertson et al. 2016b) and the results from similar estuaries in California. Sutula et al. (2014) reported that in eight Californian estuaries, macroalgal biomass of 1450g.m^{-2} wet weight, total organic carbon of 1.1% and sediment total nitrogen of 0.1% were thresholds associated with anoxic conditions near the surface (aRPD < 10 mm). Green et al. (2014) reported significant and rapid negative effects on benthic invertebrate abundance and species richness at macroalgal abundances as low as 840–930g.m^{-2} wet weight in two Californian estuaries. McLaughlin et al. (2014) reviewed Californian biomass thresholds and found the elimination of surface deposit feeders in the range of 700–800g.m^{-2}. As the Californian results were consistent with NZ findings, the latter thresholds were used to lower the OMBT good/moderate threshold from ≤500 to ≤200g.m^{-2}, the moderate/poor threshold from ≤1000 to ≤500gm^{-2} and the poor/bad threshold from >3000 to >1450g.m^{-2}. These thresholds are considered to provide an early warning of nutrient related impacts in NZ prior to the establishment of adverse enrichment conditions that are likely difficult to reverse.

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Table A3. Revised final face value thresholds and metrics for levels of the ecological quality status used in the current assessment.

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^{-2}) of AIH[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

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APPENDIX 4. INFORMATION SUPPORTING RATINGS IN THE REPORT

SEDIMENT MUD CONTENT

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more sticky and cohesive, and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon, and sediment-bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations and, on intertidal flats of estuaries, can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

APPARENT REDOX POTENTIAL DISCONTINUITY (aRPD)

aRPD depth, the visually apparent transition between oxygenated sediments near the surface and deeper more anoxic sediments, is a primary estuary condition indicator as it is a direct measure of time integrated sediment oxygenation. Knowing if the aRPD is close to the surface is important for three main reasons:

The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species. The tendency for sediments to become anoxic is much greater if the sediments are muddy. Anoxic sediments contain toxic sulphides and support very little aquatic life. As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, become released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (i.e. >3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

OPPORTUNISTIC MACROALGAE

The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with high mud and low oxygen conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014; Robertson et al 2016a,b; Zeldis et al. 2017), with results combined with those of other indicators to determine overall condition.

SEAGRASS

Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column. It is also susceptible to degraded sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent are likely to indicate an increase in these types of pressures. The assessment metric used is the percent change from baseline measurements.

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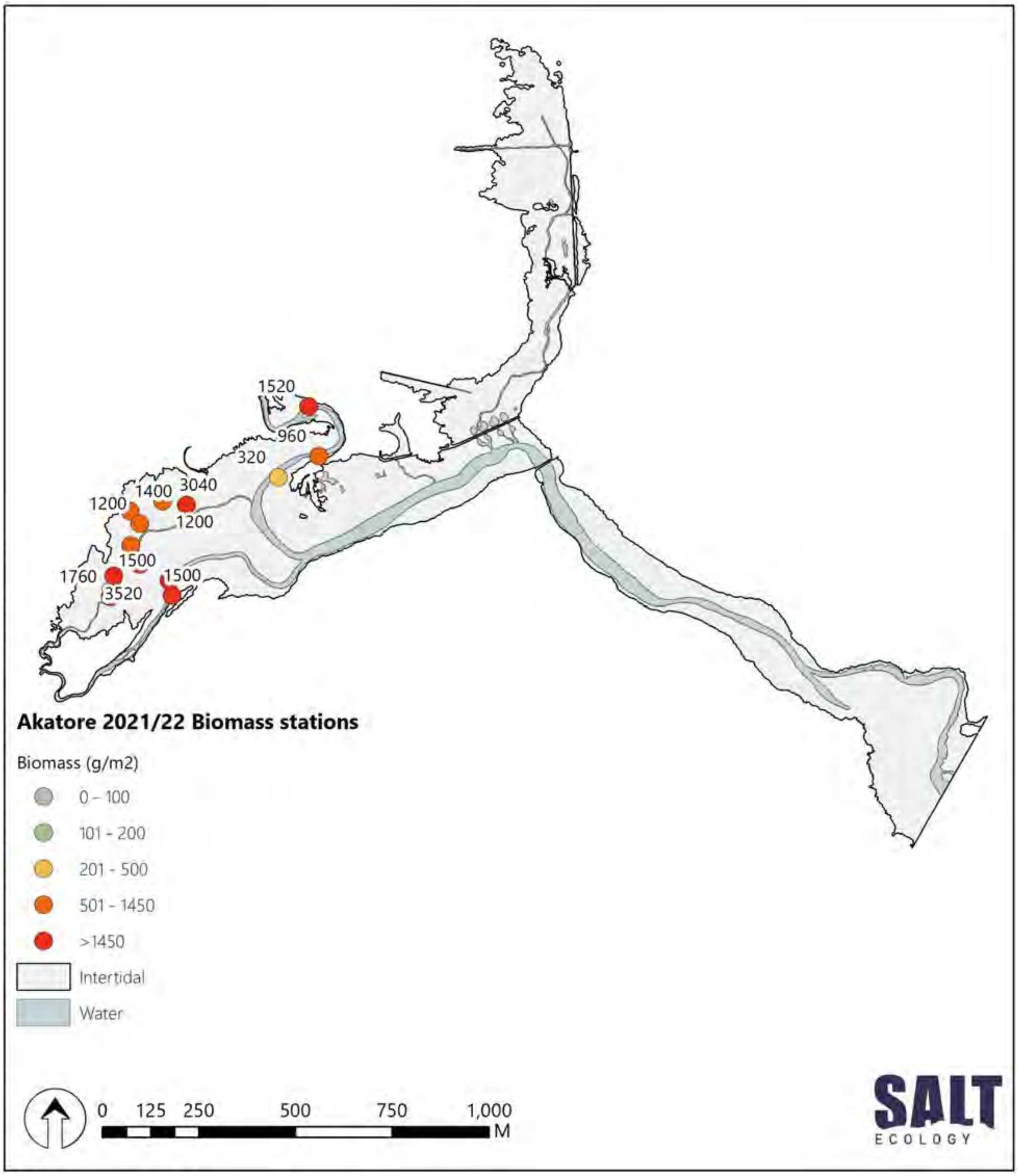
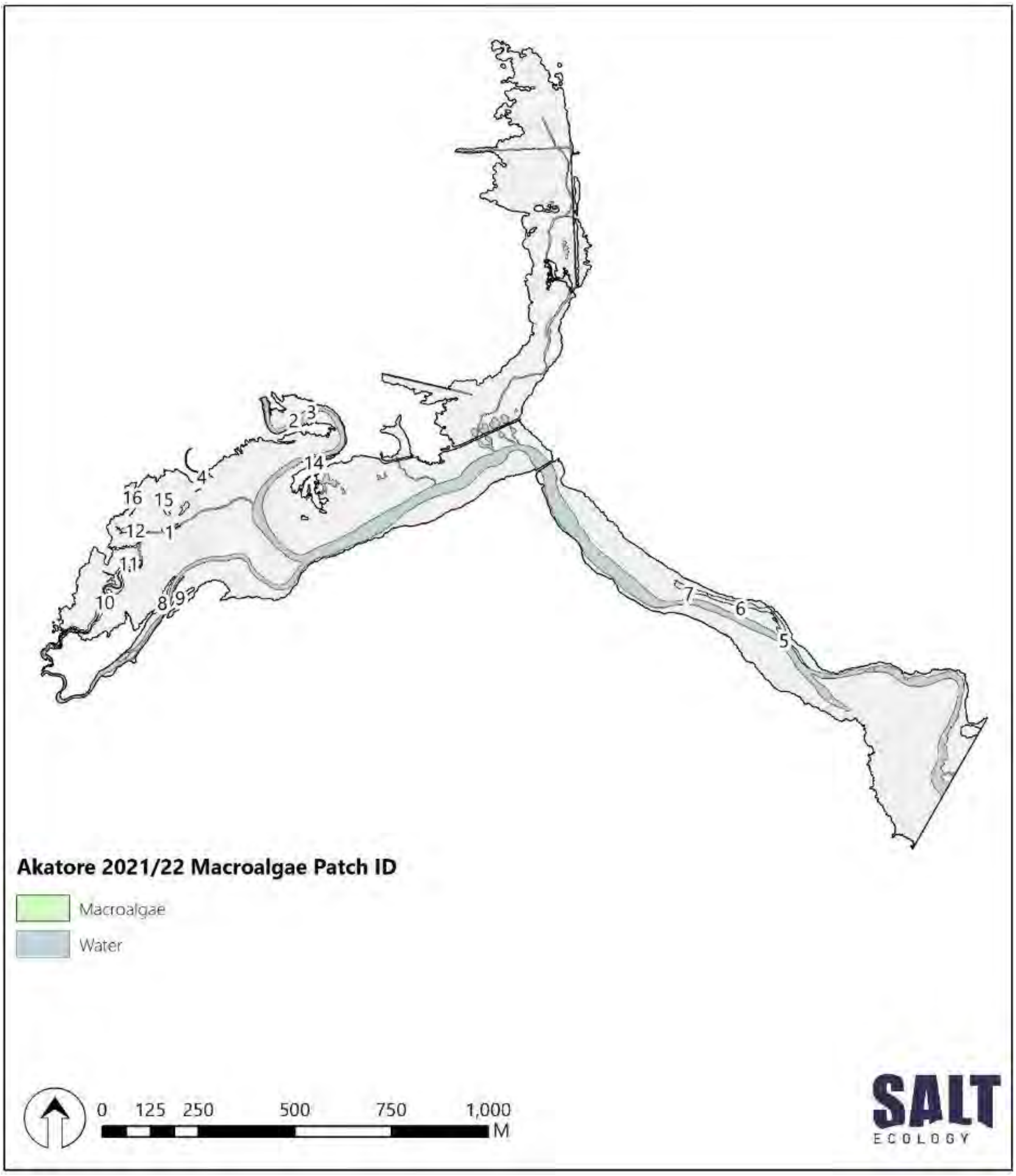
APPENDIX 5. MACROALGAL BIOMASS STATIONS & OMBT PATCH ID AND RAW DATA, AKATORE ESTUARY, NOVEMBER 2021



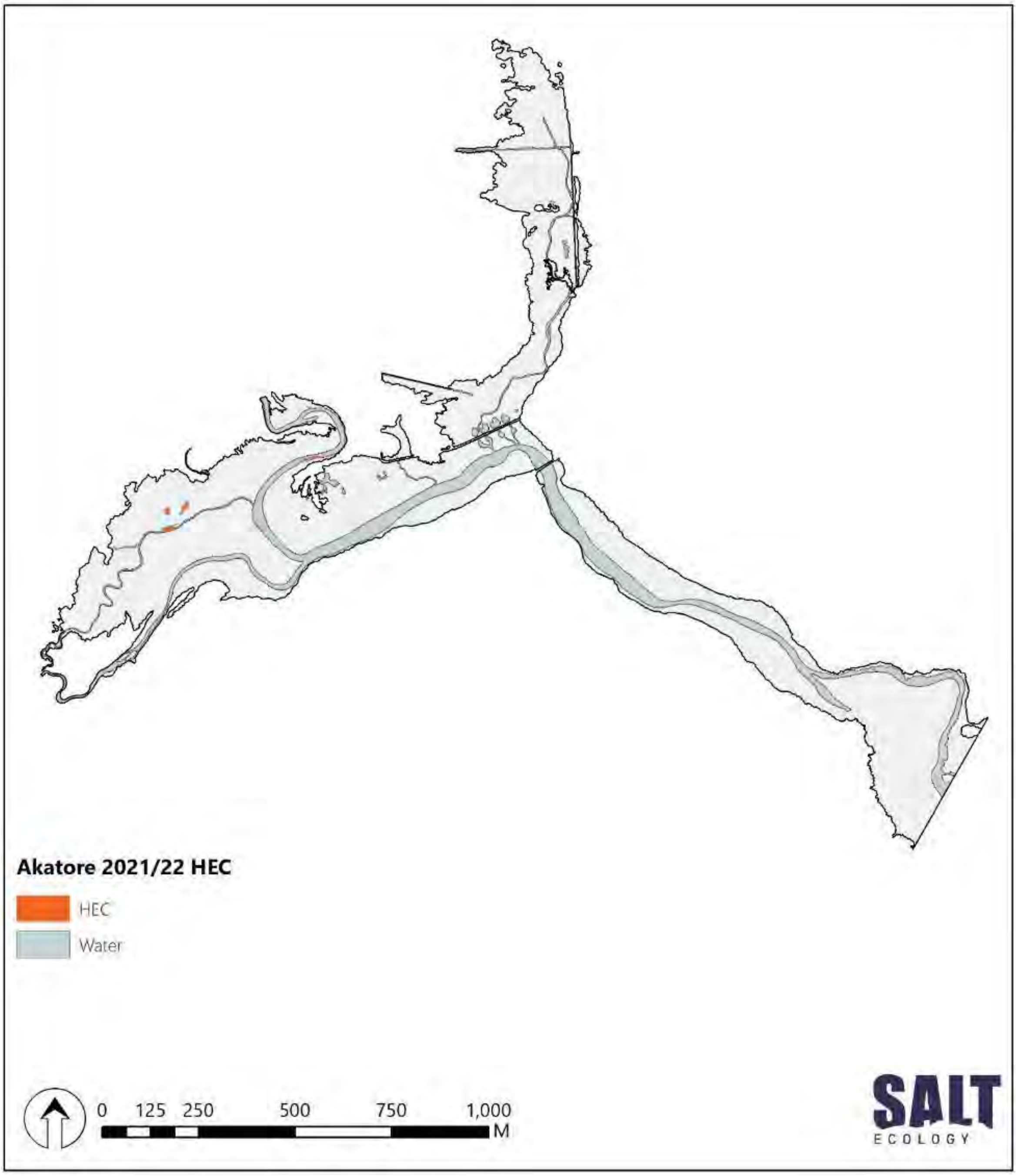
Macroalgal patch information used in the calculation of the OMBT-EQR

Estuary	Year	PatchID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (g/m^2)	Biomass Category	Entrained	Dominant Species	Sub-Dominant Species	Substrate	Area (ha)
Akatore	2021	1	Grch Ulva	80 1	81	Dense (70 to <90%)	3040	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	vsSM	0.10
Akatore	2021	2	Grch	10	10	Sparse (10 to <30%)	200	Low (101 - 200)	0	*Agarophyton* spp.		vsSM	0.004
Akatore	2021	3	Grch Ulva	70 10	80	Dense (70 to <90%)	1520	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	vsSM	0.004
Akatore	2021	4	Grch Ulva	60 20	80	Dense (70 to <90%)	1500	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	sSM	0.01
Akatore	2021	5	Grch Ulva	30 30	60	High-Moderate (50 to <70%)	750	High (501 - 1450)	0	*Agarophyton* spp.	*Ulva* spp.	fS	0.14
Akatore	2021	6	Ulva Grch	70 5	75	Dense (70 to <90%)	750	High (501 - 1450)	0	*Ulva* spp.	*Agarophyton* spp.	fS	0.17
Akatore	2021	7	Ulva	20	20	Sparse (10 to <30%)	200	Low (101 - 200)	0	*Ulva* spp.		fS	0.10
Akatore	2021	8	Ulva	80	80	Dense (70 to <90%)	1500	Very high (>1450)	0	*Ulva* spp.		sSM	0.11
Akatore	2021	9	Ulva Grch	80 5	85	Dense (70 to <90%)	1500	Very high (>1450)	0	*Ulva* spp.	*Agarophyton* spp.	sSM	0.04
Akatore	2021	10	Ulva Grch	46 43	89	Dense (70 to <90%)	2507	Very high (>1450)	0.3	*Ulva* spp.	*Agarophyton* spp.	sSM	0.49
Akatore	2021	11	Grch Other Ulva	70 25 5	100	Complete (>90%)	1120	High (501 - 1450)	1	*Agarophyton* spp.	Unspecified Macroalgae	sSM	0.03
Akatore	2021	12	Ulva	75	75	Dense (70 to <90%)	1200	High (501 - 1450)	0	*Ulva* spp.		sSM	0.09
Akatore	2021	13	Grch Ulva	70 10	80	Dense (70 to <90%)	1500	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	sSM	0.01
Akatore	2021	14	Grch Ulva	55 5	60	High-Moderate (50 to <70%)	960	High (501 - 1450)	1	*Agarophyton* spp.	*Ulva* spp.	vsSM	0.04
Akatore	2021	15	Ulva	70	70	Dense (70 to <90%)	1200	High (501 - 1450)	0	*Ulva* spp.		sSM	0.002
Akatore	2021	16	Ulva	80	80	Dense (70 to <90%)	1400	High (501 - 1450)	0	*Ulva* spp.		sSM	0.003

*0=not entrained, 1=100% entrained



APPENDIX 6. AREAS OF HEC IN AKATORE ESTUARY, NOVEMBER 2021



APPENDIX 7. DOMINANT SALT MARSH SPECIES IN AKATORE ESTUARY, NOVEMBER 2021

Sub Class	Dominant species	Sub-dominant species 1	Sub-dominant species 2	Ha	%Salt Marsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	0.4	1.4
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Leptospermum scoparium* (Manuka)	0.3	1.1
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)		1.1	4.1
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Selliera radicans* (Remuremu)	0.3	1.2
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)		0.01	0.1
	Plagianthus divaricatus (Salt marsh ribbonwood)			0.1	0.2
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)		0.01	0.02
Sedgeland	*Cyperus ustulatus* (Giant umbrella sedge)			0.1	0.4
Rushland	*Apodasmia similis* (Jointed wirerush)	*Coprosma propinqua subsp. Propinqua* (Mingimingi)		0.03	0.1
	Apodasmia similis (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	*Phormium tenax* (New Zealand flax)	3.2	12.0
	Apodasmia similis (Jointed wirerush)			1.1	3.9
	Apodasmia similis (Jointed wirerush)	*Phormium tenax* (New Zealand flax)		0.4	1.6
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	2.5	9.4
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Muehlenbeckia complexa* (Wire vine)	2.0	7.6
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		4.6	17.1
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Phormium tenax* (New Zealand flax)	3.8	14.1
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Selliera radicans* (Remuremu)	0.5	2.0
	Apodasmia similis (Jointed wirerush)	*Selliera radicans* (Remuremu)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	1.0	3.7
	Apodasmia similis (Jointed wirerush)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	0.04	0.2
Herbfield	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	*Samolus repens* (Primrose)	0.001	0.004
	Samolus repens (Primrose)			0.01	0.05
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	0.3	1.0
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)		0.2	0.9
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	0.00	0.00
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	0.3	1.2
	Sarcocornia quinqueflora (Glasswort)			0.00	0.00
	Selliera radicans (Remuremu)	*Agrostis stolonifera* (Creeping bent)		0.1	0.2
	Selliera radicans (Remuremu)	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.2	0.6
	Selliera radicans (Remuremu)	*Atriplex prostrata* (Orache, Creeping saltbush)	*Sarcocornia quinqueflora* (Glasswort)	0.01	0.05
	Selliera radicans (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	*Thyridia repens* (New Zealand musk)	0.02	0.1
	Selliera radicans (Remuremu)	*Isolepis cernua* (Slender clubrush)		0.3	1.0
	Selliera radicans (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Samolus repens* (Primrose)	0.2	0.7
	Selliera radicans (Remuremu)			0.2	0.7
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.03	0.1
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	0.1	0.3
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)		1.7	6.5
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	0.01	0.03
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	0.9	3.2
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	0.7	2.6
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)		0.1	0.3
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.1	0.2
	Selliera radicans (Remuremu)	*Thyridia repens* (New Zealand musk)		0.01	0.05
	Selliera radicans (Remuremu)	*Thyridia repens* (New Zealand musk)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.01	0.02
Grand Total				**26.9**	**100**

APPENDIX 8. RAW SEDIMENT AND MACROFAUNA DATA IN AKATORE ESTUARY, NOVEMBER 2021

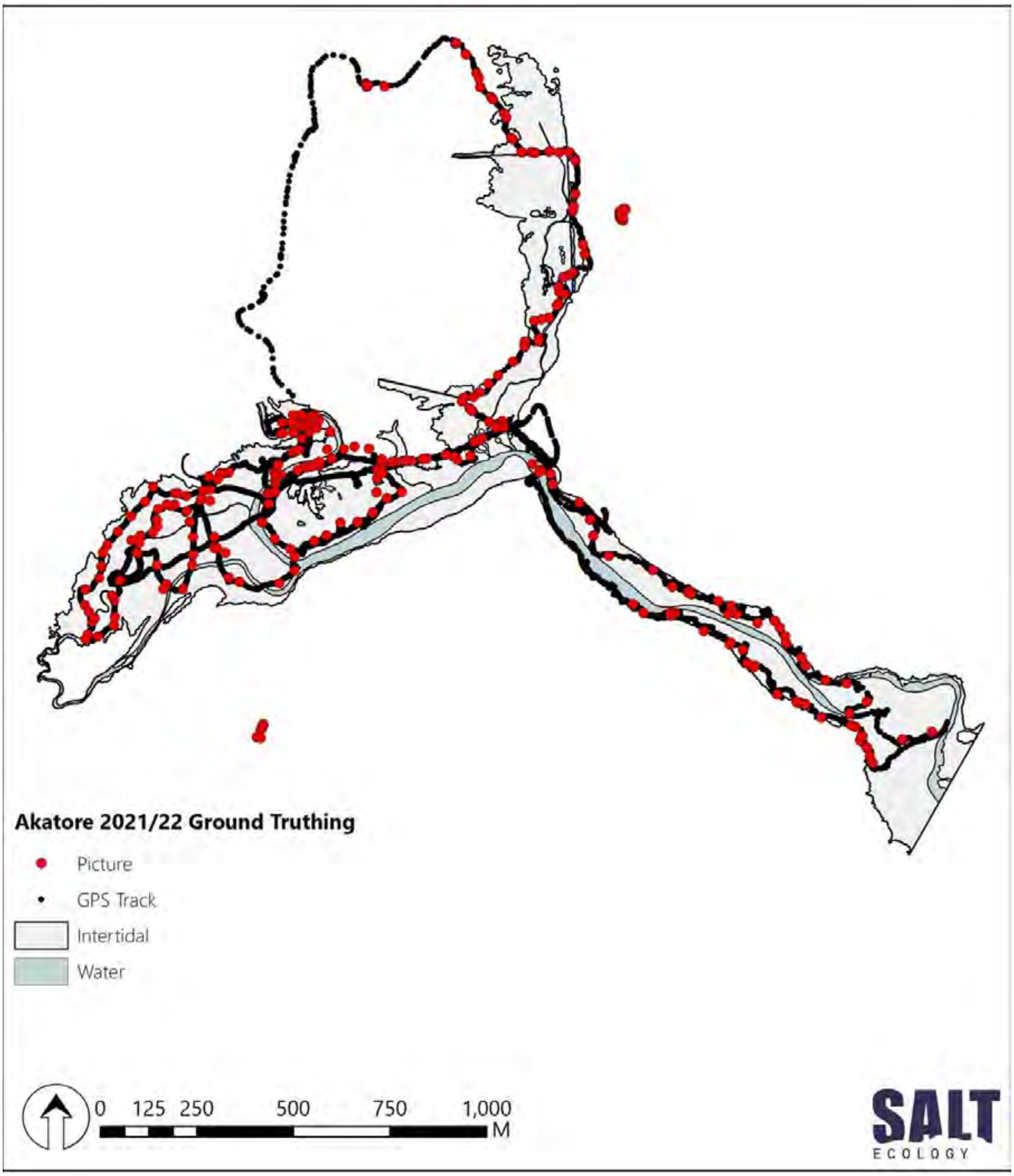
Sediment data and macrofauna indices

Parameter	Unit	AKAT-OTAG ETI-1	AKAT-OTAG ETI-2	AKAT-OTAG ETI–3
Sediment Chemistry				
Total Phosphorus (TP)	mg/kg dry wt	490	740	660
Total Sulfur (TS)	g/100g dry wt	0.23	0.59	0.62
Total Nitrogen (TN)	g/100g dry wt	0.18	0.36	0.27
Total Organic Carbon (TOC)	g/100g dry wt	1.97	3.2	2.7
Gravel (≥2mm)	g/100g dry wt	1.5	0.7	0.3
Sand (≥63mm to <2mm)	g/100g dry wt	48.6	5.4	12.2
Mud (≤63mm)	g/100g dry wt	49.9	93.8	87.6
aRPD	mm	10	1	2
Macrofauna indices				
AMBI	no unit	3.96	5.15	5.26
Abundance	Number of individuals	624	999	121
Diversity	Number of taxa	12	11	9

EG=Eco-Group, ranging from sensitive (EG-I) to tolerant (EG-V) to enrichment and other types of environmental pollution

Main group	Taxa	Habitat	EG	AKAT-OTAG ETI-1	AKAT-OTAG ETI-2	AKAT-OTAG ETI-3
Amphipoda	*Aoridae*	Infauna	I	1		
Amphipoda	*Eusiridae*	Infauna (juvenile)	II			1
Amphipoda	*Josephosella awa*	Infauna	II	92	6	4
Amphipoda	*Paracalliope novizealandiae*	Infauna	I		4	
Amphipoda	*Paracorophium excavatum*	Infauna	IV	410	517	32
Anthozoa	*Edwardsia* sp.	Epibiota	II	1		
Bivalvia	*Arthritica* sp. 5	Infauna	III	67		5
Bivalvia	*Lasaea parengaensis*	Infauna	II	1		
Gastropoda	*Amphibola crenata*	Epibiota	III	1	1	
Gastropoda	*Dotidae*	Epibiota	NA		1	
Isopoda	*Exosphaeroma planulum*	Infauna	V	19		15
Mysidacea	*Mysida*	Infauna	II		1	
Oligochaeta	*Naididae*	Infauna	V		350	57
Polychaeta	*Capitella cf. capitata*	Infauna	V	17	112	3
Polychaeta	*Nicon aestuariensis*	Infauna	III	1	1	
Polychaeta	*Perinereis vallata*	Infauna	III	2	2	
Polychaeta	*Platynereis* sp.	Infauna	III			1
Polychaeta	*Scolecolepides benhami*	Infauna	IV	12	4	3

APPENDIX 9. GROUND-TRUTHING IN AKATORE ESTUARY, NOVEMBER 2021



SALT
ECOLOGY

BLUESKIN BAY: 2021/2022 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 007. Prepared by Barrie Forrest for Otago Regional Council, March 2022

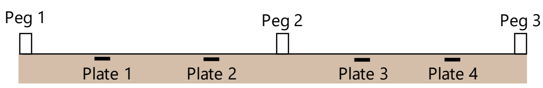
OVERVIEW

Otago Regional Council started State of the Environment monitoring in Blueskin Bay in Jan-2021, to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with a second survey carried out on 27 November 2021.

Fig. 1. Location of Blueskin Bay monitoring sites.

METHODS

Estuary sedimentation is measured using the 'sediment plate' method (e.g. Forrest et al. 2021). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate (n=3) and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories). This approach allows changes in sediment muddiness to be determined even where there are no changes in sediment depth. Sediment oxygenation is an ancillary biological health variable that is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings corresponding to the colours in Table 1.

Table 2. Indicator values and condition ratings from Nov-2021 survey.

Indicator	A	B
Sedimentation (mm/yr)*	-5.39	-1.64
Mud content (%)	4.0	6.6
aRPD (mm)	20	30

* Annual sedimentation rate relative to the baseline (n=1 year). Five years of data are required to assess a meaningful trend.

Sedimentation rate

The cumulative change in sediment depth over plates at each site is shown in Fig. 2. Erosion occurred at both sites in the first year of monitoring, corresponding to a condition rating of 'very good'. A longer time series (e.g. 5 years) will be required to establish a meaningful trend.

Table 1. Summary of condition ratings for sediment plate monitoring

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012).

Sediment mud content and oxygenation

Blueskin Bay sediments are sand-dominated, with a low mud component. Accordingly, sediment mud content was rated as 'very good' at Site A and 'good' at Site B (Table 2), with the values recorded in Nov-21 similar to the baseline survey in Jan-2021 (Fig. 3).

The average aRPD depth was 20mm at Site A and 30mm at Site B, reflecting well-oxygenated conditions (a rating of 'good'). This high level of oxygenation is likely maintained by the porous sandy sediments, and the presence of organisms such as crabs and shellfish, which turn over surface sediments and create voids that allow air and water to transfer oxygen to underlying layers.

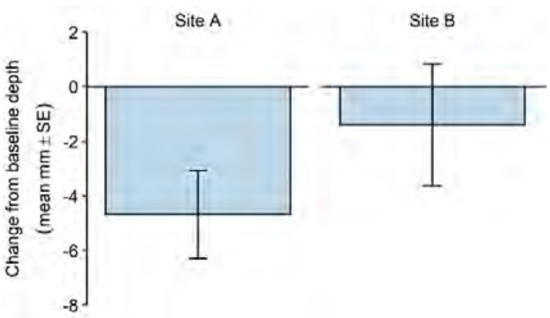


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to the Jan-2021 baseline.

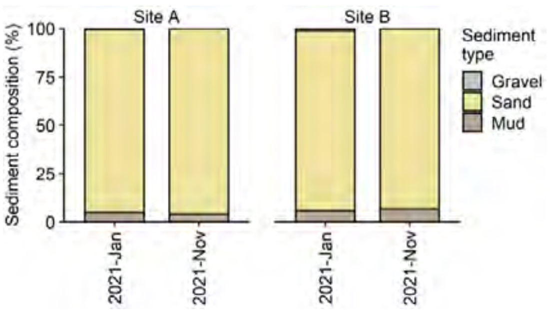


Fig. 3. Sediment particle grain size at each site. The baseline result for each site is also shown.

CONCLUSIONS

Blueskin Bay consists of clean and well-oxygenated sandy sediments, with no mud deposition recorded in the first year of monitoring. A longer time series (e.g. five years) will be required to establish a meaningful trend.

Top: well oxygenated sediment at Site A. Bottom: Site B in Nov-2021

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Comprehensive reporting should be undertaken as part of 'fine scale' ecological and sediment monitoring (next due in the summer of 2022/23).

REFERENCES

Federal Geographic Data Committee (FGDC). 2012. Coastal and Marine Ecological Classification Standard Catalog of Units, Federal Geographic Data Committee FGDC-STD-018-2012. 343p.

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CATLINS ESTUARY: 2021/2022 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 009. Prepared by Barrie Forrest for Otago Regional Council, March 2022

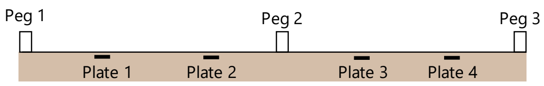
OVERVIEW

Since Dec-2016, Otago Regional Council has undertaken annual State of the Environment monitoring in Catlins River Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 1 December 2021.

Fig. 1. Location of Catlins River Estuary monitoring sites. Site A1 has been replaced Site A, which was in the same general location but washed away prior to the Feb-2019 survey.

METHODS

Estuary sedimentation is measured using the 'sediment plate' method (e.g. Forrest et al. 2021). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate (n=3) and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories). This approach allows changes in sediment muddiness to be determined even where there are no changes in sediment depth.

Sediment oxygenation is an ancillary biological health variable that is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings corresponding to the colours in Table 1.

Table 2. Indicator values and condition ratings from the Dec-2021 survey.

Indicator	A1	B
Sedimentation (mm/yr)*	5.49	7.53
Mud content (%)	3.0	34.6
aRPD (mm)	20	30

* Mean annual sedimentation rate relative to the baseline (n=2 yrs Site A1, n=5 yrs Site B). Five years of data are required to assess a meaningful trend.

Sedimentation rate

The cumulative change in sediment depth over plates at each site is shown in Fig. 2. There has been steady sediment accrual at both sites, with annual mean value exceeding the 2mm/yr guideline value (rated 'poor, Table 1). High variability between plates at Site A1 reflects the dynamic hydrological environment near the estuary entrance (see photo on next page).

Table 1. Summary of condition ratings for sediment plate monitoring

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012).

Sediment mud content and oxygenation

Sediments were sand-dominated at lower estuary Site A1, whereas the mud content at upper estuary Site B exceeded the biologically relevant threshold of 25% (Fig. 3), and was rated 'poor' (Table 2). Combined with the elevated sedimentation rate, these results suggest there is significant ongoing deposition of muddy sediment in the upper estuary, which may reflect that the dominant catchment land use is pastoral farming (Stevens & Robertson 2017).

The aRPD depths at the two sites ranged from 20-30mm, corresponding to condition ratings of 'good', Table 2). As such, despite the deposition of mud at Site B, the sediment has not become excessively enriched. Neither site showed any other symptoms of excessive enrichment such as prolific algal growths. However, in the wider vicinity of Site B, the estuary margins are characterised by extensive growths of the opportunistic macroalgae *Agarophyton chilense*.

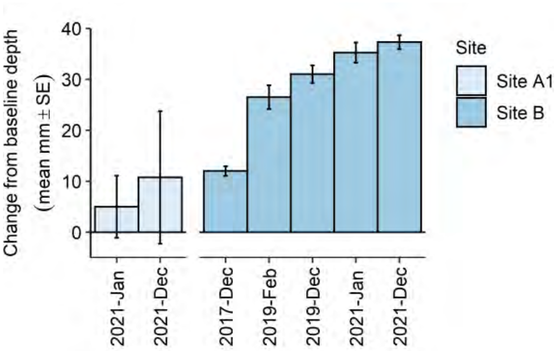


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to the baseline.

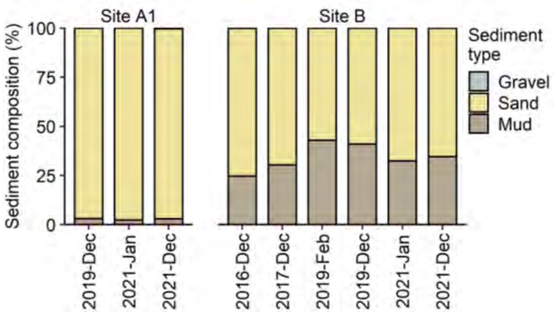


Fig. 3. Sediment particle grain size at each site. The baseline result for each site is also shown.

CONCLUSIONS

The significant sedimentation measured at upper estuary Site B over the last 4 years is consistent with the desposition of catchment-derived muddy sediment. By contrast, sand-dominated Site A1 appears to be exposed to hydrodyamic processes (e.g. scouring and erosion) that will likely limit the accrual of muddy sediments from the catchment. The Dec-2021 results overall show that the upper estuary at Site B and in the wider area is relatively degraded, which reinforces previous recommendations (e.g. Stevens & Rovertson. 2017) to manage catchment inputs to the estuary.

Mobile and undulating sand-dominated sediment at Site A1 (left) compared with mud-dominated upper estuary sediment at Site B (right) in Dec-2021.

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Comprehensive reporting should be undertaken 5-yearly as part of 'fine scale' ecological and sediment monitoring (next due in the summer of 2023/24).

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Federal Geographic Data Committee (FGDC). 2012. Coastal and Marine Ecological Classification Standard Catalog of Units, Federal Geographic Data Committee FGDC-STD-018-2012. 343p.

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Macroalgae Monitoring of Catlins/Pounawea Estuary 2021/22

Prepared for

Otago Regional Council

June 2022

Salt Ecology
Report 089

Cover photo: Entrained nuisance macroalgae growing on mudflats, Catlins Lake/Kuramea, December 2021

RECOMMENDED CITATION

Stevens LM, Roberts KL. 2022. Macroalgae Monitoring of Catlins/Pounawea Estuary 2021/22. Salt Ecology Report 089, prepared for Otago Regional Council, June 2022. 29p.

For the People
Mō ngā tāngata

Macroalgae Monitoring of Catlins River/Pounawea Estuary 2021/22

Prepared by

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for

Otago Regional Council

June 2022

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For the environment
Mō te taiao

SALT ECOLOGY

GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
HEC	High Enrichment Condition
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for reviewing the draft report. We are also grateful to Thomas Scott-Simmonds, Barrie Forrest and Bryn Forrest for field assistance. The tools used to produce GIS summaries and maps were developed by Megan Southwick (Salt Ecology). ORC provided the aerial imagery used in the mapping.

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SUMMARY

Catlins River/Pounawea Estuary is a medium sized (830ha) estuarine system located ~115km south of Dunedin on New Zealand's south coast. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary (SIDE) monitored by Otago Regional Council (ORC) as part of its State of the Environment programme using methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). This report describes a survey conducted in December 2021 which assessed macroalgal cover, biomass and entrainment.

KEY FINDINGS

- 80% of the 636ha intertidal area had <1% cover of macroalgae, indicating the majority of the estuary was not experiencing macroalgal problems.
- Opportunistic macroalgae (*Agarophyton* spp.) were present in dense beds (>50% cover) in the sheltered upper margins of Catlins Lake/Kuramea (see photo), the Ōwaka arm, and in several small embayments on the southern side of the lower estuary southeast of Hinahina. Nuisance macroalgae (>50%) covered 101ha (17.2%) of the intertidal area.
- The macroalgal Ecological Quality Rating (EQR), measuring the combined estuary-wide influence of macroalgal cover, biomass and entrainment, was 0.393, which equates to a condition rating of 'Poor'.
- 61.6ha (9.7% of the intertidal area) was classified as having High Enrichment Conditions (HECs), e.g. >50% macroalgal cover entrained in poorly oxygenated sediments with a high mud content and high organic enrichment. The largest areas of HEC were near Catlins River mouth, in the lower Ōwaka arm, and in small embayments with restricted tidal flushing near Hinahina.
- Localised areas of severe eutrophication (very soft anoxic mud with a strong rotten egg odour) were present in the lower Ōwaka arm and in the west of Catlins Lake/Kuramea.

Broad scale indicator	Unit	2016	2021
Macroalgae (OMBT)[1]	EQR	0.620	0.393
HEC[2]	Ha	14.9	61.6
HEC[2]	% of estuary	2.3	9.7

[1] OMBT = Opportunistic Macroalgal Blooming Tool
[2] High Enrichment Conditions
Condition rating colour key:

Very Good	Good	Fair	Poor

Overall, the December 2021 survey found eutrophication had increased significantly since December 2016 (see table), particularly along the western side of Catlins Lake/Kuramea where there was widespread sediment degradation. Localised areas of macroalgal dieback suggest sediment conditions have reached a state so poor that macroalgae can longer survive.

The expanded presence of entrained macroalgal growths since 2016, and the extensive presence of eutrophic symptoms including patches of extreme sediment anoxia, serve as clear indicators that the estuary's capacity to assimilate nutrients is being exceeded. These results are consistent with modelled nutrient loads to the estuary. Unless nutrient inputs to the estuary are reduced it is expected that the estuary will continue to express symptoms of eutrophication and potentially degrade further.

RECOMMENDATIONS

- Undertake annual monitoring during summer to track changes in nuisance macroalgae.
- Continue with planned work to determine limits on nutrient and sediment mass loads that would be expected to prevent further degradation and, where possible, mitigate current adverse impacts.
- Determine catchment nutrient and sediment sources as part of the mass load assessment and evaluate whether there are any effective and feasible management practices that could be undertaken to achieve ORC's desired condition for the estuary.

1. INTRODUCTION

1.1 BACKGROUND

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 based on the methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c), or variations of that approach.

NEMP monitoring is primarily designed to detect and understand changes in estuaries over time and determine the effect of catchment influences, especially those contributing to the input of nutrients and muddy sediments. Excessive nutrient and fine sediment inputs are a primary driver of estuary eutrophication symptoms such as prolific macroalgal (seaweed) growth, and poor sediment condition.

Although macroalgae is an important feature of estuaries that contributes to their high productivity and biodiversity, when high nutrient inputs combine with suitable growing conditions, nuisance blooms of rapidly-growing species can occur (Table 1). These are typically referred to as 'opportunistic' species, of which the most significant in Otago are the red seaweed *Agarophyton* spp. (previously known as *Gracilaria* spp.) and the bright green *Ulva* spp. (commonly called 'sea lettuce').

At nuisance levels, muddy sediments and macroalgal growths can smother and deprive ecologically valuable seagrass (*Zostera muelleri*, see Table 1) of light, causing its eventual decline. Decaying macroalgae can also accumulate on shorelines causing localised depletion of sediment oxygen, and nuisance odours. When high macroalgal cover is associated with soft, muddy sediments, conditions for animal life in the sediments are generally very poor due to elevated organic matter, depleted oxygen and an accumulation of toxic sulphides.

Catlins/Pounawea Estuary (Fig. 1), the study site, is one of the key estuaries in Otago's SOE programme and has been previously surveyed in 2008, 2012 and 2016. No growths of the nuisance macroalgae *Agarophyton* spp. were recorded in 2008 (Stewart & Bywater 2009) and only two moderate patches of *Ulva* spp. were recorded in the Ōwaka arm in 2012 (Stewart 2012). In 2016, the estuary had significantly deteriorated with areas of entrained macroalgae recorded in Catlins Lake/Kuramea (upper estuary), the mid estuary and in the Ōwaka arm (Stevens & Robertson 2017). In 2016, 14.9ha or 2.3% of the intertidal area was classified as eutrophic (high macroalgae cover, poor sediment oxygenation and mud-dominated sediments; Stevens & Robertson 2017).

The current report describes the methods and results of the most recent macroalgal mapping undertaken in Catlins/Pounawea Estuary over two tides on 1 December 2021. The primary purpose of the current survey was to characterise the presence and extent of nuisance

Map data © OpenStreetMap contributors, Microsoft, Esri Community Maps contributors, Map layer by Esri, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors, Esri, HERE, Garmin, FAO, NOAA, USGS

Fig. 1. Location of Catlins/Pounawea Estuary, Otago.

macroalgae. Results are discussed in terms of current state and trends in estuary health, and recommendations for future monitoring and assessment are made.

1.2 OVERVIEW OF CATLINS/POUNAWEA ESTUARY

Background information on Catlins/Pounawea Estuary has been presented in previous reports (Stewart & Bywater 2009, Stewart 2012, Stevens & Robertson 2017). This information has been summarised and paraphrased here.

Catlins/Pounawea Estuary is a large-sized (~830ha and ~12km long), shallow, intertidal dominated, estuary (SIDE) that discharges via one permanent open tidal mouth to the Pacific Ocean via a broad embayment at Pounawea, Otago (Fig. 1). The estuary is fed by two rivers, the Catlins River/ Pounawea River (mean flow ~3.7 m^3/s) and the slightly smaller Ōwaka River (mean flow 3.1m^3/s; source NIWA CLUES 10.3, 2016).

The estuary falls into two main areas, the eastern basin around Pounawea township near the estuary entrance which has strong tidal flushing and is dominated by sands, and the muddier upper reaches to the west of the Hinahina Road bridge, termed Catlins Lake (Kuramea), which is relatively shallow with more restricted flushing.

The Catlins/Pounawea catchment is ~415km^2 with land cover dominated by high producing grassland (61%), indigenous forest (20%), and exotic forest (5%; Stevens and Robertson 2017). On high producing exotic grassland, sheep and beef grazing represents the majority of recorded land use and borders the majority of the estuary, with dairy, deer and forestry being less common.

A large barrier spit is present to the north of the estuary entrance near the village of New Haven. A small area of virgin podocarp forest (rimu, totara, matai, kahikatea and miro) borders the estuary at Pounawea township, a remnant and reminder that the main industry of the Catlins from 1870 to 1970 was logging.

A large wetland is located at the western head of the estuary (Catlins Lake/Kuramea) which is an important habitat for waterfowl and fish breeding. The estuary itself is also an important habitat for marine and freshwater fish and as a coastal recreation area with boating, swimming, fishing and walking, and is listed as a coastal protection area with Kai Tahu cultural and spiritual values (Otago Regional Plan: Coast).

Overall, the estuary has moderate to high ecological habitat diversity with variable substrate types including sand, rock shell, gravel and mud, extensive shellfish beds, but relatively small areas of salt marsh (1.5% of the estuary), and seagrass (3.5% of the estuary). Historically there has been a significant loss (>300ha) of salt marsh since c.1850 as a consequence of drainage and reclamation with much of the natural vegetated margin now developed for grazing.

Macroalgae in Catlins Lake/Kuramea (upper estuary)

Table 1. Overview of the ecological significance of seagrass and opportunistic macroalgae in estuaries.

Habitat	Description
Seagrass	Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

2. METHODS

2.1 OVERVIEW OF MAPPING

Mapping was undertaken according to NEMP and New Zealand Estuary Trophic Index (ETI) methods, as used previously to delineate the spatial extent of macroalgae (Robertson et al. 2002a-c; Robertson et al. 2016a-b). This procedure combined aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology.

In 2021, 1:3000 colour aerial imagery captured between 12 January and 5 February 2021 was supplied by ORC. During field ground-truthing, macroalgae areas were drawn onto laminated aerial imagery, and percent cover and biomass were measured or estimated (as described below). The macroalgae features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet and combined with field measurements and georeferenced photographs. From this information, maps were produced showing the spatial extent and density of macroalgae.

For mapping purposes, an estuary is defined as a partly enclosed body of water, where freshwater inputs (i.e. rivers, streams) mix with seawater. The estuary entrance (i.e seaward boundary) was defined as a straight line between the seaward-most points of land that enclose the estuary, and the upper estuary boundary (i.e. riverine boundary) was based on the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For further detail see FGDC (2012).

Complete cover of *Agarophyton* spp.

2.2 MACROALGAE ASSESSMENT

The United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach was a key part of the macroalgal assessment. The OMBT, described in detail in Appendix 1, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within five overall quality status bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- *Percentage cover of opportunistic macroalgae*: The spatial extent and surface cover of algae present in intertidal soft sediment habitat in an estuary provides an early warning of potential eutrophication issues.
- *Macroalgal biomass:* Biomass provides a direct measure of macroalgal growth (wet weight biomass). Measurements and estimates of mean biomass are made within areas affected by macroalgal growth, as well as across the total estuary intertidal area.
- *Extent of algal entrainment into the sediment matrix*: Macroalgae is defined as entrained when growing in stable beds or with thalli or rhizoids ('roots') growing within the sediment matrix, which indicates that persistent macroalgal growths have established.

If an estuary supports <5% total opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' with no further sampling required.

Using this approach in Catlins/Pounawea Estuary, opportunistic macroalgae patches were mapped during field ground truthing, using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (Fig. 2). Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the extent of macroalgal entrainment were measured.

Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algal material was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale.

When sufficient representative patches had been measured to enable biomass to be reliably estimated, biomass estimates were made following the OMBT method.

Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on a five-point scale, using the biomass thresholds described in Table A3 of Appendix 1. These thresholds reflect OMBT values revised for use in New Zealand (Plew et al. 2020).

In addition to macroalgal proliferation, a subjective indication of the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment areas was provided by the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). This transition is referred to as the apparent Redox Potential Discontinuity (aRPD) depth, and provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions.

Hence, as a supporting indicator, aRPD was assessed in representative areas by digging into the underlying sediment with a hand trowel to determine whether there were any significant areas where sediment oxygenation was depleted close to the surface. Sediments were considered to have poor oxygenation if the aRPD was consistently <10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. Highly enriched sediments with a shallow aRPD also typically smell strongly of hydrogen sulphide (i.e. a rotten egg smell). As significant sampling effort is required to map sub-surface conditions accurately, the approach was intended as a preliminary screening tool to determine the need for additional sampling effort.

Sampling macroalgal biomass in Catlins/Pounawea Estuary

Weighing macroalgae in Catlins/Pounawea Estuary

2.3 DATA RECORDING AND QA/QC

Broad scale mapping provides a rapid overview of estuary macroalgae condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial imagery, the extent of ground-truthing undertaken to validate features visible on photographs, and the experience of those

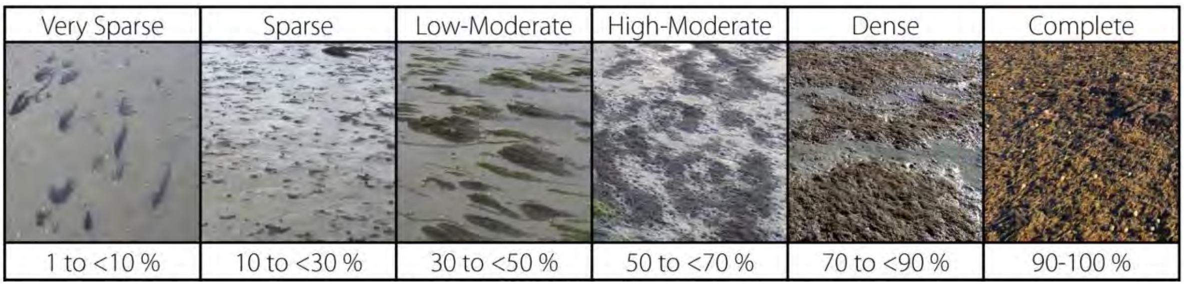


Fig. 2. Visual rating scale for percentage cover estimates. Modified from FGDC (2012).

undertaking the mapping. In most instances features with readily defined edges can be mapped at a scale of ~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse macroalgal beds. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed, but when relying on photographs alone, accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

As well as annotation of field information onto aerial photographs during the field ground truthing, point estimate macroalgae data (i.e. biomass, cover, entrainment), along with supporting measures of sediment aRPD, texture and sediment type were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP.

In December 2021, following digitising of habitat features, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables.

2.4 MACROALGAE CONDITION AND ASSESSMENT OF TEMPORAL CHANGE

In addition to the authors' interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 2). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 2. The condition ratings are primarily sourced from the ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 2. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores described above and in Appendix 1 (i.e. which range from 'high' to 'bad').

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HEC) was evaluated. For our purposes, HECs are defined as mud-dominated sediments (≥50% mud content, based on expert judgement) with >50% macroalgal cover and with macroalgae entrained and growing as stable beds within the sediment. These areas typically also have an aRPD depth shallower than 10mm due to sediment anoxia. Where areas become so enriched that macroalgae can no longer survive, e.g. areas of sulfidic and anoxic soft muds, they are included in the assessment of HECs despite not meeting the >50% macroalgal cover criterion because they represent severe levels of enrichment.

As many of the scoring categories in Table 2 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Seagrass in the well-flushed lower Catlins/Pounawea Estuary

Table 2. Indicators and condition rating criteria used to assess results in the current report.

Indicator[1]	Unit	Very Good	Good	Fair	Poor
Broad scale indicators					
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	≥ 0.8 to 1.0	≥ 0.6 to < 0.8	≥ 0.4 to < 0.6	< 0.4
High Enrichment Conditions	ha	< 0.5ha	≥ 0.5 to 5ha	≥ 5 to 20ha	≥ 20ha
High Enrichment Conditions	% of estuary	< 1%	≥ 1 to 5%	≥ 5 to 10%	≥ 10%
Sediment quality					
aRPD depth	mm	≥ 50	20 to < 50	10 to < 20	< 10

[1] General indicator thresholds derived from a New Zealand Estuary Tropic Index (Robertson et al. 2016b), with adjustments for aRPD (FDGC 2012). See text and Appendix 2 for further explanation of the origin or derivation of the different metrics.

3. RESULTS

A summary of the December 2021 survey results is provided below, with raw data in Appendix 3. Supporting GIS files (supplied to ORC as a separate electronic output) provide a more detailed dataset designed for easy interrogation and to address specific monitoring and management questions.

3.1 OPPORTUNISTIC MACROALGAE

Table 3 summarises macroalgal percentage cover and biomass classes for Catlins/Pounawea Estuary in December 2021, with the mapped cover and biomass shown in Fig. 3 and Fig. 4, respectively. Macroalgal sampling stations and raw wet weights for biomass measurements are provided in Appendix 3.

Assessing macroalgal cover in Catlins Lake/Kuramea

Table 3. Summary of intertidal macroalgal cover (A) and biomass (B), Catlins/Pounawea Estuary December 2021.

A. Cover*

Percent cover category	Ha	%
Absent or trace	508.6	80.0
Very sparse (1 to <10%)	3.7	0.6
Sparse (10 to <30%)	13.6	2.1
Low-Moderate (30 to <50%)	9.1	1.4
High-Moderate (50 to <70%)	26.7	4.2
Dense (70 to >90%)	11.7	1.8
Complete (>90%)	62.5	9.8
Total	635.9	100

B. Biomass**

Biomass category (g/m^2)	Ha	%
Trace (<1)	508.6	80.0
Very low (1 - 100)	3.9	0.6
Low (101 - 200)	13.8	2.2
Moderate (201 - 500)	12.6	2.0
High (501 - 1450)	25.7	4.0
Very high (>1450)	71.4	11.2
Total	635.9	100

* Cover categories are shown in Fig. 2.

** Thresholds for biomass categories are based on Plew et al. (2020) as per Table A3 of Appendix 1.

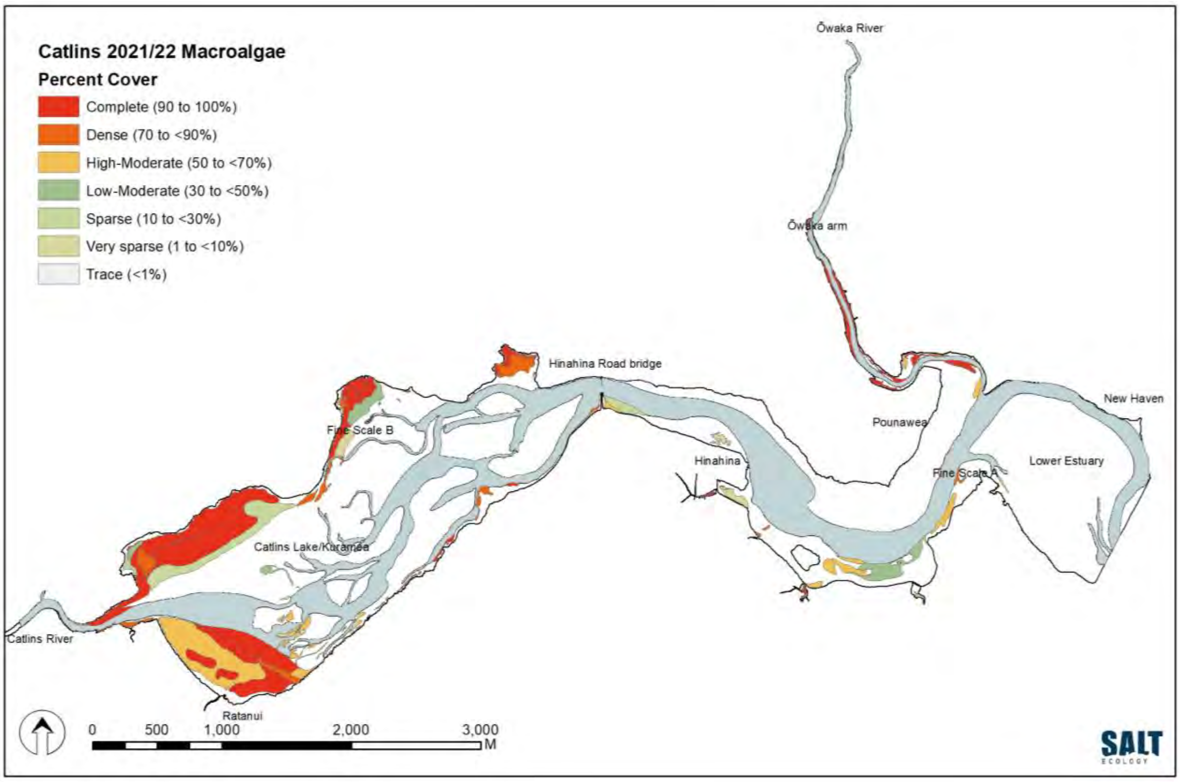


Fig. 3. Distribution and percentage cover classes of macroalgae, Catlins/Pounawea Estuary, December 2021.

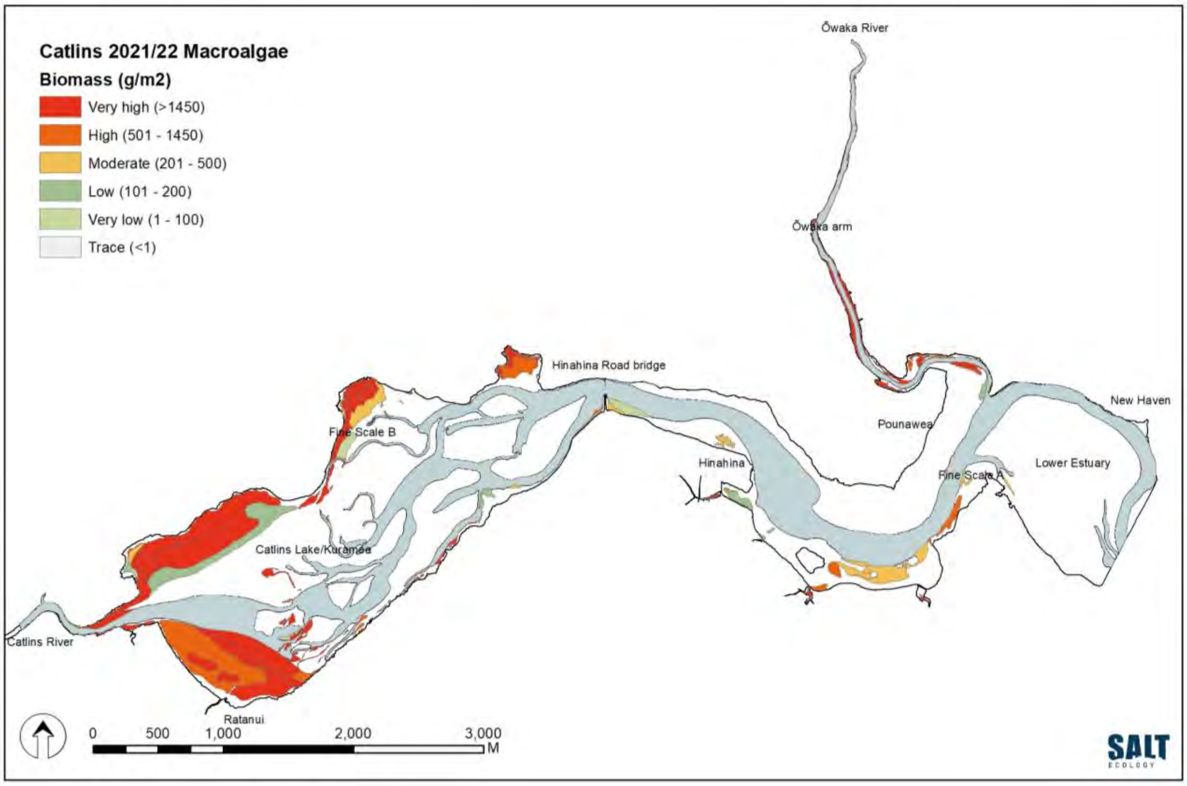


Fig. 4. Distribution and biomass (wet weight; g/m^2) classes of macroalgae, Catlins/Pounawea Estuary, December 2021.

Key results were as follows:

- Across 80% of the 636ha intertidal area, macroalgae cover was classified as absent or trace (i.e. <1% cover), indicating the majority of the estuary was not experiencing macroalgal issues (see photo; Fig. 3).
- In the sheltered upper margins of Catlins Lake/Kuramea, the Ōwaka arm, and in several small embayments on the southern side of the lower estuary (southeast of Hinahina), there were extensive dense beds (>50% cover) of *Agarophyton* spp. deeply entrained in muddy sediment (Fig. 3).
- Dense *Agarophyton* spp. beds (>50% cover) in Catlins Lake/Kuramea had wet weight biomass ranging from 0.8 to 9.97kg/m^2 (mean 4.17kg/m^2) and consisted of 5-10cm thick beds of *Agarophyton* spp. (Fig. 4). The maximum biomass recorded was ~6 times higher than the 'very high' threshold of 1.45 kg/m^2 (see photos on following page).
- Dense *Agarophyton* spp. beds (>50% cover) in the Ōwaka arm had wet weight biomass ranging from 0.8 to 6.0kg/m^2 (mean 2.6kg/m^2) and consisted of thick *Agarophyton* spp. beds (5-10cm high) deeply entrained in muddy sediment in the lower reaches of the river, and a dense cover of *Ulva* spp. (not entrained) in the upper reaches (Fig. 4). The maximum biomass recorded was ~4 times higher than the 'very high' threshold of 1.45 kg/m^2 (see photos on following page).
- Localised areas of severe eutrophication (very soft anoxic mud with a strong rotten egg odour) were present in the Ōwaka arm, but particularly in Catlins Lake/Kuramea. These included *Agarophyton* spp. beds that had died and were rotting, resulting in a reduction in surface macroalgal cover and biomass. Unfavourable sediment conditions appear to be causing a decrease in macroalgal cover in these eutrophic areas.
- The green seaweed *Ulva* spp. was present in the well flushed lower estuary, most notably between Hinihina and Fine Scale Site A, where it was generally growing on firm sands or hard substrates (e.g. cobbles or bedrock; Fig. 3).

The well-flushed central Catlins Lake/Kuramea

High biomass *Ulva* on *Agarophyton* spp. (top) and rotting beds of *Agarophyton* spp. (bottom) near Ratanui in Catlins Lake/Kuramea

High biomass *Ulva* spp. (top) and *Agarophyton* spp. (bottom) in the Ōwaka arm

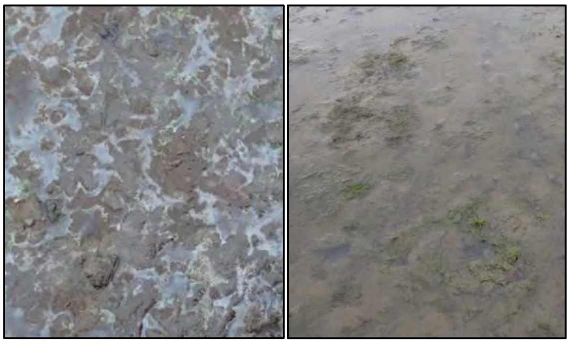
High biomass *Agarophyton* spp. (top) and rotting beds of *Agarophyton* spp. (bottom) in near fine scale Site B

High cover of *Ulva* spp. on well flushed tidal flats (top) and *Agarophyton* spp. in an embayment in the lower estuary (bottom)

In December 2021, the EQR, calculated using the OMBT method, was 0.393, which equates to a condition rating of 'Poor' (Table 4). Although the percent cover in the Available Intertidal Habitat (AIH) was rated 'Good', reflecting the absence of macroalgae over ~80% of the estuary, when present macroalgae were resulting in degraded conditions over a large area (97ha with biomass rated as high or very high – Table 3).

Compared to macroalgal mapping undertaken in 2016 (Table 5, Appendix 5), the estuary has degraded significantly over the past 5 years. The Affected Area has increased from 54ha to 127ha, mean biomass has increased from 478g/m^2 to 1564g/m^2, and the EQR rating (Table 2) has shifted from 'Good' (0.620) to 'Poor' (0.393). Of particular concern was the large increase in macroalgal cover and biomass either side of the Catlins River mouth, and the widespread presence of degraded sediment conditions (shallow aRPD, high mud content, and high organic enrichment).

In places, sulphur oxidising bacteria were observed growing among macroalgae and on surface sediments, with localised areas of macroalgal dieback suggesting sediment conditions have reached a state so poor that macroalgae are no longer able to survive (see photos below).



Sulphur oxidising bacteria among macroalgae (left) and macroalgae dieback (right)

Table 4. Summary of 2021 OMBT input metrics and overall macroalgal Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 1). The condition rating for the survey EQR score is based on Table 2.

December 2021 Metric	Face value	FEDS	Environmental Quality Class
%cover in AIH	14.6	0.608	Good
Average biomass (g/m^2) in AIH	318.8	0.521	Moderate
Average biomass (g/m^2) in AA	1564.3	0.198	Bad
%entrained in AA	38.9	0.274	Poor
Worst of AA (ha) and AA (% of AIH)		0.364	Poor
AA (ha)	127.4	0.364	Poor
AA (% of AIH)	20.4	0.569	Moderate
Survey EQR		0.393	'Poor'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating. *Table 2.

Table 5. Summary of 2016 OMBT input metrics and overall macroalgal Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 1). The condition rating for the survey EQR score is based on Table 2. See Appendix 5 for maps of %cover and biomass.

December 2016 Metric	Face value	FEDS	Environmental Quality Class
%cover in AIH	5.0	0.802	High
Average biomass (g/m^2) in AIH	41.4	0.917	High
Average biomass (g/m^2) in AA	478.1	0.415	Moderate
%entrained in AA	26.6	0.356	Poor
Worst of AA (ha) and AA (% of AIH)		0.583	Moderate
AA (ha)	54.1	0.583	Moderate
AA (% of AIH)	8.7	0.726	Good
Survey EQR		0.620	'Good'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating. *Table 2.

Across the estuary, 61.6ha (9.7% of the intertidal area) was classified as having High Enrichment Conditions (HECs; Fig. 5). The largest areas were present near the upper tidal range on the intertidal flats by Catlins River mouth, in the lower Ōwaka arm, where they were a dominant feature, and in most of the small embayments near Hinahina that have restricted tidal flushing due to the presence of piped causeways. Compared to the 14.9ha (2.3%) of HEC area reported in December 2016 (Stevens & Robertson 2017), the December 2021 results show a large increase in HEC area.

High enrichment condition, high macroalgal cover growing in mud-dominated sediments with low sediment oxygen

Anoxic soft muds with decaying macroalgae, Catlins Lake/Kuramea

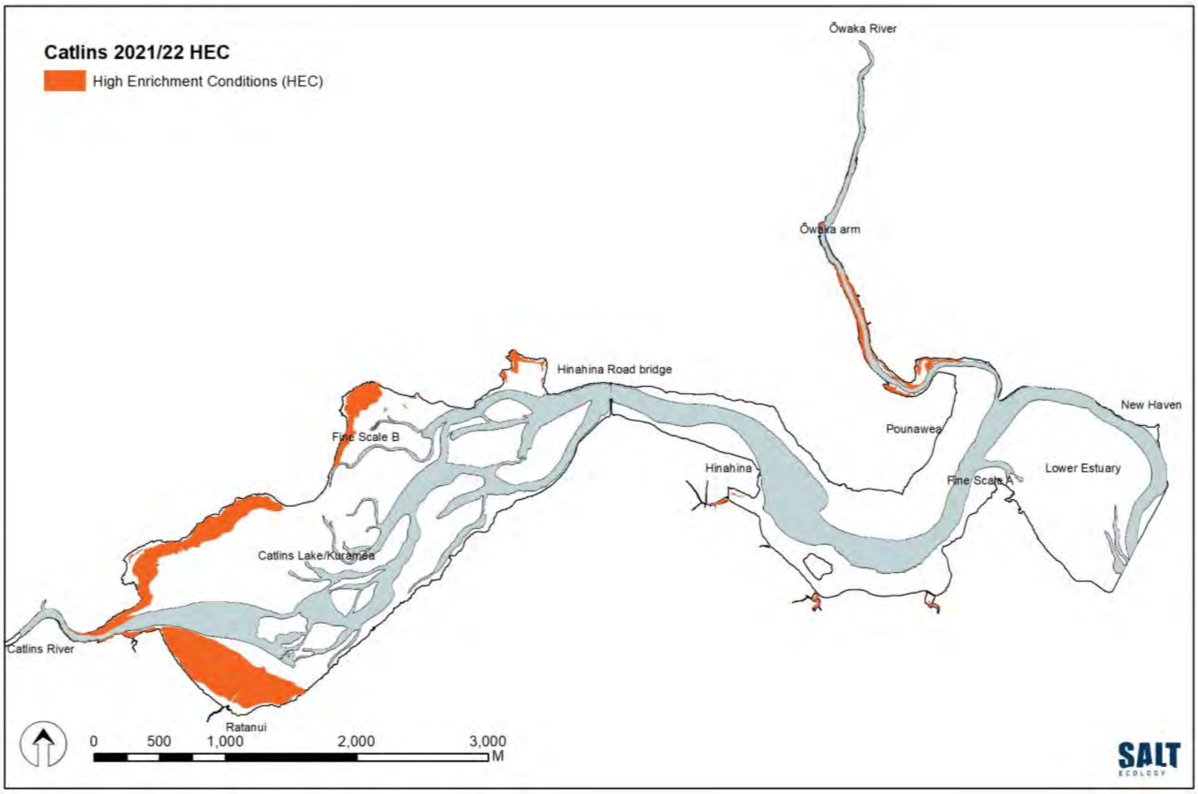


Fig. 5. Areas of High Enrichment Conditions (HEC), Catlins/Pounawea Estuary, December 2021.

4. SYNTHESIS OF KEY FINDINGS

Surveys of the estuary in 2008 (Stewart & Bywater 2009), and 2012 (Stewart 2012) did not report nuisance macroalgae as being either widespread or causing obvious eutrophication related issues. However, by 2016 nuisance macroalgae was well established with >50% cover over 32ha (5.1%) of the intertidal area and which was causing sediment condition to degrade (Stevens & Robertson 2017). Of this, 14.9ha (2.3%) of the intertidal area was classified as areas with high enrichment conditions, comprising high macroalgal cover and low oxygen, mud-dominated sediments (Stevens & Robertson 2017).

In December 2021 persistent eutrophic symptoms (nuisance macroalgae and the development of high enrichment conditions) have expanded (>50% cover over 101ha or 17.2% of the intertidal area) and become well established, particularly across the tidal flats along the western side of Catlins Lake/Kuramea. The areas of macroalgal proliferation in the Catlins/Pounewea Estuary represent sheltered deposition zones where fine sediments accrue creating the ideal environment for nuisance macroalgae to grow, particularly the red seaweed *Agarophyton* spp. In the area affected by macroalgae, there has been widespread degradation of sediment conditions including poor oxygenation, increased organic content and a build-up of mud-dominated sediments (Fig. 5; see photos). In localised areas macroalgal dieback suggests sediment conditions have reached a state so poor that macroalgae are no longer able to survive. While on a smaller scale here, these severe levels of enrichment have also been observed in New River Estuary, Southland (Roberts et al. 2021).

Between 2016 and 2021 there has been a rapid expansion of opportunistic macroalgae in Catlins/Pounawea Estuary accompanied by widespread sediment impacts, particularly in the Catlins Lake/Kuramea. These findings are reiterated when comparing the condition ratings for key macroalgal indicators between 2016 and 2021 (Table 6, see also Appendix 5). In December 2021 the extent and impact of macroalgae was rated 'Poor' whereas in December 2016 the condition ratings ranged from 'Fair' to 'Good'. This highlights conditions in the estuary are worsening and that catchment nutrient loads currently exceed the assimilative capacity of the estuary, with problems expected to persist in these areas unless there are significant reductions in nutrient inputs.

Table 6. Summary of condition rating scores for December 2016 and December 2021 based on the key indicators and criteria in Table 2.

Broad scale indicator	Unit	2016	2021
Macroalgae (OMBT)[1]	EQR	0.620	0.393
HEC[2]	Ha	14.9	61.6
HEC[2]	% of estuary	2.3	9.7

[1] OMBT = Opportunistic Macroalgal Blooming Tool
[2] High Enrichment Conditions
Condition rating colour key:

Very Good	Good	Fair	Poor

Area of HEC, sulphur oxidising bacteria visible on surface, decaying macroalgae and low oxygen mud-dominated sediments

Mix of entrained *Agarophyton* spp. and *Ulva* spp. growing on top

Blooms of opportunistic macroalgae in estuaries are directly linked to anthropogenically elevated nutrients, primarily nitrogen (Howarth 2008; Sutula et al. 2014; Woodland et al. 2015; Robertson et al. 2017; Zeldis et al. 2017). As such the management of nutrient loads to estuaries, as discussed, is essential to maintain or improve estuary health.

To help in this regard, total nitrogen (TN) thresholds (Plew et al. 2020) have been developed to indicate the point at which increasing nutrient availability is predicted to cause changes in macroalgal expression and subsequent ecological health of an estuary (Table 7). These TN thresholds have been used to both predict trophic state, and to guide estuary management by defining the likely nutrient reductions needed to meet desired states in the estuary.

Modelling of Catlins/Pounawea Estuary by Plew and Dudley (2018) estimated potential TN concentrations in Catlins Lake/Kuramea to be 260mg/m^3 ('Fair' - Band C), and in the lower estuary (downstream of Hinahina bridge) to be 99mg/m^3 ('Good' - Band B). Based on these estimates, which were largely consistent with the December 2016 macroalgal monitoring results, Plew and Dudley (2018) predicted that only a relatively small increase in the catchment TN load (from 93T/yr to 123T/yr) to Catlins Lake/Kuramea was needed to shift this area of the estuary into a 'Poor' (Band D) condition, reflecting the monitoring in December 2021. In contrast, a significant increase in TN load (from 142T/yr to 412T/yr) in the Ōwaka arm would be required to shift the lower estuary to a 'Poor' (Band D) state, largely because of extensive tidal flushing in the lower reaches.

The December 2021 macroalgal monitoring results and the findings of Plew and Dudley (2018), suggest that nutrient loads to the estuary have increased over the past 5 years. Without recent TN load data, it is not possible to determine the magnitude or source of any increased inputs. The disproportionately large increase in problems in the Catlins Lake/Kuramea arm suggests relatively large nutrient increases in the Catlins/Pounewea River catchment. However, because the Ōwaka arm was already substantially impacted in 2016, with limited areas available for further macroalgal growths to occur, changes in nutrient inputs in this part of the estuary are less easy to determine.

Entrained *Agarophyton* spp. and *Ulva* spp. in the Ōwaka arm

Table 7. Narrative ecological condition associated with macroalgal bandings in Plew and Dudley (2018) (adapted from Robertson et al. (2016b) and WFD-UKTAG (2014)).

Very Good	Good	Fair	Poor
Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are healthy and resilient. Algal cover <5% and low biomass (<50g/m^2 wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality high	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are slightly impacted by additional macroalgal growth arising from nutrients levels that are elevated. Limited macroalgal cover (5–20%) and low biomass (50–200g/m^2 wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality transitional	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are moderately to strongly impacted by macroalgae. Persistent, high % macroalgal cover (25–50%) and/or biomass (>200–1000g/m^2 wet weight), often with entrainment in sediment. Sediment quality degraded	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are strongly impacted by macroalgae. Persistent very high % macroalgal cover (>75%) and/or biomass (>1000g/m^2 wet weight), with entrainment in sediment. Sediment quality degraded with sulphidic conditions near the sediment surface

Overall, the December 2021 monitoring results have highlighted a significant expansion of high biomass, entrained macroalgae since 2016, particularly in the Catlins Lake/Kuramea (Fig. 4; Table 6). Of concern, are the areas of severe eutrophication (i.e. HEC areas; Fig. 5) that have also expanded in extent with poor sediment condition leading to macroalgal dieback, extreme anoxia and the formation of white bacterial mats (i.e. sulphur oxidising bacteria). These results combined with the modelling of Plew and Dudley (2018) suggest that the capacity of the estuary to assimilate nutrients is being exceeded resulting in a relatively rapid decline in estuary condition. Unless nutrient inputs to the estuary are reduced it is expected that the estuary will continue to express widespread signs of eutrophication and potentially degrade further.

5. RECOMMENDATIONS

Based on the December 2021 survey findings and the rapid decline in estuary state since the previous survey in December 2016, it is recommended that ORC:

- Undertake annual monitoring during summer to track changes in nuisance macroalgae.
- Continue with planned work to determine limits on nutrient and sediment mass loads that would be expected to prevent further degradation and, where possible, mitigate current adverse impacts.
- Determine catchment nutrient and sediment sources as part of the mass load assessment and evaluate whether there are any effective and feasible management practices that could be undertaken to achieve ORC's desired condition for the estuary.

Macroalgal beds in the upper tidal reaches of Catlins Lake/Kuramea viewed towards Hinahina

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Appendix 1. Opportunistic Macroalgal Blooming Tool

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multimetric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5-part multimetric OMBT, modified for NZ estuary types, is fully described below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of *mud, muddy sand, sandy mud, sand, stony mud and mussel beds.* Areas which are judged unsuitable for algal blooms e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. Percentage cover of the available intertidal habitat (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH, %).

In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric established is the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse-case scenario.

3. Biomass of AIH (g/m^2).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within ±5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. Biomass of AA (g/m^2).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. Presence of Entrained Algae (% of quadrats).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool. All the metrics are equally weighted and combined within the multimetric, in order to best describe the changes in the nature and degree of opportunistic macroalgae growth on sedimentary shores due to nutrient pressure.

TIMING

The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification; e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

SUITABLE LOCATIONS

The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing ICOLLs due to the particular challenges in setting suitable reference conditions for these water bodies.

DERIVATION OF THRESHOLD VALUES

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

REFERENCE THRESHOLDS

A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g/m^2 wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

CLASS THRESHOLDS FOR PERCENT COVER

High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to

Table A1. The final face value thresholds and metrics for levels of the ecological quality status.

ECOLOGICAL QUALITY RATING (EQR)	High	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g/m^2) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g/m^2) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).

Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

CLASS THRESHOLDS FOR BIOMASS

Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 g/m^2 wet weight was an acceptable level above the reference level of <100 g/m^2 wet weight. In Good status only slight deviation from High status is permitted so 500 g/m^2 represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 g/m^2 but less than 1,000 g/m^2 would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1kg/m^2 wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).

Thresholds applied in the current study are described on page 24 and presented in Table A3.

THRESHOLDS FOR ENTRAINED ALGAE

Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

EQR CALCULATION

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Rating** score (EQR).

The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the categories in Table A1:

The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 - where Total % cover = Sum of [(patch size) / 100] x average % cover for patch
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH (g/m^2) = Total biomass / AIH - where Total biomass = Sum of (patch size x average biomass for the patch)
- Biomass of Affected Area (g/m^2) = Total biomass / AA - where Total biomass = Sum of (patch size x average biomass for the patch)
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A2).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

*Final Equidistant Index score = Upper Equidistant range value – ([Face Value - Upper Face value range] * (Equidistant class range / Face Value Class Range)).*

Table A2 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range. Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.

The final EQR score is calculated as the average of equidistant metric scores.

A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

Metric	Quality status	Face value ranges			Equidistant class range values		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g/m^2)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g/m^2)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

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CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

Biomass thresholds included in the OMBT were lowered for use in NZ by Plew et al. (2020) based on unpublished data from >25 shallow well-flushed intertidal NZ estuaries (Robertson et al. 2016b) and the results from similar estuaries in California. Sutula et al. (2014) reported that in eight Californian estuaries, macroalgal biomass of 1450g/m^2 wet weight, total organic carbon of 1.1% and sediment total nitrogen of 0.1% were thresholds associated with anoxic conditions near the surface (aRPD < 10 mm). Green et al. (2014) reported significant and rapid negative effects on benthic invertebrate abundance and species richness at macroalgal abundances as low as 840–930g/m^2 wet weight in two Californian estuaries. McLaughlin et al. (2014) reviewed Californian biomass thresholds and found the elimination of surface deposit feeders in the range of 700–800g/m^2. As the Californian results were consistent with NZ findings, the latter thresholds were used to lower the OMBT good/moderate threshold from ≤500 to ≤200g/m^2, the moderate/poor threshold from ≤1000 to ≤500g/m^2 and the poor/bad threshold from >3000 to >1450g/m^2. These thresholds are considered to provide an early warning of nutrient related impacts in NZ prior to the establishment of adverse enrichment conditions that are likely difficult to reverse.

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Table A3. Revised final face value thresholds and metrics for levels of the ecological quality status used in the current assessment.

ECOLOGICAL QUALITY RATING (EQR)	High	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g/m^2) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g/m^2) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

Appendix 2. Information supporting ratings in the report

SEDIMENT MUD CONTENT

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more sticky and cohesive, and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon, and sediment-bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations and, on intertidal flats of estuaries, can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

APPARENT REDOX POTENTIAL DISCONTINUITY (aRPD)

aRPD depth, the visually apparent transition between oxygenated sediments near the surface and deeper more anoxic sediments, is a useful estuary condition indicator as it is a direct measure of time integrated sediment oxygenation. Knowing if the aRPD is close to the surface is important for three main reasons:

i) The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species; ii) the tendency for sediments to become anoxic is much greater if the sediments are muddy; iii) anoxic sediments contain toxic sulphides and support very little aquatic life.

As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, become released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (i.e. >3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

OPPORTUNISTIC MACROALGAE

The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication and, when combined with high mud and low oxygen conditions (see previous), can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014; Robertson et al 2016; Zeldis et al. 2017), with results combined with those of other indicators to determine overall condition.

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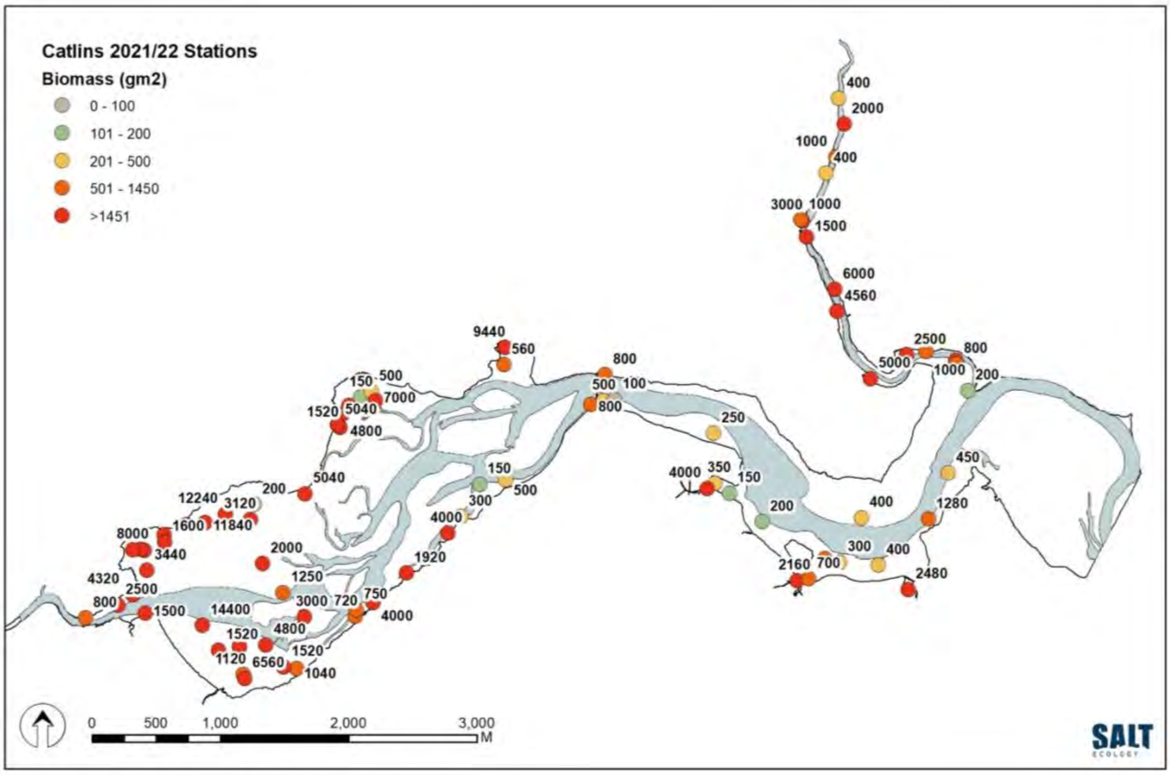
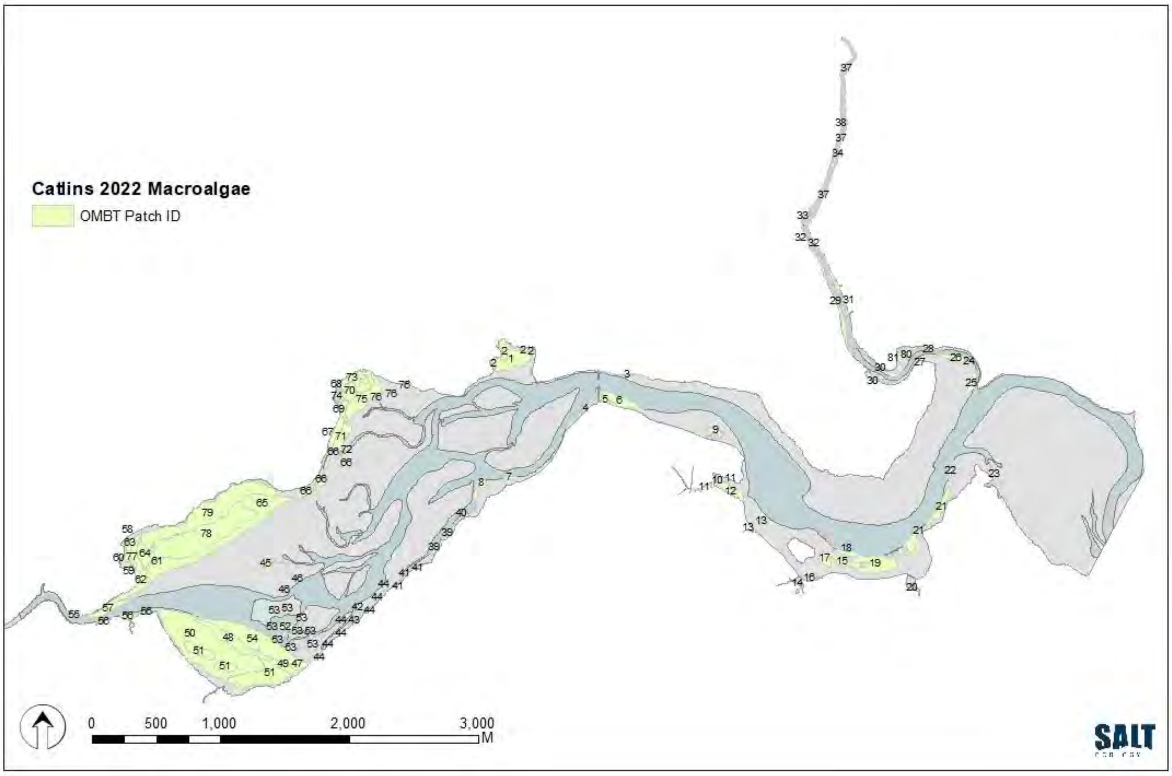
Appendix 3. Macroalgal biomass stations, OMBT patch ID and raw data, December 2021





Patch ID Table

Estuary	Year	PatchID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (gm^2)	Biomass Category	Entrained*	Dominant Species	SubDom Sp.1	SubDom Sp.2	Area_ha
Catlins	2021	1	Ulva Other Grch	70 4 1	75	Dense (70 to <90%)	560	High (501 - 1450)	0	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	3.24
Catlins	2021	2	Grch Ulva	99 1	100	Complete (>90%)	9440	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.32
Catlins	2021	3	Ulva Grch	70 10	80	Dense (70 to <90%)	800	High (501 - 1450)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.12
Catlins	2021	4	Grch Ulva	70 10	80	Dense (70 to <90%)	800	High (501 - 1450)	0	Gracilaria chilensis	Ulva (Sea lettuce)		0.28
Catlins	2021	5	Ulva Grch	40 10	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.36
Catlins	2021	6	Grch Ulva	10 1	11	Sparse (10 to <30%)	100	Very low (1 - 100)	0	Gracilaria chilensis	Ulva (Sea lettuce)		1.72
Catlins	2021	7	Ulva Grch	80 20	100	Complete (>90%)	500	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.20
Catlins	2021	8	Grch Ulva	60 20	80	Dense (70 to <90%)	150	Low (101 - 200)	0	Gracilaria chilensis	Ulva (Sea lettuce)		0.82
Catlins	2021	9	Grch Ulva	4 1	5	Very sparse (1 to <10%)	250	Moderate (201 - 500)	0	Gracilaria chilensis	Ulva (Sea lettuce)		0.70
Catlins	2021	10	Grch	10	10	Sparse (10 to <30%)	350	Moderate (201 - 500)	1	Gracilaria chilensis			0.08
Catlins	2021	11	Grch	90	90	Complete (>90%)	4000	Very high (>1450)	1	Gracilaria chilensis			0.28
Catlins	2021	12	Ulva	5	5	Very sparse (1 to <10%)	150	Low (101 - 200)	0	Ulva (Sea lettuce)			1.10
Catlins	2021	13	Ulva	80	80	Dense (70 to <90%)	200	Low (101 - 200)	0	Ulva (Sea lettuce)			0.18
Catlins	2021	14	Grch Ulva	95 1	96	Complete (>90%)	2160	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.19
Catlins	2021	15	Ulva Other	30 20	50	High-Moderate (50 to <70%)	300	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		1.17
Catlins	2021	16	Ulva	50	50	High-Moderate (50 to <70%)	700	High (501 - 1450)	0	Ulva (Sea lettuce)			0.40
Catlins	2021	17	Ulva Other	50 5	55	High-Moderate (50 to <70%)	880	High (501 - 1450)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		0.81
Catlins	2021	18	Ulsp Grch Other	40 5 5	50	High-Moderate (50 to <70%)	400	Moderate (201 - 500)	0	Ulva sp (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	0.49
Catlins	2021	19	Ulva Other Grch	40 5 2	47	Low-Moderate (30 to <50%)	400	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	4.63
Catlins	2021	20	Grch Ulva	50 1	51	High-Moderate (50 to <70%)	2480	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.10
Catlins	2021	21	Ulva Other Grch	59 5 1	65	High-Moderate (50 to <70%)	1280	High (501 - 1450)	0	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	1.41
Catlins	2021	22	Ulva Other	60 10	70	Dense (70 to <90%)	450	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		0.36
Catlins	2021	23	Ulsp Other	50 5	55	High-Moderate (50 to <70%)	450	Moderate (201 - 500)	0	Ulva sp (Sea lettuce)	Unspecified Macroalgae		0.25
Catlins	2021	24	Ulva Grch	60 30	90	Complete (>90%)	800	High (501 - 1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.23
Catlins	2021	25	Ulva Other	50 5	55	High-Moderate (50 to <70%)	200	Low (101 - 200)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		0.56
Catlins	2021	26	Grch Ulva	80 10	90	Complete (>90%)	2400	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.76
Catlins	2021	27	Ulsp Grch	70 20	90	Complete (>90%)	1100	High (501 - 1450)	1	Ulva sp (Sea lettuce)	Gracilaria chilensis		0.10
Catlins	2021	28	Ulva Grch	60 10	70	Dense (70 to <90%)	1000	High (501 - 1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.20
Catlins	2021	29	Grch	100	100	Complete (>90%)	4560	Very high (>1450)	1	Gracilaria chilensis			1.27
Catlins	2021	30	Grch Ulva	90 5	95	Complete (>90%)	5000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.91
Catlins	2021	31	Grch Ulva	99 1	100	Complete (>90%)	6000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.81
Catlins	2021	32	Ulva	50	50	High-Moderate (50 to <70%)	1500	Very high (>1450)	0	Ulva (Sea lettuce)			0.21
Catlins	2021	33	Grch	80	80	Dense (70 to <90%)	1000	High (501 - 1450)	1	Gracilaria chilensis			0.09
Catlins	2021	34	Ulva	100	100	Complete (>90%)	1000	High (501 - 1450)	0	Ulva (Sea lettuce)			0.04
Catlins	2021	35	Ulva	90	90	Complete (>90%)	2000	Very high (>1450)	0	Ulva (Sea lettuce)			0.01
Catlins	2021	36	Grch Ulva	99 1	100	Complete (>90%)	3000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.07
Catlins	2021	37	Ulsp	80	80	Dense (70 to <90%)	400	Moderate (201 - 500)	0	Ulva sp (Sea lettuce)			0.17
Catlins	2021	38	Ulva	80	80	Dense (70 to <90%)	400	Moderate (201 - 500)	0	Ulva (Sea lettuce)			0.15
Catlins	2021	39	Ulva Other Grch	80 10 10	100	Complete (>90%)	4000	Very high (>1450)	1	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	0.43
Catlins	2021	40	Grch Ulva Other	20 10 10	40	Low-Moderate (30 to <50%)	300	Moderate (201 - 500)	0	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	0.04

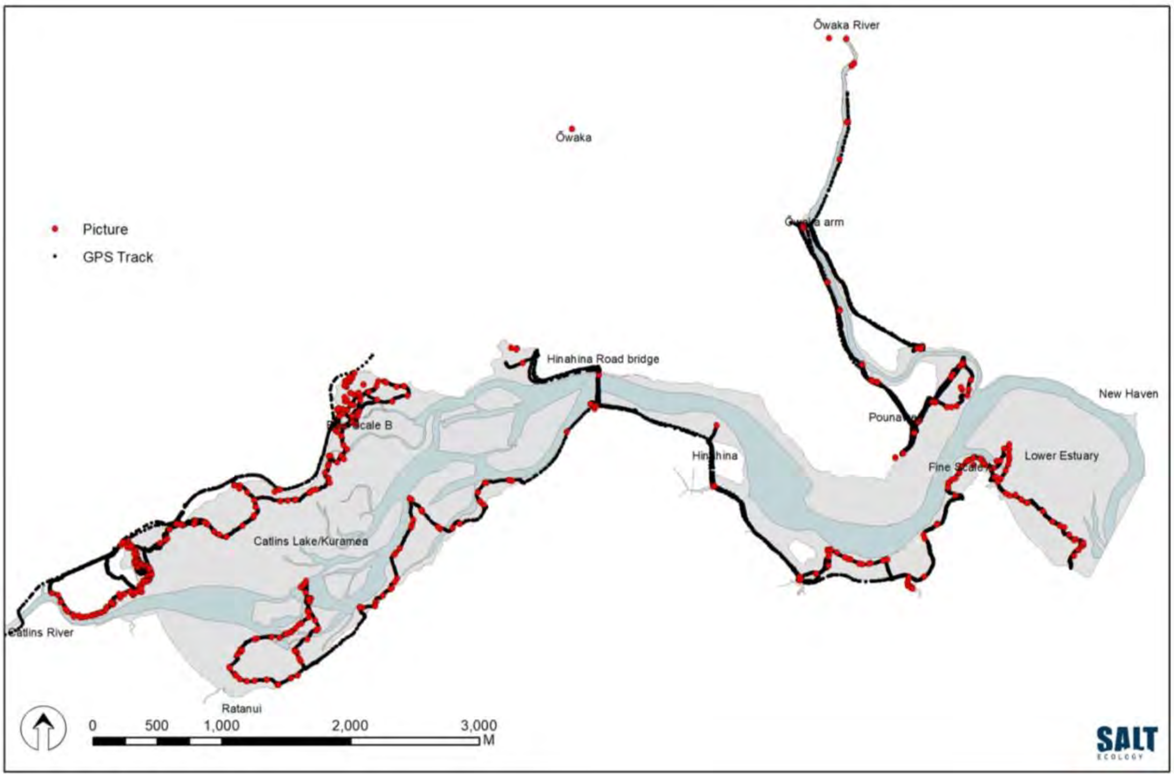
* 0=not entrained, 1=entrained

Patch ID Table continued...

Estuary	Year	PatchID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (gm^2)	Biomass Category	Entrained*	Dominant Species	SubDom Sp.1	SubDom Sp.2	Area_ha
Catlins	2021	41	Ulva Grch	50 20	70	Dense (70 to <90%)	1920	Very high (>1450)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.19
Catlins	2021	42	Grch Ulva Other	30 10 10	50	High-Moderate (50 to <70%)	750	High (501 - 1450)	0	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	0.19
Catlins	2021	43	Grch Ulva Other	30 10 10	50	High-Moderate (50 to <70%)	720	High (501 - 1450)	0	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	0.17
Catlins	2021	44	Ulva Grch	60 20	80	Dense (70 to <90%)	4000	Very high (>1450)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.27
Catlins	2021	45	Grch Ulva	30 10	40	Low-Moderate (30 to <50%)	2000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.72
Catlins	2021	46	Grch Ulva	20 5	25	Sparse (10 to <30%)	1250	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.11
Catlins	2021	47	Grch Ulva	50 10	60	High-Moderate (50 to <70%)	1040	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.83
Catlins	2021	48	Grch Ulva	99 1	100	Complete (>90%)	9360	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		3.08
Catlins	2021	49	Grch Ulva	80 1	81	Dense (70 to <90%)	1520	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.40
Catlins	2021	50	Grch Ulva	50 10	60	High-Moderate (50 to <70%)	1320	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		17.10
Catlins	2021	51	Grch Ulva	95 5	100	Complete (>90%)	6560	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		8.02
Catlins	2021	52	Grch	1	1	Very sparse (1 to <10%)	100	Very low (1 - 100)	1	Gracilaria chilensis			0.38
Catlins	2021	53	Grch Ulva	60 5	65	High-Moderate (50 to <70%)	3000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		2.33
Catlins	2021	54	Grch Ulva	80 10	90	Complete (>90%)	4800	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		7.88
Catlins	2021	55	Ulva Grch Other	40 15 1	56	High-Moderate (50 to <70%)	800	High (501 - 1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	0.14
Catlins	2021	56	Ulva Grch	75 10	85	Dense (70 to <90%)	1500	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.65
Catlins	2021	57	Ulva Grch Other	75 20 1	96	Complete (>90%)	2500	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	1.45
Catlins	2021	58	Grch Ulva	80 20	100	Complete (>90%)	2000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.12
Catlins	2021	59	Grch Ulva	5 5	10	Sparse (10 to <30%)	100	Very low (1 - 100)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.20
Catlins	2021	60	Grch Ulva	10 5	15	Sparse (10 to <30%)	200	Low (101 - 200)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.32
Catlins	2021	61	Ulva Grch	45 45	90	Complete (>90%)	3440	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.29
Catlins	2021	62	Grch Ulva Other	80 10 5	95	Complete (>90%)	4320	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	2.03
Catlins	2021	63	Grch Ulva	20 10	30	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.63
Catlins	2021	64	Grch Ulva	47 42	89	Dense (70 to <90%)	6160	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.70
Catlins	2021	65	Grch Ulva	15 5	20	Sparse (10 to <30%)	200	Low (101 - 200)	0	Gracilaria chilensis	Ulva (Sea lettuce)		10.81
Catlins	2021	66	Grch Ulva	80 5	85	Dense (70 to <90%)	5040	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.56
Catlins	2021	67	Grch Ulva	90 2	92	Complete (>90%)	3280	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.22
Catlins	2021	68	Ulva Grch	60 40	100	Complete (>90%)	3000	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.03
Catlins	2021	69	Grch Ulsp	15 2	17	Sparse (10 to <30%)	500	Moderate (201 - 500)	1	Gracilaria chilensis	Ulva sp (Sea lettuce)		0.20
Catlins	2021	70	Grch Ulva	97 1	98	Complete (>90%)	6280	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		3.22
Catlins	2021	71	Grch Ulva	5 1	6	Very sparse (1 to <10%)	50	Very low (1 - 100)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.52
Catlins	2021	72	Ulsp	15	15	Sparse (10 to <30%)	100	Very low (1 - 100)	0	Ulva sp (Sea lettuce)			0.11
Catlins	2021	73	Grch Ulsp	80 10	90	Complete (>90%)	3500	Very high (>1450)	1	Gracilaria chilensis	Ulva sp (Sea lettuce)		1.45
Catlins	2021	74	Grch	85	85	Dense (70 to <90%)	3500	Very high (>1450)	1	Gracilaria chilensis			0.34
Catlins	2021	75	Grch Ulva	27 10	37	Low-Moderate (30 to <50%)	325	Moderate (201 - 500)	0	Gracilaria chilensis	Ulva (Sea lettuce)		3.13
Catlins	2021	76	Grch Ulva	95 5	100	Complete (>90%)	7000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.08
Catlins	2021	77	Grch Ulva	60 35	95	Complete (>90%)	8000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.16
Catlins	2021	78	Ulva Grch Other	52 37 2	91	Complete (>90%)	2360	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	12.96
Catlins	2021	79	Grch Ulva	95 3	98	Complete (>90%)	9770	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		12.48
Catlins	2021	80	Grch Ulva	80 15	95	Complete (>90%)	2500	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.42
Catlins	2021	81	Grch Ulva	40 10	50	High-Moderate (50 to <70%)	1125	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.20

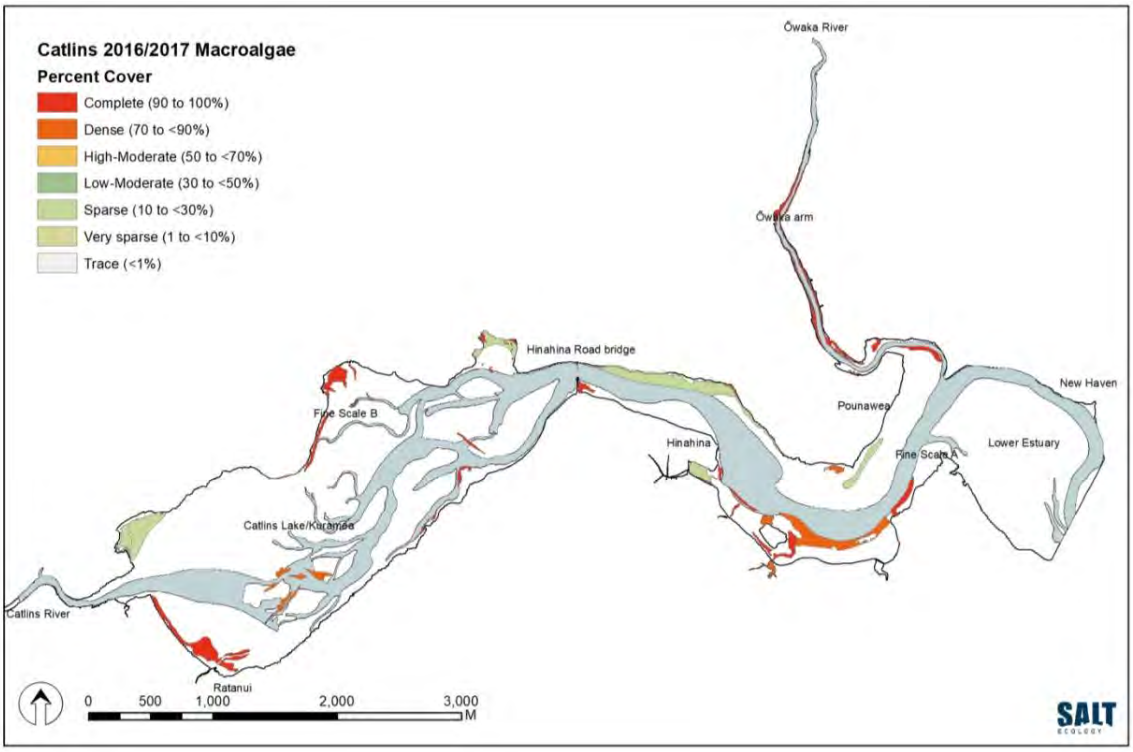
* 0=not entrained, 1=entrained

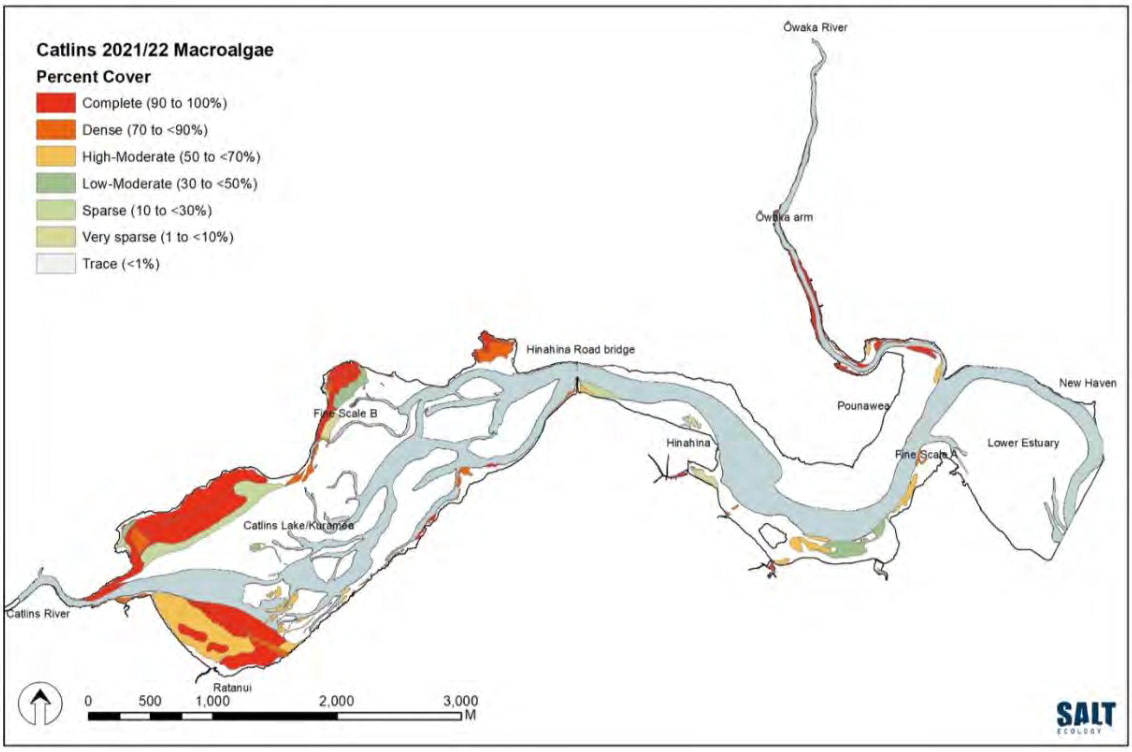
Appendix 4. Ground truthing in Catlins/Pounawea Estuary, December 2021



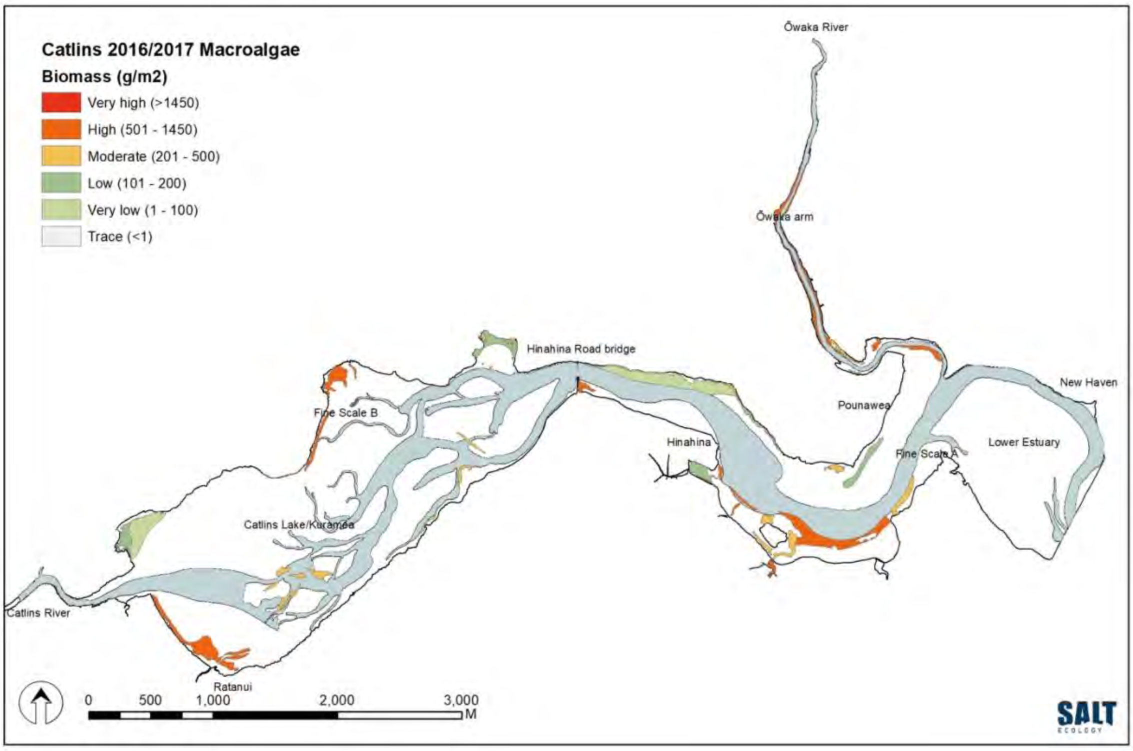
Appendix 5. Maps of (a) %cover, (b) biomass and (c) HEC, Catlins/Pounawea Estuary, December 2016 and December 2021

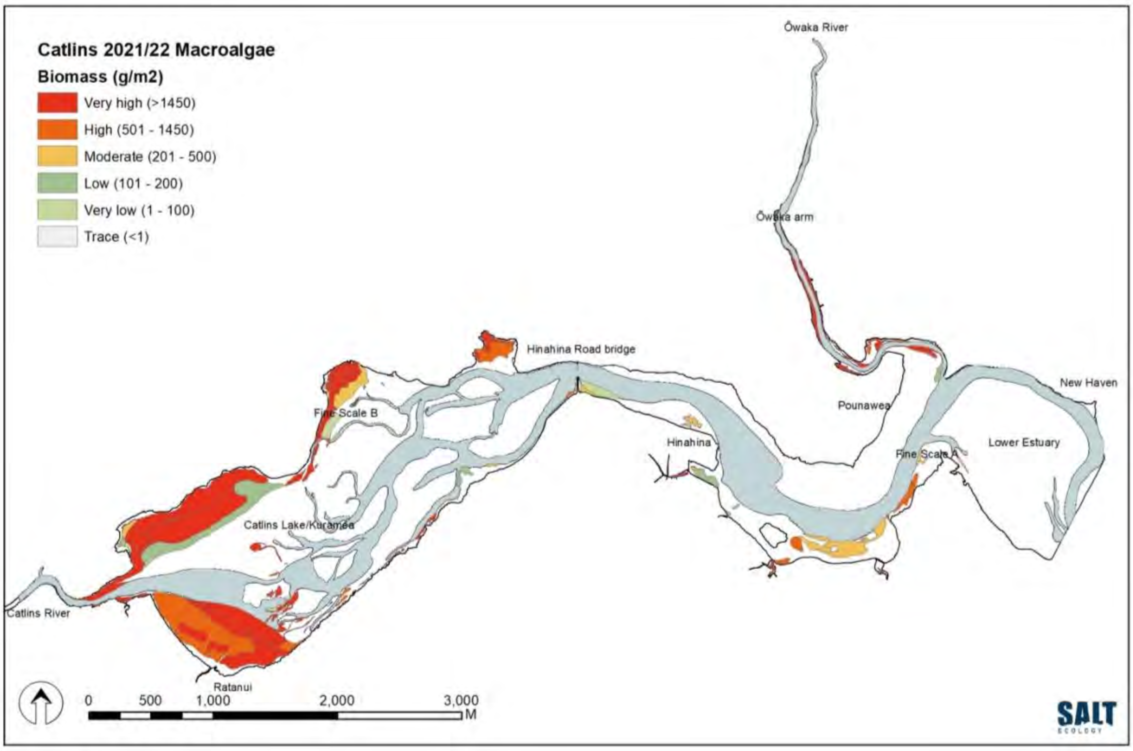
(a)



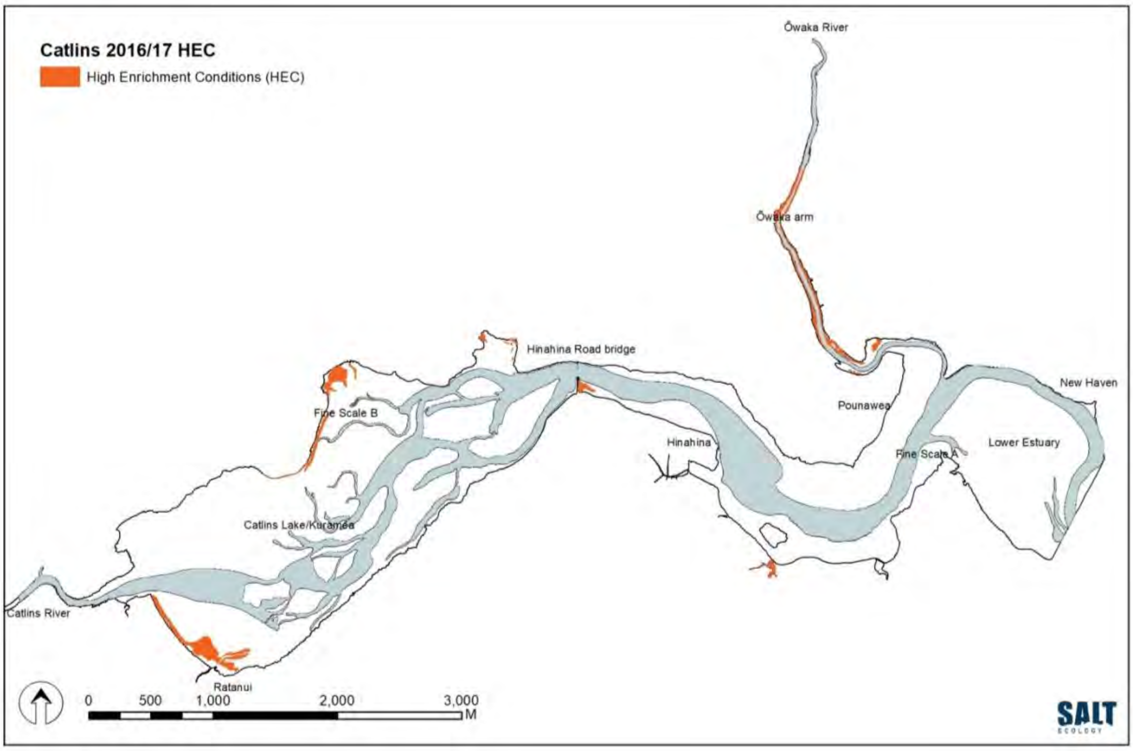


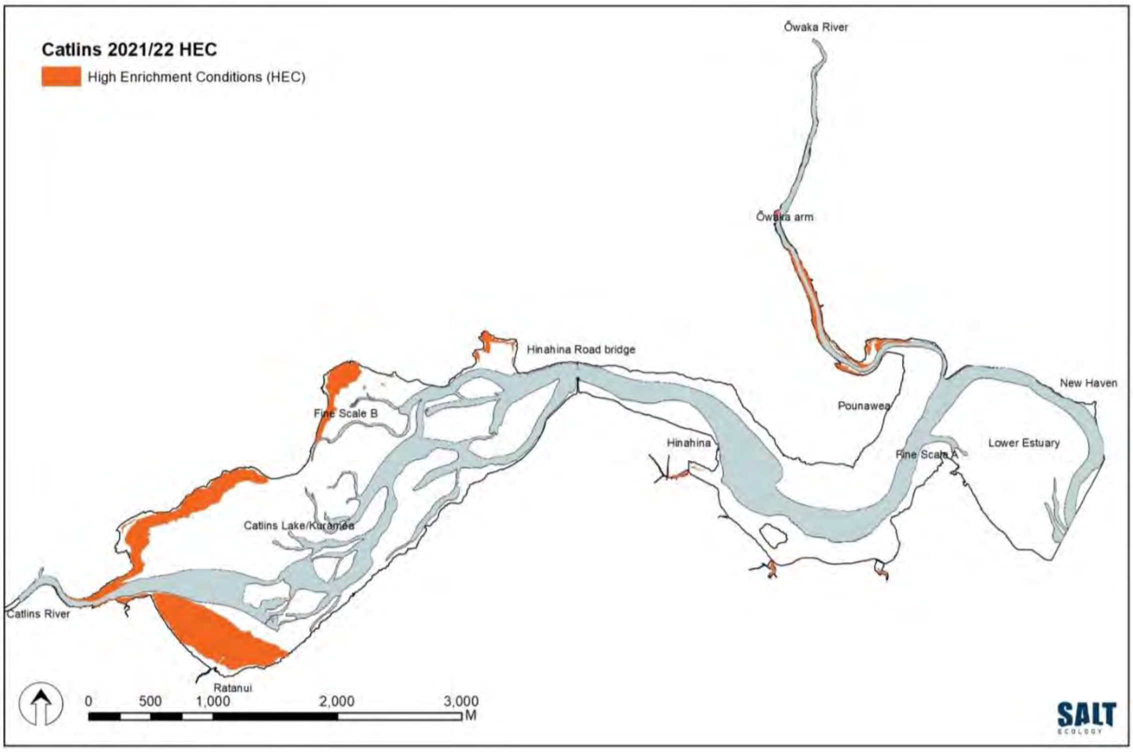
(b)


Catlins 2016/2017 Macroalgae
Biomass (g/m2)
Very high (>1450)
High (501 - 1450)
Moderate (201 - 500)
Low (101 - 200)
Very low (1 - 100)
Trace (<1)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Fine Scale B
Hinahina
Lower Estuary
Fine Scale A
Catlins Lake/Karamea
Catlins River
Ratanui
0 500 1,000 2,000 3,000 M
SALT


Catlins 2021/22 Macroalgae
Biomass (g/m2)
Very high (>1450)
High (501 - 1450)
Moderate (201 - 500)
Low (101 - 200)
Very low (1 - 100)
Trace (<1)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Fine Scale B
Hinahina
Lower Estuary
Fine Scale A
Catlins Lake/Karamea
Catlins River
Ratanui
0 500 1,000 2,000 3,000 M
SALT

(c)


Catlins 2016/17 HEC
High Enrichment Conditions (HEC)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Fine Scale B
Hinahina
Lower Estuary
Fine Scale A
Catlins Lake/Kuramea
Catlins River
Ratanui
0
500
1,000
2,000
3,000
M
SALT


Catlins 2021/22 HEC
High Enrichment Conditions (HEC)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Fine Scale B
Hinahina
Lower Estuary
Fine Scale A
Catlins Lake/Kuramea
Catlins River
Ratanui
0
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SALT

SALT ECOLOGY

KAIKORAI ESTUARY: 2021/2022 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 010. Prepared by Barrie Forrest for Otago Regional Council, March 2022

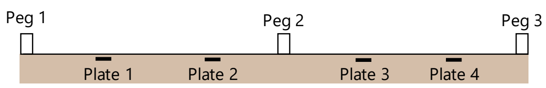
OVERVIEW

Since Dec-2017, Otago Regional Council has undertaken annual State of the Environment monitoring in Kaikorai Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at three sites (Fig. 1), with the latest survey carried out on 29 November 2021.

Fig. 1. Location of Kaikorai Estuary monitoring sites. In Feb-2019, Site D replaced nearby Site C, which was subject to river erosion.

METHODS

Estuary sedimentation is measured using the 'sediment plate' method (e.g. Forrest et al. 2021). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate (n=3) and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories). This approach allows changes in sediment muddiness to be determined even where there are no changes in sediment depth. Sediment oxygenation is an ancillary biological health variable that is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings corresponding to the colours in Table 1.

Table 2. Indicator values and condition ratings from the Nov-2021 survey.

Indicator	A	B	D
Sedimentation (mm/yr)*	6.40	2.42	0.87
Mud content (%)	10.3	86.8	26.2
aRPD (mm)	10	5	15

* Mean annual sedimentation rate relative to the baseline (n=2-4 yrs). Five years of data are required to assess a meaningful trend.

Sedimentation rate

The cumulative change in sediment depth over plates at each site is shown in Fig. 2. These cumulative rates correspond to the mean annual sedimentation at Sites A and B being classified as 'poor' due to exceedance of the 2mm/yr guideline value (Table 1). However, the apparent high sedimentation at Site A probably reflects bedload sand movement rather than deposition of fresh sediment from catchment inputs,

Table 1. Summary of condition ratings for sediment plate monitoring

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012).

due to the dynamic environment at that site. In general, it is evident that sedimentation has been highly variable over time at all sites, with periods of both accretion and erosion recorded.

Sediment mud content and oxygenation

Mud content was rated as 'fair' in the sand-dominated sediment at Site A, and 'poor' at Sites B and D where it exceeded the biologically relevant threshold of 25%. Site B consists of very soft mud - the mud fraction was ~83% in Nov-2021 and within the range recorded over the last 3 years (Fig. 3).

The average aRPD depth was shallowest in the soft mud at Site B (rated 'poor'), and slightly deeper (rated 'fair') at the other sites. These results reflect poorly-oxygenated conditions, which at Sites B and D are likely related to the elevated mud content in the sediment acting as a barrier to oxygenation. Growths of the opportunistic green macroalgae *Ulva* spp. were extensive at Site D in Nov-2021, which is potentially related to elevated nutrient inputs.

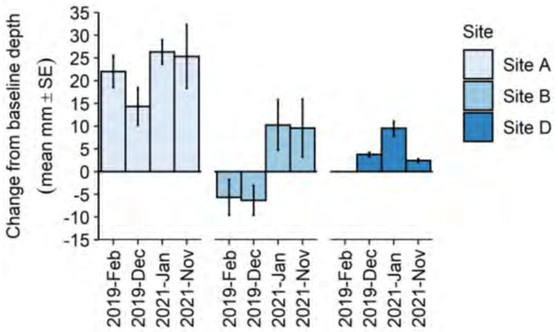


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to the baseline.

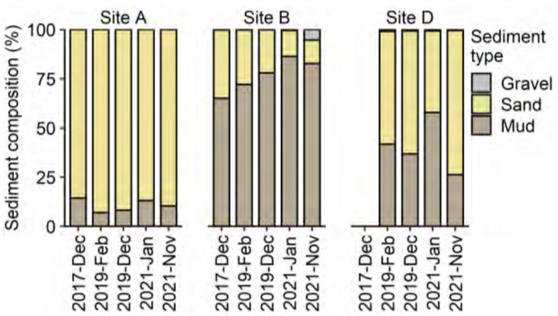
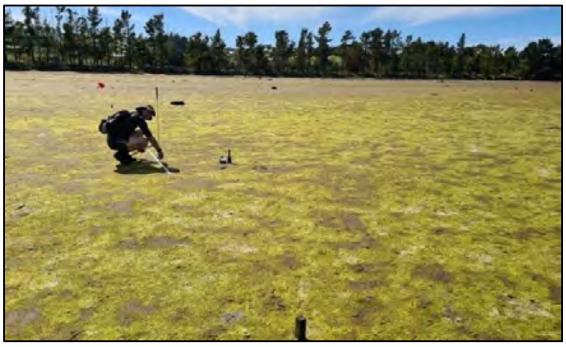


Fig. 3. Sediment particle grain size at each site. The baseline result for each site is also shown.

CONCLUSIONS

The sedimentation rate over the past 5 years has been highly variable, and exceeded the 2mm/yr national guideline value at Sites A and B, although the former is less ecologically significant as it appears related to bedload sand movement. The Nov-2021 results overall show that the estuary flats remain under pressure from fine sediment and organic/nutrient enrichment impacts, and reinforce previous recommendations (e.g. Forrest et al. 2020) to manage catchment inputs to the estuary.



Extensive cover of *Ulva* spp. at Site D in Nov-2021

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Comprehensive reporting should be undertaken 5-yearly as part of 'fine scale' ecological and sediment monitoring (next due in the summer of 2024/25).

REFERENCES

Federal Geographic Data Committee (FGDC). 2012. Coastal and Marine Ecological Classification Standard Catalog of Units, Federal Geographic Data Committee FGDC-STD-018-2012. 343p.

Forrest BM, Roberts, KL, Stevens LM. 2021. Fine Scale Intertidal Monitoring of Blueskin Bay. Salt Ecology Report 070, prepared for Otago Regional Council. 34p.

Forrest BM, Stevens LM, Rabel H. 2020. Fine scale intertidal monitoring of Kaikorai Estuary. Salt Ecology Report 042, prepared for Otago Regional Council, June 2020. 42p.

Robertson BM, Stevens L., Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver, M. 2016. NZ Estuary Trophic Index. Screening Tool 2. Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

Townsend M, Lohrer D. 2015. ANZECC Guidance for Estuary Sedimentation. NIWA client report number HAM2015-096, prepared for Ministry for the Environment 45p.

7.3. Air Plan Review: Proposed Process and Timeframes

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2315
Activity:	Governance Report
Author:	Vita Manning, Senior Policy Analyst
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	29 June 2023

PURPOSE

[1] To inform the Committee of work beginning on the review of the Regional Plan: Air for Otago ('the Air Plan') and the proposed process and timeframes.

EXECUTIVE SUMMARY

[2] The Long-Term Plan 2021-31 commits Council to notifying the reviewed Air Plan by 30 June 2025. Staff are working to this timetable.

[3] The Air Plan review has now started and is in the early stages of evidence gathering, scoping and analysis.

[4] An Issues and Options paper will be brought to the Environmental Science and Policy Committee for consideration on 11 October 2023.

RECOMMENDATION

That the Council:

1) ***Notes*** *this report.*
2) ***Notes*** *that an Air Plan Issues and Options paper will be brought to Committee for consideration on 11 October 2023 as part of the early review work.*

BACKGROUND

Existing Air Plan

[5] The existing Air Plan was prepared under the Resource Management Act 1991 (RMA) and was made operative in 2005, followed by updates in 2006 and 2009.

[6] The Air Plan outlines the main air quality issues in Otago. These are:

- Domestic heating emissions
- Outdoor burning
- Transport emissions
- Odour
- Discharges from industrial or trade premises
- Dust from area sources
- Agrichemical spray drift

[7] The Air Plan defines objectives for air quality management and sets out policies for addressing the identified issues. These policies set out the general direction that the Council will take, including regulatory and non-regulatory measures.

[8] The Air Plan also includes rules which apply to the discharge of contaminants into air in Otago. It specifies situations where consents are required for the discharge of contaminants to air and the type of information that will be required with any resource consent application. It also establishes criteria to guide the Council's decision making on resource consent applications.

[9] The RMA requires that the Air Plan be reviewed no later than 10 years from the date upon which it becomes operative. The Air Plan review has now started and is in the early stages of evidence gathering and analysis.

National Environmental Standards for Air Quality (NESAQ)

[10] Minimum standards for air quality are set out in the NESAQ. The NESAQ requires regional councils to monitor Airsheds where air quality is likely or known to exceed the standards and take action to reduce emissions where a breach of the standards has occurred.

[11] ORC produce a number of air quality monitoring reports, in particular State of the Environment Air Quality Reports which look at trends in the region. These are supplemented by Annual Air Quality Reports and Research and Technical Air Quality Reports.

[12] Monitoring air quality in Otago is focused towards polluted Airsheds. An Airshed is a legally designated air quality management area for the purposes of the NESAQ. Particulate matter is currently monitored at seven sites across Otago.

DISCUSSION

Timetable

[13] The Long-term Plan 2021-2031 (LTP) paused air quality activities, except for monitoring, until 2023. The LTP notes that ORC intends to review the Air Plan, and consider updates to existing air quality rules, policies, objectives and information to provide an appropriate regulatory framework for Otago. The LTP includes the Level of Service Measure to notify the Air Plan by 30 June 2025; the Annual Plan 2023-24 confirms this work and timetable.

[14] Whilst staff are working to the June 2025 notification deadline, the Air Plan review is currently behind schedule. It was anticipated that Issues and Options papers were completed by the end of this financial year (30 June 2023) but due to staff vacancies and workload associated with the Regional Policy Statement, the review is 6-9 months behind schedule.

[15] There are a number of emerging legislative factors which may affect the timetable and content of the Air Plan. These are set out below.

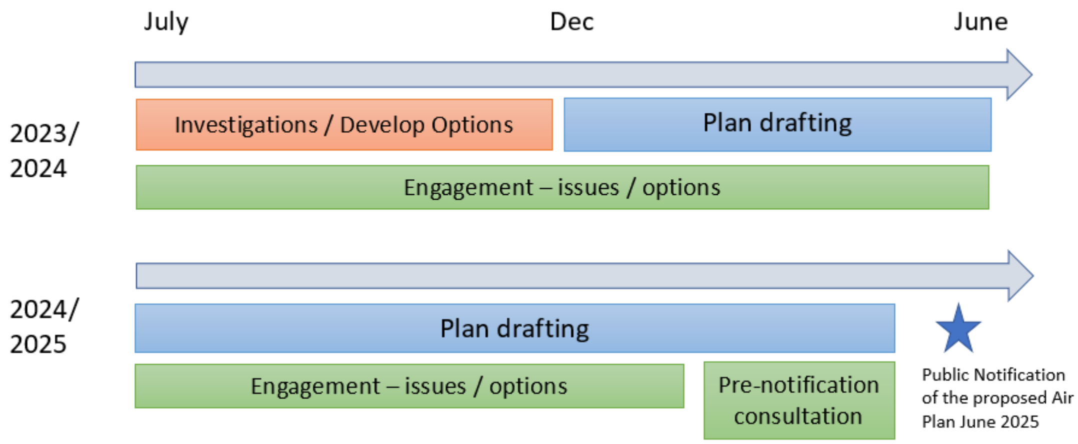
[16] Consultation on changes to the NESAQ took place in 2020, and ORC submitted comments on the proposals. The timetable for the new NESAQ is not yet known. It is

important for staff to be able to take account of any new requirements in the NESAQ when reviewing the Air Plan, and this may have an impact on the timetable.

[17] Otago's Regional Policy Statement (RPS) underpins the planning framework, directing and informing the content of the Air Plan. The proposed Otago Regional Policy Statement (pORPS) was notified in 2021 and the hearings for non-freshwater parts of the pORPS, including the Air objectives and policies, have just concluded. The panel is expected to make recommendations to Council on the pORPS by December 2023. The relevant provisions will become operative once any appeals are resolved. It is important for staff to be able to take account of the new RPS when drafting the Air Plan.

[18] The Land and Water Regional Plan (LWRP) is also being prepared by ORC and public consultation on the Air Plan will need to be timetabled to avoid any conflicts with notification of the LWRP. The proposed LWRP, which will be notified by June 2024, will replace parts of the waste plan, but will not control odour and greenhouse gas (GHG) emissions. This means that a review of the Air Plan will need to include new rules to cover odour and GHG emissions from waste.

[19] The indicative timetable to notify the Air Plan is set out below.



OPTIONS

[20] Air Quality issues and options will be identified through analysis of the following:

- The effectiveness and efficiency of policies and rules in the existing Air Plan;
- Information from monitoring which indicates whether there is a need for change;
- The identification of any significant new air quality issues in the region;
- Public comments and complaints from previous consultations, emails and the pollution hotline;
- Changes in central government policies including new or amended regulations or any other actions taken which require a response; and
- The proposed Regional Policy Statement for Otago and to other regional plans/strategies by the Otago Regional Council;

[21] A cross council internal staff working groups has been set up to inform work on the Air Plan, including staff from Consents, Compliance, Science, Strategy and Policy.

[22] The Issues and Options paper will also consider potential changes to Airshed boundaries and any new Airsheds. This will take into account growth of the settlement since the Airsheds were gazetted and any anticipated areas of development.

[23] The pORPS highlights that Air is a taoka; a treasured resource that is highly valued by Kāi Tahu. Staff intend to work in partnership with mana whenua throughout the review of the Air Plan, noting that mana whenua are subject to significant resource constraints.

[24] An Issues and Options paper will be brought to the Environmental Science and Policy Committee for consideration and direction after the initial work has been completed. This is the first step of reviewing the Air Plan.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[25] ORC's strategic directions commit Council to taking leadership on issues of significance and importance to Otago communities. Air pollution is a significant threat to human health.

[26] Preparing the Air Plan provides opportunities to improve Otago's policy framework for managing air quality and give effect to the air quality provisions in the pORPS.

Financial Considerations

[27] Reviewing the Air Plan is a funded activity under ORC's 2021/31 Long Term Plan.

Significance and Engagement

[28] The Air Plan will be subject to full public consultation under Schedule 1 of the RMA and therefore satisfies the significance criteria when assessed against He Mahi Rau Rika: ORC Significance, Engagement and Māori Participation Policy.

Legislative and Risk Considerations

[29] The Air Plan will be developed having consideration to ORC's role and responsibilities under the Resource Management Act 1991 and the National Environmental Standards on Air Quality.

Climate Change Considerations

[30] The sources of air pollution in Otago are also the sources of carbon emissions which contribute to climate change. The Air Plan review provides the opportunity to improve air quality alongside the co-benefits of reducing carbon emissions which will assist with achieving the national target for emissions reduction.

[31] The Air Plan review will take account of the emerging Climate Change Strategy.

Communications Considerations

[32] This document has been shared with Communications and an initial discussion has been had with a communications advisor around timeframes, potential audiences and notification. Comms had some early questions and is happy to be part of discussions from this point.

NEXT STEPS

[33] Staff will prepare an Issues and Options paper for the Environmental Science and Policy Committee for consideration as the first step in reviewing the Air Plan.

ATTACHMENTS

Nil

7.4. Annual Water Quality and Biomonitoring results (SoE Report Cards)

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2316
Activity:	Environmental: Water
Authors:	Markus Dengg, Water Quality Scientist Rachel Ozanne, Senior Water Quality Scientist
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	29 June 2023

PURPOSE

[1] The annual water quality and biomonitoring report cards present results of State of Environment (SoE) monitoring undertaken to inform attribute tables in Appendix 2A and Appendix 2B in the National Policy Statement-Freshwater Management (NPSFM, 2020).

[2] The water quality report card is a summary of the technical report 'State and Trends of Rivers, Lakes, and Groundwater in Otago, 2017 – 2022' (Report SPS2252).

EXECUTIVE SUMMARY

[3] Understanding the current state of water quality and ecology is key information for the proposed Land and Water Regional Plan (pLWRP).

[4] The Otago Regional Council (ORC) monitors the water quality of a selection of Otago rivers, lakes, and groundwater through long-term State of the Environment (SoE) monitoring programmes.

[5] This includes the attributes that require resource use to be limited if they are degraded or degrading (Appendix 2A, NPSFM, 2020). These attributes include phytoplankton (lakes), periphyton (rivers), total nitrogen (TN), total phosphorus (TP), ammonia (NH_4-N) and nitrate (NNN) toxicity, suspended fine sediment (SFS) and *E. coli* (the water quality report card).

[6] ORC also monitor the attributes that require action plans if they are degraded or degrading (Appendix 2B, NPSFM, 2020). These attributes include submerged plants (native and invasive), fish, macroinvertebrates, deposited fine sediment, dissolved reactive phosphorus (DRP) and ecosystem metabolism (the biomonitoring report card).

[7] As groundwater is widely used for drinking and domestic supply in Otago, its state was assessed against the Maximum Acceptable Values (MAV) in the Drinking Water Standards for New Zealand (DWSNZ), (DWSNZ, 2022).

[8] The water quality report card and the biomonitoring report card are attached to this report. Both report cards are further summarised as a two-page graphical summary, also attached.

RECOMMENDATION

That the Committee:

1) ***Notes*** *the annual State of the Environment water quality and biomonitoring report cards.*

BACKGROUND

[9] ORC monitors rivers (107 sites), eight lakes (27 sites/depths), and groundwater (55 sites) as part of its long term SoE monitoring programme for water quality.

[10] The National Policy Statement Freshwater Management (NPS-FM) defines the ranges for numeric attribute states using four (or five) attribute bands, designated A to D/E. The attribute bands represent a graduated range of support for environmental values from high (A band) to low (D/E band). For most attributes, the D band represents an unacceptable condition (with the threshold between the C and the D band being referred to as the 'bottom line').

[11] The water quality report card includes sites that have been monitored for phytoplankton (lakes), periphyton (rivers), total nitrogen (TN), total phosphorus (TP), ammonia (NH_4-N) and nitrate (NNN) toxicity, suspended fine sediment (SFS), and *E. coli*. These attributes have been graded according to the relevant attribute table and the calculation guidance in Appendix 2 of the NPSFM (Table 1).

NPS-FM Reference – NOF Attribute	Water body type	Calculation guidance	Numeric attribute state description	Units
A2A; Table 1 – Phytoplankton	Lakes	Minimum of 3 years of data	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		92nd percentile of periphyton chlorophyll-*a* for default river class[2]	mg chl-a m^{-2}
			83rd percentile of periphyton chlorophyll-*a* for productive river class[1]	mg chl-a m^{-2}
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 Rivers		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 20 - DRP	Rivers		Median concentration of DRP	mg l^{-1}
			95th percentile concentration of DRP	mg l^{-1}

Table 1: Details of the NPS-FM attributes used in the water quality report card

[12] Groundwater is assessed against the DWSNZ (DIA, 2022) focusing on *E. coli*, dissolved arsenic, and nitrate nitrogen. These parameters were selected due to their relevance for drinking water (ORC, 2021).

	Lowest risk	Low to Moderate Risk	Moderate Risk
E. coli	No detection	<10% detection	10-50% detection
Nitrate	<2.50 mg/L below MAV	2.50 - 5.50 mg/L threshold – 50% MAV	5.50 - 11.3 mg/L 50% – 75% of MAV
Dissolved Arsenic	<0.0025 mg/L <25% of MAV	0.0025 - 0.005 mg/L 25%-50% of MAV	0.005 - 0.01 mg/L 50%-MAV

[13] The biomonitoring report card includes sites monitored for submerged plants (native and invasive), fish, macroinvertebrates, deposited fine sediment, dissolved reactive phosphorus (DRP) and ecosystem metabolism. These attributes have been graded according to the relevant attribute table and calculation guidance in Appendix 2 of the NPSFM (Table 2). Habitat was assessed according to the National Rapid Habitat Assessment Protocol Development for Streams and Rivers (Clapcott 2015).

NPS-FM Reference – NOF Attribute	Water body type	Calculation guidance	Numeric attribute state description	Units
A2A; Table 1 – Phytoplankton	Lakes	Annual median	Median of phytoplankton chlorophyll-*a*	mg chl-a m^{-3}
A2A; Table 1 – Phytoplankton	Lakes	Annual maximum	Annual maximum of phytoplankton chlorophyll-*a*	mg chl-a m^{-3}
A2A; Table 2 – Periphyton	Rivers	Minimum of 3 years of monthly data	92nd percentile of periphyton chlorophyll-*a* for default river class[2]	mg chl-a m^{-2}
A2B; Table 11 Submerged plants (natives)	Lakes	State calculated once every three years	% of maximum potential score	%
A2B; Table 12 Submerged plants (invasive)	Lakes	State calculated once every three years	% of maximum potential score	%
A2B; Table 13 - Fish Index of Biotic Integrity	Rivers	State calculated as 5 year average	Average score	-
A2B; Table 14 - Macroinvertebrates	Rivers	State calculated as 5 year median	MCI score	-
A2B; Table 15 - Macroinvertebrates	Rivers	State calculated as 5 year median	ASPM score	-
A2B; Table 16 - Deposited Sediment	Rivers	Median of 5 years of at least monthly samples (at least 60 samples)	% fine sediment cover	%
A2B; Table 21 - Ecosystem metabolism	Rivers	Annual median	% cotton tensile strength loss per degree day (%CTSL dd-1)	%

Table 2: Details of the NPS-FM attributes used in the biomonitoring report card

DISCUSSION

[14] The water quality report card is attached in Appendix 1. The results show that river and lake water quality is spatially variable across Otago and is best at lakes, river and stream reaches located at high elevations under native cover or conservation land. These sites tend to be in the upper catchments of the large lakes (e.g., Hawea, Whakatipu and Wanaka) and some tributaries of the Clutha Mata-Au (e.g., Lindis River, Nevis River, Dart River). Other areas, such as urban streams in Dunedin, intensified North Otago catchments, and some Lower Clutha Rohe tributaries, have poorer water quality.

[15] Nitrate and ammonia toxicity generally achieved an 'A' attribute band across Otago. DRP was variable, with the highest concentrations of DRP found in the Lower Clutha Freshwater Management Unit (FMU). Natural processes such as tannin staining and glacial flour influenced the suspended fine sediment results, with many sites in the Clutha Mata/Au, Catlins and Taieri FMUs falling below the national bottom line. Naturally occurring processes are recognised in the NPS-FM[1]. Sites at the bottom of catchments tended to have higher concentrations of *E. coli* than upper catchment sites, i.e., the Upper Lakes Rohe generally achieved an 'A' attribute band whereas the Lower Clutha Rohe generally achieved an attribute band of 'C' or 'D'. Periphyton in Otago saw a spatial gradation from lower concentrations in the Upper Lakes Rohe to higher concentrations in the Dunedin & Coast and North Otago FMU.

[16] The lake results in the Upper Lakes Rohe achieved the 'A' attribute band for most attributes. However, lakes in the Taieri FMU, Lower Clutha Rohe and Roxburgh Rohe achieved variable results across the attributes.

[17] Like the rivers and lakes data, groundwater quality is also mixed across Otago. *E. coli* exceedances and nitrate concentrations were usually an issue in the same areas where lake and river quality were poorer. However, high dissolved arsenic concentrations were more site-specific, and dependent on local geology for example Glenorchy where schist is common.

[18] The biomonitoring report card is attached as Appendix 2. All water quality sites are monitored annually for macroinvertebrates. A subset of water quality sites is sampled monthly for deposited sediment, and all other attributes are sampled annually (Table 2).

[19] The Otago region saw approximately 30% of macroinvertebrate samples below the national bottom line, with no Macroinvertebrate Community Index (MCI) samples achieving the 'A' attribute band. Cawthron (Wagenhoff, 2021) has developed interim Otago-specific attribute bands for MCI, which are lower than the NPS-FM. This workstream is continuing as additional reference sites are required to validate model predications.

[1] NPS-FM 3.32 Naturally occurring processes

[20] ORC monitors deposited sediment at 34 sites, and all sites other than the Matukituki River obtained an 'A' attribute band reflecting a minimal impact of deposited fine sediment on instream biota.

[21] ORC measures ecological processes using cotton strip assays. The cotton strips were installed at 34 sites. Approximately two-thirds of the sites, located mainly in the Upper Lakes Rohe, Dunstan Rohe and Dunedin & Coast FMU, achieved an 'A' or 'B' attribute band. Only the Blackcleugh Burn (Lower Clutha FMU) was below the national bottom line.

[22] Stream habitat assessments were undertaken at each site, and 85% of sites across Otago achieved an 'A' or 'B' attribute band.

OPTIONS

[23] The annual report cards are a requirement under the NPS-FM. Not producing them would put ORC in contravention of the NPS-FM.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[24] This monitoring programme supports the healthy water strategic priority through monitoring and publishing of information to support public decision making around how the interact with water at popular sites in Otago.

Financial Considerations

[25] This work is planned and budgeted within existing work programmes. In the future, further investment will be required to ensure the SoE Water Quality monitoring network complies with national direction and is representative of each FMU.

Significance and Engagement

[26] Not applicable

Legislative and Risk Considerations

[27] Monitoring networks must comply with national legislation and effectively evaluate objectives in regional plans.

Climate Change Considerations

[28] The state of the environment monitoring for surface water quality may provide useful data in the future to demonstrate the effects of climate change on our rivers and lakes.

Communications Considerations

[29] The report will be available on the ORC website https://www.orc.govt.nz/plans-policies-reports/reports-and-publications/water-quality/annual-water-quality-reports

NEXT STEPS

[30] The next annual report cards will cover July 2018 to June 2024.

ATTACHMENTS

1. Water Quality Report Card 2017 to 2022 [**7.4.1** - 19 pages]
2. Otago Region Water- Quality Summary [**7.4.2** - 2 pages]
3. Biomonitoring Report Card 2017 to 2022 [**7.4.3** - 16 pages]
4. Otago Biomonitoring Summary [**7.4.4** - 2 pages]

River, Lake, and Groundwater Quality 2017 to 2022

Background

The Otago Regional Council (ORC) is responsible for managing Otago's water resources. ORC carries out regular water-quality monitoring and ecological assessments, as part of its State of Environment (SoE) programme. This report card is a snapshot of water quality monitoring undertaken between July 2017 and June 2022.

Further detail can be found in 'State and Trends of River, Lake and Groundwater in Otago, 2017-2022'. Water quality monitoring sites are shown in Figure 1.

Each site that has been monitored for nitrate (NNN) and ammonia (NH_4-N) toxicity, dissolved reactive phosphorus (DRP), suspended fine sediment (SFS), *Escherichia coli (E. coli)*, periphyton and phytoplankton (Chla), total nitrogen (TN) and total phosphorus (TP) has been graded according to the relevant attribute table and calculation guidance in Appendix 2 of the NPSFM (Table 1).

Each table of Appendix 2 of the NPSFM 2020 defines the ranges for numeric attribute states as four attribute bands, which are designated A to D/E. The attribute bands represent a graduated range of support for environmental values from high (A band) to low (D/E band). For most attributes, the D band represents an unacceptable condition (with the threshold between the C and the D band being referred to as the 'bottom line').

Table 1. Details of the NPS-FM attributes used to grade the state of the river and lake monitoring sites.

NPS-FM Reference – NOF Attribute	Water body type	Calculation guidance	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^{-2}
			83rd percentile of periphyton chlorophyll-*a* for productive river class[1]	mg chl-a m^{-2}
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 Rivers		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 20 - DRP	Rivers		Median concentration of DRP	mg l^{-1}
			95th percentile concentration of DRP	mg l^{-1}

Figure 1: Map of the Otago region showing Freshwater Management Units and monitoring sites.

NITRATE AND AMMONIA TOXICITY

High levels of nitrate-nitrite-nitrogen (NNN) or ammoniacal nitrogen (NH_4-N) in water can create conditions that make it difficult for aquatic insects or fish to survive. Click or tap here to enter text.In Otago rivers, concentrations are generally < 0.03 mg/l for NNN and <2.4 mg/l for NH_4-N. At these concentrations, NNN and NH_4-N are not expected to be harmful to most freshwater species and does not pose a risk for humans. The National Policy Statement – Freshwater Management (NPS-FM) (MfE, 2020) provides a framework for the assessment of the current state for NNN and NH_4-N (NPS-FM, Table 1).

Figure 2 and Figure 3 show nitrate and ammonia toxicity results for Otago.

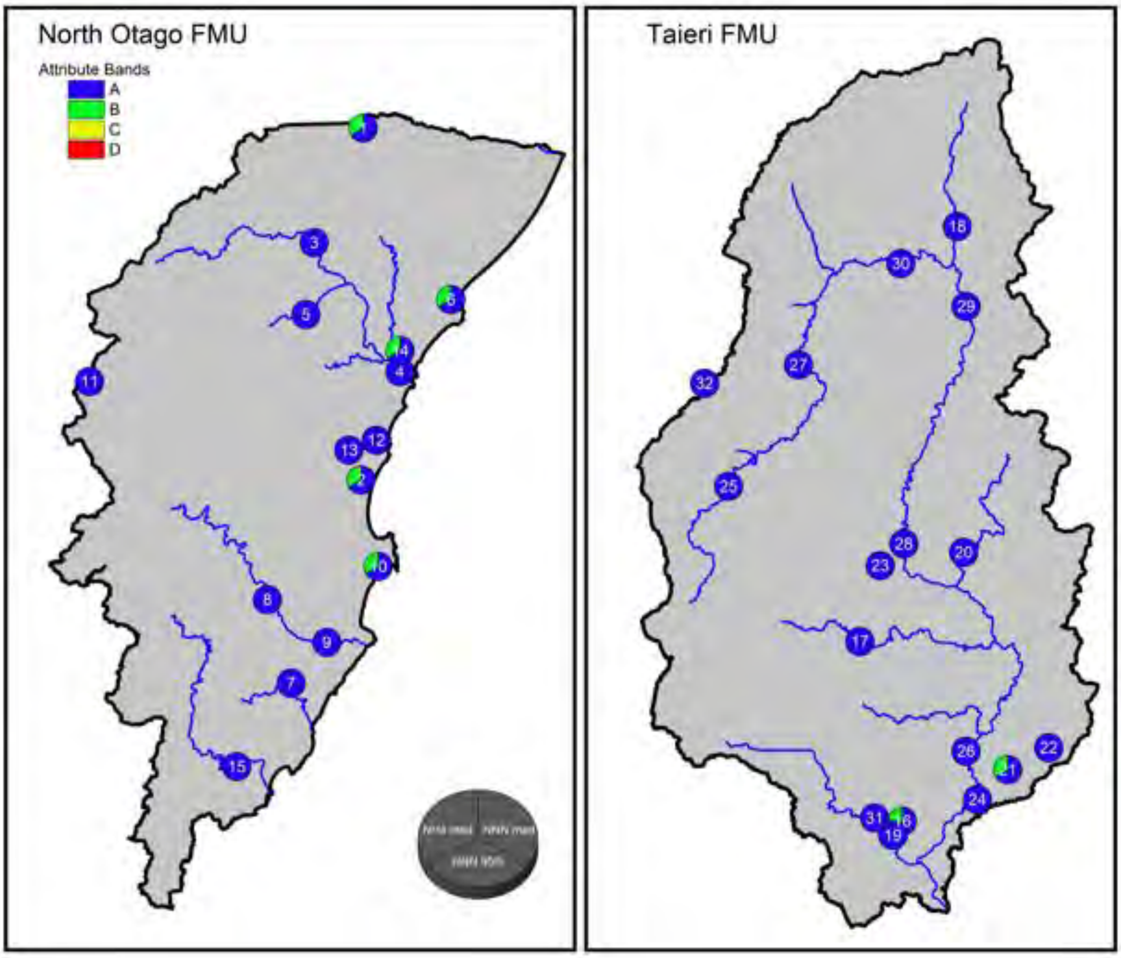


Figure 2: Median Nitrite-Nitrate-Nitrogen (NNN) and Ammonia (NH_4-N) attribute states shown for the North Otago and Taieri FMUs over the 5-year monitoring period from 2017 to 2022. Site numbers are given in Appendix 1.

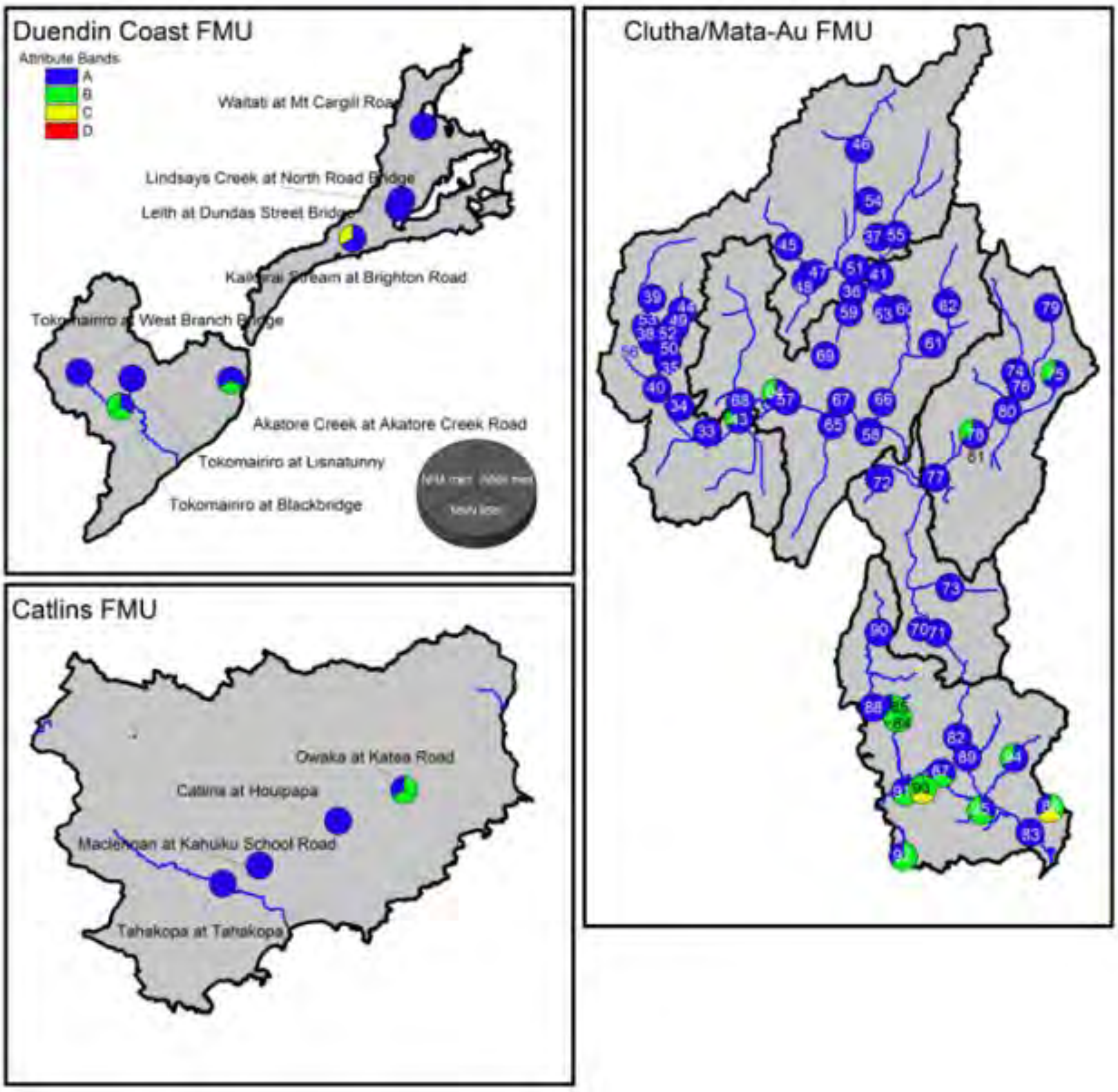


Figure 3: Median Nitrite-Nitrate-Nitrogen (NNN) and Ammonia (NH_4-N) attribute states shown for the Clutha/Mata-Au, Dunedin & Coast and Catlins FMUs over the 5-year monitoring period from 2017 to 2022. Sites that show 5-year median concentrations in the C-band (yellow) fall below the national bottom line. Site numbers are given in Appendix 1.

Sites that are experiencing higher anthropogenic pressures such as intensive farming or urban development generally have higher concentrations of NNN or NH_4-N, however most sites in Otago achieve attribute band 'A'.

The main sources of NNN and NH_4-N are fertilizers, wastewater, and animal waste. NNN and NH_4-N can come from diffuse sources, such as land runoff or point sources, such as wastewater pipes.

Sites that fall below the national bottom line (attribute band C) for the 95th percentile of NNN are Lovells Creek at Station Road (#86) and Wairuna at Millar Road (#93) while the Kaikorai Stream at Brighton Road falls below the national bottom line for NH_4-N.

DISSOLVED REACTIVE PHOSPHOROUS (DRP)

Nutrients in waterways sustain primary production by algae, however, blooms of algae can smother habitat, are aesthetically unacceptable, and are not favourable for swimming. The major nutrients, influencing algal growth, are nitrogen (N) and phosphorous (P).

Most rivers in New Zealand are P limited (McDowell, 2009) therefore algal blooms are more likely to be triggered by excess concentrations of P rather than N. DRP is a form of P that is readily available for uptake by algal cells, allowing for fast algal growth if supply is sufficient (McDowell, 2009).

The NPS-FM (2020) provides a framework for the assessment of the current state for DRP (NPSFM, Table 20). Figure 4 and Figure 5 show DRP results for Otago.

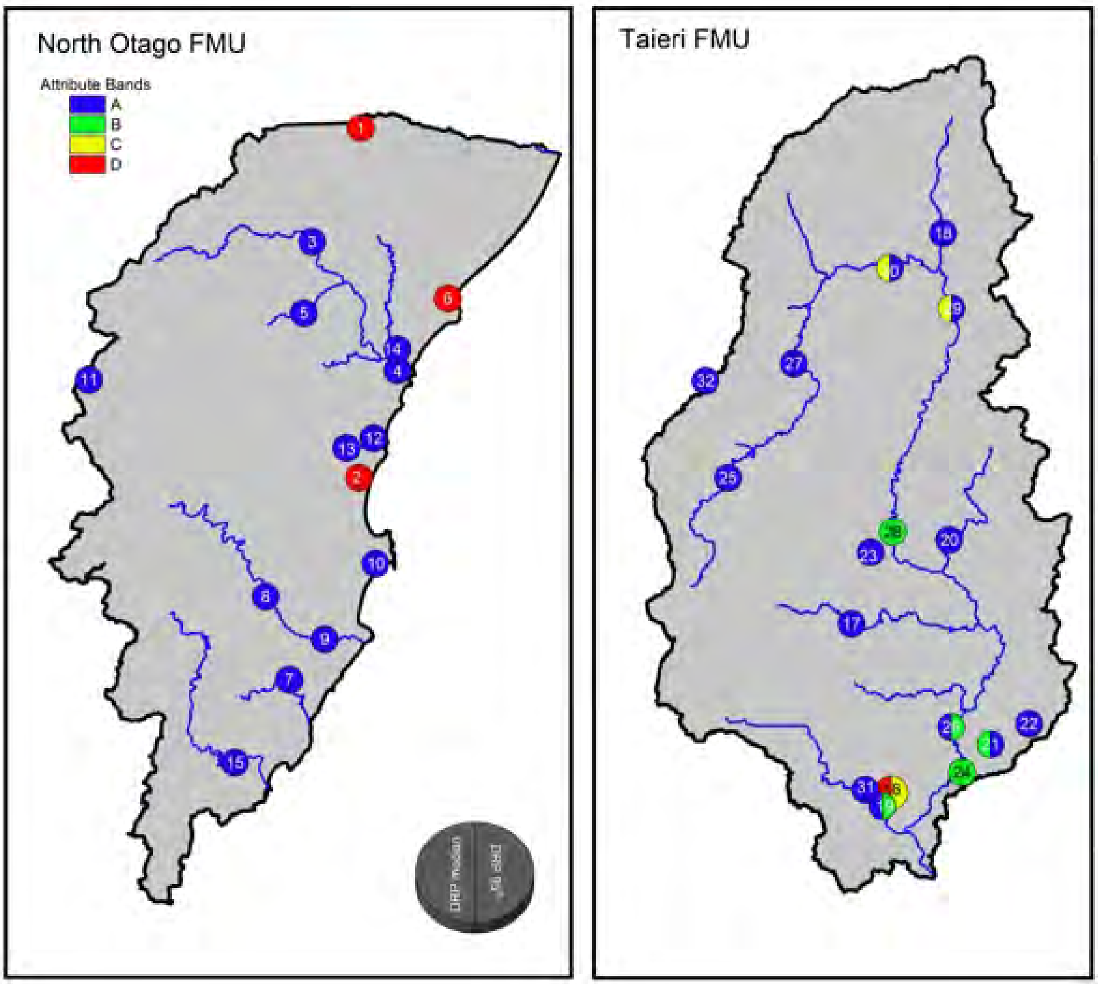


Figure 4: Median dissolved reactive phosphorous (DRP) attribute states shown for the North Otago and Taieri FMUs over the 5-year monitoring period from 2017 to 2022. Site numbers are given in Appendix 1.

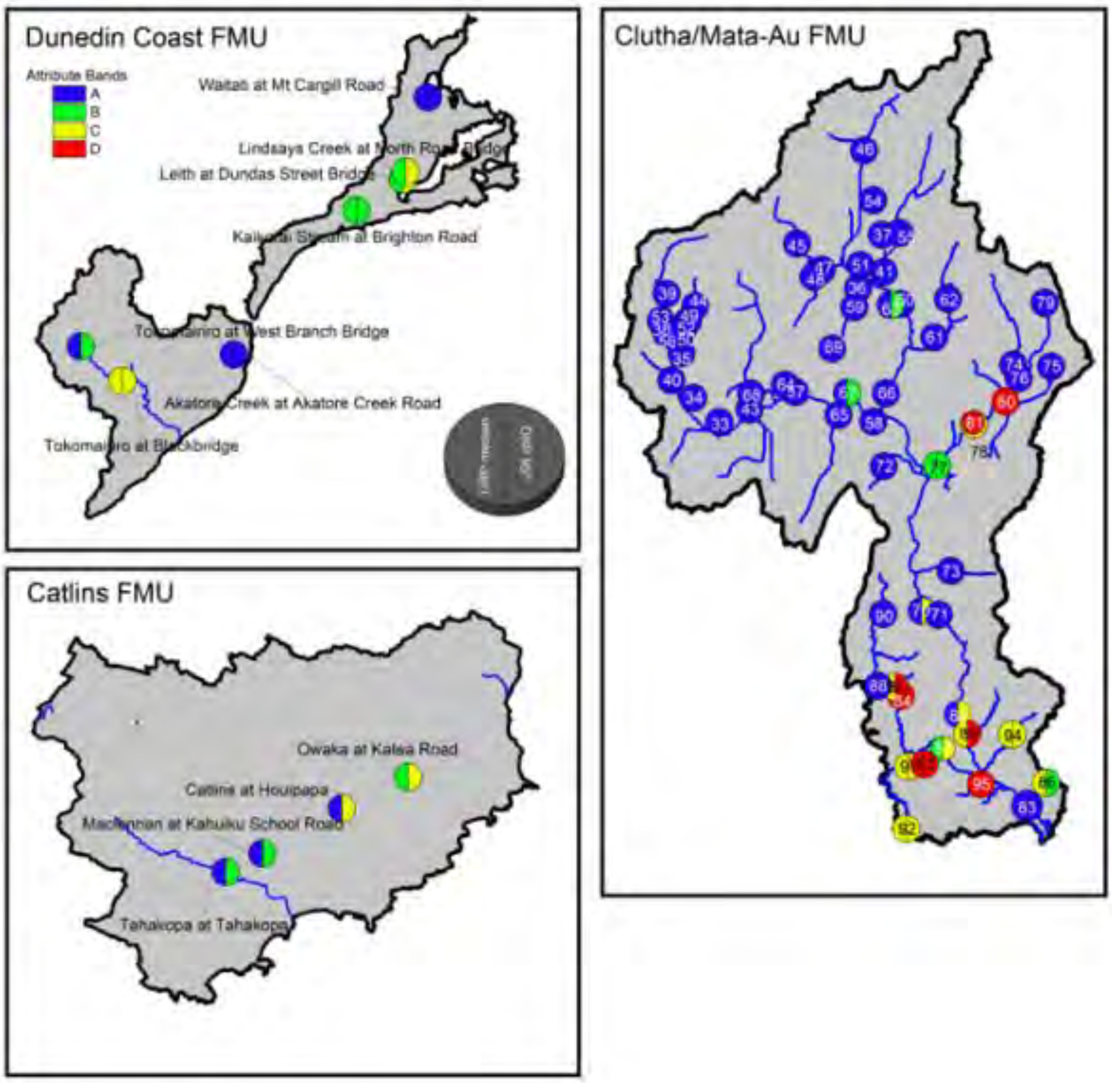


Figure 5: Median dissolved reactive phosphorous (DRP) attribute states shown for the Dunedin & Coast, Catlins and Clutha/Mata-Au FMUs over the 5-year monitoring period from 2017 to 2022. Site numbers are given in Appendix 1.

Sources of DRP can be natural (weathering of rocks or plant decomposition) or from human activities including fertilizer application and waste inputs.

Sites located in the upper reaches generally achieve a DRP attribute band of ‘A’ (e.g., in the Taieri FMU and North Otago FMU), with lower DRP attribute bands in lower reaches. Most of the Upper Lakes Rohe and Dunstan Rohe achieve an attribute band of ‘A’.

The Lower Clutha has more sites in the ‘B’ to ‘D’ band. The Manuherekia Rohe has two sites, Thomsons Creek and the Pool Burn, that achieve a ‘D’ band and DRP concentrations increase from an ‘A’ band to a ‘C’ band, between Blackstone and Ophir. Sites that show DRP concentrations at the ‘C’ and ‘D’ band are generally influenced by farming and/or urban land uses nearby and upstream of the monitoring site.

SUSPENDED FINE SEDIMENT

Elevated concentrations of suspended fine sediment (SFS) negatively influence benthic environments, fish community composition, and carry nutrients and toxins (Clapcott, 2011, Jones, 2012). In the NPS-FM (Table 8) suspended fine sediment attribute bands for a site are based REC groups described in the New Zealand River Environment Classification (MfE, 2004). Suspended fine sediment is naturally present in all rivers due to the presence of organic substances and the weathering of rocks. The two major rivers in Otago, the Clutha and Taieri, alongside some other rivers in the region, are influenced by natural sources of suspended fine sediment. High loads of glacial flour are present in the Clutha, providing for its unique turquoise colour while natural tannin staining is responsible for the brown colour of the Taieri and some rivers in the Catlins FMU. Human activities that increase the amount of suspended fine sediment include farming or construction. Suspended sediment in Otago is assessed via measurements of turbidity that are then converted to visual clarity (Ballantine, 2014). Sites obtaining attribute band 'D' are below the national bottom line.

Many Otago sites do not meet the national bottom line for suspended sediment. Sites in the Taieri FMU and Catlins FMU are affected by natural tannin staining, and sites in the Clutha FMU are affected by natural sources of glacial flour.

Figure 6 and Figure 7 show SFS results for Otago.

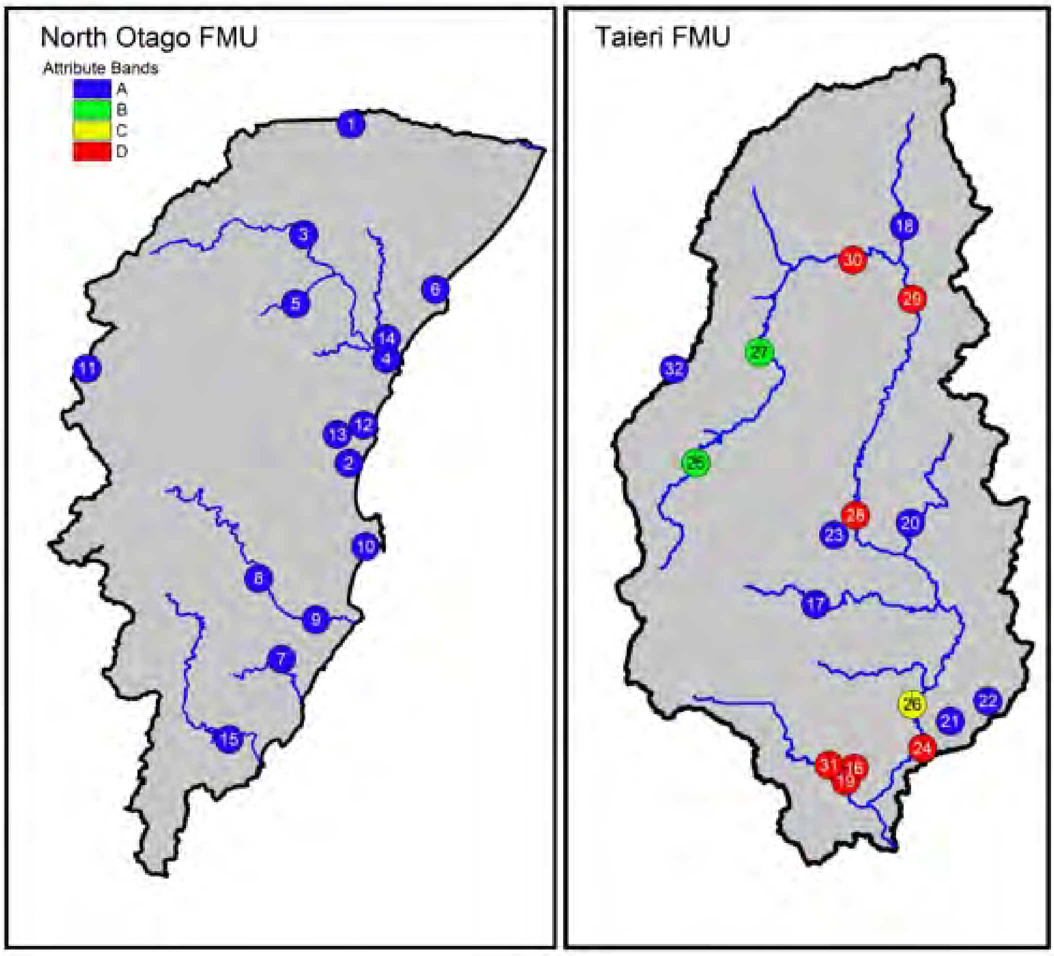


Figure 6: Suspended fine sediment attribute states shown for the North Otago and Taieri FMUs over the 5-year monitoring period from 2017 to 2022. The national bottom line for suspended sediments is set at the bottom of the C-band. Site numbers are given in Appendix 1.

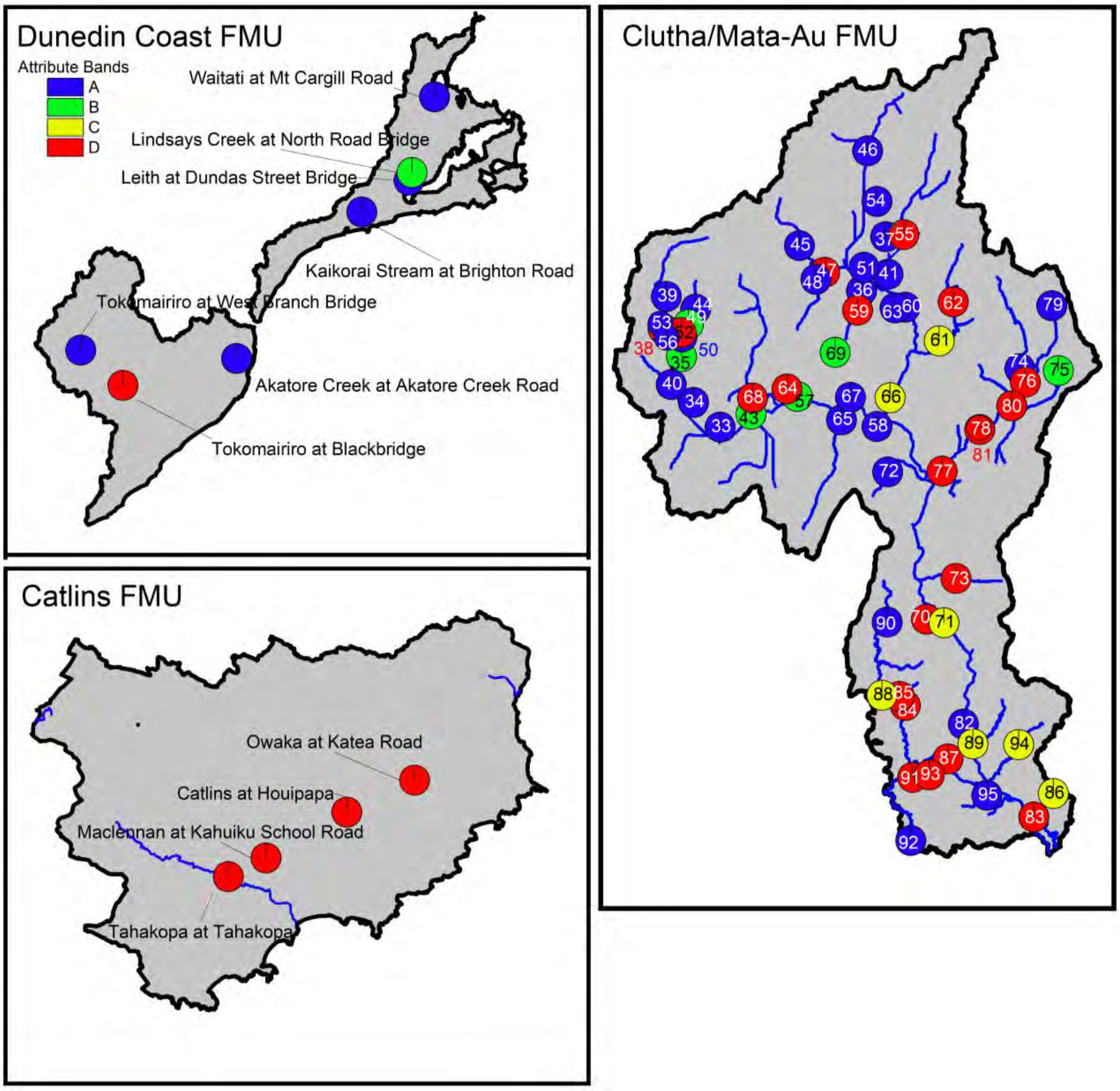


Figure 7: Suspended fine sediment attribute states shown for the Clutha/Mata-Au, Dunedin & Coast, and Catlins FMU over the 5-year monitoring period from 2017 to 2022. The national bottom line for suspended sediments is set at the bottom of the C-band. Site numbers are given in Appendix 1.

ESCHERICHIA COLI

The bacterium *Escherichia Coli* (*E. coli*) is naturally present in animal faeces and freshwater and can reach high concentrations by the addition of wastewater or runoff from agricultural pastures to streams (14). High densities of *E. coli* pose the risk of infection with several diseases, such as gastroenteritis (campylobacter), if the waterbody is used for recreational activities (15) and can diminish the value of Mahinga kai and Mana of the waterway. The NPS-FM (Table 9) uses four different metrics to inform of the current state of *E. coli* in rivers and lakes: *median, 95th percentile, 260 MPN*

(Most Probable Number)/100mL *exceedance, and 540 MPN* (Most Probable Number)/100mL *exceedance*.

While most sites in the Upper Lakes Rohe achieve attribute band 'A', many sites across the Otago region show a poor state for all four *E. coli* statistics. Sites lower in the catchment generally show higher concentrations of *E. coli* than sites closer to the source due to accumulating inputs of bacteria from land runoff or urban sources.

Sites that are most heavily impacted by high *E. coli* densities are clustered around areas with urban (Dunedin) or agricultural land uses (Pomahaka, Lower Clutha, Taieri and North Otago) (Figures 8 and 9). Sources of *E. coli* may also be from gulls/ducks/geese. The Upper Kakanui site is known to have *E. coli* source from red billed gulls roosting in the gorge.

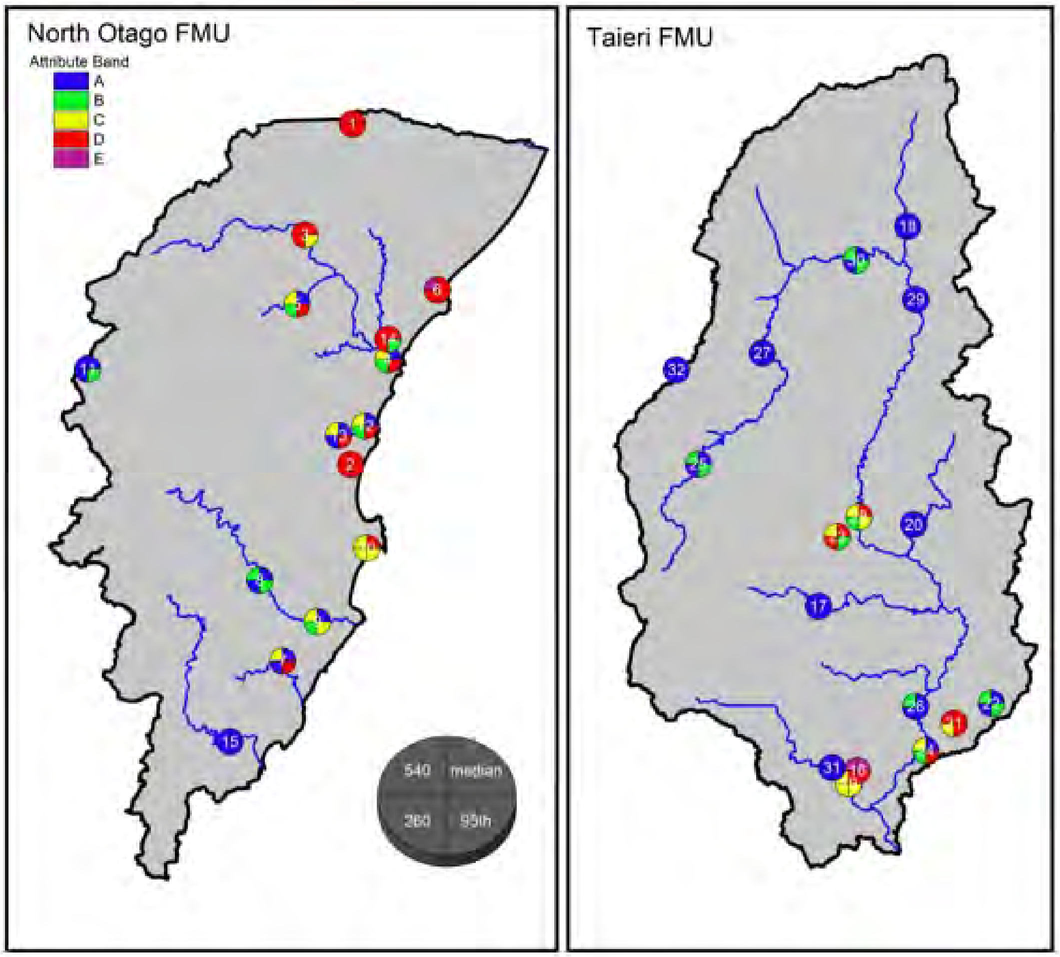


Figure 8: Escherichia Coli (E. coli) attributes (clockwise: median, 95th percentile, 260 exceedance, 540 exceedance North Otago and Taieri FMUs over the 5-year monitoring period from 2017 to 2022. No national bottom line is given for E. coli but sites in the D- and E-band are considered unsafe for recreational activities. Site numbers are given in Appendix 1.

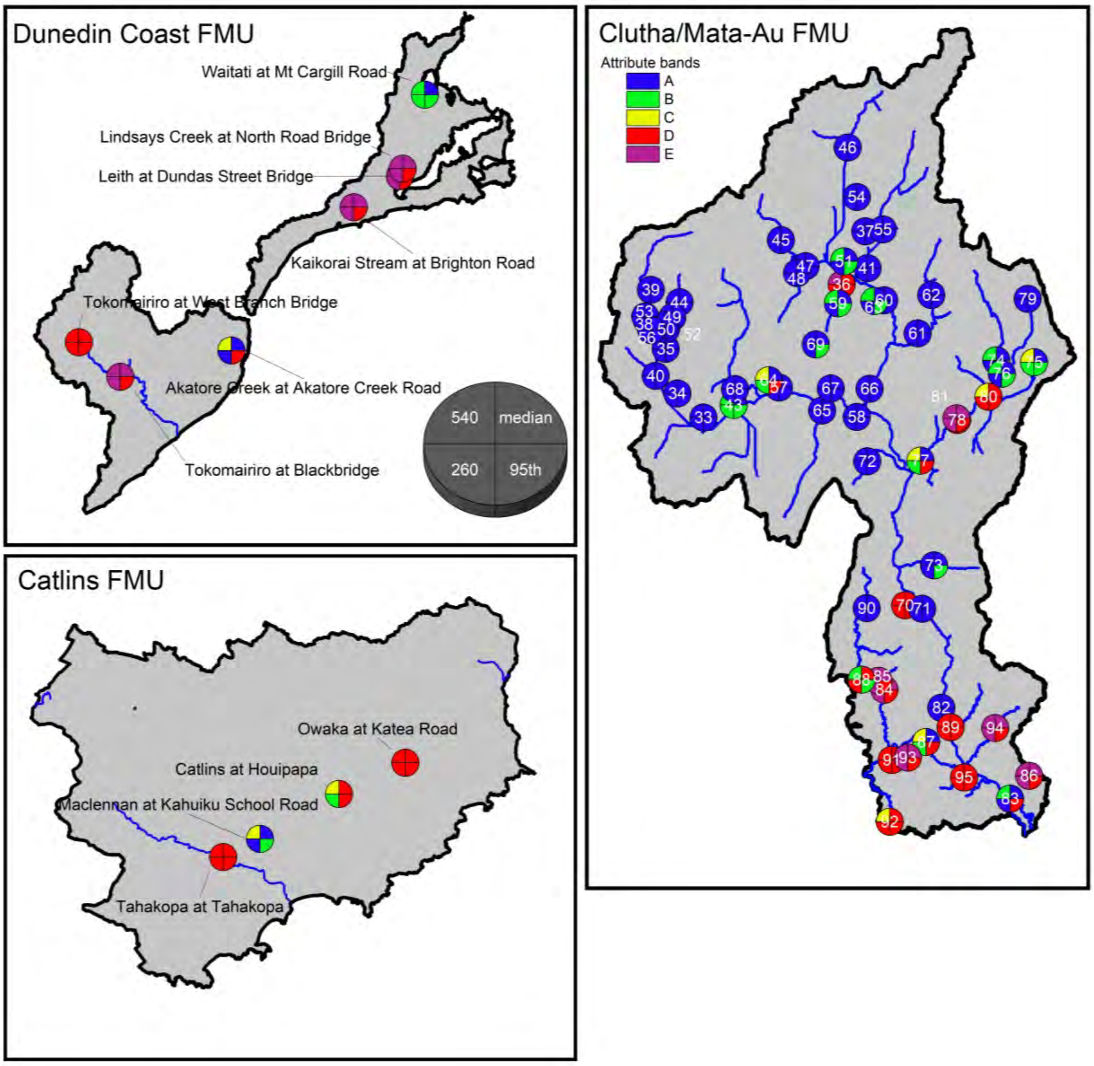


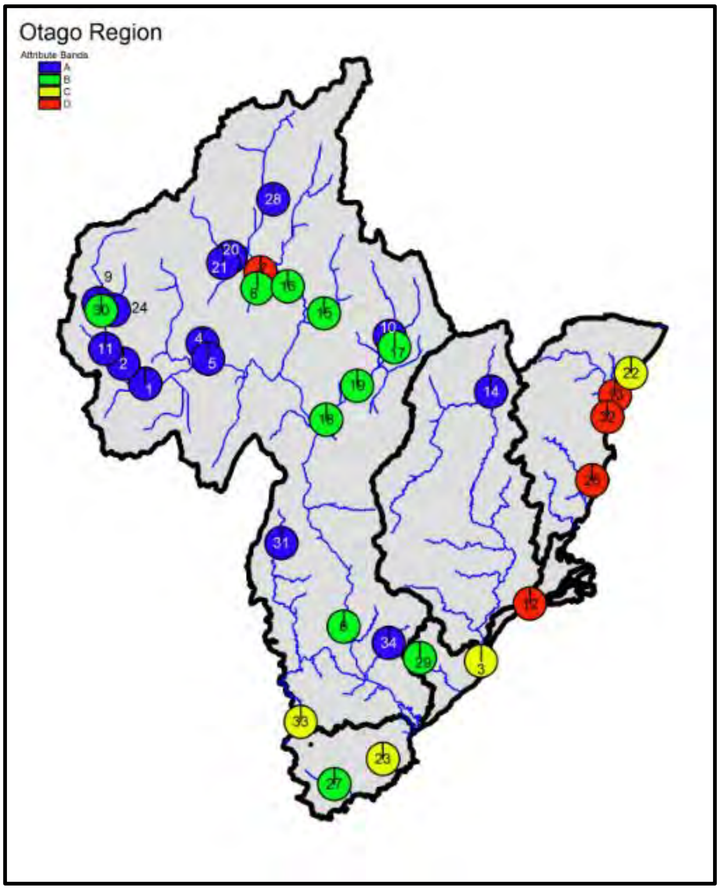
Figure 9: Escherichia Coli (E. coli) attributes (clockwise: median, 95th percentile, 260 exceedance, 540 exceedance shown for the Dunedin & Coast, Catlins and Clutha/Mata-Au FMUs over the 5-year monitoring period from 2017 to 2022. No national bottom line is given for E. coli but sites in the D- and E-band are considered unsafe for recreational activities. Site numbers are given in Appendix 1.

PERIPHYTON- RIVERS

Chlorophyll-*a* (Chl-*a*) concentration is a common method for estimating stream periphyton biomass because all types of algae (including periphyton) contain Chl-*a*, hence, 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. Healthy freshwater ecosystems have low (oligotrophic) to intermediate (mesotrophic) levels of living material and primary production (growth of plants or algae). In combination with other environmental factors such as temperature and light, 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) (Table 6). The periphyton monitoring programme includes 34 sites and the results are shown in figure 10. Note that periphyton is only monitored at a subset of all sites.

Sites that fall below the national bottom line are either located in urban areas (Bullock Creek at Dunmore Street) or are located at the bottom of streams influenced by upstream agriculture.

Sites in the A- and B-band are often associated with areas of lower anthropogenic pressure.



1	12 Mile Creek at Glenorchy Queenstown Road
2	25 Mile Creek at Glenorchy Queenstown Road
3	Akatore Creek at Creek Road
4	Arrow River at Arrow Gorge Track
5	Arrow River at Morven Ferry Road
6	Blackcleugh Burn at Rongahere Road
7	Bullock Creek at Dunmore Street
8	Cardrona River at Mt Barker
9	Dart River at The Hillocks
10	Dunstan Creek at Beattie Road
11	Greenstone River at Greenstone Station Road
12	Kaikorai Stream at Brighton Road
13	Kakanui River at McCones
14	Kye Burn at SH85 Bridge
15	Lindis River at Ardgour Road
16	Luggate Creek at SH6 Bridge
17	Manuherekia at Blackstone Hill
18	Manuherekia t Galloway
19	Manuherekia at Ophir
20	Matukituki at West Wanaka
21	Motatapu River at Wanaka Mt Aspiring Road
22	Oamaru Creek at SH1
23	Owaka River at Katea Road
24	Precipice Creek at Glenorchy Paradise Road
25	Shag River at Goodwood Pump
26	Silver Stream at Taieri Depot
27	Tahakopa River at Tahakopa
28	The Neck Creek at Meads Road
29	Tokomairiro River at West Branch Bridge
30	Turner Creek at Kinloch Road
31	Upper Pomahaka River at Aitchisons Run Road
32	Waianakarua River at Browns
33	Waipahi River at Waipahi
34	Waitahuna River at Tweeds Bridge

Figure 10: *Periphyton cover shown for the Otago region over the 5-year monitoring period from 2017 to 2022. the national bottom line is at the bottom of the C-band.*

Lakes, Water Quality 2017 to 2022

NUTRIENTS – TOTAL NITROGEN (TN) AND TOTAL PHOSPHOROUS (TP)

The growth of algae, forming the basis of food-webs in lakes, is controlled by the amount and availability of nutrients. The major nutrients algae need for growth are nitrogen (N) and phosphorous (P) and the concentrations of these nutrients in freshwater often give an indication for the possible magnitude of algal growth. If nutrients and algal growth is low, lakes are classified as 'oligotrophic'. Conversely, if nutrient concentrations and algal growth are high, to the extent of large surface blooms, the lake is classified as 'eutrophic' or 'hypertrophic'. Lakes with intermediate nutrient levels and algal growth are classified as 'mesotrophic'. Lake nutrient state is based on the concentrations of nitrogen and phosphorus. The NPS-FM (2020) provides a framework for the assessment of the current state for TN and TP (NPSFM, Table 3 and 4).

Lakes in the Upper Lake Rohe (Lake Wakatipu, Lake Wanaka, and Lake Hawea) and Lake Dunstan show the A-band for all monitored attributes, however rapid urban development with associated stormwater and drainage infrastructure is a threat to the lakes water quality.

Lakes in other parts of Otago show a poorer current state, i.e., Lake Hayes achieves the C-band for TN and TP (Figure 12). There are substantial efforts by community groups and ORC to minimise sediment and nutrient inputs into Lake Hayes.

Lake Waihola and Lake Tuakitoto are both shallow wetlands with mainly agricultural activity in their catchments. Shallow lakes commonly have high sediment re-suspension due to wind activity which enriches lake nutrient concentrations. The attribute state for lake TN and TP are shown in Figure 12.

PHYTOPLANKTON - LAKES

Phytoplankton or algal growth depends on the availability of nutrients and other physicochemical factors such as temperature, wave action, light intensity, and pH. The best proxy for phytoplankton growth is the measurement of chlorophyll (Chl-*a*), which is indicative of photosynthetically active cells. Therefore, higher Chl-*a* concentrations (mg/m^3) are equivalent to increased phytoplankton growth (16). The NPS-FM uses Chl-*a* as an indicator of phytoplankton in lakes (NPSFM, Table 1). The attribute state for lake TN and TP are shown in Figure 12.

Lake Tuakitoto is the only monitored lake that falls below the national bottom line for maximum Chl-a concentrations. This indicates that lake ecological communities are at risk of a regime shift to a degraded state.

AMMONIA TOXICITY AND E. COLI

Both attributes are described in the respective section for rivers. All monitored lakes in the Otago region achieve the 'A' band for ammonia toxicity.

Lakes Wakatipu, Wanaka, Hawea, Dunstan, Hayes and Onslow have *E. coli* concentrations in the 'A' band. Lake Tuakitoto and Lake Waihola south show *E. coli* concentrations that make the lakes unsuitable for recreational activities.

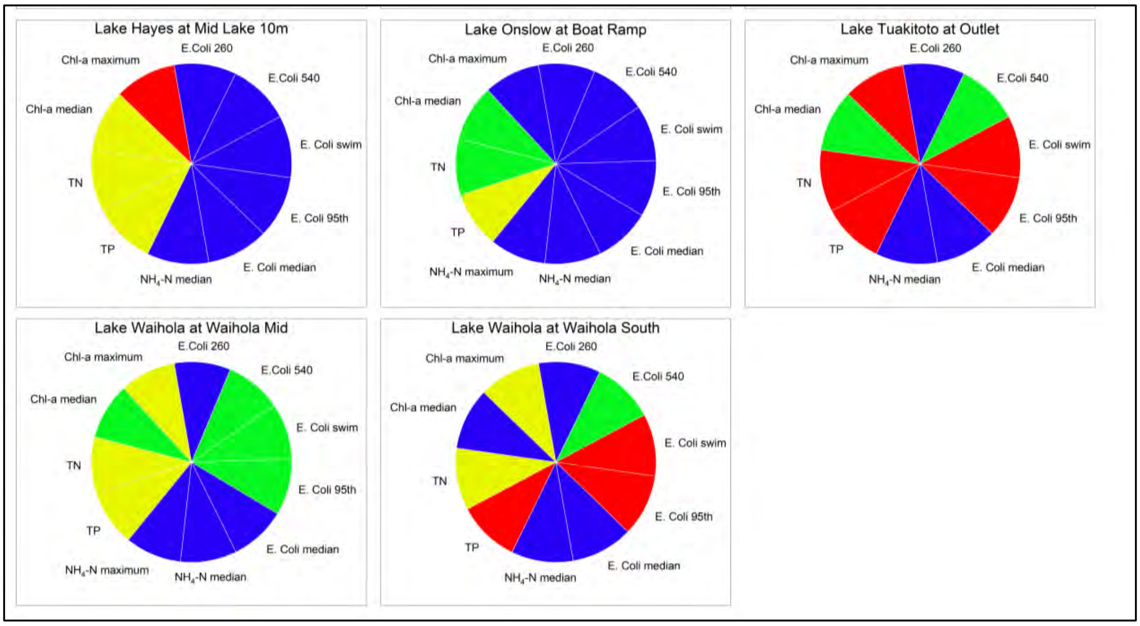


Figure 12: Attribute bands for all lake attributes monitored according to the NPS-FM. All other lakes show achieve 'A' bands for each attribute

Groundwater Quality
2017 to 2022

GROUNDWATER QUALITY CURRENT STATE

The NPS-FM does not contain attribute tables for groundwater quality. Groundwater quality state was therefore assessed against the Maximum Acceptable Value (MAV) in the Drinking Water Standards for New Zealand (DWSNZ) [Department of Internal Affairs, 2022], following a similar approach to other Regional Councils (e.g., ECan, 2018). This was done due to the wide use of shallow groundwater for drinking and domestic supply across Otago, particularly in rural communities without reticulated water. However, this analysis only provides a general picture of groundwater quality state, and it does not mean whether groundwater in certain FMU/Rohe or bores are safe for domestic supply/drinking. Further information regarding drinking water can be found on the regulator's (Taumata Arowai) website https://www.taumataarowai.govt.nz/

E. COLI

Groundwater is less vulnerable than surface water to contamination by potentially pathogenic microorganisms. However, this risk still exists. Faecal bacteria contamination in groundwater can originate from livestock, wastewater discharges, effluent application, and stormwater discharges, with contamination risk increasing following heavy rainfall. *E. coli* is used as the indicator organism for bacterial contamination. The DWSNZ (2022)-MAV for *E. coli* is <1 MPN (Most Probable Number)/100mL. Groundwater state for E. Coli was assessed by calculating the percentage of exceedances of the MAV for each site over the 5-year reporting period (Figure 14).

The results show groundwater *E. coli* contamination across all of Otago, with exceedances detected in most FMU (although the Catlins and Dunedin & Coast, which did not have any, currently only have one monitoring bore each). The highest percentage of exceedances were measured in the North Otago FMU and persistent exceedances were also recorded in sites in the Taieri FMU, and the Lower Clutha and Roxburgh Rohe (Figure 14). The E. coli is potentially sourced from intensive farming and septic tanks. However, *E. coli* exceedances can also be a site-specific issue, exacerbated by poor bore security (which some SoE bores suffer from), which increases the risk of groundwater contamination. One of the aims of the new Land and Water Regional Plan is to improve bore security through more targeted provisions. The ORC is also currently expanding and upgrading its SoE monitoring bores network, which will help assess whether *E. coli* exceedances are site specific or a wider issue. Nevertheless, it is very important that bore owners maintain good bore security and regularly test their groundwater in an accredited laboratory to ensure that the water quality is suitable for the intended use

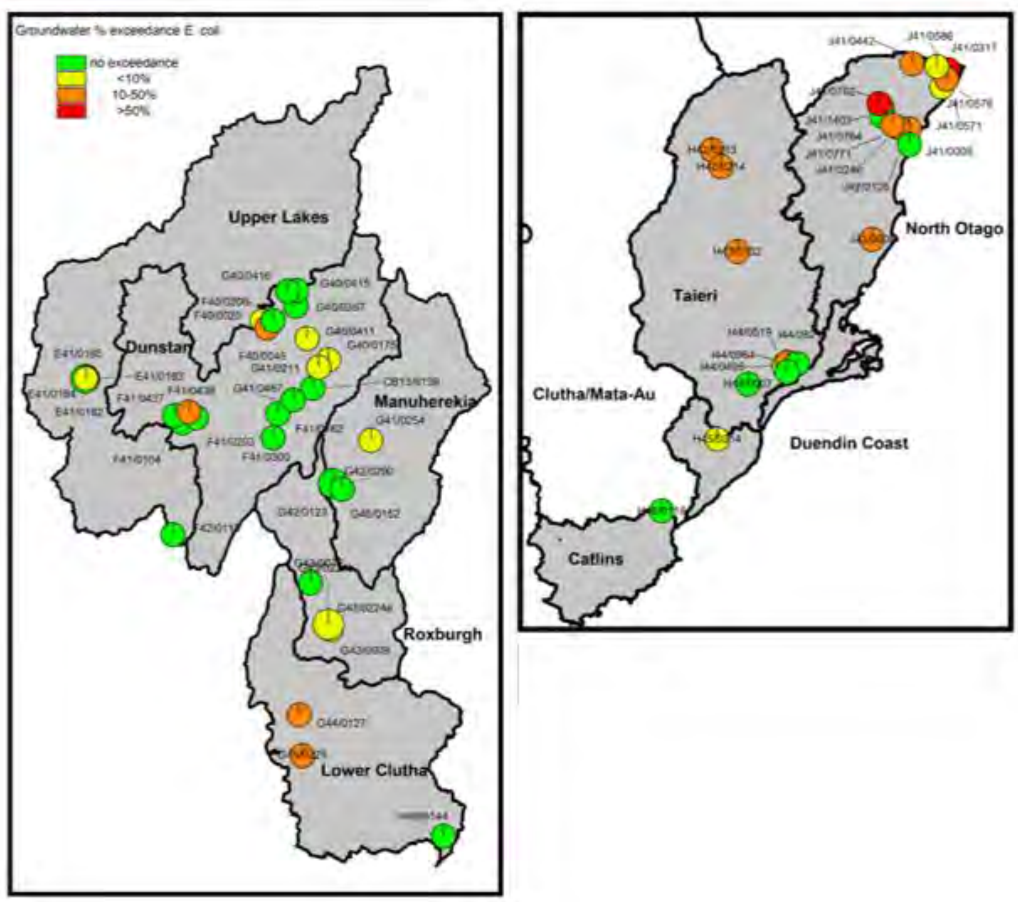


Figure 14: Groundwater E. coli percentage exceedances for SoE sites in the Clutha/Mata-Au (left), Catlins, Dunedin & Coast, Taieri and North Otago (right)

NITRATE

Nitrate (NO_3-N) is a dissolved, inorganic form of nitrogen (N), a key nutrient required for the growth of plants and algae. However, excess nitrate can adversely impact water quality, ecosystem health, and human health (e.g., ORC, 2021). The DWSNZ (2022) MAV for nitrate nitrogen is 11.3mg/L –N. The state of nitrate in groundwater was based on the median nitrate concentrations in the SoE bores. These were classified based on proportions of the DWSNZ (2022) MAV (Figure 15).

The results show wide variability in median groundwater nitrate concentrations across Otago, with generally low concentrations in the Upper Lakes, Dunstan, and Manuherekia Rohe. Higher concentrations were measured in the Roxburgh and Lower Clutha Rohe and the Taieri FMU. The highest concentrations were measured in the North Otago FMU, where concentrations in many sites exceeded the DWSNZ-MAV (Figure 15).

The measured high nitrate concentrations can have adverse impacts on human health and surface water quality, especially in areas with strong groundwater-surface water interaction (e.g., North Otago). High nitrate concentrations can be attributed to land use (intensive dairy farming, market garden, septic tanks), and can also be impacted by geology and aquifer properties (e.g., high permeability soils or slow-moving groundwater). Some of these issues are aimed to be improved with more targeted provisions in the new Land and Water Regional Plan. However, under the current land use and management practiced in some parts of the region it is unlikely that groundwater nitrate concentrations will improve.

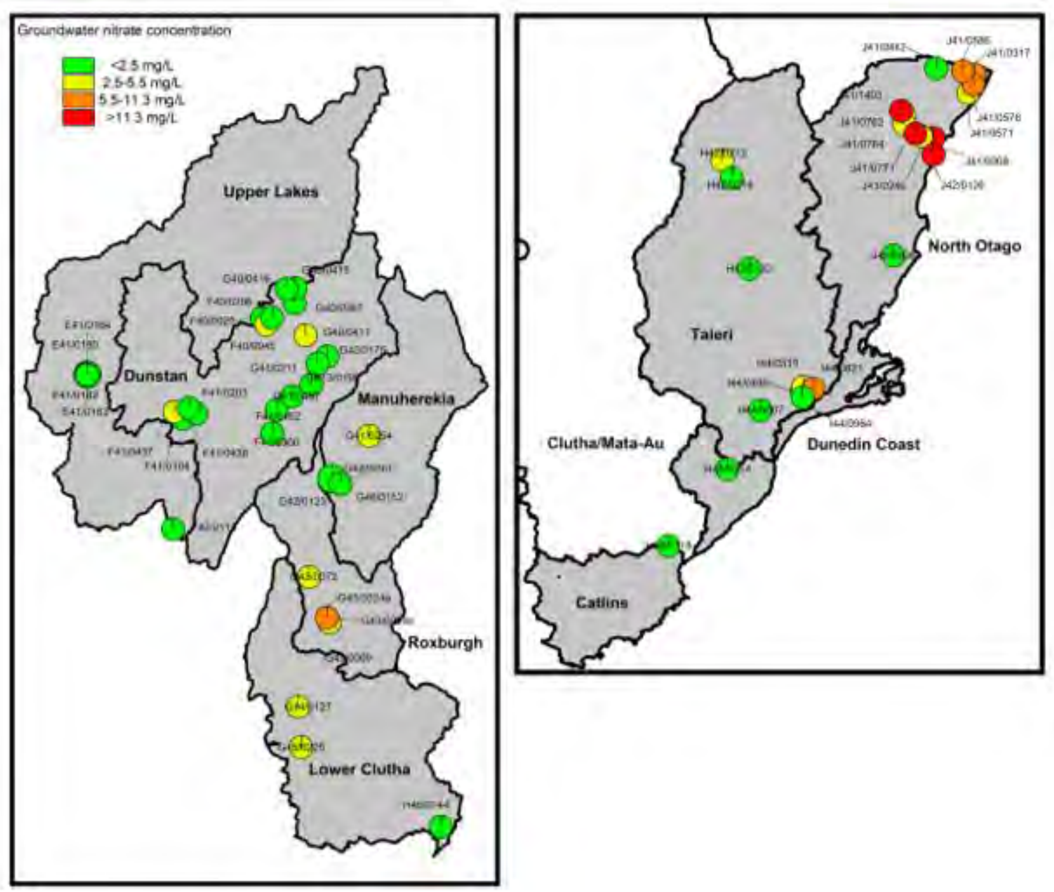


Figure 15: Median groundwater nitrate concentrations for the SoE bores in the Clutha/Mata-Au (left), Catlins, Dunedin & Coast, Taieri and North Otago (right)

DISSOLVED ARSENIC

Arsenic is a toxic, though naturally occurring element, present at low concentrations in soil, water, plants, and animals. Chronic exposure to elevated arsenic is a risk to human health. Arsenic in groundwater can originate from anthropogenic (e.g., sheep dips, treated timber posts) and geological sources, e.g., schist lithology, reduced peat deposits, and volcanic rocks (Piper and Kim, 2006). The DWSNZ (2022)-MAV for arsenic is 0.01mg/L (equivalent to 10 microgram/Litre [µg/L], shown as some laboratories report using this unit). The state of groundwater arsenic concentrations was based on the maximum concentrations and assessed against the DWSNZ- (2022) MAV (Table 10). The spatial variability in maximum arsenic concentrations is shown in Figure 16.

High spatial variability in groundwater dissolved arsenic concentrations was observed across Otago. The highest concentrations were measured in the Upper Lakes Rohe, particularly in Glenorchy and Kingston. High concentrations were also measured in some sites in the Dunstan Rohe, Lower Clutha Rohe, and the Taieri FMU. Conversely, concentrations in the North Otago and most of the Taieri FMU were substantially lower than the DWSNZ (2022)-MAV. However, there was also wide spatial variability on a smaller scale (e.g., Glenorchy) where concentrations in some bores within the same locality exceeding the MAV while concentrations in other nearby bores were below it.

It is likely that the main source for arsenic in Otago groundwater is geological (i.e., not human), and is mainly from weathering of the abundant schist lithology. Arsenic concentrations can also vary due to groundwater reduction/oxidation conditions (i.e., dissolved oxygen concentrations), where low oxygen concentrations can increase arsenic mobility in groundwater. This process, caused by low dissolved oxygen due to discharge from septic tanks, in combination with the local schist lithology, was attributed to the high dissolved arsenic concentrations in some SoE bores in Glenorchy (ORC, 2021).

Due to the high spatial variability in Otago, which can vary on a small spatial scale, it is strongly recommended that bore owners regularly test their groundwater for arsenic to ensure compliance with the DWSNZ. Some laboratory testing suites do not automatically contain arsenic, hence, it strongly advised that this testing is requested specifically.

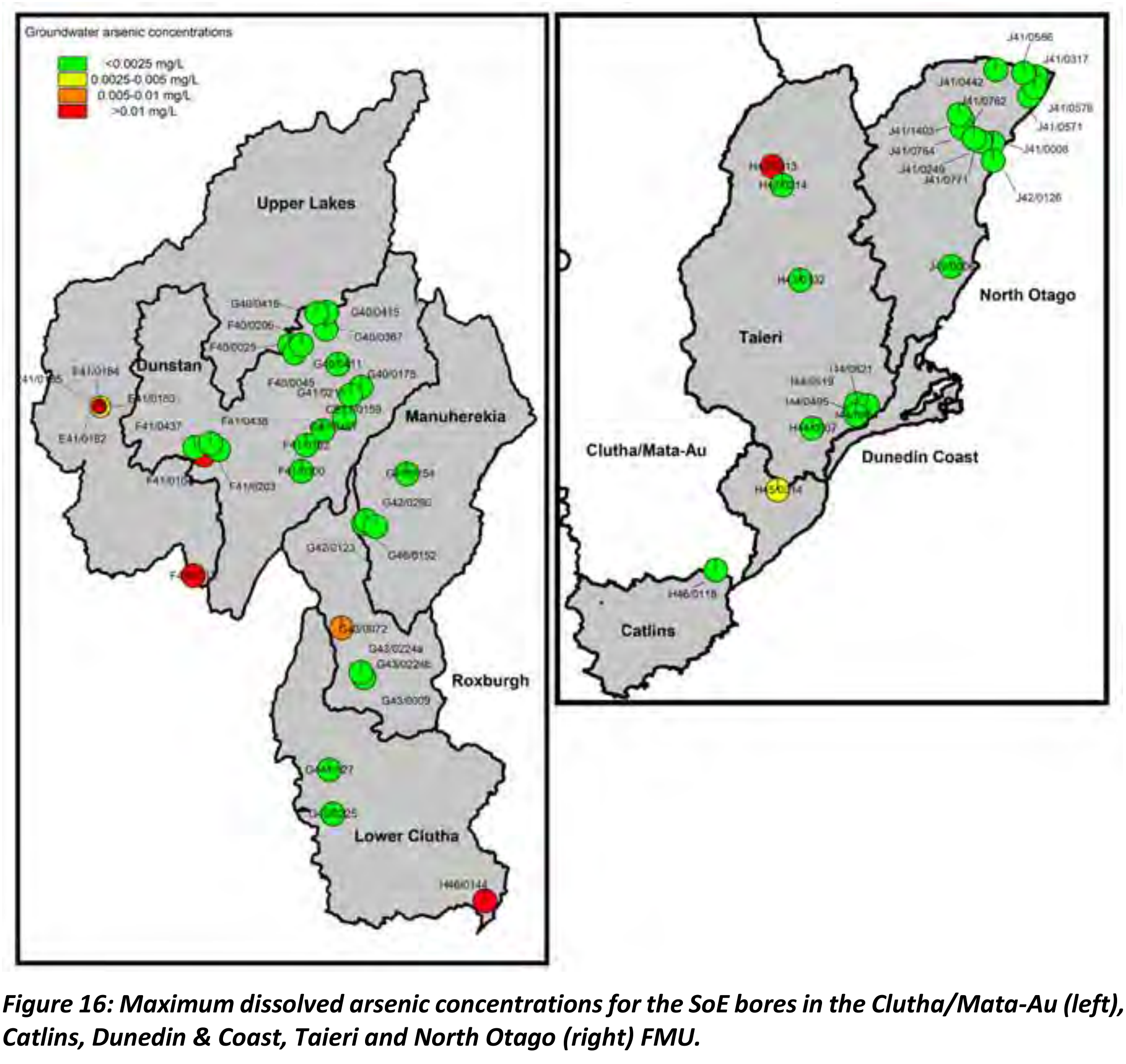


Figure 16: Maximum dissolved arsenic concentrations for the SoE bores in the Clutha/Mata-Au (left), Catlins, Dunedin & Coast, Taieri and North Otago (right) FMU.

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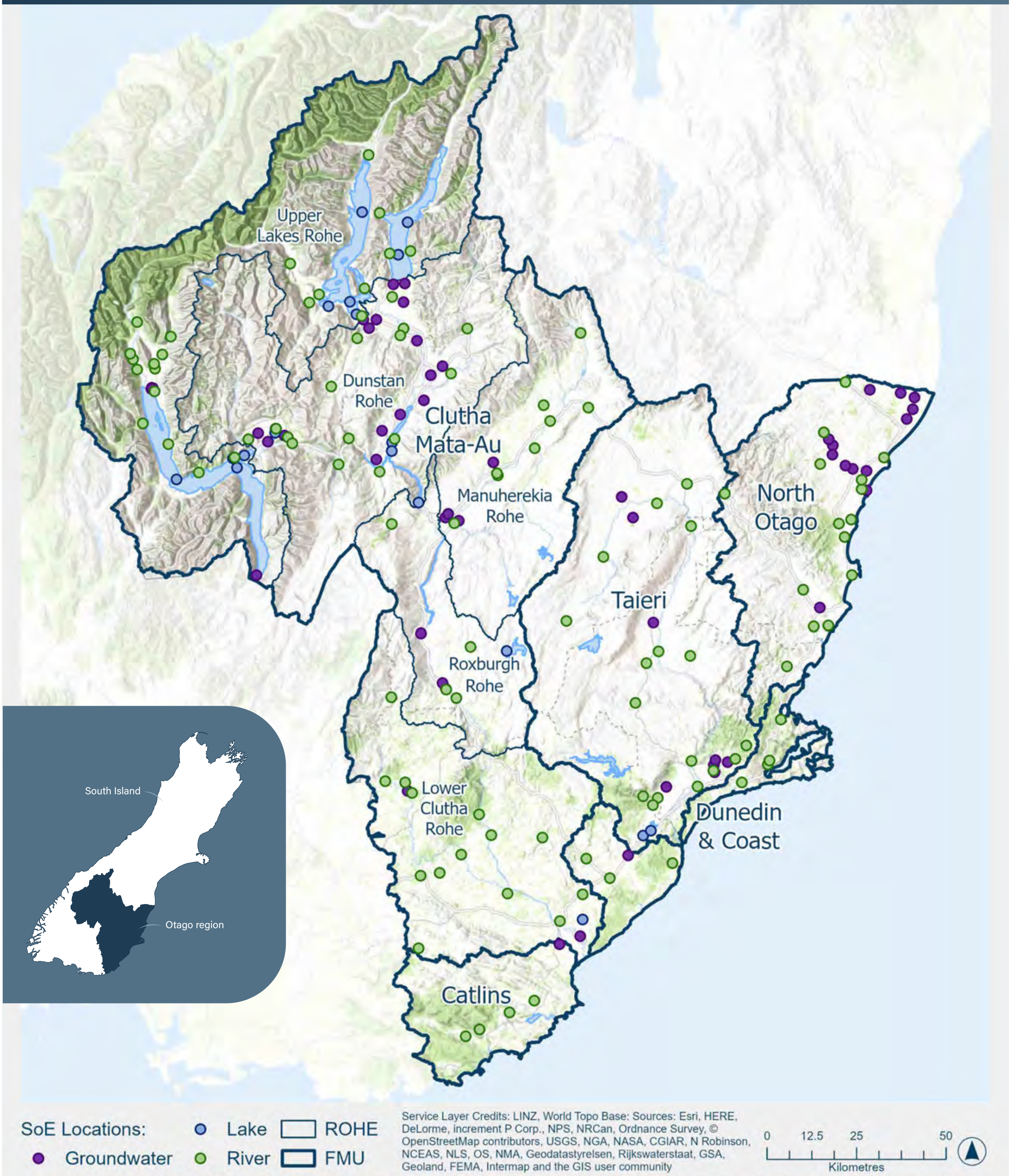
Appendix 1: Site numbers and names for Figures 2 to 9.

Site #	**Site Name**	**Site #**	**Site Name**
1	Awamoko at SH83	49	Ox Burn at Rees Valley Road
2	Kakaho Creek at SH1	50	Precipice Creek at Glenorchy Paradise Road
3	Kakanui at Clifton Falls Bridge	51	Quartz Creek at Maungawera Valley Road
4	Kakanui at McCones	52	Rees at Glenorchy Paradise Road Bridge
5	Kauru at Ewings	53	Scott Creek at Routeburn Road
6	Oamaru Creek at SH1	54	The Neck Creek at Meads Road
7	Pleasant at Patterson Road Ford	55	Timaru at Peter Muir Bridge
8	Shag at Craig Road	56	Turner Creek at Kinloch Road
9	Shag at Goodwood Pump	57	Arrow at Morven Ferry Road
10	Trotters Creek at Mathesons	58	Bannockburn at Lake Dunstan
11	Upper Shag at SH85 Culvert	59	Cardrona at Mt Barker
12	Waianakarua at Browns	60	Clutha at Luggate Br
13	Waianakarua at South Branch SH1	61	Lindis at Ardgour Road
14	Waiareka Creek at Taipo Road	62	Lindis at Lindis Peak
15	Waikouaiti at 200m d/s DCC intake	63	Luggate Creek at SH6 Bridge
16	Contour Channel at No. 4 Bridge	64	Mill Creek at Fish Trap
17	Deep Stream at SH87	65	Nevis at Wentworth Station
18	Kye Burn at SH85 Bridge	66	Quartz Reef Creek at SH8
19	Meggat Burn at Berwick Road	67	Roaring Meg at SH6
20	Nenthorn at Mt Stoker Road	68	Shotover at Bowens Peak
21	Silverstream at Taieri Depot	69	Upper Cardrona at Tuohys Gully Road
22	Silverstream at Three Mile Hill Road	70	Benger burn at Booths
23	Sutton Stream at SH87	71	Clutha at Millers Flat
24	Taieri at Allanton Bridge	72	Fraser at Old Man Range
25	Taieri at Linnburn Runs Road	73	Teviot at Bridge Huts Road
26	Taieri at Outram	74	Dunstan Creek at Beattie Road
27	Taieri at Stonehenge	75	Hills Creek at SH85
28	Taieri at Sutton	76	Manuherekia at Blackstone Hill
29	Taieri at Tiroiti	77	Manuherekia at Galloway
30	Taieri at Waipiata	78	Manuherekia at Ophir
31	Waipori at Waipori Falls Reserve	79	Manuherekia downstream of Fork
32	Whare Creek at Whare Flat Road	80	Poolburn at Cob Cottage
33	12 Mile Creek at Glenorchy Queenstown Road	81	Thomsons Creek at SH85
34	25 Mile Creek at Glenorchy Queenstown Road	82	Blackcleugh Burn at Rongahere Road
35	Buckler Burn at Glenorchy Queenstown Road	83	Clutha at Balclutha
36	Bullock Creek at Dunmore Street Footbridge	84	Crookston Burn at Kelso Road
37	Craig Burn at SH6	85	Heriot Burn at Park Hill Road
38	Dart at The Hillocks	86	Lovells Creek at Station Road
39	Dundas Creek at Mill Flat	87	Pomahaka at Burkes Ford
40	Greenstone at Greenstone Station Road	88	Pomahaka at Glenken
41	Hawea at Camphill Bridge	89	Tuapeka at 700m u/s bridge
42	Kawarau at Chards Rd	90	Upper Pomahaka at Aitchison Runs Road
43	Horn Creek at Queenstown Bay	91	Waipahi at Cairns Peak
44	Invincible Creek at Rees Valley Road	92	Waipahi at Waipahi
45	Leaping Burn at Wanaka Mt Aspiring Road	93	Wairuna at Millar Road
46	Makarora at Makarora	94	Waitahuna at Tweeds Bridge
47	Matukituki at West Wanaka	95	Waiwera at Maws Farm
48	Motatapu at Wanaka Mt Aspiring Road		

Water Quality

Otago Region: 2017 – 2022



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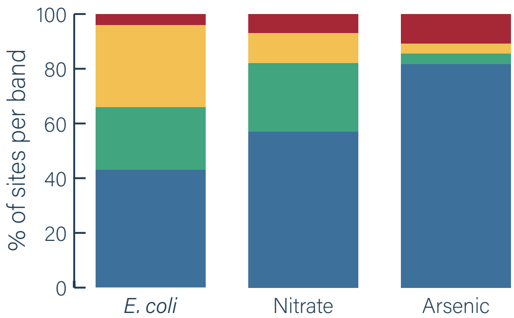
Quick Results

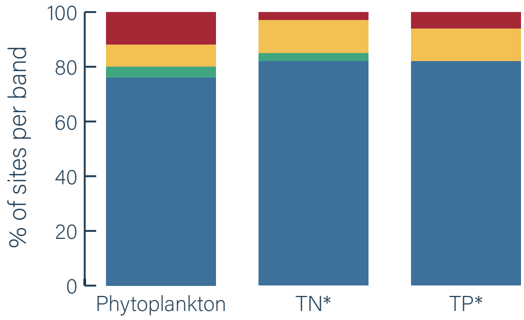
Band A
Band B
Band C
Band D
Band E (*E. coli* only)

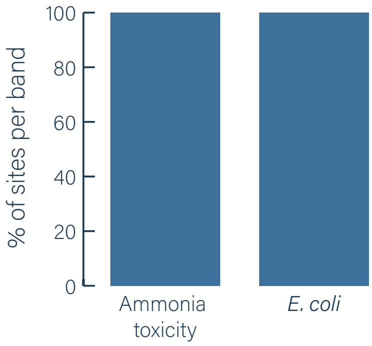
Decreasing water quality

Groundwater

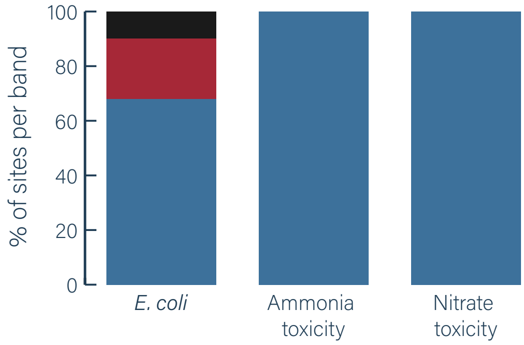


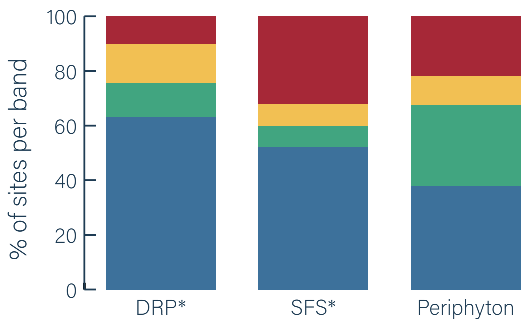
Lakes





Rivers





***KEY:**

DRP: Dissolved reactive phosphorus

SFS: Suspended fine sediment

TN: Total nitrogen

TP: Total phosphorus

Biomonitoring Report Card 2017 to 2022

Background

The Otago Regional Council (ORC) is responsible for managing Otago's surface-water resources and carries out regular ecological assessments, as part of its State of Environment (SoE) programme. This report card is a snapshot of biomonitoring undertaken between July 2017 and June 2022. The last report card can be found here https://www.orc.govt.nz/media/12479/wq-soe-report-card-2016-2021.pdf.

Each site that has been monitored for submerged plants, fish index of biotic integrity (Fish-IBI), macroinvertebrates, deposited sediment, or ecological processes has been graded according to the relevant attribute table and calculation guidance in Appendix 2 of the NPS-FM (Table 1). An assessment of habitat has also been included, although this attribute is not an NPS-FM attribute.

Each table of Appendix 2 of the NPS-FM 2020 defines the ranges for numeric attribute states as four attribute bands, which are designated A to D. The attribute bands represent a graduated range of support for environmental values from high (A band) to low (D band). For most attributes, the D band represents an unacceptable condition (with the threshold between the C and the D band being referred to as the 'bottom line').

Table 1. Details of the NPS-FM attributes used to grade the state of the river and lake monitoring sites.

NPS-FM Reference – NOF Attribute	Water body type	Calculation guidance	Numeric attribute state description	Units
A2B; Table 11 -Submerged plants (natives)	Lakes	State calculated once every three years	% of maximum potential score	%
A2B; Table 12 -Submerged plants (invasive)	Lakes	State calculated once every three years	% of maximum potential score	%
A2B; Table 13 - Fish Index of Biotic Integrity	Rivers	State calculated as 5-year average	Average score	-
A2B; Table 14 - Macroinvertebrates	Rivers	State calculated as 5-year median	MCI score	-
A2B; Table 15 - Macroinvertebrates	Rivers	State calculated as 5-year median	ASPM score	-
A2B; Table 16 – Deposited Sediment	Rivers	Median of 5 years of at least monthly samples (at least 60 samples)	% fine sediment cover	%
A2B; Table 21 – Ecosystem metabolism	Rivers	Annual median	% cotton tensile strength loss per degree day (%CTSL dd-1)	%

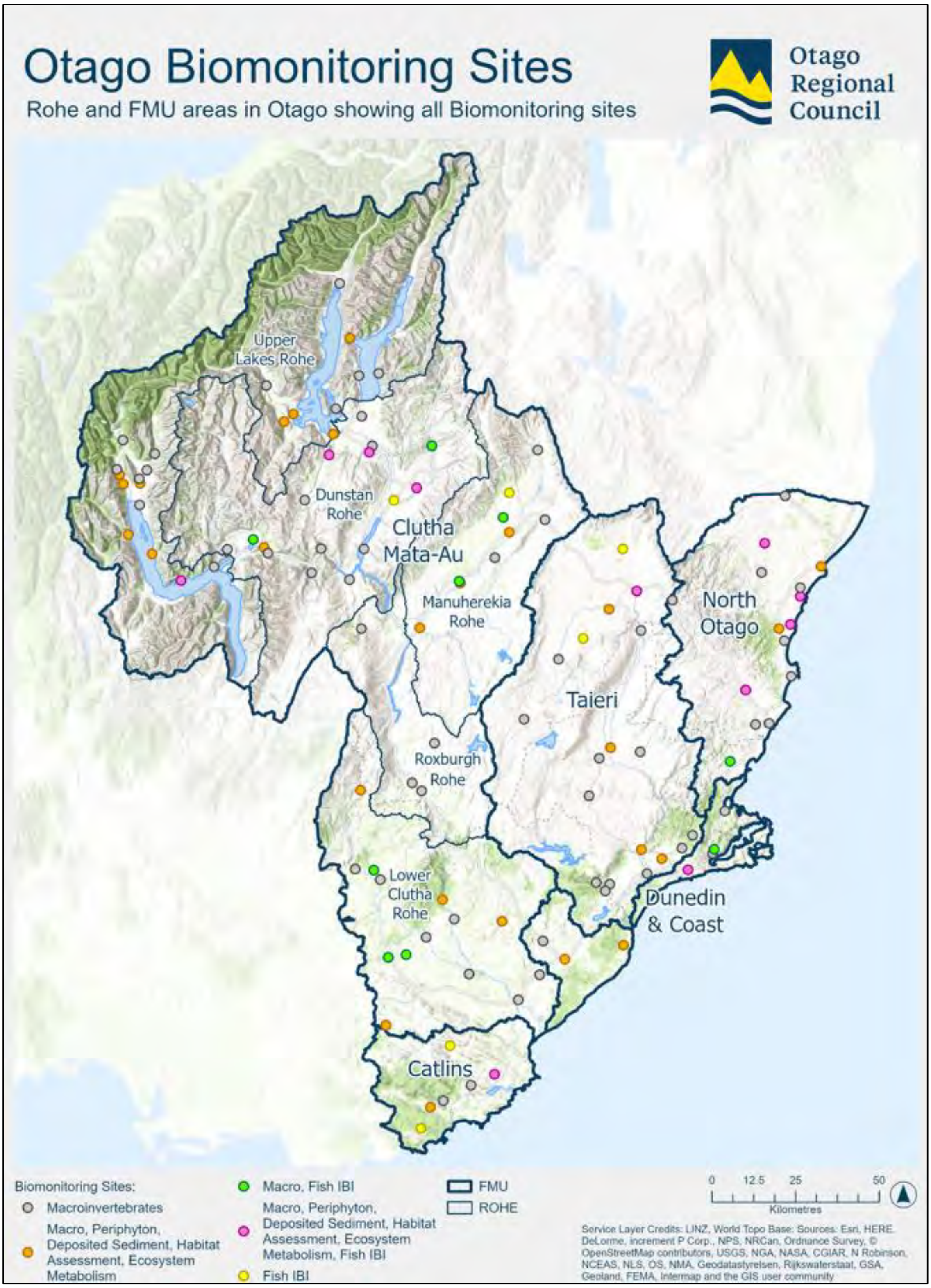


Figure 1: Otago region showing Freshwater Management Units and biomonitoring sites.

Submerged Plants- Lakes

The lake submerged plant indicator (Lake SPI) index is used to assess the presence (or absence) and density of native and invasive plants on the lakebed. Lake SPI gives an indication of lake productivity, ecosystem health and changes to the ecosystem since the last assessment. To cater for the large variety of lakes, the Lake SPI index is expressed as a percentage of a lakes maximum scoring potential, which is defined by several parameters, including lake depth and lake type. Submerged plants are identified and counted, and the total areal cover calculated. This work is repeated every 3 years, the latest assessment was completed in 2020/2021 (Figure 2) and the next one planned for summer 2023/2024. The NPS-FM gives two attribute tables to assess the state of Lake SPI, one for native plants and one for invasive plants (Tables 2 and 3). Both attributes need to be looked at to infer the ecological state of the lake.

Table 2: Submerged native plant indicator score (%) attribute bands – NPS-FM Table 11.

	Submerged Plants (native) Aquatic health	
	Description	Numeric attribute state
		% of maximum potential score
A	Excellent ecological condition. Native submerged plant communities are almost completely intact.	>75%
B	High ecological condition. Native submerged plant communities are largely intact.	>50 and ≤75%
C	Moderate ecological condition. Native submerged plant communities are moderately impacted.	≥20 and ≤50%
	National bottom line	20%
D	Poor ecological condition. Native submerged plant communities are largely degraded or absent.	<20%

Table 3: Submerged native plant indicator score (%) attribute bands – NPS-FM Table 12.

	Submerged Plants (native) Aquatic health	
	Description	Numeric attribute state
		% of maximum potential score
A	No invasive plants present in the lake. Native plant communities remain intact.	0%
B	Invasive plants having only a minor impact on native vegetation. Invasive plants will be patchy in nature co-existing with native vegetation. Often major weed species not present or in early stages of invasion.	>1 and ≤25%
C	Invasive plants having a moderate to high impact on native vegetation. Native plant communities likely displaced by invasive weed beds particularly in the 2 – 8 m depth range.	>25 and ≤90%
	National bottom line	90%
D	Tall dense weed beds exclude native vegetation and dominate entire depth range of plant growth. The species concerned are likely hornwort and Egeria.	>90%

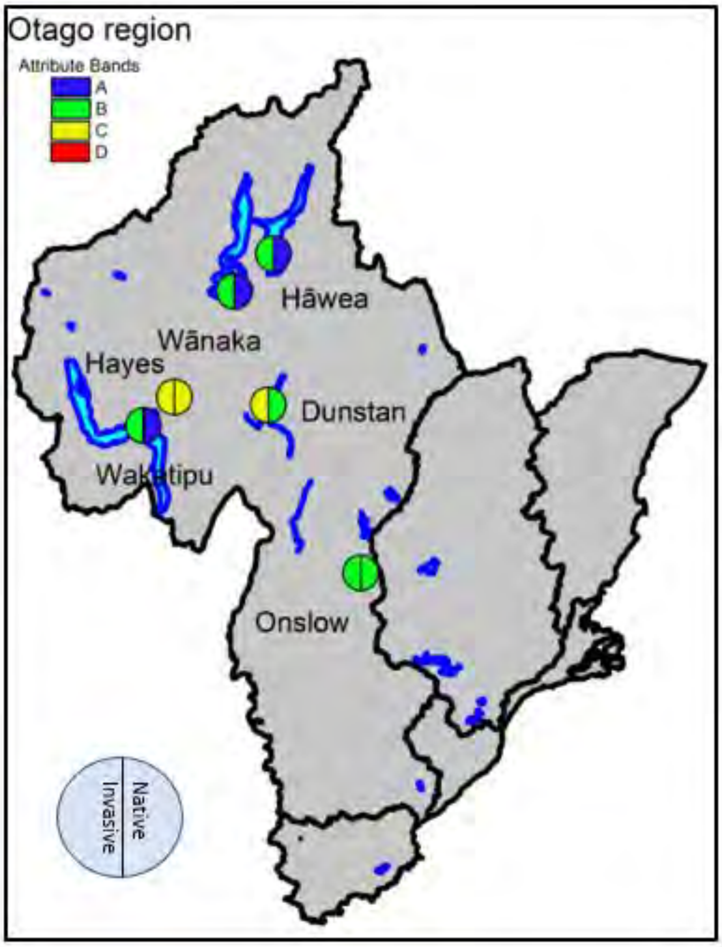


Figure 2: Lake SPI scores (2020) according to NPSF Attribute Tables 11 and 12.

- Lakes Wanaka, Hawea and Wakatipu show healthy native plant communities but are slightly impacted by invasive plants. An increase in nutrient loads, or further introduction of invasive plants will further affect the amenity value of these lakes.
- Lake Hayes is moderately impacted by the absence of native plants and the presence of invasive plants.
- Lakes Dunstan and Onslow are both in high ecological condition for native plants, but Lake Dunstan is moderately impacted by invasive plants which need to be managed carefully.
- Lagarosiphon is present in Lakes Dunstan and Roxburgh, and parts of Lake Wanaka. LINZ aerial or boat-based aquatic weed spraying helps control the spread. Isolated, individual Lagarosiphon plants are regularly removed from Frankton Arm in Lake Wakatipu, which is thought to be a result of weed transfer by boats from other waterways in the region.
- The next submerged plant survey is planned for summer 2023/2024.

Fish

New Zealand's freshwater environments support more than 50 known native fish species (Dunn et al, 2018). There is a high degree of endemism, with 92 per cent of New Zealand's named native fish species found nowhere else in the world (Joy and Death, 2013). New Zealand's native freshwater fish species have several unusual characteristics: most are small, benthic, largely nocturnal, and more than half are diadromous, moving between the sea and freshwater habitats during their lifecycle (Joy and Death, 2013).

Freshwater fish are an important component of freshwater ecosystems and a valued resource for Māori and recreational fishers. The community of fish species found at a site can be affected by changes in catchment land cover and land use, in-stream habitat, fish passages (routes for moving up and down waterways), pests, and contaminants. The fish index of biotic integrity (IBI) is a measure of the condition of fish communities at a particular site.

Healthy ecosystems depend on and are characterized by a healthy and diverse fish population. Fish are the major consumers of algae and are important for the function of freshwater food webs. Further, healthy fish communities are beneficial for the cultural health and mana of a river and Māori depend on taonga species like tuna for mahinga kai.

The NPS-FM describes Fish Index of Biotic Integrity (F-IBI) attribute states in Appendix 2, Table 13. Fish-IBI results (2017-2022) are shown in Figure 3.

Table 4: Fish Index of Biotic Integrity attribute bands – NPS-FM, Table 13.

	Fish Index of Biotic Integrity (F-IBI)	
	Description	**Numeric Attribute State**
A	High integrity of fish community. Habitat and migratory access have minimal degradation	≥34
B	Moderate integrity of fish community. Habitat and/or migratory access are reduced and show some signs of stress.	<34 and ≥28
C	Low integrity of fish community. Habitat and/or migratory access is considerably impairing and stressing the community	<28 and ≥18
D	Severe loss of fish community integrity. There is substantial loss of habitat and/or migratory access, causing a high level of stress on the community.	<18

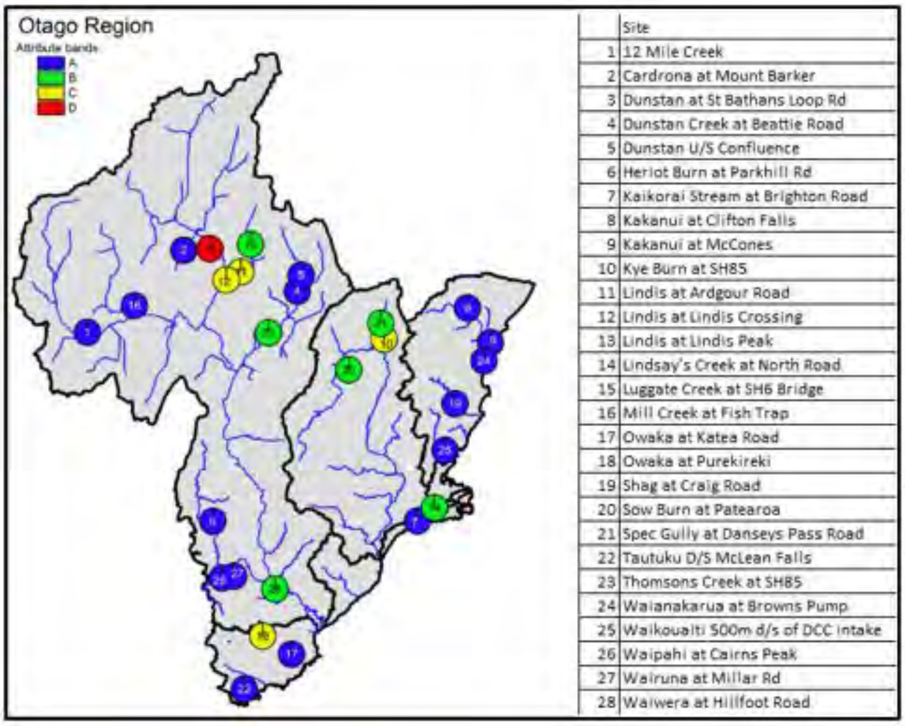


Figure 3: Fish IBI results from 2017 to 2022 (5-year median), NPS-FM Table 13.

- Fish IBI scores are generally in the 'A' or 'B' bands reflecting high to moderate integrity of fish community. There may be some reduced habitat or impediments in migratory access.
- Of the Dunstan Rohe tributaries, the Lindis is noticeable in having lower Fish IBI scores and Luggate Creek (Figure 4) is the only site monitored that has a Fish IBI below the national bottom line.
- Fish IBI is generally impaired by physical structures that limit upstream migration, such as dams.
- Generally, streams further from the coast are expected to have lower species richness than sites closer to the coast. This is due to diadromous fish migrating between freshwater and the ocean, but also because human activities, such as stream bed alterations, can prevent upstream migration of fish.

Figure 4: Luggate Creek and Cardrona River at Mt Barker

Macroinvertebrates

Macroinvertebrates are animals that lack a backbone and are large enough to see with the naked eye. Examples of macroinvertebrate species in Otago include freshwater crayfish (Kōura) and may fly larvae. Macroinvertebrates can be used as water quality indicators as different species have different pollution tolerances. The presence or absence of species can indicate nutrient levels or toxicants in the water (Stark, 2007, Shearer, 2015), however macroinvertebrates can be affected by factors other than water quality, such as habitat type (Stark, 2007)

The NPS-FM gives two attribute tables (NPS-FM, Tables 14 and 15) to assess the state of macroinvertebrates, one for Macroinvertebrate Community Index (MCI) and the other for Average Score Per Metric (ASPM), (Table 5). A description of both metrics is given below.

Macroinvertebrate Community Index (MCI): The MCI is based on the tolerance or sensitivity of species (taxa) to organic pollution and nutrient enrichment. For example, mayflies, stoneflies, and caddis flies are generally sensitive to pollution. They are only abundant in clean and healthy streams, whereas worms and snails are more tolerant and found in polluted streams. Most benthic invertebrate taxa have been assigned a tolerance value ranging from 1 (very tolerant) to 10 (very sensitive). Higher MCI scores indicate better stream conditions.

Average Score Per Metric (ASPM): The ASPM index aggregates three other metrics that are averaged to indicate stream health. The component metrics are the MCI, the richness of Ephemeroptera, Plecoptera and Trichoptera (EPT taxa) and %EPT abundance.

Table 5: Macroinvertebrate Community Index (MCI) and Average Score per Metric (ASPM) (NPS-FM Tables 14 and 15).

	Macroinvertebrate Community Index (MCI) score;	
	Description	MCI Score
A	Rare blooms reflecting negligible nutrient enrichment and/or alteration of the natural flow regime or habitat.	≥130
B	Occasional blooms reflecting low nutrient enrichment and/or alteration of the natural flow regime or habitat	≥110 and <130
C	Periodic short-duration nuisance blooms reflecting moderate nutrient enrichment and/or moderate alteration of the natural flow regime or habitat.	≥90 and <110
	National bottom line	**90**
D	Regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat	<90

	Macroinvertebrate Average Score Per Metric (ASPM)	
	Description	ASPM Score
A	Macroinvertebrate communities have high ecological integrity, similar to that expected in reference conditions.	>0.6
B	Macroinvertebrate communities have mild-to-moderate loss of ecological integrity.	>0.6 and <0.4
C	Macroinvertebrate communities have moderate-tosevere loss of ecological integrity.	>0.4 and <0.3
	National bottom line	**0.3**
D	Macroinvertebrate communities have severe loss of ecological integrity.	<0.3

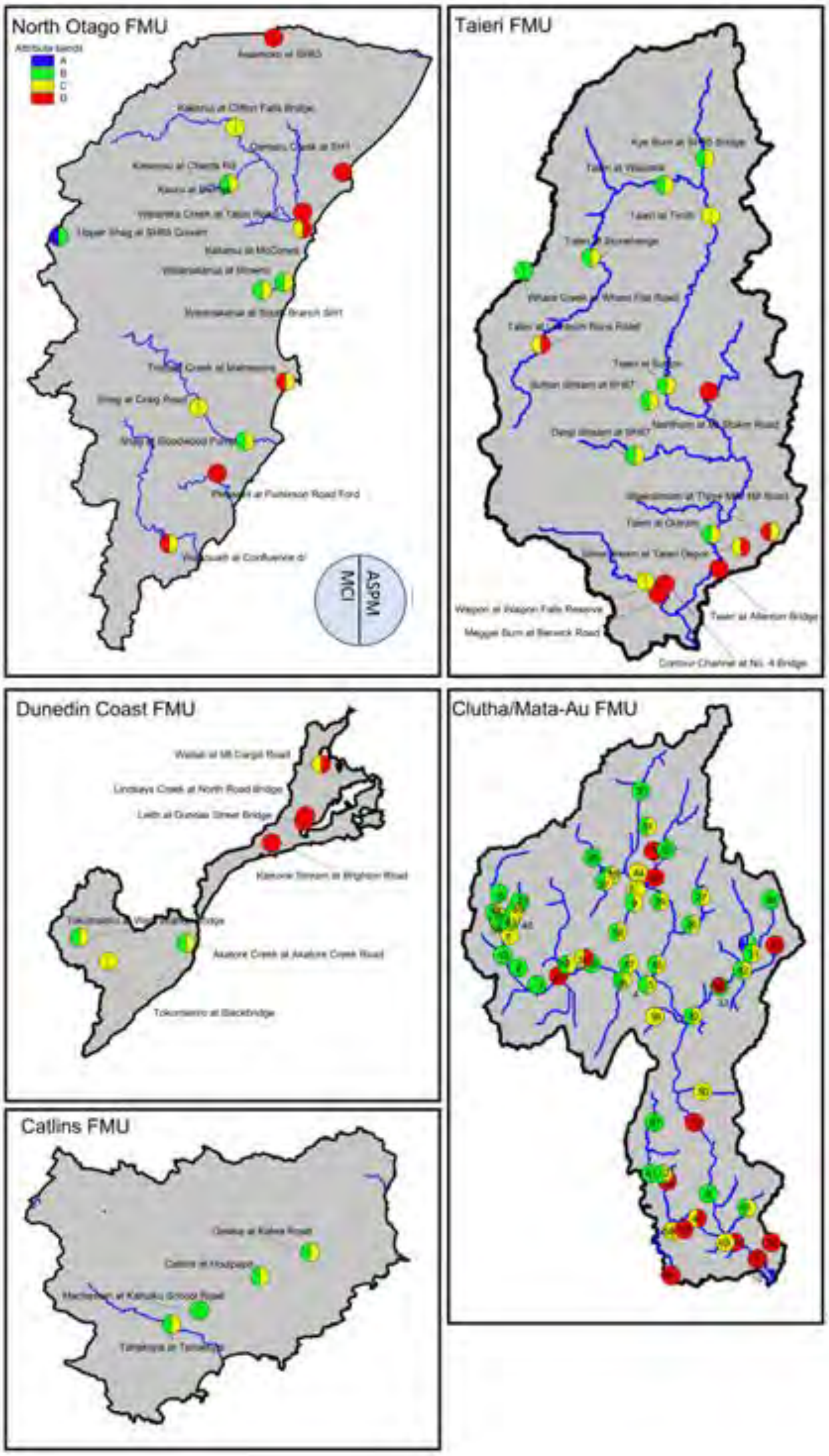


***Figure 5**: Macroinvertebrate results from 2017 to 2022 (5-year median). NPS-FM Tables 14 and 15. Site names for the Clutha Mata/Au FMU are given in Table 7*

- Only the Upper Shag River achieves the A-band for MCI, and no sites achieve an 'A' band for ASPM.
- Every FMU other than the Catlins has sites with MCI and ASPM scores below the national bottom line.
- Sites in the lower catchment tend to show lower MCI and ASPM scores, with many sites achieving an attribute band of 'D' (below the national bottom line). These sites tend to be the most affected by anthropogenic activities, including loss of habitat quality, departure from natural flow regimes and degraded water quality.
- Cawthron (Wagenhoff, 2021) looked at Otago-specific factors that control species distribution and developed interim Otago-specific attribute bands for MCI based on the River Environment Classification (REC), (Snelder et al. 2010). While the national bottom line remains at MCI 90, the 'A' band drops from 130 to 120, the 'B' band from 110 to 105
- If the interim attribute bands were adopted, three additional sites would achieve an 'A' grade (Dundas Creek at Millers Flat, Blackcleugh Burn and the Dart at the Hillocks).

Table 6: Site names and numbers for Figure 4.

Site	Site name	Site	Site name
1	Contour Channel at No. 4 Bridge	41	Invincible Creek at Rees Valley Road
2	Deep Stream at SH87	42	Leaping Burn at Wanaka Mt Aspiring Rd
3	Kye Burn at SH85 Bridge	43	Lindis at Ardgour Road
4	Meggat Burn at Berwick Road	44	Lindis at Lindis Peak
5	Nenthorn at Mt Stoker Road	45	Lovells Creek at Station Road
6	Silverstream at Taieri Depot	46	Luggate Creek at SH6 Bridge
7	Silverstream at Three Mile Hill Road	47	Makarora at Makarora
8	Sutton Stream at SH87	48	Manuherekia at Blackstone Hill
9	Taieri at Allanton Bridge	49	Manuherekia at Galloway
10	Taieri at Linnburn Runs Road	50	Manuherekia at Ophir
11	Taieri at Outram	51	Manuherekia downstream of Fork
12	Taieri at Stonehenge	52	Matukituki at West Wanaka
13	Taieri at Sutton	53	Mill Creek at Fish Trap
14	Taieri at Tiroiti	54	Motatapu at Wanaka Mt Aspiring Road
15	Taieri at Waipiata	55	Nevis at Wentworth Station
16	Waipori at Waipori Falls Reserve	56	Ox Burn at Rees Valley Road
17	Whare Creek at Whare Flat Road	57	Pomahaka at Burkes Ford
18	12 Mile Creek at Glenorchy Queenstown Rd	58	Pomahaka at Glenken
19	25 Mile Creek at Glenorchy Queenstown Rd	59	Poolburn at Cob Cottage
20	Arrow at Morven Ferry Road	60	Precipice Creek at Glenorchy Paradise Rd
21	Bannockburn at Lake Dunstan	61	Quartz Creek at Maungawera Valley Rd
22	Benger burn at Booths	62	Quartz Reef Creek at SH8
23	Blackcleugh Burn at Rongahere Road	63	Rees at Glenorchy Paradise Road Bridge
24	Buckler Burn at Glenorchy Queenstown Rd	64	Roaring Meg at SH6
25	Bullock Creek at Dunmore Street Footbridge	65	Scott Creek at Routeburn Road
26	Cardrona at Mt Barker	66	Shotover at Bowens Peak
27	Clutha at Balclutha	67	Teviot at Bridge Huts Road
28	Clutha at Luggate Br	68	The Neck Creek at Meads Road
29	Clutha at Millers Flat	69	Thomsons Creek at SH85
30	Craig Burn at SH6	70	Timaru at Peter Muir Bridge
31	Crookston Burn at Kelso Road	71	Tuapeka at 700m u/s bridge
32	Dart at The Hillocks	72	Turner Creek at Kinloch Road
33	Dundas Creek at Mill Flat	73	Upper Cardrona at Tuohys Gully Road
34	Dunstan Creek at Beattie Road	74	Upper Pomahaka at Aitchison Runs Road
35	Fraser at Old Man Range	75	Waipahi at Cairns Peak
36	Greenstone at Greenstone Station Road	76	Waipahi at Waipahi
37	Hawea at Camphill Bridge	77	Wairuna at Millar Road
38	Heriot Burn at Park Hill Road	78	Waitahuna at Tweeds Bridge
39	Hills Creek at SH85	79	Waiwera at Clutha confluence u/s 1km
40	Horn Creek at Queenstown Bay	80	Waiwera at Maws Farm

Deposited Fine Sediment

High amounts of sediment can smother benthic environments, influence fish community composition, act as a carrier of nutrients and affect the aesthetic appeal of rivers (Jones, 2012, Walling, 2008, Clapcott, 2011) Deposited fine sediment occurs naturally in the beds of rivers and streams. It usually enters a stream because of terrestrial weathering or bank erosion, and in-stream fluvial processes. Because sediment is naturally transported longitudinally through a river network, its state at any given point will be influenced by climate, geology, topography, and current velocity.

Deposited sediment is generally classified by sediment particle sizes >0.0625 mm. However, the particle size of deposited sediment is strongly influenced by stream bed morphology and flow velocity. For example, higher velocity can transport larger particles.

Human activities can affect this natural sediment cycle by accelerating sediment delivery to streams and increasing the quantity of smaller particle sizes. The effect of excess in-stream sedimentation is recognised as a major impact of changing land use on river health. Sediment alters the physical habitat by clogging interstitial spaces used as refugia by benthic invertebrates and fish, altering food resources, and removing sites used for egg-laying. As such, sediment can affect the diversity and composition of biotic communities. Excess sediment can also affect the aesthetic appeal of rivers and streams for human recreation

Deposited sediment is scored as a percentage cover of the streambed and the numeric attribute states are shown in Table 7.

The national bottom line is different for each sediment class, ranging between 21% to 29% of deposited sediment cover of the streambed. Deposited sediment classes are described in the NPS-FM, Appendix C, Tables 24 and 26. Figure 6 shows RHA results from 2017-2022.

Table 7: Deposited sediment attribute bands - NPS-FM, Table 16.

		% fine sediment cover			
	Description	**Numeric attribute state by deposited sediment class**			
		1	2	3	4
A	biota. Ecological communities are similar to those	≤7	≤10	≤9	≤13
B	Low to moderate impact of deposited fine sediment on instream biota. Abundance of sensitive macroinvertebrate species may be reduced	>7 and ≤14	>10 and ≤19	>9 and ≤18	>13 and ≤19
C	Moderate to high impact of deposited fine sediment on instream biota. Sensitive macroinvertebrate species may be lost.	>14 and ≤21	>19 and ≤29	>18 and ≤27	>19 and ≤27
	National bottom line	21	29	27	27
D	High impact of deposited fine sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.	>21	>29	>27	>27

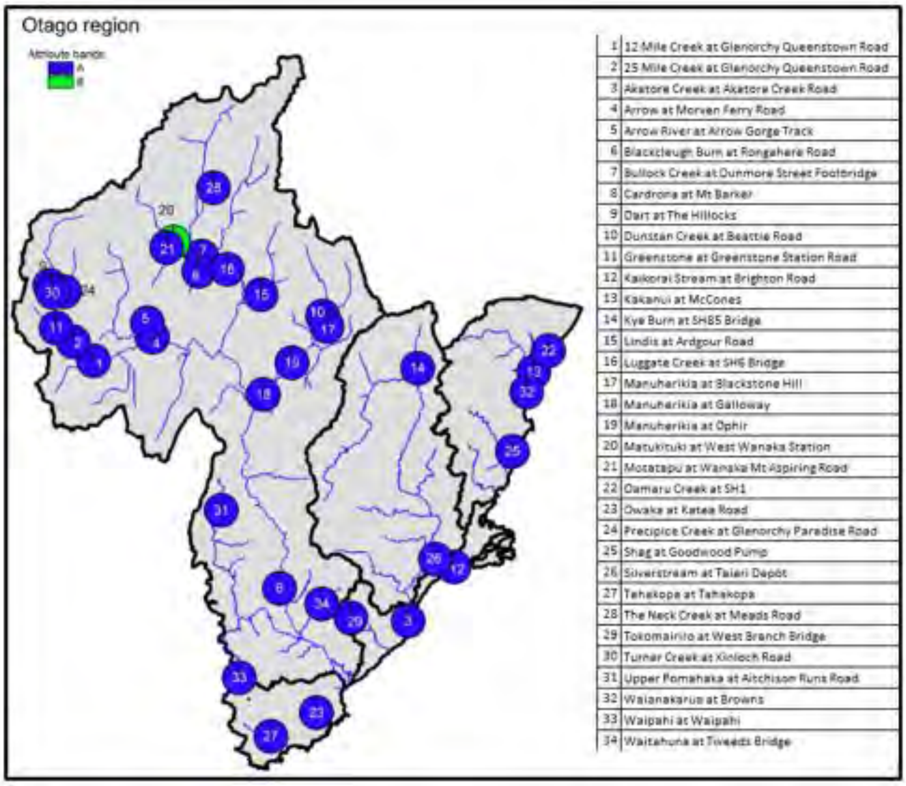


Figure 6: Deposited fine sediment from 2017 to 2022 (5-year median). NPS-FM Attribute Table 16.

- All but one site attains attribute band ‘A’, which is described by the NPS-FM as ‘close to reference condition’.
- The only site that does not achieve the A-band for deposited sediment is Matukituki at West Wanaka Station (Upper Lakes Rohe) which achieves a B-band (Figure 8)

Ecosystem metabolism

Ecosystem metabolism (gross primary production and ecosystem respiration) assesses the ecological processes component of the compulsory ecosystem health value in rivers. Ecosystem metabolism gives an indication of gross primary production (GPP) during summer and assesses an ecosystem’s primary productivity and respiration. Higher ecosystem respiration and higher GPP indicate nutrient-enriched conditions. Ecosystem metabolism is strongly influenced by land-use near the sampling site.

To measure ecosystem metabolism, the NPS-FM requires the deployment of a logger to continuously record dissolved oxygen and temperature for at least 7 days during the summer period. In the ecosystem health framework (Clapcott, 2018), alternative measures of ecological processes are discussed, including a cotton strip assays (CSA). The CSA provides an estimate of organic matter processing and is less resource intensive to measure than ecosystem metabolism. However, the same as for ecosystem metabolism, there are currently no national guideline values (within the NPS-FM) for assessing ecological processes using this method.

Cawthron explored the development of attribute bands for ORC to support the application of the CSA as an alternative action planning attribute (Wagenhoff et al., 2020), the draft attribute bands are given Table 8 and CSA results 2020-2022 are shown in Figure 7.

Table 8: Otago specific draft cotton strip attribute bands, developed by Cawthron (Wagenhoff, 2023)

	Percent cotton tensile strength loss per degree day (%CTSL dd-1)	
	Description	**Numeric attribute state**
A	River ecological processes are healthy and resilient, like natural reference conditions.	≤0.12
B	River ecological processes are slightly impacted by nutrient levels that are elevated above natural reference conditions and/or by altered flows/habitat due to land use impacts	>0.12 and ≤0.24
C	River ecological processes are moderately impacted by nutrient levels that are elevated above natural reference conditions and/or by altered flows/habitat due to land use impacts.	>0.24 and ≤0.37
	National bottom line	0.37
D	River ecological processes are unhealthy and significantly impacted by nutrient levels that are elevated above natural reference conditions and/or by altered flows/habitat due to land use impacts.	>0.37

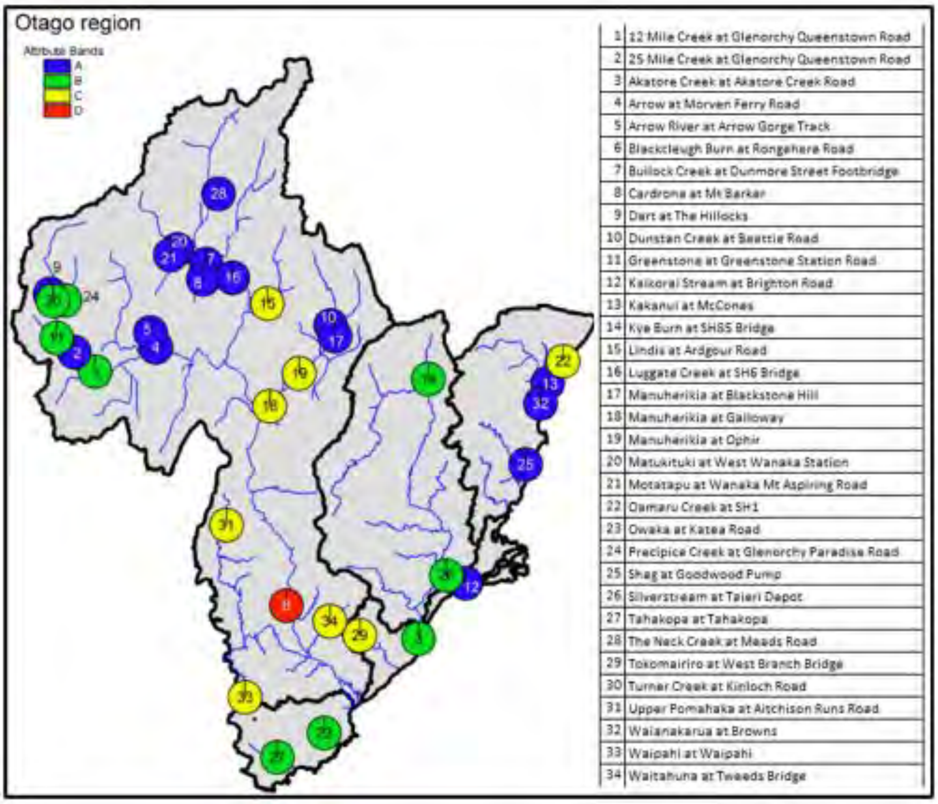


Figure 7: Ecosystem metabolism from 2017 to 2022 (5-year median). NPS-FM Table 21.

- The Upper Clutha sites achieve either 'A' or 'B' band, showing similarities to natural reference conditions.
- Only the Blackcleugh Burn at Rongahere Road (Lower Clutha Rohe) falls below the national bottom line. This site is close to reference (Figure 8)
- Sites achieving 'C' bands are generally in areas of high productivity (Waipahi, Figure 10)
- Sites along the coast achieve either 'A' and 'B' band, other than Oamaru Creek.

- Factors that negatively influence ecosystem respiration include temperature and nutrient concentration, as both parameters lead to higher productivity in freshwater.

Habitat

The physical character of a stream determines the quality and quantity of habitat available to biological organisms and the stream's aesthetic and amenity values. Physical habitat is the living space for all in-stream flora and fauna, it is spatially and temporally dynamic and its condition and characteristics set the background for any assessment of the health of a waterway. Aquatic life is dependent on various features of stream habitat and riparian areas. Knowing what types of habitats are present, in what amounts and how these habitats might be changing over time helps the understanding of overall stream health.

Stream habitat assessments were undertaken at each site according to the National Rapid Habitat Assessment Protocol Development for Streams and Rivers (Clapcott 2015). Appendix 1 shows the ten parameters covered and how each parameter is scored.

Rapid habitat assessment (RHA) scores are reported for 2021-2022 and give information about habitat properties at a particular site and consider factors such as deposited sediment, stream width and bank vegetation.

Each attribute is assigned a value between 1 and 10, where 10 represents the best conditions for the given habitat type. The sum of all attribute values is allocated to an 'A', 'B', 'C' or 'D' band intended to reflect the NPS-FM scoring system. Note that the NPS-FM does not provide an attribute table for habitat. The A-band (RHA >75) represents near to natural rivers with little deposited sediment, high habitat heterogeneity and diverse bank vegetation. The B- (RHA 50-75) and C-band (RHA 25-50) reflect degrading conditions from a natural state. The ORC RHA attribute bands are shown in Table 9.

Table 9: Developed attribute table for RHA scores reflecting NPS-FM attribute band grades.

	Rapid Habitat Assessment	
	Description	**Numeric attribute state**
A	Habitat is healthy and resilient, like natural reference conditions.	≤75
B	Habitat is impacted due to land use impacts	>75 and ≤50
C	Habitat is moderately impacted due to land use impacts.	>50 and ≤25
D	Habitat is unhealthy and significantly impacted by land use impacts.	>25


Figure 8: Matutituki River at West Wanaka Station and Blackcleugh Burn at Rongahere Rd

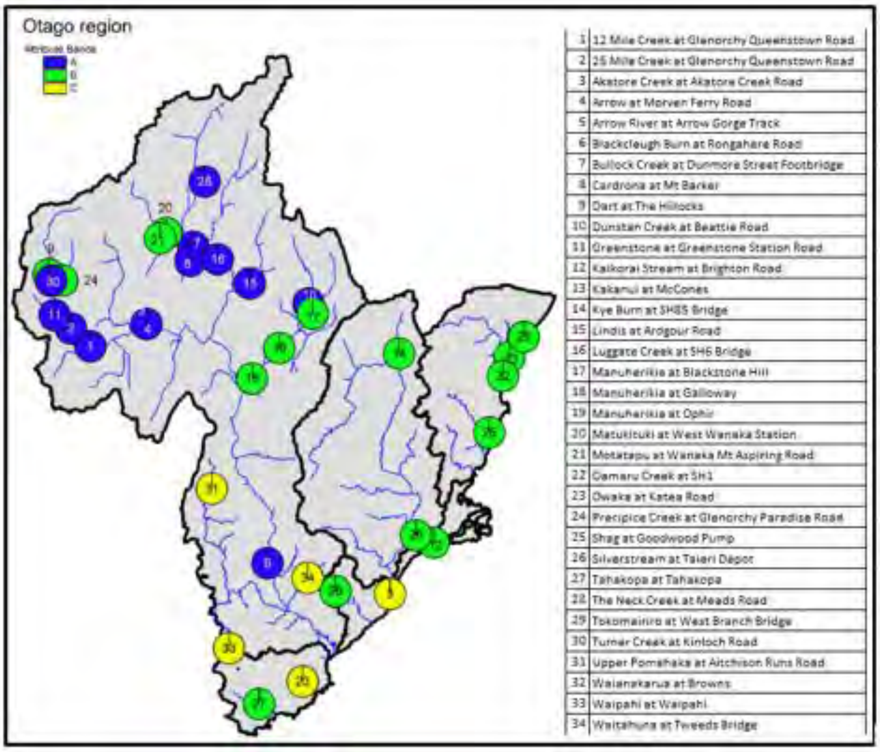


Figure 9: Rapid Habitat Assessment (2017 to 2022) graded to reflect NPS-FM attribute bands.

- No site in the Otago region has RHA values below 39 (C-band). Sites in the North of the region and in higher altitudes generally show the A-band.
- Sites in lower altitude regions where anthropogenic pressures increase and channel morphology is often strongly altered, show the B- and C-band.
- Lower RHA scores are generally linked to streambed alteration, channelling, lack of riparian vegetation and bank erosion intensity (Clapcott, 2015)

Figure 10: Manuherekia River at Blackstone and Waipahi River at Waipahi

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Appendix 1 - Stream Habitat Assessment

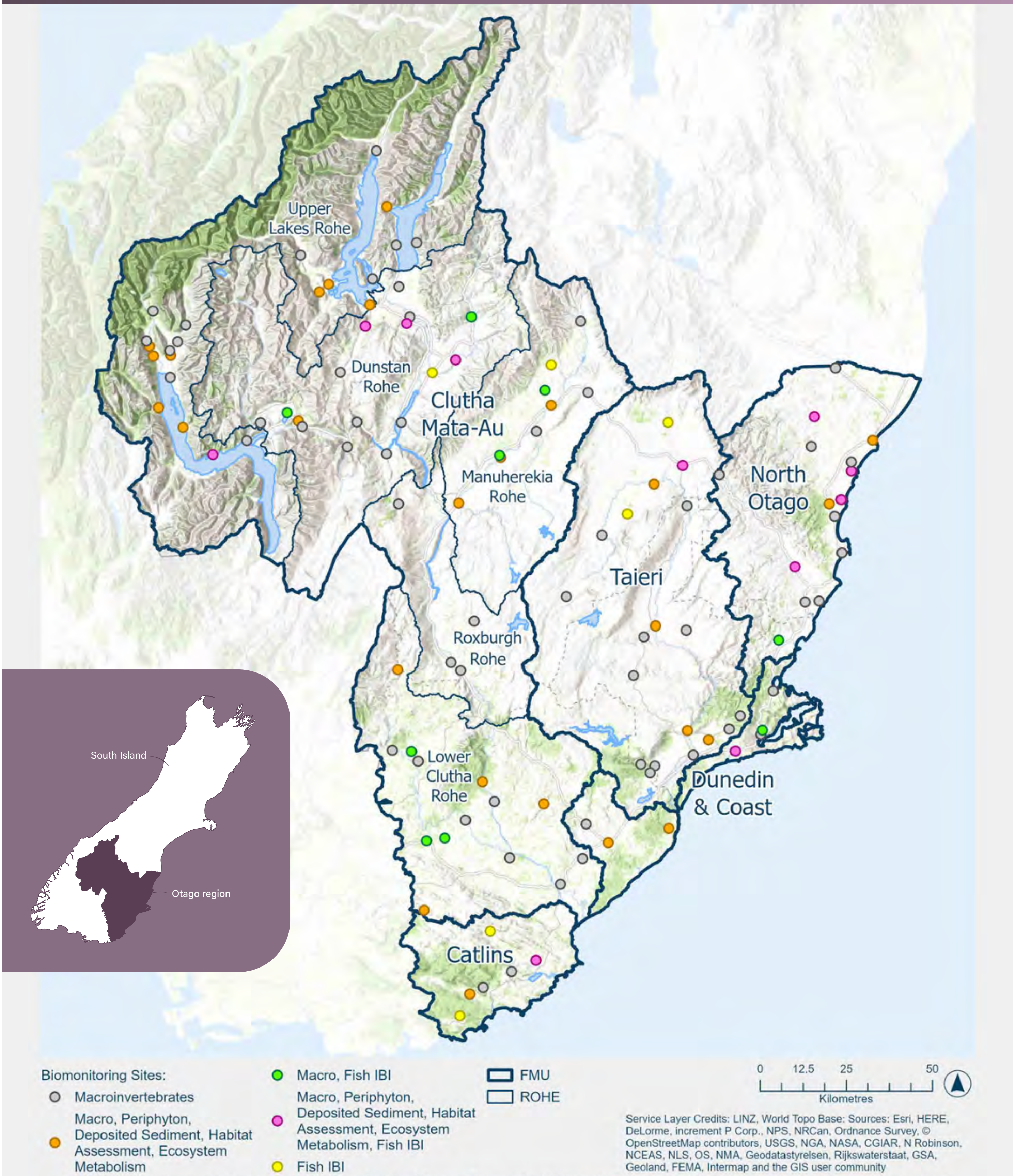
Stream habitat assessments were undertaken at each site according to the National Rapid Habitat Assessment Protocol Development for Streams and Rivers (Clapcott 2015). Table A1 shows how the assessment covers ten parameters, and how each parameter is scored.

Table A1. The habitat quality score matrix

Habitat parameter	Condition category										SCORE
1. Deposited sediment	*The percentage of the stream bed covered by fine sediment.*										
	0	*5*	*10*	*15*	*20*	*30*	*40*	*50*	*60*	*≥ 75*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
2. Invertebrate habitat diversity	*The number of different substrate types such as boulders, cobbles, gravel, sand, wood, leaves, root mats, macrophytes, periphyton. Presence of interstitial space score higher.*										
	≥ 5	*5*	*5*	*4*	*4*	*3*	*3*	*2*	*2*	*1*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
3. Invertebrate habitat abundance	*The percentage of substrate favourable for EPT colonisation, for example flowing water over gravel-cobbles clear of filamentous algae/macrophytes.*										
	95	*75*	*70*	*60*	*50*	*40*	*30*	*25*	*15*	*5*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
4. Fish cover diversity	*The number of different substrate types such as woody debris, root mats, undercut banks, overhanging/encroaching vegetation, macrophytes, boulders, cobbles. Presence of substrates providing spatial complexity score higher.*										
	≥ 5	*5*	*5*	*4*	*4*	*3*	*3*	*2*	*2*	*1*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
5. Fish cover abundance	*The percentage of fish cover available.*										
	95	*75*	*60*	*50*	*40*	*30*	*20*	*10*	*5*	*0*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
6. Hydraulic heterogeneity	*The number of of hydraulic components such as pool, riffle, fast run, slow run, rapid, cascade/waterfall, turbulence, backwater. Presence of deep pools score higher.*										
	≥ 5	*5*	*4*	*4*	*3*	*3*	*2*	*2*	*2*	*1*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
7. Bank erosion	*The percentage of the stream bank recently/actively eroding due to scouring at the water line, slumping of the bank or stock pugging.*										
Left bank	*0*	*≤ 5*	*5*	*15*	*25*	*35*	*50*	*65*	*75*	*> 75*	
Right bank	*0*	*≤ 5*	*5*	*15*	*25*	*35*	*50*	*65*	*75*	*> 75*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
8. Bank vegetation	*The maturity, diversity and naturalness of bank vegetation.*										
Left bank AND Right bank	*Mature native trees with diverse and intact understorey*		*Regenerating native or flaxes/sedges/tussock > dense exotic*			*Mature shrubs, sparse tree cover > young exotic, long grass*			*Heavily grazed or mown grass > bare/impervious ground.*		
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
9. Riparian width	*The width (m) of the riparian buffer constrained by vegetation, fence or other structure(s).*										
Left bank	*≥ 30*	*15*	*10*	*7*	*5*	*4*	*3*	*2*	*1*	*0*	
Right bank	*≥ 30*	*15*	*10*	*7*	*5*	*4*	*3*	*2*	*1*	*0*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
10. Riparian shade	*The percentage of shading of the stream bed throughout the day due to vegetation, banks or other structure(s).*										
	≥ 90	*80*	*70*	*60*	*50*	*40*	*25*	*15*	*10*	*≤ 5*	
SCORE	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
TOTAL	(Sum of parameters 1-10)										

Biomonitoring

Otago Region: 2017 – 2022



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Quick Results

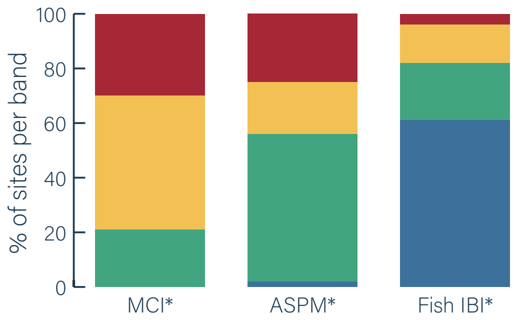
Band A

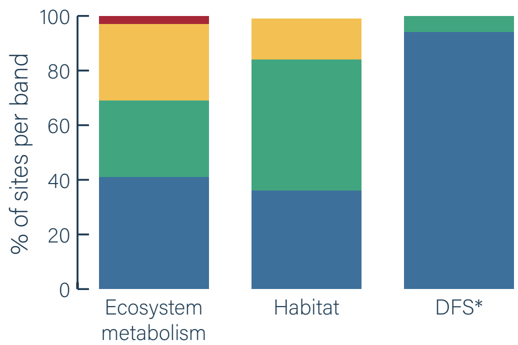
Band B

Band C

Band D

Decreasing water quality





***KEY:**

MCI: Macroinvertebrate Community Index

ASPM: Macroinvertebrate Average Score Per Metric

Fish IBI: Fish Index of Biotic Integrity

DFS: Deposited fine sediment

7.5. Vulnerable Ecosystems in Otago

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2317
Activity:	Governance Report
Author:	Scott Jarvie, Scientist – Biodiversity
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	12 June 2023

PURPOSE

[1] This paper sets out work currently underway in the biodiversity area at Otago Regional Council (ORC). It describes Otago's very diverse range of ecosystems, such as those identified as naturally uncommon; provides a rationale for the development of monitoring programmes for such ecosystems under the Resource Management Act 1991; and includes details of the monitoring programmes developed for two of these ecosystem types found in the Otago region.

EXECUTIVE SUMMARY

[2] This report details the development of monitoring programmes for two naturally uncommon ecosystem types in Otago: inland saline ecosystem and coastal turf ecosystem.

[3] By using an evidence-based research approach, the monitoring programmes will allow for assessment of both extent and ecological integrity for these vulnerable ecosystems.

[4] Information from the monitoring programmes will inform policy, and biodiversity and biosecurity management in the Otago region.

RECOMMENDATION

That the Council:

1) ***Notes*** *this report.*
2) ***Notes*** *that the monitoring programmes have been developed for two naturally uncommon ecosystems: inland saline and coastal turf.*
3) ***Notes*** *that this work is part of a broader programme to inform management of naturally uncommon ecosystems in the Otago region.*

BACKGROUND

[5] Otago has a very diverse range of ecosystems. Some of these are naturally rare which means they were limited in extent and/or number before people arrived in Aotearoa New Zealand. They can also be referred to as naturally uncommon ecosystems. Such ecosystems often have highly specialised and diverse assemblages of flora (plants) and fauna (animals), characterised by endemic species (i.e., found nowhere else, either at particular sites, regionally, or nationally) or those that are nationally threatened or at-risk. A national-scale typology (classification) identified a list of 71 of these naturally uncommon ecosystems across the country.

[6] Otago has 38 of these types of naturally uncommon ecosystems, which is over half of these types of ecosystems[1], amongst the highest of any region in the country. Of those 38, 27 of these ecosystems are classified in the Threatened category[2] when using International Union for Conservation of Nature[3] criteria (IUCN; Critically Endangered = 10 – the highest level of threat; Endangered = 11; Vulnerable = 6). Those ecosystems assessed as threatened are at higher risk of elimination due to the degree to which they are geographically restricted, face serious ongoing threats, and have undergone declines in geographic extent, ecological function, and ecosystem processes.

[7] The Otago region has one naturally uncommon ecosystem type that is only found here [i.e., inland saline (salt pans)], and others that have a large proportion of sites or area in the region (e.g., coastal turfs, inland outwash gravels). The rarity and distinctive physical environments of these ecosystems means they are often poorly understood, threatened with ecological collapse due to human activities, and are extremely difficult to restore. This means that adverse effects on these threatened naturally uncommon ecosystems by human activities have been identified to be avoided from an ecological perspective for indigenous biodiversity to be maintained, as emphasised in a recent publication[4] referencing the Resource Management Act 1991 (RMA).

[8] Under section 6(c) of the RMA, local authorities are required to recognise and make provision for the protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna. This includes regional councils' obligations under section 30 in relation to indigenous biodiversity in their regions[5].

[9] Given that naturally uncommon ecosystems hold a disproportionately high number (85%) of Aotearoa New Zealand's threatened plant species, with this being the only taxonomic (species) group where such an assessment to the contribution to biodiversity is possible as numbers of species and taxonomy (classification of species) are reasonably well-resolved, the avoidance of loss in habitats for biota in these ecosystems has been highlighted in a strategic thinkpiece report endorsed by Regional Councils on the future of biodiversity management in Aotearoa New Zealand[6]. The focus of monitoring programmes for naturally uncommon ecosystems has been outlined as involving two main components – *extent* and *condition/ecological integrity*.

[10] The Otago Regional Council (ORC) has recently developed monitoring plans for two of these naturally uncommon ecosystems: inland saline and coastal turfs. Over the spring-summer period of 2022-2023, field-testing to refine these monitoring plans and

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[1] As identified by researchers from Manaaki Whenua – Landcare Research in 2012

[2] The Threatened category has three subcategories – Critically Endangered, Endangered and Vulnerable. The other categories are Not Threatened, Data Deficient etc.

[3] The New Zealand Threat Classification System (NZTCS) was based on the IUCN classification, except made specific for NZ conditions. The NZTCS is for species only, while the IUCN has classifications for both species and ecosystems.

[4] Walker S, Bellingham PJ, Kaine G, Richardson S, Greenhaigh S, Simcock R, Brown MA, Stephens T, Lee WG 2021. What effects must be avoided, remediated or mitigated to main indigenous biodiversity. New Zealand Journal of Ecology 45: 3445

[5] S30(ga) the establishment, implementation, and review of objectives, policies, and methods for maintaining indigenous biological diversity

[6] Willis G 2017. Addressing New Zealand's Biodiversity Challenge. A Regional Council thinkpiece on the future of biodiversity management in New Zealand. Pukekohe, Enfocus. 88 pp

establish plots was undertaken to make sure they captured the two main components of monitoring: extent and condition or ecological integrity.

[11] The inland saline ecosystem was identified to be monitored because they are identified as a Critically Endangered ecosystem type, have been estimated to have reduced in extent to about 100 ha or about 0.25% of their estimated distribution since the 1960s, and are only found in the Otago region.

[12] The coastal turf ecosystem was chosen as 86% of coastal turfs occur on land that is not formally protected (i.e., not on public conservation land, under a QEII covenant, or Ngā Whenua Rāhui), the Otago region contains one-fifth of all known coastal turf sites and has the only locations on the east coast of the South Island.

[13] The work understanding these two ecosystems is briefly described below, including the monitoring programme developed for them, in order to work toward meeting ORC's statutory obligations under the RMA.

[14] Information from these two monitoring programmes will inform ORC's work programmes over time, for example, the coastal turf ecosystem programme is one of the ecosystems that ORC would seek to protect through the review of the Regional Plan: Coast and as part of implementing the New Zealand Coastal Policy Statement. The inland saline programme is the type of ecosystem that the exposure draft of the National Policy Statement for Indigenous Biodiversity would seek to protect so having an understanding of its nature and extent ahead of the proposed NPSIB puts ORC in a useful position. As Freshwater Farm Plans are rolled out, understanding where our significant biodiversity areas are is also helpful for making on farm decisions.

DISCUSSION

Inland saline (salt pan) ecosystem

[15] Working with leading experts, the ORC developed a fit-for-purpose monitoring plan for inland saline ecosystems. These experts had previously addressed a major knowledge gap in Aotearoa New Zealand's terrestrial geoecology (the study of geology and ecology) and botany (the study of plants) for species interacting with substrates and processes in settings where soil has been lost or is very thin, such as inland saline ecosystems in Central Otago. While earlier studies of Otago's inland saline systems largely examined sites through a biological lens, few attempts were made to define context in relation to physical attributes and evolutionary time scales. This limitation led to poor understanding and misnomers over the functionality of Otago's inland saline ecosystems and is likely to have contributed to further loss of habitat for significant indigenous fauna and flora from the wider landscape.

[16] The monitoring programme of inland saline ecosystems has been developed by resolving knowledge-based inaccuracies for inland saline site and developing field trials for saline areas. This includes methods to monitor extent (area), including the use of remote-sensing products, and for ecological integrity (condition), including the establishment of plots at a representative number of inland saline sites (7 of the 24 remaining sites) in 2022-2023. This will enable information to be collected on soil condition (pH and conductivity) in the field, that will in turn be associated with presence and abundance of threatened halophytes (salt-tolerant plants), some of which are amongst the most threatened vascular plants in the country. The work in this

programme will allow for ongoing assessment of the status and trends of inland saline sites in the Otago region.

Coastal turf ecosystem

[17] The ORC worked with leading experts on coastal turfs to develop a fit-for-purpose monitoring programme for the Otago region. These experts have specific knowledge of coastal turfs, with some sites having been studied for 20 years. The research underpinning monitoring programme investigated environmental drivers for coastal turfs.

[18] Using evidence-based research, a representative number of sites was identified in Otago across the geographical distribution, habitat types and types of coastal turf communities. The field-testing for coastal turfs in the Otago region for 2022–2023 was at four sites (of the six identified in the monitoring plan) to establish protocols moving forward. Additionally, a set of permanent vegetation plots and photo-points were established at these four sites for future monitoring, with data archived for future use. The work on coastal turfs has methods to monitor extent, including the use of remote-sensing products, and for ecological integrity, where presence and abundance of indigenous turf communities will be related to environmental drivers to establish limits that need to be maintained to ensure persistence into the future. The work in this programme will allow for ongoing assessment of the status and trends of coastal turfs in the Otago region. This monitoring plan was funded by an Envirolink Medium Advice Grant, so other councils could adopt the methodology[7].

OPTIONS

[19] This paper is for noting and there are no particular options associated with the paper.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[20] This work contributes towards the *Healthy and diverse ecosystems* strategic priorities. The work outlined in this paper contributes to:

a. Biodiversity Strategy 2018: Our Living Treasure | Tō tatou Koiora Taoka
b. Biodiversity Action Plan Te Mahi hei Tiaki I te Koiora 2019–2024.

[21] This work will inform how best to manage these two naturally ecosystem types.

Financial Considerations

[22] The work is funded and part of the planned work stream.

Significance and Engagement

[23] Engagement will be ongoing between stakeholders on a project-by-project basis.

[24] Collaboration between key agencies with the aim to develop Collaborate Agreements between agencies or organisations will occur, such as the Department of Conservation | Te Papa Atawhai, University of Otago, QEII Trust, and Manaaki Whenua Landcare Research.

[7] Brownstein GE, Mason N, Monks 2022. Coastal turfs of Otago: monitoring plan. Envirolink Grant: 2242-ORC002. Manaaki Whenua - Landcare Research

Legislative and Risk Considerations

[25] The Terrestrial Ecology programme in the Biodiversity section of the Science Team is being developed to address legislative requirements under the RMA.

Climate Change Considerations

[26] Monitoring programmes are designed with human-induced climate change as a key consideration, and the monitoring will help to assess environmental changes in response to climate change.

Communications Considerations

[27] Communication between key stakeholders will occur on a project-by-project basis.

NEXT STEPS

[28] These monitoring programmes will continue as outlined above.

ATTACHMENTS

Nil

7.6. Otago Lakes Management Approach

Prepared for:	Council
Report No.	STG2301
Activity:	Environmental - Water
Author:	Hilary Lennox, Consultant, Strategy Team, Andrea Howard, Acting Manager Strategy
Endorsed by:	Anita Dawe, General Manager Policy and Science Gavin Palmer, General Manager Operations Amanda Vercoe, General Manager Governance, Culture and Customer
Date:	29 June 2023

PURPOSE

[1] To outline the range of activities underway to better manage Otago lakes (and other water bodies) and to provide a further update on the recommendations contained within the report titled *Otago Lakes Management Review,* prepared for Council by Landpro Ltd (Landpro) in 2022.

[2] To recommend:

a) that the National Objectives Framework (NOF) continues to be implemented for each Freshwater Management Unit (FMU)/rohe;
b) that robust FMU/rohe-based objectives, policies, limits, rules and Catchment Action Plans (CAPs) continue to be developed and implemented through the Regional Policy Statement (pRPS), proposed Land and Water Regional Plan (pLWRP) and Integrated Catchment Management (ICM) work programmes; and
c) that four additional actions are expedited as soon as possible.

[3] This should ensure that environmental outcomes for lakes (and other water bodies) are at least maintained, if not improved as required by the National Policy Statement for Freshwater Management 2020 (NPS-FM).

EXECUTIVE SUMMARY

[4] In 2022, ORC engaged Landpro Ltd to undertake a scoping study in response to the suggestion of an Otago Lakes Strategic Plan that creates lake management plans aimed at improving environmental and amenity values. It was concluded that the pLWRP and CAPs have the potential to provide components of a robust management framework for the region, but that overarching guidance and direction was needed.

[5] There is a lot of existing work underway or planned to ensure better management of lakes and other water bodies in Otago, in large part to implement the NPS-FM. However, this is often presented to Council at a workstream (or Directorate) level rather than at a cross-organisational, or programme level, which means that it is harder to 'connect the dots' to provide a global picture of work being undertaken and areas that require more attention. This paper attempts to draw all major strands of work together to provide a better understanding of what is happening and to draw Council's attention to where more work is needed.

[6] ORC is already in the process of rolling out the National Objectives Framework (NOF)[1] for each of the region's FMU/rohe (and the lakes within).

[7] ORC is required to set desired environmental outcomes for each FMU/rohe, specify timeframes within which these will be achieved, make a plan for how these will be achieved, monitor progress, and take action when degradation is detected. This is shown diagrammatically in Figure 1.

[8] All of this work is new (since 2020). This means that the way freshwater bodies will be managed in the future will be different to how they are currently managed.

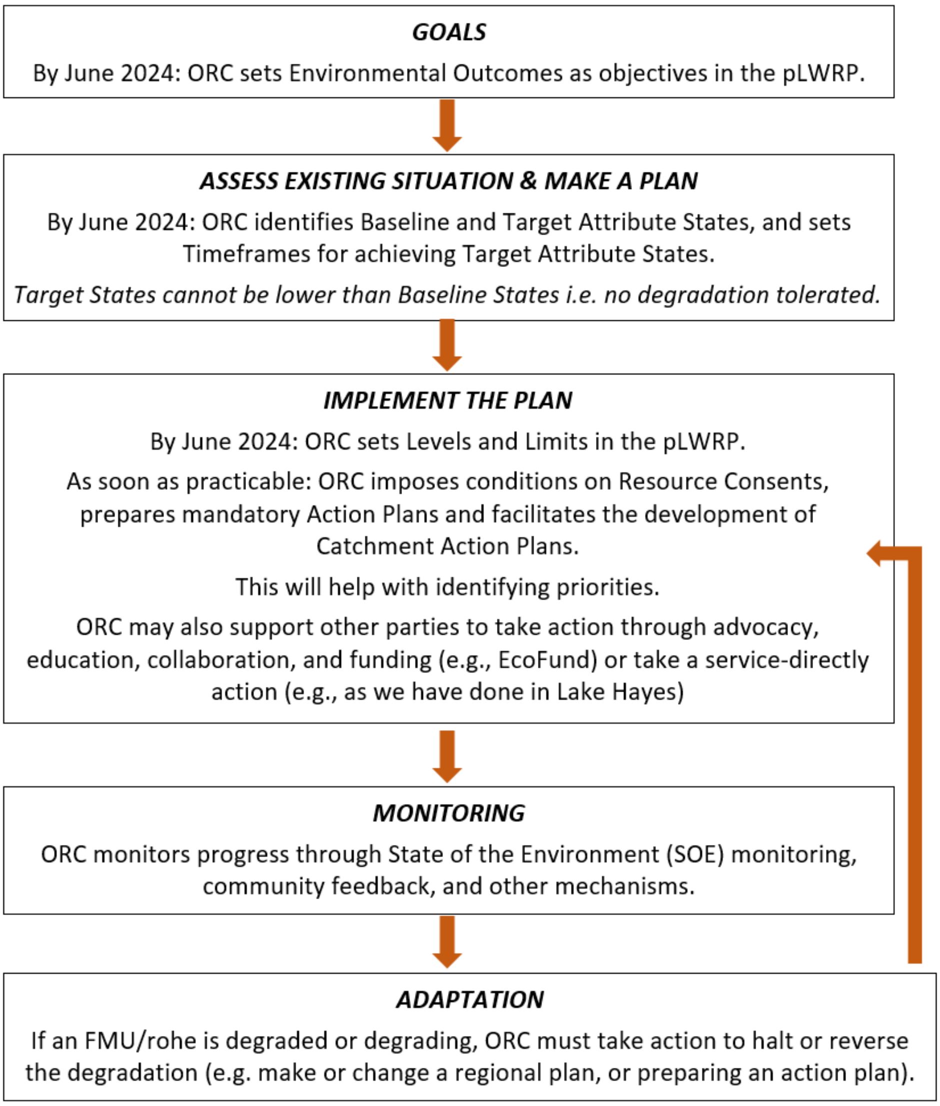

Figure 1: Outline of the key components of the NOF showing how it follows a strategic planning framework

[1] The National Objectives Framework is a core component of the National Policy Statement for Freshwater Management.

[9] In terms of overarching guidance and direction, the proposed pRPS and pLWRP will introduce FMU/rohe-scale policies as well as region-wide policies. This will provide more specific regulatory control than has existed in the past.

[10] Depending on which desired environmental outcomes are set for each FMU/rohe, this will determine what actions are needed to move from baseline (current) states to target attribute (future) states. This will help to inform how actions are prioritised - including actions relating to lakes.

[11] Given that the NPS-FM has introduced a fundamental change in the way that freshwater is managed, and that ORC has a responsibility to ensure that the pRPS and pLWRP are delivered on time and to the required standard, then it would be in ORC's interest to ensure that all available resources are focussed on these existing commitments.

[12] Landpro identified missing pieces of the current regime that need to be addressed to ensure that they do not exist under the new, LWRP-based framework. This paper has closely examined Landpro's 43 recommendations and identified which of these have already been addressed or will soon be addressed through current work programmes. Where there are still gaps (e.g., in our understanding of the three deep lakes), then it is recommended that action is taken sooner rather than later.

[13] The overall recommendation of this paper is, therefore:

- that the National Objectives Framework (NOF) continues to be implemented for each Freshwater Management Unit (FMU)/rohe;
- that robust FMU/rohe-based objectives, policies, limits, rules and Catchment Action Plans (CAPs) continue to be developed and implemented through the Regional Policy Statement (pRPS), proposed Land and Water Regional Plan (pLWRP) and Integrated Catchment Management (ICM) work programmes; and
- that four additional actions are expedited as soon as possible.

[14] This should ensure that robust regional- and FMU/rohe-based objectives, policies, limits and rules and Catchment Action Plans are prepared and implemented so that environmental outcomes for lakes (and other water bodies) are maintained and/or improved.

RECOMMENDATION

That the Council*:*

1) ***Notes*** *this report.*

2) ***Notes*** *the range of existing work programmes that have addressed / will address the majority of the recommendations contained in the Otago Lakes Management Review report.*

3) ***Notes*** *the four actions not currently under active consideration (through current or planned work programmes) that will be reviewed, prioritised, and costed by the relevant Council departments as part of the 2024- 2034 Long-Term Plan process. These actions centre around gaining an improved understanding of the three deep lakes, undertaking a stocktake of related work of other agencies, groups and other*

stakeholders within each FMU, further consideration of aquatic pest management programmes and enhanced land use mapping.

4) ***Directs** staff to focus on the pRPS, pLWRP and ICM work programmes and continue rolling out the NOF for each FMU/rohe rather than developing a separate Otago Lakes Strategic Plan.*

5) ***Recommends** that the previously established Lakes Management Working Group focus their attention specifically on Lakes Hāwea, Wānaka, and Whakatipu-Wai-Māori/Wakatipu and that Council, through this group, seek to establish a joint work programme with the Ministry of the Environment (and other experts) to improve understanding of these inland deep lakes.*

6) ***Notes** that the Lakes Management Working Group will be kept informed of the broader initiatives underway that are planned to improve management of all lakes (and water bodies) across the region.*

BACKGROUND

[15] On 27 May 2021 the Finance Committee requested the "establishment and funding of a scoping study for an Otago Lakes Strategic Plan, in association with relevant stakeholders, that creates lake management plans aimed at improving the environmental and amenity value of these water bodies, and acquire the science, partnerships and information for these purposes with an initial budget of $100,000 in each of years one and two of the LTP 2021-31".

[16] Given the evolving planning context (pRPS and pLWRP), and the risk of overlap between documents and work programmes, it was proposed to divide the scoping study into two separate stages:

- Stage 1 – confirm the case for the development of an Otago Lakes Strategic Plan; and
- Stage 2 – clarify the purpose, scope and function of said strategic plan.

[17] On 10 November 2021, the Strategy and Planning Committee approved the scoping study and Landpro Ltd (Landpro) was subsequently engaged via an open tender process. The study included a stocktake of 83 of the region's ~7,000 lakes and a brief overview of regulatory and non-regulatory management tools. Information regarding values associated with Otago's lakes and feedback from stakeholders was also collated.

[18] The subsequent report[2] concluded that the pLWRP and Catchment Action Plans have the potential to provide components of a robust management framework for the region, but that lakes management in Otago requires overarching guidance and direction, and that missing pieces of the current regime need to be addressed. The report then provides 43 recommendations for achieving this.

[19] On 7 December 2022, Council approved proceeding to Stage 2 of the scoping study, and directed staff to draft, scope, and investigate the internal and external resourcing

[2] Mandis, K, Muller, T, Perkins, C (2022) Otago Lakes Management Review, Landpro Ltd (https://www.orc.govt.nz/media/13431/agenda-council-20221207.pdf)

required to address the recommendations from the Landpro report to inform the 2024-2034 Long-Term Plan process.

[20] For the purpose of progressing Stage 2 of the scoping exercise, this paper revisits the National Policy Statement for Freshwater Management 2020 (NPS-FM) as this provides local authorities with direction on how they should manage freshwater under the RMA 1991 and is informing the development of the pRPS and pLWRP.

[21] This paper then provides an update on the ICM programme as this will inform the development of the CAPs that will incorporate the action plans required under the NPS-FM. This report also includes a discussion on the recommendations contained within the Landpro report.

DISCUSSION

NPS-FM 2020: National Objectives Framework

[22] The sole objective of the NPS-FM is to ensure that natural and physical resources are managed in a way that prioritises:

1) first, the health and well-being of water bodies and freshwater ecosystems;
2) second, the health needs of people (such as drinking water); and
3) third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.

[23] Policy 5 of the NPS-FM requires that freshwater is managed through the National Objectives Framework (NOF) to ensure that the health and well-being of degraded water bodies and freshwater ecosystems is improved, and the health and well-being of all other water bodies and freshwater ecosystems is maintained and (if communities choose) improved.

[24] Implementing the NOF requires ORC to apply the following compulsory values for each FMU:

- Ecosystem Health (water quality, water quantity, habitat, aquatic life, ecological processes);
- Human contact;
- Threatened species; and
- Mahinga kai.

[25] Implementing the NOF requires ORC to also consider whether the following values apply:

- Natural form and character;
- Drinking water supply;
- Wai tapu;
- Transports and Tauranga waka;
- Fishing;
- Hydro-electric power and generation;
- Animal drinking water;
- Irrigation, cultivation and production of feed and beverages; and
- Commercial and industrial use.

[26] There is nothing precluding ORC from considering any other values that it considers important. As shown in Attachment 1, Council (and its communities) have already identified values for each FMU/rohe.

[27] Implementing the NOF requires ORC to identify environmental outcomes for every value and include these as objectives in the pLWRP. ORC must identify attributes for each value and identify the baseline state. The NOF process also requires ORC to set target attributes states, environmental flows (rivers) and levels (rivers, lakes, groundwater), and other criteria to support the achievement of the specified environmental outcomes. ORC must also specify a timeframe for achieving the target attribute states. To achieve environmental outcomes, ORC is required to set limits on resource use, environmental flows and levels, and other criteria as required.

[28] These activities must all be completed before ORC notifies the draft pLWRP in June 2024, as they form part of that plan to be notified. Council has already made significant progress with this work, as shown in Attachment 1.

[29] ORC is also required to prepare Action Plans (as appropriate) and impose consent conditions on resource consents to implement the NPS-FM. Attributes requiring action plans are listed in Appendix 2B of the NPF-FM and include submerged plants, fish, macroinvertebrates, deposited fine sediment, dissolved oxygen, dissolved reactive phosphorous, ecosystem metabolism and *E. coli*.

[30] The NPS-FM states that Action Plans must be published as soon as practicable. The section 32 report that accompanies the pLWRP will address how much of the water quality improvement measures will be included in the pLWRP (e.g., through rules) and to what extent Action Plans will be relied upon for achieving the outcomes in the plan.

[31] The section 32 report will also need to demonstrate a clear pathway to roll-out Action Plans within the timeframes for achieving the environmental outcomes in the pLWRP and visions in the RPS, and a clear commitment from council to follow this pathway, which can be demonstrated through LTPs and other strategic partnerships.

[32] Action Plans may be prepared for whole FMUs, parts of FMUs, or multiple FMUs. An action plan may describe both regulatory measures (such as proposals to amend regional policy statements and plans, and actions taken under the Biosecurity Act 1993 or other legislation) and non-regulatory measures (such as work plans and partnership arrangements with tangata whenua and community groups).

[33] In addition, implementing the NOF requires ORC to establish methods for monitoring progress towards achieving target attribute states and environmental outcomes. If ORC detects that an FMU or part of an FMU is degraded or degrading, it must take action to halt or reverse the degradation (for example, changing a regional plan or preparing an action plan). Any action taken must be proportionate to the likelihood and magnitude of the deteriorating trend, the risk of adverse effects on the environment, and the risk of not achieving target attribute states.

[34] In short, implementing the NOF requires ORC to set target attribute states and environmental outcomes for the region's waterbodies, specify timeframes within which these will be achieved, make a plan for how these will be achieved, monitor progress, and take action when degradation is detected.

[35] The NOF follows a strategic planning framework. In the simplest terms, strategic planning involves identifying **goals** for the future, determining what the **existing situation** is, developing a **plan**, **implementing** the plan, **monitoring** progress, and **adapting** the plan as necessary to ensure that progress towards the goals is maintained.

[36] Through implementation of the NOF, ORC must identify environmental outcomes for the values of each FMU/rohe and target attribute states/flows/levels that will result in these outcomes (**goals**), determine baseline attribute states (**existing situation**), set limits on resource use that will achieve the targets attribute states and any nutrient outcomes needed (**plan**), develop action plans and impose consent conditions (**implementation**), establish methods for monitoring progress towards achieving target attribute states and environmental outcomes (**monitoring**), and take action if an FMU/rohe or part thereof is degraded or degrading (**adaptation**). This is summarised in the following diagram.

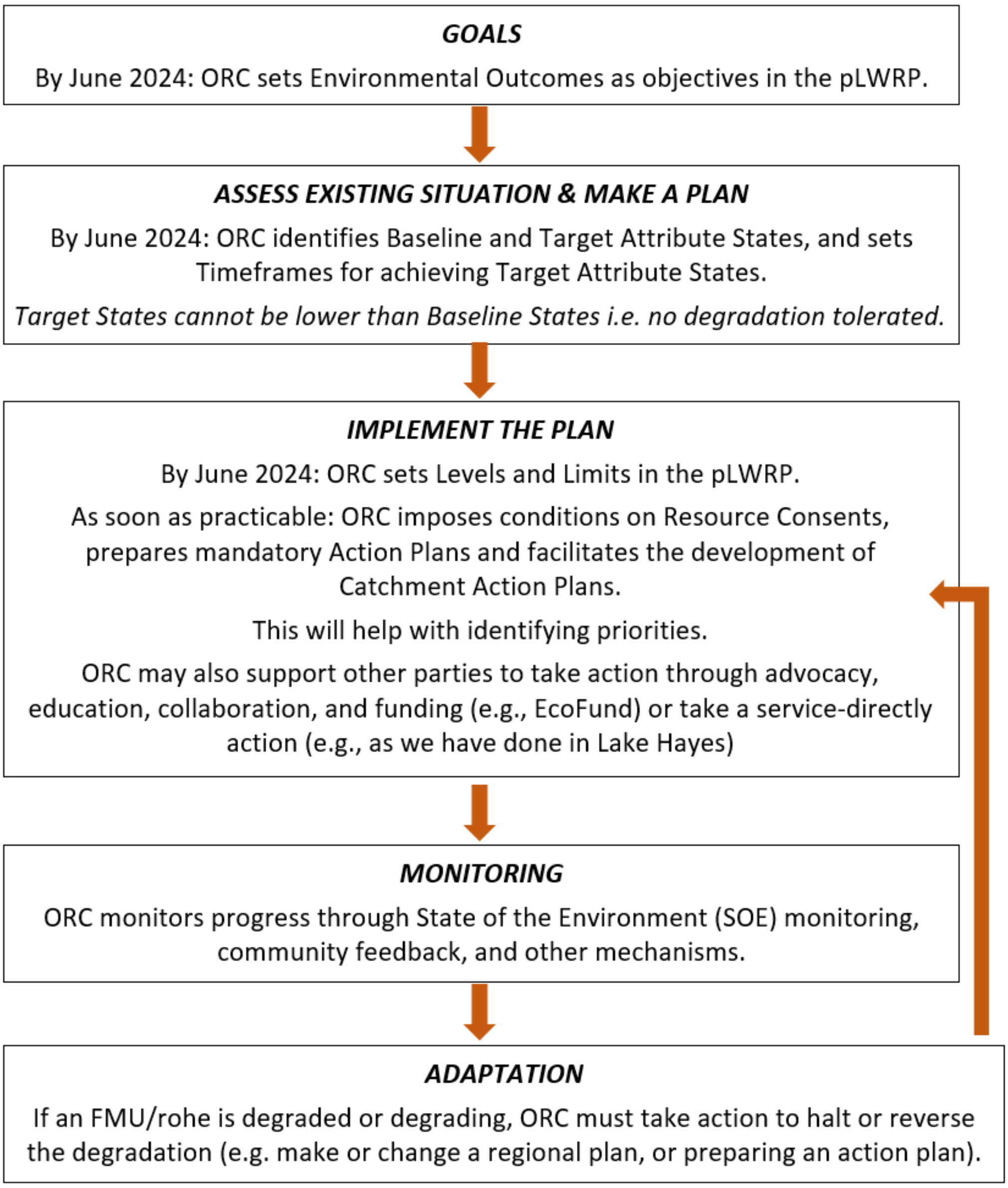

Figure 2: Outline of the key components of the NOF showing how it follows a strategic planning framework

[37] The timeframes within which target attribute states must be achieved will dictate where resources are directed, particularly where the difference between the baseline and the target attribute state is significant (noting that the target attribute state must be set no lower than the national bottom line). This may inform how actions are prioritised by ORC.

[38] Attachment 1 provides an overview of the work that has been undertaken to date through implementation of the NOF and shows that considerable progress has already been made. As noted above, most of this needs to be completed before the pLWRP is notified in June 2024.

[39] In summary, ORC is already in the process of rolling out the NOF (which follows a strategic planning framework) for each of the region's FMU/rohe. This will include development of FMU/rohe-level CAPs through the ICM programme.

Integrated Catchment Management and Catchment Action Plans

[40] As advised to the Strategy and Planning Committee on 1 December 2020, ORC has historically focussed on achieving integrated catchment management through the Regional Policy Statement and regional plans as part of its RMA functions. It has been less active in[3]:

- Undertaking / coordinating non-regulatory activities / programmes.
- Coordinating activities across functions in the same catchment.
- Facilitating and coordinating initiatives across agencies at a catchment scale.
- Providing a wholistic overview of catchments natural resources health, trends, and risks to enable informed engagement and integrated decision making.

[41] ICM is a practice and a process that addresses natural resource management from a catchment perspective. It uses the catchment as the appropriate organising unit and includes all of the catchment's people, plants, animals, soils, water and climate. ICM requires collaborative and collective planning and action by iwi and multiple stakeholders, including community, all levels of government, industry, and interest groups. ICM is underpinned by knowledge (including mātauraka māori) and science, bounded by policy and legislation and informed by iwi and community goals and priorities. Through collaborative planning and action with iwi and the community, an ICM approach can improve the way ORC achieves its statutory functions to protect ecosystems, freshwater bodies, biodiversity, coastal and soil values.

[42] Council has been supportive of an ICM approach since its first introduction in a Council workshop in October 2020. This support was formalised through the adoption of the Long-term Plan 2021-31 (LTP) in June 2021, which includes the performance measure: *Lead the development, implementation, and review of integrated catchment plans in collaboration with iwi and community*.

[43] The first Catchment Action Plan (CAP) being developed is for the Catlins FMU. This is a pilot from which the process and/or approach can be adapted as required for the next CAP. As part of this process, a working group has been established. Initial tasks of the working group include developing a community collaboration plan, a process for CAP development, a communications plan and beginning implementation of these.

[44] Once the working group is satisfied that sufficient groundwork is in place to initiate the development of the first CAP for the Catlins, collaboration with the wider Catlins community will begin in July.

[45] The Catlins CAP development process will be adaptive in response to lessons learned, and this will enable refinement of the process for the next CAP where appropriate. This process will ensure that ORC is ahead of the game in terms of developing the action plans required under the NPS-FM when target attribute states are notified in June 2024 for values associated with each FMU/rohe.

[3] Similar observations were also recorded in the Landpro report.

[46] The ICM Programme is not constrained or driven by statutory timeframes or policy planning directives. Council can, therefore, choose a timeframe for development and delivery that is acceptable to ORC, its iwi partners and the community.

[47] Whilst Action Plans are not required to be finalised before the pLWRP is notified, they must be published as soon as practicable and ORC has already made significant progress towards developing a pilot CAP and refining the process for CAP development in other FMUs/rohe.

Recommendations from the Landpro Report

[48] As noted above, Landpro was engaged to undertake Stage 1 of the Otago Lakes Strategic Plan scoping exercise. The subsequent report divides the region's lakes into five categories. Other than the deep water lakes (which are all in the Upper Lakes Rohe), these categories are not exclusive to any rohe, FMU or catchment.

[49] The 5-category approach developed by Landpro was useful for the purpose of the scoping study but there is no recommendation that lakes need to be managed according to category, and in fact the report notes that many lakes will require bespoke management.

[50] Preparing management plans for lakes on an FMU/rohe basis (with specific sub-catchment plans for certain lakes if required) would be more consistent with the approach required by the NPS-FM. This process is already underway, as explained above.

[51] In terms of long-term visions for lakes, the Landpro report explains that these are being determined for each FMU/rohe through the implementation of the NPS-FM. Regarding lake management plans, the Landpro report acknowledges that these will be addressed through implementation of the NOF and the development of CAPs, and recommends that some lakes will require specific management plans in addition to the CAP for the FMU/rohe. FMU/rohe-scale policies and CAPs (and sub-catchment management plans where applicable) as required by the NPS-FM will provide for freshwater management at a more localised scale than has been provided in the past.

[52] Regarding existing regulatory instruments, the Landpro report provides a brief overview but does not undertake a deep dive assessment into the how well these have been implemented or how effective they have/have not been. There are gaps in the current regulation and these should be addressed through the implementation of the NPS-FM.

[53] The Landpro report explains that the pLWRP and CAPs have the potential to provide components of a robust management framework for the region, but that lakes management in Otago requires overarching guidance and direction and the missing pieces of the current regime need to be addressed. The report provides 43 recommendations to achieve this.

[54] Landpro's proposed strategy for lakes management is to address these recommendations. A detailed analysis of the recommendations has been undertaken to determine which of these are/are not being addressed through existing work programmes. This analysis, which is an expansion of the table provided to Council on 7 December 2022, is provided as Attachment 2.

[55] Key observations about the recommendations are:

- Many of the recommendations reinforce matters that ORC is already addressing through the pLWRP and ICM programmes. Other recommendations have already been addressed/are being addressed through other work programmes.
- Many of the recommendations are general comments regarding procedural matters. Some of these (e.g. ensuring that participants in consultation processes feel heard) are not dissimilar to the 'Key Learnings' section of the recent Otago Catchment Stories Summary Report[4].
- Many of the recommendations are not exclusive to lakes, and would apply to all waterbodies.
- The Landpro report emphasises the need to ensure that the efforts of stakeholders are not duplicated and that resources are not spread too thinly given the pLWRP and ICM programmes already underway.

[56] Since the Landpro report was finalised in November 2022, significant progress has been made in the development of the pLWRP, implementation of the NOF via the pLWRP, and rolling out of the ICM programme (as detailed in Attachment 2). Once these programmes of work are completed (or furthered), the parallel workstreams should result in accelerated progress towards improved management of Otago's lakes (and other waterbodies). In that regard, most of Landpro's recommendations have already been addressed, are currently being addressed, or will be addressed in the near future.

[57] Several recommendations are not, however, being addressed through current work programmes and should be actioned sooner rather than later. These are listed below (in order of priority) and described in more detail in the following paragraphs:

1) Improve understanding of the three deep lakes (Landpro recommendations 1.9, 4.5, 4.9, 4.10, 4.13, 4.15);
2) Stocktake of agencies, groups and other stakeholders within each FMU (Landpro recommendations 1.2, 2.3, 2.4, 2.7, 3.3, 3.5, 3.6, 4.3);
3) Further consideration of aquatic pest management programmes (Landpro recommendations 1.8, 2.6, 4.14); and
4) Enhanced land use mapping as an extension of work already underway (Landpro recommendations 2.8, 4.2, 4.5, 4.15).

Action No. 1 - Improve understanding of the three deep lakes

[58] As described above, implementation of the NOF requires ORC to determine baseline attribute states and then prepare a plan of how to achieve target attribute states within a set time period. In order to do this there must be a good understanding of the waterbodies in question, both in terms of their current condition (and reasons for this conditions) and how they are likely to respond to management interventions.

[59] It is recognised that the three deep lakes are not well understood. For example, recent chlorophyl-a monitoring has shown a deteriorating trend in all three lakes, but the limited duration of the monitoring programme and the lack of understanding about these lakes mean that it is not possible to determine whether this trend will be continuous, what the cause of this trend is, or what management interventions would

[4] Landpro Limited, 2022, Otago Catchment Stories Summary Report

be effective if water quality is found to be degrading due to anthropogenic causes. It is reasonable, therefore, to assume that further research into the deep lakes may be necessary to inform the pLWRP and to provide more information on these lakes, and so actioning this now is recommended. The research must, however, be developed in conjunction with monitoring requirements of the NOF to avoid duplication and ensure that gaps are not missed.

[60] The Great Lakes Programme research proposal from Dr Schallenberg et al, which was developed in collaboration with ORC staff, aims to improve understanding of the functioning of the deep water lakes including threats and likely responses. It also aims to inform monitoring, management and policy development to minimise anthropogenic impacts, and develop much-needed innovative approaches such as using satellite imagery to detect changes over time, and more closely study the effects of climate change. It is recommended that this is recognised as a priority project and resources allocated accordingly.

[61] Another priority project to help improve understanding of the deep lakes is nutrient budget modelling. Determining what land use controls are required to achieve target attribute states will require nutrient budget modelling for the three deep lakes (and many other waterbodies). To date, there has not been adequate data to commence this project, however, the recent installation of buoys means that continuous monitoring, including testing of deep water conditions, is now possible. Phytoplankton has been monitored since 2017 and changes over time are now able to be detected. Monitoring at the point where rivers and streams (including some smaller streams) enter the lakes has also commenced for the first time. With a few more years of data from the buoys and other sites, ORC will be in a good position to commence nutrient budgeting of Lake Whakatipu and Lake Wānaka. It is recommended that resources are allocated accordingly to expedite this programme of work where possible.

Action No. 2 - Stocktake of agencies, groups and other stakeholders within each FMU

[62] It is clear from the consultation undertaken by Landpro that several parties do not have a thorough understanding of the roles and responsibilities for lakes management, and that this has possibly led to misunderstanding and frustration. Mapping roles and responsibilities for lakes management would, therefore, be a worthwhile exercise.

[63] So that this exercise also supports the ICM programmes, it could be expanded to include all groups and other stakeholders operating in the freshwater space within an FMU/rohe, not just those with a focus on lakes. Given that there are many groups operating in specific catchments only, then undertaking this mapping exercise on an FMU/rohe basis rather than a regional basis is more logical. This exercise could be informed in part by the recent “Otago Catchment Stories Summary Report”, 2023, by Landpro.

[64] This process should clearly identify where there are overlapping functions and interests. It will help with understanding who is doing what, where, and whether there are opportunities for efficiencies through improved collaboration. It will also help to identify areas where there is a lack of coverage.

[65] This exercise will help with understanding how everyone can give effect to the desired environmental outcomes for each FMU/rohe (and lakes within), not just ORC.

[66] Through the ICM programme, ORC is already undertaking a similar stocktake for the pilot CAP (Catlins). This stocktake/mapping exercise will need to be repeated for each FMU/rohe. With adequate resourcing this could be completed sooner than currently scheduled and would be useful in informing the ICM programme.

Action No. 3 – Further consideration of aquatic pest management programmes

[67] The aquatic pests managed under the Regional Pest Management Plan (RPMP) are hornwort (exclusion programme), Egeria (exclusion programme), spartina (progressive containment programme), and lagarosiphon (site led programme). According to the Otago Biosecurity Strategy, ORC is involved in national control programmes for didymo and lake snow. As noted in Attachment 2, ORC has recently taken the issue of lake snow to central government and all regional councils to generate support for solutions and is undertaking ongoing monitoring of, and research into, lake snow in Lakes Whakatipu-wai -Māori, Wānaka, Hāwea, Hayes and Dunstan. Also noted in Attachment 2, ORC has recently drafted a Lagarosiphon Monitoring Programme that has added a significant increase in the number of monitoring sites.

[68] It may be worth exploring ways to ensure that interested parties are better informed about which biosecurity programmes are underway and what progress that is being made towards stated outcomes/objectives. For example, ORC provides funding to LINZ to undertake control work in Lake Dunstan. ORC has also provided funding for work in the Kawarau River but this is not guaranteed to continue beyond this year. LINZ provide annual reporting on control work undertaken via public meetings. Information is typically disseminated using presentations, and is focussed on what has been achieved over the previous year. Providing this information in a form so that it is more readily shared with a wider audience (e.g in a written report), along with an assessment of trends over time, and an assessment of how well progress is being made towards achieving the RPMP's objectives, could be beneficial. This will require collaboration with the delivery partner of the programme, LINZ.

[69] If the RPMP or other objectives are being met, but the results are still unsatisfactory, then it may be worth revisiting the objectives to determine whether or not they are still appropriate. This would, however, need to carefully consider the reasons why the current management levels were adopted in the first place, and the feasibility and cost of achieving different outcomes. The RPMP is due for review in 2029 and so any review of the plan before then would be outside the planned review cycle.

Action No. 4 - Enhanced Land Use Mapping

[70] ORC has a collection of maps for each catchment showing changes in land use over time. These maps are, however, still quite coarse and don't show some of high risk land use changes e.g., change from grazing on pasture to winter grazing on fodder crop.

[71] Data from these maps was used during a recent pLWRP presentation to show changes in land use over time in the Upper Lakes Rohe. This showed that the percentage of grazed land has decreased and the percentage of conservation land has increased. This alone does not tell the full picture, however, as it may be for example that there is still the same number of stock units in the catchment but they are now grazed more intensively on a smaller area. Furthermore, natural events in these catchments such as large landslides in the upper Dart and Rees catchments can contribute more sediment to Lake Whakatipu than gradual changes in land ever will. Mapping changes in land use

is, therefore, just one way of predicting changes in water quality and must not be used in isolation of other monitoring methods.

[72] With the introduction of new land use controls and Farm Plans through the NPS-FM, NES-F and pLWRP, more information on land use will be gathered which will enable a greater level of resolution to be provided. This mapping exercise also needs to take into account that farming practices (e.g., the area in fodder crop) can change from year to year and so farm-scale resolution is required. Urban growth at least is more static once it is established, but is usually a very small percentage (<1%) of the catchment area.

[73] Enhanced land use monitoring in areas such as the Upper Lakes could be used as a way of predicting adverse effects on the deep lakes before they arise. Preventing degradation will be more cost effective and feasible than trying to remedy the harm once it has been done. This could be trialled in the Upper Lakes rohe, with the view of rolling it out in other FMUs/rohe if worthwhile. This would, however, require resourcing additional to that already in place, as refining and maintaining these maps would be an ongoing exercise.

Other Recommendations

[74] Other recommendations that warrant follow-up but which are not critical to lakes management include:

- Creation and maintenance of a database of engagement that has been undertaken by the various ORC departments and when, who was involved, what was asked, and why (following from Landpro recommendation 3.2). This could also record who attended and what the outcomes were, but wouldn't necessarily capture exactly what was said. Managing this database would require resourcing, but it could serve as a valuable tool to ensure that different departments are better coordinating their efforts, to ensure that participants can attend one session on one day for multiple purposes, and to help staff identify when communities might be suffering from consultation fatigue.
- Provide ORC policy staff with more opportunity to undertake field visits to see the implications of policy in real life (following from Landpro recommendation 3.8). There could benefit in some ORC staff shadowing staff from other departments which currently occurs on an adhoc basis. For example, Policy staff could shadow Environmental Monitoring staff and the Environmental Implementation team to better understand the technical implications of new policy and how this affects various operators in the region.

Conclusion

[75] When Landpro was engaged to undertake a scoping study in response to the suggestion of an Otago Lakes Strategic Plan, it was concluded that the upcoming pLWRP and CAPs have the potential to provide components of a robust management framework for the region, but that overarching guidance and direction was needed.

[76] ORC is already implementing the National Objectives Framework (under the National Policy Statement for Freshwater Management (NPS-FM)) for all of the region's waterbodies - including lakes. ORC is required to set desired environmental outcomes for each Freshwater Management Unit (FMU)/rohe, specify timeframes within which these will be achieved, make a plan for how these will be achieved, monitor progress,

and take action when degradation is detected. This includes creating CAPs for each FMU/rohe, and could include sub-catchment plans for specific lakes if required.

[77] In terms of overarching guidance and direction, the pRPS and pLWRP will introduce FMU/rohe-scale policies as well as region-wide policies. This will provide more specific regulatory control than has existed in the past.

[78] Depending on which desired environmental outcomes are set for each FMU/rohe, this will determine what actions are needed to move from baseline (current) states to target attribute (future) states. This will help to inform how actions are prioritised - including actions relating to lakes.

[79] Embarking on a separate programme of work to create a specific strategic plan for lakes could divert resources from progressing the pRPS, pLWRP, and CAPs, and may in fact result in duplication and inconsistency with these work programmes.

[80] Given that the NPS-FM has introduced a fundamental change in the way that freshwater is managed, and that ORC has a responsibility to ensure that the pRPS and pLWRP are delivered on time and to the required standard, then it would be in ORC's interest to ensure that resources are focussed on these existing commitments.

[81] Both Aukaha and Te Ao Marama have advised that their preference is to rely on existing methods for consultation through partnerships agreements, and see the development of the pLWRP and CAPs as the key mechanisms to provide a comprehensive framework for managing all lakes[5]. Furthermore, the Landpro report notes that stakeholders and communities are suffering from 'consultation fatigue'.

[82] Landpro identified missing pieces of the current regime that need to be addressed. This paper has closely examined Landpro's 43 recommendations and identified which of these have already been addressed or will soon be addressed through current work programmes. Where there are still gaps (e.g. in our understanding of the three deep lakes), then it is recommended that action is taken sooner rather than later.

[83] The overall recommendation of this paper is, therefore:

- that the National Objectives Framework (NOF) continues to be implemented for each Freshwater Management Unit (FMU)/rohe;
- that robust FMU/rohe-based objectives, policies, limits, rules and Catchment Action Plans (CAPs) continue to be developed and implemented through the Regional Policy Statement (pRPS), proposed Land and Water Regional Plan (pLWRP) and Integrated Catchment Management (ICM) work programmes; and
- that four additional actions are expedited as soon as possible.

[84] This should ensure that robust regional- and FMU/rohe-based objectives, policies, limits and rules and Catchment Action Plans are prepared and implemented so that environmental outcomes for lakes (and other water bodies) are maintained and/or improved.

OPTIONS

[85] The three options at this stage are:

[5] Section 5.3, Mandis, K, Muller, T, Perkins, C (2022) Otago Lakes Management Review, Landpro Ltd

1. Develop a separate strategic plan for lakes. This would divert focus away from the pRPS, pLWRP and ICM work programmes and would have a high chance of duplicating and/or being inconsistent with the outputs of the pLWRP and ICM work programmes. It would also require stakeholders and the community to engage in overlapping consultation processes.

2. Continue to implement the NOF for each FMU/rohe, plus continuing the pRPS, pLWRP and ICM work programmes to ensure that robust regional- and FMU/rohe-based objectives, policies, limits and rules and CAPs are prepared and implemented so that environmental outcomes for lakes (and other water bodies) are maintained and/or improved. This is the status quo.

3. Focus attention and resources on the pRPS, pLWRP and ICM work programmes (as described in 2) but also expedite the four additional actions described in this paper. This is the status quo, with additional targeted investment.

[86] Option 3 is the recommendation of this paper.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[87] This paper explains how the priority actions identified are in alignment with, and add value to, existing work programmes.

Financial Considerations

[88] The four priority actions will be reviewed, prioritised, and costed by the relevant Council departments as part of the 2024- 2034 Long-Term Plan process. Should funding be identified within the recently approved 23-24 budgets work to undertake these actions will be expedited.

Significance and Engagement Considerations

[89] The assessment described in this paper is consistent with ORC's Significance, Engagement and Māori Participation policy. Both Aukaha and Te Ao Mārama see the development of the pLWRP and CAPs as the key mechanisms to provide a comprehensive framework for managing all lakes, which is also the conclusion of the assessment described in this paper.

[90] Opportunities for improved engagement will be addressed via the forthcoming revised engagement framework and guidance tools and specific suggestions have been fed back to relevant departments.

Legislative and Risk Considerations

[91] Given that the NPS-FM has introduced a fundamental change in the way that freshwater is managed, and that ORC has a responsibility to ensure that the pRPS and pLWRP are delivered on time and to the required standard, then it would be in ORC's interest to ensure that all available resources are focussed on these existing commitments.

[92] Along with the four priority actions described in this paper, this should ensure that robust regional- and FMU/rohe-based objectives, policies, limits and rules and

Catchment Action Plans are prepared and implemented so that environmental outcomes for lakes (and other water bodies) are maintained and/or improved.

Climate Change Considerations

[93] The effects of climate change on quality and quality of water in lakes (and other waterbodies) will be a key consideration with setting desired environmental outcomes and making a plan of how to achieve these outcomes through the pLWRP. The effects of climate change on the three deep lakes is also a question to be answered if/when further research is undertaken as recommended by this above.

Communications Considerations

[94] This paper is public and will be available on ORC's website as per standard practice.

NEXT STEPS

[95] The four priority actions will be reviewed, prioritised, and costed by the relevant Council departments as part of the 2024-2034 Long-Term Plan process. If approved, staff will provide updates on progress towards completing the recommendations.

ATTACHMENTS

Attachment 1: Progress made by ORC under the NPS-FM National Objectives Framework

Attachment 2: Analysis of Recommendations from *Otago Lakes Management Review*, Landpro, 2022

1. Lakes Management Attachments [**7.6.1** - 28 pages]

Attachment 1: Progress made by ORC under the NPS-FM National Objectives Framework

Note: this must all be completed before the draft LRWP is notified in June 2024

Clause 3.7(2) of the NPS-FM	**Work underway / completed**
By way of summary, the NOF process requires regional councils to undertake the following steps: (a) identify FMUs in the region (clause 3.8)	Work on the identification of Freshwater Management Units for the Otago region commenced in January 2019. A preferred option for splitting the Otago region into FMUs and rohe (sub-FMUs) was presented to and adopted by Council during its meeting on 3 April 2019. The FMU framework that was developed by Council was subsequently included in the proposed Otago Regional Policy Statement that was notified on 26 June 2021.
(b) identify values for each FMU (clause 3.9)	The first round of FMU community consultation (“Stage 1”) for the LWRP was completed over the period November 2021 to April 2022 across all FMU and rohe. Stage 1 was aimed at confirming relevant values for each FMU and rohe and giving communities an opportunity to discuss the characteristics of these values.
(c) set environmental outcomes for each value and include them as objectives in regional plans (clause 3.9)	The second round of FMU community consultation (“Stage 2”) for the LWRP was completed over the period November 2022 to December 2022 across all FMU and rohe. Stage 2 was aimed at seeking feedback on: • draft environmental outcomes for each FMU and rohe; and • seeking feedback on a range of actions that will inform the development of regulatory (rules) and non-regulatory mechanisms to achieve these outcomes.
(d) identify attributes for each value and identify baseline states for those attributes (clause 3.10)	During Stage 2 of the LWRP we also shared the following information: • suggested attributes for a number of key values identified (provided to people at the meetings); and • State of the Environment information for key attributes (made available online).

(e) set target attribute states, environmental flows and levels, and other criteria to support the achievement of environmental outcomes (clauses 3.11, 3.13, 3.16)	During Stage 2 of the LWRP we also shared the following information: • draft target attributes states for a number of key values identified (provided to people at the meetings); • overall approach to setting environmental flows and take limits in catchments (not numbers, but where will we rely on defaults limits and where will we set bespoke limits). The timeframes for achieving the target attribute states will be based on the timeframes for achieving long-term freshwater visions in the proposed RPS.
(f) set limits as rules and prepare action plans (as appropriate) to achieve environmental outcomes (clauses 3.12, 3.15, 3.17)	During the third round of FMU community consultation ("Stage 3") - scheduled to take place in third quarter of 2023 - we will share: • minimum flows/take limits, target attribute states that we are intending to set in the proposed plan; and • objectives, policies and rules that we are intending to set in the proposed plan.

Attachment 2: Analysis of Recommendations from *Otago Lakes Management Review*, Landpro, 2022

Recommendation from the Landpro Report	Analysis
Recommendation 1.1 (within the next 12 months) Develop an Otago Lakes Strategy for lakes management in Otago, in partnership with key stakeholders and mana whenua, addressing: • Desired outcomes for lakes management in Otago • Guiding principles for how ORC will work in relation to lakes management • Roles and responsibilities for lakes management, including overlapping functions (see Recommendation 1.2) • Forums for collaboration between lake management agencies and other stakeholders (see Recommendation 1.3) • Criteria for identifying and reviewing vulnerable and degraded lakes (see Recommendation 1.4 and 1.5) • Criteria for prioritising projects in these catchments (see Recommendation 1.4 and 1.5) • Identification of lakes that require (sub catchment) specific management (see Recommendation 1.6) • Criteria for alignment of ORC funding (e.g. via the Long Term Plan or the Eco Fund) with management priorities (see Recommendation 1.7) • Prioritisation of monitoring and research efforts, potentially through the creation of a lakes assessment working group (see Recommendations 4.1 - 4.13) • Actions or efforts required urgently in relation to lakes management, monitoring and research ahead of the development of other tools such as the LWRP and CAPs.	Both Aukaha and Te Ao Marama were approached by Landpro and advised that the preference is to rely on existing methods for consultation through partnerships agreements, and see the development of the LWRP and CAPs as the key mechanisms to provide a comprehensive framework for managing all lakes. Based on this, it is unlikely that it would be possible to develop a separate lakes strategy in partnership with mana whenua in the next 12 months as recommended. RE the first bullet point, the NPS-FM requires ORC to identify environmental outcomes for the values of each FMU/rohe (including lakes contained within) and include these as objectives in the LWRP by June 2024. RE the second bullet point, experience to date gained through the ICM programme is that ORC's role in the development of CAPs is likely to vary between each FMU/rohe depending on which groups and other organisations are already active in the area and how those groups/organisations operate. RE the remaining bullet points, commentary is provided alongside the relevant recommendation below. RE the last bullet point, if action is taken (e.g., embarking on new research projects) in response to issues/opportunities in advance of strategic direction being provided by the LWRP, then could be considered somewhat reactive. In certain situations this may, however, be considered acceptable to ensure that issues/opportunities arising are not missed and to avoid delaying necessary action any longer.

Recommendation 1.2 (within the next 12 months) Clearly document roles and responsibilities for lakes management across the region, identifying where there are overlapping functions and interests, and open channels for communication and collaboration between agencies with roles in lakes management i.e. through a lake management group forum.	It is clear from the consultation undertaken by Landpro that several parties do not have a thorough understanding of the roles and responsibilities for lakes management, and that this has possibly led to misunderstanding and frustration. One example is that there is uncertainty regarding the responsibilities of ORC and LINZ when it comes to the lakes that are within LINZ's administration. Mapping roles and responsibilities for lakes management would, therefore, be a worthwhile exercise. This could be expanded to include all stakeholders operating in the freshwater space within an FMU/rohe, not just those with a focus lakes. Given that there are many groups operating in specific catchments only, then undertaking this mapping exercise on an FMU/rohe basis rather than a regional basis is more logical. This mapping exercise could be informed in part by the recent "Otago Catchment Stories Summary Report", 2023, by Landpro. Through the ICM programme, ORC is already undertaking a stocktake for the pilot CAP (Catlins) of environmental-based activities being undertaken by all organisations and groups. The focus is not currently on roles and responsibilities, but this could be included. This stocktake/mapping exercise will need to be repeated for each FMU/rohe. With adequate resourcing this could be completed sooner than currently scheduled and would be useful in informing the ICM programme. The focus for the ICM programme is developing CAPs. Looking for overlaps and opportunities for ORC to improving existing management is not necessarily a focus of this, although it may fall out from the CAP development work.

	Examples can be given where different agencies are already collaborating well in regards to lakes management. One such example is the collaboration between ORC and LINZ in the management of lagarosiphon under the Regional Pest Management Plan (RPMP). In addition to this, LINZ host annual stakeholder management meetings in May in Cromwell, Queenstown and Wānaka to discuss aquatic weeds. These meetings include attendees from LINZ, ORC's Biosecurity Team, ORC's Harbour Master, Contact Energy, Fish & Game, Councillors, local community boards, and local community groups.
Recommendation 1.3 (within 1 – 2 years) Take a leadership role in providing an avenue for coordination and collaboration between lakes management agencies. ORC is well placed to provide principal oversight to lakes management activities. A lake management group/forum could act as an information sharing opportunity between all parties, outline current and proposed research, identify areas requiring further research, discuss new initiatives, identify opportunities for future initiatives and generally improve coordination between agencies.	ORC and LINZ meet monthly, and meetings also occur with multiple parties, when required, on biosecurity and water quality matters as they relate to lakes (e.g., with respect to restoration efforts or biosecurity management). Creating a group/forum for all lakes in Otago would be problematic as many participants will have an interest in specific areas only, and this may detract their resources from participating in groups/forums at a more local level. Focussing on lakes only and not freshwater would also limit the purpose of the group and possibly duplicate and/or conflict with the efforts of the CAP development working groups. The need for forums for specific lakes is, therefore, best be determined through the CAP development process.
Recommendation 1.4 (within the next 12 months) Develop and implement criteria for the identification of degraded lakes and selection of priority projects for these waterbodies to align with overall catchment visions and aspirations.	This recommendation could apply to all of the region's waterbodies, not just lakes. Environmental outcomes for each FMU/rohe are currently being determined through implementation the NOF. When baseline attribute states are compared to the national bottom line and target attribute states, and timelines for improvement are set, it will be clearer which lakes are degraded/vulnerable and require attention as a priority. This will be clear by the time the LWRP is notified (i.e. by June 2024).
Recommendation 1.5 (within the next 12 months) Develop and implement criteria for the identification of vulnerable lakes and consider extending the current programme	

of priority projects for degraded water bodies to include at risk lakes that are not yet degraded. *Recommendation 1.6 (within the next 12 months)* Using the criteria developed above to identify vulnerable and degraded lakes, identify individual lakes or categories of lakes which require a tailored management approach (i.e. individual management plan within the Catchment Action Plan, or direction in the LWRP).	Identifying lakes (or other waterbodies) that require specific management is required as part of implementing the NPS-FM, which is underway. Note that the round 2 consultation for the LWRP has been addressing this issue explicitly, e.g. with respect to Lake Hayes.
Recommendation 1.7 (within the next 1 – 2 years) Align funding provided through the Long Term Plan, the EcoFund and other funding avenues to address priority areas of concern through set criteria. Use the document proposed in Recommendation 1 to prioritise key areas and assess applications in a consistent but targeted way.	This recommendation could apply to all of the region's waterbodies, not just lakes. As noted above, by June 2024 it will be clear for which waterbodies the baseline attribute states are a long way from the target attribute states and, therefore, where efforts must be focussed to make necessary improvements within the set timeframes. This will inform the LTP process. Embarking on new projects in the meantime may be more reactive in response to opportunities/issues arising, but this may be considered acceptable in certain situations to avoid delaying action any longer.
Recommendation 1.8 (within the next 2 – 5 years) Encourage integration between the current biosecurity programme and developing lakes management framework (i.e. Catchment Action Plans and Lakes management forum, if adopted).	It may be worth exploring ways to ensure that interested parties are better informed about which biosecurity programmes are underway and whether the stated outcomes/objectives are being achieved. This may include reviewing and reporting on the management approaches for aquatic pests as detailed in the RPMP and Biosecurity Strategy, *the Lindavia intermedia* (lake snow) lake monitoring programme, and any activities relating to didymo.

	It should be noted that a draft Lagarosiphon Management Programme has been developed by ORC's Biosecurity Team. This includes biannual undertaking compliance inspections at nine priority non-LINZ waterbodies, Blue Lake, and Pinders Pond. Staff will also be conducting additional inspections of waterbodies and major river systems to collect baseline data and confirm whether there has been any further spread of the species throughout the region. In total, an additional 94 sites have been identified and split into the following categories: (1) Pond Inspection Sites (Formal Compliance Inspections) – 25 sites (2) River Monitoring Sites (Non-Compliance) – 51 sites (3) Extended Surveillance Sites (Non-Compliance) – 18 sites
Recommendation 1.9 (within the next 12 months) Establish a working group of suitably qualified experts to identify research and monitoring needs and assist with prioritisation of these efforts, particularly in relation to the Deep Water Lakes (but with the possibility to extend this concept to other lake categories).	ORC's letter to the Parliamentary Commissioner for the Environment, dated 6 December 2022, stated: *The Upper Lakes are in good health when considered on a national scale (meeting the 'A' band set out in the NPSFM), but factors such as the recent chlorophyll-a trend support additional research and intervention being required.* *ORC also broadly supports the proposal to establish a multi-agency panel of experts to develop and oversee a study work programme over 5-6 years with a budget in the order of $15 million. Having the key players brought into that process early would set everyone up for success if we were to determine that an active management stage was required.* The Robertson report[1] also refers to a proposal from Dr Schallenberg et al (The Great Lakes Programme MBIE Endeavour Programme 2022). The aim of this programme

[1] Robertson, D., 2021. Understanding and protecting Otago's deep water lakes. A Jobs For Nature Strategy for WAI Wanaka

	would be to improve understanding of the functioning of the deep water lakes including threats and likely responses, and to inform monitoring, management and policy development to minimise anthropogenic impacts. Desired environmental outcomes for the deep water lakes and necessary actions to achieve target attribute states will be identified in the LWRP by June 2024. Prior to this being determined, committing resources to further research in response to the recent chlorophyll-a trend could be considered somewhat reactive. However, the NPS-FM requires that target attribute states must be no worse than the baseline, which means that degradation will not be tolerated. Identifying emerging issues now and preventing further degradation will be more feasible and cost effective rather than trying to remedy harm once it has been done. It is reasonable, therefore, to assume that further research is going to be required for the deep lakes and so acting now before the LWRP has been notified may be acceptable. The research must, however, be developed in conjunction with monitoring requirements of the NOF to avoid duplication and ensure that gaps not missed. See also Recommendations 2.1 (lake levels, load limits etc), 2.8 (land use planning controls), 4.2 (map of changes in catchments), 4.5 (improvements to monitoring), and 4.15 (nutrient budgeting).
Management	
Recommendation 2.1 (within the next 12 months) Address lake levels, water quality load limits, aquatic lake biodiversity and cumulative land use management for lake catchments in the Land and Water Regional Plan development.	This recommendation could apply to all of the region's waterbodies, not just lakes. This is underway through the implementation of the NOF, whereby limits must be set as rules in the LWRP and actions plans must be prepared (as appropriate) to ensure that target attribute states, flows and levels (and subsequent desired environmental outcomes) are achieved within specified time limits.

	See also Recommendations 1.9 (Deep Lakes working group), 2.8 (land use planning controls), 4.2 (map of changes in catchments), 4.5 (improvements to monitoring), and 4.15 (nutrient budgeting).
Recommendation 2.2 (within the next 12 months) Highlight vulnerable or degrading lakes (or lake categories) within the Catchment Action Plan process, to ensure that specific issues with these waterbodies is not lost through and FMU or Rohe scale action plan.	This is the same as Recommendation 1.6.
Recommendation 2.3 (within the next 12 months) Ensure that Catchment Action Plan development working groups include representatives or input from key lakes management stakeholders such as District Councils, LINZ or electricity generators.	The mapping exercise described above will help to inform the ICM programme and ensure that key stakeholders are not missed when CAP collaborative groups are formed. See also comments on Recommendation 1.2.
Recommendation 2.4 (within the next 1 – 2 years) Maintain a register of existing ORC and other agency-led or funded projects, and community-led projects related to catchment improvements, including EcoFund recipients at an FMU level. Ensure that these efforts are integrated into Catchment Action Plans where appropriate. Use this register to identify areas that are underrepresented in terms of improvement projects. Incorporated with the identification of vulnerable or degrading lakes, this information can be used to encourage initiatives in priority areas if shared publicly.	This recommendation could apply to all of the region's waterbodies, not just lakes. The mapping exercise described above will also be beneficial in terms of identifying who's doing what, where. This could be informed by the recent "Otago Catchment Stories Summary Report", 2013, by ORC and Landpro. See also comments on Recommendation 1.2. There may be areas that are under-represented in terms of projects for a number of reasons and identifying these could be used as part of prioritising projects, but prioritisation will also be driven through implementation of the NOF.

Recommendation 2.5 (within the next 1 – 2 years) Using the lake initiative register described above, identify projects (particularly Ecofund recipients) that require ongoing efforts to sustain the benefits realised. ORC can use this to encourage future Ecofund applicants to build on previous efforts and ensure that benefits are not lost over time.	This may lead to an expectation of ongoing support from ECO Fund, which is not feasible nor the intent of the fund.
Recommendation 2.6 (within the next 1 – 2 years) Engage with other lakes management agencies to identify key concerns and areas requiring additional focus as well as planned monitoring and restoration work in order to avoid redundancies and maximise efficiency. Work plans can be shared to coordinate activities between agencies. For example DOC are liaising with individual landowners in catchments containing endangered freshwater species. A collaborative approach between DOC and ORC could deliver more benefits.	Regular engagement is already occurring. This will be extended to focus on strategic priorities via implementation of the NOF. Again, this will be in the context of freshwater as a whole in each FMU/rohe. The need for forums for specific lakes could be determined through the CAP development process.
Recommendation 2.7 (within the next 1 – 2 years) Where there are areas with overlapping roles or functions from multiple agencies, proactively liaise with these groups to determine where there are efficiencies to be made or where ORC could assist with the other agency's function (or vice versa). Recognise that not all agencies have the ability to address all issues under their remit in a timely manner, find synergies where these agencies can work together to fill the gaps. The example of Tomahawk Lagoon is useful here, where DOC holds responsibility for management of the area in Wildlife Reserve, but this provides benefits (e.g. flood buffering) that are within ORC's remit, so	See comments on Recommendation 1.2.

working together will assist in achieving better outcomes for both parties.	
Recommendation 2.8 (within the next 2 - 5 years) Identify areas in lakes catchments (in collaboration with District Councils) that are more sensitive land use and development, and employ planning controls to minimise effects on the relevant lakes (See also Recommendation 4.15)	This is already underway, noting that regulatory controls in relation to land use are generally not exclusively for the benefit of water quality in lakes alone (i.e. they seek to protect all types of waterbody). Some of this is within ORC's functions under s30 RMA 1991, and will be addressed in the RPS and LWRP. Note that consenting requirements increased through Plan Change 7 and 8. Plan Change 8 in particular is acknowledged as a significant but interim step to improve the existing planning framework until the LWRP is finalised. ORC has also demonstrated local and national leadership in the introduction of intensive winter grazing rules and in implementing the NPSFM 2020 more generally. There are gaps in the current planning framework and implementing the NPS-FM will ensure those gaps are addressed. See also Recommendations 1.9 (Deep Lakes working group), 2.1 (lake levels, load limits etc), 4.2 (map of changes in catchments), 4.5 (improvements to monitoring), and 4.15 (nutrient budgeting).
Recommendation 2.9 (within the next 12 months) Recognise the constraints on Electricity Generators and Irrigators who provide an essential service to the region but have other obligations (i.e. dam safety and provision of electricity) and consider whether hydro and irrigation lakes require bespoke management in the Land and Water Regional Plan and Catchment Action Plans.	Note the imperative of te mana o te wai as set out in the NPS-FM. The LWRP and CAPs will need to be consistent with this hierarchy. The existing constraints for all catchments and stakeholders will be considered as a part of developing workable management approaches.
Collaboration, Coordination and Consultation	

Recommendation 3.1 (within the next 2 - 5 years) Expand public understanding on lakes and their management through the development and promotion of a public education programme about the state, monitoring and management of lakes (e.g. annual public information days to present SOE monitoring results, bringing in experts on key water quality or ecology topics, or introduce new initiatives such as the CAP programme). This could be extended to encompass all catchment issues. Currently, information available on lake water quality and ecology is technical in nature and generally found on the ORC website. This could help to promote the work ORC is undertaking and allow further opportunities for collaboration and information sharing between parties.	This recommendation could apply to all of the region's waterbodies, not just lakes. ORC staff have been working with Tūhura Otago Museum's science communication staff regarding how to make the next round of SOE reporting more accessible to a wider audience. This will likely include a summary SOE report in addition to the regular reporting. The recommendation for public information days for all catchment issues has merit, but these would need to be tailored for each FMU/rohe and would require several sessions at different locations within each FMU/rohe to ensure maximum coverage. Careful consideration would need to be given to who would likely attend given that many stakeholders will already be involved in CAP processes. This is something that could be considered if there is still a need following the extensive consultation and engagement that will be necessary as part of the CAP development process. Aspects of lake management education also occur through Council's annual 'Clean, Check, Dry' summer programme. See also comments on Recommendation 4.1 regarding the Aquarius Project.
Recommendation 3.2 (within the next 1 – 2 years) Create a repository for the outcomes and feedback from all ORC consultations, to avoid repeat and over consultation. While this cannot replace genuine and important engagement processes, it can be referred to for future developments to ensure the feedback obtained is not lost.	This recommendation could apply to all of ORC consultation processes, not just those relating to lakes. This is a good idea in principle, however, it will be difficult to aggregate issue-specific information and there is a need to recognise the representativeness (or lack thereof) of any particular input. The composition of different communities changes over time as people come and go. Consultation captures views at a point in time, but issues and views change over time.

	In recent times, when multiple engagement sessions have been occurring, ORC staff have been explaining the different between what was asked last time and what is being asked this time, and why, so that participants better understand why it isn't as repetitive as it might feel. What might be beneficial is a database of what engagement has undertaken by the various ORC departments and when, who was involved, what was asked, and why. This database could also record who attended and what the outcomes were, but wouldn't necessarily capture exactly what was said. Managing this database would require resourcing, but it could serve as a valuable tool to ensure that different departments are better coordinating their efforts. This may help to ensure that participants can attend one session on one day for multiple purposes, rather than having to take time out of their day on multiple occasions. It could also be used to guide staff when considering how and when to undertake consultation as they will have a better appreciation of when communities might be suffering from consultation fatigue.
Recommendation 3.3 (within the next 12 months) Tailor public consultation processes to the stakeholder groups identified through stakeholder mapping. Public meetings and online surveys are generally not the most appropriate way to obtain feedback from groups like DOC, Fish and Game, Electricity Generators etc.	The Local Government Act 1974 imposes significant obligations for public participation, openness and accountability in local authority decision-making. Local authorities are expected to include the community in the decision-making process and "consult" with the community on a broad front. Furthermore, case law (*Wellington International Airport Ltd v Air New Zealand*) describes the nature of the consultation obligation and provides the details of how consultation should be conducted. Multiple modes of engagement are required to obtain a broad range of input. This can be resource intensive (in terms of both budget and time), and processes are needed to ensure that no particular stakeholder has influence above that of iwi partners or the general public.

	In that regard, care must be taken to ensure that public consultation processes are not unduly tailored to any particular stakeholders.
Recommendation 3.4 (within the next 1 - 2 years) Collaborate with other New Zealand councils and overseas regulators with similar issues around lakes, to share learnings from their experiences that could be applicable in Otago, such as Waikato and Bay of Plenty Regional Councils.	Staff already participate in a range of regional and national level forums on matters of mutual interest, but none of these are exclusive to lakes. Once the region's priorities are established, collaboration can be focused on matters of priority e.g. ORC has taken the issue of lake snow to central government and all regional councils, and is generating support for solutions.
Recommendation 3.5 (within the next 1 - 2 years) Develop, encourage and support effective community groups, both urban and rural, focused on lakes or catchment issues. Leverage this resource and incentivise communities to work together around the management of lakes in the region. Recognise that community groups expend significant personal input and that leaving these groups to it if they are performing well is not the best way to realise the benefits provided by these groups.	These recommendations need not be exclusive to lakes as most of the region's catchment and community groups have interests that extend beyond lakes. ORC provides substantial funding to Otago Catchment Communities to support catchment groups. Catchment Advisors are also supporting all catchment groups. In regards to other community groups, the degree to which groups want or need support from ORC varies. Funding for community can be sought through the EcoFund, and free advice can be accessed via Catchment Advisors, Biosecurity Officers, Consents Officers and other ORC departments. These groups can also seek support from their district councils, DOC, other key stakeholder groups, and funding from various contestable funds available to non-profit organisations. Experience to date gained through the ICM programme is that ORC's role in the development of CAPs is likely to vary between each FMU/rohe depending on which groups and other organisations are already active in the area and how those groups/organisations operate.
Recommendation 3.6 (within the next 1 - 2 years)	

Enable ORC representatives to attend catchment group, community group and other forums relating to lake management on an ongoing basis. In particular, ORC attendance at the Guardians of Lake Wānaka forum is recommended.	ORC staff attend various forum and have membership on a number of groups, when invited and as resources allow. One example is the Lake Hawea stakeholder group meeting that includes representatives from various groups. If staff are invited to a meeting for a particular meeting then they will make an effort to attend, but staff don't have the time to attend every meeting of every group. When groups prefer managers to be in attendance, this may not always be possible given the number of meetings and groups across Otago. Representation is a regional opportunity, not confined to one particular group. The mapping exercise described alongside Recommendation 1.2 above will help with understanding who is doing what, where, and whether there are opportunities for efficiencies through improved collaboration. It will also help to identify areas where there is a lack of coverage. This will be further developed through the ICM programme as it is rolled out in each FMU/rohe.
Recommendation 3.7 (within the next 1 - 2 years) Recognise community group management plans and values assessments in ORC's management framework, particularly Catchment Action Plans. Where appropriate, these measures and information can be adopted into the ORC framework. Use the efforts of these groups as a resource.	The recommendation is not exclusive to lakes. This is already underway through the ICM programme and is a key part of CAP development. Where necessary activities to achieve environmental outcomes can be actioned via non-regulatory means then this will likely be encouraged and supported.
Recommendation 3.8 (within the next 12 months) Improve understanding by ORC Policy Makers of the constraints faced by Electricity Generators and Irrigators by undertaking field visits to these sites to better appreciate the processes at play. Expand knowledge in general through field visits by Policy	This occurs already across all departments (and is not exclusive to lakes), but continuous improvement and further engagement is always supported. This recommendation has merit and there could be a lot of benefit in some ORC staff shadowing staff from other departments. For example, Policy staff could shadow Environmental Monitoring staff and the Environmental Implementation team to

makers, potentially in collaboration with the Environmental Implementation and Compliance teams.	better understand the technical implications of new policy and how this affects various operators in the region.
Recommendation 3.9 (within the next 12 months) Engage with mana whenua through existing partnership channels to better understand iwi concerns, opportunities and aspirations in relation to lakes management in Otago and obtain input into the development of an Otago Lakes Strategy (as outlined in Recommendation 1.1).	Note that both Aukaha and Te Ao Marama were approached by Landpro and advised that the preference is to rely on existing methods for consultation through partnerships agreements, and see the development of the LWRP and CAPs as the key mechanisms to provide a comprehensive framework for managing all lakes. Based on this, it is unlikely that it would be possible to develop a strategy for lakes management in partnership with mana whenua in the next 12 months.
Information and Monitoring	
Recommendation 4.1 (within the next 12 months) Create and maintain a database of water quality information submitted with consent applications, compliance monitoring or in published articles, similar to the databases for water take records, potentially contaminated sites, or GIS bore locations. Information on drinking water taken from lakes and other surface water sources may also be available from Taumata Arowai and/or District Councils and would be relevant for any samples collected pre-treatment, or for variables such as heavy metals which would not be expected to change significantly during standard forms of treatment (chlorination/UV etc.)	This recommendation need not be exclusive to water quality information relating to lakes, and should include other waterbodies too (including aquifers). The transparency and availability of data held by ORC has been increased recently through the Aquarius Project. This saw the replacement of Hilltop, which was previously used to store data collected through SOE and consent monitoring. The final step of the Aquarius Project included launching the Environmental Data Portal in February 2023: **envdata.orc.govt.nz** The Environmental Data Portal is: "*a significant change in the way the ORC and our partners share water information. Now you can access the most up-to-date information and download all quality approved data available for a site, which in some cases goes back more than 80 years.*" Consideration is being given to whether more narrative is provided on the portal to accompany the data, similar to what Bay of Plenty Regional Council has provided on their portal (envdata.boprc.govt.nz)

	ORC also already maintains a database of data submitted for consent compliance monitoring purposes. This has not been provided on a web platform due to the wide range of data submitted, the different ways in which compliance is determined (e.g. absolute limits versus 90the %ile rolling averages etc), multiple consents being monitored at the same point (e.g., multiple water permits being recorded by one meter) and the need to consider this data in the context of the wording of the consent condition. All of this information is publicly available upon request though. See also comments on Recommendation 3.1.
Recommendation 4.2 (within the next 12 months) Generate a map of lake catchments (potentially adapted from existing Ministry for the Environment river/stream catchment GIS layers) and overlay this with Land Cover Data Base layers to identify land use at catchment scale, including changes over time. Catchments with a high or increasing proportion of urban or intensive agricultural land uses should be prioritised for input modelling, monitoring and management.	This recommendation relates to catchments and not just lakes and is, therefore, better aligned with the direction provided by the NPS-FM. ORC already has a collection of maps for each catchment showing changes in land use over time. These were created using data from AsureQuality's Agribase database, ORC's rating database, and Landcare Research's Land Cover Database. These maps are, however, still quite coarse and don't show some of high risk land use changes e.g. change from grazing on pasture to winter grazing on fodder crop. Data from these maps was used during a recent LWRP presentation to show changes in land use over time in the Upper Lakes Rohe. This showed that the percentage of grazed land has decreased and the percentage of conservation land has increased. This alone does not tell the full picture, however, as it may be that there is still the same number of stock units in the catchment but they are now grazed more intensively on a smaller area. Furthermore, natural events in these catchments such as large landslides in the upper Dart and Rees catchments can contribute more sediment to Lake Whakatipu than gradual changes in land ever will. Mapping changes in land use is, therefore, just one way of predicting changes in water quality and must not be used in isolation of other monitoring methods.

	With the introduction of new land use controls and Farm Plans through the NPS-FM, NES-F and LWRP, it may be possible to gather more information so that a greater level of resolution can be provided. These maps need to be accurate so as not to raise false alarms or create a false sense of security either. This mapping exercise also needs to take into account that farming practices (e.g. the area in fodder crop) can change from year to year and so farm-scale resolution is required. Urban growth at least is more static once it is established, but is usually a very small percentage (<1%) of the catchment area. Enhanced land use monitoring in areas such as the Upper Lakes could be used as a way of predicting adverse effects on the deep lakes before they arise. As noted above, preventing degradation will be more cost effective and feasible than trying to remedy the harm once it has been done. This could be trialled in the Upper Lakes rohe, with the view of rolling it out in other FMUs/rohe if worthwhile. This would, however, require resourcing as refining and maintaining these maps would be an ongoing exercise. Regarding prioritisation, see also comments on Recommendations 1.4, 1.5 and 1.6. See also Recommendations 1.9 (Deep Lakes working group), 2.1 (lake levels, load limits etc), 2.8 (land use planning controls), 4.5 (improvements to monitoring), and 4.15 (nutrient budgeting).
Recommendation 4.3 (within the next 2 – 5 years) Undertake a stakeholder mapping exercise for each FMU or Rohe, and where appropriate, lake catchment, to ensure that all stakeholders who are involved in lakes management are identified and documented.	A stocktake for each FMU will be undertaken through the ICM programme. This is already underway for the pilot CAP in the Catlins. The stocktake looks at environmental based activities being undertaken by all organisations and groups, and will ensure that all stakeholders who are involved in lakes management (and other areas of environmental management) are identified and documented.

	See also comments on Recommendation 1.2.
Recommendation 4.4 (within the next 12 months) Recognise and document local knowledge about lakes (and other waterbodies) in the region. This information is currently collected on an ad-hoc basis and generally not documented. Many landholders, such as farmers, have a deep connection to the land they work on, and in many cases have been there for generations. This depth of understanding could be used as a resource for ORC in their decision making around lakes management.	This recommendation is not exclusive to lakes. This is a good idea in principle, but the collection would be resource intensive and would need a robust approach to e.g. protect privacy and resolve conflicting knowledge. This would need to apply to all landowners, urban and rural. Consultation plays this role at present.
Recommendation 4.5 (within the next 1 – 2 years) Overall, in our opinion there is a need to increase the scope of monitoring. In particular, a number of lakes have specific issues (e.g. urban stormwater discharges to Wānaka and Whakatipu and sedimentation in Lake Dunstan) that are not addressed by the current state of the environment monitoring, which is primarily focussed on nutrient concentrations and related variables. Additionally, the geographical scope should be expanded where possible – Lake Roxburgh is a notable omission from the current list of monitored sites. Additional monitoring sites within the larger lakes should also be considered. We recommend that ORC review the scope of its state of the environment monitoring programme in light of these limitations, as well as the information elsewhere in this report (particularly Table 14).	In 2017, NIWA reviewed ORC's state of the environment (SOE) network. A significant change is that monitoring of lakes has been changed from outlet/shore sampling to mid-lake sampling. A timeline of other recent lake SOE monitoring improvements follows: **2016** • Lake Wanaka - increased to 4 sites, 3 sites of them monitored monthly and 1 quarterly at various depths. • Lake Whakatipu - increased to 4 sites, 3 sites of them monitored monthly and 1 quarterly at various depths. • Lake Hawea - increased to 2 sites, 1 monitored monthly and 1 quarterly at various depths. • Lake Hayes - 1 site monitored monthly at various depths. • Lake snow tows/monitoring for all the above lakes. **2017** Lakes Whakatipu, Wanaka, Hawea, Hayes, Onslow - phytoplankton identification and cell counts.

	2018 A new profiler sonde was acquired and all the mentioned lakes above are profiled monthly for Temp, Dissolved oxygen, Chl-a, Phycocyanin, Conductivity, and Turbidity. **2019** • Lake Dunstan - 3 sites monitored monthly (2 of them are new which are monitored at various depth) + lake snow monitoring. • Lake Hayes - a multiprofiler lake buoy was installed. **2020/2021** Start of the Lake Submerged Plant Indicators (LakeSPI) monitoring on Otago SOE lakes **2022** • Inclusion of Tomahawk Lagoon (upper lagoon to the SOE network) • Addition of SOE mid-lake sites to Lakes Tuakitoto and Waihola • Inclusion of Lakes Waihola, Tuakitoto and Tomahawk lagoon on the phytoplankton monitoring **2023** • Lakes Wanaka and Wakatipu – installation of 2 lake buoys, one in each lake. • New techniques such as Lake SPI (Lake Submerged Plant Indicators) on Lakes Waihola, Tuakitoto, and Tomahawk lagoon to assess and report on ecological condition. ORC has already started monitoring all of the attributes required in the NOF table as part of the SOE monitoring programme. Some of these data sets are relatively new and so haven't been reported on yet. An updated SOE report (both current state and trends) will be reported to Council on 29 June 2023. This will provide more detail, including a map of all the SOE sites.

	Existing SOE sties can also be viewed on the Environmental Data Portal (envdata.orc.govt.nz), although some new sites and parameters haven't been loaded on the portal yet (e.g. chlorophyll-a and cyanobacteria). The SOE programme will be reviewed once the LWRP is notified to ensure that it is In alignment with the new framework and still fit for purpose to deliver all of the monitoring required for the implementation of the NOF. This review will inform any additional monitoring or sites that need to be established, and identify whether any existing sites are adding little value (although long-term monitoring sites will not be discontinued without careful consideration). Implementation will require additional FTE and CAPEX to support/install and maintain new sites. For the three big lakes, it's unlikely that any additional monitoring points will be required through the implementation of the NOF. It is possible, however, that more lakes will be added to the SOE monitoring programme. There is likely to be a need to look beyond what it required as a minimum by the NPS-FM e.g., there may be a drive to monitor heavy metals in urban settings, and/or undertake specific research projects to predict deterioration before it occurs (e.g., The Great Lakes Programme research project referred to in the comments on Recommendation 1.9). Note that many of the urban discharges of concern relate to stormwater discharges. These are typically under by TLAs as a permitted activity, and ORC's Compliance Team typically don't monitor permitted activity discharges. A bespoke approach will be required in many areas given the diversity of the region. The number of SOE monitoring sites needs to be adequate to capture the various

	characteristics of the waterbody i.e. more homogenous waterbodies might require fewer monitoring sites. If the ORC Science Team were larger then this might enable staff members to be delegated to individual FMUs/rohe where they could focus their efforts and spend more time really figuring out what was going on and how environmental conditions were responding to anthropogenic and climatic influences. Regarding Lake Roxburgh, the SOE monitoring undertaken at Clyde has been used as a proxy on the basis that if an issue is identified at Clyde then this indicates that there may also end up being an issue at Roxburgh. Note again that this may change because the SOE programme will be reviewed after notification of the new LWRP. The grading applied to lakes also needs to be considered in context when setting expectations. Coastal swamps and lagoons will never be in the same water quality bands as headwater lakes purely by virtue of the type of lake that they. Many of these coastal 'lakes' are actually designed to act more like wetlands, filtering nutrients in the water like a sponge. It is not appropriate, therefore, to assume that the definition of 'success' for every lake will be achieving an A-grade rating. It should also be noted that monitoring is only one part of the solution, and when deterioration is detected then it is the resulting action that will determine the environmental outcomes. Other recent specific investments in lakes include: • Partnering with MfE and community groups such as Wai Wanaka to enable additional water testing through combined funding with Jobs for Nature funding; • Undertaking ongoing investigation and research into lake snow in Lake Wanaka; • Mitigation project in Lake Hayes at an initial cost of $3.5M over 10 Years;

	See also Recommendations 1.9 (Deep Lakes working group), 2.1 (lake levels, load limits etc), 2.8 (land use planning controls), 4.2 (map of changes in catchments), and 4.15 (nutrient budgeting).
Recommendation 4.6 (within the next 12 months) As well as potential additions to the state of the environment monitoring programme, it is noteworthy that elevated and likely increasing heavy metal concentrations were identified in Blue Lake approximately 20 years ago (see Section 3.5.3), and no follow up monitoring appears to have been conducted. Additional monitoring of this lake should be prioritised, including confirming the original findings, testing for additional heavy metals that may also be present, assessing whether concentrations are indeed increasing, and carrying out a risk assessment to identify whether any meaningful threats to lake ecosystems and/or human health exist.	Note comments on monitoring above. No specific monitoring is planned for Blue Lake at this point and the NPS-FM doesn't require monitoring of heavy metals. This will be considered further through LWRP/NOF/CAP processes for the Manuherekia Rohe that are currently planned or underway.
Recommendation 4.7 (within the next 1 – 2 years) In considering any increases in the scope of monitoring ORC may make in response to Recommendation 4.2, in our opinion ORC should not 'let perfect be the enemy of good', so to speak. While it is important to maintain the 'gold standard' of high-quality, frequent monitoring for existing monitoring sites, for sites that are not currently being actively monitored, any information is better than no information (provided that the data quality is fit for purpose, of course). Where budget or other constraints limit ORC's ability to test additional sites, or test for additional	This recommendation is not exclusive to lakes and could apply to any waterbodies. This recommendation is not endorsed. Less frequent monitoring of new sites/parameters will lead to resources being spread so thin that no meaningful data is collected at any of the new sites. Patchy data sets can also create a false picture, which can result in false alarms or a false sense of security. The more consistent, frequent, and long-term the monitoring period, the better. Whilst monitoring programmes might not always be optimal, monitoring still needs to be carefully considered and stored and collected in a way that it can be useful for management purposes and reliable enough to inform decision making.

relevant variables, consideration should be given to less frequent monitoring of new sites/parameters.	
Recommendation 4.8 (within the next 1 – 2 years) Additionally, ORC should investigate the use of citizen science in collaboration with community groups (e.g. iwi, Enviroschools, Otago University Tramping Club, local helicopter operators) to facilitate sampling and monitoring of lake water quality, biodiversity or pest species where funding is not available for this to be done in the traditional manner by ORC staff, particularly for the remote high alpine lakes.	This recommendation is not exclusive to lakes. The Science/EM/EI teams are considering how to best support ongoing monitoring, including citizen science and better industry/community group collaboration.
Recommendation 4.9 (within the next 1 – 2 years) Continue to investigate and (where appropriate) implement innovative new lake water monitoring techniques including buoys, deepwater sampling, 'drifter' studies and remote sensing of surface water.	See comments on Recommendation 4.5.
Recommendation 4.10 (within the next 1 – 2 years) Develop and publish a list of priority lake water quality research projects that ORC does not currently have funding for. This would be useful for researchers looking for projects, and it may assist them in finding funding from other sources if ORC has publicly stated that the research would be beneficial.	The Great Lakes Programme research project referred to in the comments on Recommendation 1.9 has been identified as a priority project. In addition to better understanding how Lakes Whakatipu, Wānaka and Hawea function, this project aims to develop much-needed innovative approaches such as using satellite imagery to detect changes over time, and more closely studying the effects of climate change. Nutrient budgeting for Lake Whakatipu and Lake Wānaka is another priority project (see comments on Recommendation 4.15). Other projects can be developed with working groups of freshwater scientists but these needs to be strategically aligned with the LWRP.

Recommendation 4.11 (within the next 2 - 5 years) [Landpro's] literature search uncovered a large body of literature, not all could be reviewed within this project (noting that the literature review was a relatively small component of the scope). Additionally, the Lakes 380 project will provide considerable additional relevant data in the near future. It is important that lake management is informed by the latest and best information, and we recommend that a further, comprehensive literature review be carried out. In our opinion, it would be most efficient to do this on a catchment by catchment/lake by lake scale, either as part of or in advance of the Catchment Action Plan process. Such literature reviews can use the attached list of documents identified as relevant but not yet reviewed as a starting point, and should be in accordance with the Collaboration for Environmental Evidence's guidance on systematic reviews, as far as is practicable.	Literature reviews will be part of the CAP process, but time and resources will dictate how comprehensive this will be and at what scale.
Recommendation 4.12 (within the next 1 - 2 years) Undertake an economic evaluation of the value of Otago's lakes, in collaboration with economic development managers at District Council, to quantify the benefits these lakes bring to the region and further validate their protection. The ecosystem services framework could be used to assist this evaluation.	The Economic Work Programme for Otago comprises four workstreams: 1) Farmers and Growers – working with MPI and industry groups to develop robust information for the region and then testing the impacts of actions on different types of rural businesses. 2) Catchment Stories – showing what local communities are already doing to manage land and water and their specific issues and challenges. 3) Te Ōhanga ki Kāi Tahu – considering the Ōhanga of mana whenua. 4) Regional Economic Profile for Freshwater - exploring the economy's use of water as inputs and outputs, the value of that use (as income and employment), and connections between industries. This knowledge will point

	towards the broader flow-on impacts of the new Land and Water Regional Plan. Whilst the emphasis of the fourth workstream is not on lakes specifically, it is intended to tell a story of the relationship between Otago's natural resource in general and the economy. The report is due out by July. Whilst this might not be exactly what Recommendation 4.12 calls for, lakes will inevitably be a significant component of what is considered. In terms of validating further protection for lakes, the NPS-FM requires ORC to set target attribute states that are no worse than the baseline state, i.e. no further deterioration will be tolerated.
Recommendation 4.13 (within the next 2 - 5 years) Enhance preparedness for modelling and managing effects of climate change on lakes' hydrodynamics and ecosystem health, including by identifying species and ecosystems (particularly in the remote high alpine lakes and coastal and lowland lakes) which are vulnerable to direct and indirect effects of climate change and prioritising these for management.	ORC's climate change work programme is progressing, but there is not a specific lakes focus. The Great Lakes Programme research project referred to in the comments on Recommendation 1.9 project aims (amongst other things) to study more closely the impacts of climate change on Lakes Whakatipu, Wānaka and Hawea. There has also been a greater focus in recent years on reviewing data through a climate lens to see if trends are linked to climatic conditions, particularly increasing temperatures. Data from cyanobacteria and D.O. monitoring in particular (which are monitored as requirement under NPS-FM), needs to be analysed to determine whether any changes over time are linked to climatic changes or more direct anthropogenic causes. Whilst TN and TP levels are not necessarily increasing in Lakes Whakatipu, Wānaka and Hawea this does not mean that the recent upward trend in chlorophyll-a is not associated with an increase in nutrient levels. This is because point-source nutrients flowing into lakes of that size can be quickly taken up by aquatic plants before being

	detected, and so it is only the residual nutrients remaining in the water column. A specific research project looking at this relationship might seek to undertake more frequent sampling over a year and then use this data to develop models. In terms of prioritisation, see comments on Recommendations 1.4, 1.5 and 1.6.
Recommendation 4.14 (within the next 2 - 5 years) Information is available on pest species present in Otago from ORC's Pest Hub web page and a variety of other sources. However, there may be a benefit to providing this information in a more co-ordinated way, such as by producing a regular pest management report similar to the state of the environment reports produced on water quality and other issues.	This recommendation is not exclusive to lakes. A system for "SOE reporting" of the region's pests is already under development and will hopefully be released later in 2023.
Recommendation 4.15 (within the next 2 - 5 years) There would be a benefit to nutrient budgeting and modelling of contaminant sources and hydrological loads to lakes, particularly Deep Water Lakes and Accessible High-altitude Lakes to identify whether current and reasonably foreseeable future land use patterns in the catchments are compatible with the ongoing health of the lake ecosystems, and if not, put preventative management measures in place (See Recommendation 2.8). This recommendation is applicable for most other lake categories too, though perhaps to a lesser extent.	Through the development of the LWRP and NOF processes, limits must be set as rules and actions plans must be prepared (as appropriate) to ensure that target attribute states, flows and levels (and subsequent desired environmental outcomes) for each FMU/rohe (and the lakes within) are achieved within specified time limits. This may or may not require nutrient budgeting to determine what land use controls are required to achieve target attribute states. Nutrient budgeting for Lakes Whakatipu and Lake Wānaka is, however, a priority project for ORC. This has been identified as a need for some time but there has not been adequate data to commence this project. The SOE monitoring programme was designed to be in alignment with the NPS-FM, but wasn't designed to collect the sort of data required for lakes nutrient budgeting. However, the recent installation of buoys means that continuous monitoring, including testing of deep water conditions, is now possible. Phytoplankton has been monitored since 2017 and changes over time are now able to be detected. Monitoring at the point where rivers and streams

	(including some smaller streams) enter the lakes has also commenced for the first time. With a few more years of data from the buoys and other sites, ORC will be in a good position to commence nutrient budgeting of Lake Whakatipu and Lake Wānaka. See also Recommendations 1.9 (Deep Lakes working group), 2.1 (lake levels, load limits etc), 2.8 (land use planning controls), 4.2 (map of changes in catchments), and 4.5 (improvements to monitoring).
Recommendation 4.16 (within the next 2 - 5 years) Make monitoring data more accessible to other organisations and the general public. The information gained via the actions in recommendations 4.1, 4.2, 4.14, 4.15 or other initiatives could be presented using GIS and other tools to create an information portal for lakes in the Otago Region.	This is similar to Recommendation 4.1. See comments on Recommendations 3.1 and 4.1.

7.2. Water Quality State and Trends - Lakes, Rivers, and Groundwater

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2252
Activity:	Environmental - Regional Plan: Water Quality
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Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	29 June 2023

PURPOSE

[1] This paper reports on the state (2017-2022) and trends (2002-2022) of lake, river, and ground water quality in the Otago Region. The full technical report is attached as Appendix 1.

[2] This report was prepared to inform the proposed Land and Water Regional Plan (pLWRP) and is an update to the report 'Water Quality SOE – Rivers and Lakes' presented to DAIC in April 2021.

[3] A technical report summary is presented separately as a report card and a graphical summary (Report No2316).

EXECUTIVE SUMMARY

[4] This paper reports on the state and trend analysis of water quality data in the Otago Region. The data was collected from 107 river sites, eight lakes (27 sites/depths) and 55 groundwater bores - State of Environment (SoE) monitoring sites that are situated across Otago's five Freshwater Management Units (FMU).

[5] River, lake, and groundwater state was based on water quality samples collected over five years from 1 July 2017 to 30 June 2022.

[6] River and lake water quality was compared to attribute bands designated in Appendix 2A and 2B of the National Policy Statement – Freshwater Management (NPS-FM) (MfE, 2020). The attributes included in the analysis were chlorophyll-a, total nitrogen, total phosphorus, ammoniacal nitrogen, nitrate, suspended fine sediment, dissolved reactive phosphorus and *E. coli*. Each attribute was graded as a National Objective Framework (NOF) band (A, B, C, D, and band E for *E. coli*) for each variable based on comparing the assessed state with the relevant criteria.

[7] Groundwater quality was compared to the Drinking Water Standards for New Zealand (DWSNZ, 2022) Maximum Acceptable Values (MAV). The attributes included in the analysis were arsenic, nitrate, and *E. coli*.

[8] This report also analyses water quality trends for each site (when sufficient data was available) across Otago over 5, 10 and 20 years, ending on 30 June 2022.

[9] ORC engaged Land Water People (LWP) to evaluate the water quality state (Fraser, 2022a) and water quality trends (Fraser, 2022b).

[10] The State of the Environment state and trend reporting is generally undertaken once every five years. This report is an out of cycle report to inform the proposed Land Water Regional Plan.

RECOMMENDATION

That the Committee*:*

1) ***Notes*** *this report.*

DISCUSSION

[11] ORC monitors 107 river sites and eight lakes across the Otago region as part of its long-term SoE monitoring programme for surface water quality.

[12] Clear spatial patterns in water quality, based on the NPS-FM attribute bands were observed across Otago. For rivers, good water quality across all attributes is associated with the Upper Lakes Rohe, and to some extent, the Dunstan Rohe (i.e., river and stream reaches located at high or mountainous elevations under predominantly native cover). Conversely, water quality is generally poorer at sites located on smaller, low-elevation streams that drain agricultural or urban catchments, including the Lower Clutha Rohe, Dunedin and Coast FMU and North Otago FMU. Almost all river and lake sites achieved a state attribute band 'A' for ammoniacal-N and nitrate toxicity. For lakes, all lakes in the Upper Lakes Rohe returned an 'A' band for all attribute states. The smaller lakes across Otago (Lake Hayes, Lake Tuakitoto, Lake Onslow, and Lake Waihola) had varying states of compliance across the attributes.

[13] Like surface water, the current groundwater quality state also varied across Otago. Elevated *E. coli* and nitrate concentrations were generally observed in areas with intensive land use, septic tanks, and insecure bores. Arsenic in groundwater is found in many regions of Otago and is generally of geological origin, i.e. is naturally occurring.

[14] Trend analysis in rivers returned a mix of results. The 10-year trend analysis showed fewer degrading trends than the 20-year trend analysis. In particular, there was an overall improvement in the number of degrading trends for *E. coli*, TN, NNN and turbidity. The 5-year trend analysis for lakes showed many degrading trends. However, these results must be treated cautiously as trends for shorter timescales are strongly influenced by interannual climate variability. The trend for groundwater over 10 years shows North Otago and Taieri FMUs having mainly improving groundwater quality.

[15] In July 2018, the river and lake monitoring SoE programme was expanded to statistically represent the environmental classes for rivers in Otago, based mainly on the River Environment Classification (REC) (MfE, 2004). The pLWRP will require the SoE network to be reviewed to ensure it meets the requirements of the NPS-FM in terms of ensuring representative monitoring sites at an FMU level across Otago.

[16] Some NPS-FM (2020) Appendix 2A attributes are not yet monitored (i.e., dissolved oxygen below point-source). There are additional attributes in Appendix 2B of the NPS-FM that have limited datasets as monitoring programmes have only been established recently (i.e., submerged plants, ecosystem metabolism).

[17] In nearly all cases, monitoring sites identified as degraded in previous reports (ORC, 2012; 2017) or from targeted catchment studies, remain degraded.

[18] There has previously been a lack of detailed information held by ORC on land use changes or changes to management practices. This lack of data significantly restricts any analysis for investigating the effect of land use activity on water quality.

[19] Science's Land Team are building knowledge and information on land type, management, and use. This information will help understanding any improvement or degradation in water quality. This work, combined with the improved provisions in Plan Change 8 and the pLWRP, will enable evidence-based commentary on drivers and direction of water quality trends, now and into the future.

OPTIONS

[20] Undertaking SoE reporting is a requirement for regional councils and contributes toward improved understanding of water quality across Otago.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[21] This programme supports the healthy water strategic priority through monitoring and publishing of information to support public decision making around how the interact with water at popular sites in Otago.

Financial Considerations

[22] This work is both planned and budgeted within existing work programmes.

Significance and Engagement Considerations

[23] Not applicable

Legislative and Risk Considerations

[24] Monitoring networks must comply with national legislation and effectively evaluate objectives in regional plans.

[25] The NPS-FM (2020) requires freshwater to be managed in an integrated way, considering the effects of the use and development of land on a whole-of-catchment basis, including effects on receiving environments. The pLWRP and action plans are intended to assist with mitigating the risk of continued degradation. However, there is likely to be a lag between mitigation and water quality improvement, with a real possibility of continued degradation in the interim.

[26] Continued water quality degradation is a significant risk for Otago, impacting Te Mana o Te Wai. ORC's catchment advisors will play a key role by providing land managers with the tools and knowledge to adopt best management practices.

Climate Change Considerations

[27] SoE monitoring for surface water quality may provide useful data in the future to demonstrate the effects of climate changes on our rivers and lakes.

Communications Considerations

[28] This report will be available on the ORC website

NEXT STEPS

[29] State of the Environment reporting is generally undertaken once every five years. This report updates the 2020 state and trends report to inform the proposed Land Water Regional Plan. The state and trends report was last presented to Committee on 14 April 2021 (https://www.orc.govt.nz/news-and-events/events/2021/april/council-meeting-14-april).

[30] The next SoE state and trends report will cover the period up to June 2027 and will be reported in late 2027.

ATTACHMENTS

1. ORC River Lake Groundwater - State and Trends 2017 - 2022 [**7.2.1** - 159 pages]

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

May 2023

Otago Regional Council

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Contents

Executive Summary

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

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

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

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

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

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

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

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

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

1 Introduction

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

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

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

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

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

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

[1] ORC has not yet defined baseline state.

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

2 Otago Region

2.1 Regional Description

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

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

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

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

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

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

2.2 Freshwater management units

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

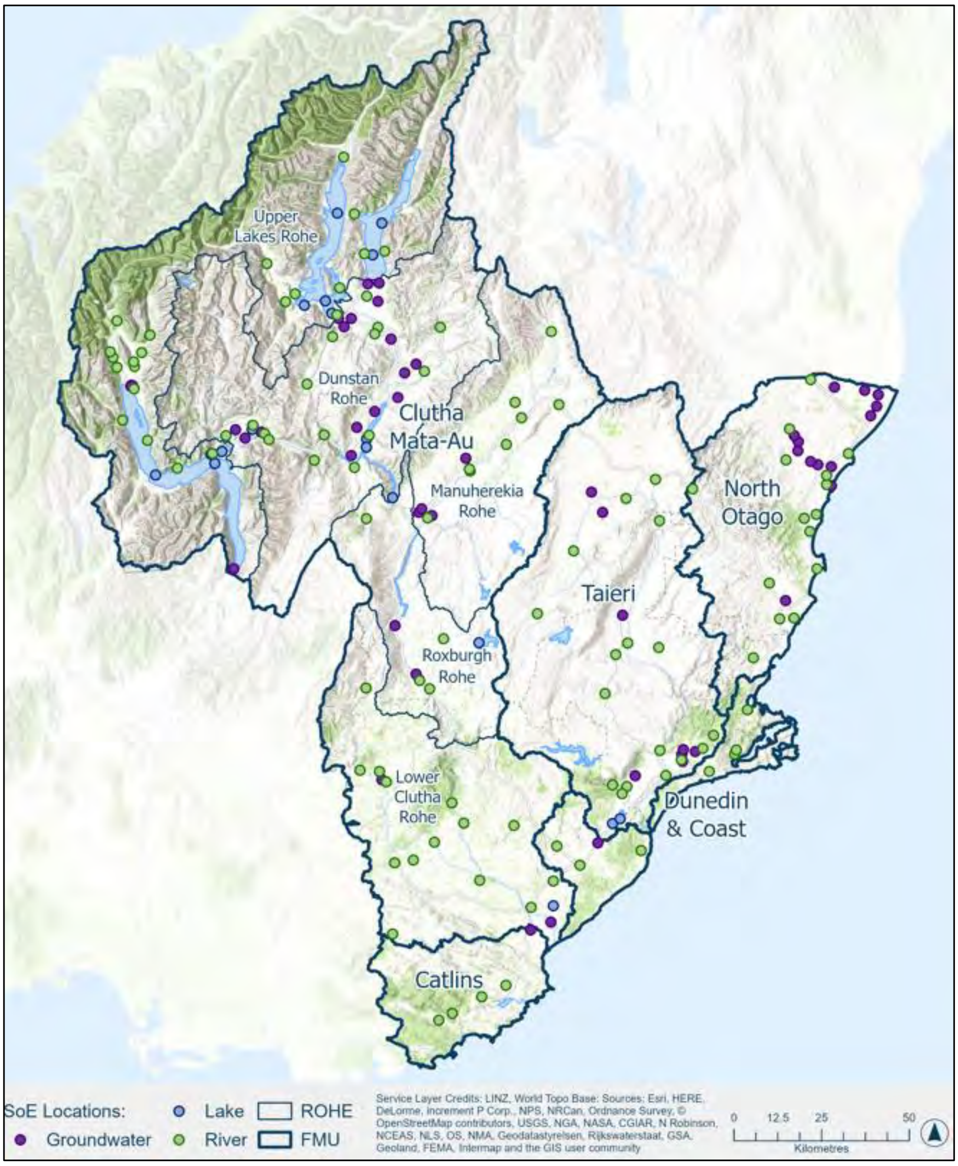

Figure 1 Map showing the FMU and Rohe boundaries, State of Environment monitoring site locations are also shown.

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

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

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

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

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

3 ORC monitoring programme

3.1 Water Quality Sites

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

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

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

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

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

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

3.2 Surface water quality variables

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

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

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

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

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

3.2.1 Phytoplankton, Periphyton and Nutrients

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

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

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

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

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

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

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

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

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

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

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

3.2.2 Toxicants

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

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

3.2.3 Suspended sediment

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

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

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

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

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

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

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

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

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

3.2.5 Ecological Assessments

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

3.3 Groundwater quality parameters

3.3.1 Escherichia coli (*E. coli*)

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

3.3.2 Dissolved arsenic

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

[8] This report does not assess compliance with Table 22, Appendix 2B (E. coli at primary contact sites)
[9] https://www.orc.govt.nz/plans-policies-reports/reports-and-publications/water-quality/annual-water-quality-reports

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

3.3.3 Nitrate nitrogen

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

4 Methods

4.1 Water Quality State Analysis

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

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

4.1.1 Data Collection and Grading of Attributes

4.1.1.1 River and Lakes

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

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

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

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

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

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

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

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

[11] Nitrate Nitrite Nitrogen has been used as a proxy for Nitrate-N
[12] The SFS attribute state has four different sets of numeric thresholds to correct for natural variability in catchment geology, climate, and topography

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

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

4.1.1.2 Groundwater

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

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

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

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

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

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

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

4.2 Water Quality Trend Analysis

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

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

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

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

Table 3.

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

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

4.2.1 Interpretation of Trends

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

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

Categorical level of confidence trend was decreasing	*Colour used in report*	*Value of C_d (%)*
Virtually certain	(dark green)	0.99–1.00
Extremely likely	(green)	0.95–0.99
Very likely	(yellow-green)	0.90–0.95
Likely	(light green)	0.67–0.90
About as likely as not	(yellow)	0.33–0.67
Unlikely	(orange-yellow)	0.10–0.33
Very unlikely	(orange)	0.05–0.10
Extremely unlikely	(dark red)	0.01–0.05
Exceptionally unlikely	(red)	0.0–0.01

5 Clutha Mata-Au FMU

5.1 Upper Lakes Rohe

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

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

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

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

5.1.1 River and Lake State Analysis Results

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

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

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

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

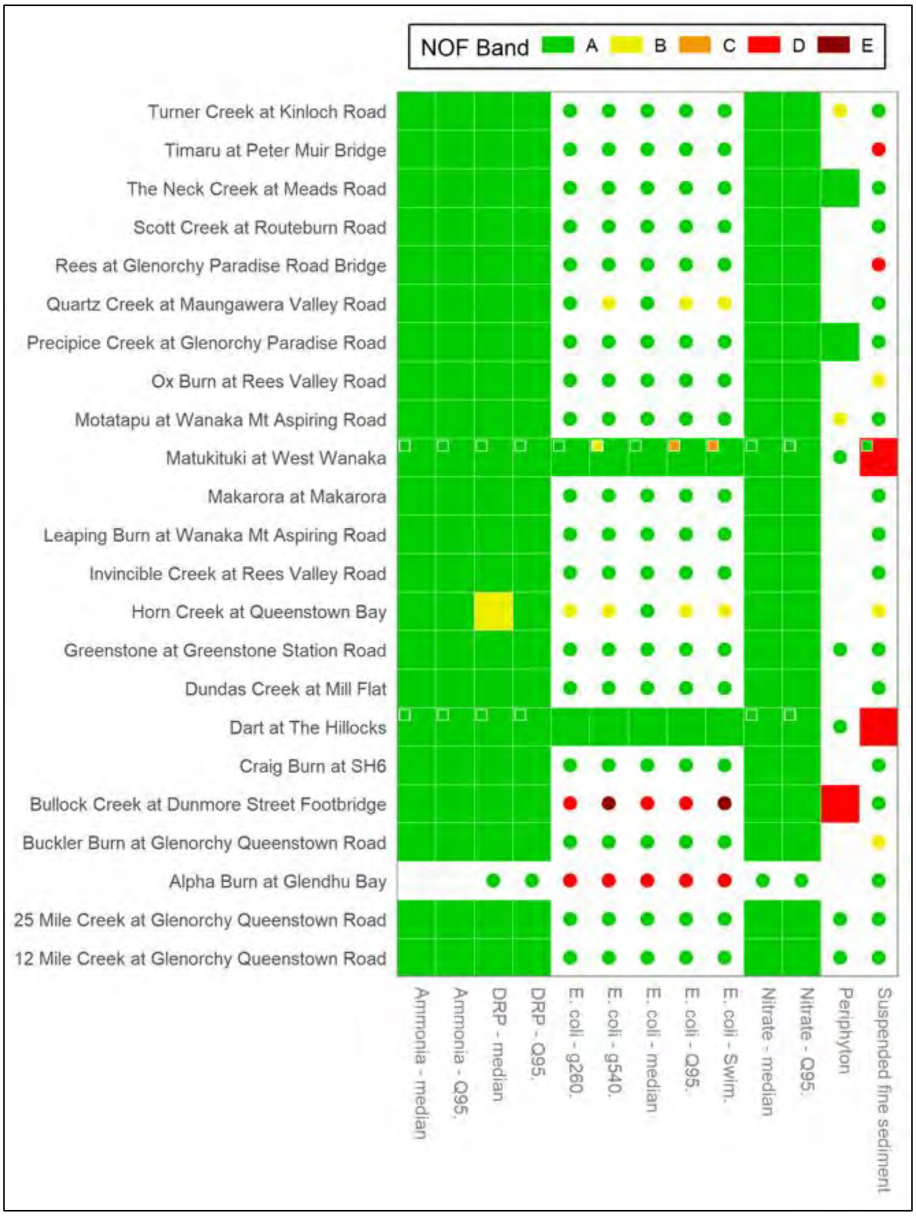


Figure 4 Grading of the river sites of the Upper Lakes Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper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

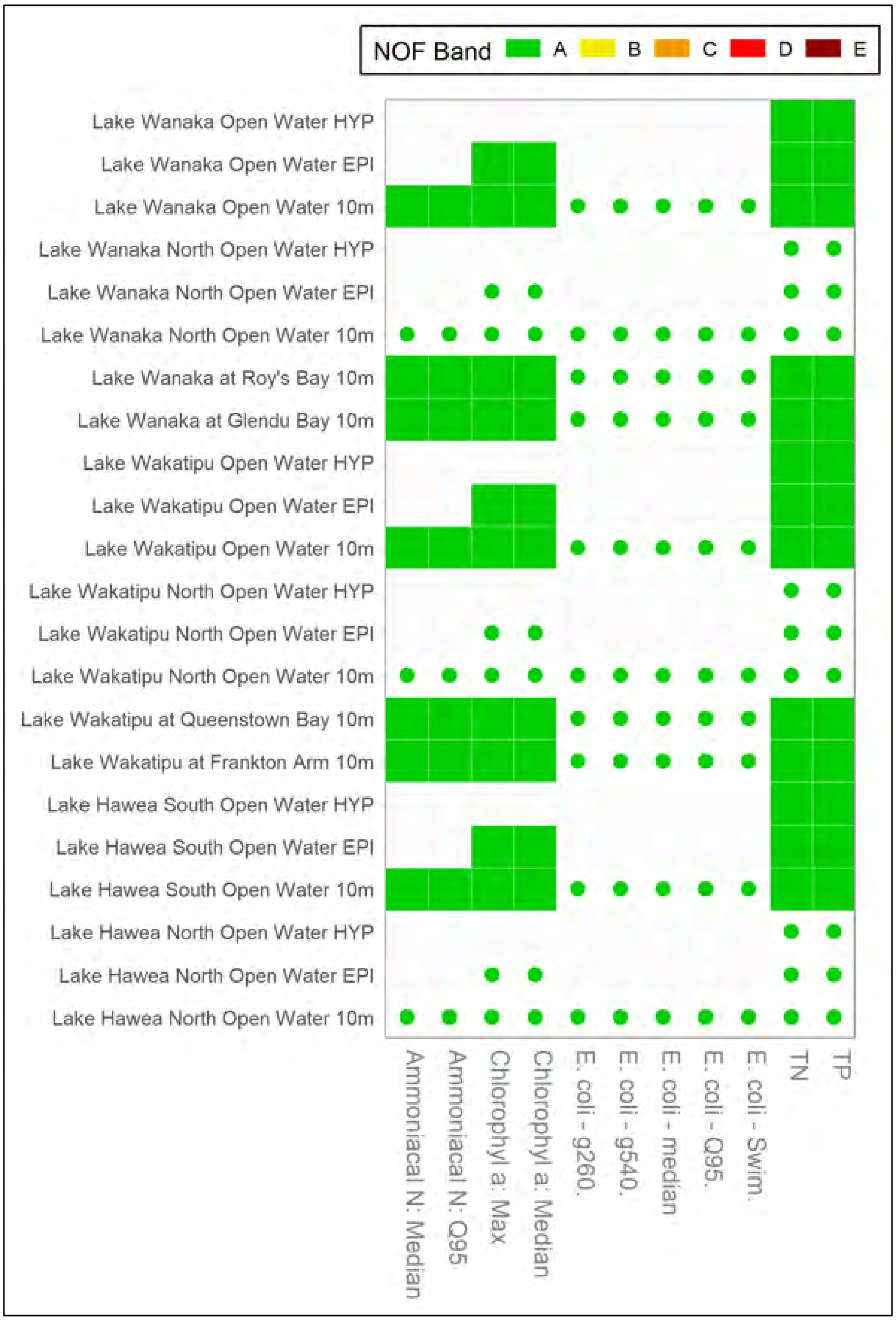


Figure 5 Grading of the lake sites of the Upper Lakes Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left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

5.1.2 Phytoplankton, Periphyton and Nutrients

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

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

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

5.1.2.1 Toxicants

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

5.1.2.2 Suspended fine sediment (Rivers)

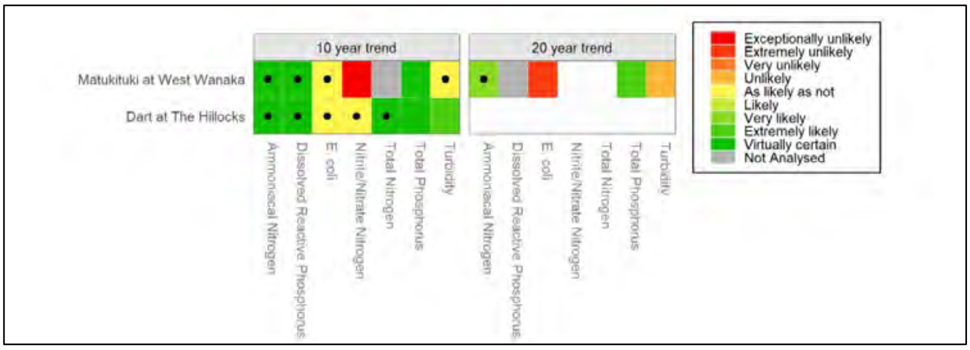
The clarity results for the Upper Lakes Rohe are shown in Figure 4 and Appendix 2 gives the clarity numerical results and sediment classes for each site. All sites were either sediment Class 1 or 3. Sites that have a high degree of glacial flour present in the river are exempt from the NOF process, these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

5.1.2.3 Human health for recreation

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

5.1.3 River and Lake Trend Analysis Results

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



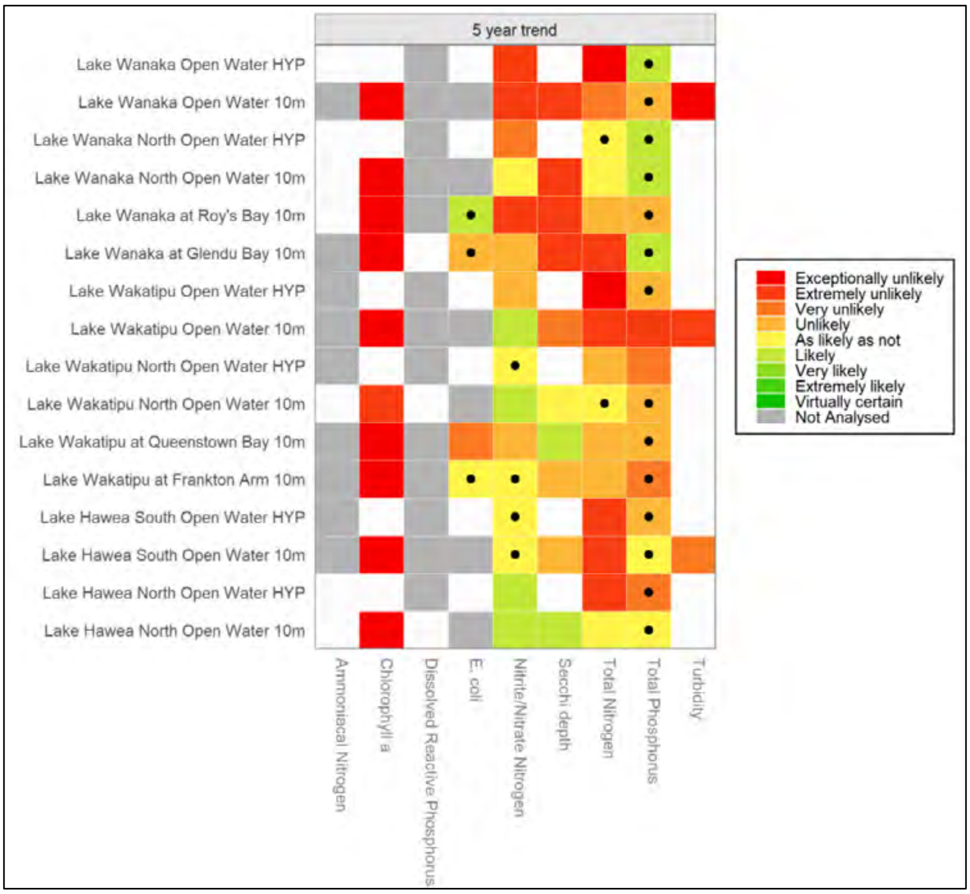


Figure 6 Summary of Upper Lakes sites (rivers top, lakes bottom) categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero

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

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

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

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

5.1.4 Groundwater State Results

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

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

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

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

5.1.5 Groundwater Trends

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

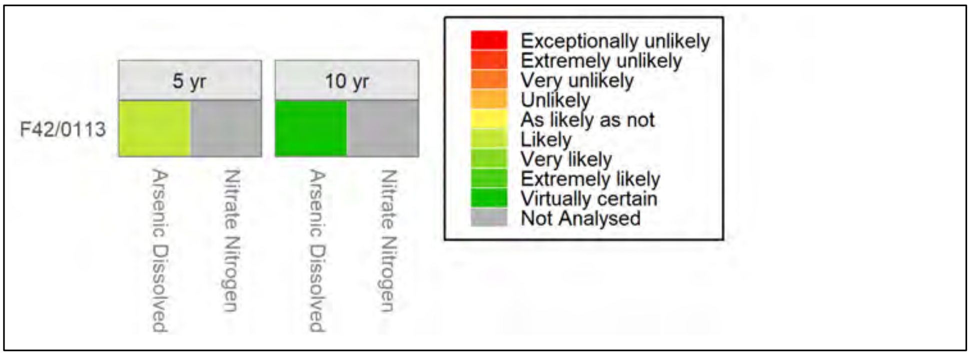


Figure 7 Summary of the Upper Lakes groundwater monitoring sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement.

5.1.6 Water quality summary and discussion: Upper lakes Rohe

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

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

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

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

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

[13] See accompanying report 'ORCRiverState_072017to062022' and Appendix 1

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

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

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

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

5.2 Dunstan Rohe

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

5.2.1 Dunstan Rohe Description

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

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

5.2.2 River and Lake: State Analysis

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

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

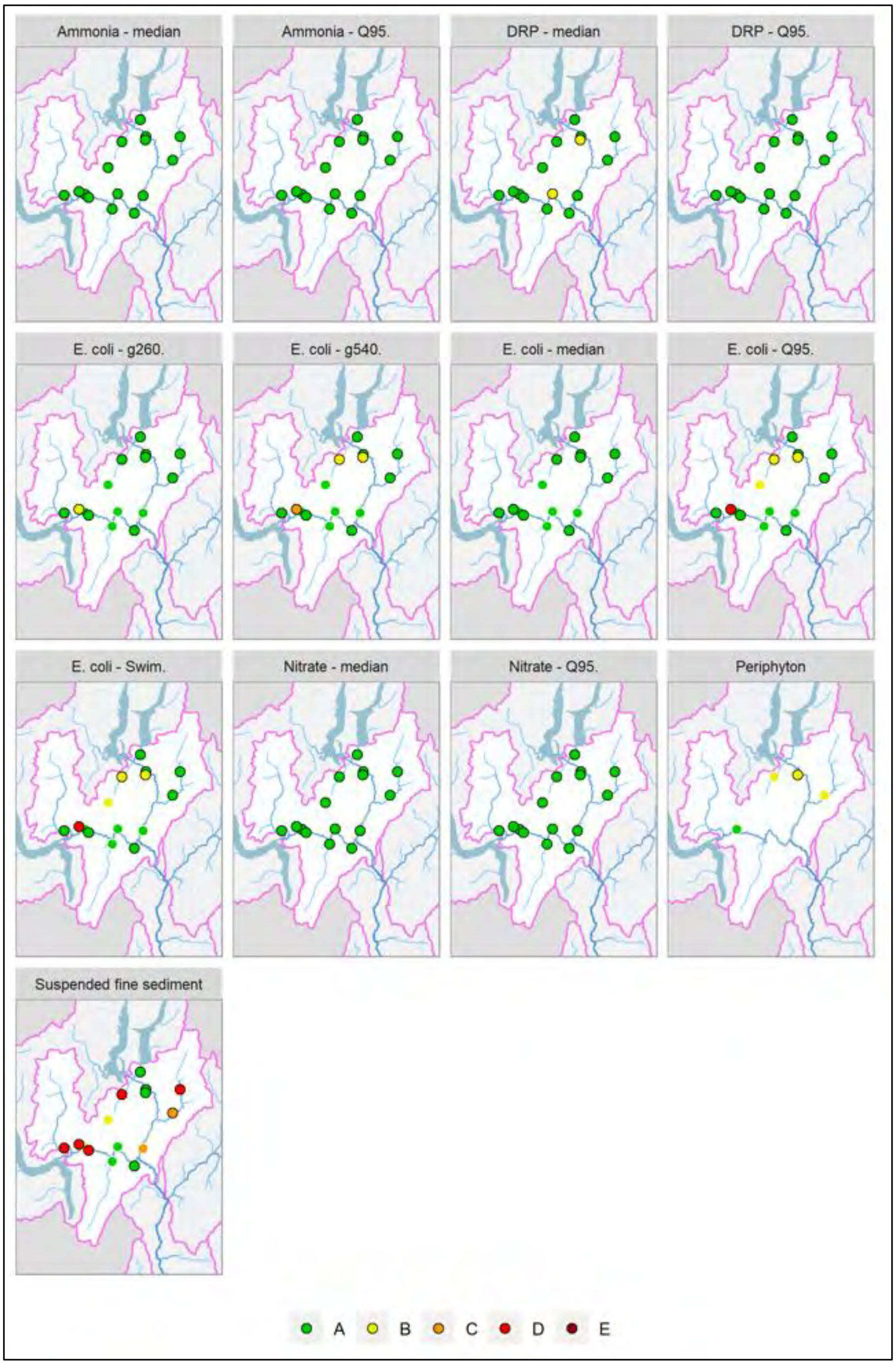


Figure 9 Maps showing Dunstan Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.

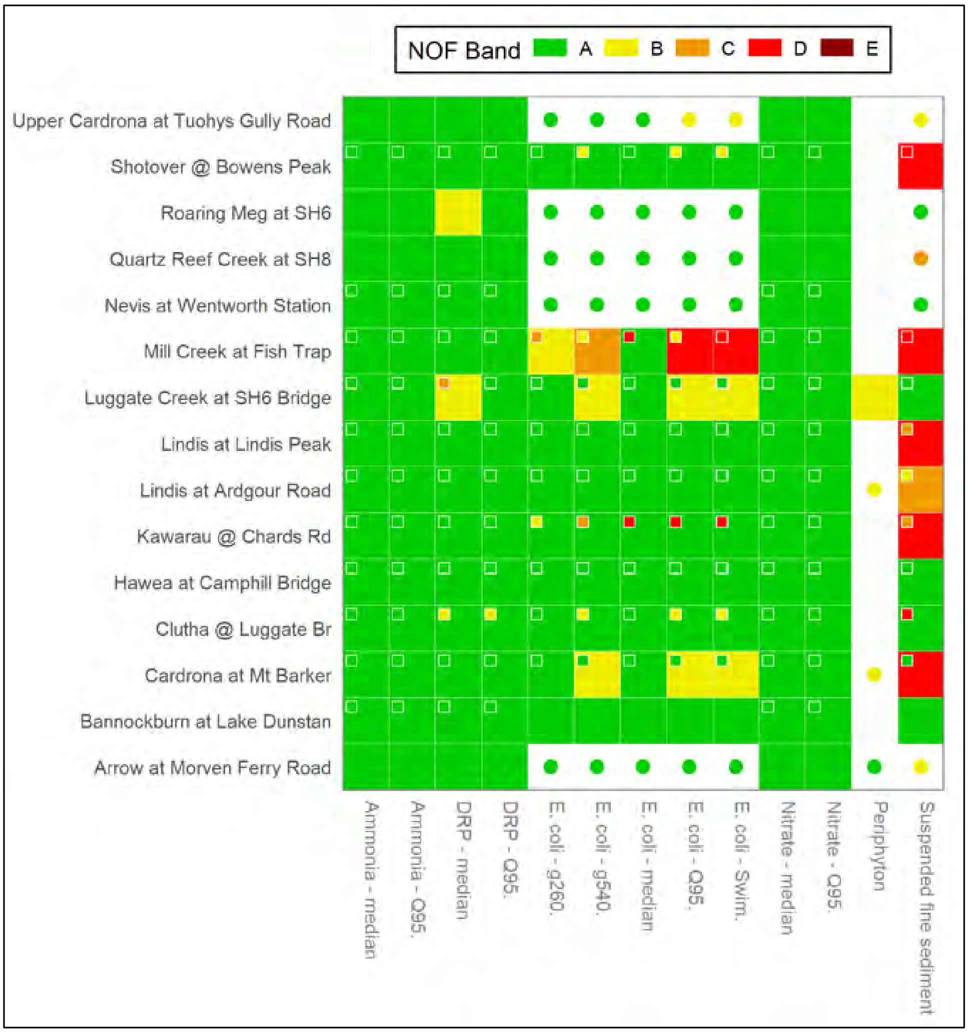


Figure 10 Grading of the river sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left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

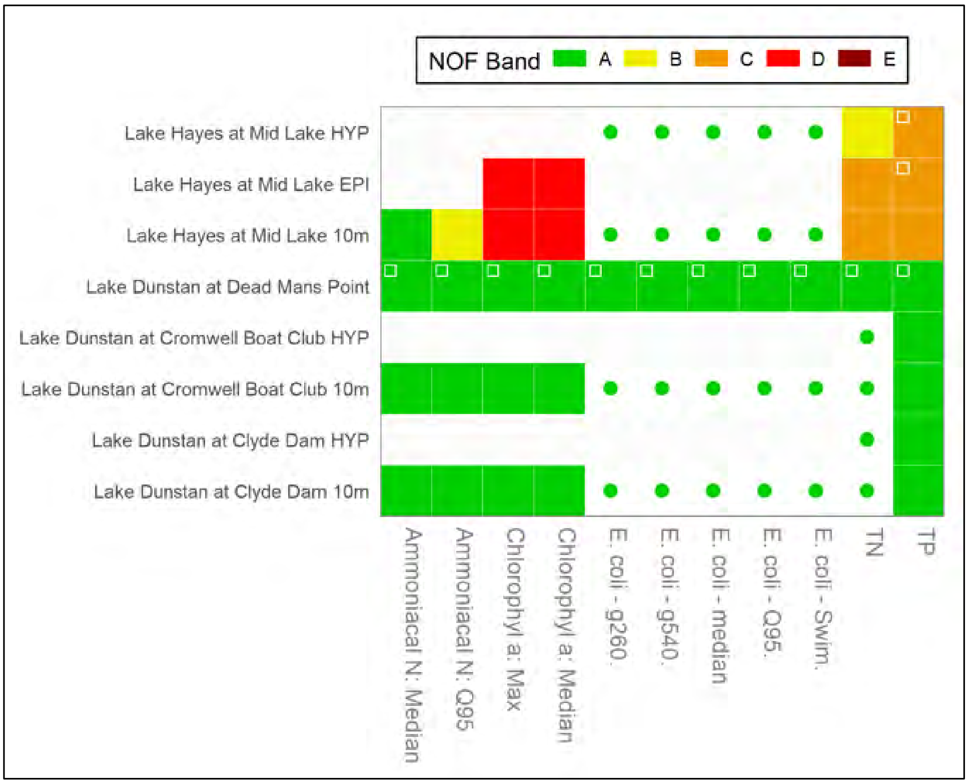


Figure 11 Grading of the lake sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left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

5.2.2.1 Phytoplankton, Periphyton and Nutrients

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

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

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

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

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

5.2.2.2 Toxicants

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

5.2.2.3 Suspended fine sediment (Rivers)

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

5.2.2.4 Human health for recreation (Rivers and lakes)

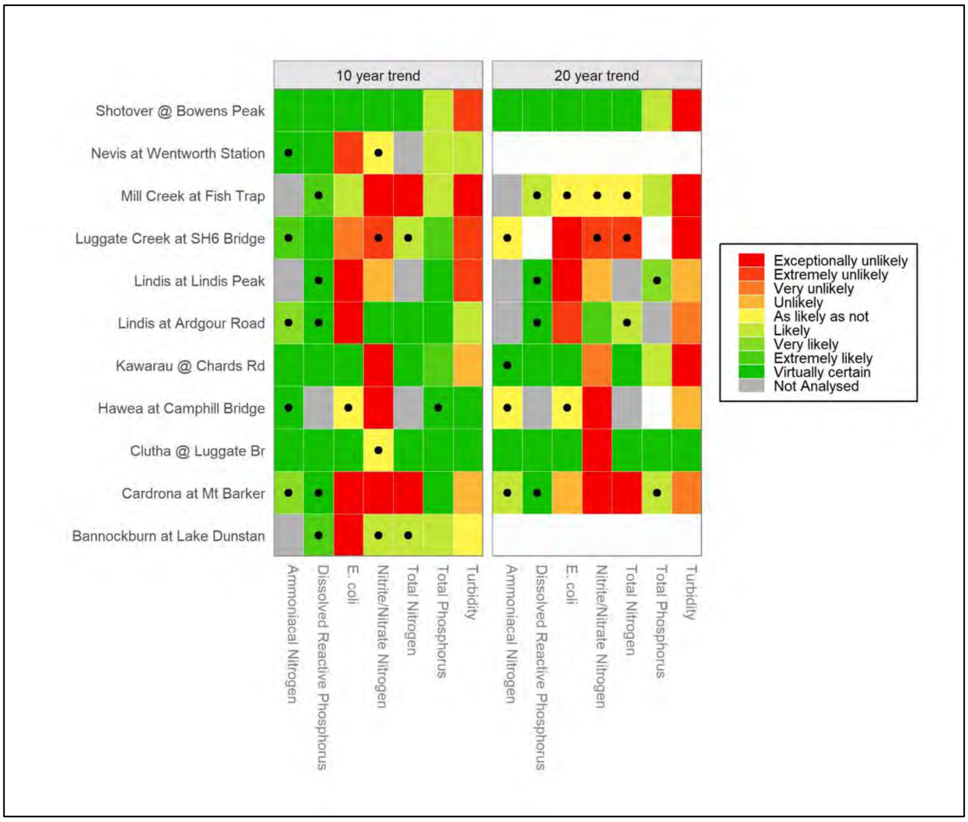
Figure 10 summarise river compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Compliance is generally excellent across in the Dunstan Rohe, with all sites other than Mill Creek having bacterial water quality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

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

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

5.2.3 River and Lake Trend Analysis

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



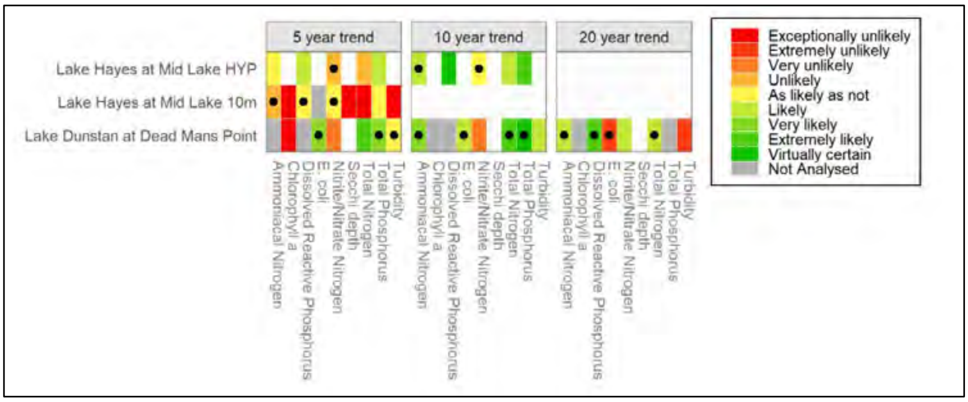


Figure 12 Summary of Dunstan Rohe trends categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

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

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

5.2.4 Groundwater State

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

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

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

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

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

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

5.2.5 Groundwater Trends

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

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

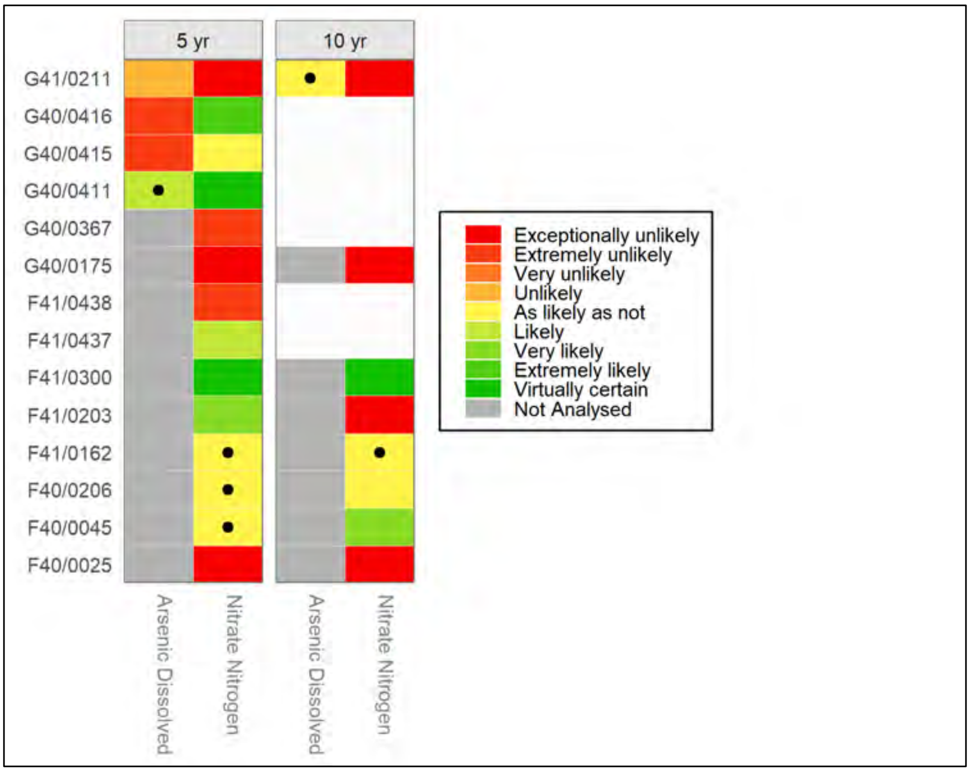


Figure 13 Summary of groundwater quality trends for the Dunstan Rohe

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

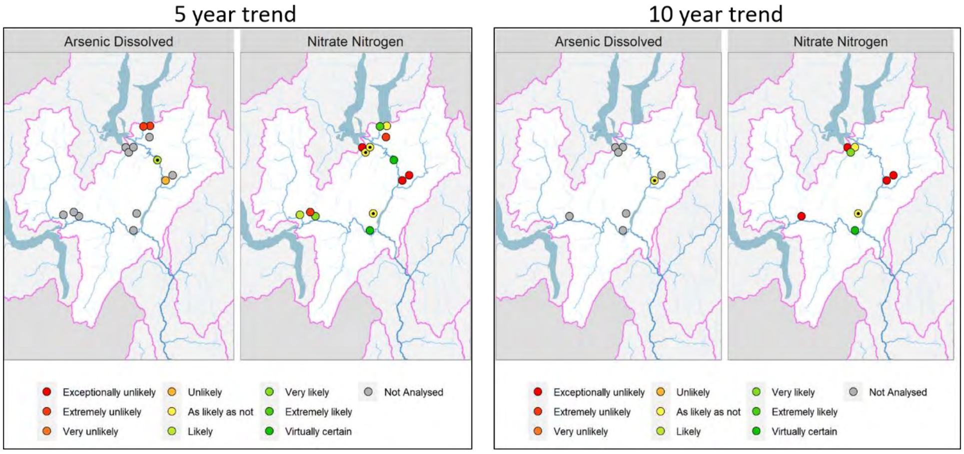


Figure 14 Groundwater quality 5-year and 10-year trend results for the Dunstan Rohe (LWP, 2023)

5.2.6 Water quality summary and discussion: Dunstan Rohe

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

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

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

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

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

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

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

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

5.3 Manuherekia Rohe

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

5.3.1 Manuherekia Rohe Description

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

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

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

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

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

5.3.2 River: State Analysis

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

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

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

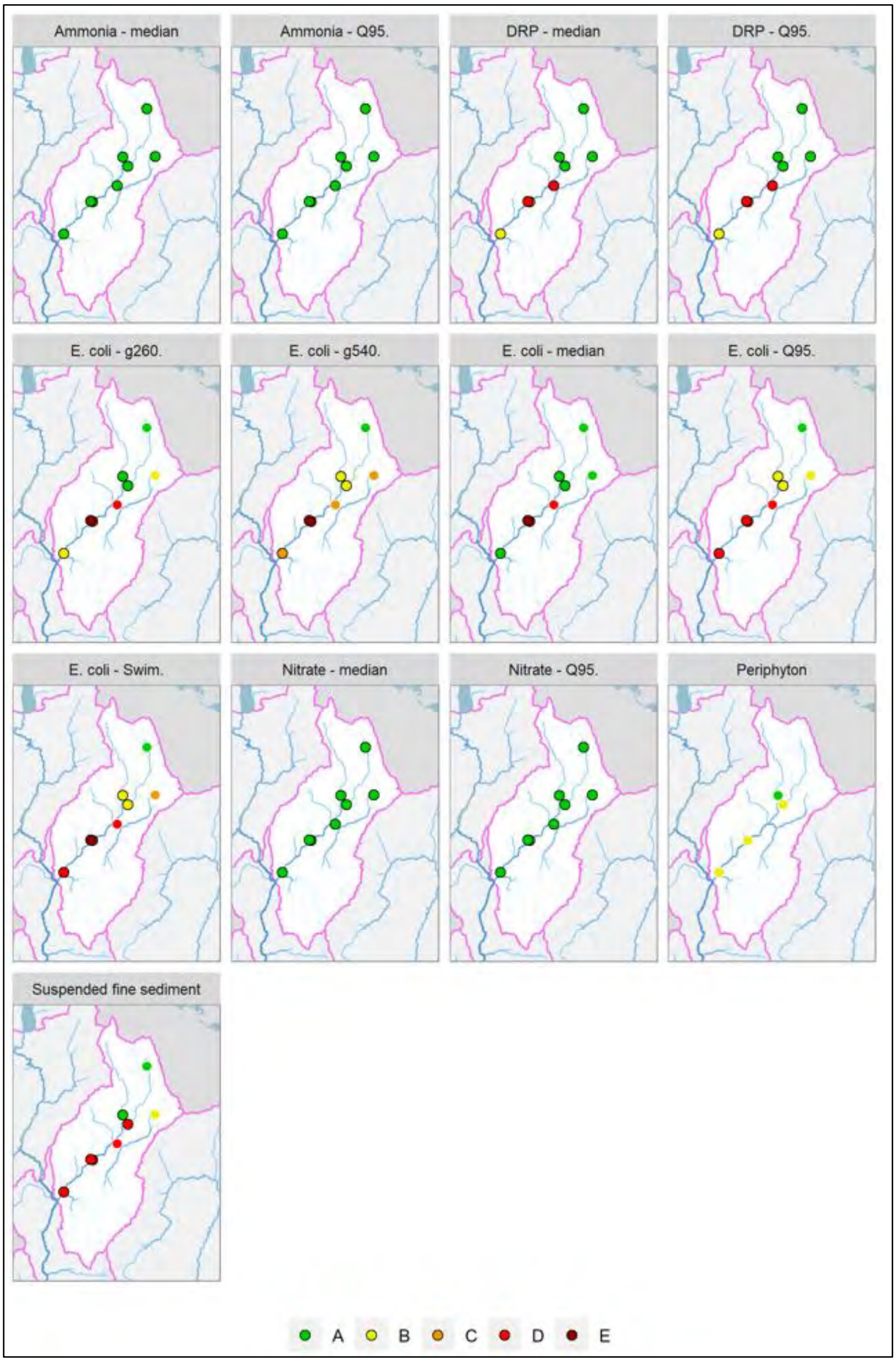

Ammonia - median
Ammonia - Q95.
DRP - median
DRP - Q95.
E. coli - g260.
E. coli - g540.
E. coli - median
E. coli - Q95.
E. coli - Swim.
Nitrate - median
Nitrate - Q95.
Periphyton
Suspended fine sediment
A
B
C
D
E

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

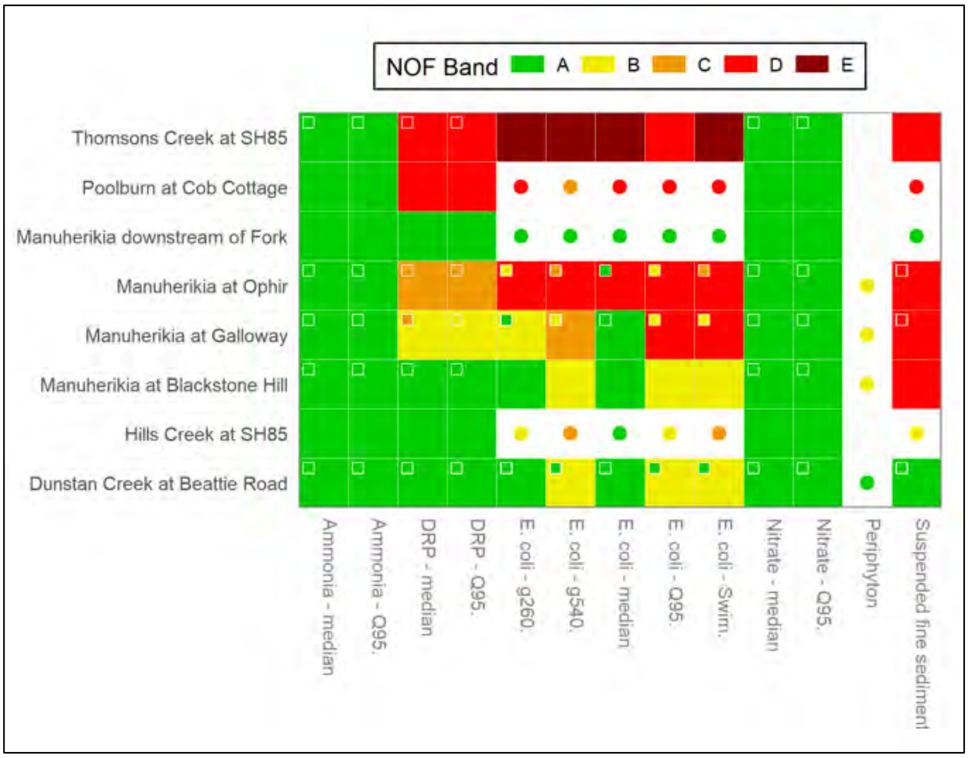


Figure 17 Grading of the river sites of the Manuherekia Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper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

5.3.2.1 Periphyton and Nutrients

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

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

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

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

5.3.2.2 Toxicants

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

5.3.2.3 Suspended fine sediment

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

5.3.2.4 Human health for recreation

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

5.3.3 River: Trend Analysis

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

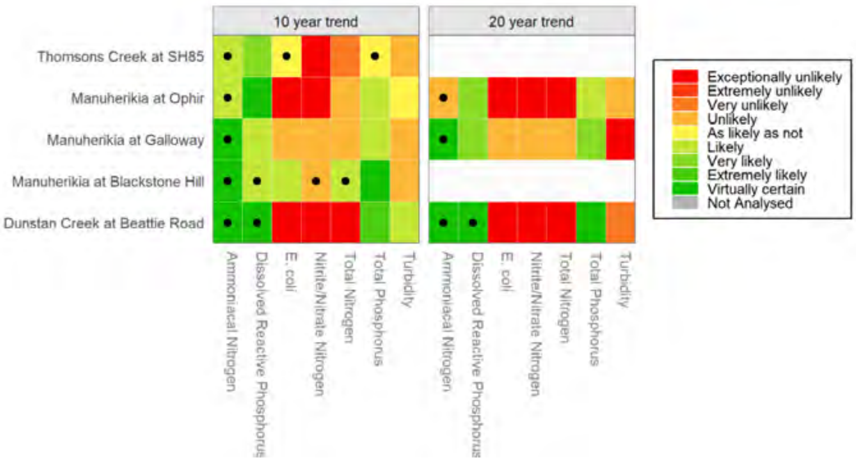


Figure 18 Summary of Manuherekia sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement.

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

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

5.3.4 Groundwater: State Analysis

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

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

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

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

5.3.5 Groundwater: Trend Analysis

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

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

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

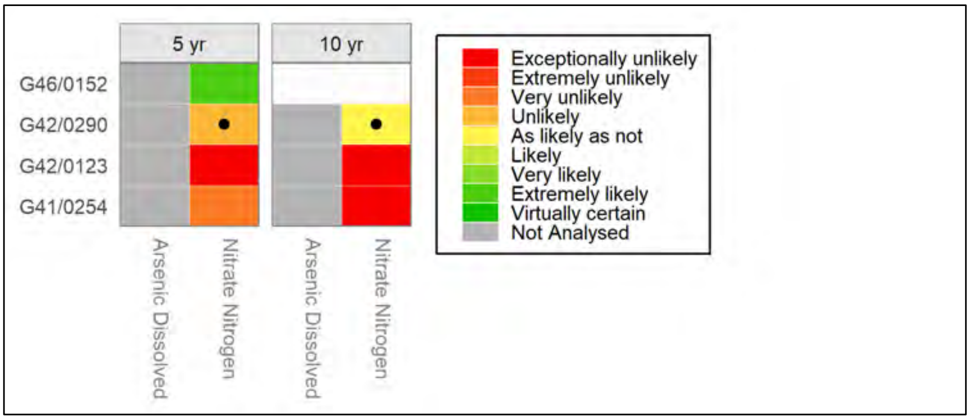


Figure 19 Summary of Manuherekia Rohe sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend

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

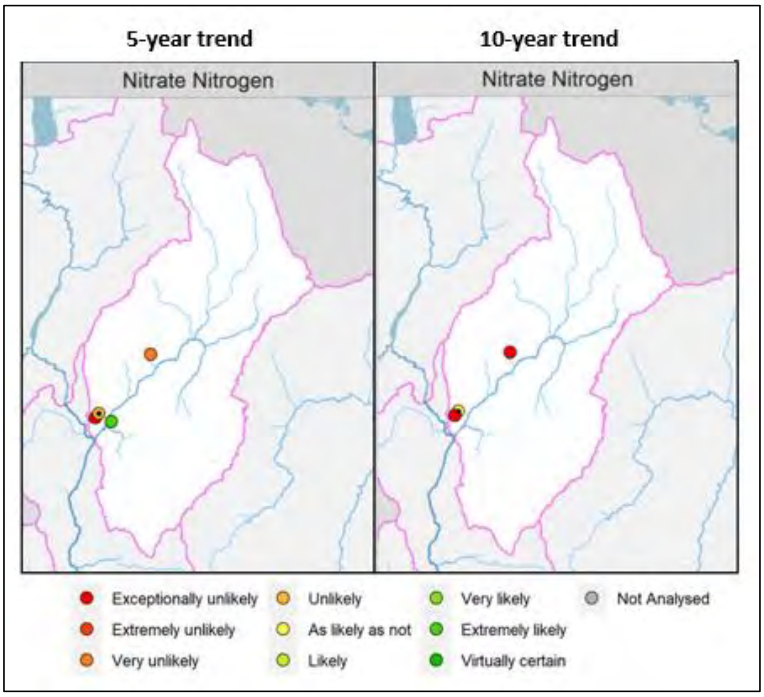


Figure 20: Groundwater quality 5- and 10-year trend results for the Manuherekia Rohe (LWP, 2023)

5.3.6 Water quality summary and discussion: Manuherekia Rohe

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

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

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

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

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

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

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

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

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

5.4 Roxburgh Rohe

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

5.4.1 Roxburgh Rohe Description

The Roxburgh Rohe extends from the Clyde Dam to Beaumont, and includes the townships of Alexandra, Clyde, and Roxburgh. The Rohe covers around 180,000 hectares of land, with grassland being the most common land cover. Low producing grasslands such as that found on steep hill and high country, occupy 32% of the Rohe while high-producing grasslands such as intensified grazing occupy 2%. Tall tussock grasslands cover 24% and exotic forests cover 2% of the Rohe.
The Roxburgh Rohe is in the heart of Central Otago and subject to the typical weather conditions for this area with hot, dry summers and cold, frosty, dry winters. Mean annual rainfall ranges from about 1200mm on the Obelisk/Old Man Mountain ranges, around 900mm on the hills south of the mountains, to about 360mm near Alexandra, and 450-500mm further south. However, the evaporation is also high, and at times exceeds precipitation, leading to soil moisture deficits. Temperatures can range from above 38°C in summer to around -10°C in winter. Rivers and streams originating in this Rohe do not have large flows and generally have very low flows in summer. The main exception is the Clutha/Mata-Au River, which runs through the centre of this Rohe.

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

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

5.4.2 River and Lake: State Analysis

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

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

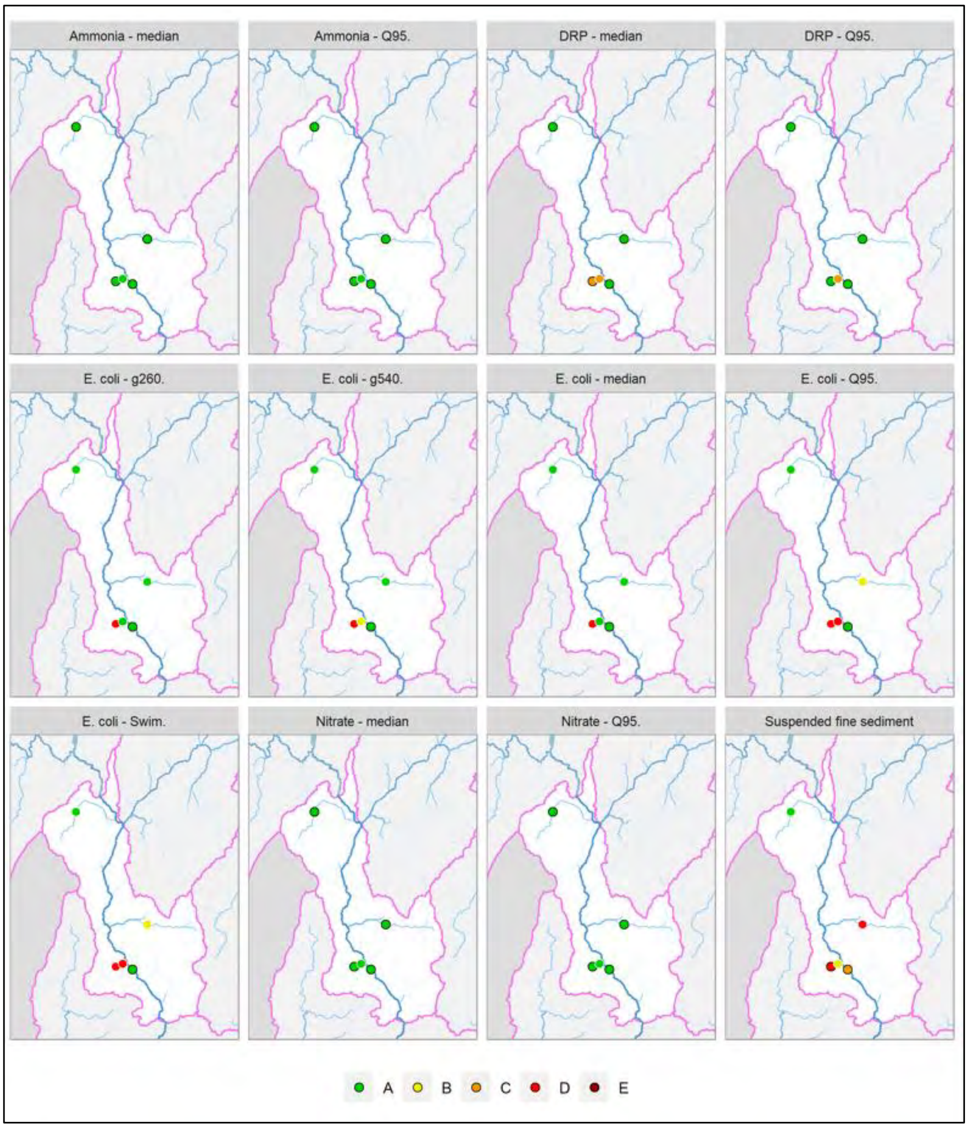


Figure 22 Maps showing Roxburgh Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.

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

5.4.2.1 Phytoplankton, Periphyton and Nutrients

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

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

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

5.4.2.2 Toxicants

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

5.4.2.3 Suspended fine sediment

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

5.4.2.4 Human health for recreation

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

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

5.4.3 River and Lake: Trend Analysis

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

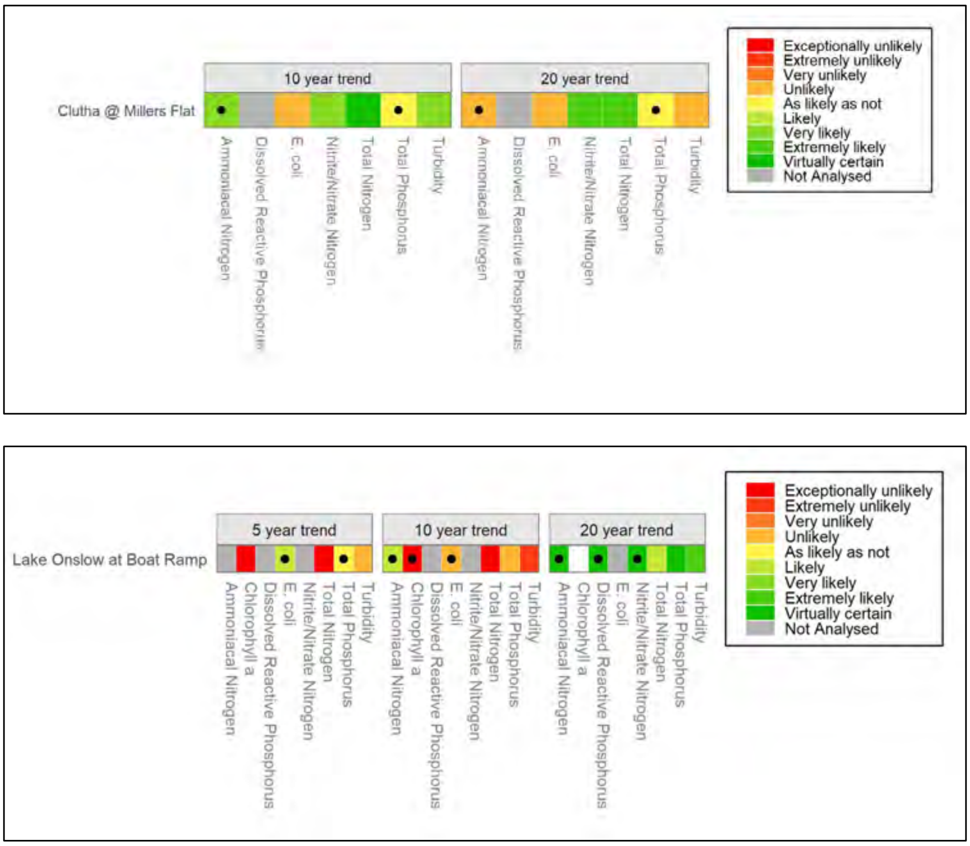


Figure 24 Summary of Roxburgh Rohe sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

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

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

5.4.4 Groundwater: State Analysis

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

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

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

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

5.4.5 Groundwater: Trend Analysis

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

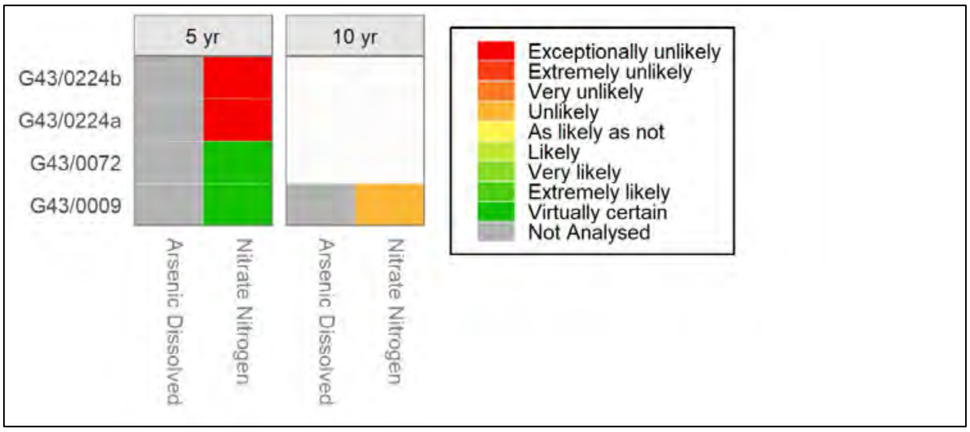


Figure 25: Summary of Roxburgh Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 4. White cells indicate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

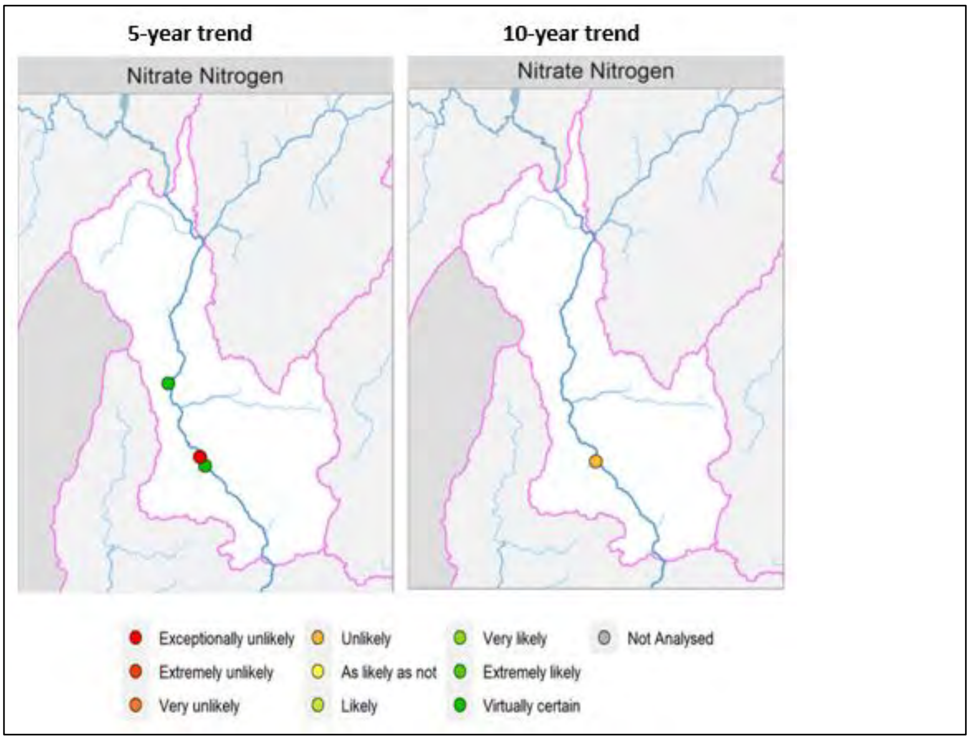


Figure 26: Groundwater quality 5 -and 10-year trend results for the Roxburgh Rohe (LWP, 203)

5.4.6 Water quality summary and discussion: Roxburgh Rohe

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

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

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

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

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

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

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

5.5 Lower Clutha Rohe

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

5.5.1 Lower Clutha Rohe Description

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

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

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

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

5.5.2 River and Lake State Analysis Results

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

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

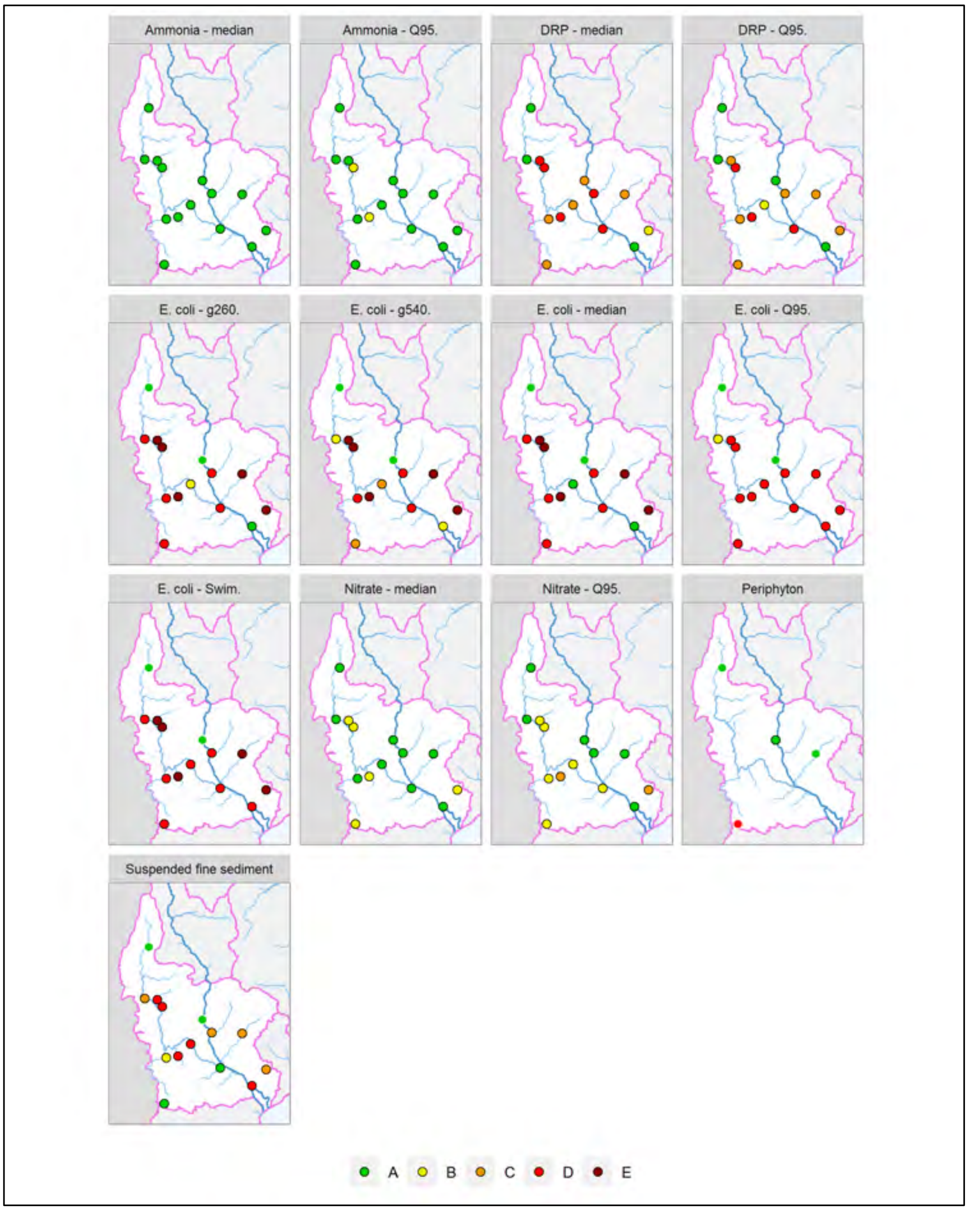


Figure 28 Maps showing Lower Clutha Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.

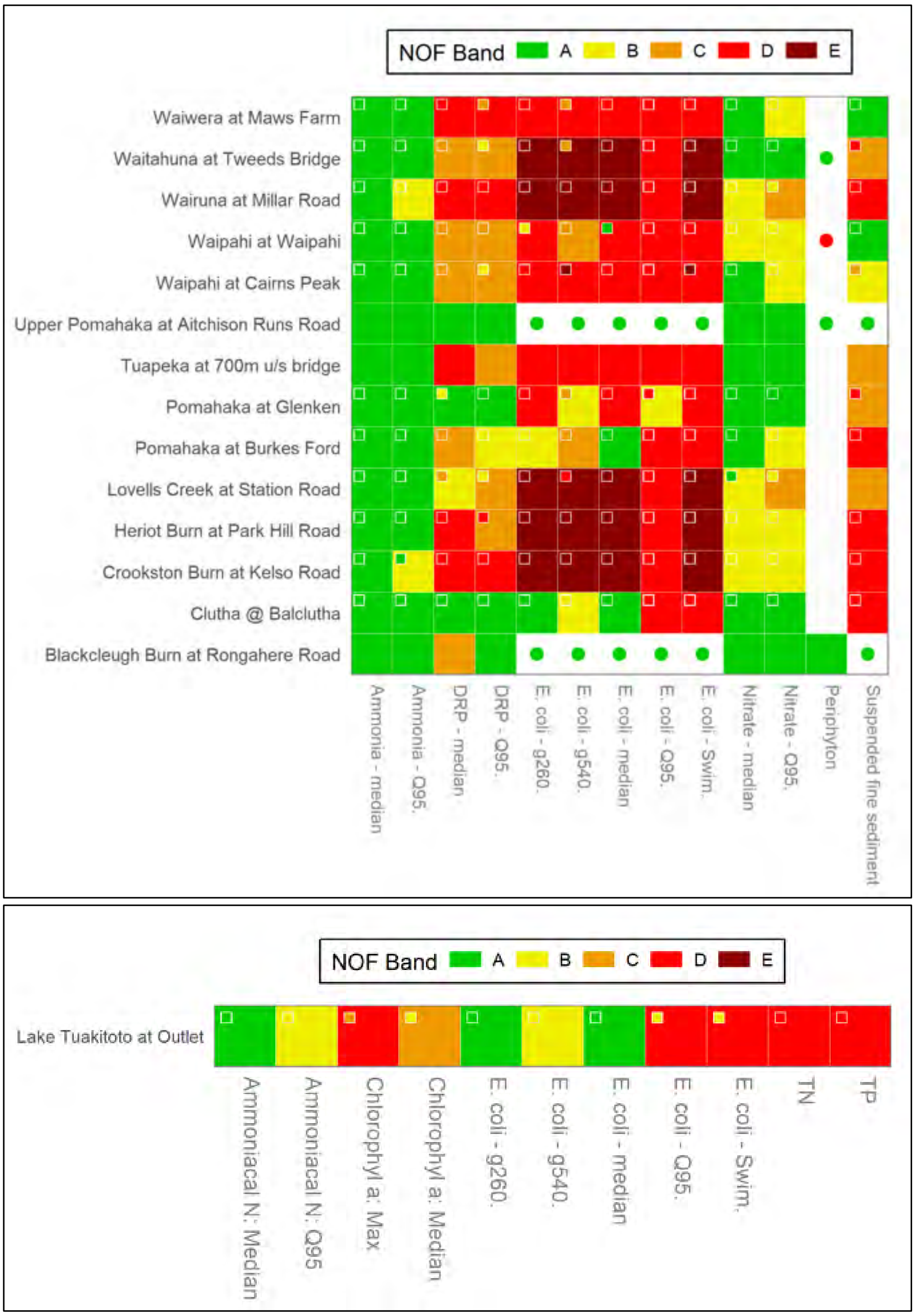


Figure 29 Grading of River and Lake sites in the Lower Clutha Rohe, based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells

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

5.5.2.1 Phytoplankton, Periphyton and Nutrients

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

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

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

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

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

5.5.2.2 Toxicants

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

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

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

5.5.2.3 Suspended fine sediment

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

5.5.2.4 Human health for recreation

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

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

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

5.5.3 River and Lake: Trend Analysis

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

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

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

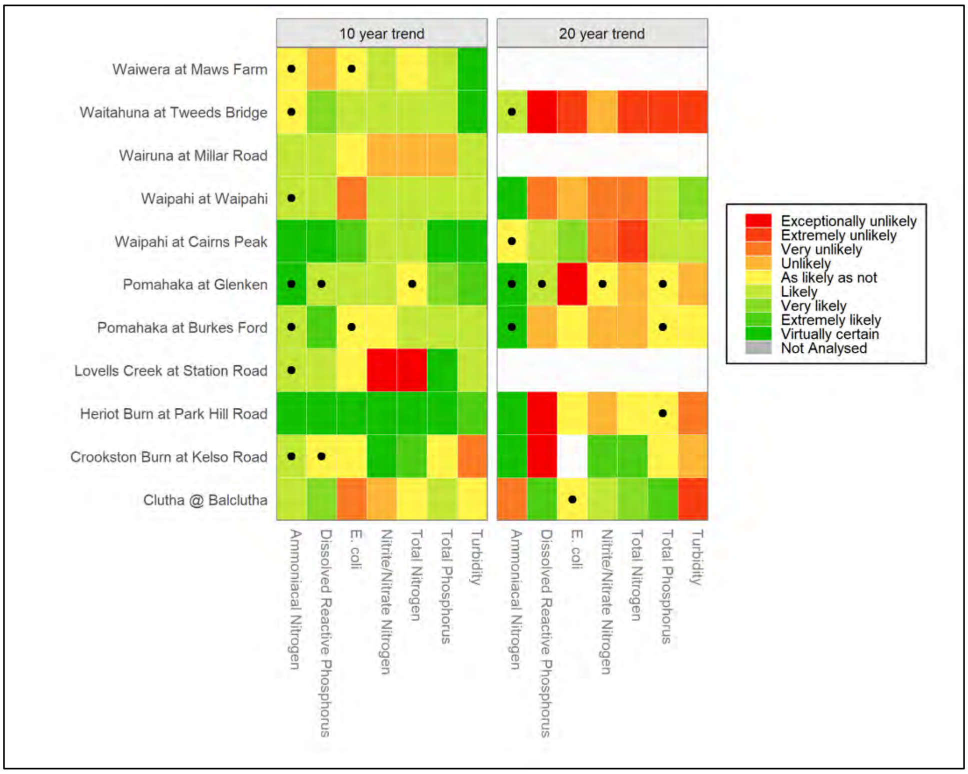


Figure 30 Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

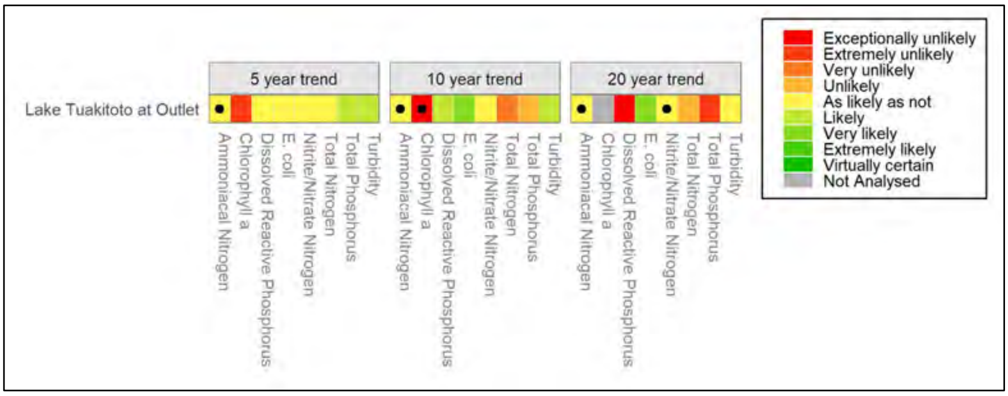


Figure 31 Summary of Lake Tuakitoto trends, categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

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

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

5.5.4 Groundwater: State Analysis

The results for the groundwater state analysis are shown in

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

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

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

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

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

5.5.5 Groundwater: Trend Analysis

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

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

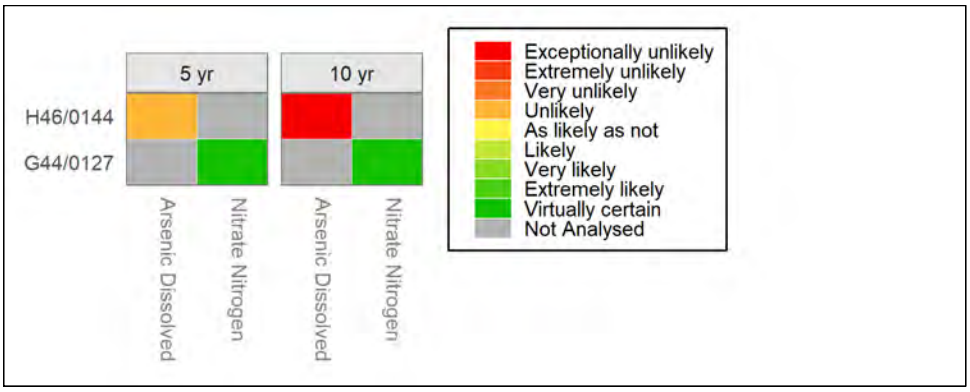


Figure 32: Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

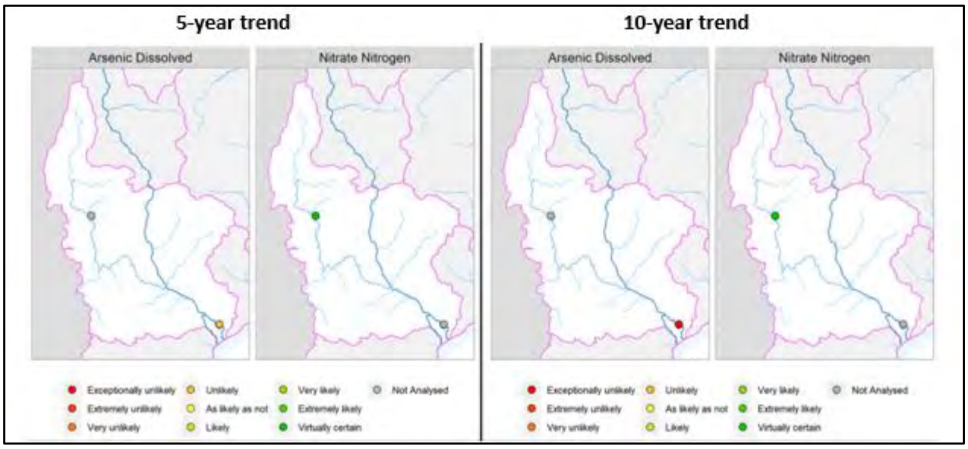


Figure 33: Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Water quality summary and discussion: Lower Clutha Rohe

5.5.6 Water quality summary Lower Clutha Rohe

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

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

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

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

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

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

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

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

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

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

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

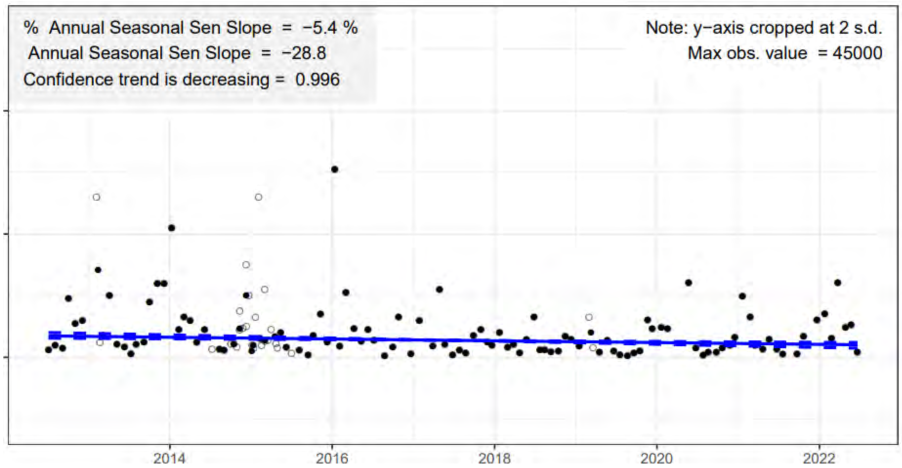


Figure 34 Heriot Burn trend graph showing a 'virtually certain' improving trend in E. coli.

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

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

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

6 Taieri FMU

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

6.1.1 Taieri FMU Description

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

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

The upper Taieri headwaters drain a relatively undeveloped area of native tussock country on the northern side of the Lammerlaw Range. The river then flows through the dry Maniototo Plain (660km^2) which features an intensely meandering channel, oxbow lakes and wetlands and is the best example of a 'scroll plain' in New Zealand. The Maniototo Irrigation Company (MIC) distributes water from the Taieri River, and water stored in the Loganburn Reservoir.

Beyond the northern end of the Rock and Pillar Range, the Kye Burn flows into the Taieri and contributes high levels of sediment to the river. These high sediment loads are in part due to historic gold mining activities in the Kye Burn Catchment. The midreaches of the Taieri River flow through the smaller Strath Taieri Plain, occupying an area of 85km^2, past Middlemarch, and through the Taieri Gorge onto the Taieri Plain. Many small tributaries join the main stem of the river along this sub-region.

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

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

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

6.1.2 State Analysis Results

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

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

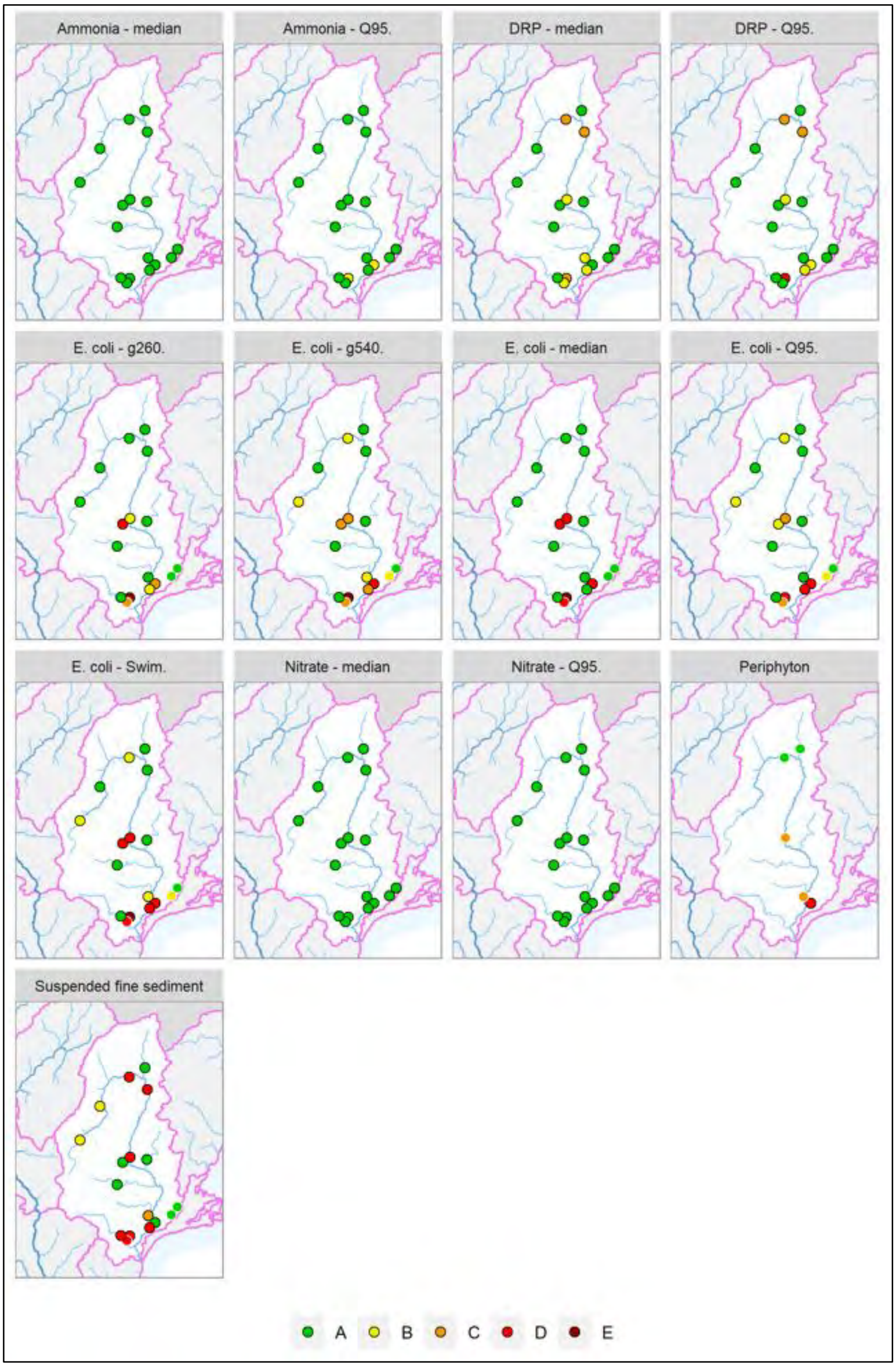

Ammonia - median
Ammonia - Q95.
DRP - median
DRP - Q95.
E. coli - g260.
E. coli - g540.
E. coli - median
E. coli - Q95.
E. coli - Swim.
Nitrate - median
Nitrate - Q95.
Periphyton
Suspended fine sediment
A
B
C
D
E

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

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

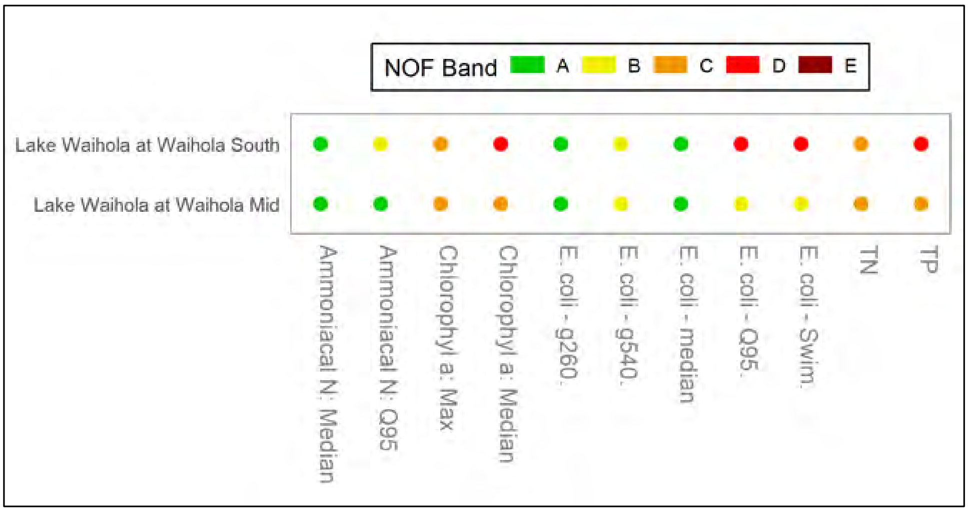


Figure 38 Grading of the lake sites of the Taieri FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements shown as white cells with coloured circles.

6.1.2.1 Phytoplankton, Periphyton and Nutrients

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

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

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

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

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

6.1.2.2 Toxicants

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

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

6.1.2.3 Suspended fine sediment

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

6.1.2.4 Human health for recreation

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

6.1.3 Trend Analysis

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

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

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

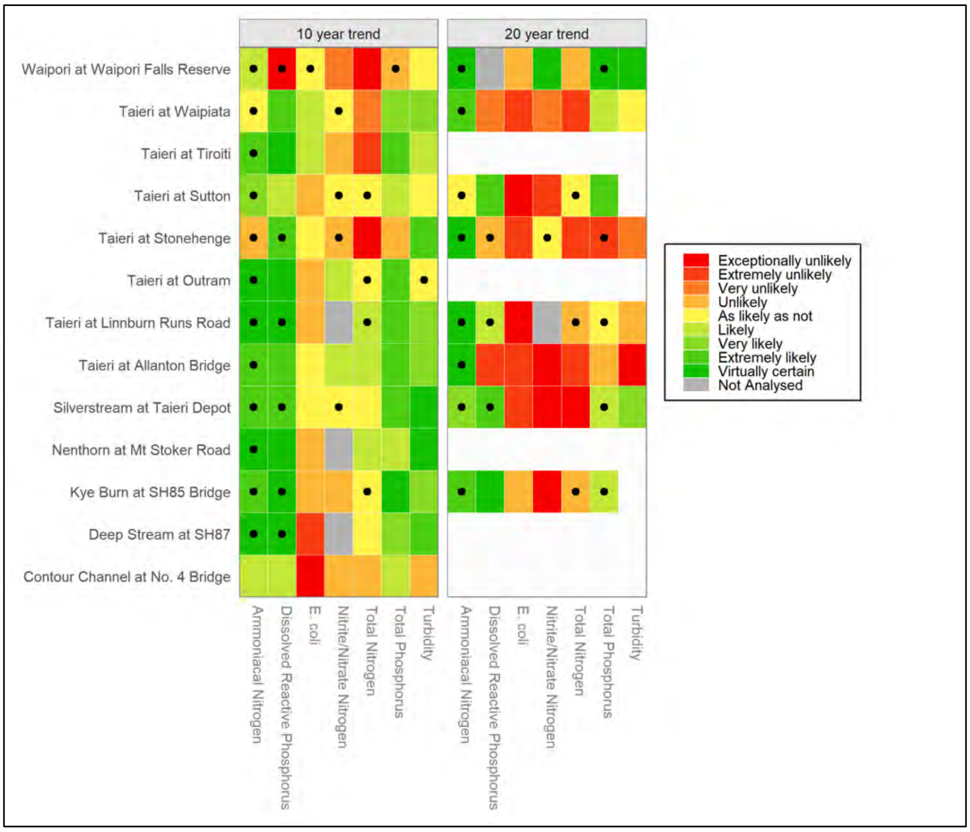


Figure 39 Summary of Taieri FMU river sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

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

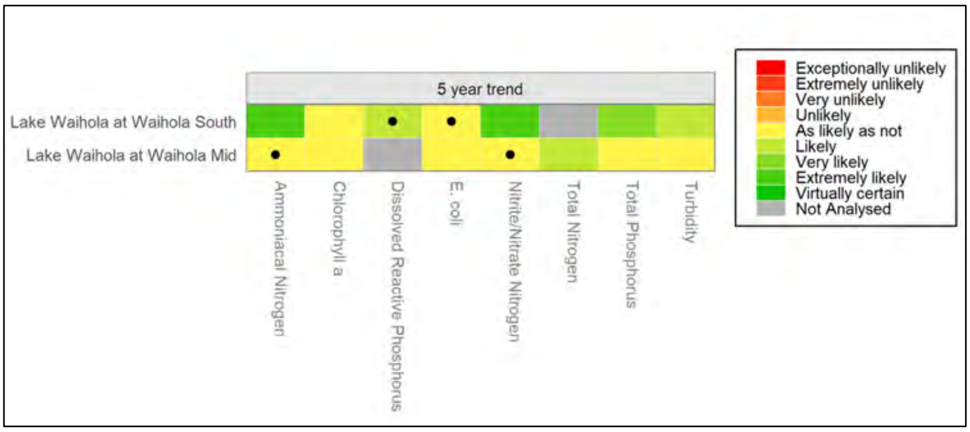


Figure 40 Summary of Taieri FMU lake sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

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

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

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

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

6.1.4 Groundwater

6.1.4.1 Groundwater State

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

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

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

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

6.1.4.2 Groundwater Trends

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

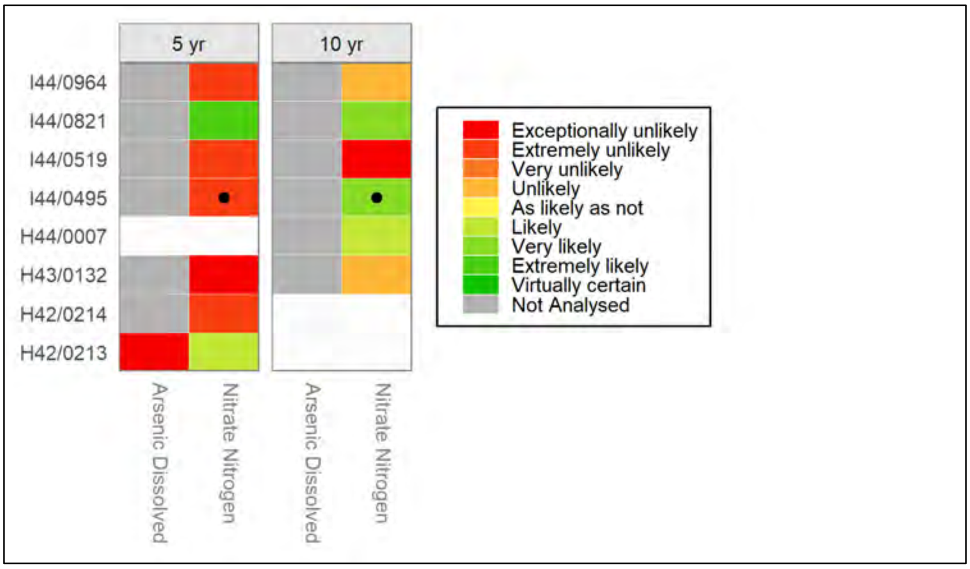


Figure 41: Summary of Taieri FMU sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

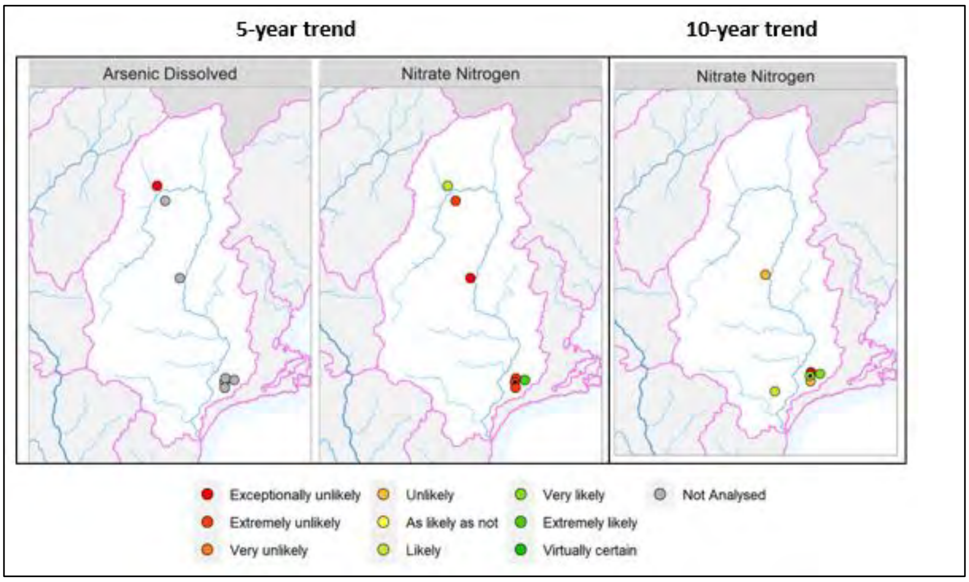


Figure 42: Groundwater quality 5 -and 10-year trend results for the Taieri FMU (LWP, 2023). Note that the 10-year trend for dissolved arsenic were not analysed.

6.1.5 Water quality summary Taieri FMU

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

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

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

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

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

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

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

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

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

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

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7 Dunedin & Coast FMU

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

7.1.1 Dunedin & Coast Description

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

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

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

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

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

7.1.2 State Analysis Results

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

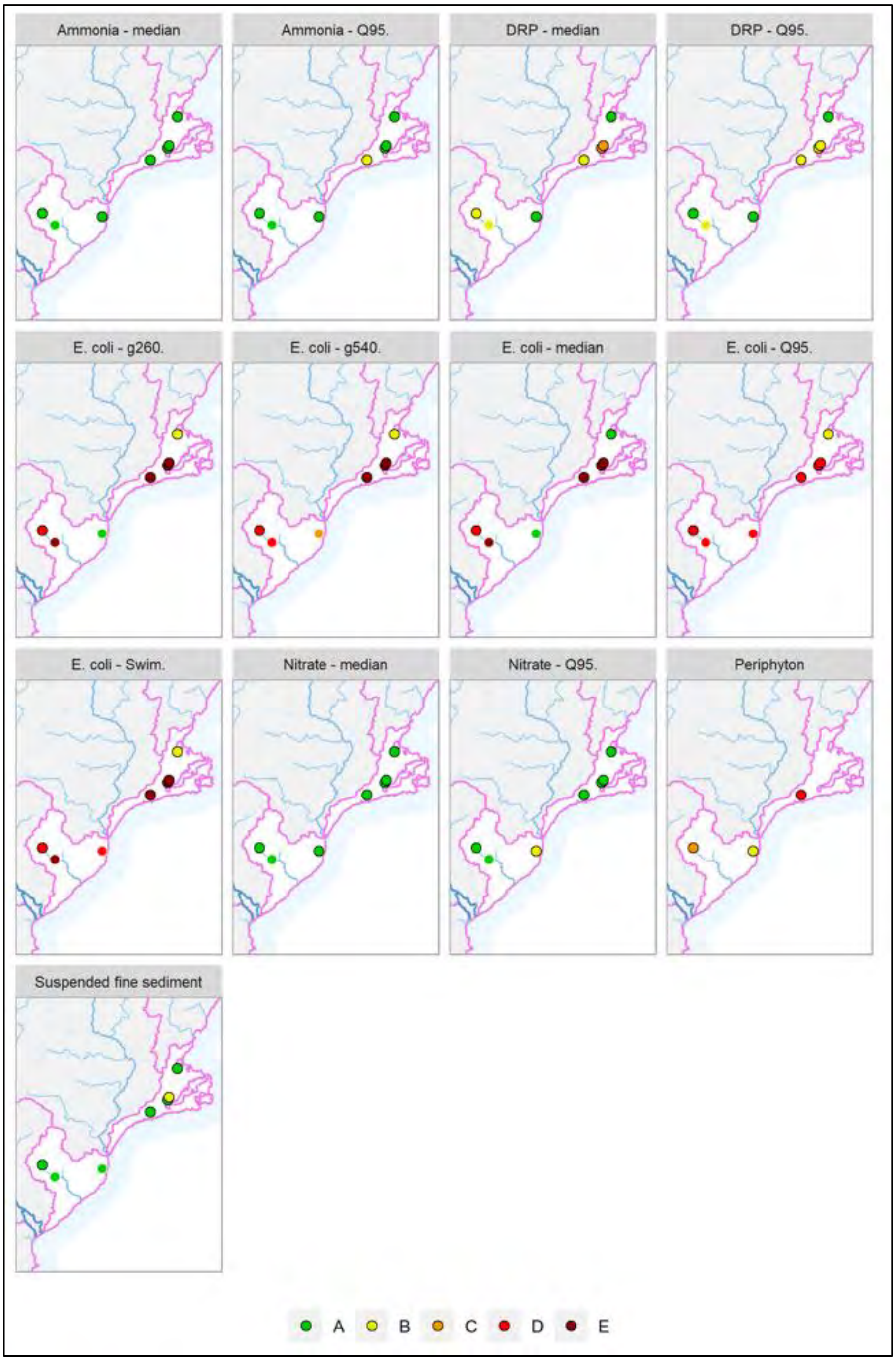


Figure 44 Maps showing Dunedin & Coast FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines.

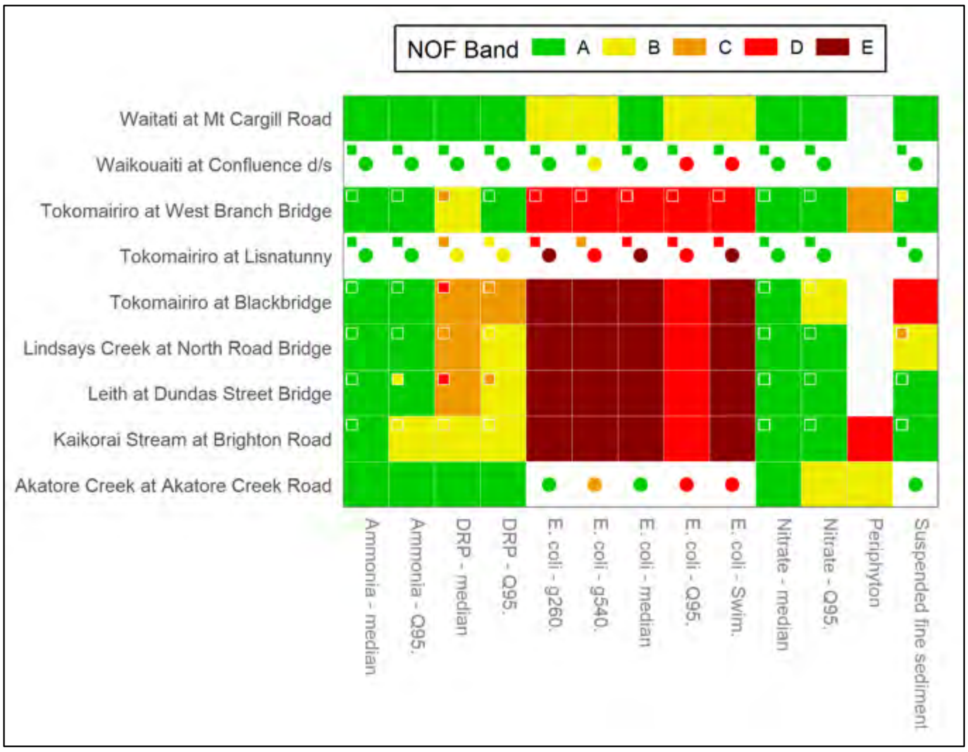


Figure 45 Grading of the river sites of the Dunedin & Coast FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper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

7.1.2.1 Periphyton and Nutrients

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

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

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

7.1.2.2 Toxicants (Rivers)

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

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

7.1.2.3 Suspended fine sediment (Rivers)

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

7.1.2.4 Human health for recreation (Rivers)

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

7.1.3 Trend Analysis: Rivers

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

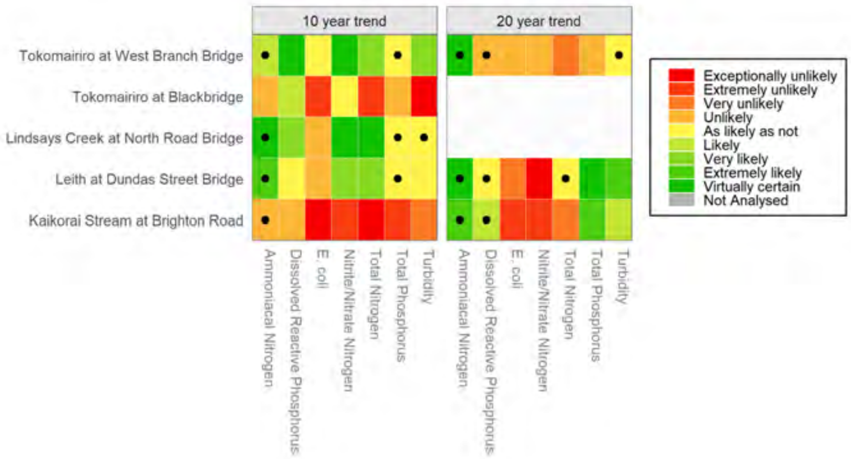


Figure 46 Summary of Dunedin & Coast surface water FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend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

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

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

7.1.4 Groundwater

7.1.4.1 Groundwater State

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

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

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

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

7.1.4.2 Groundwater Trends

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

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

7.1.5 Water quality summary Dunedin & Coast FMU

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

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

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

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

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

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

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

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

8 North Otago FMU

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

8.1.1 North Otago FMU Description

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

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

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

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

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

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

8.1.2 State Analysis Results

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

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

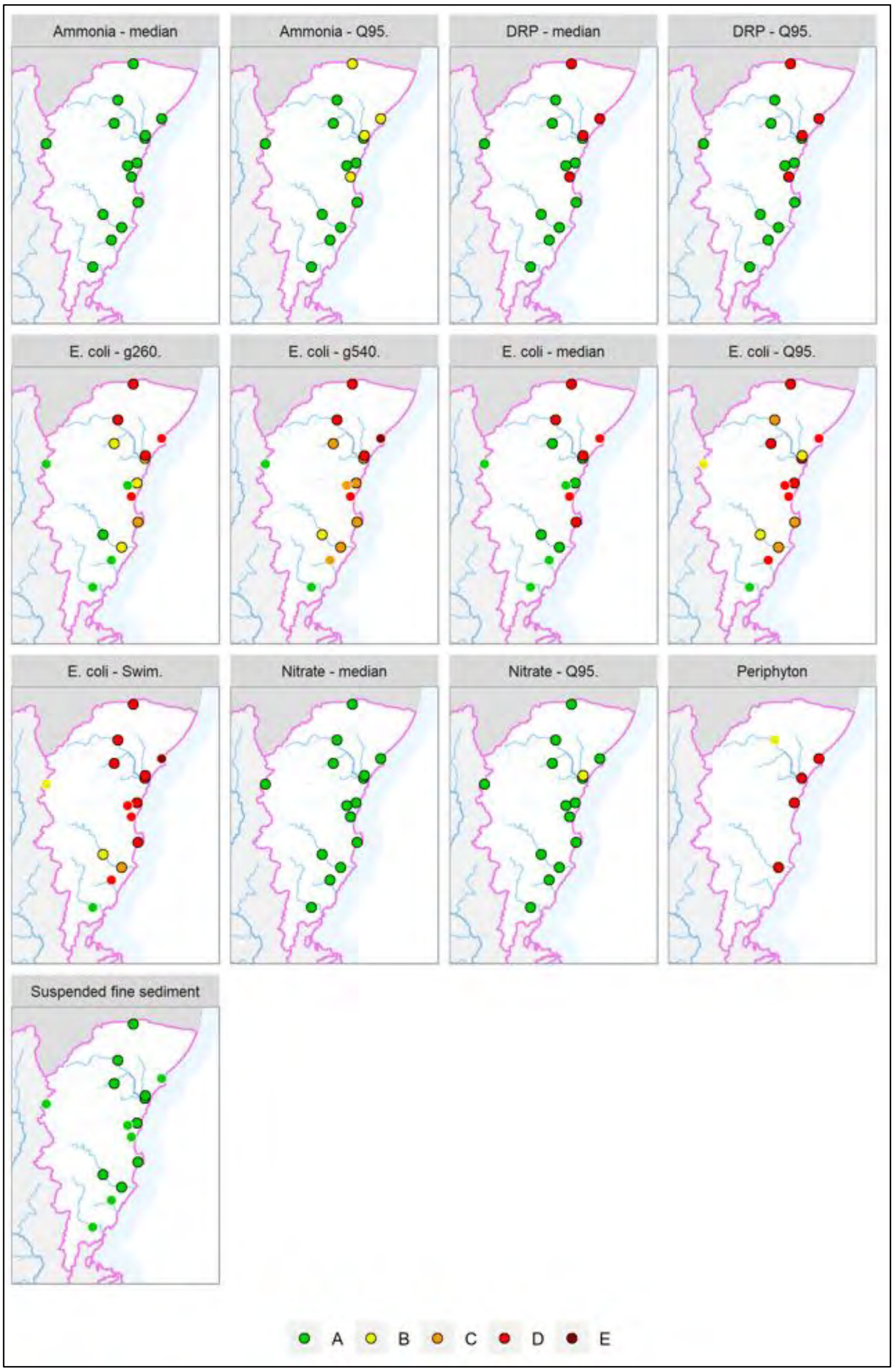

Ammonia - median
Ammonia - Q95.
DRP - median
DRP - Q95.
E. coli - g260.
E. coli - g540.
E. coli - median
E. coli - Q95.
E. coli - Swim.
Nitrate - median
Nitrate - Q95.
Periphyton
Suspended fine sediment
A
B
C
D
E

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

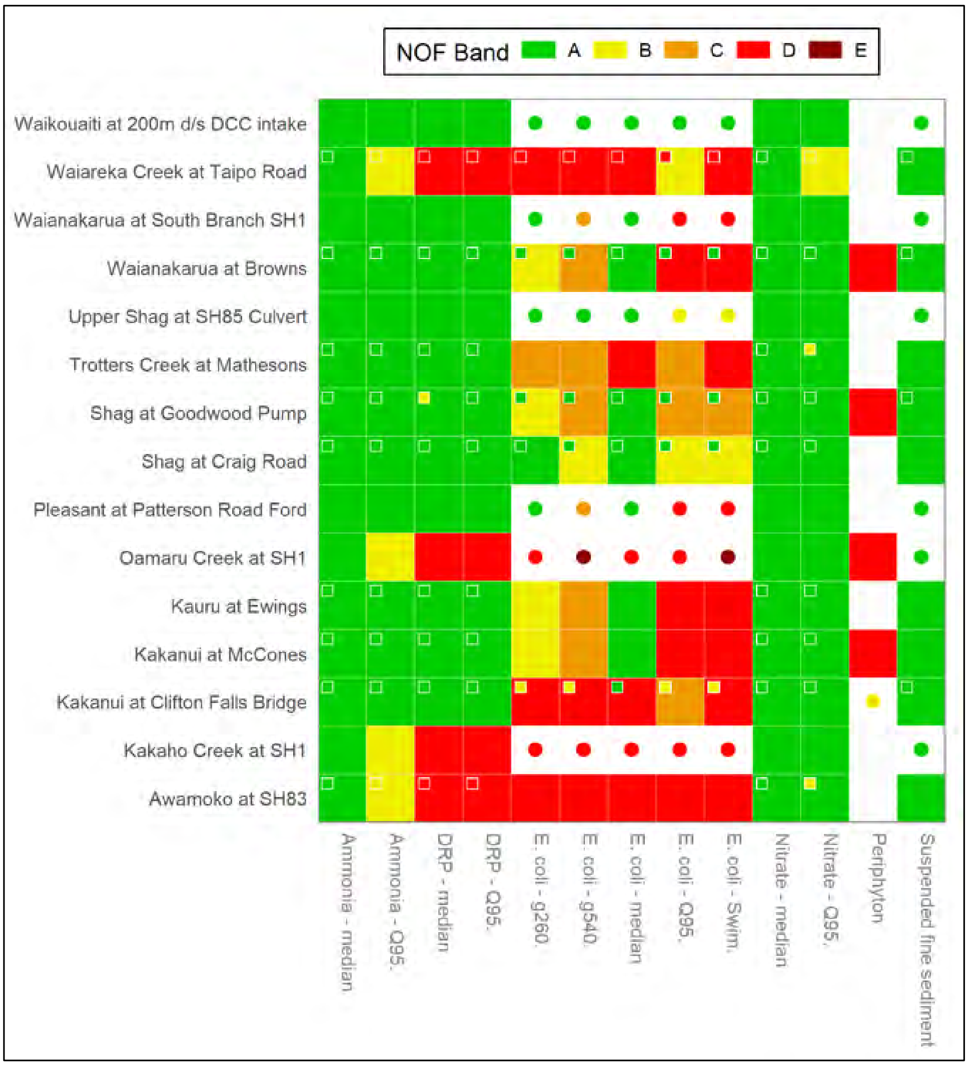


Figure 50 Grading of the river sites of the North Otago FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 *are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in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

8.1.2.1 Periphyton and Nutrients

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

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

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

8.1.2.2 Toxicants (Rivers)

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

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

8.1.2.3 Suspended fine sediment (Rivers)

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

8.1.2.4 Human health for recreation

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

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

8.1.2.5 Trend Analysis: Rivers

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

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

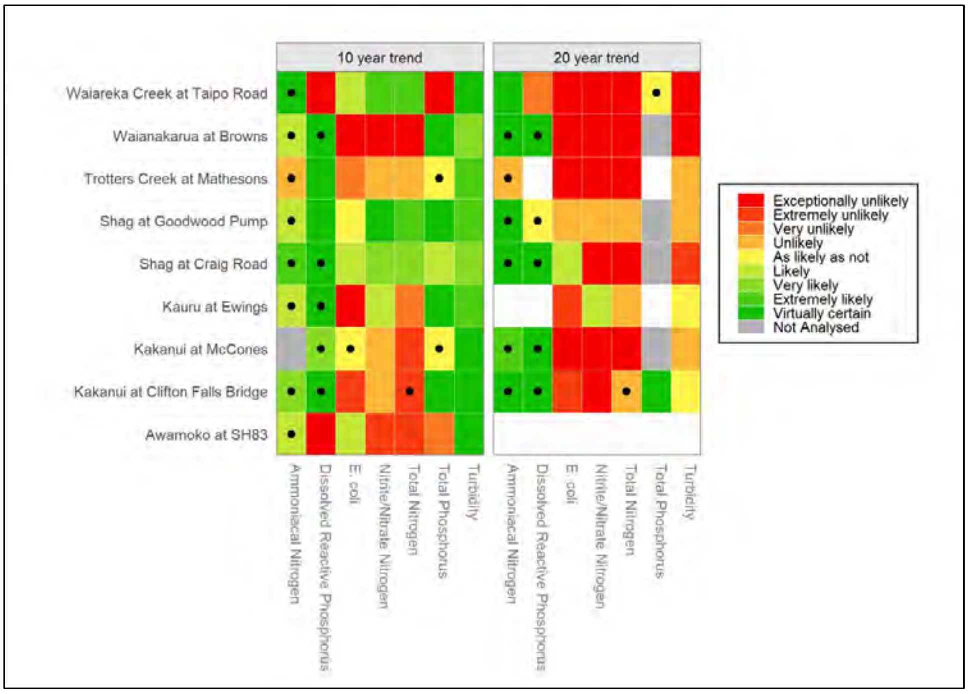


Figure 51 Summary of North Otago FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

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

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

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

8.1.3 Groundwater

8.1.3.1 Groundwater State

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

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

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

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

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

8.1.3.2 Groundwater Trends

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

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

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

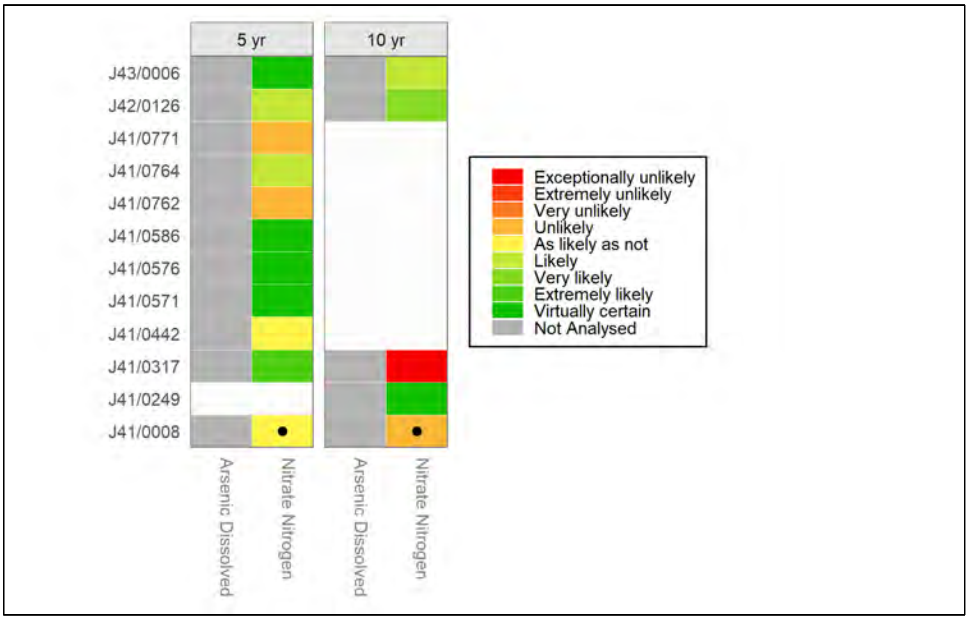


Figure 52: Summary of North Otago FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

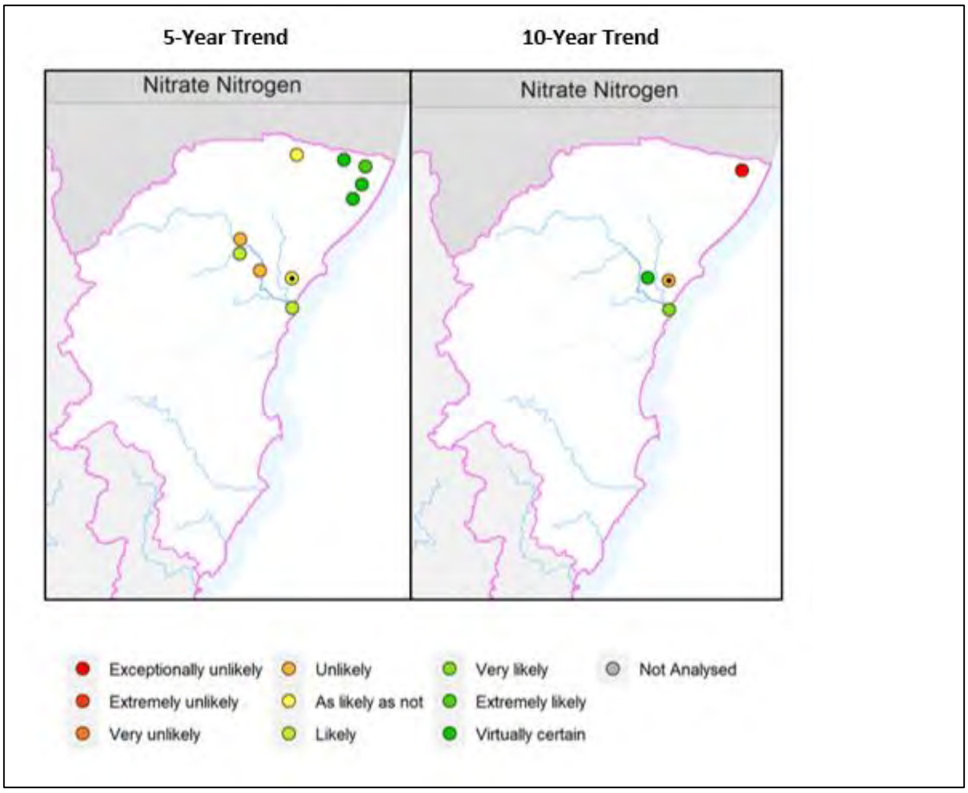


Figure 53: Maps showing summary of North Otago FMU sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 4

8.1.4 Water quality summary North Otago FMU

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

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

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

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

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

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

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

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

9 Catlins FMU

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

9.1.1 Catlins FMU Description

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

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

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

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

9.1.2 State Analysis Results

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

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

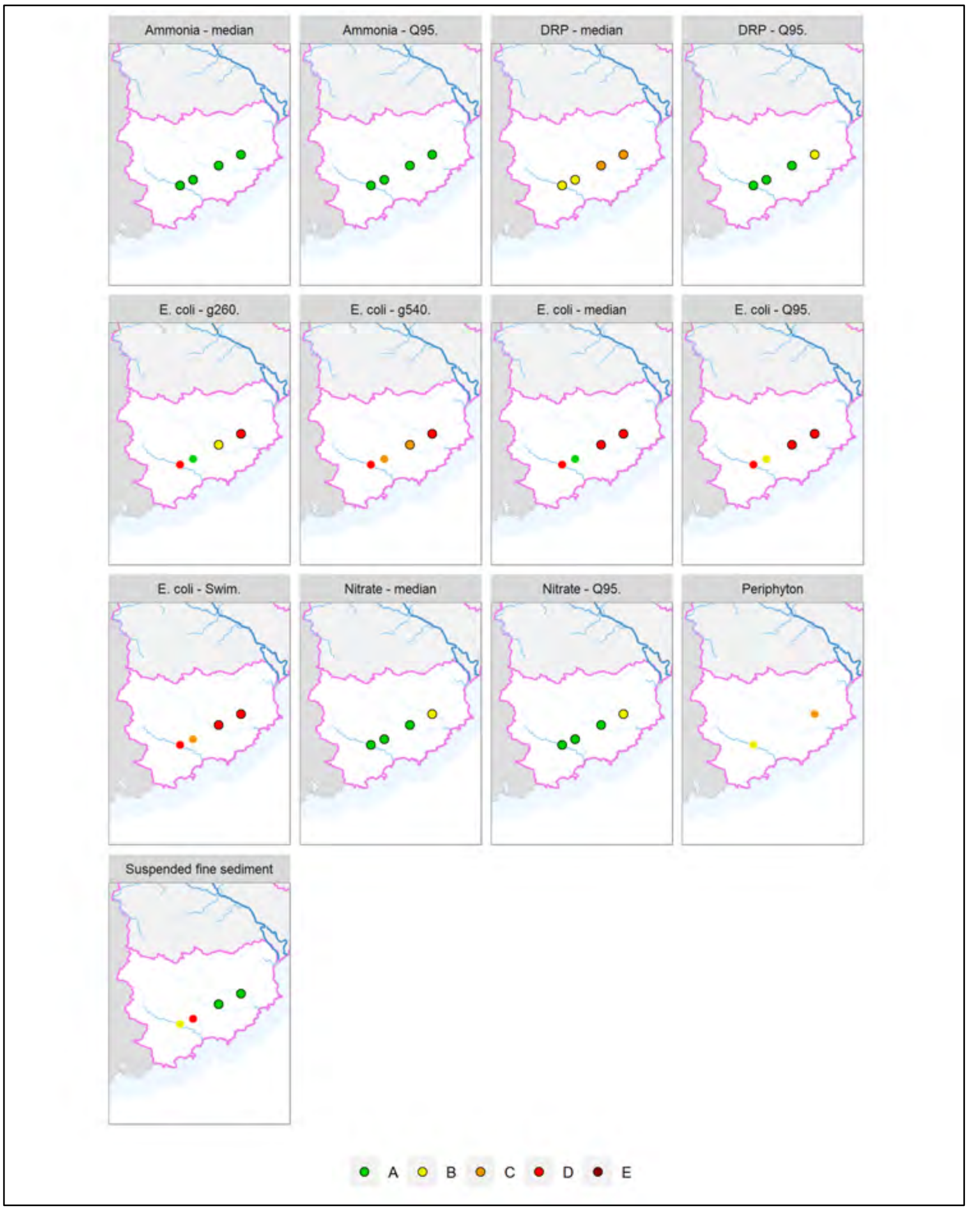


Figure 55 Maps showing Catlins FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines.

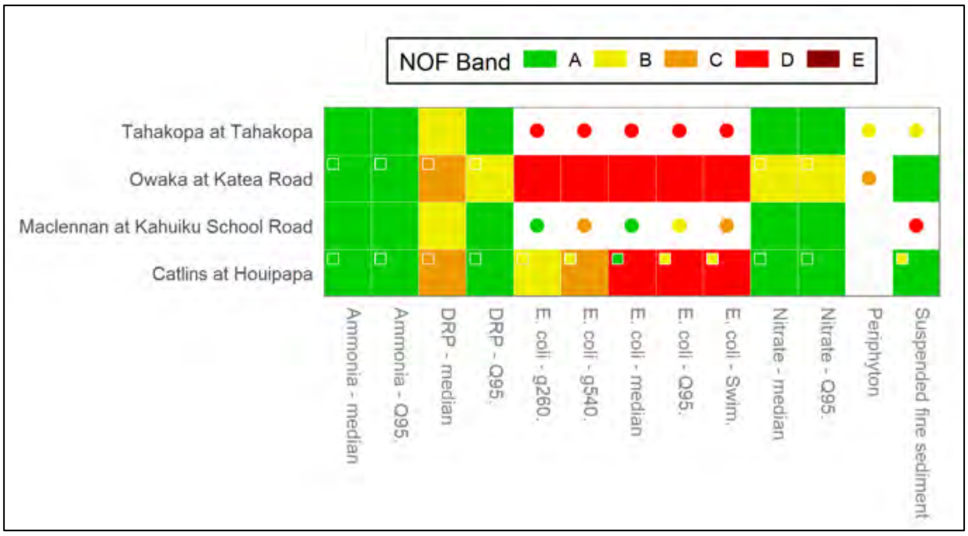


Figure 56 Grading of the river sites of the Catlins FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left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

9.1.2.1 Periphyton and Nutrients

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

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

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

9.1.2.2 Toxicants (Rivers)

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

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

9.1.2.3 Suspended fine sediment (Rivers)

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

9.1.2.4 Health for recreation (Rivers)

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

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

9.1.2.5 Trend Analysis Results – Rivers

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

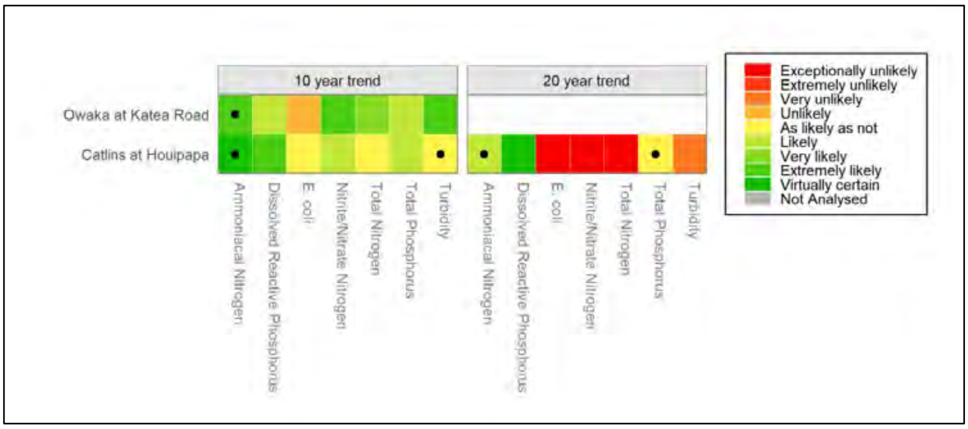


Figure 57 Summary of Catlins FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

9.1.3 Groundwater

9.1.3.1 State

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

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

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

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

9.1.3.2 Trends

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

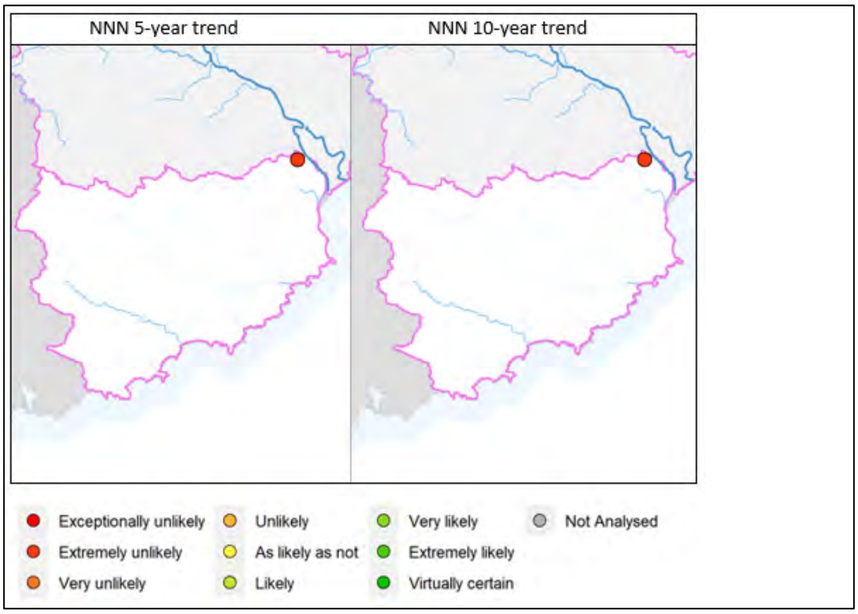


Figure 58: Catlins FMU site categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement.

9.1.4 Water quality summary Catlins FMU

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

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

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

10 Otago Regional Summary

10.1.1 State analysis results

10.1.1.1 Rivers

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

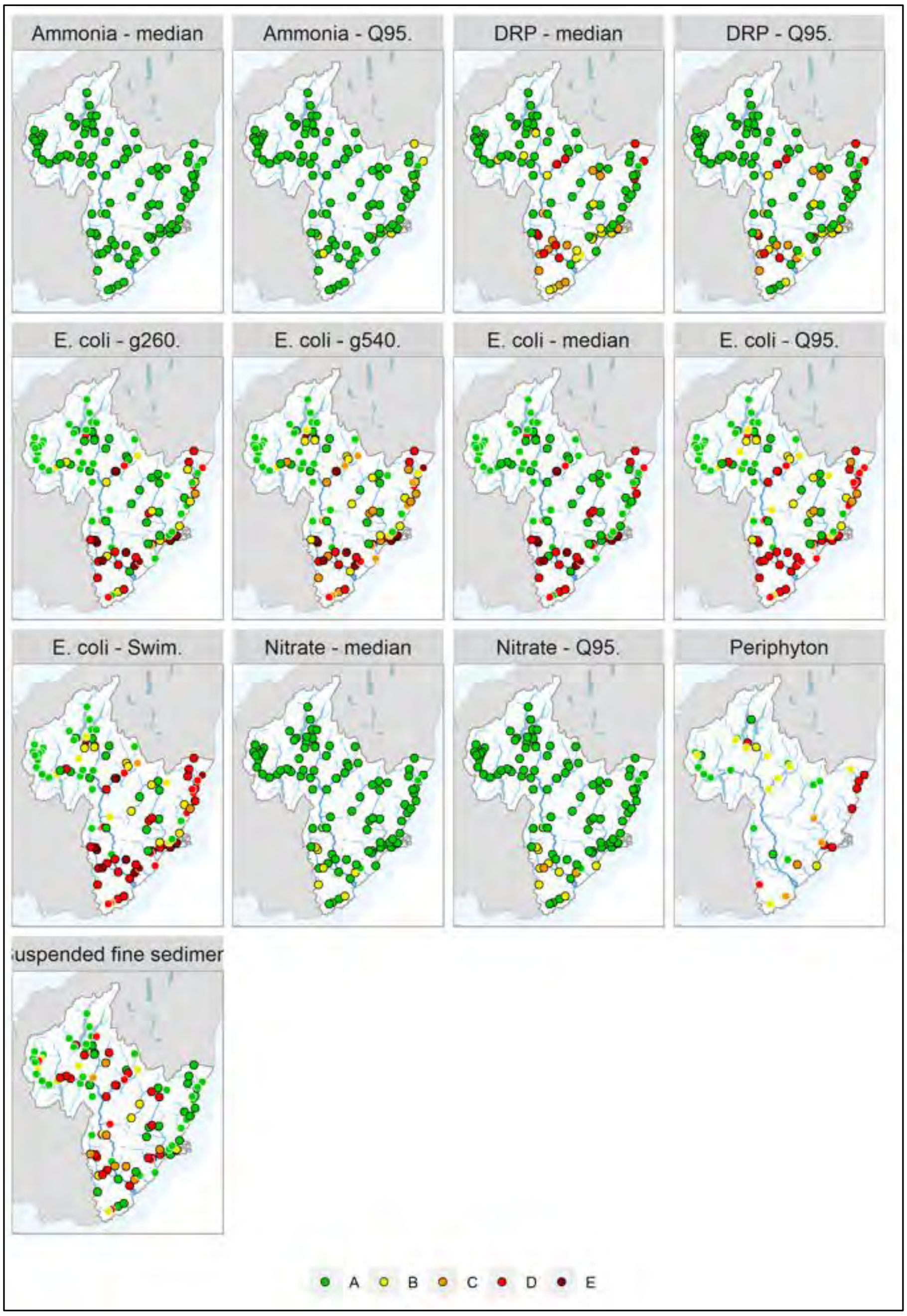


Figure 59: Maps showing river SoE monitoring sites across Otago coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines

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

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

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

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

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

10.1.1.2 Lakes

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

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

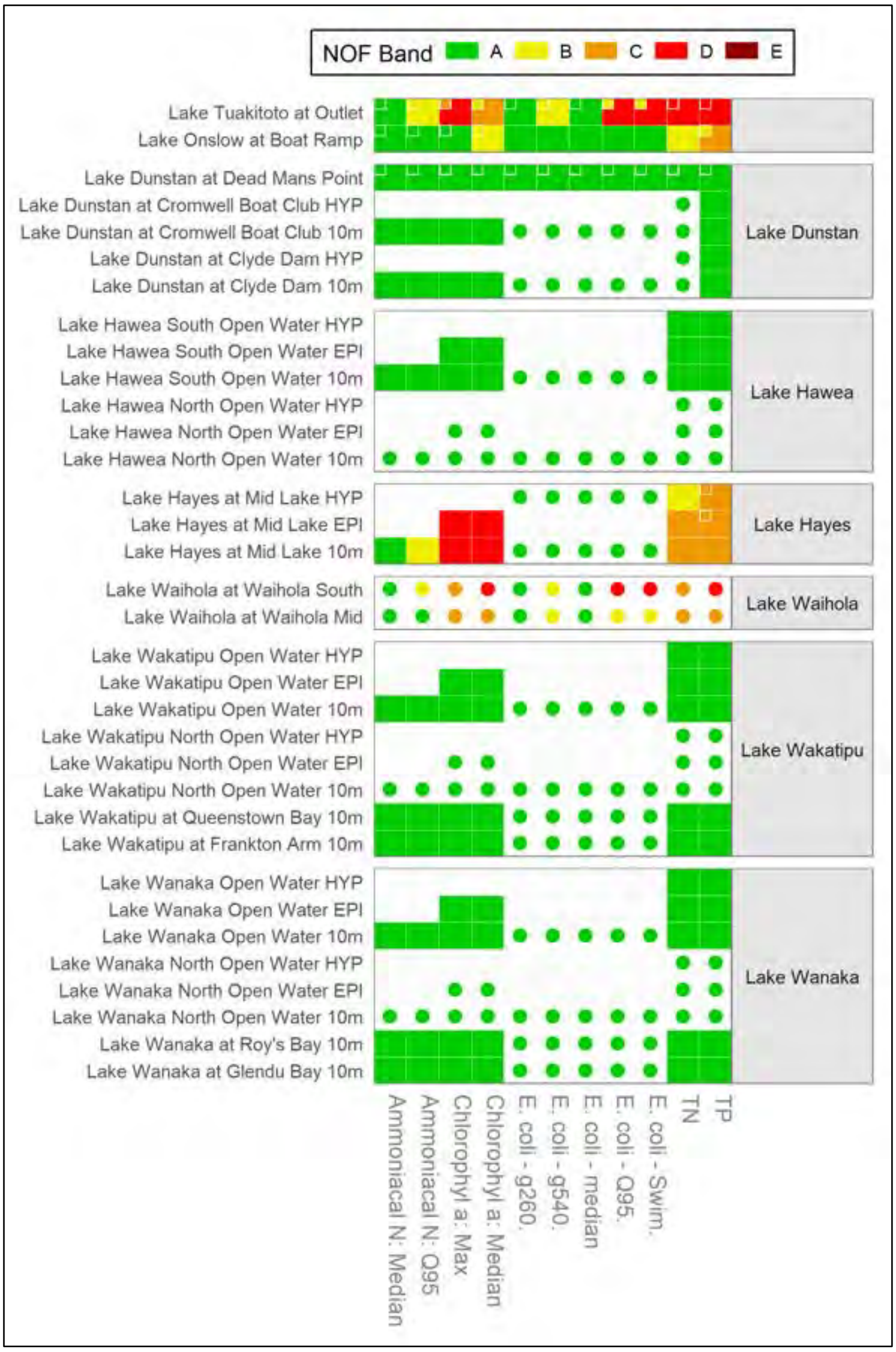


Figure 60: Maps showing lake SoE monitoring sites across Otago coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines

10.1.1.3 Groundwater

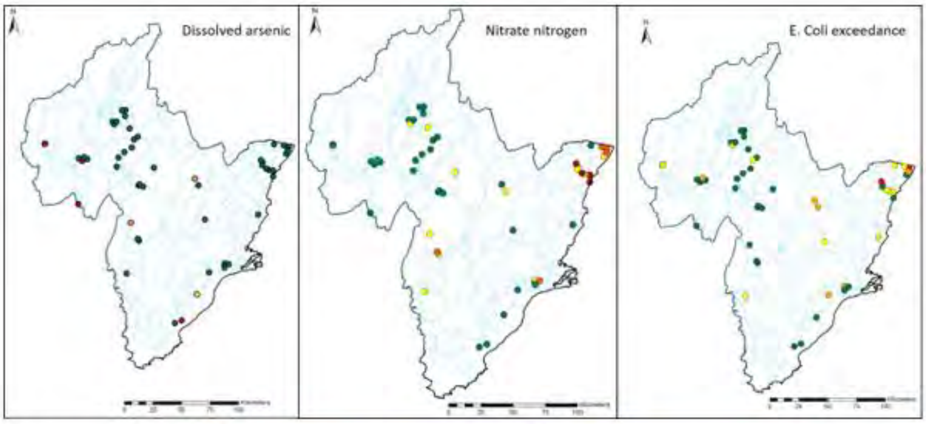
This report analysed groundwater quality against the DWSNZ MAV for *E. coli*, nitrate-N, and dissolved arsenic (*Table* 2). Similar to the river and lakes water data, the state of groundwater quality also varies across Otago, where groundwater quality is good in some areas and poor in others. There was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

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

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

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

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



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

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

10.1.2 Trend Analysis results

10.1.2.1 Rivers

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

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

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

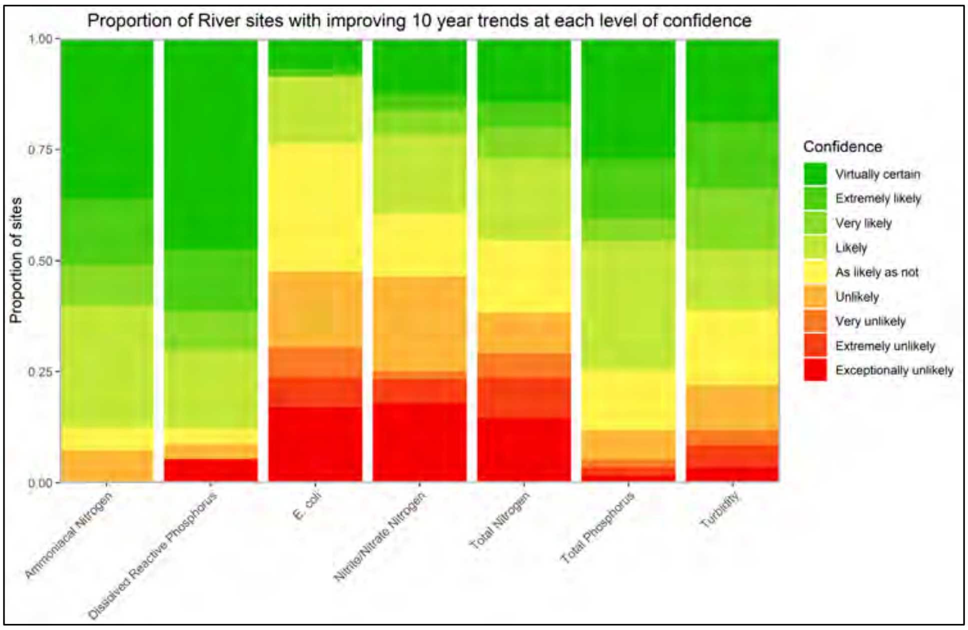


Figure 62 River sites classified by confidence that their 10-year raw water quality trend direction indicated improving water quality. LWP (2020b). Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

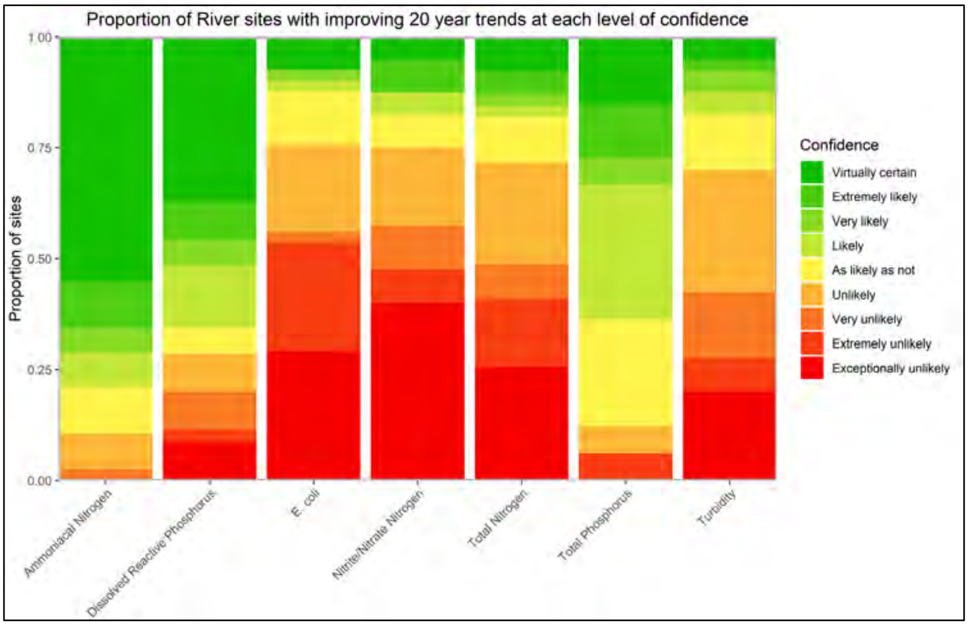


Figure 63 River sites classified by confidence that their 20-year raw water quality trend direction indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends

10.1.2.2 Lakes

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

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

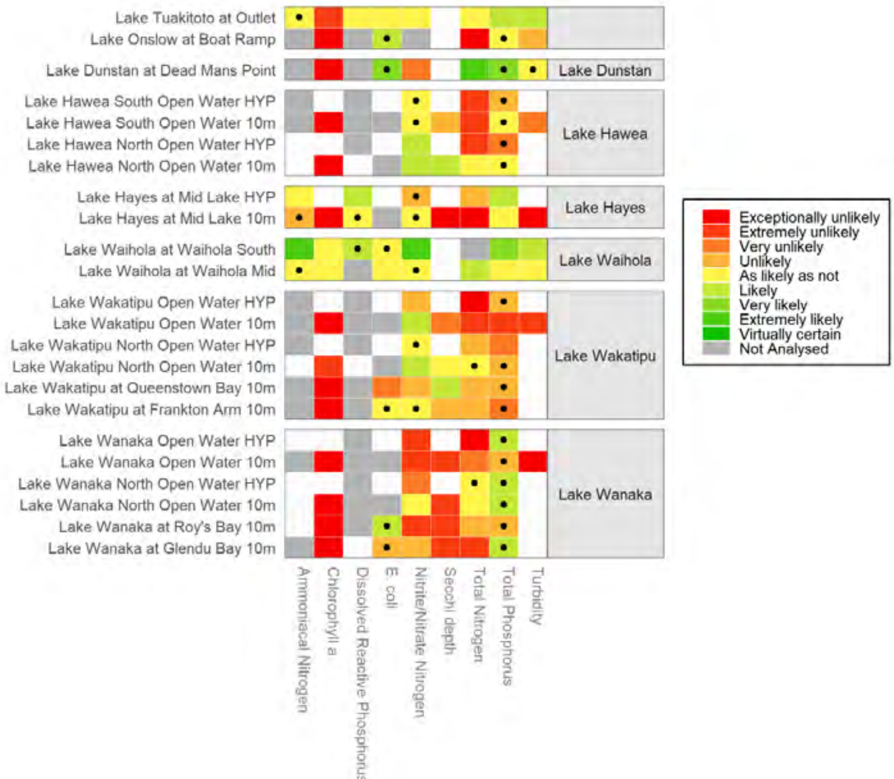
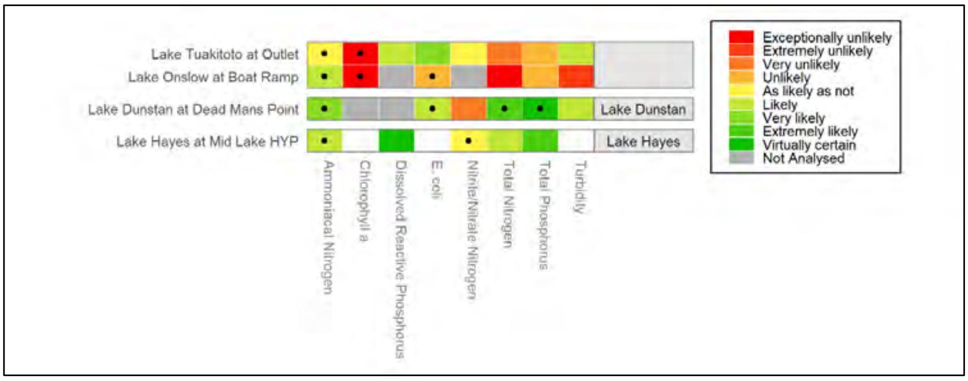


Figure 64 Summary of Otago Lake sites categorised according to the level of confidence that their 5-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified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

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

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

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



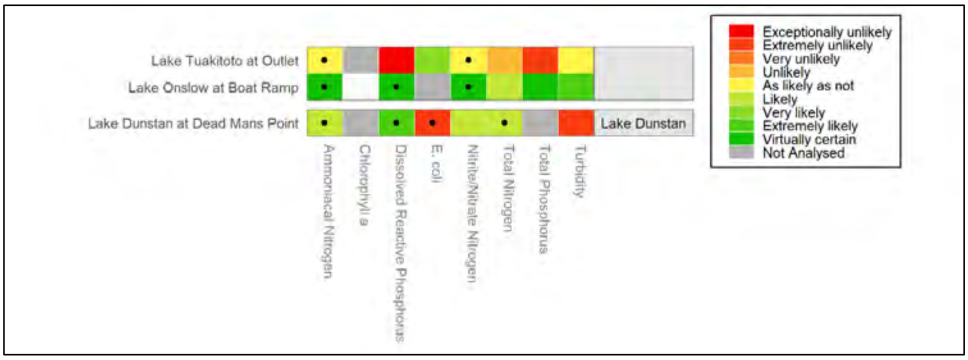


Figure 65 Summar*y of Otago Lake sites categorised according to the level of confidence that their 10- and 20-year (top and bottom figures, respectively) raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as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

10.1.2.3 Groundwater

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

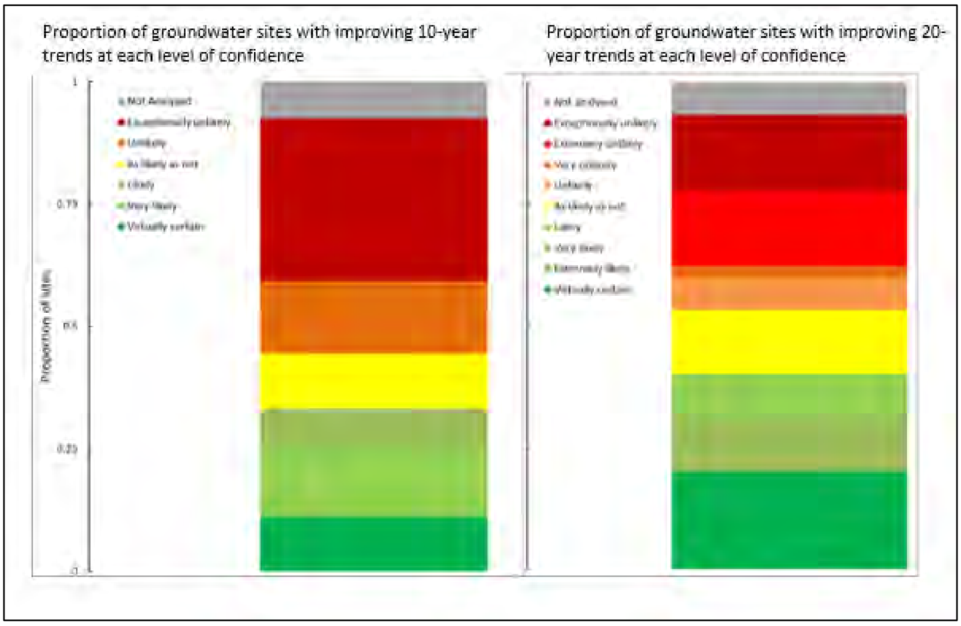


Figure 66: Groundwater sites classified by confidence that their 10- and 20-year trends in groundwater nitrate-N concentrations indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends

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

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

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

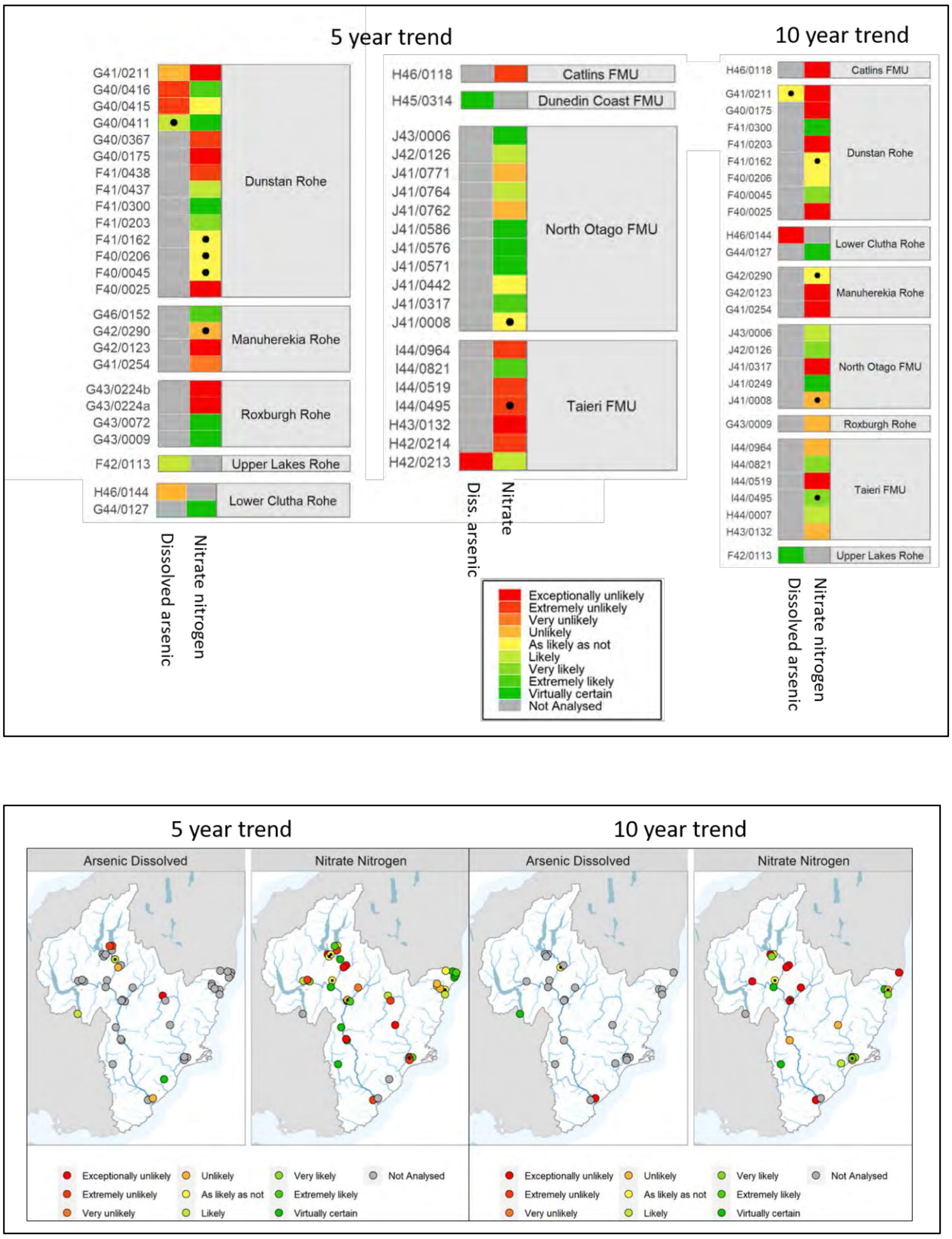


Figure 67: Map of groundwater sites classified by confidence that their 5-year and 10-year raw water quality trend direction indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

10.1.3 Otago water quality summary and discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

11 References

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12 Appendix 1 Water Quality Summary Results

12.1 River - Dissolved Reactive P and Nitrate-N

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

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

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

12.2 Rivers - Clarity and *E. Coli*

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

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

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

12.3 Rivers - Ammonia and Periphyton

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

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

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

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

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

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

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

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

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

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

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

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

13 Appendix 3

13.1 State Assessment Methods

13.1.1 Handling censored values

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

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

13.1.2 Time period for assessments

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

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

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

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

13.1.3 Calculation of water clarity

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

$$\ln(CLAR) = 1.21 - 0.72 \ln(TURB)$$

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 were calculated first, and then calculated median clarity using the above relationship in order to grade the sites against the NPS-FM suspended fine sediment attribute.

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

13.1.4 pH Adjustment of Ammonia

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

13.1.5 Evaluation of compliance statistics

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

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

13.2 Trend Assessment Methods

13.2.1 Sampling dates, seasons, and time periods for analyses

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

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

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

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

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

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

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

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

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

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

13.2.2 Handling censored values

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

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

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

13.2.3 Seasonality assessment

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

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

13.2.4 Analysis of trends

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

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

13.2.5 Trend direction assessment

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

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

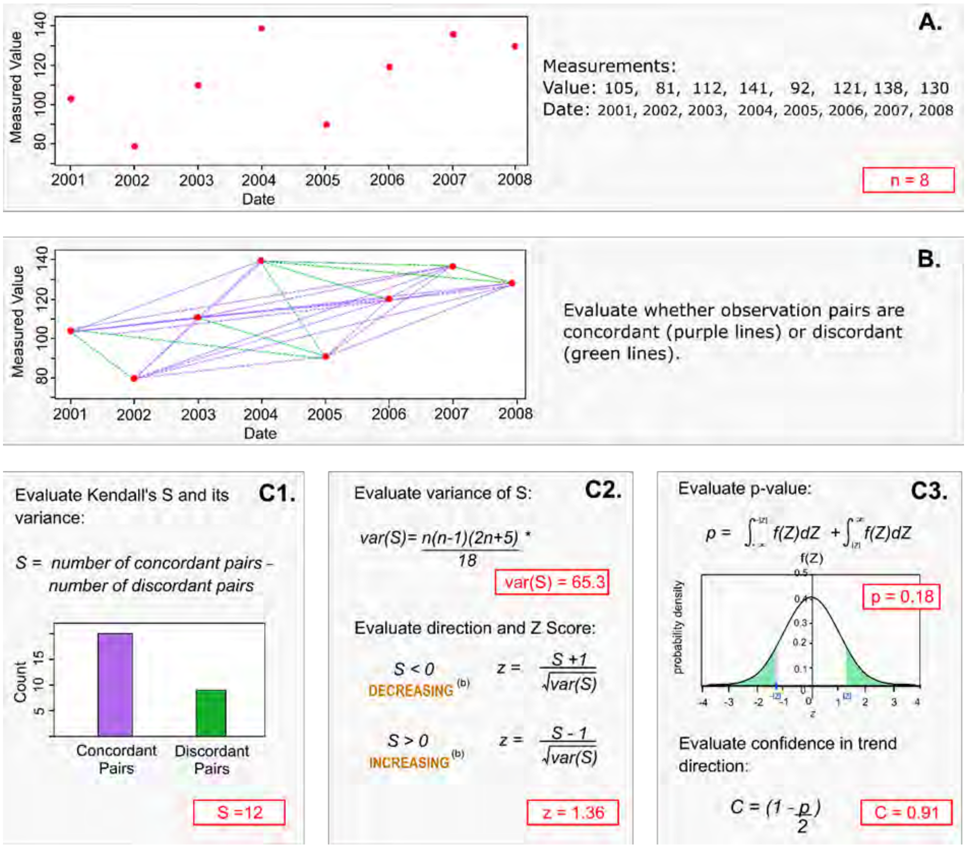

Figure 68. Pictogram of the steps taken in the trend direction assessment to calculate the Kendall S statistic and its confidence in trend direction. Notes: [a] the calculation of the variance in S has some adjustments to account for ties (numerically equal values) and censored values. Details of these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

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

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

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

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

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

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

13.2.6 Assessment of trend rate

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

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

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

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

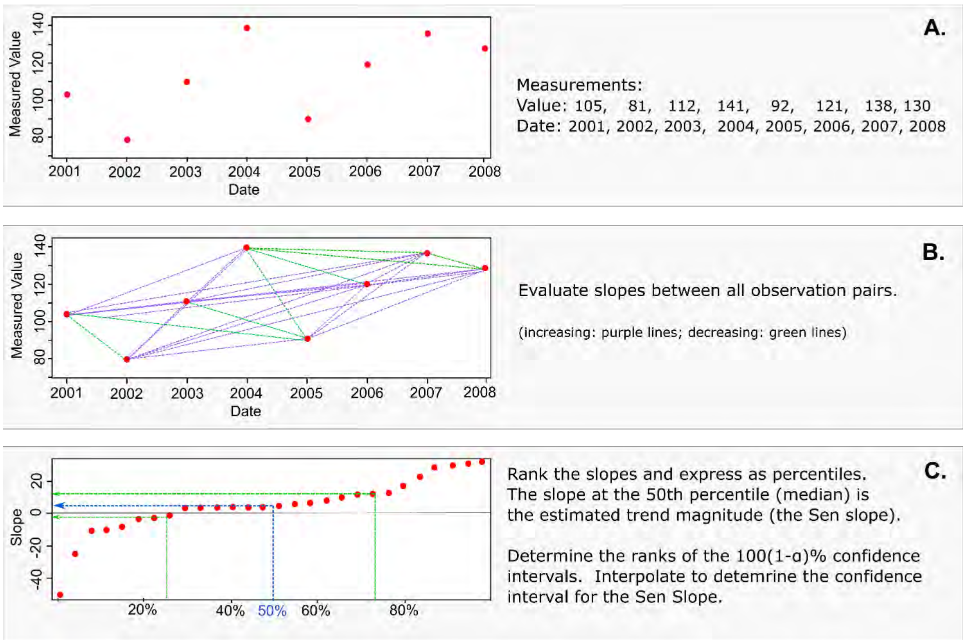

Figure 69 Pictogram of the calculation of the Sen slope, which is used to characterise trend rate.

13.2.7 Interpretation of trends

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

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

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

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

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

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

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

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

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

13.3 LWP Output

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

Table 16 Description of Supplementary Data: Trends

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

13.3.1 River data availability

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

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

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

13.3.2 Evaluated trends

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

13.4 Groundwater

13.4.1 Groundwater data availability

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

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

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

13.4.2 Evaluated trends

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

13.5 Lakes

13.5.1 Lake Data Availability

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

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

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

13.5.2 Evaluated trends

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

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Contents

Executive Summary

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

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

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

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

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

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

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

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

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

1 Introduction

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

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

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

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

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

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

[1] ORC has not yet defined baseline state.

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

2 Otago Region

2.1 Regional Description

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

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

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

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

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

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

2.2 Freshwater management units

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

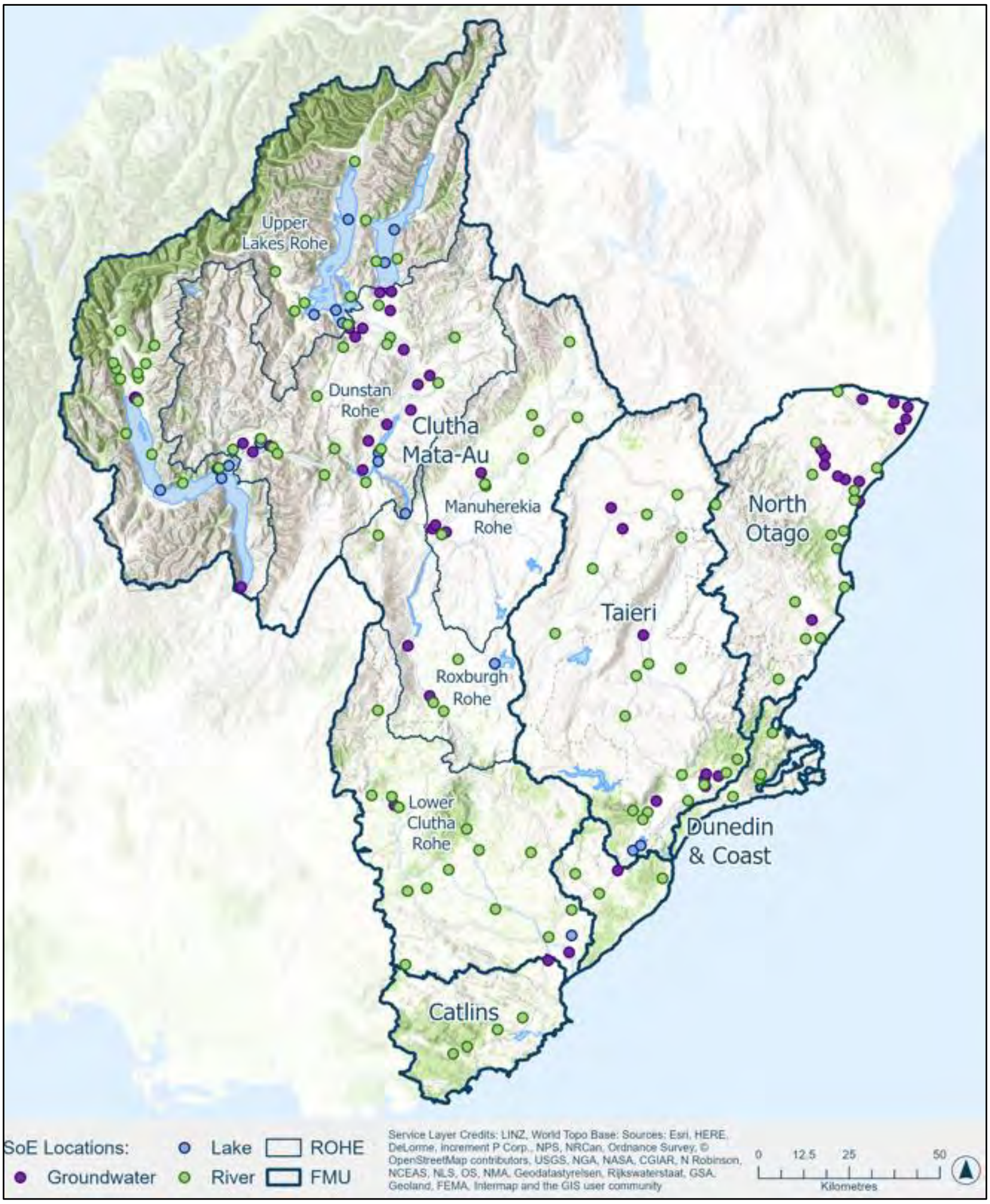


Figure 1 Map showing the FMU and Rohe boundaries, State of Environment monitoring site locations are also shown.

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

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

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

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

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

3 ORC monitoring programme

3.1 Water Quality Sites

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

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

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

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

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

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

3.2 Surface water quality variables

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

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

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

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

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

3.2.1 Phytoplankton, Periphyton and Nutrients

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

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

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

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

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

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

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

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

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

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

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

3.2.2 Toxicants

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

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

3.2.3 Suspended sediment

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

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

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

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

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

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

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

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

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

3.2.5 Ecological Assessments

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

3.3 Groundwater quality parameters

3.3.1 Escherichia coli (*E. coli*)

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

3.3.2 Dissolved arsenic

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

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

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

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

3.3.3 Nitrate nitrogen

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

4 Methods

4.1 Water Quality State Analysis

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

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

4.1.1 Data Collection and Grading of Attributes

4.1.1.1 River and Lakes

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

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

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

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

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

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

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

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

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

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

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

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

4.1.1.2 Groundwater

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

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

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

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

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

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

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

4.2 Water Quality Trend Analysis

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

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

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

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

Table 3.

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

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

4.2.1 Interpretation of Trends

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

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

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

5 Clutha Mata-Au FMU

5.1 Upper Lakes Rohe

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

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

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

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

5.1.1 River and Lake State Analysis Results

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

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

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

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

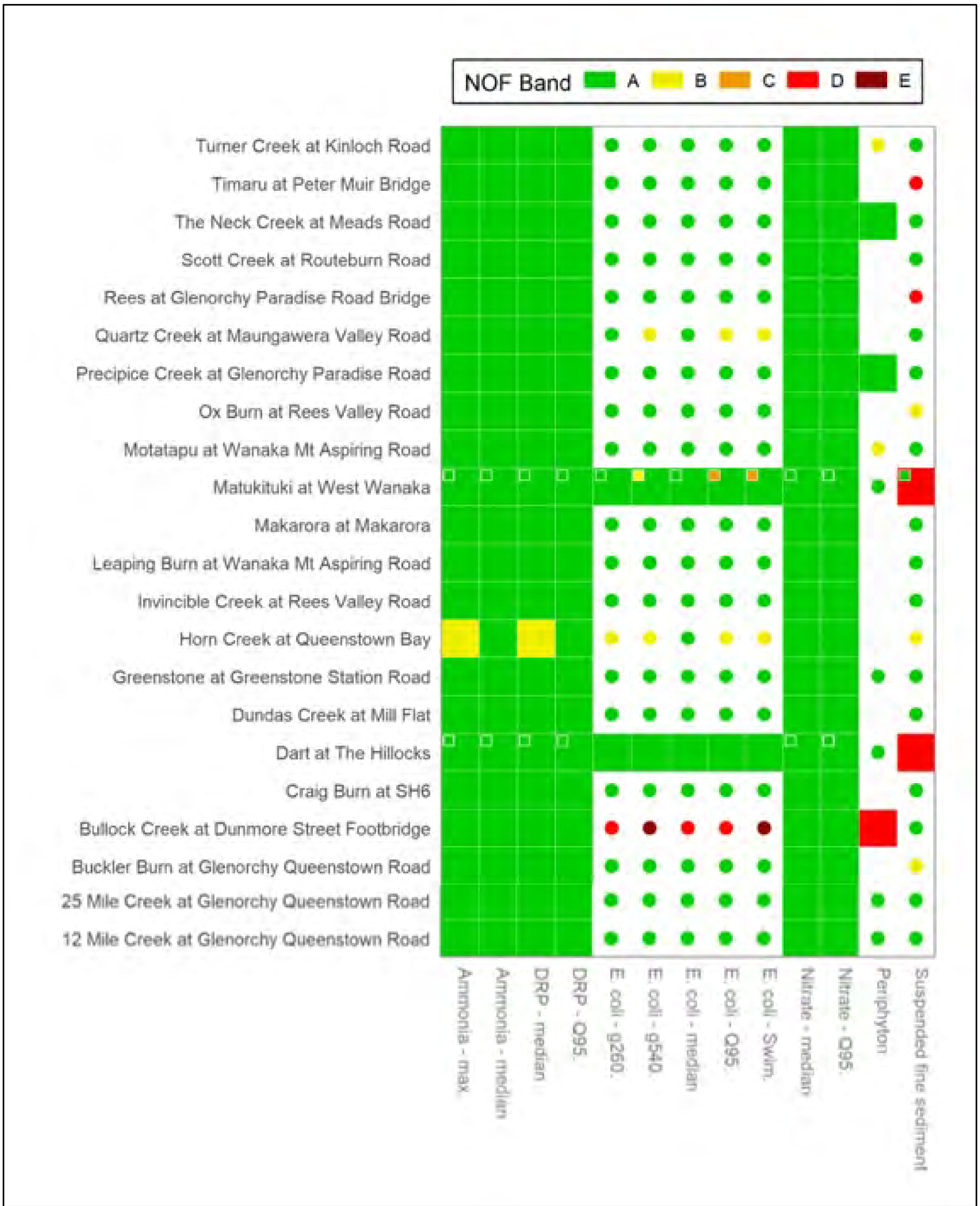


Figure 4 Grading of the river sites of the Upper Lakes Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper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

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

5.1.2 Phytoplankton, Periphyton and Nutrients

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

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

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

5.1.2.1 Toxicants

NOF attribute bands for NH4-N and nitrate-N (measured as NNN) toxicity (Figure 4) show excellent protection levels against toxicity risk for all Upper Lakes Rohe river and lake SoE monitoring sites, with all sites returning an 'A' band (highest level of protection) for NH4-N; and all sites returning an 'A' band for NNN. The only exception is the maximum NH4-N concentration at Horn Creek which achieves an attribute band 'B'.

5.1.2.2 Suspended fine sediment (Rivers)

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

5.1.2.3 Human health for recreation

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

5.1.3 River and Lake Trend Analysis Results

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

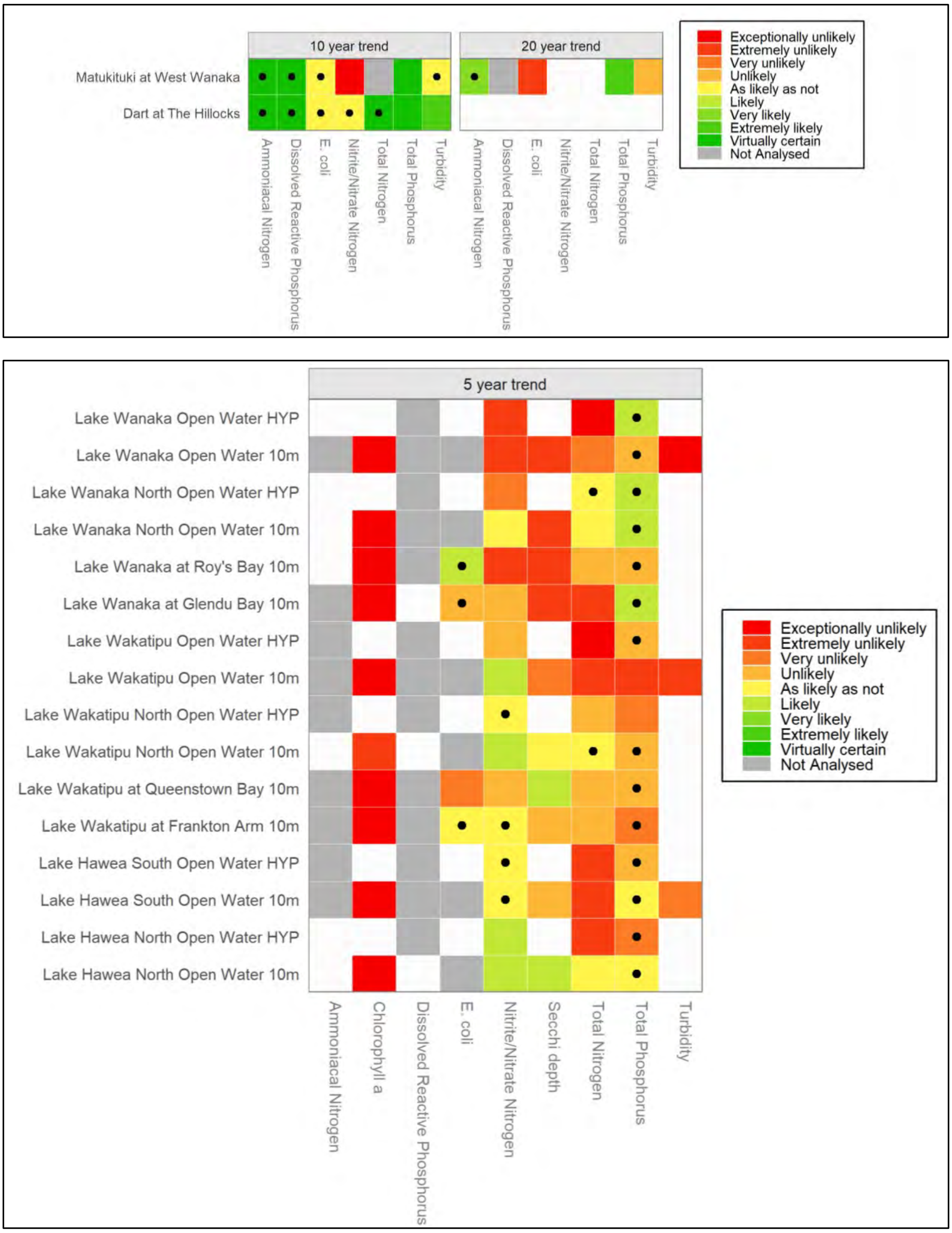


Figure 6 Summary of Upper Lakes sites (rivers top, lakes bottom) categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero

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

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

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

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

5.1.4 Groundwater State Results

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

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

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

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

5.1.5 Groundwater Trends

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

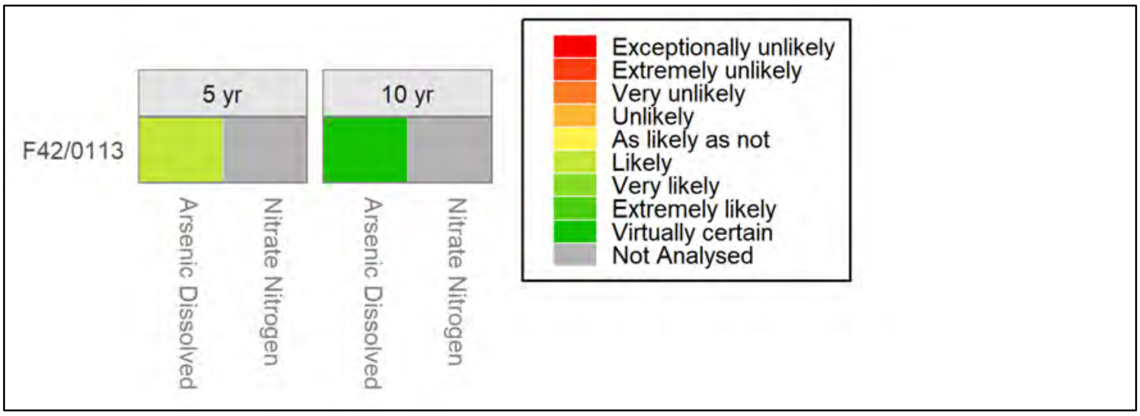


Figure 7 Summary of the Upper Lakes groundwater monitoring sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement.

5.1.6 Water quality summary and discussion: Upper lakes Rohe

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

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

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

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

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

[13] See accompanying report 'ORCRiverState_072017to062022' and Appendix 1

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

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

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

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

5.2 Dunstan Rohe

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

5.2.1 Dunstan Rohe Description

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

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

5.2.2 River and Lake: State Analysis

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

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

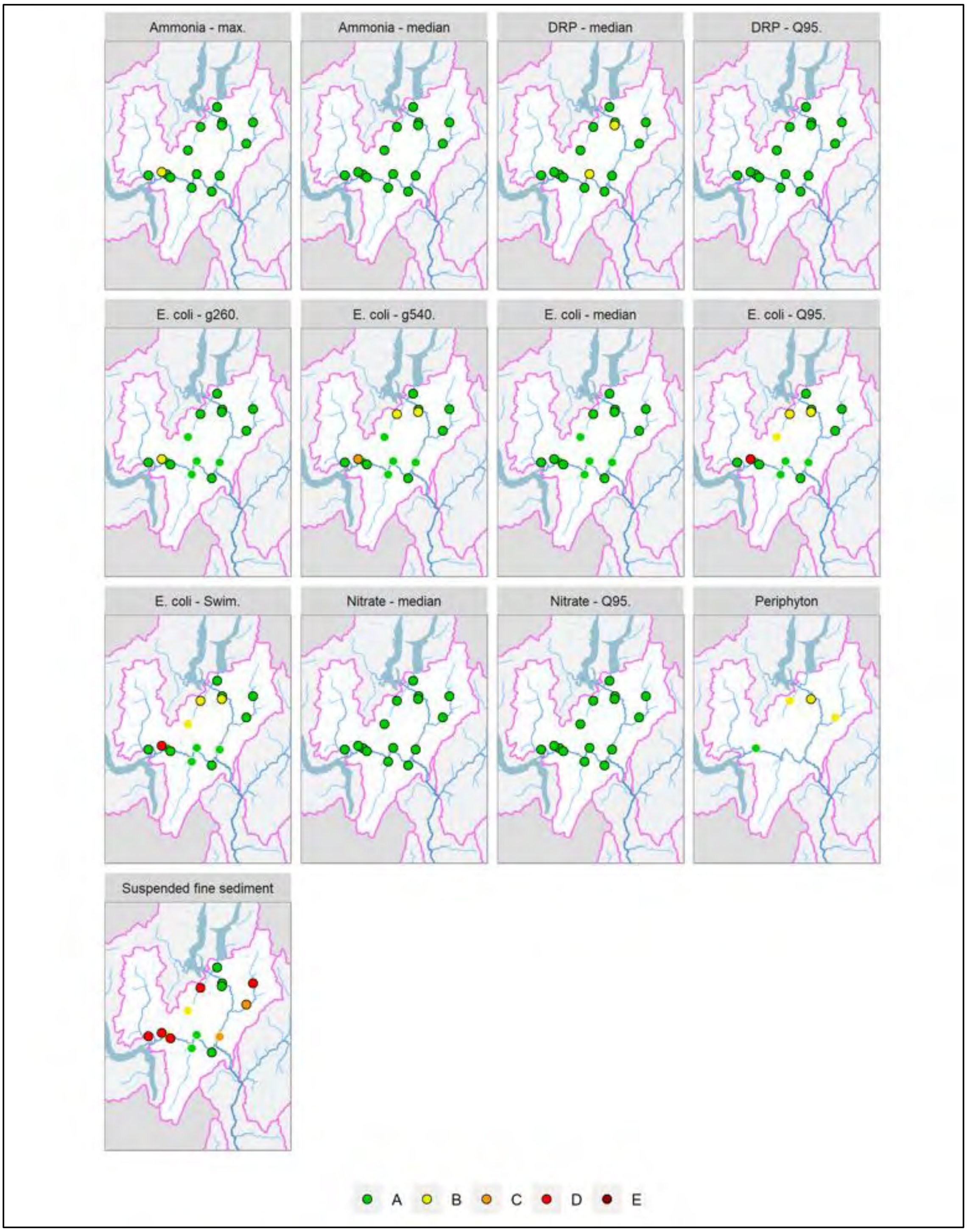


Figure 9 Maps showing Dunstan Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.

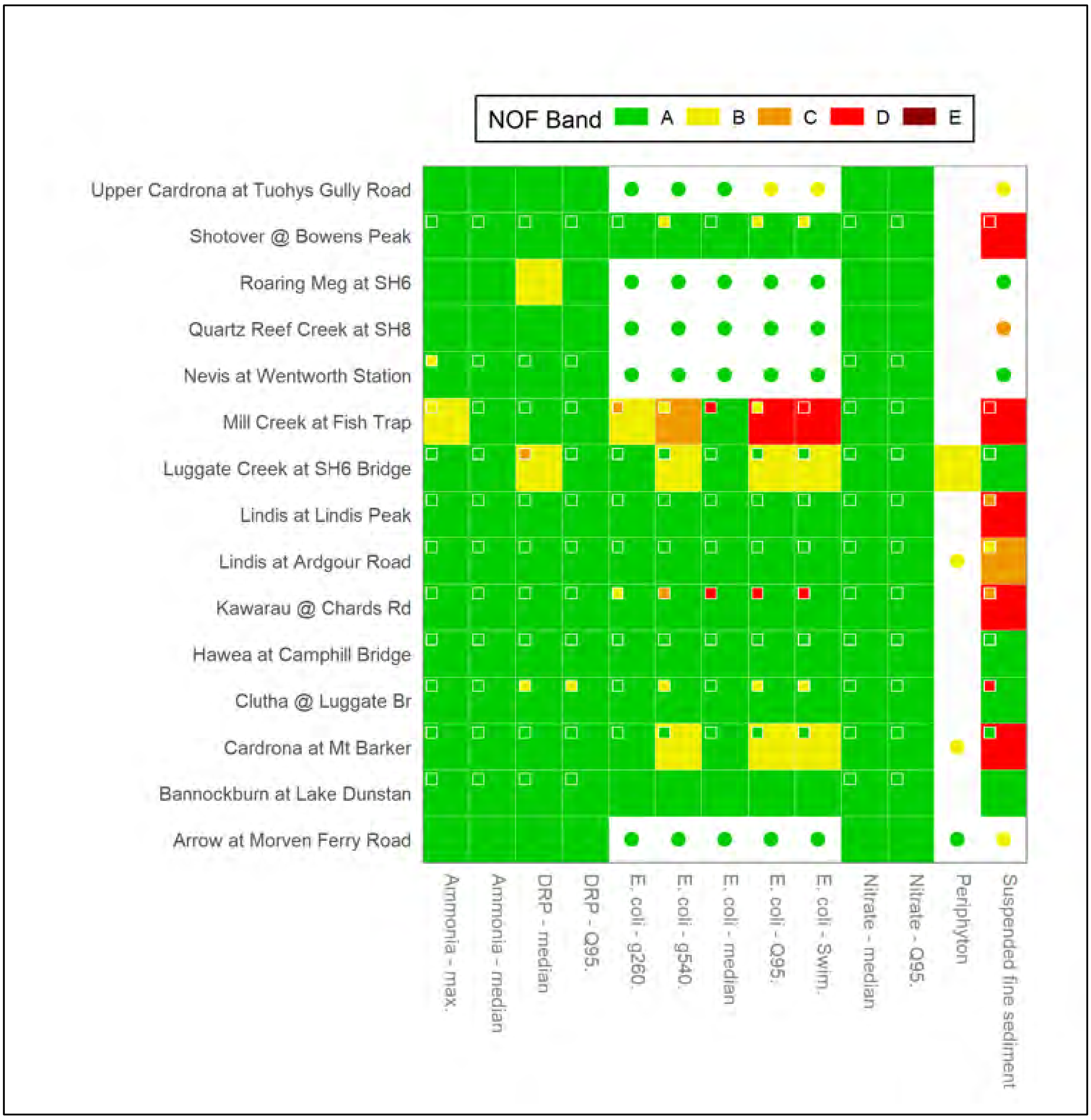


Figure 10 Grading of the river sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left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

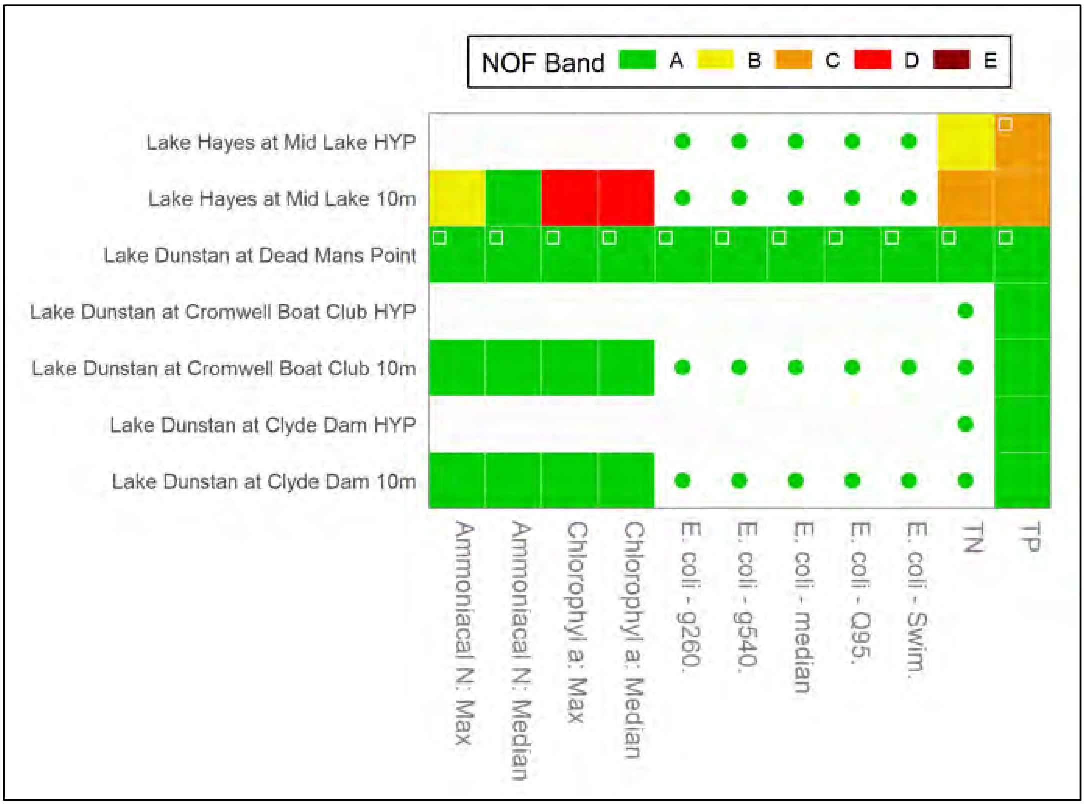


Figure 11 Grading of the lake sites of the Dunstan Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements in are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left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

5.2.2.1 Phytoplankton, Periphyton and Nutrients

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

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

Appendix 1 gives DRP and NNN results, as both are required for periphyton growth. Mill Creek has the highest median NNN concentration (0.35 mg/l) and the third highest DRP concentration. Luggate Creek, although having the highest DRP concentration, has a low NNN concentration (0.0018 mg/l) compared to other sites in the Rohe.

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

5.2.2.2 Toxicants

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

5.2.2.3 Suspended fine sediment (Rivers)

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

5.2.2.4 Human health for recreation (Rivers and lakes)

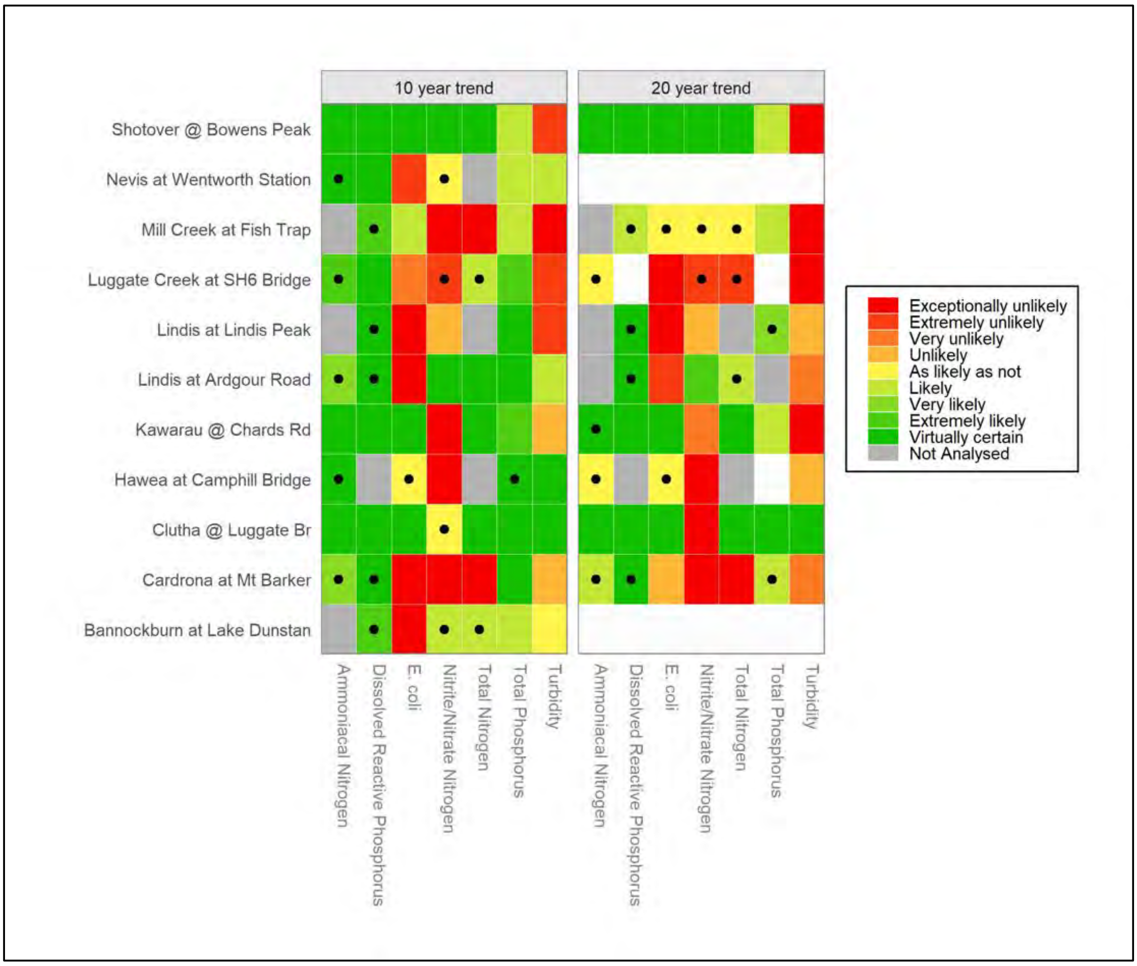
Figure 10 summarise river compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Compliance is generally excellent across in the Dunstan Rohe, with all sites other than Mill Creek having bacterial water quality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

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

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

5.2.3 River and Lake Trend Analysis

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



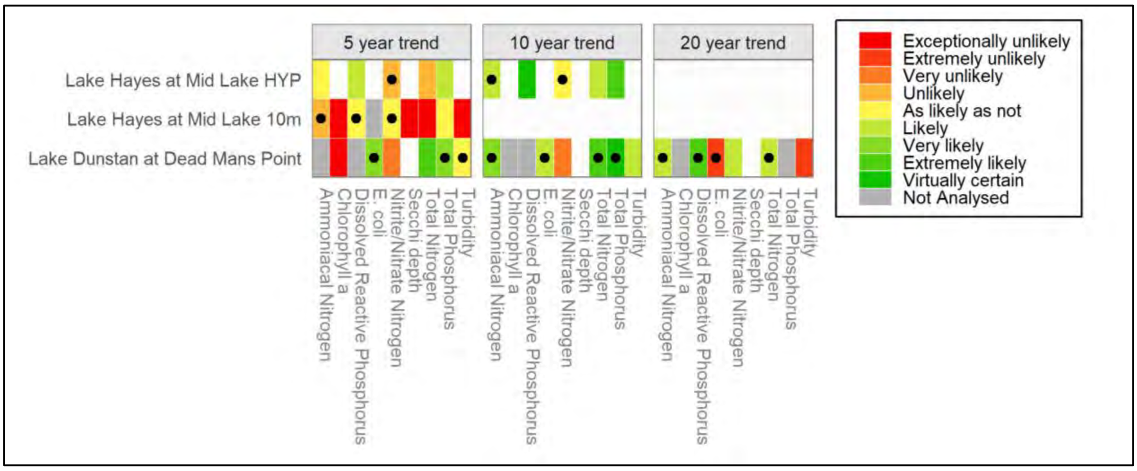


Figure 12 Summary of Dunstan Rohe trends categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot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

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

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

5.2.4 Groundwater State

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

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

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

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

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

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

5.2.5 Groundwater Trends

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

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

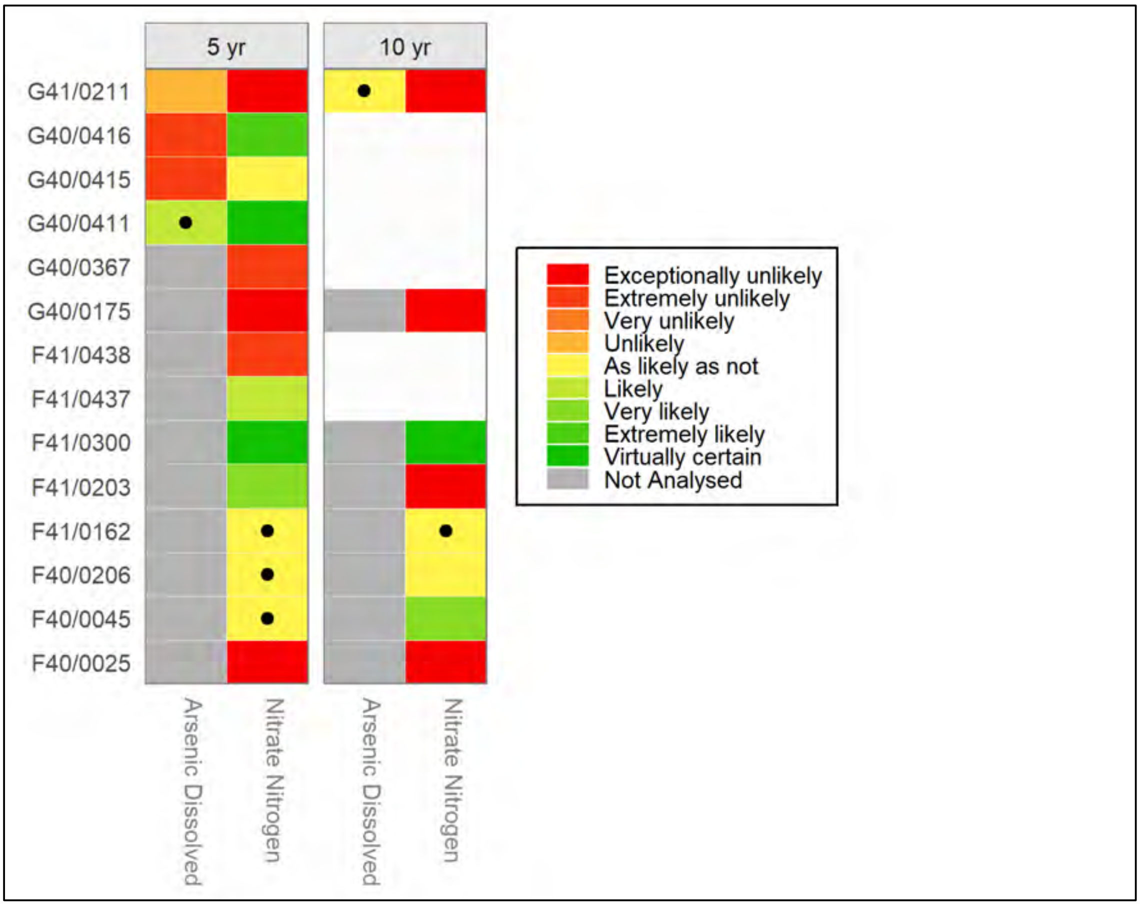


Figure 13 Summary of groundwater quality trends for the Dunstan Rohe

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

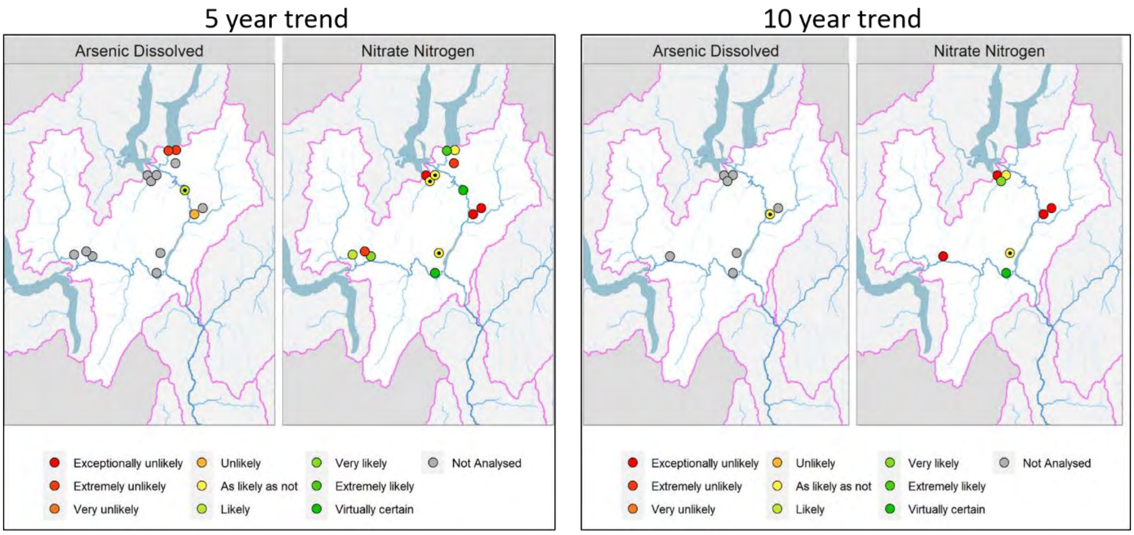


Figure 14 Groundwater quality 5-year and 10-year trend results for the Dunstan Rohe (LWP, 2023)

5.2.6 Water quality summary and discussion: Dunstan Rohe

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

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

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

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

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

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

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

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

5.3 Manuherekia Rohe

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

5.3.1 Manuherekia Rohe Description

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

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

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

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

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

5.3.2 River: State Analysis

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

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

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

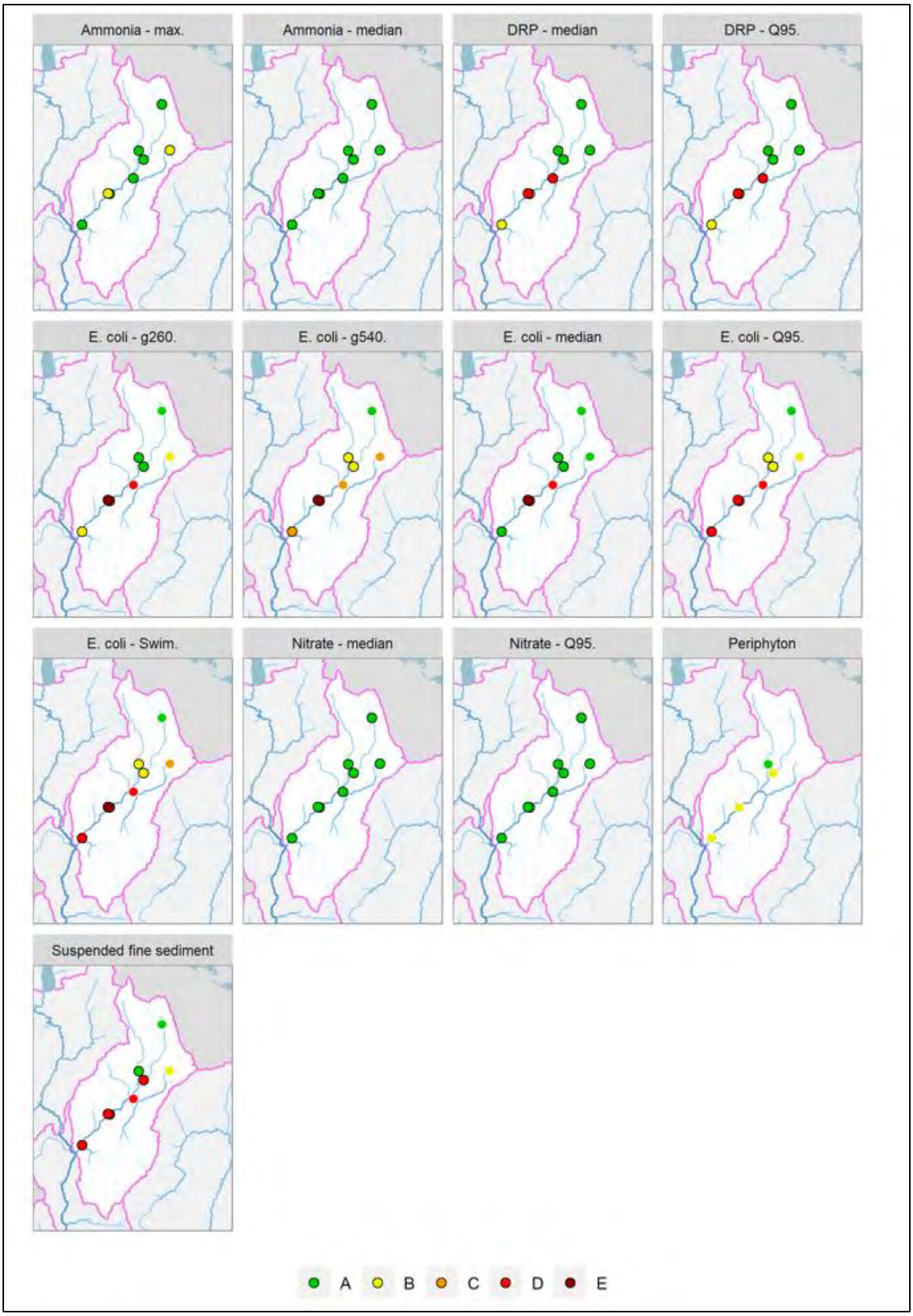


Figure 16 Maps showing Manuherekia Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines.

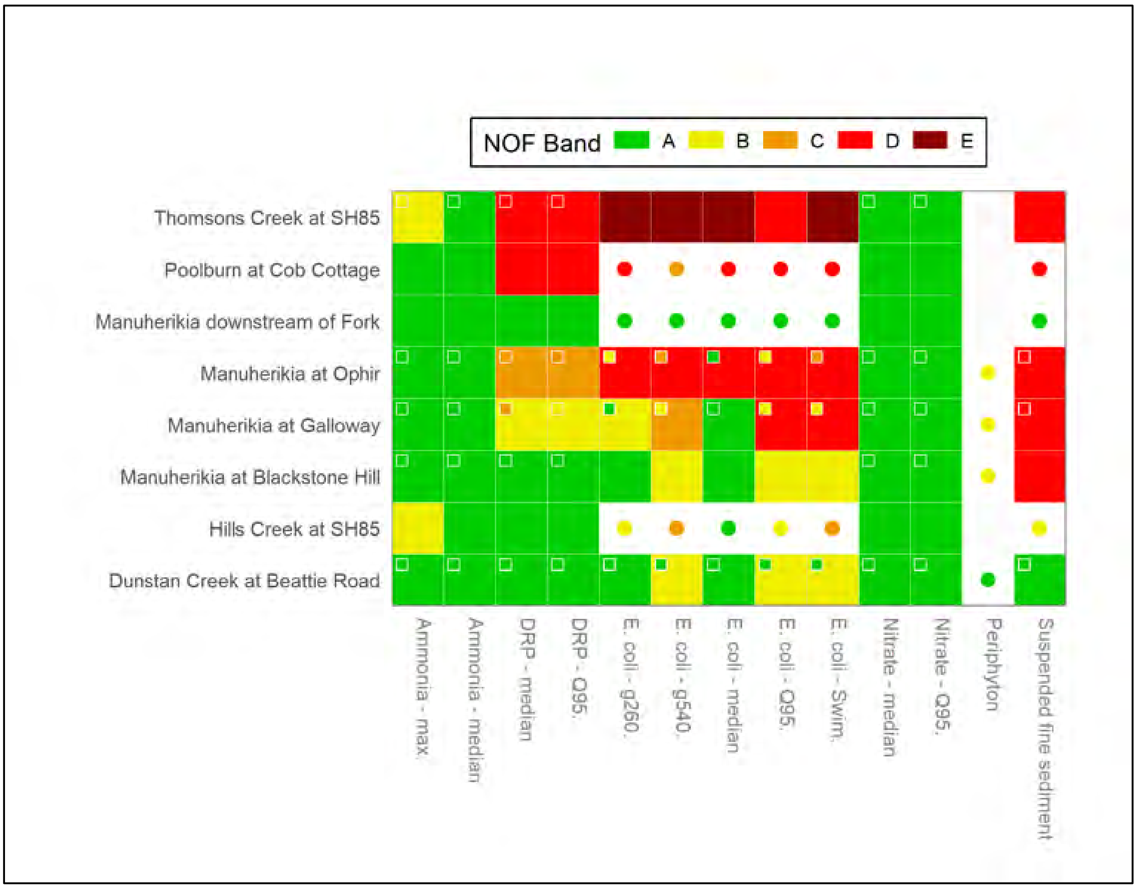


Figure 17 Grading of the river sites of the Manuherekia Rohe based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper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

5.3.2.1 Periphyton and Nutrients

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

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

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

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

5.3.2.2 Toxicants

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

5.3.2.3 Suspended fine sediment

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

5.3.2.4 Human health for recreation

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

5.3.3 River: Trend Analysis

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

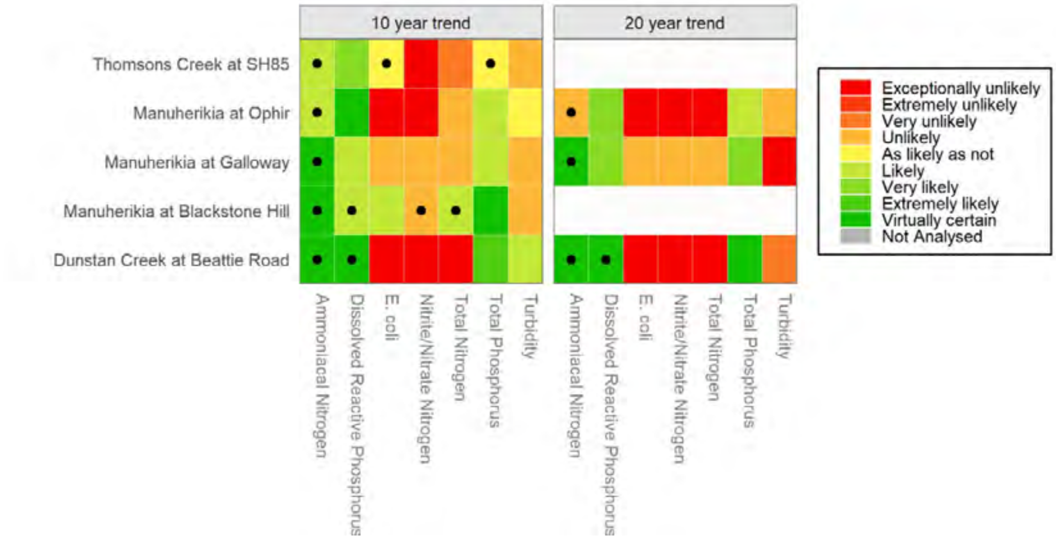


Figure 18 Summary of Manuherekia sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement.

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

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

5.3.4 Groundwater: State Analysis

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

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

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

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

5.3.5 Groundwater: Trend Analysis

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

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

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

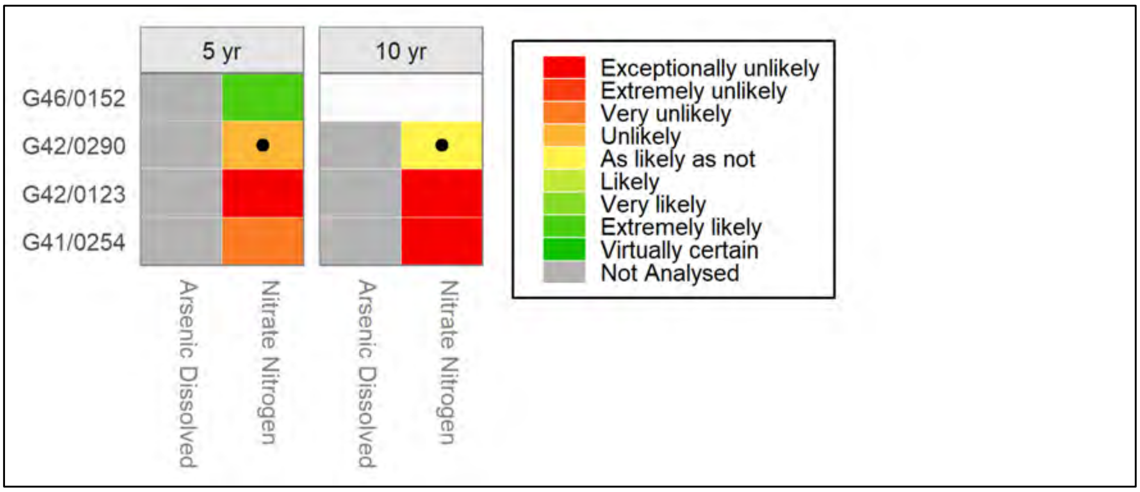


Figure 19 Summary of Manuherekia Rohe sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend

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

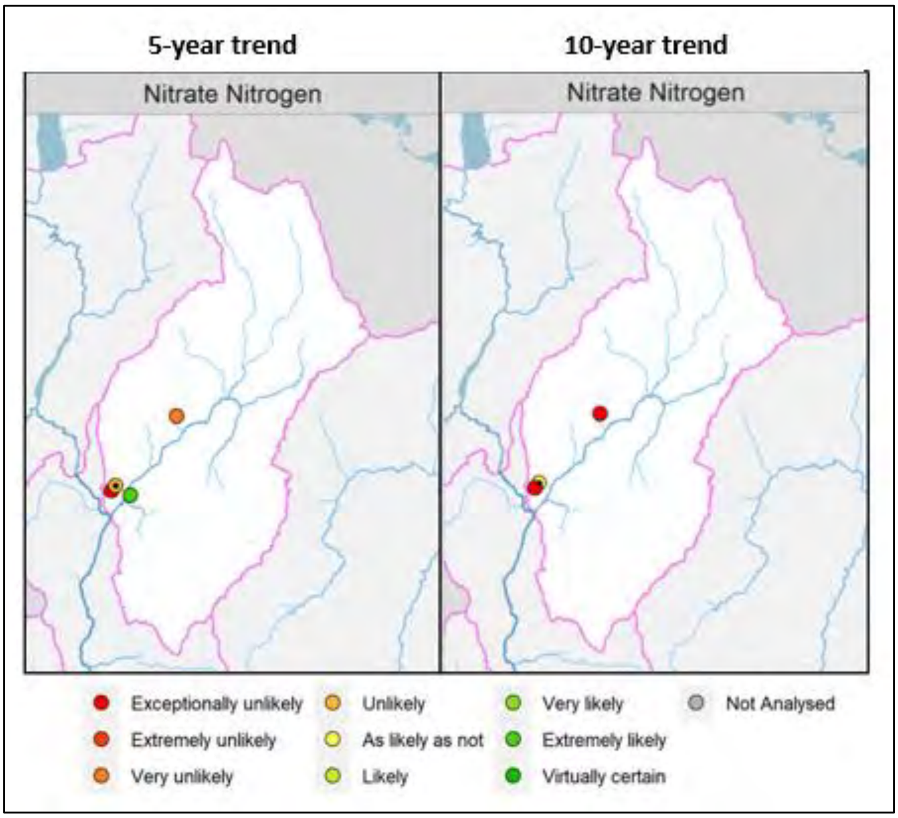


Figure 20: Groundwater quality 5- and 10-year trend results for the Manuherekia Rohe (LWP, 2023)

5.3.6 Water quality summary and discussion: Manuherekia Rohe

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

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

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

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

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

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

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

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

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

5.4 Roxburgh Rohe

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

5.4.1 Roxburgh Rohe Description

The Roxburgh Rohe extends from the Clyde Dam to Beaumont, and includes the townships of Alexandra, Clyde, and Roxburgh. The Rohe covers around 180,000 hectares of land, with grassland being the most common land cover. Low producing grasslands such as that found on steep hill and high country, occupy 32% of the Rohe while high-producing grasslands such as intensified grazing occupy 2%. Tall tussock grasslands cover 24% and exotic forests cover 2% of the Rohe.
The Roxburgh Rohe is in the heart of Central Otago and subject to the typical weather conditions for this area with hot, dry summers and cold, frosty, dry winters. Mean annual rainfall ranges from about 1200mm on the Obelisk/Old Man Mountain ranges, around 900mm on the hills south of the mountains, to about 360mm near Alexandra, and 450-500mm further south. However, the evaporation is also high, and at times exceeds precipitation, leading to soil moisture deficits. Temperatures can range from above 38°C in summer to around -10°C in winter. Rivers and streams originating in this Rohe do not have large flows and generally have very low flows in summer. The main exception is the Clutha/Mata-Au River, which runs through the centre of this Rohe.

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

ORC monitors four river and one lake sites in the Roxburgh Rohe. There are four groundwater SoE monitoring bores, situated in the Roxburgh basin and Ettrick aquifer. The monitoring sites are shown in Figure 21.

5.4.2 River and Lake: State Analysis

The results of grading the SoE sites in the Roxburgh Rohe according to the NPS-FM NOF criteria are mapped in Figure 22 and summarised in Figure 23 and Figure 24. Many sites in the Roxburgh Rohe did not meet the sample number requirements and accordingly are shown as white cells with coloured circles

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements. The only site with grades for the baseline period is the Clutha at Millers Flat.

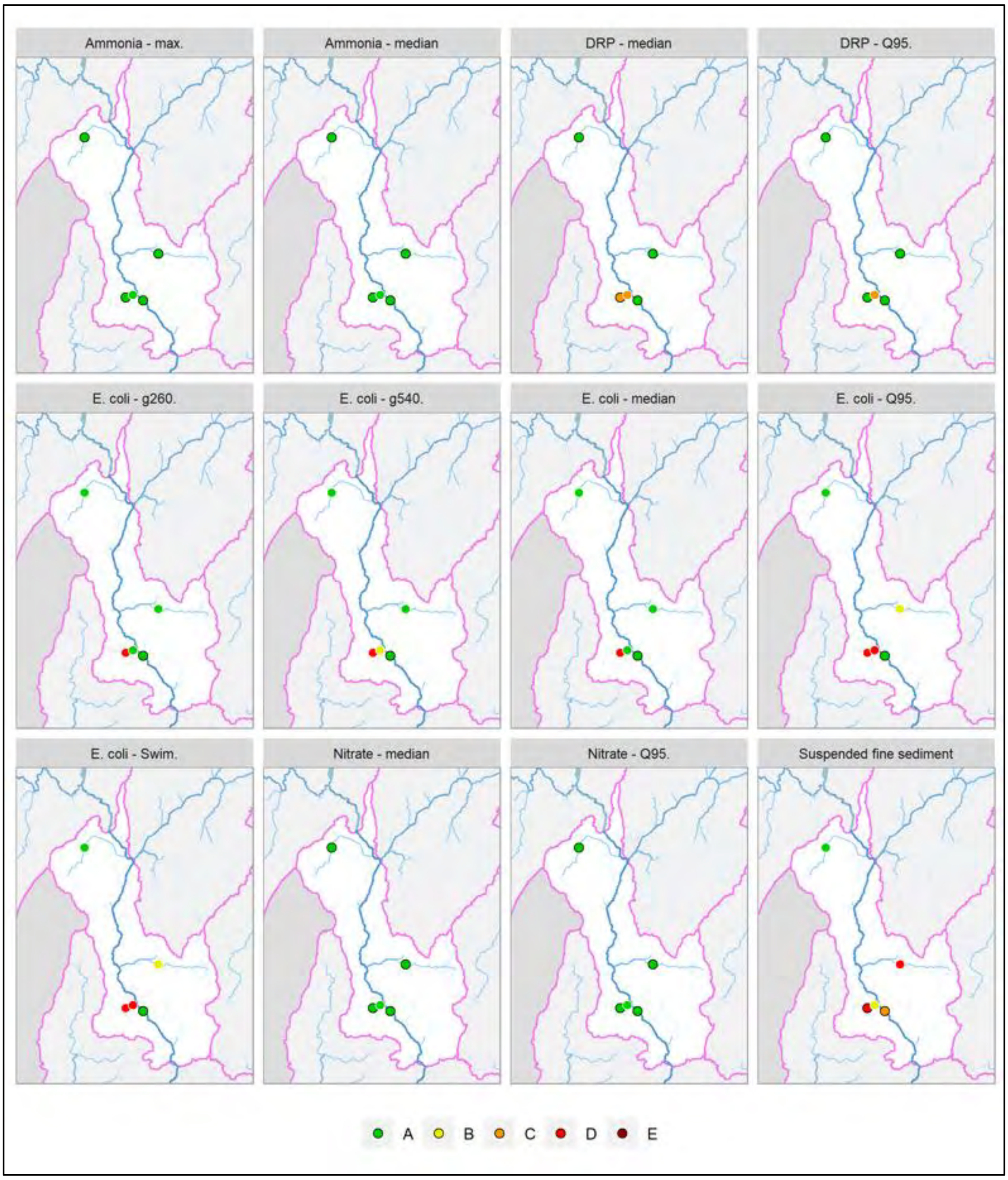
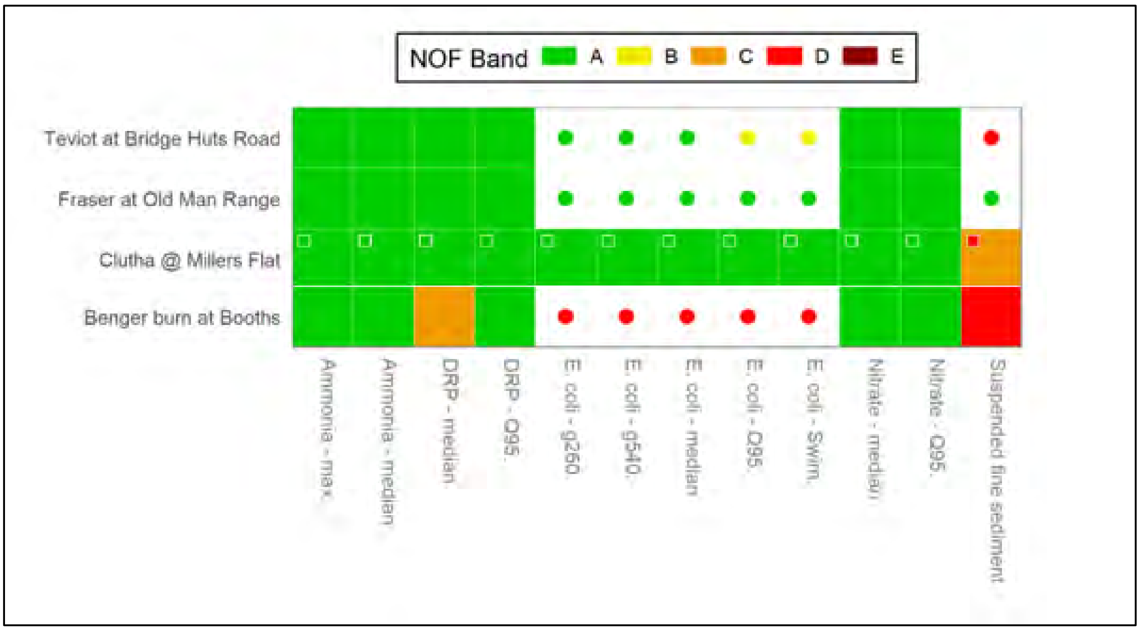


Figure 22 Maps showing Roxburgh Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.



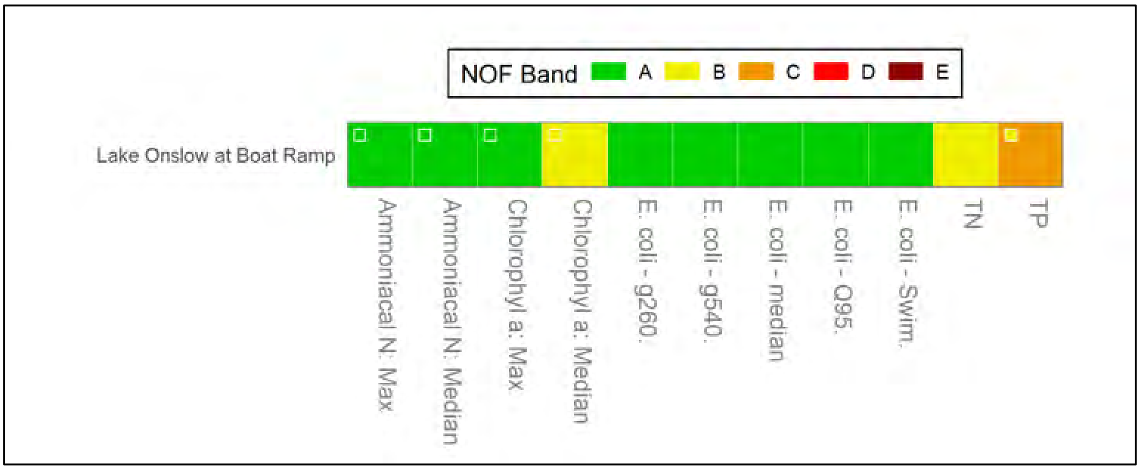


Figure 23 Grading of the river and lake sites in the Roxburgh based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

5.4.2.1 Phytoplankton, Periphyton and Nutrients

Figure 23 shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Roxburgh Rohe show that every site achieves a band 'A', other than the Benger burn which achieves band 'B' for DRP median. The NPS-FM (2020) describes band 'A' as *'Ecological communities and ecosystem processes are similar to those of natural reference conditions. No adverse effects attributable to dissolved reactive phosphorus (DRP) enrichment are expected.' Results for NNN are given in Appendix 1.* No periphyton monitoring is undertaken in the Roxburgh Rohe.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. In the Roxburgh Rohe, the Benger Burn at Booths has the highest concentration of both nutrients (NNN 0.182mg/l and DRP 0.01 mg/l) the other sites have much lower nutrient concentrations.

The NPS-FM (2020) describes how phytoplankton affects lake ecological communities. If the chlorophyll a concentration is in the 'A' band, then '*Lake ecological communities are healthy and resilient, similar to natural reference conditions'*. Results for Lake Onslow are shown in Figure 23 , the lake achieves an 'A' band for maximum chlorophyll a, but drops to a 'B' band for median chlorophyll a. Lake Onslow achieves a 'B' band for TN and a 'C' band for TP. The NPS-FM (2020) describes the C band for TP as *'Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions'*.

5.4.2.2 Toxicants

In the Roxburgh Rohe the NOF attribute bands for NH4-N and NNN toxicity at river sites and Lake Onslow show excellent protection levels against toxicity risk as all monitoring sites return an 'A' band for NH4-N and NNN.

5.4.2.3 Suspended fine sediment

The clarity results for the Roxburgh Rohe are shown in Figure 23 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3. . The Fraser River returns a NOF band of 'A' which denotes '*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions'* (NPS-FM, 2020). The Clutha at Millers Flat returns a NOF band of 'B' and the Benger burn and Teviot return a NOF band of 'D' for suspended fine sediment, which is below the national bottom line.

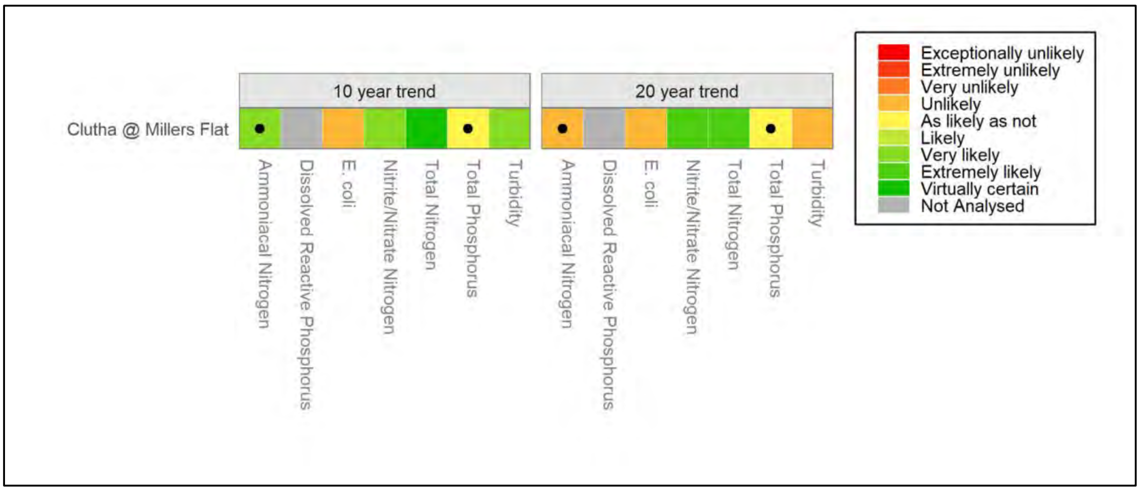
5.4.2.4 Human health for recreation

Figure 23 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading.

Lake Onslow, the Fraser River, and the Clutha at Millers Flat return 'A' bands across all four statistical tests, the Teviot achieved a 'B' band because it's 95^{th} percentile was just above the 'A' band criteria. The Benger Burn achieved a 'D' band across all four statistical tests.

5.4.3 River and Lake: Trend Analysis

Results from trend analysis for the Roxburgh Rohe is shown in Figure 24.



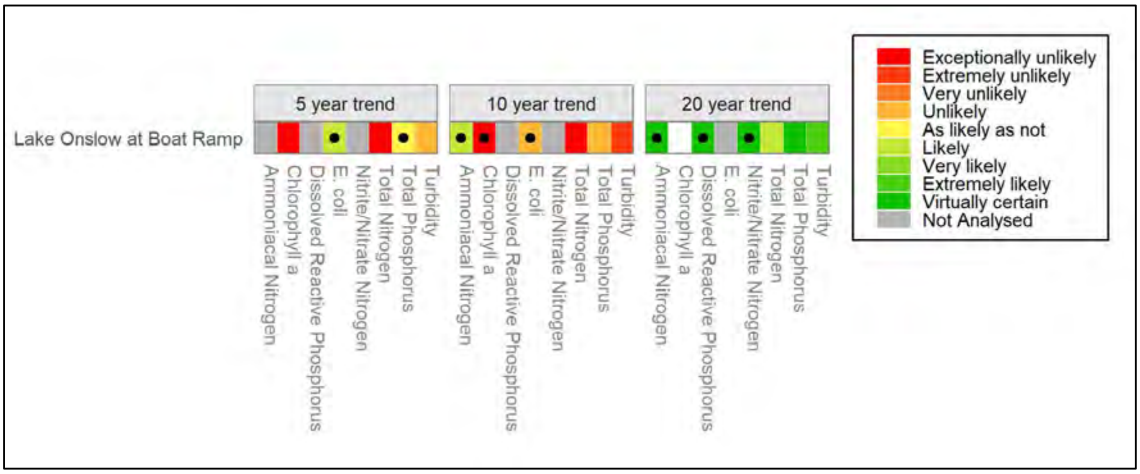


Figure 24 Summary of Roxburgh Rohe sites categorised according to the level of confidence that their 10 and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend.

Trend analysis for both rivers and lakes are given in Figure 24. In the 20-year time frame, Lake Onslow shows that all attributes are likely to be improving. In the 10-year time frame this is reversed with all attributes other than NH4-N 'unlikely' to 'exceptionally unlikely' to be improving. In the 5-year trend analysis it is only *E. coli* that is 'likely' to be improving.

For the Clutha River at Millers Flat, trend analysis shows a 20-year 'unlikely' improvement in turbidity, NH4-N and *E. coli* and an 'extremely likely' improvement in NNN and TN. Over the 20-year period NH4-N, however nutrient concentrations have improving trends, NNN is 'virtually certain' to have improved over 10-years, *E. coli* is 'unlikely' to have improved, but all other attributes are 'as likely as not' to virtually certain' to have improved.

5.4.4 Groundwater: State Analysis

The current state of groundwater quality in the Roxburgh Rohe is shown in Table 8. The results show some groundwater quality issues, notably *E. coli* exceedances in most bores and median nitrate-N concentrations between 4.750 and 8.400mg/L, which exceeds the threshold for low intensity land use (Morgenstern and Daughney, 2012) and approaches ¾ of the DWSNZ MAV. Dissolved arsenic concentrations in most bores are substantially below the DWSNZ MAV, with the exception of bore G43/0072 (situated in Roxburgh), where a maximum concentration of 0.006mg/L, above ½ of the DWSNZ MAV of 0.01mg/L, was measured. The other bores are situated in Ettrick, where bore G43/0224 a/b is a multi-level bore, with two monitoring piezometers at different depths (G43/0224a is shallower, screened between 9.73 and 12.73m and G43/0024b is screened between 17.33 and 20.33m). The monitoring results show high nitrate-N concentrations in this bore, which are close to the DWSNZ MAV. Furthermore, these concentrations are much higher than the NPS-FM (2020) nitrate-N limits for surface water.

Table 8 Groundwater current state results for the Roxburgh Rohe. The key for the colour classification is shown at the bottom of the table

Site	Aquifer/ location	Total no. of samples	No. of detections	*E. coli* % exceedance	Median Nitrate concentration (mg/L)	Max. arsenic concentration (mg/L)
G43/0009	Ettrick	25	1	4	4.750	0.000
G43/0072	Roxburgh	20	0	0	4.450	0.006
G43/0224a	Ettrick	29	3	10	8.400	0.000
G43/0224b	Ettrick	29	1	3	8.300	0.000

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Dissolved Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

5.4.5 Groundwater: Trend Analysis

The groundwater trend analysis is summarised in Figure 25 and is shown spatially in Figure 26 The five-year trend for nitrate-N concentrations was computed for the four monitoring bores in the Rohe. The results are mixed, with 'extremely likely' improvement for bores G43/0072 and G43/0009. Conversely, nitrate-N concentrations in bore G43/0224 are "extremely unlikely" improving. A 10-year trend was only available for bore G43/0009, which shows a worsening trend over the longer time period, going from "extremely likely improving" to "unlikely improving".

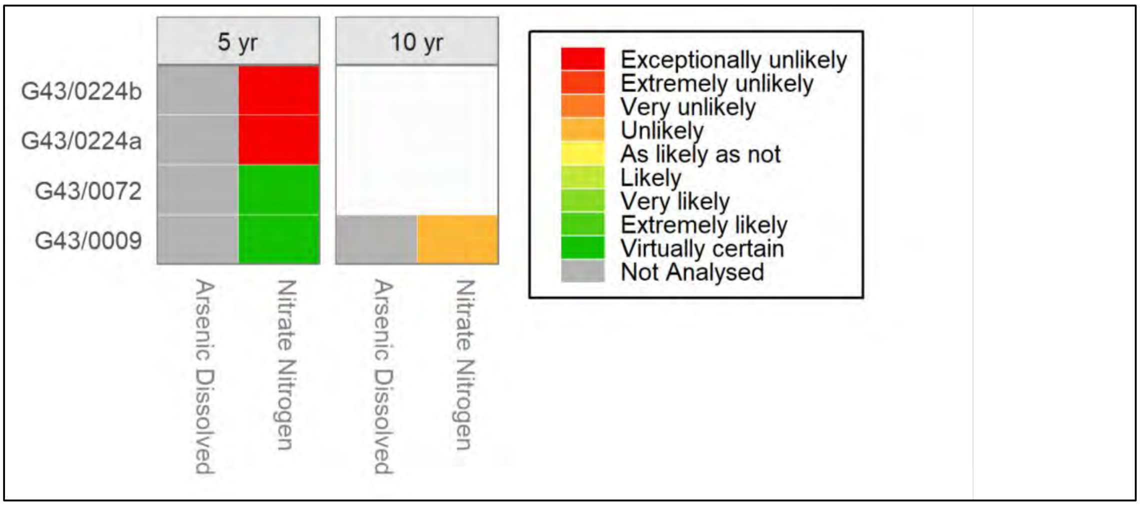


Figure 25: Summary of Roxburgh Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 4. White cells indicate site/variables where there were insufficient data to assess the trend

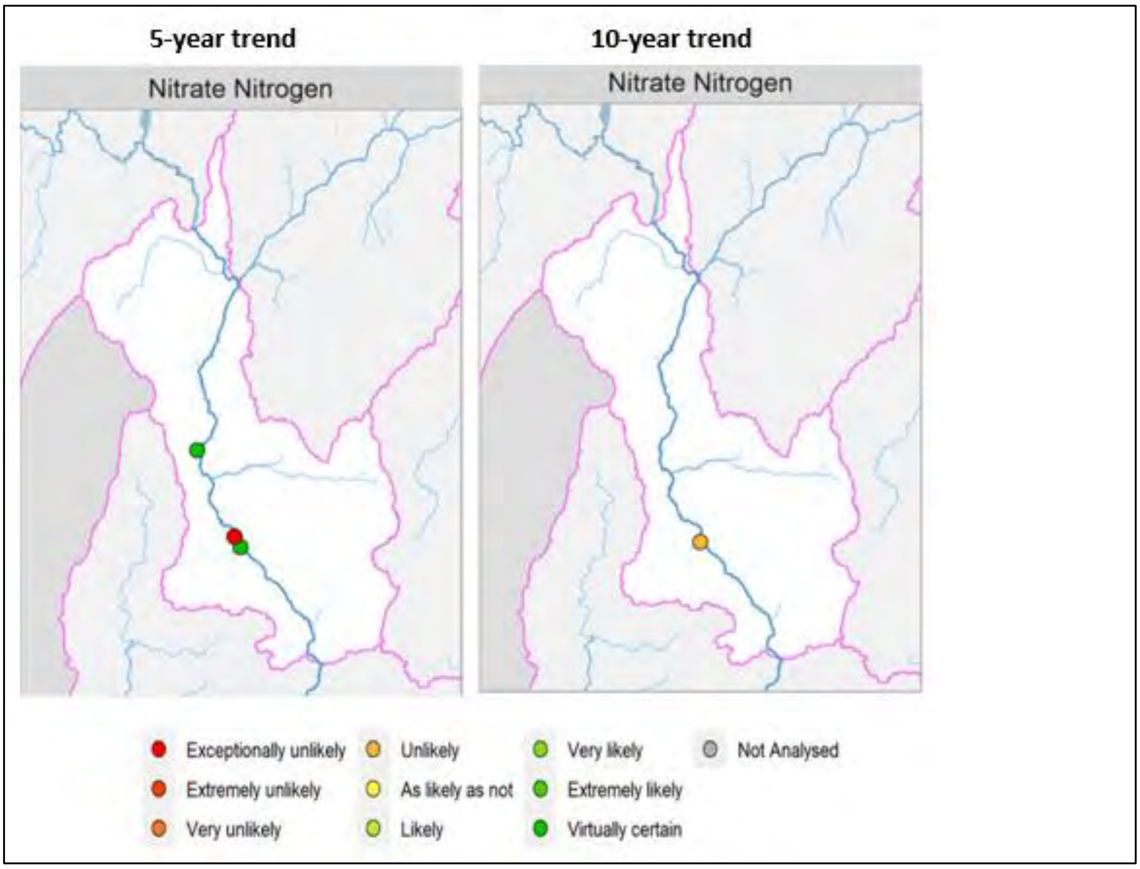


Figure 26: Groundwater quality 5 -and 10-year trend results for the Roxburgh Rohe (LWP, 203)

5.4.6 Water quality summary and discussion: Roxburgh Rohe

The dominant land use in the Roxburgh Rohe is drystock farming (77%), comprising of sheep and beef (65%); mixed sheep, beef, and deer (6%); and sheep farming (6%). Conservation estate occurs on approximately 10% of the Rohe. Forestry, and nurseries/vineyards/orchards occur on 2% of the area. The notable trends in land use change over the past three decades have been an increase in the extent of conservation estate (by 980%), forestry (by 156%), nurseries/ vineyards/orchards (by 17%) and urban area (by 8%). The extent of dry-stock farming decreased by 12%, although it remains the dominant land use activity in the Roxburgh area.

The analysis identified that water quality state in three of the four rivers monitored (Teviot River, Fraser River and Clutha at Millers Flat) are generally good and the NPS-FM band 'A' was achieved for most attributes other than for suspended fine sediment in the Teviot and Clutha. Both these rivers have naturally low water clarity due to their water source, i.e., glacial meltwater in the Clutha and tannin staining from tussock of the high country between the Knobby Range and the Lammerlaw Range for the Teviot. In contrast to that, the Benger Burn falls below the national bottom for all four statistics for *E. coli.* The source of the river is in the Mt Bengerburn, where land use in the higher country is mainly extensive sheep and beef, although this becomes more intensive when the river reaches the flat of the Ettrick basin. The reason for both the high bacteria concentration and the low clarity has not been established.

Lake Onslow is a man-made lake, formed in 1890 by the damming of the Teviot River and Dismal Swamp. TN achieves a 'B' band and TP a 'C' band. This grading should be considered typical of a shallow lake draining a tussock environment. Chl-a receives a grading of 'B' reflecting the higher nutrient concentration.

Trend analysis is only available for the Clutha River at Millers Flat, a comparison of the 20 and 10-year trends indicate that generally water quality has improved in the last 10 years, however due to the volume and size of the Clutha/Mata-Au catchment, any trend should be looked at with caution, it is preferable to look at the trends from tributaries discharging to the Clutha.

Groundwater quality state results highlight some issues in the Roxburgh Rohe, notably *E. coli* detections in most bores and high median nitrate-N concentrations. The nitrate-N concentrations from the bore in Ettrick (G43/0224a/b) approach ¾ of the DWSNZ MAV and exceed the threshold for low intensity land use (Morgenstern and Daughney, 2012) and the NPS-FM (2020) nitrate-N limits for surface water. These results are potentially due to the intensive farming and septic tanks in the Ettrick area, where further land use intensification and housing expansion continues to occur. Dissolved arsenic concentrations in most monitoring bores are substantially below the DWSNZ MAV, with the exception of bore G43/0072 (situated in Roxburgh), where a maximum concentration of 0.006mg/L was measured. This is above ½ of the DWSNZ MAV of 0.01mg/L. However, further look in the data shows that this was an isolated incident, and the concentrations usually range between 0.001 – 0.002mg/L (ORC, 2021). Nevertheless, it is strongly recommended that bore owners regularly test their water.

The 5-year trend for groundwater nitrate-N concentrations shows mixed results, with 'extremely likely' improvement for bores G43/0072 and G43/0009. Conversely, nitrate-N concentrations in bore G43/0224 are 'extremely unlikely' to have improved. This is likely due to the intensification of farming in the area. A 10-year trend was only available for bore G43/0009, which goes from 'unlikely improving' to 'extremely likely improving'. As the bore is located in a residential area, this is potentially due to improvements to wastewater system around the bore.

In light of these results, it is strongly recommended to practice good land and nutrient management to reduce nitrate-N leaching while continuing the nitrate-N monitoring in the area. It is also important to maintain good bore security to prevent the entry of contaminants into bores and to regularly test bore water. In addition to that, it is strongly recommended to ensure all septic tanks are well maintained and upgrade aging wastewater systems. If housing expansion continues in the Rohe it may also be worth considering replacing septic tanks with a centralised reticulated wastewater system.

5.5 Lower Clutha Rohe

Figure 27 Location of water quality monitoring sites in the Lower Clutha Rohe

5.5.1 Lower Clutha Rohe Description

The Lower Clutha Rohe runs from Beaumont to the Pacific Ocean where the Clutha /Mata-Au River discharges to the sea near Balclutha. The Rohe includes the catchments of the Pomahaka River (catchment area of 2,060 km^2), Waitahuna River (406 km^2), Waipahi River (339 km^2), Tuapeka River (249 km^2), and Waiwera River (208 km^2).

The most common land cover is high-producing grassland which supports intensive agriculture. Dry stock farming consists mainly of pasture grazing beef cattle, sheep, and deer for meat, wool, and velvet production. While dry stock farming has decreased by 9%, it still remains the main land use in the Lower Clutha area at 56%. Dairy farming occurs on approximately 17% of land and has notably increased by 37% between 1990 and 2018, as has forestry which increased by 39% between 1990 and 2018 and now covers 9% of the Rohe. The Lower Clutha Rohe has about 7% conservation estate which has increased by 40% in the last 30 years.

The Pomahaka River is the largest catchment of the Lower Clutha Rohe. The upper reaches of which are steep and dominated by tussock, while the lower reaches are primarily pastoral rolling hill country with intensive land use. Soils in the lower catchment are generally poorly drained, requiring artificial drainage, predominantly in the form of tile and mole drains. The main urban settlements in the Rohe are Balclutha and Tapanui.

ORC monitors 14 river sites and one lake in the Lower Clutha Rohe. There are three groundwater SoE monitoring bores in the Rohe, located in the Pomahaka Alluvial Ribbon aquifer and the Inch Clutha aquifer. The monitoring sites are shown in Figure 27.

5.5.2 River and Lake State Analysis Results

The results of grading the SoE sites in the Lower Clutha Rohe according to the NPS-FM NOF criteria are mapped in Figure 28 and summarised in Figure 29 . Some sites in the Lower Clutha Rohe did not meet the sample number requirements and accordingly are shown as white cells with coloured circles. Chl-a (periphyton) was only monitored at four sites, white cells indicates that this variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicates the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

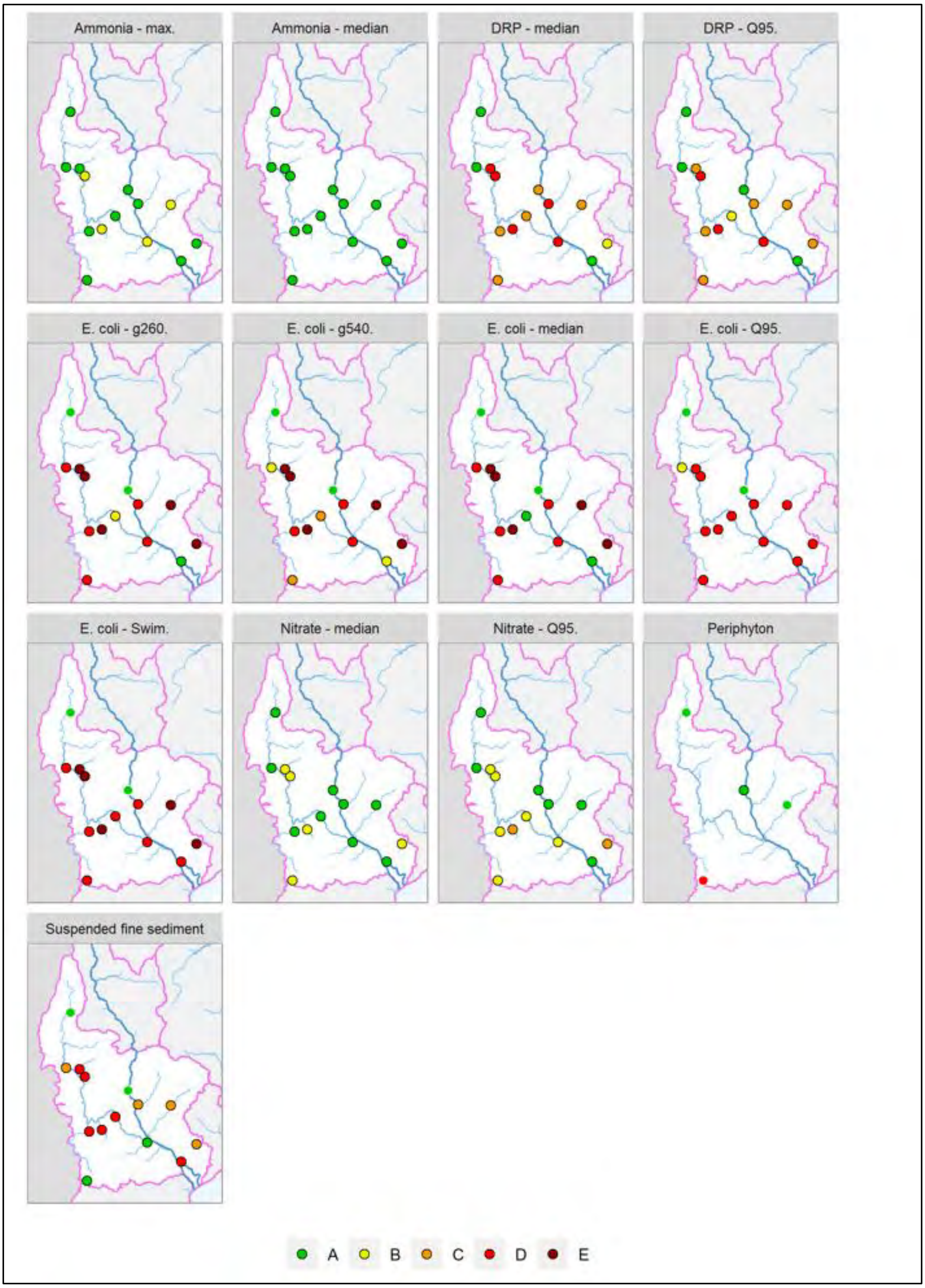
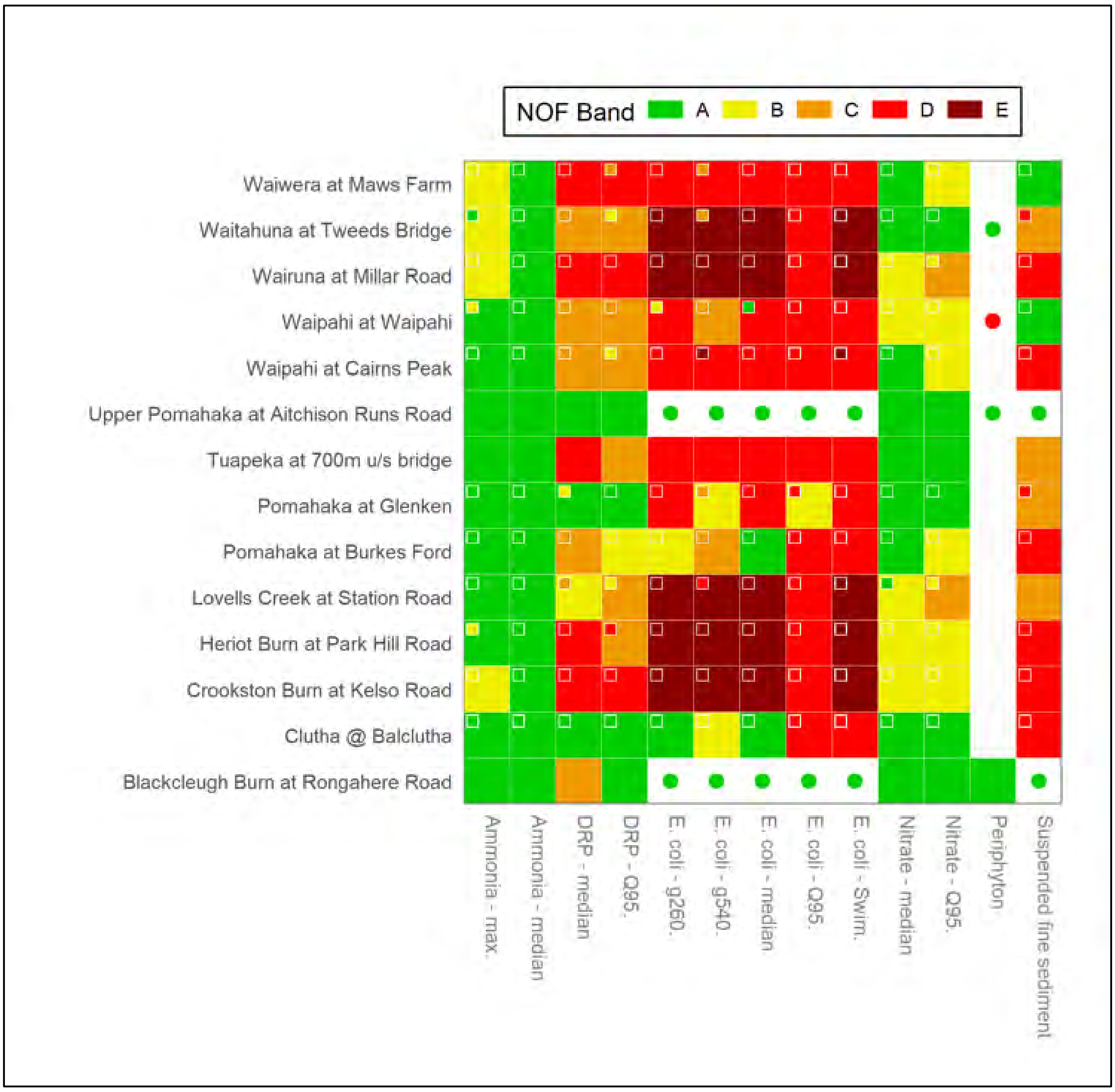


Figure 28 Maps showing Lower Clutha Rohe sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines.



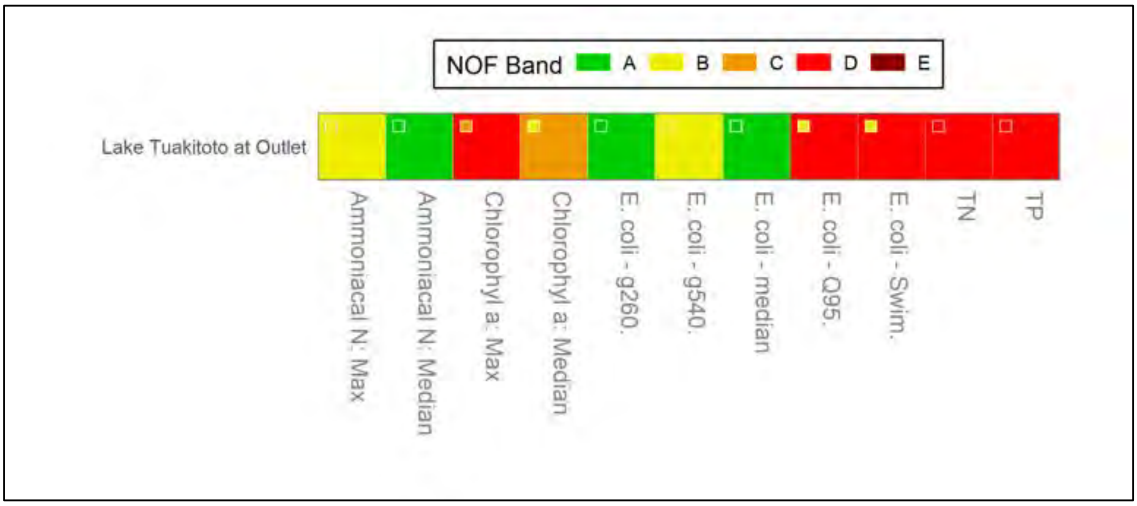


Figure 29 Grading of River and Lake sites in the Lower Clutha Rohe, based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells

with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline.

5.5.2.1 Phytoplankton, Periphyton and Nutrients

Periphyton trophic state results for the four sites monitored are given in Figure 29 and show that the Lower Clutha Rohe returns a band 'A' at three sites and a 'D' band for Waipahi at Waipahi, the NPS-FM (2020) describes this attribute state as '*regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat*'.

Figure 29 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Lower Clutha Rohe are varied. Sites with elevated DRP (achieving 'D' band for at least one of the DRP attribute statistics include the Waiwera, Wairuna, Crookston Burn, Waitahuna, Waipahi at Waipahi, Waipahi at Cairns Peak and Heriot Burn. All other sites achieved 'B' band or higher with three sites achieving an 'A' band across both statistics. including the two upper Pomahaka sites (Upper Pomahaka and Pomahaka at Glenken) as well as the Clutha at Balclutha.

The Pomahaka catchment has eight sites, the upper two sites (Upper Pomahaka and Pomahaka at Glenken) achieve 'A' bands. The tributaries entering the Pomahaka tend to have very high DRP, for example the Crookston Burn, Heriot Burn and Wairuna achieve band 'D'. High DRP tributary inputs to the Pomahaka River, result in an increase from 'A' band at Glenken to a 'C' band at Burkes Ford.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. The Crookston Burn (NNN 1.24 mg/l, DRP 0.026 mg/l), Heriot Burn (NNN 1.32 mg/l, DRP 0.026 mg/l) and Wairuna (NNN, 1.385 mg/l, DRP 0.031 mg/l) have the highest concentrations of NNN and DRP in the Rohe, the Pomahaka at Aitchison Runs Road has the lowest median NNN concentration (0.0132 mg/l) and the second lowest median DRP concentration (0.0047 mg/l).

The NPS-FM (2020) describes how phytoplankton (measured as Chl-a) affects lake ecological communities. If phytoplankton is in the 'A' band, then '*Lake ecological communities are healthy and resilient, similar to natural reference conditions*'. Figure 29 shows that Lake Tuakitoto is in the 'D' band, which is described as '*ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients'*. Lake Tuakitoto achieves 'D' bands for both TN and TP, a 'D' band reflects high nutrient enrichment, which is consistent for a shallow (normal lake levels of about one metre) freshwater wetland (ORC, 2004).

5.5.2.2 Toxicants

NOF attribute bands for NH4-N are given in Figure 29. The national bottom line for NH4-N is below band 'B'. In the Lower Clutha Rohe, all sites achieve band 'A' band other than the Crookston Burn, Waiwera at Maws Farm, Wairuna and Waitahuna which achieve a band 'B', which affords a 95% species protection level.

NOF attribute bands for nitrate-N (measured as NNN) toxicity are given in Figure 29, again the national bottom line is below band 'B'. In the Lower Clutha Rohe, most sites achieve either an 'A' or 'B' band, other than Wairuna and Lovells Creek which achieve a 'C' band (annual 95^{th} percentile). The NPS-FM describes the 'C' band as NNN having *'growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.'*

Lake Tuakitoto returns a 'B' band (95% species protection level) for NH4-N toxicity, showing good protection levels against toxicity risk.

5.5.2.3 Suspended fine sediment

The clarity results for Lower Clutha Rohe are shown in Figure 29 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3 other than Waipahi at Cairns Peak which is in sediment class 4. Of the 14 sites monitored, six return a NOF band of 'D', which the NPS-FM describes as *'high impact of suspended sediment on instream biota. Ecological communities are significantly altered, and sensitive fish and macroinvertebrate species are lost or at high risk of being lost'.* Of these sites, two have naturally low clarity, the Upper Waipahi site at Cairns Peak and the Clutha at Balclutha. Four sites; Waiwera at Maws, Waipahi at Waipahi, Upper Pomahaka and Blackcleugh Burn, return an 'A' band.

5.5.2.4 Human health for recreation

Figure 29 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grade of the four.

Compliance is generally poor across the Lower Rohe, with 13 of 15 sites returning bacterial water quality below band 'C'. The NPS-FM (2020) describes band 'D' as *'30% of the time the estimated risk of Campylobacter infection is ≥50 in 1,000 (>5% risk). The predicted average infection >3%'*. Band 'D' is generally considered not safe for primary contact (i.e., swimming).

In the Pomahaka catchment, of the eight sites monitored one site, the Upper Pomahaka achieved an 'A' band, three sites (the Crookston Burn, Heriot Burn and Wairuna) achieved an 'E' band, four sites (Waipahi at Cairns Peak, Pomahaka at Burkes Ford, Waipahi at Waipahi and Pomahaka at Glenken) achieved a 'D' band. Lake Tuakitoto is graded a 'D' band.

5.5.3 River and Lake: Trend Analysis

Trend analysis results for the Lower Clutha Rohe are shown in Figure 30 and Figure 31

Trend analysis for the Lower Clutha Rohe rivers is shown in Figure 30. Of immediate note is the 10-year trend block shows very few trends that are considered degrading ('unlikely' to 'exceptionally unlikely' to be improving)

A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods. Generally, across the Lower Clutha Rohe the predominance of degrading 20-year trends for NNN, TN and turbidity shifted to a predominance of improving 10-year trends for the same analytes. In addition, three sites, the Heriot Burn, the Waitahuna and the Waipahi at Waipahi saw a shift from the predominance of degrading 20-year trends to a predominance of improving 10-year trends.

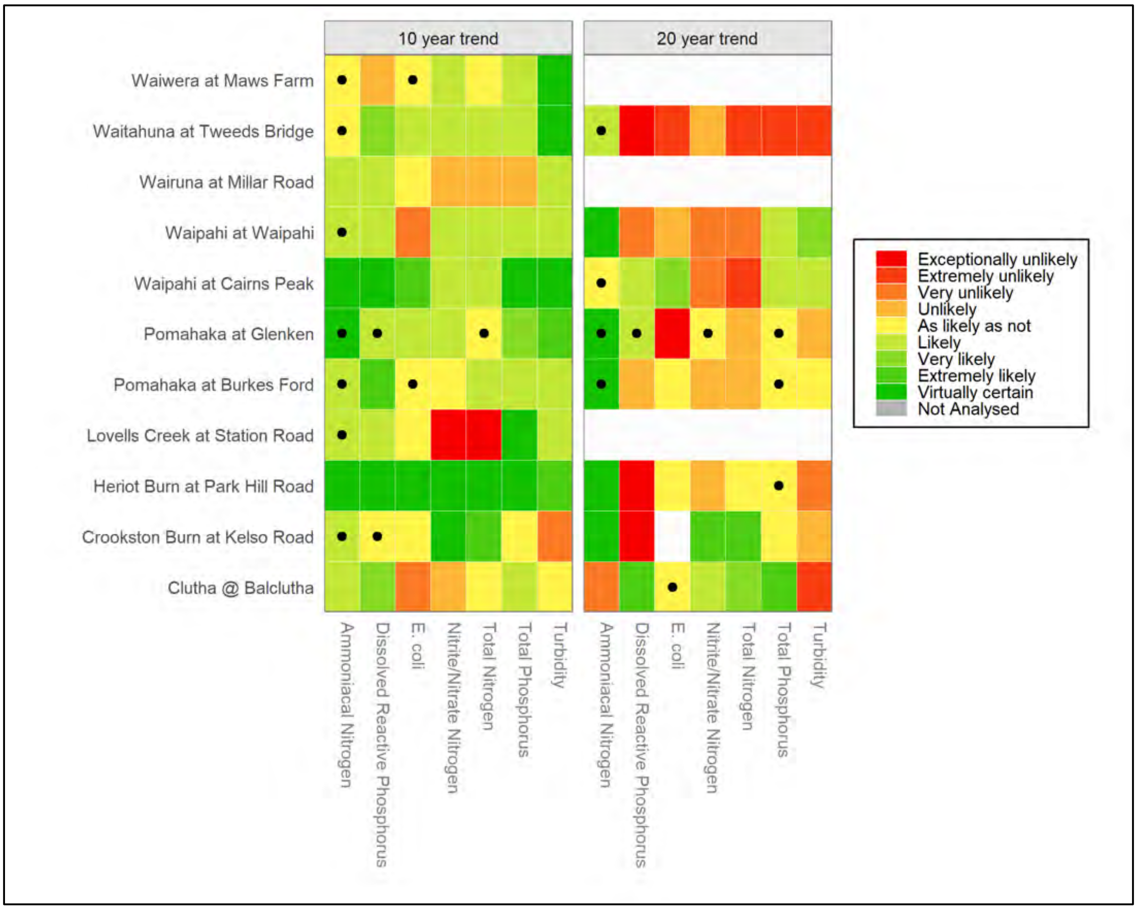


Figure 30 Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend.

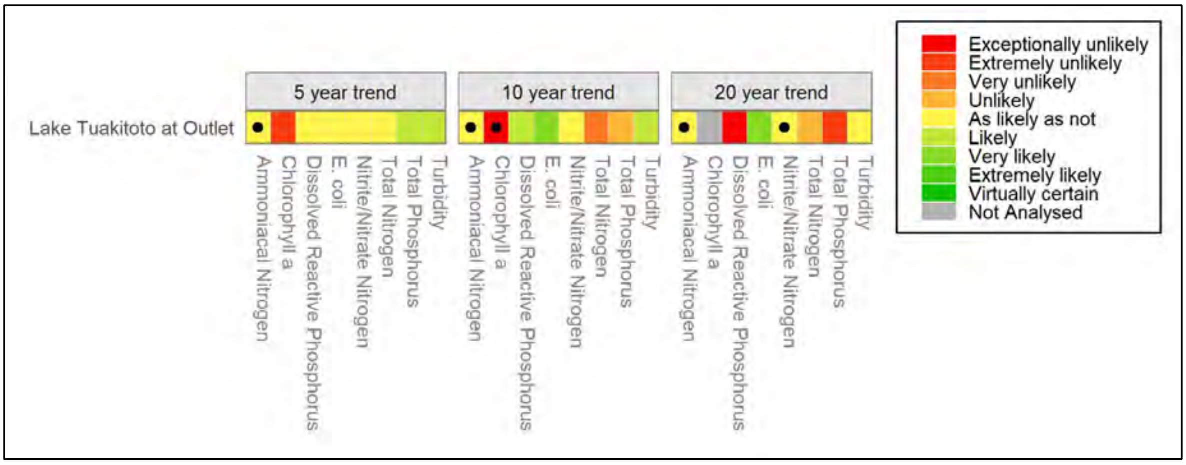


Figure 31 Summary of Lake Tuakitoto trends, categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring).

A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods. Generally, across the Lower Clutha Rohe the predominance of degrading 20-year trends for NNN, TN and turbidity shifted to a predominance of improving 10-year trends for the same analytes. In addition, three sites, the Heriot Burn, the Waitahuna and the Waipahi at Waipahi saw a shift from the predominance of degrading 20-year trends to a predominance of improving 10-year trends.

Trend analysis for 5-, 10-and 20-years for Lake Tuakitoto is shown in Figure 31 TP and DRP have changed from degrading over 20-years, to the five-year trend indicating stability or improvement. The only degrading trend for lake Tuakitoto over the five-year period is for Chl-a, which is consistent with the 10-year trend.

5.5.4 Groundwater: State Analysis

The results for the groundwater state analysis are shown in

Table *9*. Further description of the monitoring sites and aquifers in the Rohe is found in ORC (2021). These show a mixed pattern, with differences between the monitoring sites in the Inch Clutha (H46/0144) and Pomahaka (G44/0127 & G45/0225) aquifers. The data from the Pomahaka bores shows some exceedances of the DWSNZ MAV for E. coli and median nutrient concentration above the threshold for low intensity land use (Morgenstern and Daughney, 2012). Conversely, the dissolved arsenic concentrations are substantially below the DWSNZ MAV of 0.01mg/L.

The results for bore H46/0144 (situated in the Inch Clutha) highlight different issues, with maximum dissolved arsenic concentrations that substantially exceed the DWSNZ MAV of 0.10mg/L. Conversely, there were no *E. coli* detections in the bore and the median concentrations are below the threshold for low intensity land use.

Table 9 Groundwater current state results for the Lower Clutha Rohe. The key for the colour classification is shown at the bottom of the table

Site	Aquifer/ location	Total no. of samples	No. of detections	*E. coli* % exceed-ance	Median Nitrate concentration (mg/L)	Maximum arsenic concentration (mg/L)
G44/0127	Pomahaka Alluvial Ribbon	18	3	17	3.350	0.000
G45/0225	Pomahaka Alluvial Ribbon	18	3	17	4.05	0.001
H46/0144	Inch Clutha	18	0	0	0.000	0.018

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Dissolved Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

5.5.5 Groundwater: Trend Analysis

The 5- and 10-year trends for groundwater nitrate-N and dissolved arsenic concentrations are shown in Figure 32. The trend for nitrate-N in bore G44/0127 is 'extremely likely' improving' for both the 5 and 10-year trends. Nitrate-N trends for bore H44/0144 were not analysed, likely due to the high number of results below the analytical limit of detection.

The trends for dissolved arsenic for bore H44/0144 are 'unlikely' improving for the 5-year trend and 'extremely unlikely' improving for the 10-year trend. The dissolved arsenic trends for bore G44/0127 were not analysed, as most results were below the analytical limit of detection.

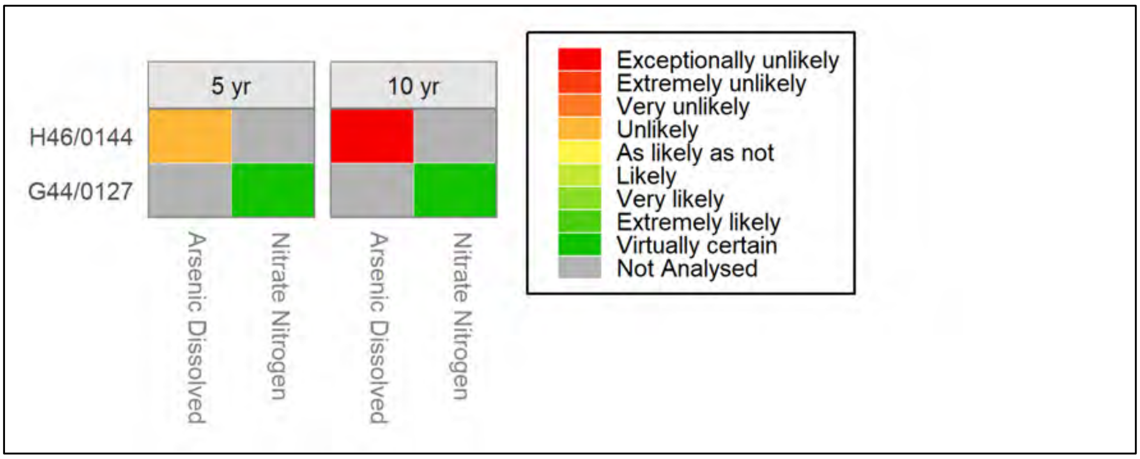


Figure 32: Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

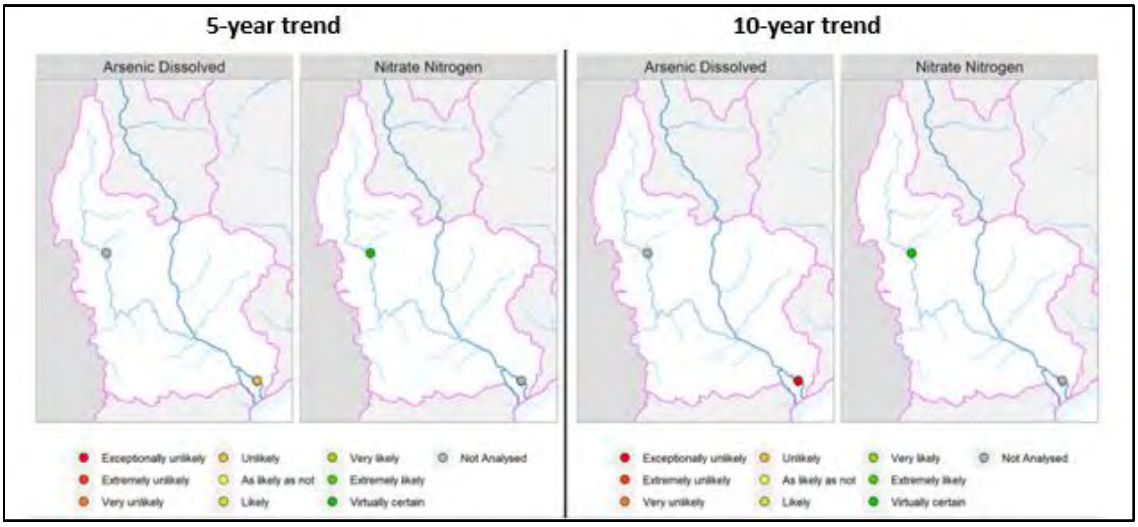


Figure 33: Summary of Lower Clutha Rohe sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Water quality summary and discussion: Lower Clutha Rohe

5.5.6 Water quality summary Lower Clutha Rohe

The Pomahaka catchment is the largest in the Rohe and is characterised by poor draining pallic soils, which has resulted in tile and mole drainage being installed to improve grazing land use. Tile drains influence water quality in the streams they discharge into, with the level of influence depending on several factors, including the frequency and volume of flow from individual tile or mole drains, the concentration of nutrients carried by the flowing drain, the total number of flowing drains in the area, land use and land management (ORC, 2011).

The need to improve water quality in the catchment has long been recognised and in 2014 the Pomahaka Water Care Group was established (https://www.pwcg.co.nz/), a farmer-led group to address and improve water quality, this is now supported by NZ Landcare Trust. A large part of this effort is focused on improving bacterial water quality. The high *E. coli* and nutrient concentrations are most likely because of a prevalence of mole and tile drains as well as instances of insufficient effluent storage. Provisions of farm effluent management has been addressed through Plan Change 8 (ORC, 2022).

In the Lower Clutha Rohe, of the 14 sites monitored, eight are in the Pomahaka catchment, six of which have been monitored for more than 20 years. The mainstem Pomahaka shows a gradual deterioration from the Upper Pomahaka (which has good water quality and achieves NPS-FM band ‘A’ across all attributes), to the Pomahaka at Glenken (which achieves ‘A’ bands across all attributes, other than a ‘D’ band for *E. coli* and a ‘B’ band for suspended fine sediment), to the Pomahaka at Burkes Ford (which achieves a ‘C’ band for DRP, ‘D’ band for E. coli, ‘C’ band for nitrate-N toxicity and ‘C’ band for suspended sediment). This is illustrated in

Table 10 which shows how the water quality of the Pomahaka degrades from the Upper Pomahaka to the lower Pomahaka at Burkes Ford, the sites in blue are the downstream tributary sites that enter the mainstem Pomahaka.

Table 10 Pomahaka Monitoring Sites, Mainstem sites shown in black, tributary sites shown in blue. The arrow shows the direction of river flow.

Site and Flow Direction	NH4-N	DRP	*E. coli*	Nitrate	S. Sediment
Upper Pomahaka at Aitchison Runs Road	A	A	A	A	A
Pomahaka at Glenken	A	A	D	A	C
Heriot Burn at SH95	A	C	E	B	D
Crookston Burn at Kelso	B	D	E	B	D
Waipahi at Waipahi	A	D	D	B	A
Wairuna	A	D	E	C	D
Pomahaka at Burkes Ford	A	C	D	B	D

The Waipahi River originates in a wetland and water quality is monitored just downstream of the wetland at Waipahi at Cairns Peak. The low clarity found at this site is likely to be due to tannin from the wetland, rather than suspended sediment. Tributaries of the Pomahaka returning high suspended fine sediment results contribute to the 'D' grade of the lower Pomahaka at Burkes Ford, compared to the upper reaches that return an 'A' grade. The Clutha at Balclutha receives a 'D' band for suspended fine sediment due to its source water being meltwater from glaciers in the Upper Lakes Rohe.

The Waipahi at Waipahi receives a 'D' band for periphyton. The Waipahi is a nutrient rich river and at Waipahi the river is generally dominated by macrophytes. Abundant periphyton growth will occur during the summer months particularly in the absence of flushing flows. The other three sites (Upper Pomahaka, Blackcleugh Burn and Waitahuna) all achieved 'A' bands which may reflect that water quality is low in nutrients, but also that higher rainfall in the area dislodges algal growth to prevent prolific growth.

The *E. coli* NOF attribute state was below attribute band 'C' in 12 of the 14 sites monitored, with five sites graded 'E', of these five sites three were smaller tributaries in the Pomahaka catchment and most likely reflect the contaminants associated with tile and mole artificial drainage of the heavier soils. Suspended fine sediment was below the national bottom line in seven of the 14 sites and DRP was below attribute band 'C' in five of the monitored sites.

Lake Tuakitoto is a large freshwater wetland situated in the Lower Clutha River Rohe, Lovells Creek is the main inflow into the Lake. Lovells Creek scores poorly across all attribute states other than NH4-N and reflects the catchment, which is dominated by intensively grazed pasture supporting sheep, beef, dairy farming, and plantation forestry. Lake Tuakitoto scores 'D' bands for *E. coli*, TP, TN and Chl-a (phytoplankton), this situation is unlikely to change, due to the shallow nature of the lake and poor flushing flows.

Although water quality state is generally poor, trend analysis shows that the predominance of degrading 20-year trends has generally shifted to a predominance of improving 10-year trends. An example of this is the 'virtually certain' improving trend is *E. coli* concentrations in the Heriot Burn. Although state results are still elevated ('E' band) the direction of the trend indicates a substantial improvement in water quality. The lower Pomahaka site at Burkes Ford also shows encouraging results, with DRP showing 'extremely likely' improvement. The Waitahuna which had degrading trends for DRP, *E. coli*, NNN, TN, TP, and turbidity over the 20-year period, has no degrading trends over the 10-year period.

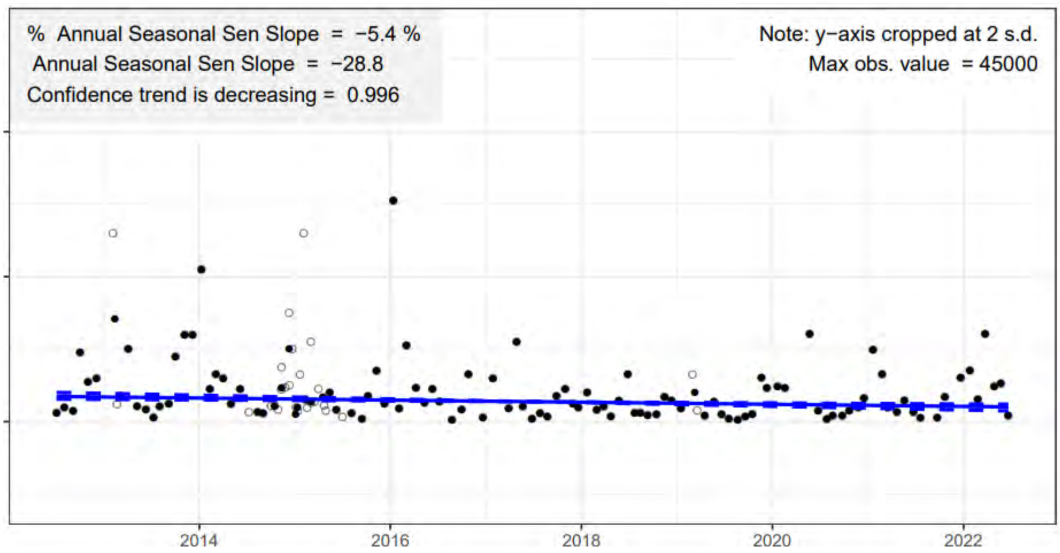


Figure 34 Heriot Burn trend graph showing a 'virtually certain' improving trend in E. coli.

The 5-, 10- and 20-year trends in Lake Tuakitoto show a degrading trend for Chl-a over the three time periods. The major inflow to Lake Tuakitoto, Lovells Creek has degrading trends for TN and NNN, as well as a 'C' band for state analysis for DRP. The added input of nutrients into a wetland that is already nutrient rich is conducive to phytoplankton growth.

Groundwater state analysis show a mixed pattern in the Rohe, with substantial differences between the monitoring sites. The data from the bores in the Pomahaka (G44/0127 and G45/0225) show several exceedances of the DWSNZ MAV for E. coli and median nitrate-N concentrations above the threshold for low intensity land use (Daughney and Morgenstern, 2012). Conversely, the dissolved arsenic concentrations are substantially below the DWSNZ MAV of 0.01mg/L. The E. coli and nitrate-N concentrations are likely due to land use around the bores (e.g., farming), their shallow depths, and poor bore security, which allows easy entry of contaminants to the bore (ORC, 2021).

The results from the Inch Clutha bore (H46/0144) highlight different issues, particularly dissolved arsenic concentrations that substantially exceed the DWSNZ MAV of 0.10mg/L. The causes for these are unclear, although may be attributed to arsenic sourced from organic matter or schist sediments (e.g., Piper and Kim, 2006). The low nitrate-N concentrations may potentially be due to the bore's depth and reducing conditions (which may also increase arsenic mobility), where nitrates break down. Hence nitrate-N concentrations in groundwater may be masked by these geochemical processes which may not reflect the impact of land use on groundwater quality (e.g., Close *et al.*, 2016). It is also important to note that, as there are currently only three monitoring bores in the Rohe, these results do not necessarily provide a comprehensive representation of groundwater quality in it. In light of this, ORC is planning to expand its monitoring network in the Rohe within the next 1-2 years. Nevertheless, it is strongly recommended that bore owners in the Rohe maintain good borehead security, land use and nutrient management, and regularly test their bore water.

6 Taieri FMU

Figure 35 Location of water quality monitoring sites in the Taieri FMU

6.1.1 Taieri FMU Description

The Taieri River is the fourth-longest river in New Zealand, draining the eastern Otago uplands and following an almost circular path from its source to the sea. The Taieri River rises in the Lammerlaw (1210m) and Lammermoor Ranges (1160m) and flows through the dry Maniototo Plain, Strath Taieri Plain and the low-lying Taieri Plain before reaching the Pacific Ocean about 30km south-west of Dunedin. The main tributaries of the Taieri River are the Kye Burn, Sutton Stream, Deep Stream, Lee

Stream, Silverstream and the Waipori River. Water from the Taieri and its tributaries feed seven small rural water supply schemes, three small urban supply schemes, and Dunedin city. The main urban settlements in the Taieri FMU are Mosgiel, Middlemarch, and Ranfurly.

The upper Taieri headwaters drain a relatively undeveloped area of native tussock country on the northern side of the Lammerlaw Range. The river then flows through the dry Maniototo Plain (660km²) which features an intensely meandering channel, oxbow lakes and wetlands and is the best example of a 'scroll plain' in New Zealand. The Maniototo Irrigation Company (MIC) distributes water from the Taieri River, and water stored in the Loganburn Reservoir.

Beyond the northern end of the Rock and Pillar Range, the Kye Burn flows into the Taieri and contributes high levels of sediment to the river. These high sediment loads are in part due to historic gold mining activities in the Kye Burn Catchment. The midreaches of the Taieri River flow through the smaller Strath Taieri Plain, occupying an area of 85km², past Middlemarch, and through the Taieri Gorge onto the Taieri Plain. Many small tributaries join the main stem of the river along this sub-region.

The lower Taieri is dominated by a large floodplain and the associated Lake Waipori/Waihola wetland complex. Part of the lower Taieri plain lies below sea level, and the potential for flooding has resulted in extensive flood protection works, including floodbank construction and channel straightening (e.g., the lower Silverstream) which has significantly altered the physical habitat quality of some river reaches. Lake Mahinerangi (hydro-electricity generation) is situated in the upper Waipori River catchment, and the Waipori confluence with the Taieri is located near Henley.

The main urban settlements in the Taieri FMU are Mosgiel, Middlemarch, and Ranfurly.

ORC monitors 17 river sites and one lake in the Taieri FMU. There are nine SoE groundwater monitoring bores, situated across the Maniototo Tertiary aquifer, the Strath Taieri aquifer, and the Lower Taieri aquifer. Monitoring sites are shown in Figure 35.

6.1.2 State Analysis Results

The results of grading the SoE sites in the Taieri FMU according to the NPS-FM NOF criteria are mapped in Figure 36 and summarised in Figure 37 and Figure 38. Many sites in the Taieri FMU did not meet the sample number requirements and accordingly are shown as white cells with coloured circles. Chl-a was only monitored at a subset of sites, white cells indicates that the variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

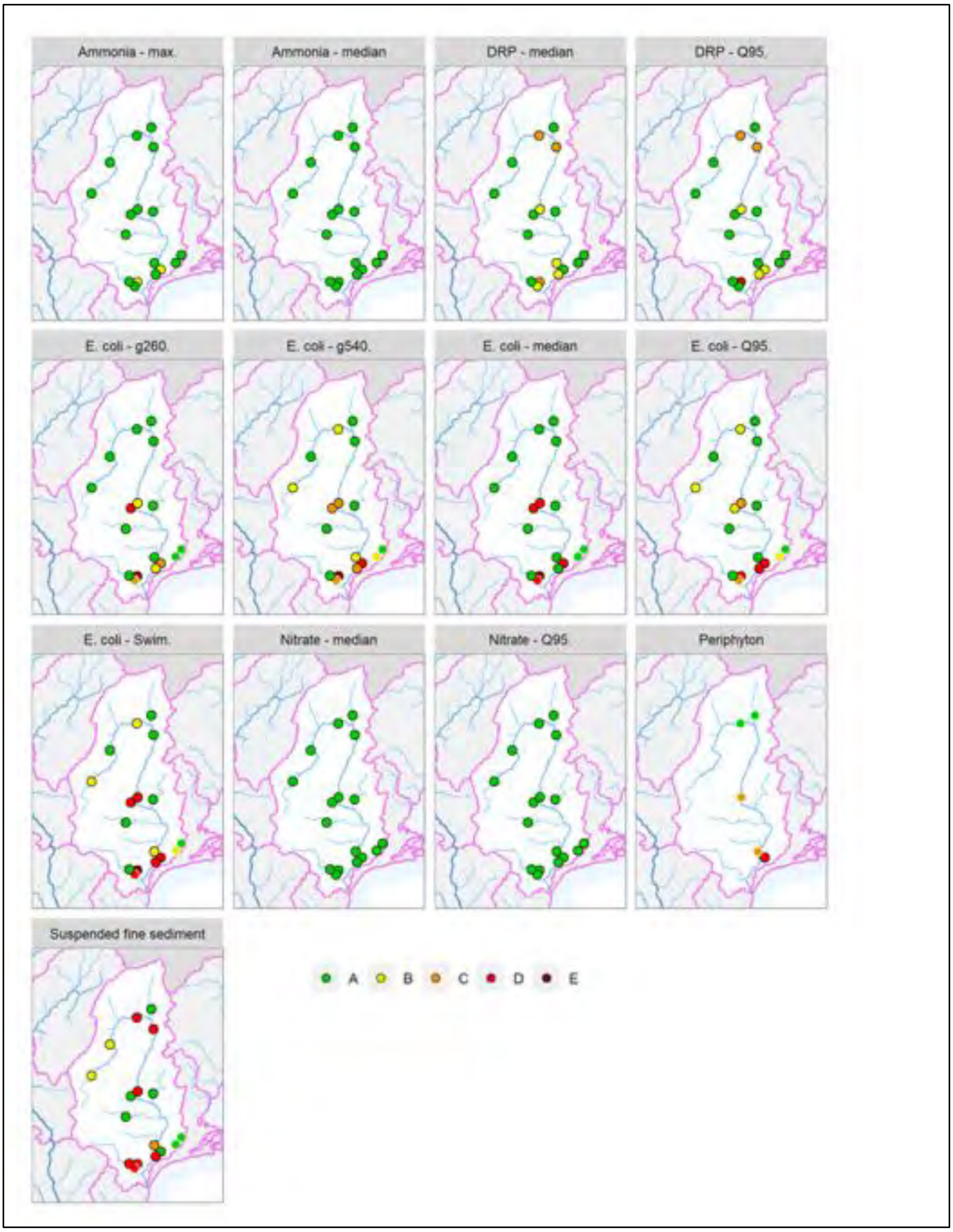


Figure 36 Maps showing Taieri FMU river sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines

Figure 37 Grading of the river sites of the Taieri FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

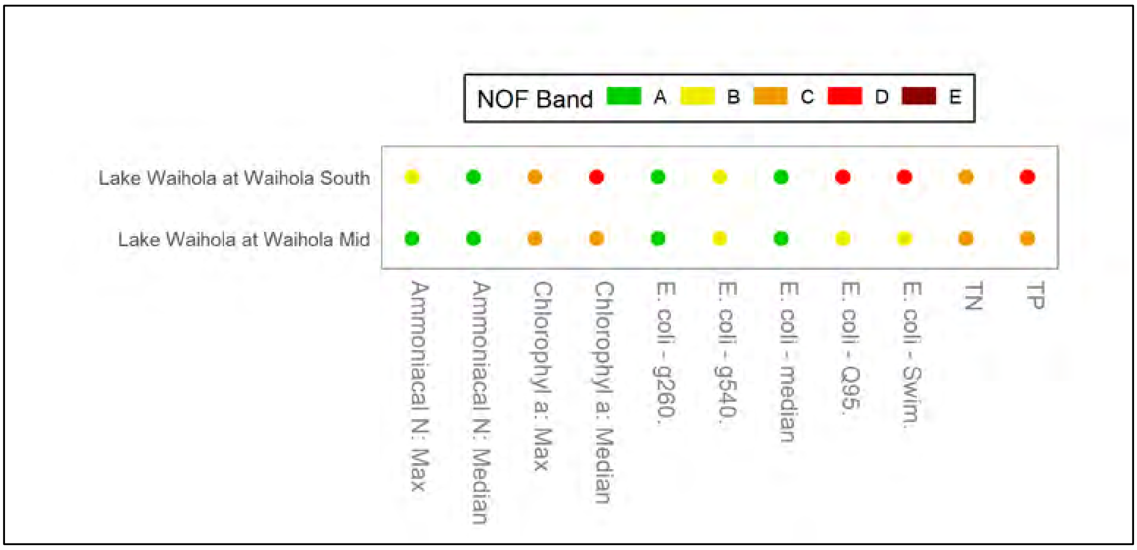


Figure 38 Grading of the lake sites of the Taieri FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements shown as white cells with coloured circles.

6.1.2.1 Phytoplankton, Periphyton and Nutrients

Periphyton trophic state results for the five sites monitored are shown in Figure 37. Results are interim as the monitoring programme started in July 2018, interim results show that the Kye Burn (26 samples) and Taieri at Waipiata (17 samples) achieve an interim ‘A’ band as few results exceed 50 chl-*a*/m^2, reflecting negligible nutrient enrichment. The Taieri at Sutton (15 samples) and Taieri at Outram (19 samples) achieve an interim ‘B’ band and the Silverstream (31 samples) is graded ‘D’ which the NPS-FM, 2020 describes ‘*regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat low nutrient enrichment but the possibility of occasional blooms’*

Figure 37 shows median DRP for an attribute state around wider ecological health. The results in the Taieri FMU show that most sites achieve either an ‘A’ or ‘B’ band, indicating that DRP concentrations are similar to, or only slightly elevated from natural reference conditions. Two sites achieved a ‘C’ band, including two mainstem Taieri sites (Taieri at Tiroiti and Taieri at Waipiata). The Contour Channel on the Lower Taieri Plain achieved a band ‘D’ for the DRP Q95 statistic.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. In the Taieri FMU, the Taieri Plain had the highest nutrient concentrations. The Silverstream at Taieri Depot has the highest median NNN concentration (0.41 mg/l) but the DRP at this site was #12 of 16 sites in the FMU (0.0031 mg/l). The contour channel had the highest DRP concentration at 0.017 mg/l, this site had the second highest NNN concentration. Deep Stream had some of the lowest nutrient concentrations.

The NPS-FM (2020) describes how phytoplankton affects lake ecological communities. If phytoplankton is in the ‘A’ band, then ‘Lake ecological communities are healthy and resilient, similar to natural reference conditions’. Figure 38 shows that Lake Waihola is generally in the ‘C’ band, which the NPS-FM (2020) describes as ‘*ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state, due to impacts of elevated nutrients’*. Lake Waihola Mid achieves ‘C’ bands for both TN and TP, a ‘C’ band reflecting nutrient enrichment well above natural reference conditions, which is consistent for a shallow freshwater wetland (ORC, 2004), Lake Waihola South has a TP grade of 'D' band.

6.1.2.2 Toxicants

The NOF attribute bands for NH4-N are shown in Figure 37 and Figure 38 show excellent protection levels against toxicity risk. All sites return an 'A' band other than the Contour Channel and Silverstream which both achieve a 'B' band. Lake Waihola Mid returns an 'A' band for NH4-N toxicity, at the South site a 'B' band is achieved.

The NOF attribute band for nitrate-N toxicity (measured as NNN) are shown in Figure 37. All sites return an 'A' band. The NPS-FM (2020) describes this state as '*high conservation value system. Unlikely to be effects even on sensitive species*'.

6.1.2.3 Suspended fine sediment

The suspended fine sediment results for the Taieri FMU are shown in Figure 37 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 3 other than Whare Creek which was in sediment class 2. Of the 17 sites monitored, eight sites return a NOF band of 'D' which the NPS-FM (2020) describes as 'high *impact of suspended sediment on instream biota'.* Four of these sites are mainstem Taieri sites; Taieri at Waipiata, Taieri at Tiroiti, Taieri at Sutton and Taieri at Outram, at these mainstem sites the 'D' band is due to natural tannin staining of the river, originating from the tussock country and the significant wetland in the Maniototo plain. At the other end of the scale, six sites returned 'A' band, they are all tributary sites and include Whare Creek, Sutton Stream, Silverstream (upper and lower), Nenthorn, Kyeburn, and Deep Stream.

6.1.2.4 Human health for recreation

Figure 37 and 38 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Compliance is generally good across the Taieri FMU, of the 17 sites, seven achieve an 'A' band, four a 'B' band (Taieri main-stem sites at Linnburn, Waipiata and Outram and the Silverstream), the other sites returned bacterial water quality below the national bottom line (five 'D' bands and one an 'E' band). Lake Waihola graded as a 'B' band mid lake and a 'D' band at the Waihola South site.

6.1.3 Trend Analysis

Trend analysis results for the Taieri FMU is shown in Figure 39 and Figure 40.

Trend analysis for the Taieri rivers is shown in Figure 39. A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods.

Generally, across the Taieri FMU in the last 10-years compared to the 20-year period there are more improving trends 'likely to virtually certain to be improving' than degrading trends 'unlikely to exceptionally unlikely to be improving'. In the most recent 10-years the degrading trends for *E. coli*, NNN, TN still outweigh improving trends for these analytes, however the trend direction is good as certainty has changed from mainly 'exceptionally unlikely to be improving' to 'unlikely' to be improving.

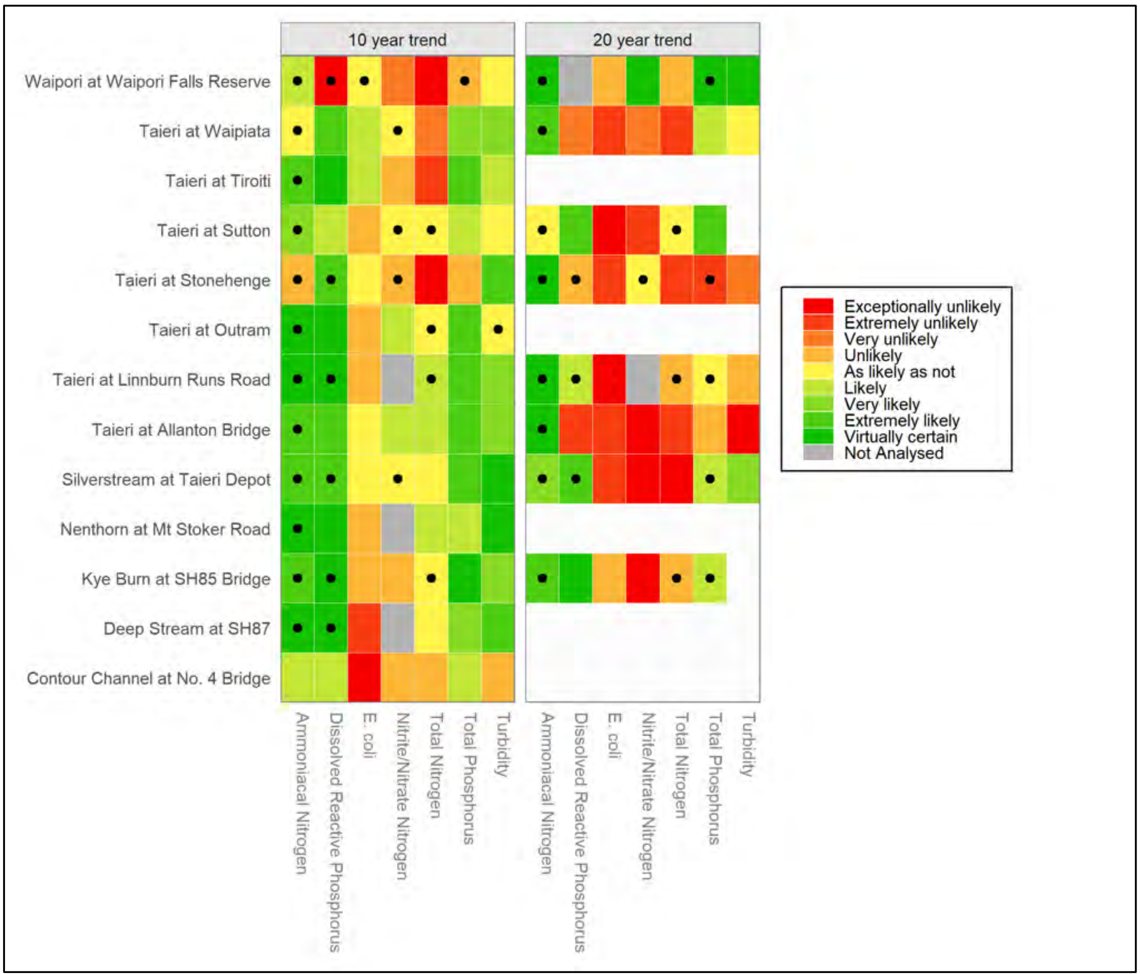


Figure 39 Summary of Taieri FMU river sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend.

Three sites, the Taieri at Waipiata, Taieri at Allanton, Silverstream at Taieri saw a change from the predominance of degrading 20-year trends to a predominance of improving 10-year trends. Conversely, Waipori at Waipori Falls shows more degrading trends in the 10-year analysis, compared to the 20-year analysis.

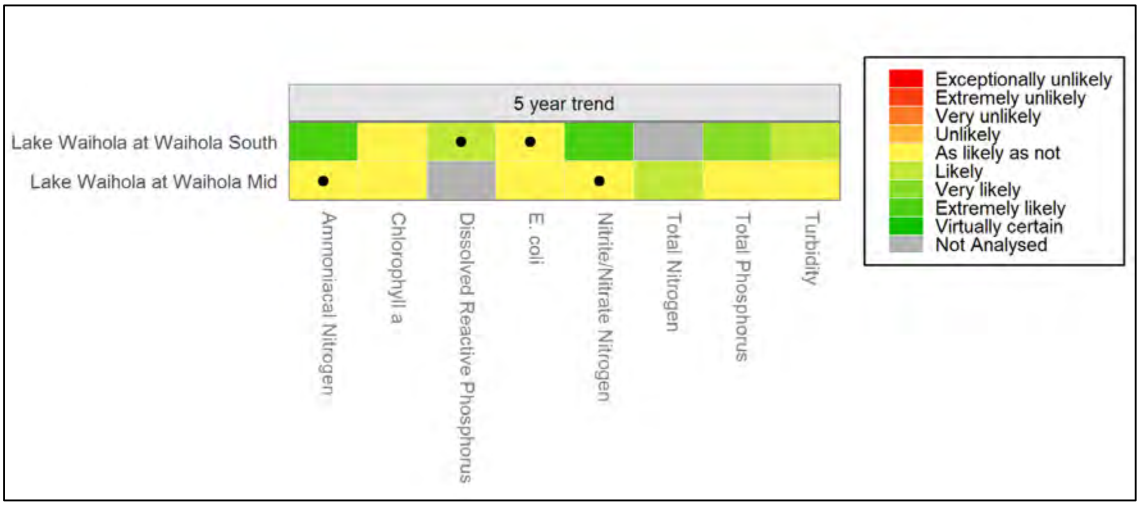


Figure 40 Summary of Taieri FMU lake sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

Trend analysis for the Taieri rivers is shown in Figure 39. A comparison of 10- and 20-year trends in river water quality revealed several changes between the two time periods.

Generally, across the Taieri FMU in the last 10-years compared to the 20-year period there are more improving trends 'likely to virtually certain to be improving' than degrading trends 'unlikely to exceptionally unlikely to be improving'. In the most recent 10-years the degrading trends for *E. coli*, NNN, TN still outweigh improving trends for these analytes, however the trend direction is good as certainty has changed from mainly 'exceptionally unlikely to be improving' to 'unlikely' to be improving.

Three sites, the Taieri at Waipiata, Taieri at Allanton, Silverstream at Taieri saw a change from the predominance of degrading 20-year trends to a predominance of improving 10-year trends. Conversely, Waipori at Waipori Falls shows more degrading trends in the 10-year analysis, compared to the 20-year analysis.

Trend analysis for 5-year for Lake Waihola is shown in Figure 40. There are no degrading trends during this short time period.

6.1.4 Groundwater

6.1.4.1 Groundwater State

Groundwater quality state for the Taieri FMU is shown in Table 11. The results show high risk of potential faecal contamination, with most bores in the FMU having exceedances of the E. coli DWSNZ MAV, comprising between 10-33% of the samples. All median nitrate-N concentrations are below the DWSNZ nitrate-N MAV of 11.3mg/L. However, nitrate-N concentrations in three bores (H42/0214, situated in the Maniototo Tertiary Aquifer, I44/0519 and I44/0821, both situated in the Lower Taieri aquifer) are above the 2.50mg/L threshold for low intensity land use (Daughney and Morgenstern, 2012), with concentrations in bore I44/0821 exceeding ½ of the DWSNZ MAV. Dissolved arsenic concentrations in the FMU are generally substantially below the DWSNZ MAV of 0.01mg/L. However, much higher concentrations (0.0096mg/L, rounded up in Table 11 i.e., just below the MAV) were measured in bore H42/0213 (situated in the Maniototo Tertiary Aquifer).

Table 11 Groundwater current state results for the Taieri FMU. The key for the colour classification is shown at the bottom of the table.

Site	Location/ aquifer	Total no. of *E. coli* samples	No. of Detects	*E. coli* % exceed-ance	Median Nitrate concentration (mg/L)	Max. Arsenic concentration (mg/L)
H42/0213	Maniototo	20	5	25	0.019	0.010
H42/0214	Maniototo	18	6	33	4.500	0.000
H43/0132	Strath Taieri	18	2	11	1.510	0.002
H44/0007	Lower Taieri	11	3	27	0.230	0.000
I44/0495	Lower Taieri	20	2	10	0.006	0.000
I44/0519	Lower Taieri	20	5	25	3.150	0.001
I44/0821	Lower Taieri	20	0	0	5.700	0.000
I44/0964	Lower Taieri	13	0	0	1.570	0.001

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

6.1.4.2 Groundwater Trends

The groundwater trend analysis for the Taieri FMU is summarised in Figure 41 and is shown spatially in Figure 42. The results show that nitrate-N concentrations are 'very'/'extremely unlikely' improving in most bores in the FMU. This includes most bores in the lower Taieri and Strath Taieri (H43/0132) aquifers. The only exceptions, where the trend is 'likely improving' (bore H42/0213) or 'extremely likely improving' (Bore I44/0821), are located in the Maniototo Tertiary the Lower Taieri aquifers, respectively Figure 42. The 10-year trends show a mixed, and more positive outlook, with 'likely' or 'very likely improving' trends in three bores, all located in the lower Taieri aquifer. Conversely, other two bores in the aquifer show 'exceptionally unlikely improving' (I44/0519) or 'unlikely improving' (I44/0964) trends. The comparison between the 10 and 5-year trends was generally not favourable, with most trends either remaining in the same confidence level (e.g., I44/0821, I44/0519) or degrading (e.g., I44/0964, H43/0132). The 10-year trends were not assessed for the bores in the Maniototo Tertiary aquifer (H42/0213, H42/0214) as they were only monitored since 2015. The five-year trend for dissolved arsenic was only analysed for bore H42/0213, which shows that arsenic concentrations are 'exceptionally unlikely improving'. Ten-year trends for arsenic were not analysed due to lack of data and high number of samples below the analytical limit of detection.

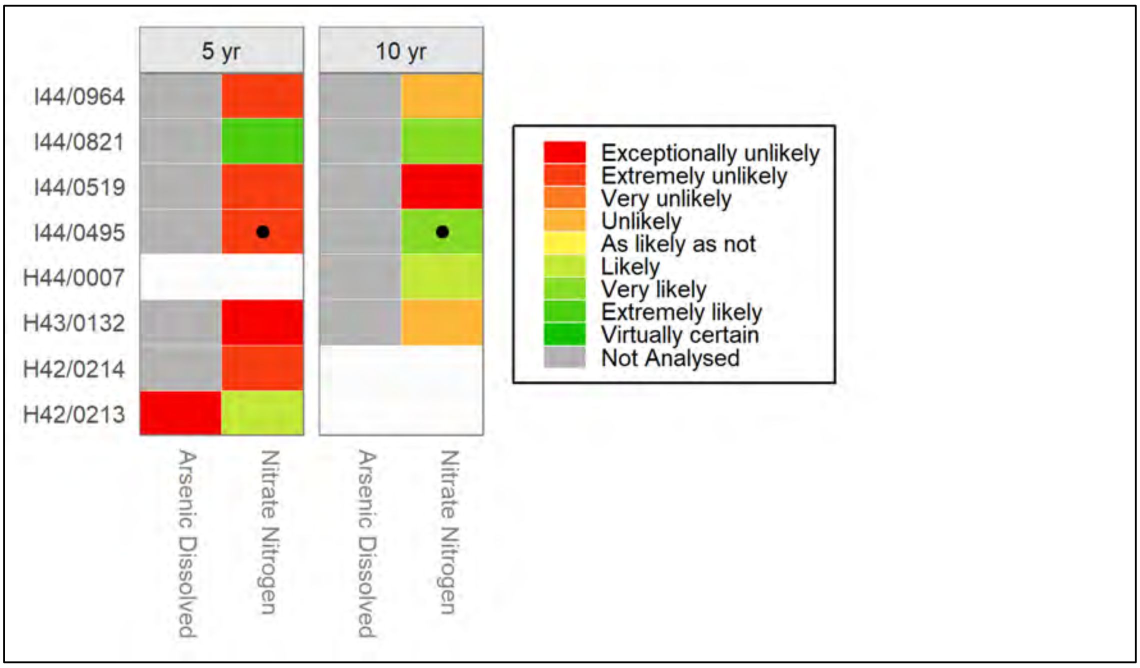


Figure 41: Summary of Taieri FMU sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

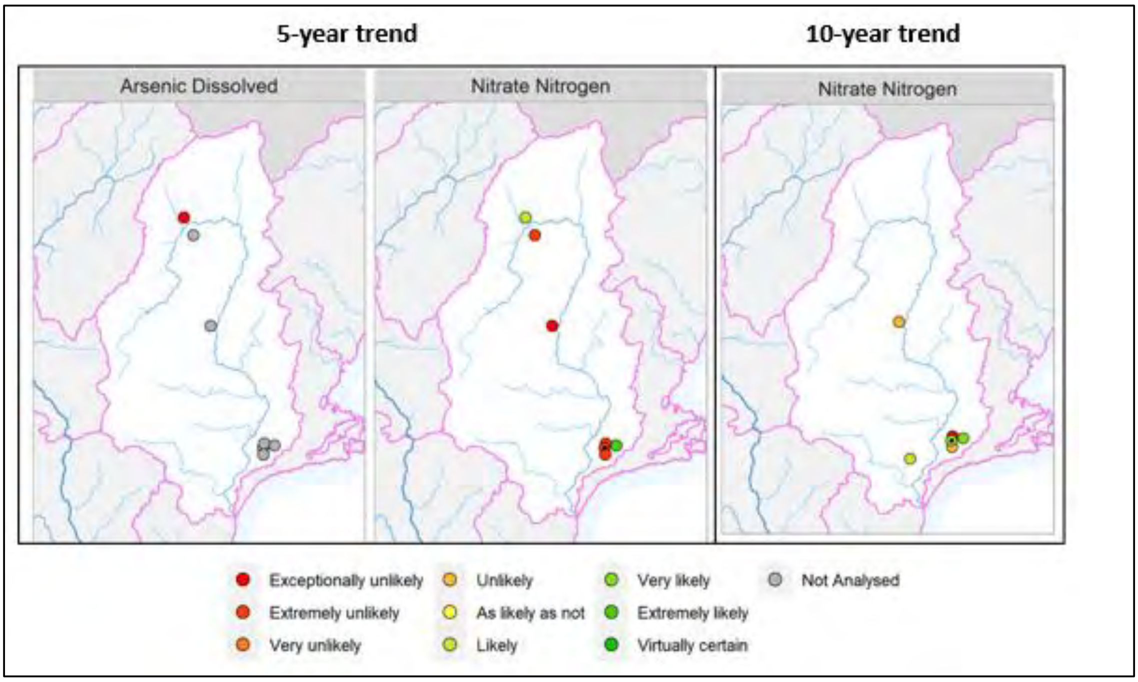


Figure 42: Groundwater quality 5 -and 10-year trend results for the Taieri FMU (LWP, 2023). Note that the 10-year trend for dissolved arsenic were not analysed.

6.1.5 Water quality summary Taieri FMU

The Taieri FMU covers about 570,000 hectares of land. The dominant land use in the Taieri FMU is dry-stock farming (71%), comprising of sheep and beef (57%); mixed sheep, beef, and deer (8%); and sheep farming (6%). Conservation estate occurs on approximately 10% of the Rohe. Forestry and Dairy farming occur on 5% and 4% of the FMU, respectively. The notable trends in land use change over the past three decades have been an increase in the extent of dairy farming (31%), conservation estate (by 58%), forestry (by 7%), urban area (by 15%), and nurseries/ vineyards/orchards (by 18%). The extent of dry-stock farming decreased by 8%, although it remains the dominant land use activity in the Taieri area.

Water quality in the Taieri FMU is generally good with the majority of sites and attributes achieving ‘A’ and ‘B’ bands, as seen in Figure 37, however some of the tributaries on the lower Taieri plain have some of the poorest water quality in the region. Two streams are monitored in the Plain: the Contour Channel and the Silverstream. Both these watercourses are maintained for flood protection purposes with contoured bed and banks, have little riparian vegetation and drain a catchment that is predominantly intensively farmed in their lower reaches, as well as hosting the largest settlement in the Taieri, Mosgiel, with its associated stormwater infrastructure in the township and many lifestyle blocks that use septic tanks for their wastewater.

Although the upper Silverstream has good water quality and meets NOF attribute ‘A’ or ‘B’ bands, the lower Silverstream has a poorer outcome. The lower Silverstream returned ‘D’ bands for three of four *E. coli* statistics and periphyton. Although the Silverstream has low DRP concentrations, the lack of shade and few flushing flows create ideal conditions for cyanobacteria, which blooms in the lower reaches of the Silverstream most years. Appendix 1 shows that NNN concentrations in the Silverstream increase from a median of 0.0076 mg/l at Three Mile Hill Road to 0.41 mg/l at the lower Silverstream site. The high NNN concentrations allow for prolific algal growth.

The Contour Channel achieves a ‘D’ band for *E. coli,* DRP and suspended fine sediment. The Contour Channel is a manmade channel that conveys water off the Maungatua’s directly to Lake Waipori, it will also drain some of the low-lying agricultural land on the Taieri Plain. It is similar to the Silverstream, being open with no riparian vegetation.

Despite relatively good bacterial water quality throughout the Taieri FMU, *E. coli* is the worst performing attribute with six of the 17 sites failing to meet the national bottom line. The six include two mainstem Taieri sites; Sutton and Allanton. The change from ‘A’ band *E. coli* at Tiroiti at the top of the Strath Taieri, to a ‘D’ band at Sutton at the bottom of the Strath Taieri is concerning.

Lake Waihola shows nutrient and phytoplankton concentrations generally in the NOF ‘C’ bands, this is typical of a productive lake (wetland complex) where elevated concentrations of nutrients are expected compared to deep alpine lakes. Lake Waihola has episodic algal blooms typical of such a eutrophic lake.

Trend analysis shows that the generally degrading 20-year trends has shifted to a predominance of improving 10-year trends. An example of this is the Taieri at Waipiata, which over 20-years had degrading trends for DRP, *E. coli*, NNN and TN, however over the last 10-years the trends for DRP and *E. coli* are ‘likely to ‘extremely likely’ to be improving. The upper Taieri catchment group (Upper Taieri Wai) are instrumental in pushing for improvement, the multistakeholder group’s goals are to enhance environmental and community values throughout the Upper Taieri catchment. The recent 5-year Tiaki Maniototo project received funding from the Ministry for the Environment (MfE) and is run by the Upper Taieri Wai with the aim of improving freshwater quality, ecosystem values and biodiversity in the Upper Taieri catchment.

An example of the possible impact of improved farming practice and catchment group work in the Upper Taieri is that in the 20-year period there were 19 attributes with ‘very unlikely to extremely unlikely’ improving trends, whereas in the 10-year period, this had decreased to eight.

Groundwater quality state analysis from the Taieri FMU showed a high potential risk for faecal contamination, with E. coli exceedances measured in most monitoring bores. All median nitrate-N concentrations are below the DWSNZ MAV of 11.3mg/L. However, nitrate-N concentrations in some bores are above the 2.50mg/L threshold for low intensity land use (Morgenstern and Daughney, 2012) and one exceeds ½ of the DWSNZ MAV. Dissolved arsenic concentrations in the FMU are generally substantially below the DWSNZ MAV of 0.01mg/L. However, the maximum concentration in bore H42/0213 (situated in the Maniototo Tertiary Aquifer) was much higher, at just below the DWSNZ MAV. The trend analysis of groundwater nitrate-N concentrations in the FMU paints a sombre picture. The 10-year trends show a mixed, pattern, with ‘likely’ or ‘very likely improving’ in three bores, all in the lower Taieri aquifer. Conversely, other two bores in the aquifer show ‘exceptionally unlikely improving’ (I44/0519) or ‘unlikely improving’ (I44/0964) trend. However, the 5-year trends within most bores in the FMU, with all bores apart from I44/0821 falling to ‘very’/’extremely unlikely’ improving, which suggesting that groundwater quality is not improving for this period. The 5-year trend for dissolved arsenic was only analysed for bore H42/0213, which shows that arsenic concentrations are ‘exceptionally unlikely improving’. However, as arsenic concentrations are likely to be mainly controlled by factors such as geology this result is probably not very meaningful. Ten-year trends for arsenic were not analysed due to lack of data and high number of samples below the analytical limit of detection.

The *E. coli* exceedances and nitrate-N concentrations are likely because most monitoring bores in the FMU are located in areas of intensive farming and/or septic tanks, particularly in the Lower Taieri plain aquifer. In addition to that, most monitoring bores are poorly secured, hence these results are not surprising. Dissolved arsenic concentrations in the FMU are generally much lower than the DWSNZ MAV of 0.01mg/L, apart from bore H42/0213 (situated in the Maniototo Tertiary Aquifer). The source of the arsenic is unknown, although it is likely to be the local schist lithology of the ridges surrounding the Maniototo basin. The variability in arsenic concentrations between this bore and the other ones further illustrates the spatial variability of arsenic in groundwater, which was also illustrated in other parts of the region, e.g., the Upper Lakes (Section 5.1.5). Based on these results, it is therefore strongly recommended that bore owners across the FMU maintain good bore security, practice good land/nutrient management and septic tank maintenance, and regularly test their bore water.

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7 Dunedin & Coast FMU

Figure 43 Location of water quality monitoring sites in the Dunedin & Coast FMU

7.1.1 Dunedin & Coast Description

The Dunedin & Coast Freshwater Management Unit (FMU) spans over 1,000 square kilometres and runs from just south of Karitane down to the mouth of the Clutha/Mata-Au. Dunedin city is the largest urban area in the FMU and has the largest population in Otago. Many of the rivers are short river or stream catchments, some associated with estuaries and/or wetlands, especially where the Taieri River cuts through the FMU.

The main catchments are the Waitati River, Leith Stream and Kaikorai Stream catchments within Dunedin city and the Tokomairaro (Tokomairiro) River in the south near Milton.

The Waitati River has a catchment area of 46.5 km^2, the main stem flows for approximately 5.5km in a north easterly direction from Swampy Summit to join Blueskin Bay at Waitati. The Leith Stream catchment covers an area of 42 km^2. The headwaters of the Leith Stream originate at the saddle between Mount Cargill and Swampy Summit and flow for 12 km in a south-easterly direction to discharge directly to Otago Harbour, Dunedin. The Kaikorai Stream has a total catchment area of 55 km^2 and flows in a south westerly direction for approximately 15 km down the Kaikorai Valley into Kaikorai Estuary. The Tokomairiro River, located about 48 km south-west of Dunedin, has a catchment area of 403 km^2.

The area has a marine-temperate climate and outstanding features, including a natural character and form of coastal landscape, e.g., Otago Peninsula; ecological values, e.g., cloud forests of the Leith and Ōrokonui Ecosanctuary; healthy estuaries, e.g., Hoopers/Papanui, Blueskin, Akatore, Pūrākaunui; wetlands, e.g., Swampy Summit Swamp; notable wildlife, e.g., hoiho, northern royal albatross, seals, sea lions, red-billed gulls, black-billed gulls; and healthy marine habitats. It is also home to threatened species, including lamprey in coastal streams.

ORC monitors seven river sites and one groundwater site in the Dunedin & Coast FMU. There is currently only one monitoring bore with this FMU, situated in the Tokomairaro GWMZ. Monitoring sites are shown in Figure 43.

7.1.2 State Analysis Results

The results of grading the SoE sites in the Dunedin & Coast FMU according to the NPS-FM NOF criteria are mapped in Figure 44 and summarised in Figure 45. Many sites in the Dunedin & Coast FMU did not meet the sample number requirements and accordingly are shown as white cells with coloured circles. Periphyton (Chl-a) was only monitored at a subset of sites, white cells indicate that this variable was not monitored at a site. A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements

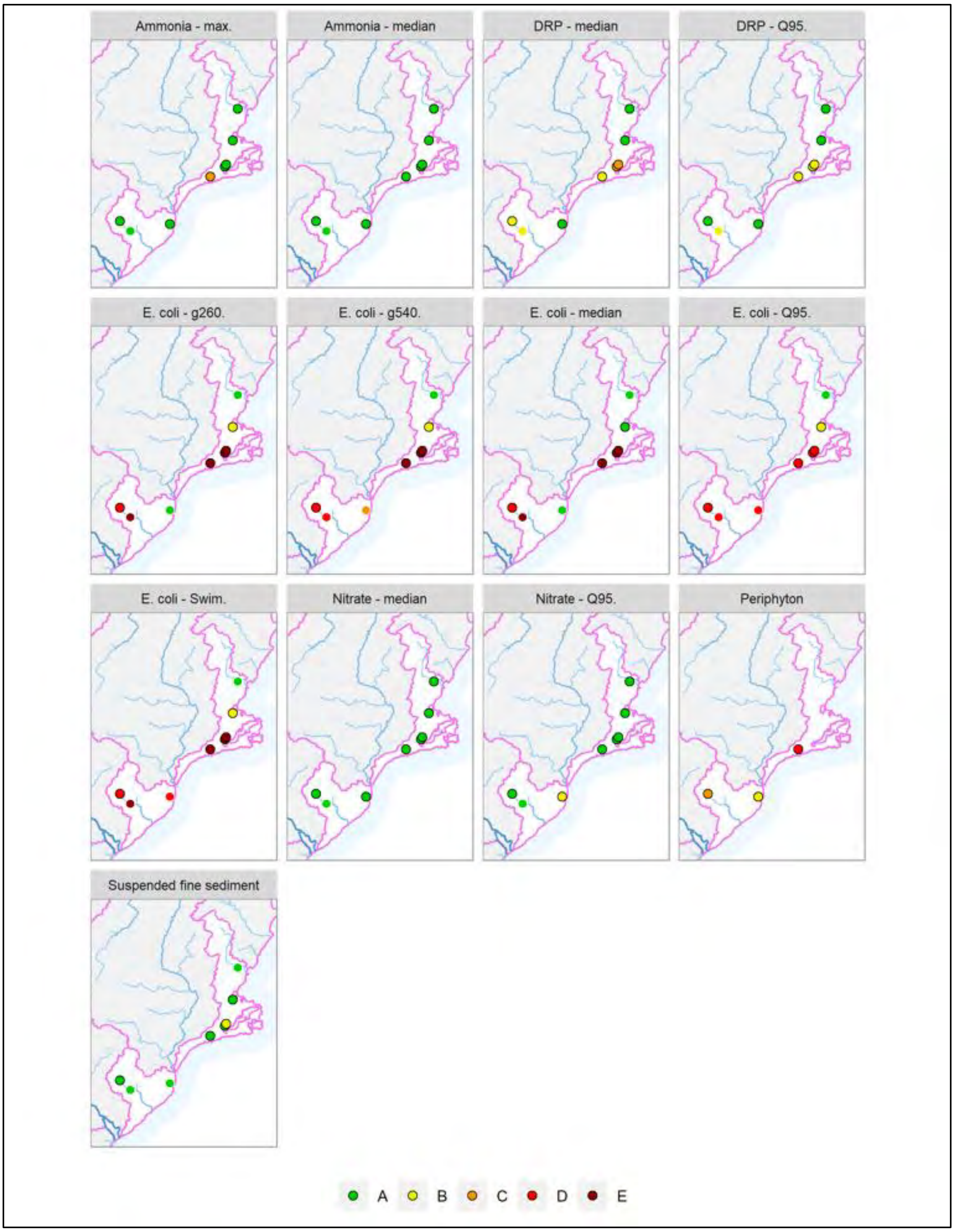


Figure 44 Maps showing Dunedin & Coast FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines.

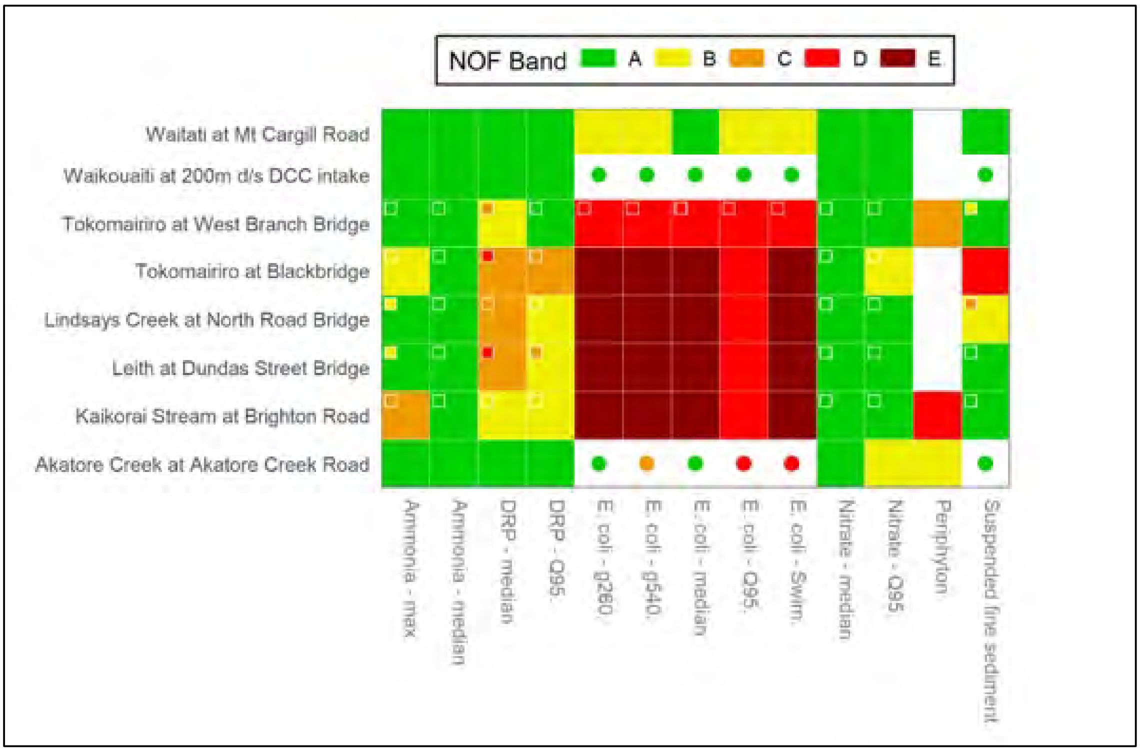


Figure 45 Grading of the river sites of the Dunedin & Coast FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

7.1.2.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 44 and Figure 45 (periphyton). Periphyton trophic state results to date show that Akatore Creek is in attribute band 'B' as results tend to be between >50 and ≤120 chl-*a*/m^2 meaning low nutrient enrichment. The Kaikorai Stream is in attribute band 'D' for periphyton as results tend to be >200 chl-*a*/m^2 reflecting high nutrient enrichment and the possibility of regular nuisance blooms and the Tokomairiro has an attribute band of 'C' indicating moderate nutrient enrichment.

Figure 44 and Figure 45 show DRP attribute states for ecosystem health (DRP median and Q95). The results in the Dunedin & Coast FMU show that three sites achieve an 'A' band for DRP (Waitati River, Waikouaiti River, Akatore Creek), two sites achieve a 'B' band (Kaikorai Stream, Tokomairiro at West Branch Bridge) and three sites a 'C' band (Leith at Dundas Street, Lindsay's Creek, Tokomairiro at Blackbridge). The NPS-FM (2020) describes band 'C' as *'Ecological communities impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate and fish taxa, and high rates of respiration and decay'.*

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. Sites with the highest median NNN concentrations are Lindsay's Creek at North Road Bridge (0.58 mg/l), the Leith at Dundas Street (0.46 mg/l), Kaikorai Stream (0.4 mg/l) and Tokomairiro at Blackbridge (0.39 mg/l) respectively. These four sites also have the highest median DRP concentrations.

7.1.2.2 Toxicants (Rivers)

NOF attribute bands for NH4-N are shown in Figure 44 and Figure 45, the national bottom line for toxicants (NH4-N and NNN is below band ‘B’. In the Dunedin & Coast FMU, of the eight sites monitored, six sites have excellent protection levels against ammonia toxicity returning an ‘A’ band (highest level of protection) for NH4-N. Of the remaining sites, the Tokomairiro at Blackbridge achieved a ‘B’ band for the annual maximum and the Kaikorai Stream returned a ‘C’ band for the annual maximum which is below the national bottom line. The NPS-FM describes the ‘C’ band as *‘ammonia starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)’.*

NOF attribute bands for nitrate-N (measured as NNN) toxicity are shown in Figure 44 and Figure 45, again the national bottom line is below band ‘B’. In the Dunedin & Coast FMU all sites achieve an ‘A’ band across both statistics, other than Tokomairiro at Blackbridge and Akatore Creek which achieved ‘B’ band for the Q95 statistic.

7.1.2.3 Suspended fine sediment (Rivers)

The clarity results for the Dunedin & Coast FMU are shown in Figure 44 and Figure 45 and Appendix 2 gives the clarity numerical results and sediment classes for each site, all sites were either Class 1 or Class 2. Of the eight sites monitored, six returned a NOF attribute band of ‘A’ which denotes ‘*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions’* (NPS-FM, 2020). Lindsay’s Creek returns a NOF band of ‘B’ and the Tokomairiro at Blackbridge achieves a ‘D’ band, which the NPS-FM describes as *‘moderate to high impact of suspended sediment on instream biota. Sensitive fish species may be lost’*

7.1.2.4 Human health for recreation (Rivers)

Figure 44 and Figure 45 summarise compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading. Compliance is generally poor across the Dunedin & Coast FMU, with all sites other than the Waitati River (Band ‘B’) and Waikouaiti River (Band ‘A’) returning bacterial water quality below the ‘C’ band.

7.1.3 Trend Analysis: Rivers

Trend analysis results for the Dunedin & Coast FMU is shown in Figure 46.

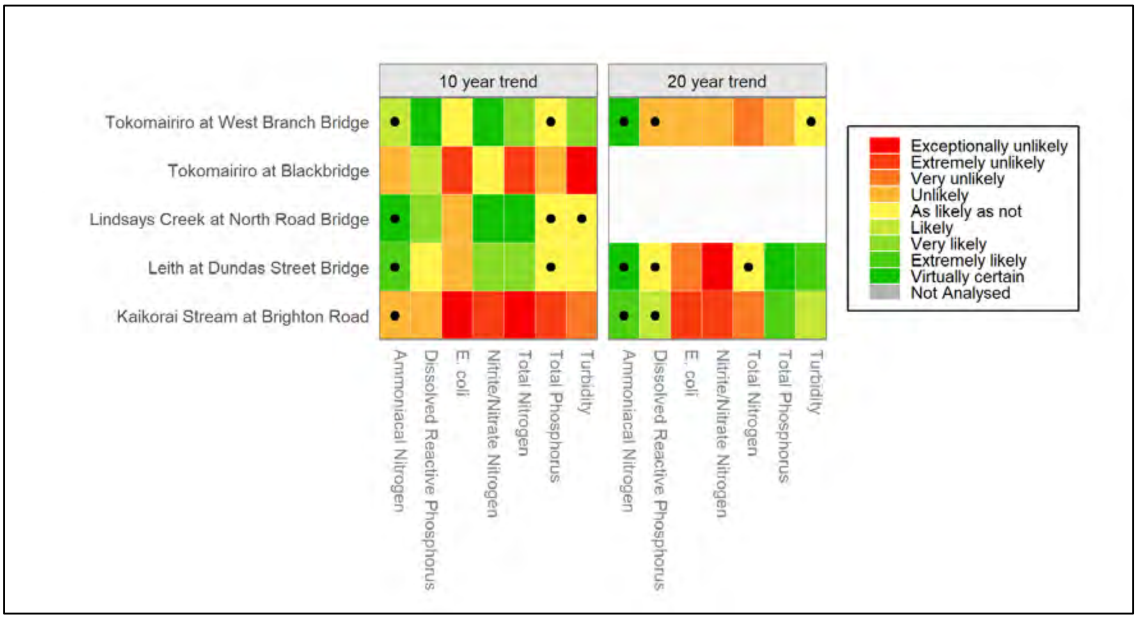


Figure 46 Summary of Dunedin & Coast surface water FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

Trend analysis for the Dunedin & Coast FMU rivers is shown in Figure 46. The Tokomairiro at Blackbridge and Lindsay's Creek at North Road only have 10-year trends available, the other three sites have both 10- and 20-year trends available.

Comparing sites with both 10- and 20-year trends (Tokomairiro at Blackbridge, Leith at Dundas, Kaikorai at Brighton Road) the Tokomairiro and Leith saw a change from the predominance of degrading 20-year trends to a predominance of improving 10-year trends. The converse was the case for the Kaikorai Stream with a change from predominantly improving trends, to one of degrading trends over the 20-year period. The Tokomairiro at Blackbridge, has 'extremely unlikely' to 'exceptionally unlikely' improving trends for *E. coli*, TN, and turbidity, when the upstream site at West Branch Bridge shows improving trends. The Leith and it's tributary, Lindsay's Creek have similar 10-year trends with *E. coli* being the only degrading ('unlikely' to be improving) trend of the analytes monitored.

7.1.4 Groundwater

7.1.4.1 Groundwater State

The state of groundwater quality in the Dunedin & Coast FMU is summarised in Table 12. The results generally show good groundwater quality, with no exceedances of the DWSNZ MAV. There were no detections of E. coli in the bore. The median nitrate-N concentration, 0.001mg/L, is substantially lower than the threshold for low intensity land use (and Daughney, 2012). Conversely, the maximum arsenic concentrations are high, at 0.0047mg/L (rounded up in Table 12). However, concentrations have dropped since 2018, and were below the limit of detection since September 2020 (ORC, 2021).

Table 12 Groundwater current state results for the Dunedin & Coast FMU. The key for the colour classification is shown at the bottom of the table.

Site	Aquifer	Total no. of *E. coli* samples	No. of *E. coli* Detections	*E. coli* % exceedance	Median Nitrate concentration (mg/L)	Max. Arsenic concentration (mg/L)
H45/0314	Tokomairiro GWMZ	18	0	0	0.001	0.005

E. coli	nitrate	diss. Arsenic
no detections	<2.50 mg/L	<0.0025 mg/L
<10%	2.50 - 5.50 mg/L	0.0025 - 0.005 mg/L
10-50%	5.50 - 11.3 mg/L	0.005 - 0.01 mg/L
>50%	>11.3 mg/L	>0.01 mg/L

7.1.4.2 Groundwater Trends

The five-year trends for the Dunedin & Coast FMU are shown in. Dissolved arsenic is the only parameter analysed and the analysis was only done for a five-year period. Nitrate-N is likely not to have been analysed due to the low concentrations. The results show that dissolved arsenic concentrations are 'extremely likely' improving.

Figure 47 Summary of Dunedin & Coast groundwater FMU sites categorised according to the level of confidence that their 5-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend.

7.1.5 Water quality summary Dunedin & Coast FMU

The dominant land use in the Dunedin & Coast FMU is plantation forestry (28%). Dry-stock farming comprising of sheep and beef (19%); mixed sheep, beef and deer (4%); beef (5%) and sheep farming (8%), also cover a significant portion of the FMU. Dairy farming occurs on approximately 8% of the area. Approximately 7% of the FMU is for urban use. The notable trends in land use change over the past three decades have been an increase in the extent of dairy farming (38%), public conservation estate (by 55%), plantation forestry (by 19%), and urban land use (by 4%). The extent of dry-stock farming decreased by 14%, although it remains amongst dominant land use activities in the Dunedin & Coast area.

In the Dunedin & Coast FMU water quality generally has high bacteria and nutrient concentrations. The Kaikorai has an ammonia toxicity band of 'C' placing it below the national bottom line, it is the only site in Otago that has a NH4-N toxicity below band 'B'. Nitrate-N toxicity across the FMU achieved an 'A' band, other than the Tokomairaro at Blackbridge and the Kaikorai Stream which achieved 'B' band when compared to the Q95 nitrate-N statistic.

E. coli was below attribute band 'C' in six of the eight sites monitored. The Kaikorai, Leith and Lindsay's Creek are Dunedin urban streams, their catchments have a high degree of urbanisation in their lower reaches. Urbanisation comes with associated stormwater drains that discharge directly into the rivers. The quality of stormwater is generally poor with elevated nutrients and *E. coli* concentrations.

All urban sites and sites in the Tokomairaro catchment have high median bacteria concentrations which may indicate an *E. coli* source that is affecting water quality even under low flow conditions. In agricultural settings this could be the presence of waterfowl, stock, or artificial drainage and in urban streams this could be due to point source discharges. Both the Tokomairiro River sites are located in rural settings, the upper site, West Branch Bridge is located just downstream of hill country and the Manuka Gorge, whereas Blackbridge is located downstream of the intensive farming area of the Tokomairaro flats to the West of Milton township. Although both sites return *E. coli* results below the national bottom line, median *E. coli* at the lower site was over four times that of the upper site. The disparity may be due to differences in land use and the soil type below the gorge being generally fine textured silt or clay requiring artificial drainage to lower the water table and improve soil drainage. Although this allows more oxygen into the soil limiting the reduction capacity and minimising the occurrence of runoff, it creates a pathway for water to transport contaminants through the soil to the river.

Alongside the poor state, trend analysis shows that water quality trends over 10-years is improving for all sites other than the Kaikorai Stream and the Tokomairiro at Blackbridge. Of the urban streams, the Kaikorai stream continues to degrade over the 10-year trend (all attributes), however the Leith and Lindsay's creek show improving trends across all attributes, other than for DRP with is 'unlikely' to be improving at both sites.

The Tokomairiro at Blackbridge has degrading trends for *E. coli*, TN, and turbidity, when the upstream site at West Branch Bridge shows improving trends. The poor water quality with high nutrient concentrations at the bottom of the Tokomairaro catchment will likely affect ecosystem health of the Tokomairiro estuary.

The groundwater monitoring results show good compliance with the DWSNZ, particularly for E. coli and nitrate-N. The median nitrate-N concentration is substantially lower than the threshold for low intensity land use (Daughney and Morgenstern, 2012). However, as there is grazing around the bore this may be due to the potentially reducing conditions in the area, which may lead to nitrate-N breakdown (Close *et al.,* 2016) and mask nitrate-N use in the catchment. This may also affect dissolved arsenic concentrations.

The trend assessment for arsenic shows improvement. However, arsenic is more likely to be geologically sourced hence this trend may not be very meaningful. Although the state and trend results are generally good, there is only monitoring bore in the FMU, hence it does not provide a representative reflection of groundwater quality in the FMU. Nevertheless, it is recommended that groundwater users regularly test their bore water, maintain good bore security, and practice good land/nutrient management.

8 North Otago FMU

Figure 48 Location of water quality monitoring sites in the North Otago FMU

8.1.1 North Otago FMU Description

The North Otago Freshwater Management Unit (FMU) covers about 296,000 hectares and extends from Waitaki Bridge down through Oamaru, Moeraki, and Palmerston townships to the bottom of the southern branch of the Waikouaiti River. It includes coastal margins to the north and east of Waitaki and Oamaru and the coastal strip from Glen Creek to the Waikouaiti River. Some major rivers within the FMU include the Waitaki, Kakanui, Shag, Waikouaiti, Waianakarua, and Pleasant. High natural character values exist in the upper catchments of the Kakanui and Waianakarua rivers, Trotters Gorge, and the south branch of the Waikouaiti River.

From its source in the Kakanui Mountains, the Kakanui River flows north-east for about 40 km, through gorges incised in rolling or downland country, before emerging onto plains at Clifton. The Kakanui River's water resource is heavily used for irrigation. The North Otago Irrigation Scheme services much of the lower Kakanui River and Waiareka Creek. In contrast, land use in the Kauru and upper Kakanui are typified by red tussock, native forest, plantation forestry or pasture for red deer, sheep, and beef. Large areas of the North Otago FMU are underlain by volcanic soils, where market garden farming is common. This leads to high nitrate-N concentrations in groundwater in the area (ORC, 2021).

The Waianakarua River is a small river with a catchment area of 262 km^2 which rises in the Horse Range and Kakanui Mountains in North Otago. Much of the catchment consists of extensively grazed grasslands and scrub, native forest, and plantation forestry but intensification of land use in the lower catchment has occurred in recent years.

The Shag River catchment covers an area of 550 km^2. The Shag is a medium sized river with its headwaters originating on the south-western slopes of Kakanui Peak in the Kakanui Mountains. From here it flows 90km in a south-easterly direction past the township of Palmerston before entering the Pacific Ocean to the south of Shag Point.

The Waikouaiti catchment area covers 421 km^2, the river has two main branches, the North Branch (283 km^2) and South Branch 86 km^2.

ORC monitors 15 river sites and 13 groundwater sites in the North Otago FMU. The groundwater bores are found in the lower Waitaki Plains aquifer, the North Otago Volcanic Aquifer (NOVA), the Kakanui-Kauru Alluvial Aquifer, and the Shag Alluvial Aquifer. Monitoring sites are shown in Figure 48.

8.1.2 State Analysis Results

The results of grading the SoE sites in the North Dunedin FMU according to the NPS-FM NOF criteria are mapped in Figure 49 and summarised in Figure 50. Many sites in the North Otago FMU did not meet the sample number requirements and are shown as white cells with coloured circles. Chl-a was only monitored at five sites in the North Otago FMU, white cells indicate that this variable was not monitored at a site.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

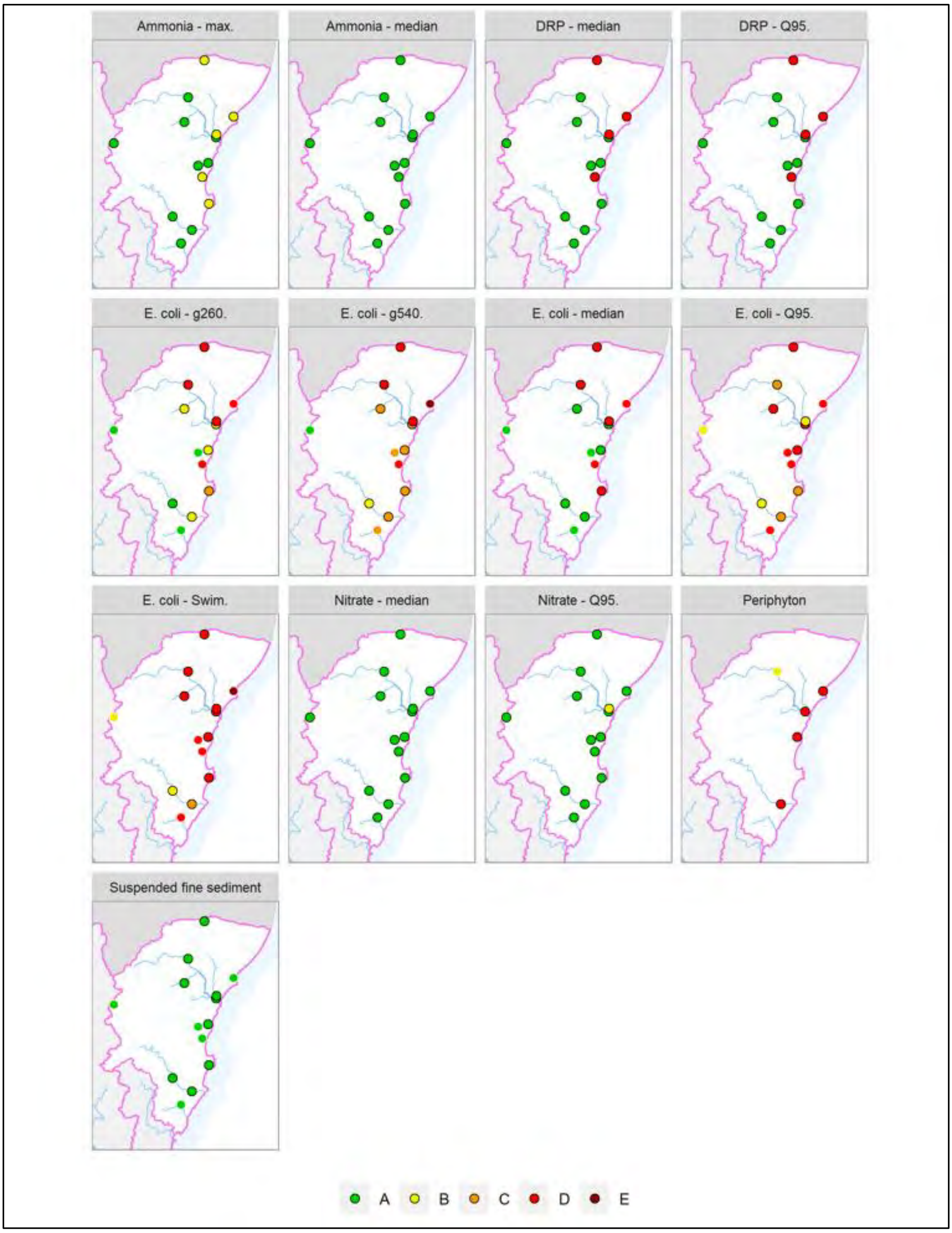


Figure 49 Maps showing North Otago FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines

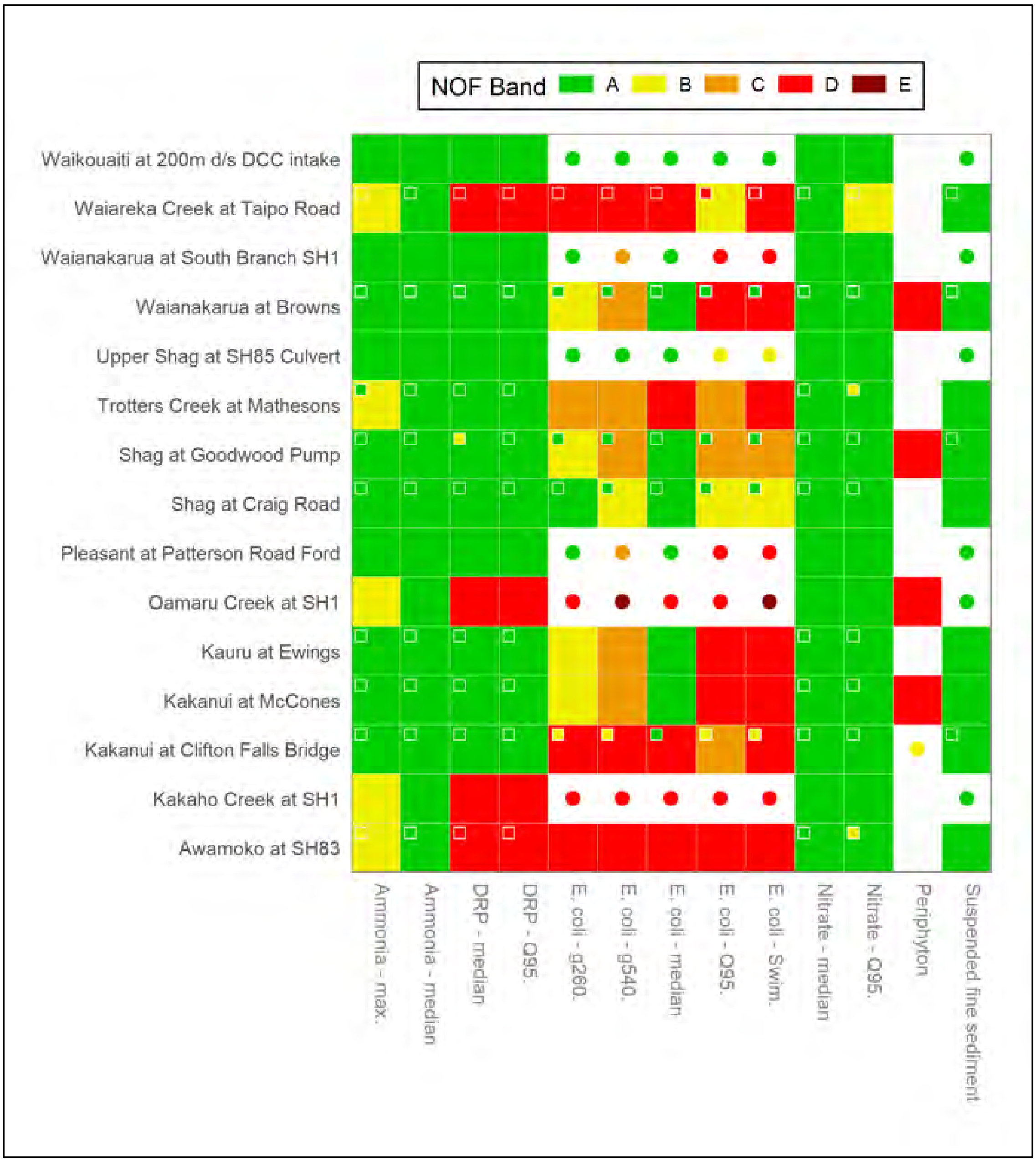


Figure 50 Grading of the river sites of the North Otago FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements in Table 1 *are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline*

8.1.2.1 Periphyton and Nutrients

Results for the river periphyton trophic state results are shown in Figure 49 and Figure 50. Periphyton trophic state results to date show that the North Otago FMU returns mainly 'D' bands which is below the national bottom line, this reflects elevated nutrient enrichment and the possibility of regular nuisance blooms. The Kakanui River at Clifton Falls achieves a NOF attribute band of 'B'.

Figure 49 and Figure 50 also show DRP attribute states for ecosystem health (DRP median and Q95). The results in the North Otago FMU show that of the 15 sites monitored, 11 achieve NOF attribute band 'A'. Four sites, Awamoko, Kakaho Creek, Oamaru Creek and Waiareka Creek achieve attribute band 'D', which the NPS-FM (2020) describes as '*ecological communities impacted by substantial DRP elevation above natural reference conditions*'.

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. Sites with the highest median NNN concentrations are Oamaru Creek (0.52 mg/l), Waiareka Creek (0.48 mg/l) and the Awamoko (0.48 mg/l). These sites also have the highest DRP concentrations.

8.1.2.2 Toxicants (Rivers)

NOF attribute bands for NH4-N are shown for the North Otago sites in Figure 49 and Figure 50. In the North Otago FMU 10 sites have excellent protection levels against ammonia toxicity with all sites returning an 'A' band (highest level of protection) for both maximum NH4-N and median NH4-N. The remaining sites (Waiareka Creek, Trotters Creek, Oamaru Creek, Kakaho Creek and Awamoko Stream), returned 'B' bands for the annual maximum. The NPS-FM describes the 'B' band as *'ammonia starts impacting occasionally on the 5% most sensitive species'.*

NOF attribute bands for nitrate-N (measured as NNN) toxicity are given for North Otago FMU sites in Figure 49 and Figure 50. All sites achieve an 'A' band across both the median and Q95 other than Waiareka Creek, which achieved a 'B' band for Q95. The NPS-FM describes 'B' band as NNN having *'some growth effect on up to 5% of species'*

8.1.2.3 Suspended fine sediment (Rivers)

The clarity results for the North Otago FMU are shown in Figure 49 and Figure 50. All sites return a NOF band of 'A' which denotes '*minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions'* (NPS-FM, 2020).

8.1.2.4 Human health for recreation

Figure 49 and Figure 50 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading.

Compliance is in the North Otago FMU is poor, with eleven of 15 sites returning bacterial water quality below attribute band 'C'. The NPS-FM (2020) describes band 'D' as *'30% of the time the estimated risk is ≥50 in 1,000 (>5% risk). The predicted average infection >3%'*. Only the Waikouaiti River achieved an 'A' band, the upper Shag River sites (SH85 and Craig Road) achieved 'B' bands, and the lower Shag River site (Goodwood) achieved a 'C' band.

8.1.2.5 Trend Analysis: Rivers

Trend analysis results for the North Otago FMU is shown in Figure 51.

A comparison of 10- and 20-year trends in river water quality revealed that generally, across the North Otago FMU the predominance of degrading 20-year trends for *E. coli*, NNN, TN and turbidity shifted to a predominance of improving 10-year trends for the same analytes. In addition, the Shag River at Craig Road and the Shag River at Goodwood shifted from mainly degrading 20-year trends to a predominance of improving 10-year trends.

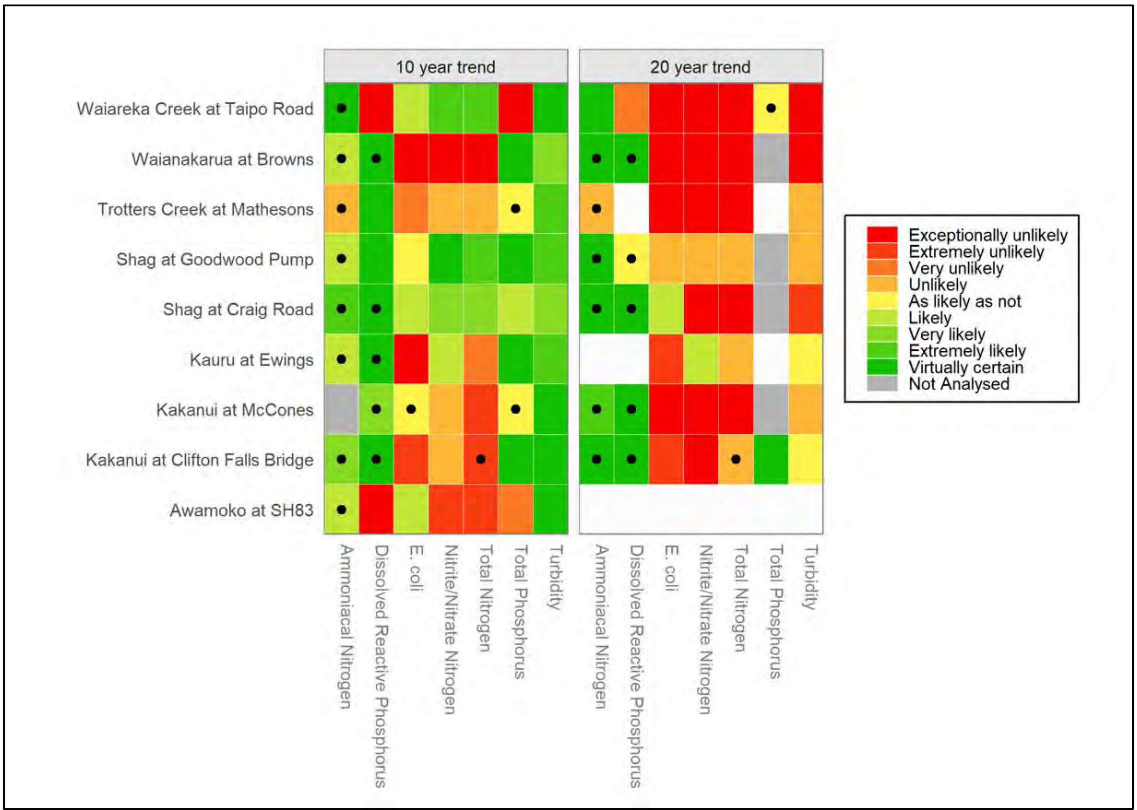


Figure 51 Summary of North Otago FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

In the Kakanui catchment, the Waiareka at Taipo Road showed that the TN and NNN changed from a degrading 20-trend to an improving 10-year trend, but during the same timeframes, TP and DRP have shown 'exceptionally unlikely' improvement. The Kakanui at Clifton shows little change and the Kakanui at McCones shows that E. coli has shifted from a 'exceptionally unlikely improving' degrading 20-year trend to a 10-year stable 'as likely as not' improving trend.

The Waianakarua at Browns continues to show 'exceptionally unlikely' improvement in E. coli, NNN and TN, although turbidity has changed from degrading over the 20-year period to improving over the most recent 10-year period.

The Awamoko Stream, only has 10-year trends, which are generally degrading, other than for NH4-N, E. coli and turbidity.

8.1.3 Groundwater

8.1.3.1 Groundwater State

The groundwater quality current state for the North Otago FMU is shown in Table 13. The results indicate substantial groundwater quality issues, with many exceedances of the DWSNZ MAV for *E. coli* and very high nitrate-N concentrations. Conversely, dissolved arsenic in all the monitoring sites across the FMU were substantially below the DWSNZ MAV of 0.010mg/L.

The *E. coli* data shows many exceedances in almost all the SoE sites in the FMU (apart from two bores). Most exceedances were between 10-50% of the results, with higher proportion of exceedances in two bores (situated in the North Otago Volcanic Aquifer [NOVA] and the Kakanui-Kauru Alluvial Aquifer). Median nitrate-N concentrations in the FMU also show significant issues, with the highest concentrations in Otago. Concentrations in four sites in the NOVA and the Kakanui-Kauru Alluvial Aquifer exceeded the DWSNZ MAV of 11.3mg/L. The median concentrations in three other bores are 50-75% of the DWSNZ MAV, whilst concentrations in four bores exceed the threshold for low intensity land use (Morgnestern & Daughney, 2012). Median concentrations below the threshold were measured in only two SoE bores, situated in the lower Waitaki aquifer and the Shag Alluvial Aquifer.

Table 13 Groundwater current state results for the North Otago FMU. The key for the colour classification is shown at the bottom of the table.

Site	Aquifer/ location	Total no. of *E. coli* samples	Detection	*E. coli* % exceedance	Median Nitrate concentration (mg/L)	Max. Arsenic concentration (mg/L)
J41/0008	NOVA	19	4	21	26.000	0.000
J41/0249	NOVA	14	2	14	4.200	0.001
J41/0317	Lower Waitaki	20	13	65	5.750	0.000
J41/0442	Lower Waitaki	21	4	19	0.530	0.001
J41/0571	Lower Waitaki	21	1	5	4.600	0.001
J41/0576	Lower Waitaki	20	7	35	6.400	0.000
J41/0586	Lower Waitaki	21	2	10	6.800	0.001
J41/0762	Kakanui-Kauru	14	2	14	4.800	0.001
J41/0764	Kakanui-Kauru	18	0	0	3.100	0.001
J41/0771	Kakanui-Kauru	17	2	12	11.600	0.001
J41/1403	Kakanui-Kauru	8	6	75	11.750	0.001
J42/0126	NOVA	19	0	0	19.700	0.000
J43/0006	Shag	17	2	12	0.645	0.000

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

8.1.3.2 Groundwater Trends

The 5- and 10-year trends for groundwater concentrations are summarised in Figure 51 and presented spatially in Figure 53. The trend analysis was only done for nitrate-N as most dissolved arsenic concentrations were below the analytical detection limit. The 10-year trend was only analysed for five SoE bores, as the other ones were not monitored for a sufficiently long period.

The 5-year trend analysis for nitrate-N shows that eight of 11 of the sites in the North Otago FMU are either 'extremely likely improving' or 'likely improving'. Two sites were 'as likely as not improving' whilst the remaining two, situated in the Kakanui-Kauru Alluvial aquifer, are 'unlikely improving'.

The 10-year trends generally show an improving pattern, notably in bore J41/0317, which changed from 'extremely unlikely improving' to 'extremely likely' improving, and bore J41/0008, which changed from 'unlikely' to 'as likely as not' improving. The other bores were in the green confidence levels (i.e., 'likely', 'very likely' or 'extremely likely' improving) and either moved up or down one level (the 10-year trend for J41/0249 was 'virtually certain' improving, but there was no 5-year trend calculated for this bore).

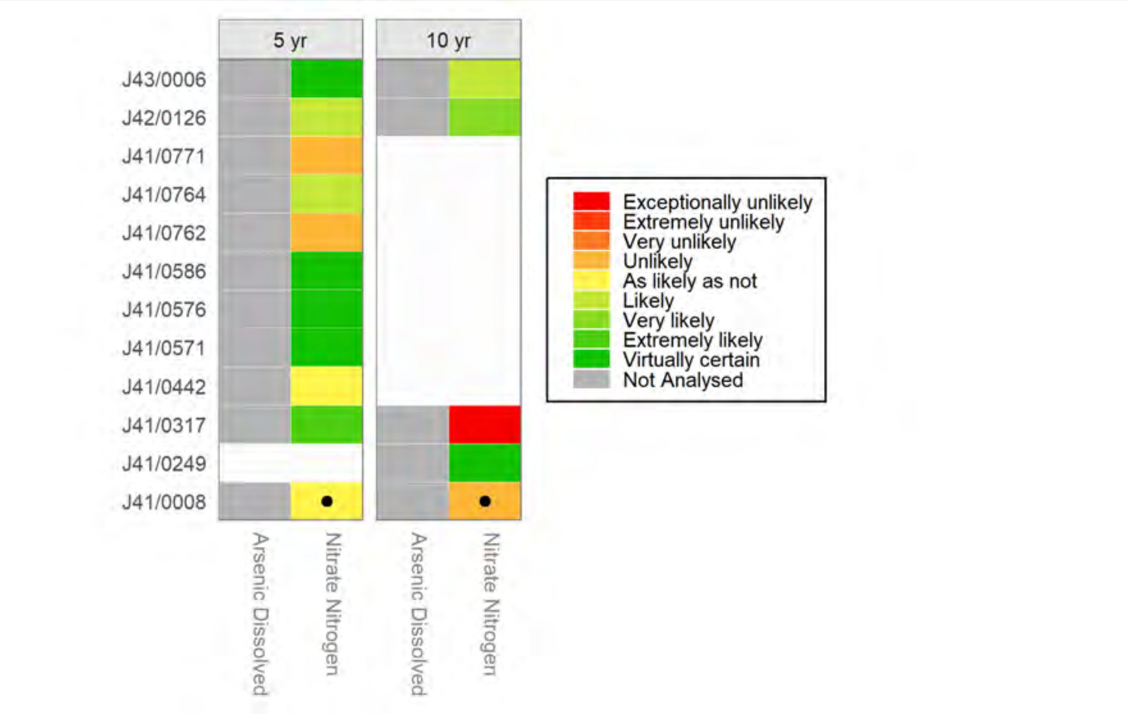


Figure 52: Summary of North Otago FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. White cells indicate site/variables where there were insufficient data to assess the trend

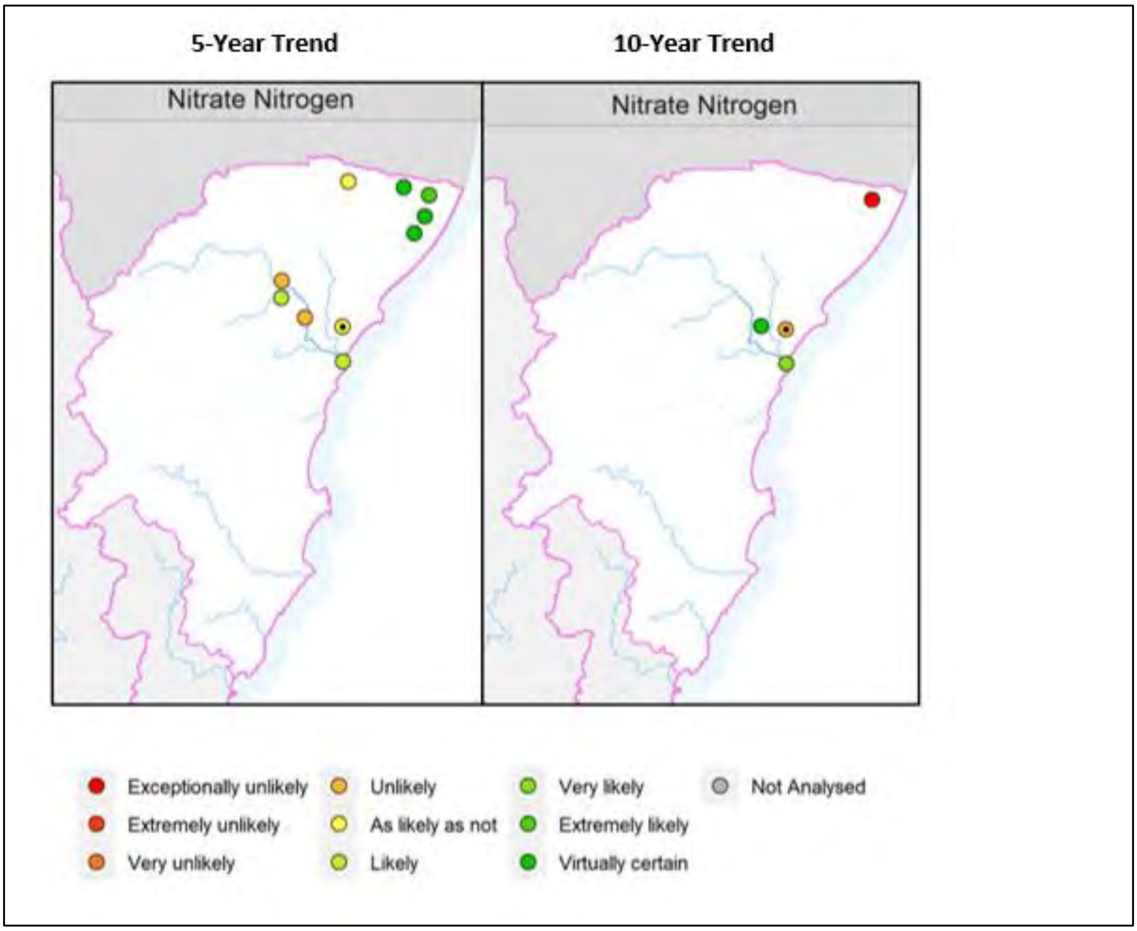


Figure 53: Maps showing summary of North Otago FMU sites categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement. Confidence that the trend indicates improvement is expressed using the categorical levels of confidence defined in Table 4

8.1.4 Water quality summary North Otago FMU

Land use in North Otago is currently dominated by dry-stock farming (58%), comprising predominantly of sheep and beef (45%); mixed sheep, beef, and deer (6%); beef (5%); and sheep farming (2%). Dairy farming occurs on approximately 12% of the Rohe. Forestry, and conservation estate occur on 7% and 6% of the area, respectively. The notable trends in land use change over the past three decades have been an increase in the extent of dairy farming (by 57%), forestry (by 67%), and conservation estate (by 117%). The extent of dry-stock farming decreased by 12%, although it remains the dominant land use activity in the North Otago area.

Oamaru Creek has poor water quality, mainly returning 'D' bands, likely due to the influence of its urban setting. High nutrient concentrations are reflected in the 'D' band obtained for periphyton and drain discharges to the Creek are likely to add to bacteria concentrations. Waiareka Creek, Kakaho Creek and the Awamoko also return mostly 'D' bands, these sites are in a rural settings and ruminant or avian sources are the most likely sources of bacteria in these catchments.

Trend analysis identifies many 'exceptionally unlikely' improving trends over both the 10- and 20-year periods. In the last 10 years, four sites continue to show degrading trends 'exceptionally unlikely improving', these are Waiareka Creek (DRP, TP), Waianakarua (*E. coli*, NNN, TN), Kauru (*E. coli*), Kakanui at Clifton Falls (*E. coli*) and the Awamoko Stream (DRP). The source of *E. coli* at Kakanui at

Clifton has been identified as red billed gulls roosting in the gorge upstream of the monitoring site. When sites have a zero sen slope alongside a reasonably high-level of confidence in trend direction the rate of the trend (i.e., the Sen slope) is at a level that is below the detection precision of the monitoring programme. In the North Otago FMU, these sites include NH4-N and DRP at the Kakanui at Clifton site, DRP at Ewings, NH4-N at the Shag at Craig Road and the Waianakarua, and DRP at the Waikouaiti and the Shag at Goodwood.

Previous reports have identified land-use intensification as a driver of poor water quality however ORC do not collect detailed information on land-use, land management practices or changes in either of the two that allow for inference as to the drivers of degrading or improving trends in water quality.

Groundwater quality results indicate significant issues in the North Otago FMU, notably very high nitrate-N concentrations, and E. coli exceedances. Nitrate-N concentrations in the FMU are the highest in Otago, with concentrations in several bores also substantially exceeding the DWSNZ MAV. Conversely, dissolved arsenic concentrations in all the monitoring sites across the FMU were substantially below the DWSNZ MAV of 0.010mg/L.

Very high groundwater nitrate-N concentrations are a major issue in the North Otago FMU and are the highest in Otago. Concentrations in four sites, situated in the North Otago Volcanic Aquifer and the Kakanui-Kauru Volcanic Aquifer, exceed the DWSNZ MAV of 11.3mg/L (Table 2). The median concentrations in three other bores are 50-75% of the DWSNZ MAV. These nitrate-N concentrations are also much higher than the NPS-FM limits for surface water, which can adversely impact surface water. These issues are likely to adversely impact river quality and ecosystem health (ORC, 2021), and are particularly important in North Otago due to the strong groundwater-surface water interaction in some of the FMU's rivers (e.g., Kakanui). The E. coli results also indicate groundwater quality issues, with exceedances of the DWSNZ MAV measured in most SoE bores in the FMU. Most exceedances were between 10-50% of the results, with higher proportion of exceedances in two bores (situated in the NOVA and the Kakanui Kauru Alluvial Aquifer).

The trend analysis generally shows improvement, with most sites in the green (i.e., 'improving') categories for the 5-year trend. A 10-year trend was only calculated for 5 sites, of which two are showing improvements (from green to red and orange to yellow) and the others are moving one level either up or down the green categories. However, although these are positive results, nitrate-N concentrations in most bores in the FMU are still very high and exceed the DWSNZ and NPS-FM limits. The elevated nitrate-N concentrations and E. coli exceedances are likely due to a combination of poor bore security, shallow bores, intensive land use and fertiliser application (dairy farming, market garden), and septic tanks (ORC, 2021). These are exacerbated in the North Otago FMU due to the high permeability (providing high infiltration rates) and shallow groundwater in some aquifers (e.g., Kakanui-Kauru Alluvial Aquifer) whilst the slow groundwater velocity in the NOVA (which reduces dilution) also contribute to the excessive nitrate-N concentrations in this aquifer. ORC also recently expanded the SoE monitoring network in the FMU with 11 new, dedicated monitoring bores. This will enable to determine whether some of the issues, such as E. coli exceedances, are local and due to poor bore security or more of an aquifer/FMU wide issue. Nevertheless, it is important that bore owners ensure adequate bore security and good land/nutrient management practices. Due to the high nitrate-N concentrations in the NOVA and Kakanui-Kauru it is also recommended that raw groundwater (untreated) in these aquifers is not used for drinking/domestic supply.

9 Catlins FMU

Figure 54 Location of water quality monitoring sites in the Catlins FMU

9.1.1 Catlins FMU Description

The Catlins Freshwater Management Unit (FMU) is located along the southern coast of Otago.

This FMU contains Otago's portion of the Catlins Conservation Park. The coast is dominated by sandy bays and cliffs and from there, the land rises steadily from the south-east to north-west, reaching its maximum altitude (720 m) at Mt Pye, in the headwaters of the Tahakopa and Catlins Rivers, and then it falls again, through rolling country, towards the Mataura River (in Southland) and the Clinton lowlands. The forested ridges provide a contrast to the cleared valleys, where more intensive agricultural activities are concentrated. Headwaters of all major rivers rising from within the Catlins have their vegetation intact.

ORC monitors four rivers in the Catlins FMU. The Catlins River (42km) and Owaka River (30km) share an estuary. The Tahakopa River (32km) flows south-east to the Pacific Ocean 30 km east of Waikawa, close to the settlement of Papatowai. The Maclennan River is 17.5 km long and enters the Tahakopa River near Maclennan.

There is one groundwater SoE bore in the Catlins FMU, although geographically it is more appropriate to have been included in the Inch Clutha aquifer (located in the Lower Clutha Rohe). The monitoring sites are shown in Figure 54.

9.1.2 State Analysis Results

The results of grading the SoE sites in the Catlins FMU based on the NPS-FM NOF criteria are mapped in Figure 55 and summarised in Figure 56. Many sites in the Catlins FMU did not meet the sample number requirements (shown in Table 1) and accordingly are shown as white cells with coloured circles. Most sites for some variables have white cells, this indicates that the variable was not monitored.

A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.

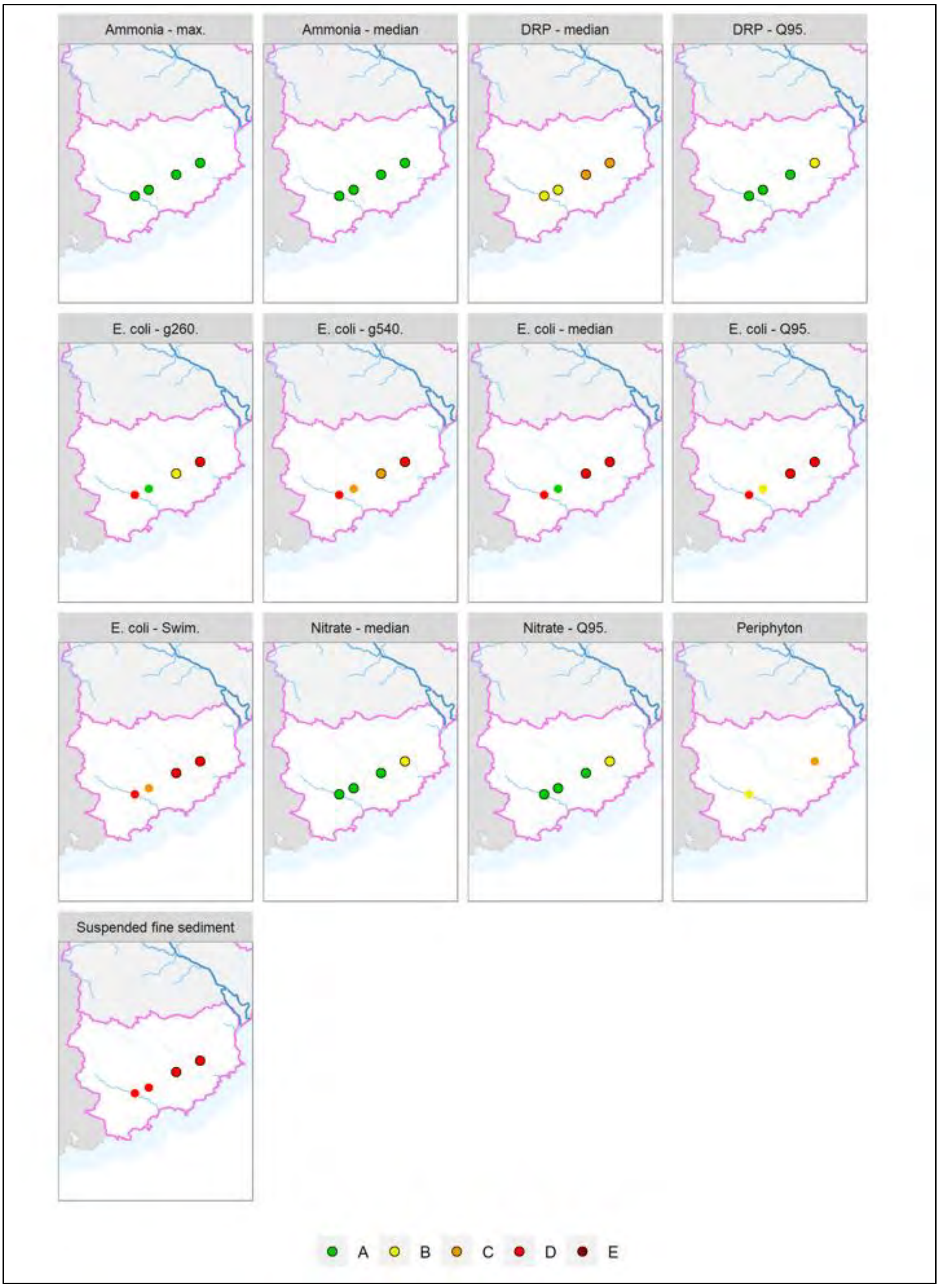


Figure 55 Maps showing Catlins FMU sites coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements are shown without black outlines.

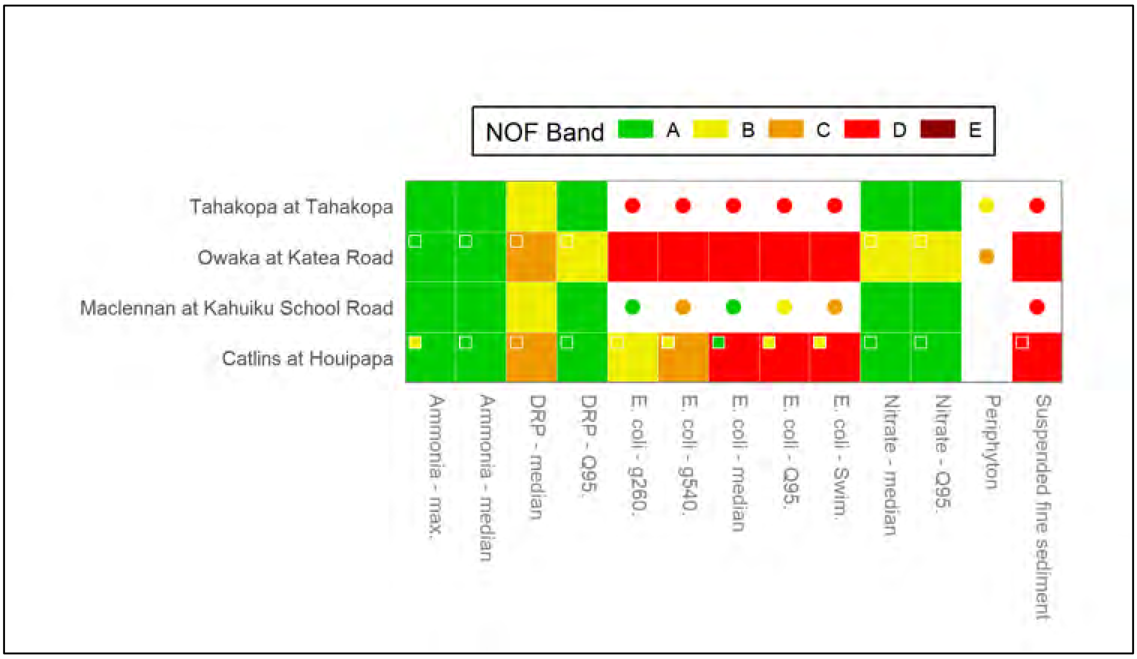


Figure 56 Grading of the river sites of the Catlins FMU based on the NOF criteria. Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles. The white cells indicate sites for which the variable was not monitored. Small square in the upper left quadrant of the cells indicate the site grade for the baseline

9.1.2.1 Periphyton and Nutrients

Periphyton trophic state results to date are given in Figure 55 and Figure 56 and show that of the two sites monitored in the Catlins FMU, the Tahakopa returns an interim 'B' band as few results exceed 120 chl-*a*/m^2 reflecting low nutrient enrichment and the Owaka returned a 'C' band reflecting a more nutrient rich environment.

Figure 55 and Figure 56 also shows DRP attribute states for ecosystem health (DRP median and Q95). The results in the Catlins FMU show that the Tahakopa River and Maclennan River achieve a 'B' band, while the Owaka River and Catlins River achieve a 'C' band. The NPS-FM (2020) describes band 'C' as *'Ecological communities impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate and fish taxa, and high rates of respiration and decay'*

Appendix 1 gives DRP and NNN numerical results, as both are required for periphyton growth. Sites in the Catlins FMU with the highest NNN concentration are the Owaka River (1.04 mg/l) and the Catlins at Houipapa (0.4 mg/l), these sites also have the highest median DRP concentration.

9.1.2.2 Toxicants (Rivers)

NOF attribute bands for NH4-N are given in Figure 55 and Figure 56, the national bottom line for toxicants is below band 'B'. All sites in the Catlins FMU achieve an 'A' band (highest level of protection) for NH4-N. The remaining site (the Catlins) returned a 'B' band for the annual maximum. The NPS-FM describes the 'A' band as *'99% species protection level: No observed effect on any species tested'.*

NOF attribute bands for nitrate-N (measured as NNN) toxicity are given in Figure 55 and Figure 56. In the Catlins FMU all sites achieve an 'A' band, other than the Owaka which achieves a 'B' band across both statistical metrics, the NPS-FM describes 'B' band as NNN having *'some growth effect on up to 5% of species'*

9.1.2.3 Suspended fine sediment (Rivers)

The clarity results for the Catlins FMU are shown in Figure 55 and Figure 56. All rivers in the Catlins have a high degree of tannin staining due to the forested catchments. in the river, such as the Dart (Whakatipu), Rees (Whakatipu) and Matukituki (Wanaka) rivers return some high turbidity (and suspended sediment) levels despite the rivers being close to natural state.
The suspended fine sediment results for the Catlins FMU are shown in Figure 55 and Figure 56. All 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*' (NPS-FM, 2020).

9.1.2.4 Health for recreation (Rivers)

Figure 55 and Figure 56 summarises compliance for *E. coli* against the four statistical tests of the NOF *E. coli* attribute. The overall attribute state is based on the worst grading.

Compliance is quite poor across the Catlins FMU, with the Tahakopa, Owaka and Catlins Rivers returning bacterial water quality below attribute band 'C' on all four statistical metrics. The Maclennan River returned an overall 'C' band despite returning an 'A' band in the median and g260 statistic.

9.1.2.5 Trend Analysis Results – Rivers

Trend analysis results for the Catlins River is shown in Figure 57. Over a 20-year period the Catlins has 'exceptionally unlikely' improving trends for *E. coli,* NNN and TN. In the shorter timeframe the Catlins River has 'extremely likely' or 'virtually certain' improving trends for NH4-N and DRP and no degrading trends. Most trends over 10-years in the Owaka are improving ('likely' to 'extremely likely') apart from *E. coli* which is degrading ('unlikely' to be improving).

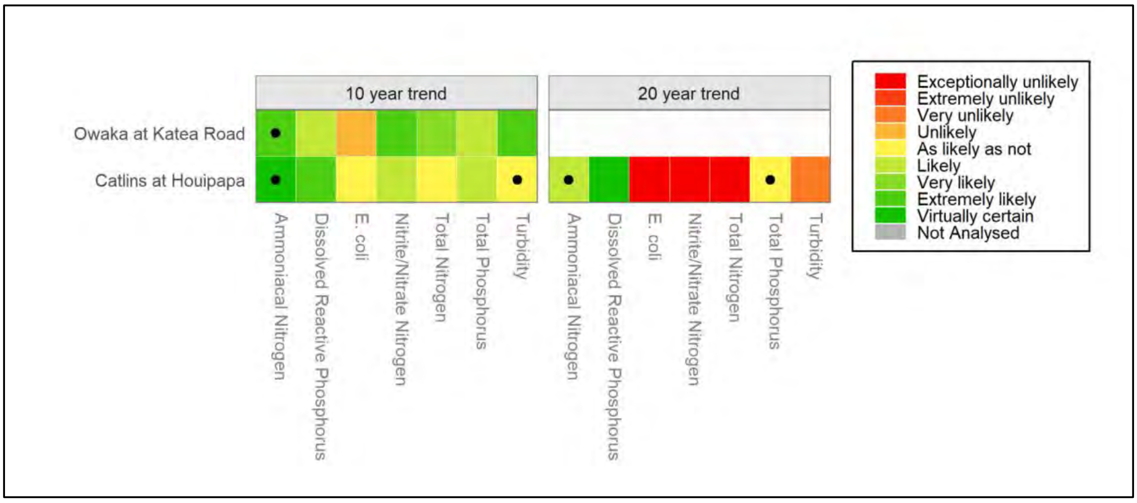


Figure 57 Summary of Catlins FMU sites categorised according to the level of confidence that their 10- and 20-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend

9.1.3 Groundwater

9.1.3.1 State

There is currently only one SoE monitoring bore in the Catlins FMU, no. H46/0118. A description of the bore can be found in ORC (2021). The current state of groundwater quality from this bore is shown in Table 14. There are no exceedances of any of the DWSNZ MAV. The main issue is a single detection of E. coli in the bore. The median nitrate-N concentrations are substantially below the DWSNZ MAV and also below the threshold for low intensity land use (Morgenstern and Daughney, 2012). Dissolved arsenic concentrations are also substantially below the DWSNZ MAV.

Table 14 Groundwater current state results for the Catlins FMU. The key for the colour classification is shown at the bottom of the table.

Site	Aquifer/ location	Total no. of *E. coli* samples	No. of Detects	*E. coli* % exceed-ance	Median Nitrate concentration (mg/L)	Max. Arsenic concentration (mg/L)
H46/0118	Inch Clutha	18	1	6	0.240	0.000

E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

9.1.3.2 Trends

The trends for groundwater quality for the Catlins FMU are shown in Figure 58. The results show 'extremely unlikely' improving trend for groundwater nitrate-N for both the 5- and 10-year analysis periods.

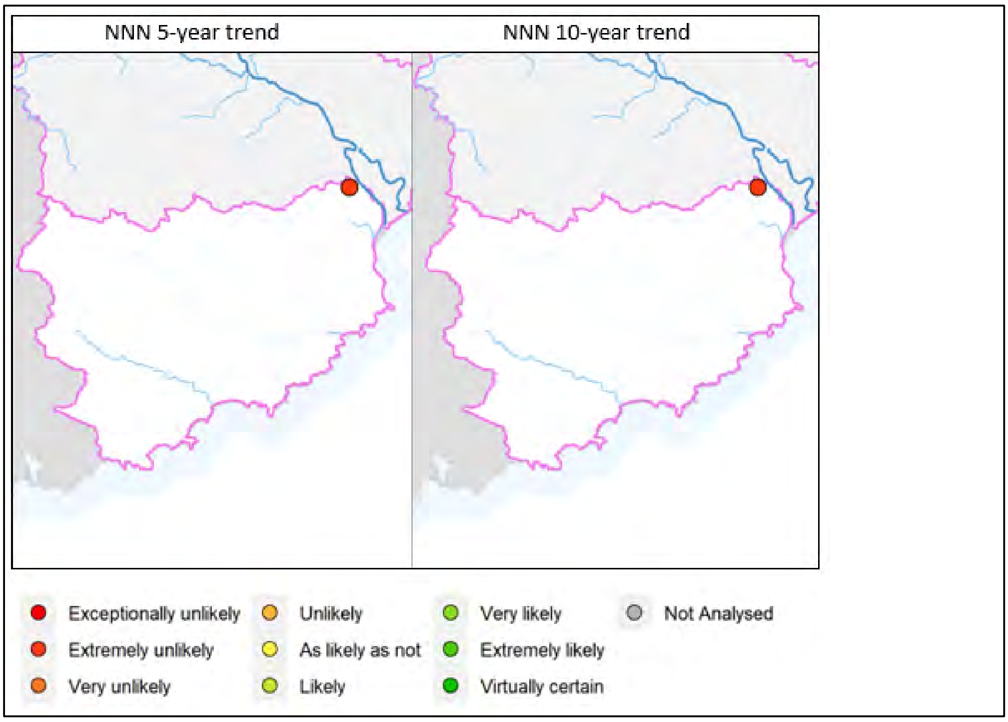


Figure 58: Catlins FMU site categorised according to the level of confidence that their 5- and 10-year raw water quality trends indicate improvement.

9.1.4 Water quality summary Catlins FMU

The Catlins FMU is expected to have good water quality, due to the intact nature of the headwaters and native vegetation, however cleared valleys allow intensive farming activities. When comparing to the NOF attribute states, water quality is variable. All sites return 'A' or 'B' bands for ammonia and nitrate-N toxicity. The Owaka, Catlins and Tahakopa return 'D' bands for *E. coli*. Suspended fine sediment returns 'D' bands at all sites. Water in the Catlins FMU has naturally highly coloured brown water or tannin stained, the Catlins Rivers are an exception because the low the clarity is naturally occurring, rather than occurring through high sediment input.

In the Catlins River, over 20-years, *E. coli*, NNN and TN showed degrading trends ('exceptionally unlikely to be improving), this was not the case in the 10-year trend analysis. In the Owaka River the only degrading trend over 10-years was for E. coli ('unlikely' to be improving)

Groundwater quality results from the SoE monitoring bore are generally good. The median groundwater nitrate-N concentrations are substantially below the DWSNZ MAV and also below the threshold for low intensity land use. The dissolved arsenic substantially below the DWSNZ MAV. The only issue was one exceedance of the E. coli MAV. It is unclear why the trend analysis for nitrate-N is ''exceptionally unlikely improving'. Although the results from this monitoring bore are generally good, it does not necessarily reflect groundwater quality in the Catlins FMU, as this is currently the only SoE bore in the Catlins FMU. Furthermore, this bore is found in the Inch Clutha aquifer, and its surrounding land use and lithological setting (dairy farming) is likely to be more reflective of the Inch Clutha aquifer and delta (which is located in the Lower Clutha Rohe). ORC is planning, however, to drill dedicated SoE monitoring bores in the Catlins FMU.

10 Otago Regional Summary

10.1.1 State analysis results

10.1.1.1 Rivers

Figure 59 gives an overview of river water quality in the Otago Region, sites are coloured according to their state grading as indicated by NOF attribute bands.

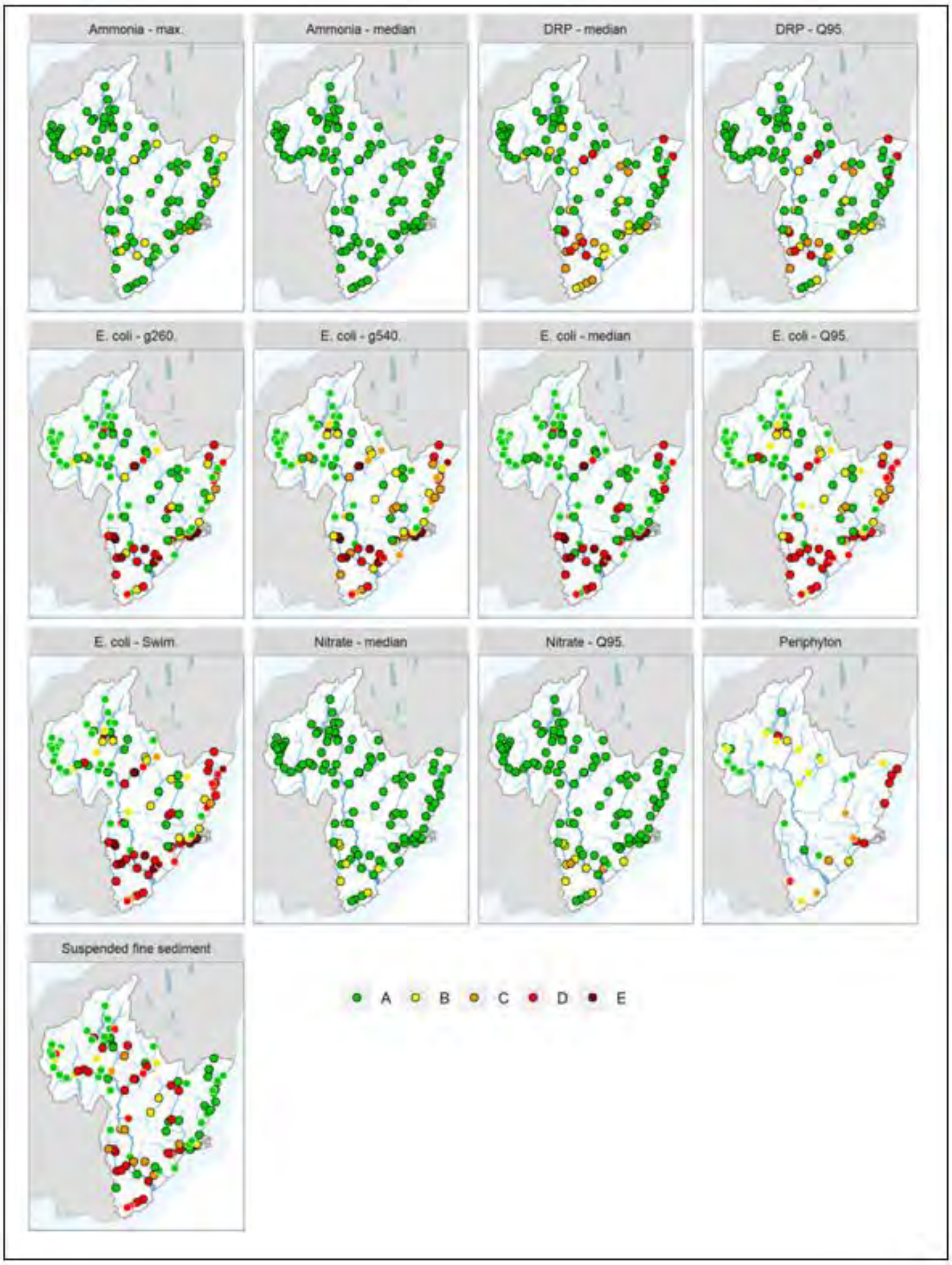


Figure 59: Maps showing river SoE monitoring sites across Otago coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified in Table 1 are shown without black outlines

Results for ammonia and nitrate-N toxicity show low concentrations across the region. The national bottom line for nitrate-N and ammonia toxicity is below the 'B' band. Nitrate-N toxicity results generally meet NOF band 'A' for the median statistic, with six sites (five in the Lower Clutha Rohe) meeting band 'B'. For NH4-N toxicity (median) all sites met NOF band 'A'.

E. coli results show a clear spatial pattern across Otago. Figure 59 shows *E. coli* -SWIM which is the worst grade of the four statistics (G260, G540, Median and P95). Across Otago 46 sites did not meet the national bottom line with 13 sites (including five sites in the Lower Clutha Rohe as well as five urban stream sites*)* achieving an *'E' gr*ade. At the other end of the scale, in the Upper Lakes Rohe 19 of 23 sites achieve an 'A' band *E. coli* 'swim' grade.

DRP follows a similar spatial distribution as *E. coli*. Although there is no bottom line for DRP, eleven sites achieved an attribute band of 'D', four sites in the North Otago FMU, two sites in the Manuherekia Rohe and five sites in the Lower Clutha Rohe.

Periphyton, monitored as Chl-a is shown in Figure 59. Only Akatore Creek, Kaikorai Stream and Oamaru Creek fall into the NPS-FM 'productive class' for periphyton (Table 2), all other sites fit the 'default class' category. Eight sites fall below the national bottom line for periphyton, including four in North Otago, and one each in Dunedin & Coast Rohe, Dunstan Rohe, Taieri FMU and Catlins FMU. The North Otago FMU coastal sites stand out has having the highest concentration of Chl-a. The median concentration of DRP is highest at Oamaru Creek, which also has a 'D' band for periphyton. The median NNN at this site is also elevated at 0.25 mg/l (#17 of 107 sites). Bullock Creek, although having an elevated median nitrate-N concentration, has DRP concentration of 0.011 mg/l (#52 of 107 sites).

Suspended fine sediment fell below the national bottom line at 34 sites in Otago. SFS can be elevated due to natural processes, tannin affects water colour in the Catlins FMU (all sites achieve a 'D' band) and Taieri FMU (seven of 17 sites achieve a 'D' band). Glacial flour elevates suspended fine sediment in the Clutha Mata/Au FMU (Matukituki, Dart and Rees Rivers achieve 'D' band). Much of the Lower Clutha FMU does not meet the national bottom line for suspended fine sediment, this is probably due to land use practice, lack of riparian vegetation coupled with erodible banks rather than natural causes.

10.1.1.2 Lakes

Figure 60 shows results for all lakes in the Otago Region, all lakes achieve NOF band A for all attributes, other than Lake Tuakitoto, Lake Onslow, Lake Hayes, and Lake Waihola. Lakes with NOF attribute bands below the national bottom line are Lake Tuakitoto (*E. coli*, TN, TP, and Chl-a max), Lake Hayes (Chl-a) and Lake Waihola (Chl-a, *E. coli* and TP).

Lakes were graded across the range from 'A' to 'D' for all attributes other than NH4-N which consistently achieved an 'A' or 'B' band at all sites. The pattern of grades for Chl-a, *E. coli,* TN and TP was consistent with expectations, with lakes grade 'A' in mountainous and hilly areas with low, land use pressure with poorer grades becoming dominant in low elevation parts of the region, or parts of the region with land use pressure.

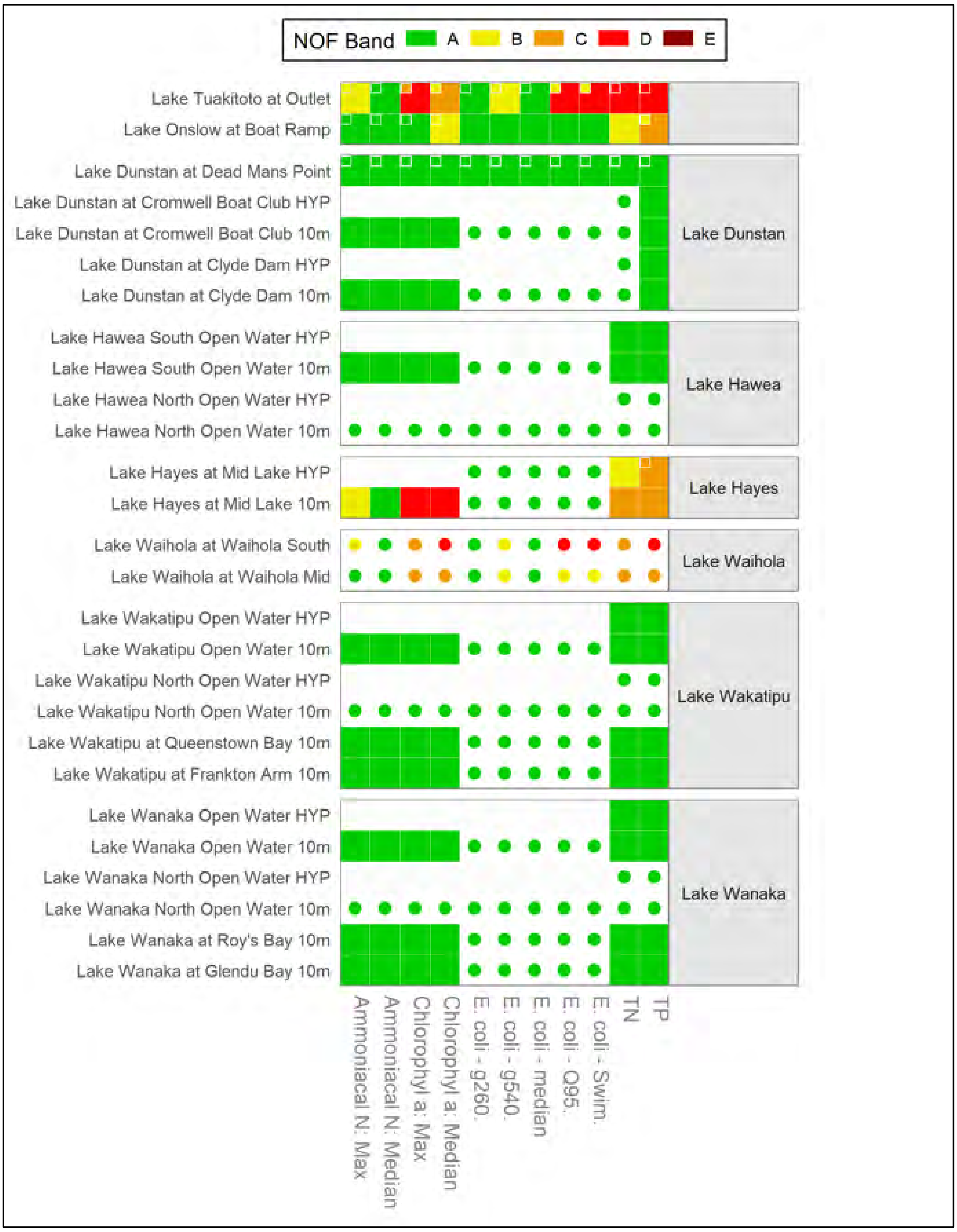


Figure 60: Maps showing lake SoE monitoring sites across Otago coloured according to their state grading as indicated by NOF attribute bands. Bands for sites that did not meet the sample number requirements specified are shown without black outlines

10.1.1.3 Groundwater

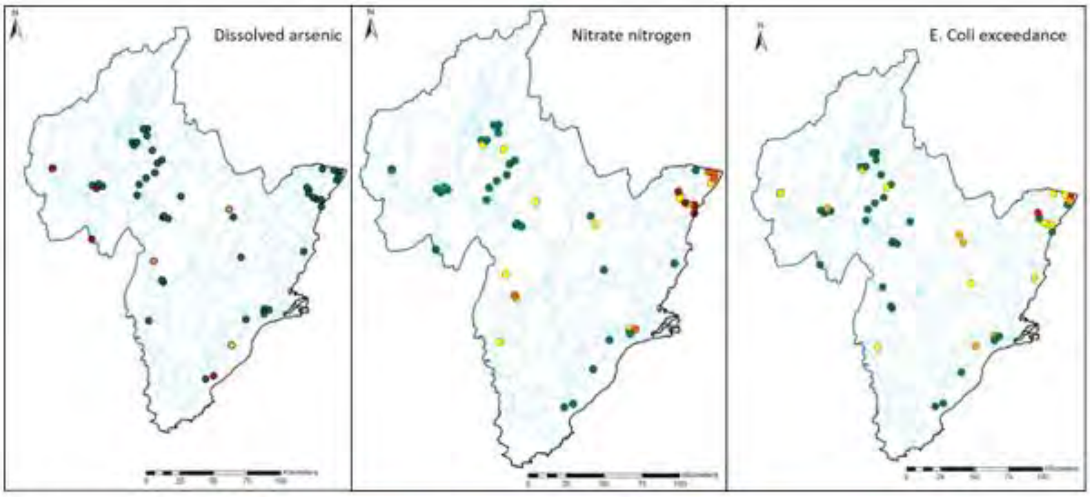
This report analysed groundwater quality against the DWSNZ MAV for *E. coli*, nitrate-N, and dissolved arsenic (*Table* 2). Similar to the river and lakes water data, the state of groundwater quality also varies across Otago, where groundwater quality is good in some areas and poor in others. There was also spatial variability for the different parameters, where *E. coli* exceedances and elevated nitrate-N concentrations were usually observed in the same areas while high dissolved arsenic concentrations were more site-specific. The regional variability in groundwater quality state is shown in Figure 61, where sites shown in green show results below the MAV whilst sites in red show exceedances of the MAV.

The mapping shows wide spatial variability in groundwater quality state between the Rohe of the Clutha Mata-Au FMU. Groundwater quality in the Upper Lakes, Dunstan, and the Manuherekia Rohe is generally good in relation to the DWSNZ MAV for E. coli, with either no exceedances or <10% exceedances in most bores. Median nitrate-N concentrations in these Rohe are also generally low, with most sites below the 2.50mg/L threshold for low intensity land use (Morgenstern and Daughney 2012). Although concentrations in two sites exceeded this threshold, all median nitrate-N concentrations in the Rohe were less than ½ of the DWSNZ MAV (i.e., below 5.50mg/L). In contrast to that, dissolved arsenic concentrations in these Rohe highlighted some issues, with several bores in the Upper Lakes (Glenorchy and Kingston) and one in the Dunstan Rohe (F41/0104) exceeding the DWSNZ MAV. Conversely, concentrations in other bores in the Rohe were substantially below the DWSNZ MAV.

The results indicate more serious groundwater quality issues in the Roxburgh and Lower Clutha Rohe, particularly median nitrate-N concentrations. None of the sites exceeded the DWSNZ MAV, however, concentrations in the Roxburgh Rohe (in Ettrick and Roxburgh) and the Lower Clutha (Pomahaka) were, respectively, between ½ and ¾ of the MAV (and over the low land use intensity threshold). There were also E. coli exceedances in most of the sites, although the proportions were relatively low, usually between 10-17%. Dissolved arsenic concentrations in the Roxburgh Rohe and most sites in the Lower Clutha Rohe are generally below the DWSNZ MAV. However, concentrations in one bore in the Lower Clutha (H44/0144) are persistently high.

Groundwater quality results for the Taieri FMU showed some issues, particularly high frequency of E. coli exceedances, which were measured in all but two monitoring bores. All median nitrate-N concentrations are below the DWSNZ MAV. However, the spatial pattern is mixed, with some concentrations in the lower Taieri and one in the Maniototo Tertiary aquifer elevated above the low land use intensity threshold (Daughney and Morgenstern, 2012) while concentrations in the other bores were below the threshold. The maximum dissolved arsenic concentrations are below the DWSNZ MAV. However, concentrations in one bore in the Maniotioto Tertiary aquifer are high and almost at the MAV while concentrations in the other monitoring bore are much lower. This again illustrates the high spatial variability of dissolved arsenic concentrations across Otago (e.g., ORC, 2021).

The results show significant groundwater quality issues in the North Otago FMU, especially very high nitrate-N concentrations, which are the highest in the region, and many E. coli exceedances. Median nitrate-N concentrations in many sites in the NOVA and the Kakanui Kauru aquifer exceed the DWSNZ MAV while concentrations in other sites are 50%-75% of the MAV. Intrinsically, as the state on this report refers to the median concentrations, the maximum concentrations will be even higher. In contrast to those, dissolved arsenic concentrations in all bores in the FMU were substantially below the DWSNZ MAV. The results from the Catlins and the Dunedin & Coast FMU were below the DWSNZ MAV and do not highlight any immediate issues. However, there is currently only one monitoring bore in each of these FMU, hence, this does not provide adequate representation of groundwater quality state in these FMU.



E. coli	no detections	<10%	10-50%	>50%
Nitrate	<2.50 mg/L	2.50 - 5.50 mg/L	5.50 - 11.3 mg/L	>11.3 mg/L
Diss. Arsenic	<0.0025 mg/L	0.0025 - 0.005 mg/L	0.005 - 0.01 mg/L	>0.01 mg/L

Figure 61 Regional groundwater quality state against the DWSNZ (2022) MAV.

10.1.2 Trend Analysis results

10.1.2.1 Rivers

Figure 62 and Figure 63 show 10- and 20-year trend periods, respectively, indicating improving and degrading water quality. Interpretation of these plots should be made with caution as there were variable numbers of sites included in the different time periods.

The worst performing variables over 10 years were *E. coli*, NNN and TN where close to 50% of sites had a degrading trend (‘unlikely’ to ‘exceptionally unlikely’ to be improving) over both the 10--year period. Conversely, NH4-N and DRP had approximately 90% of sites showing an improving trend (‘likely’ to ‘virtually certain’ to be improving)

Comparison of 10-and 20-year trends is difficult because sites have changed. The pattern of degrading and improving trends is similar, with *E coli*, NNN, TN and turbidity having a higher percentage of degrading compared to improving trends across the region. Over the 20-year period, NH4-N, DRP and TP showed a higher percentage of improving, compared to degrading, trends.

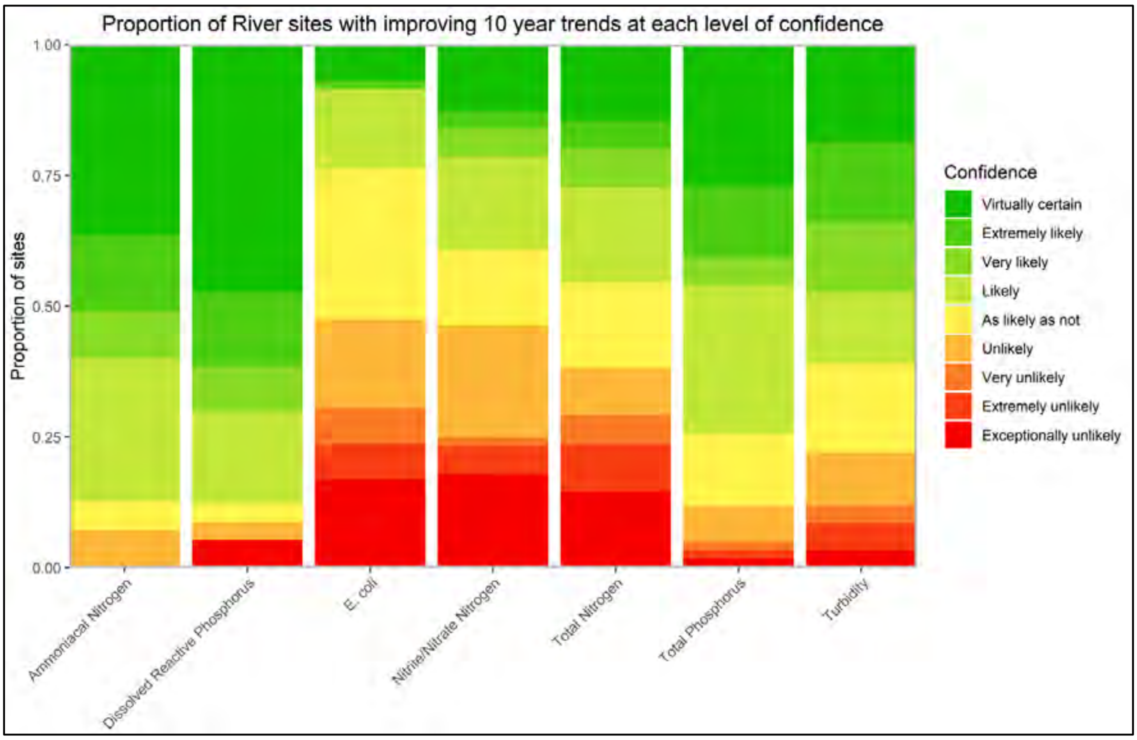


Figure 62 River sites classified by confidence that their 10-year raw water quality trend direction indicated improving water quality. LWP (2020b). Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

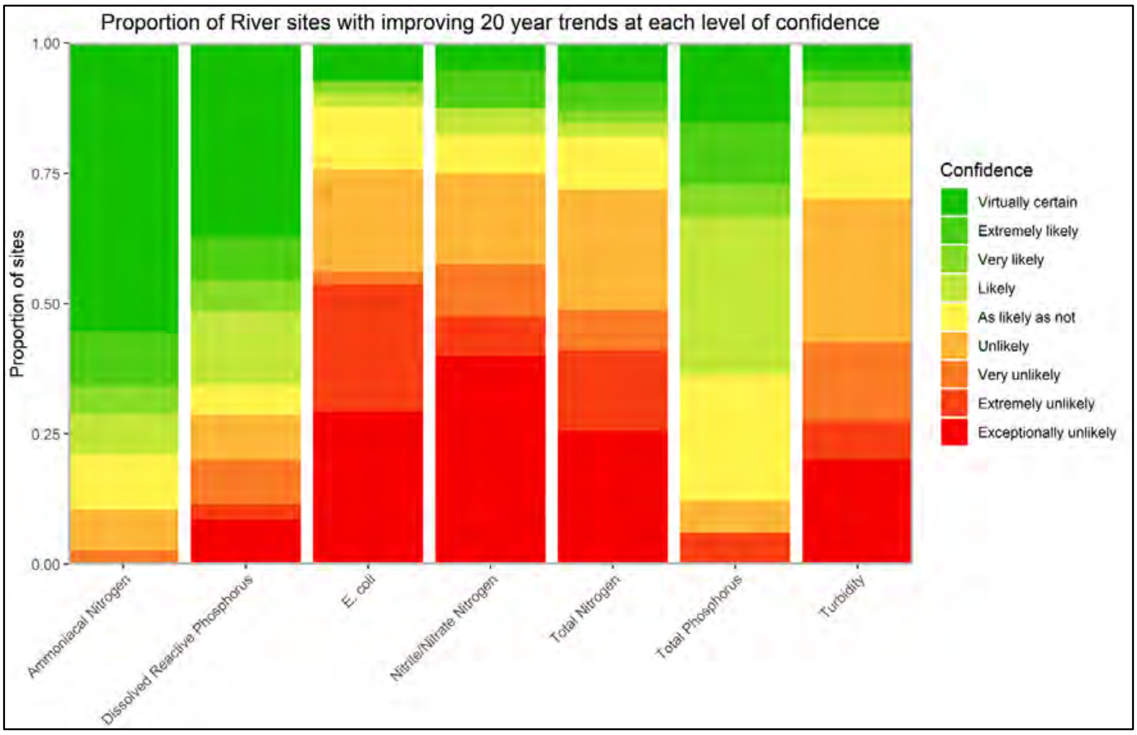


Figure 63 River sites classified by confidence that their 20-year raw water quality trend direction indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends

10.1.2.2 Lakes

Figure 64 shows a summary grid of lake sites by water quality variable classified by confidence that their 5-year water quality trend direction indicated improving water quality. These results should be interpreted with caution as previous studies have shown that trends for shorter timescales are strongly influenced by interannual climate variability.

Over the 5-years trend, variables such as Chl-a (14 out of 16 analysed sites) and TN (15 out of 22 analysed sites) showed the highest degrading trends ('unlikely' to 'exceptionally unlikely' to be improving) amongst all variables. The variable that showed most improving trends was TP, 8 sites in total.

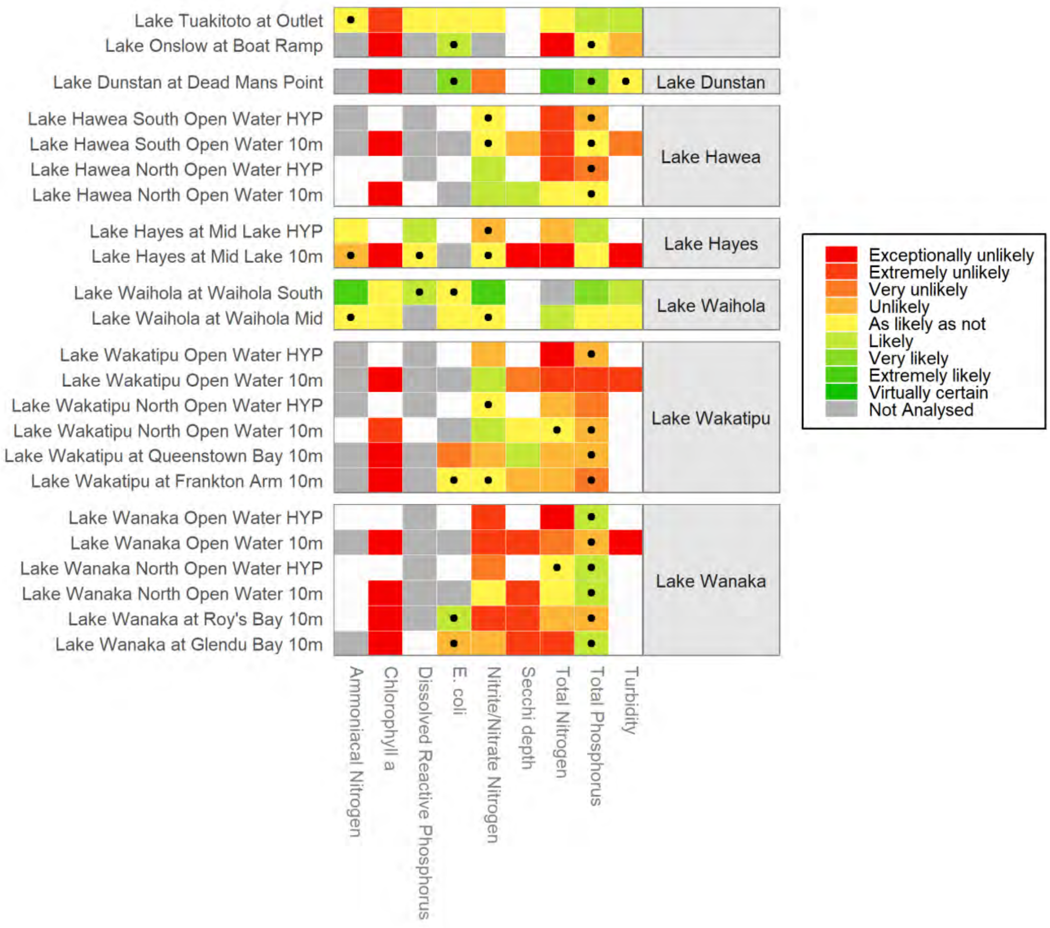
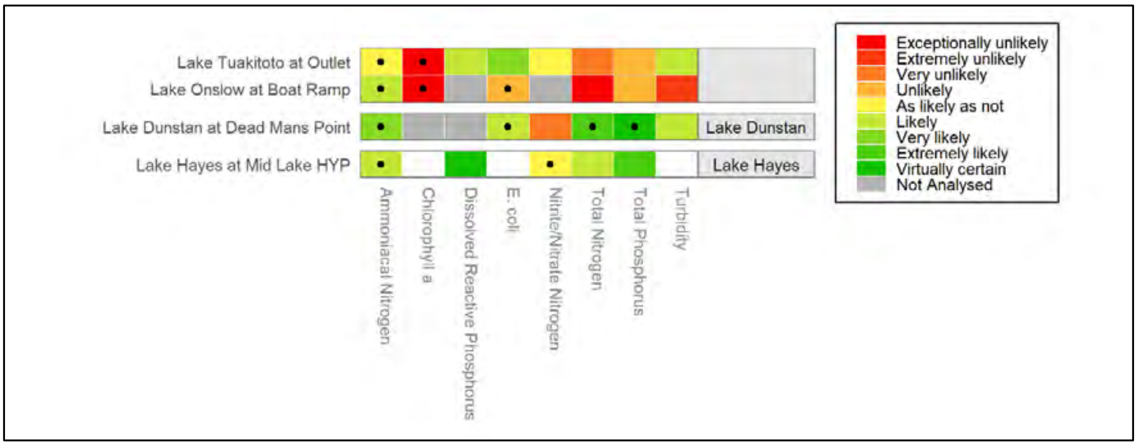


Figure 64 Summary of Otago Lake sites categorised according to the level of confidence that their 5-year raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

With the review of our SOE programme in 2017 and addition of new fit for purpose mid-lake sites to ORC's lakes network, only 4 sites had enough data for the 10-years trend analysis, and 3 for the 20-years (Figure 65). Again, Chl-a showed degrading trends on both analysed sites for the 10-years trends. Conversely, NH4-N, DRP, *E. coli*, TN, TP, and Turbidity showed improving trends ('likely' to 'virtually certain' to be improving) in two out of the four sites.

Over the 20-years trend analysis, most variables showed improving trends with the exception of Lake Tuakitoto at Outlet's DRP, TN and TP variables, and Lake Dunstan at Deadman's Point *E. coli* and Turbidity, indicating degrading water quality. When comparing the 10- and 20-years trend of Lake Onslow at Boat Ramp site, 100% of the variables analysed are improving over 20 years, while over 10 years only NH4-N showed an improving trend.



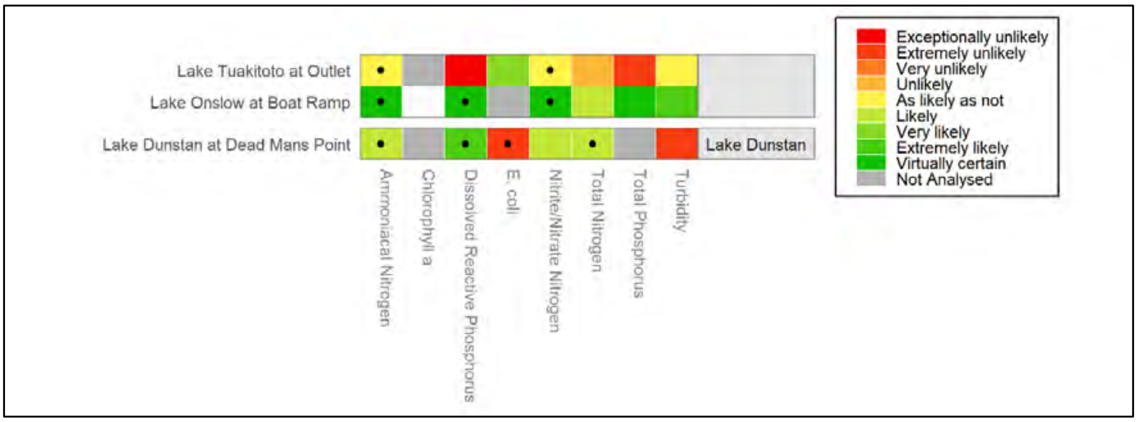


Figure 65 Summar*y of Otago Lake sites categorised according to the level of confidence that their 10- and 20-year (top and bottom figures, respectively) raw water quality trends indicate improvement. Cells containing a black dot indicate site/variable combinations where the Sen Slope was evaluated as zero (i.e., a trend rate that cannot be quantified given the precision of the monitoring). White cells indicate site/variables where there were insufficient data to assess the trend. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.*

10.1.2.3 Groundwater

The proportion of sites in each confidence level for an improving 5- and 10-year trends in groundwater nitrate-N concentrations are shown in Figure 66. This shows that the proportion of sites with a 5-year improving (green) trend are similar to those not improving (orange/red), at around 40%. The 10-year trends generally show worse results, with around 48% of the sites having trends that are not improving (orange/red). Trends in dissolved arsenic were not obtained for many sites due to the high number of results below the analytical detection limit. However, when available, they are discussed in the relevant FMU/Rohe sections of this report.

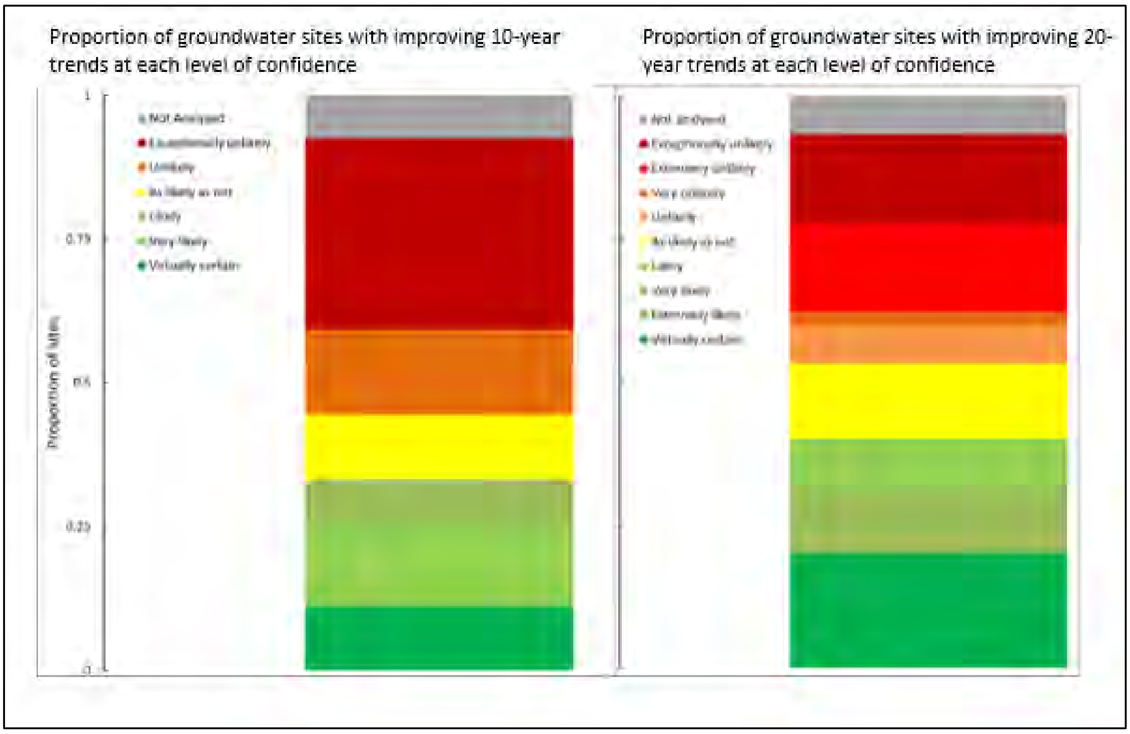
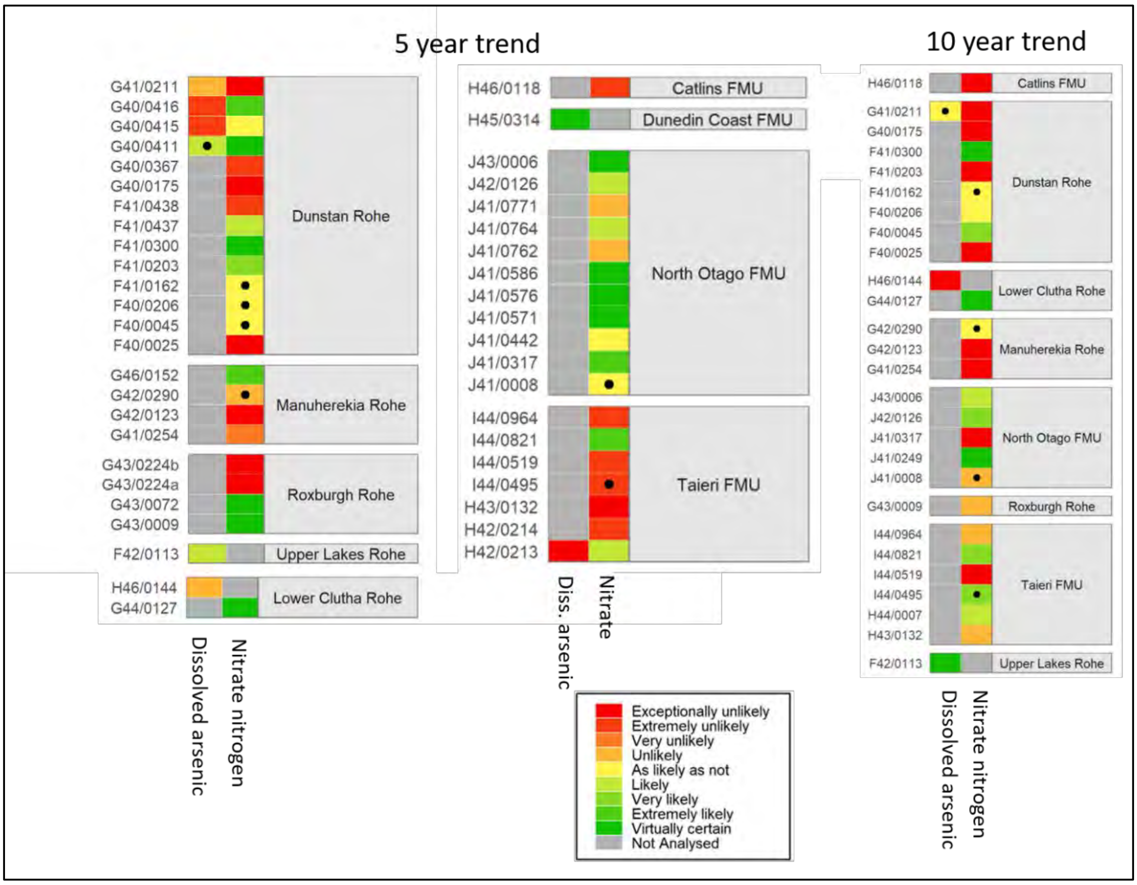


Figure 66: Groundwater sites classified by confidence that their 10- and 20-year trends in groundwater nitrate-N concentrations indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends

The spatial variability of the confidence level for improving trends is shown in Figure 67. This shows that the 10-year trends in most of the Rohe within the Clutha Mata-Au FMU are not improving (red/orange colours). The results for the Taieri and North Otago are more encouraging, with around half the sites showing improvement (i.e., green colours). The trends in the Catlins FMU are not improving.

The 5-year trend analysis intrinsically included more sites, which shows a more complex picture. Comparison between the 10-year and 5-year trends showed that most sites in the Dunstan Rohe do not show change. However, one site was getting worse (F40/0045) whilst another was improving (F41/0203). The 5-year analysis showed a mixed pattern in Hawea and the Whakatipu Basin. Mixed patterns were also observed in the Manuherekia and Roxburgh Rohe. There was no change in the Lower Clutha.

The trends in the Taieri FMU are also mixed, with some sites slightly improving between the 10- and 5-year trends while others getting worse. The 5-year trends for newer bores in the Maniototo (which did not have sufficient data for a 10-year trend analysis) are not improving. The North Otago FMU had some sites improving between the 10- and 5-year trends, and more improvements for the 5-year trend.



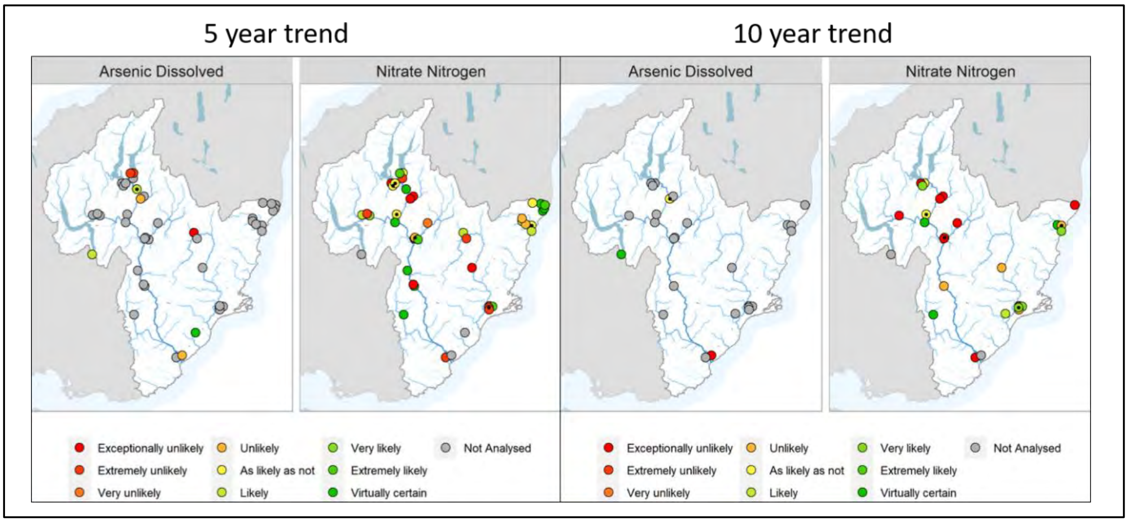


Figure 67: Map of groundwater sites classified by confidence that their 5-year and 10-year raw water quality trend direction indicated improving water quality. Green colours indicate sites with improving trends, and red-orange colours indicate sites with degrading trends.

10.1.3 Otago water quality summary and discussion

This report assessed state and trends in rivers, lakes, and groundwater quality across Otago. Water quality was assessed against attributes in Appendix 2A and 2B of the NPS-FM; NH4-N, NNN, DRP, Chl-a, *E. coli*, TN, TP, suspended fine sediment, comment was also made on NNN concentrations as a driver of periphyton growth. River and lake state results show that water quality across Otago is spatially variable, water quality is best at lakes, river and stream reaches located at high or mountainous elevations under predominantly native cover. These sites tend to be associated with the Upper Lakes Rohe and the upper catchments of larger rivers (e.g., Lindis River, Pomahaka River, Nevis River) and the large lakes (e.g., Hawea, Whakatipu and Wanaka). Other areas, such as urban streams in the Dunedin, intensified catchments in North Otago and some tributaries in the Lower Clutha FMU have poorer water quality.

Trend analysis returned a mix of results, the 10-year trend analysis showed fewer degrading trends compared to the 20-year trend analysis, in particular there was an overall improvement in *E. coli*, TN, NNN and turbidity, however caution should be made interpreting this as variable numbers of sites were included in the different time periods. Tributaries of the Lower Clutha FMU, over a 10 year period, show many ‘extremely likely’ or ‘virtually certain’ improvements across multiple attributes. The Lower Clutha FMU is intensively farmed in challenging conditions, with artificial drainage and higher rainfall patterns. Catchment groups have been working in the area for 10+ years and the improving water quality may be due to increased awareness and on ground action promoted through farmer led groups.

Although lake state results across Otago are mainly placed in the A-band for most attributes , the 5-years trends show degradation in most sites. We note here that on time scales of this period, there is potential for climate driven changes in water quality to dominate those derived from changes within lake catchments (Snelder *et al*. 2021). In particular, lower rainfall and higher temperatures in the past few years associated with land use pressures could be responsible for driving incresead chl-a and nutrients in lakes.

As reported in previous ORC state and trend water quality reports (2007, 2012, 2020) there has been a lack of detailed information held by ORC on local or catchment scale land use change or land management practice changes which has severely limited the ability to comment on drivers of trends of water quality evident across Otago. Since 2020, there has been a shift in water quality management. The first was Plan Change 8 (PC8) becoming operative (September 2022) and the second the upcoming Land Water Regional Plan (LWRP).

Plan Change 8 introduced a range of amendments targeting specific issues or activities known to be contributing to water quality problems in parts of Otago. Promoting good farming practices was addressed, including better managing contaminant loss from intensive grazing and stock access to water bodies as well as incentivising the use of small in-stream sediment traps.

In areas of Otago which are intensively farmed with heavier soil, direct losses of animal waste can occur when it is applied to soils that have limited capacity to store moisture (resulting in ponding), or on slopes, where there is increased risk of overland flow. Effluent storage and application to land has been addressed through new minimum standards. Water quality in the Lower Clutha FMU is likely to benefit from PC8, as in this area nutrient-enriched discharges in this area have been found to be the result of inappropriate effluent application when the soil was saturated, or the application rate was too high for soils to absorb (ORC, 2011). Rivers in the Lower Clutha FMU generally have shown high *E. coli* concentrations, which is likely to be caused, at least in part, by animal waste storage issues as well as a high prevalence of subsurface drainage (Uytendaal & Ozanne, 2018).

In many areas of Otago, intensive grazing (winter grazing) forms an integral part of pasture-based livestock farming due to low pasture growth (during winter months) and large areas of poorly drained soils. Intensive grazing can also have adverse effects on water quality and soil, particularly from pugging which increases the risk of overland flow. Prior to PC8 there were no controls on intensive grazing practices, these are now covered by either permitted or prohibited activity rules. PC8 has two other key focus areas, mitigating against sediment loss (i.e., from earthworks) by enabling the installation and maintenance of sediment traps as a permitted activity, subject to standards and restrictions to stock access, depending on stock type, water body and slope. The water quality outcome of amendments introduced by PC8 will be positive and measurable in the long term.

ORC is in the process of developing a new Land and Water Regional Plan (LWRP), in partnership with Kāi Tahu iwi. The objective of the LWRP (and NPS-FM) is to ensure that the health and well-being of degraded water bodies and freshwater ecosystems is improved, and that the health and well-being of all other water bodies and freshwater ecosystems is maintained or improved. The LWRP will include rules and limits on water and land use in line with the NPS-FM (2020) and ORC is required to act if there is degradation or a deteriorating trend in water quality. This is a significant change in direction for water management in Otago, accordingly resources in the science team have increased to manage this change. where E. coli exceedances and nitrate-N concentrations were usually an issue in the same areas, while high dissolved arsenic concentrations were more site-specific.

The groundwater nitrate-N data shows a considerable spatial variability across Otago. The highest median nitrate-N concentrations are in the North Otago FMU, where median concentrations in around half the sites exceeded the MAV of 11.3mg/L or were at least ¾ of it. Conversely, most median nitrate-N concentrations in the Clutha Mata-Au and Taieri FMU are much lower, with most concentrations lower than ½ of the MAV and many below the 2.50mg/L threshold for low intensity land use (Morgenstern and Daughney, 2012).

The highest nitrate-N concentrations were usually measured in unconfined aquifers that underlie areas of intensive nitrate-N application (e.g., dairy farming, market garden) or septic tanks. This report highlighted high nitrate-N concentrations in many areas that fit these characteristics e.g., the Ettrick basin (Roxburgh Rohe), Pomahaka basin (Lower Clutha Rohe), the NOVA, the Kakanui-Kauru, the Lower Waitaki Plains (North Otago FMU), and the Lower Taieri (Taieri FMU). In addition to land use, these results can also be attributed to variability in geology, water table depth and geochemical conditions which impact nitrate-N breakdown (e.g., ORC, 2021). Geology influences nitrate-N concentrations as high permeable substrate allow rapid nitrate-N leaching into the aquifer, as was observed in the Kakanui-Kauru. Geology also contributes to the high nitrate-N concentrations in the NOVA, where slow groundwater velocity, due to low permeability, encourages nitrate-N accumulation. Nitrate-N concentrations can also be impacted by groundwater geochemistry, where reducing (i.e., low oxygen) conditions can lead to nitrate-N decomposition (e.g., Close *et* al., 2016). This process can mask the impact of nitrate-N application and may help explain low groundwater nitrate-N concentrations in areas underlain by intensive land use (Lower Taieri, Tokomairiro GWMZ, Inch Clutha). However, this hypothesis was not tested further in this report.

The *E. coli* data indicates that potential faecal contamination is a serious threat across Otago. However, it is also important to note that elevated *E. coli* can be a local issue and is strongly dependent on bore security and land use, hence the SoE monitoring data does not provide a complete mapping of this risk. ORC is currently upgrading the groundwater SoE monitoring programme, replacing many insecure bores with dedicated new ones. This will help determine whether the E. coli exceedances are site-specific or indicate wider issues. Nevertheless, it is strongly recommended that bore owners ensure adequate borehead security to prevent contaminant entry into the aquifer through the borehead. It is also recommended that groundwater used for drinking is regularly tested in an accredited laboratory, with testing being particularly important after periods of heavy rainfall. If *E. coli* is detected, water should be boiled or disinfected (MoH, 2018). Further information regarding bore security can be found in the ORC website (https://www.orc.govt.nz/media/5634/bore-brochure.pdf) or through the drinking water regulator Taumata Arowai https://www.taumataarowai.govt.nz/.

The arsenic data shows high spatial variability across Otago, with several areas where arsenic concentrations exceeded or are near the DWSNZ MAV. Most of the exceedances and high concentrations were in the Upper Lakes Rohe (Glenorchy and Kingston) but others were also measured in the Dunstan Rohe (Howards Drive), the Maniototo, and the Lower Clutha. Conversely, concentrations in most bores in the North Otago and Taieri FMU were low. Furthermore, high spatial variability in arsenic groundwater concentrations was observed on much smaller scales, including in bores situated within close proximity in some areas (e.g., Glenorchy). It is likely that these results are due to geologically sourced arsenic, which originates in schist lithology (in the Upper Lakes/Dunstan Rohe) or organic sediments (Lower Clutha) [Piper and Kim, 2006; ORC, 2021]. Combined with arsenic from these sources, groundwater concentrations can also increase due to enhanced arsenic mobility, caused by reducing geochemical (low oxygen) conditions. These are caused by microbial activity stimulated by organic carbon, usually sourced from septic tanks. These processes were attributed to the high arsenic concentrations in some bores in Glenorchy (ORC, 2021). Due to the high abundance of geological arsenic sources in Otago and its spatial variability in groundwater it is therefore strongly recommended that bore owners regularly test their bore water in an accredited laboratory for arsenic. As concentrations can also be impacted by fluctuations in groundwater levels, it is further recommended that testing is also conducted during different seasons (e.g., MoH, 2018).

In summary, similar to surface water, groundwater quality also varied across Otago. The main issues are elevated *E. coli* and nitrate-N concentrations, generally observed in areas of intensive land use, septic tanks, and insecure bores. Arsenic in groundwater is also an issue in many areas of Otago, although this is mainly geologically controlled. The report highlights the importance of good bore security, land use management, and frequent testing of bore water to ensure it is suitable for the intended use. Some of these issues are aimed to be improved with the new Land and Water Regional Plan and the addition of new, dedicated monitoring bores. However, under the current land use and management practiced found in some parts of the region it is unlikely that groundwater quality will improve.

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12 Appendix 1 Water Quality Summary Results

12.1 River - Dissolved Reactive P and Nitrate-N

FMU	Site Name	# values	NNN Median	NNN Q95	DRP Median	DRP Q95
Catlins FMU	Catlins at Houipapa	58	0.4	0.75	0.01005	0.01378
Catlins FMU	Maclennan at Kahuiku School Road	45	0.021	0.06475	0.0096	0.0139
Catlins FMU	Owaka at Katea Road	58	1.04	2.38	0.0152	0.0268
Catlins FMU	Tahakopa at Tahakopa	45	0.31	0.5925	0.0068	0.01032
Dunedin & Coast	Akatore Creek at Akatore Creek Road	43	0.185	1.853	0.0047	0.00975
Dunedin & Coast	Kaikorai Stream at Brighton Road	57	0.4	1.012	0.0078	0.0245
Dunedin & Coast	Leith at Dundas Street Bridge	56	0.46	0.786	0.017	0.02875
Dunedin & Coast	Lindsay’s Creek at North Road Bridge	57	0.58	1.0625	0.01515	0.0237
Dunedin & Coast	Tokomairiro at Blackbridge	59	0.39	2.81	0.0161	0.04865
Dunedin & Coast	Tokomairiro at West Branch Bridge	59	0.25	1.1065	0.0074	0.01422
Dunedin & Coast	Waitati at Mt Cargill Road	57	0.022	0.4095	0.00326	0.00805
Dunstan Rohe	Arrow at Morven Ferry Road	46	0.084	0.1586	0.00141	0.00309
Dunstan Rohe	Bannockburn at Lake Dunstan	58	0.00048	0.0117	0.0028	0.0054
Dunstan Rohe	Cardrona at Mt Barker	57	0.078	0.21	0.0016	0.004
Dunstan Rohe	Clutha @ Luggate Br	57	0.03	0.04965	0.0002	0.00119
Dunstan Rohe	Hawea at Camphill Bridge	58	0.0172	0.04	0.0014	0.00296
Dunstan Rohe	Kawarau @ Chards Rd	56	0.0185	0.032	0.0008	0.00523
Dunstan Rohe	Lindis at Ardgour Road	57	0.033	0.17775	0.00185	0.00442
Dunstan Rohe	Lindis at Lindis Peak	57	0.0196	0.078	0.00202	0.00528
Dunstan Rohe	Luggate Creek at SH6 Bridge	57	0.0044	0.01626	0.0089	0.01247
Dunstan Rohe	Mill Creek at Fish Trap	59	0.35	0.49	0.00365	0.01212
Dunstan Rohe	Nevis at Wentworth Station	46	0.0018	0.01178	0.00287	0.00575
Dunstan Rohe	Quartz Reef Creek at SH8	45	0.0061	0.05025	0.00171	0.00332
Dunstan Rohe	Roaring Meg at SH6	46	0.0114	0.0404	0.0065	0.00946
Dunstan Rohe	Shotover @ Bowens Peak	58	0.0155	0.0344	0.0005	0.00176
Dunstan Rohe	Upper Cardrona at Tuohys Gully Road	44	0.01905	0.0461	0.00093	0.00242
Lower Clutha Rohe	Blackcleugh Burn at Rongahere Road	42	0.0515	0.1556	0.01425	0.021
Lower Clutha Rohe	Clutha @ Balclutha	59	0.06178	0.35834	0.0011	0.00604
Lower Clutha Rohe	Crookston Burn at Kelso Road	56	1.24	2.41	0.03	0.06175
Lower Clutha Rohe	Heriot Burn at Park Hill Road	56	1.32	1.96	0.026	0.04475
Lower Clutha Rohe	Lovells Creek at Station Road	59	1.11	3.655	0.01	0.03375
Lower Clutha Rohe	Pomahaka at Burkes Ford	56	0.65	2.47	0.0104	0.02625
Lower Clutha Rohe	Pomahaka at Glenken	56	0.0585	0.374	0.0058	0.01458
Lower Clutha Rohe	Tuapeka at 700m u/s bridge	57	0.168	1.036	0.0195	0.03665
Lower Clutha Rohe	Upper Pomahaka at Aitchison Runs Rd	45	0.0132	0.049	0.0047	0.00915
Lower Clutha Rohe	Waipahi at Cairns Peak	56	0.79	1.955	0.01105	0.0491
Lower Clutha Rohe	Waipahi at Waipahi	56	1.215	2.88	0.01345	0.0334
Lower Clutha Rohe	Wairuna at Millar Road	56	1.385	6.86	0.031	0.1907
Lower Clutha Rohe	Waitahuna at Tweeds Bridge	59	0.175	1.3515	0.0114	0.0352
Lower Clutha Rohe	Waiwera at Maws Farm	59	0.98	3.02	0.022	0.06085
Manuherekia Rohe	Dunstan Creek at Beattie Road	58	0.084	0.1928	0.0027	0.00634
Manuherekia Rohe	Hills Creek at SH85	45	0.041	0.26	0.0022	0.00688
Manuherekia Rohe	Manuherekia at Blackstone Hill	58	0.00455	0.0776	0.00255	0.00666

FMU	Site Name	# values	NNN Median	NNN Q95	DRP Median	DRP Q95
Manuherekia Rohe	Manuherekia at Galloway	58	0.0485	0.23	0.009	0.0282
Manuherekia Rohe	Manuherekia at Ophir	58	0.081	0.286	0.01085	0.0354
Manuherekia Rohe	Manuherekia downstream of Fork	47	0.0017	0.01188	0.0037	0.00602
Manuherekia Rohe	Poolburn at Cob Cottage	47	0.064	0.38	0.027	0.0673
Manuherekia Rohe	Thomsons Creek at SH85	57	0.25	0.6165	0.0187	0.1049
North Otago FMU	Awamoko at SH83	55	0.48	1.1125	0.0535	0.145
North Otago FMU	Kakaho Creek at SH1	33	0.142	0.812	0.022	0.07285
North Otago FMU	Kakanui at Clifton Falls Bridge	55	0.024	0.10775	0.00145	0.00872
North Otago FMU	Kakanui at McCones	55	0.38	0.845	0.00283	0.01304
North Otago FMU	Kauru at Ewings	55	0.014	0.05925	0.00246	0.00616
North Otago FMU	Oamaru Creek at SH1	43	0.52	1.1145	0.25	0.4735
North Otago FMU	Pleasant at Patterson Road Ford	43	0.0152	1.201	0.00229	0.0105
North Otago FMU	Shag at Craig Road	56	0.11025	0.4927	0.00323	0.0121
North Otago FMU	Shag at Goodwood Pump	55	0.23	0.6875	0.0045	0.01375
North Otago FMU	Trotters Creek at Mathesons	55	0.46	1.29	0.0036	0.00868
North Otago FMU	Upper Shag at SH85 Culvert	46	0.0154	0.0682	0.0019	0.00356
North Otago FMU	Waianakarua at Browns	55	0.3	0.59	0.00249	0.01092
North Otago FMU	Waianakarua at South Branch SH1	43	0.37	0.7605	0.0016	0.00553
North Otago FMU	Waiareka Creek at Taipo Road	54	0.48	1.99	0.187	0.3685
North Otago FMU	Waikouaiti at 200m d/s DCC intake	44	0.029	0.291	0.00116	0.00388
Roxburgh Rohe	Benger burn at Booths	54	0.182	1.146	0.01035	0.01942
Roxburgh Rohe	Clutha @ Millers Flat	59	0.02987	0.05804	0.00065	0.00293
Roxburgh Rohe	Fraser at Old Man Range	45	0.0035	0.01368	0.0024	0.0041
Roxburgh Rohe	Teviot at Bridge Huts Road	45	0.004	0.01842	0.0011	0.0037
Taieri FMU	Contour Channel at No. 4 Bridge	59	0.184	0.5875	0.0179	0.07865
Taieri FMU	Deep Stream at SH87	58	0.00105	0.0616	0.0019	0.00466
Taieri FMU	Kye Burn at SH85 Bridge	59	0.078	0.241	0.00328	0.00619
Taieri FMU	Meggat Burn at Berwick Road	46	0.0695	0.424	0.00905	0.019
Taieri FMU	Nenthorn at Mt Stoker Road	58	0.00128	0.029	0.0058	0.01828
Taieri FMU	Silverstream at Taieri Depot	59	0.41	0.8595	0.00314	0.02408
Taieri FMU	Silverstream at Three Mile Hill Road	46	0.00765	0.1116	0.0018	0.004
Taieri FMU	Sutton Stream at SH87	55	0.0049	0.0645	0.004	0.0086
Taieri FMU	Taieri at Allanton Bridge	57	0.08	0.2595	0.008	0.02525
Taieri FMU	Taieri at Linnburn Runs Road	58	0.00215	0.01168	0.002	0.00524
Taieri FMU	Taieri at Outram	60	0.05	0.1765	0.0065	0.0204
Taieri FMU	Taieri at Stonehenge	59	0.0093	0.0322	0.004	0.01096
Taieri FMU	Taieri at Sutton	59	0.039	0.13065	0.0078	0.0261
Taieri FMU	Taieri at Tiroiti	59	0.038	0.12785	0.0102	0.0333
Taieri FMU	Taieri at Waipiata	59	0.023	0.0922	0.0168	0.0466
Taieri FMU	Waipori at Waipori Falls Reserve	59	0.023	0.129	0.00214	0.00764
Taieri FMU	Whare Creek at Whare Flat Road	46	0.035	0.1748	0.00192	0.00354
Upper Lakes Rohe	12 Mile Creek at Glenorchy QT Rd	44	0.0024	0.00795	0.00255	0.00433
Upper Lakes Rohe	25 Mile Creek at Glenorchy QT Rd	44	0.00435	0.01189	0.00305	0.00666
Upper Lakes Rohe	Buckler Burn at Glenorchy QT Rd	44	0.01835	0.0536	0.00106	0.00226
Upper Lakes Rohe	Bullock Creek at Dunmore Street	45	0.73	0.815	0.0011	0.00195
Upper Lakes Rohe	Craig Burn at SH6	37	0.0038	0.01958	0.0028	0.00573
Upper Lakes Rohe	Dart at The Hillocks	56	0.0285	0.044	0.00185	0.00328

FMU	Site Name	# values	NNN Median	NNN Q95	DRP Median	DRP Q95
Upper Lakes Rohe	Dundas Creek at Mill Flat	43	0.032	0.05635	0.00236	0.00368
Upper Lakes Rohe	Greenstone at Greenstone Station Road	43	0.0119	0.024	0.00107	0.00201
Upper Lakes Rohe	Horn Creek at Queenstown Bay	45	0.147	0.205	0.0085	0.01498
Upper Lakes Rohe	Invincible Creek at Rees Valley Road	43	0.0093	0.02025	0.00065	0.00204
Upper Lakes Rohe	Leaping Burn at Wanaka Mt Aspiring Rd	45	0.0183	0.04925	0.00062	0.00215
Upper Lakes Rohe	Makarora at Makarora	45	0.044	0.07775	0.0011	0.0036
Upper Lakes Rohe	Matukituki at West Wanaka	58	0.0595	0.0954	0.0023	0.00416
Upper Lakes Rohe	Motatapu at Wanaka Mt Aspiring Road	45	0.031	0.053	0.0005	0.00198
Upper Lakes Rohe	Ox Burn at Rees Valley Road	43	0.014	0.02705	0.0012	0.00211
Upper Lakes Rohe	Precipice Creek at Glenorchy Paradise	44	0.0037	0.01797	0.0013	0.00223
Upper Lakes Rohe	Quartz Creek at Maungawera Valley Rd	41	0.059	0.15405	0.0015	0.00378
Upper Lakes Rohe	Rees at Glenorchy Paradise Road Bridge	44	0.01265	0.022	0.00097	0.00203
Upper Lakes Rohe	Scott Creek at Routeburn Road	44	0.0235	0.0343	0.00105	0.00274
Upper Lakes Rohe	The Neck Creek at Meads Road	45	0.0021	0.01135	0.0015	0.0026
Upper Lakes Rohe	Timaru at Peter Muir Bridge	43	0.0076	0.0207	0.0044	0.00705
Upper Lakes Rohe	Turner Creek at Kinloch Road	44	0.042	0.0533	0.0018	0.00306

12.2 Rivers - Clarity and *E. Coli*

FMU	*Site Name*	*Turbidity Median*	*SS Class App 2C*	*Clarity Median*	*E. coli G260*	*E. coli G540*	*E. coli Median*	*E. coli Q95*
Catlins FMU	Catlins at Houipapa	3.4	4	1.39	0.21	0.16	145	1540
Catlins FMU	Maclennan at Kahuiku	1.97	3	2.06	0.16	0.11	70	758
Catlins FMU	Owaka at Katea Road	2.6	4	1.69	0.44	0.23	231	2524
Catlins FMU	Tahakopa at Tahakopa	3.6	4	1.33	0.36	0.25	172	3927
Dun/ Coast	Akatore Creek at Akatore	0.96	2	3.45	0.16	0.14	91	2173
Dun/ Coast	Kaikorai Stream	3.3	2	1.42	0.91	0.73	1162	9908
Dun/ Coast	Leith at Dundas Street	2.15	1	1.93	0.88	0.70	707	2476
Dun/ Coast	Lindsay's Creek at North	2.7	1	1.64	0.74	0.51	548	3106
Dun/ Coast	Tokomairiro at Blackbridge	6	1	0.92	0.81	0.73	980	8865
Dun/ Coast	Tokomairiro at West Br Br	2.4	1	1.79	0.44	0.29	225	2714
Dun/ Coast	Waitati at Mt Cargill Road	1.18	1	2.98	0.21	0.09	96	998
Dunstan Rohe	Arrow at Morven Ferry	1.38	3	2.66	0.04	0.02	15	287
Dunstan Rohe	Bannockburn at Lake D	1.12	3	3.09	0.09	0.02	43	316
Dunstan Rohe	Cardrona at Mt Barker	1.81	3	2.19	0.11	0.05	60	616
Dunstan Rohe	Clutha @ Luggate Br	0.805	3	3.92	0.00	0.00	4	47
Dunstan Rohe	Hawea at Camphill Bridge	0.37	3	6.86	0.00	0.00	2	18
Dunstan Rohe	Kawarau @ Chards Rd	2.7	3	1.64	0.05	0.02	6	253
Dunstan Rohe	Lindis at Ardgour Road	1.54	3	2.46	0.11	0.04	76	485
Dunstan Rohe	Lindis at Lindis Peak	2.3	3	1.84	0.13	0.04	75	500
Dunstan Rohe	Luggate Creek at SH6 Br	1.16	1	3.01	0.12	0.05	64	608
Dunstan Rohe	Mill Creek at Fish Trap	4.3	3	1.17	0.28	0.16	122	1296
Dunstan Rohe	Nevis at Wentworth St	0.885	1	3.66	0.00	0.00	11	162
Dunstan Rohe	Quartz Reef Creek at SH8	1.68	3	2.31	0.00	0.00	49	241
Dunstan Rohe	Roaring Meg at SH6	0.89	1	3.65	0.00	0.00	16	113
Dunstan Rohe	Shotover @ Bowens Peak	9.575	1	0.66	0.05	0.04	6	322
Dunstan Rohe	Upper Cardrona Tuohys	1.42	3	2.61	0.07	0.05	38	604
Lower Clutha	Blackcleugh Burn at Rong	1.05	3	3.24	0.05	0.00	12	155
Lower Clutha	Clutha @ Balclutha	3.865	3	1.27	0.14	0.08	50	1300
Lower Clutha	Crookston Burn at Kelso	5.05	3	1.05	0.80	0.55	579	2117
Lower Clutha	Heriot Burn at Park Hill	5.1	1	1.04	0.63	0.46	400	2290
Lower Clutha	Lovells Creek at Station	3.2	1	1.45	0.54	0.31	276	3411
Lower Clutha	Pomahaka at Burkes Ford	4.15	1	1.20	0.29	0.18	114	1986
Lower Clutha	Pomahaka at Glenken	1.715	3	2.27	0.39	0.05	192	836
Lower Clutha	Tuapeka at 700m u/s Br	3.5	1	1.36	0.49	0.26	236	5960
Lower Clutha	Upper Pomahaka ARR	0.77	3	4.05	0.13	0.04	73	480
Lower Clutha	Waipahi at Cairns Peak	3.9	4	1.26	0.36	0.23	193	1656
Lower Clutha	Waipahi at Waipahi	2.6	2	1.69	0.36	0.14	186	6635
Lower Clutha	Wairuna at Millar Road	9.05	1	0.69	0.86	0.55	625	5218
Lower Clutha	Waitahuna at Tweeds Br	3.5	1	1.36	0.63	0.31	326	5721
Lower Clutha	Waiwera at Maws Farm	2.5	2	1.73	0.46	0.22	248	1634
Lower Clutha	Dunstan Creek at Beattie	0.765	3	4.07	0.09	0.05	59	558
Manuherekia	Hills Creek at SH85	1.26	3	2.84	0.29	0.16	93	895

FMU	Site Name	Turbidity Median	SS Class App 2C	Clarity Median	*E. coli* G260	*E. coli* G540	*E. coli* Median	*E. coli* Q95
Manuherekia	Manuherekia Blackstone	2.65	3	1.66	0.10	0.05	52	748
Manuherekia	Manuherekia at Galloway	3.2	3	1.45	0.24	0.10	83	1228
Manuherekia	Manuherekia at Ophir	3.45	3	1.37	0.40	0.22	202	2702
Manuherekia	Manuherekia d/s of Fork	0.26	1	8.85	0.02	0.00	7	107
Manuherekia	Poolburn at Cob Cottage	2.5	3	1.73	0.36	0.15	179	2156
Manuherekia	Thomsons Creek at SH85	6	3	0.92	0.58	0.47	410	5228
North Otago	Awamoko at SH83	1.01	2	3.33	0.49	0.22	199	1720
North Otago	Kakaho Creek at SH1	2.9	2	1.56	0.36	0.27	147	26629
North Otago	Kakanui at Clifton Falls Br	0.35	3	7.14	0.36	0.29	214	1115
North Otago	Kakanui at McCones	0.5	3	5.52	0.22	0.13	107	1255
North Otago	Kauru at Ewings	0.32	3	7.62	0.25	0.15	119	3512
North Otago	Oamaru Creek at SH1	1.69	2	2.30	0.44	0.30	236	16424
North Otago	Pleasant at Patterson Rd	2.9	2	1.56	0.16	0.12	59	10090
North Otago	Shag at Craig Road	0.6	3	4.84	0.09	0.05	53	638
North Otago	Shag at Goodwood Pump	0.72	1	4.25	0.22	0.11	100	1074
North Otago	Trotters Creek Mathesons	1.63	2	2.36	0.33	0.16	148	1164
North Otago	Upper Shag at SH85	0.275	3	8.50	0.09	0.04	39	628
North Otago	Waianakarua at Browns	0.45	3	5.96	0.20	0.11	98	1518
North Otago	Waianakarua at S Brh SH1	0.37	3	6.86	0.19	0.12	101	2864
North Otago	Waiareka Creek at Taipo	1.78	2	2.21	0.44	0.20	212	856
North Otago	Waikouaiti at 200m d/s	0.655	3	4.55	0.07	0.02	43	317
Roxburgh Rohe	Benger burn at Booths	1.93	3	2.09	0.42	0.21	230	2716
Roxburgh Rohe	Clutha @ Millers Flat	1.75	3	2.24	0.03	0.02	15	162
Roxburgh Rohe	Fraser at Old Man Range	0.39	1	6.61	0.00	0.00	3	31
Roxburgh Rohe	Teviot at Bridge Huts Rd	4.1	3	1.21	0.13	0.04	28	562
Taieri FMU	Contour Channel No4 Br	3.9	1	1.26	0.54	0.44	340	4377
Taieri FMU	Deep Stream at SH87	0.755	3	4.11	0.12	0.02	75	420
Taieri FMU	Kye Burn at SH85 Bridge	1.1	3	3.13	0.09	0.03	67	407
Taieri FMU	Meggat Burn Berwick Rd	2.3	3	1.84	0.30	0.13	150	1100
Taieri FMU	Nenthorn at Mt Stoker Rd	0.91	3	3.59	0.10	0.02	44	387
Taieri FMU	Silverstream Taieri Dep	0.88	1	3.68	0.32	0.22	148	2324
Taieri FMU	Silverstream at 3 Mile Hill	0.64	1	4.62	0.09	0.07	48	704
Taieri FMU	Sutton Stream at SH87	1.07	3	3.19	0.40	0.15	219	821
Taieri FMU	Taieri at Allanton Bridge	4.7	3	1.10	0.28	0.14	127	2862
Taieri FMU	Taieri Linnburn Runs Rd	1.245	3	2.86	0.18	0.07	62	703
Taieri FMU	Taieri at Outram	3	1	1.52	0.08	0.05	62	437
Taieri FMU	Taieri at Stonehenge	1.3	3	2.78	0.05	0.03	59	284
Taieri FMU	Taieri at Sutton	4.5	1	1.14	0.24	0.12	148	1051
Taieri FMU	Taieri at Tiroiti	4	3	1.24	0.12	0.02	78	393
Taieri FMU	Taieri at Waipiata	3	3	1.52	0.19	0.05	105	836
Taieri FMU	Waipori at Waipori Falls	1.8	3	2.20	0.00	0.00	12	79
Taieri FMU	Whare Creek Whare Flat	1.02	2	3.31	0.00	0.00	13	142
Upper Lakes	12 Mile Creek at GQT Rd	0.23	1	9.66	0.00	0.00	3	20
Upper Lakes	25 Mile Creek at GQT Rd	0.275	1	8.50	0.00	0.00	14	60
Upper Lakes	Buckler Burn at GQT Rd	2.5	1	1.73	0.02	0.02	5	38

FMU	*Site Name*	Turbidity Median	SS Class App 2C	Clarity Median	*E. coli* G260	*E. coli* G540	*E. coli* Median	*E. coli* Q95
Upper Lakes	Bullock Creek at Dunmore	0.26	3	8.85	0.40	0.33	205	1706
Upper Lakes	Craig Burn at SH6	0.54	3	5.23	0.00	0.00	42	169
Upper Lakes	Dart at The Hillocks	19.1	3	0.40	0.07	0.02	9	361
Upper Lakes	Dundas Creek at Mill Flat	0.2	3	10.68	0.00	0.00	1	13
Upper Lakes	Greenstone at GS Station	0.32	1	7.62	0.00	0.00	19	139
Upper Lakes	Horn Creek at Queenstown	1.43	3	2.59	0.27	0.09	88	794
Upper Lakes	Invincible Creek at Rees V	1.2	1	2.94	0.00	0.00	1	8
Upper Lakes	Leaping Burn W Mt As Rd	0.27	1	8.61	0.12	0.05	31	491
Upper Lakes	Makarora at Makarora	0.97	3	3.43	0.09	0.05	23	523
Upper Lakes	Matukituki at W Wanaka	3.75	1	1.29	0.05	0.02	25	284
Upper Lakes	Motatapu at W Mt As Rd	0.73	1	4.21	0.02	0.02	23	113
Upper Lakes	Ox Burn at Rees Valley Rd	2.7	1	1.64	0.00	0.00	5	21
Upper Lakes	Precipice Creek at G P Rd	0.335	1	7.37	0.02	0.00	7	69
Upper Lakes	Quartz Creek at Maungatua	0.24	3	9.37	0.13	0.05	54	717
Upper Lakes	Rees at Glenorchy P Rd Br	6.05	1	0.92	0.05	0.05	10	424
Upper Lakes	Scott Ck at Routeburn R	0.49	1	5.60	0.02	0.00	7	42
Upper Lakes	The Neck Creek at Meads	0.17	1	12.01	0.02	0.00	5	118
Upper Lakes	Timaru at Peter Muir Br	14.5	1	0.49	0.00	0.00	5	18
Upper Lakes	Turner Creek Kinloch Rd	0.295	1	8.08	0.00	0.00	4	41

12.3 Rivers - Ammonia and Periphyton

FMU	*Site Name*	*NH4-N #*	*NH4-N Median*	*NH4-N Ann Max*	*Chla #*	*Chla Q83*	*Chla Q92*
Catlins FMU	Catlins at Houipapa	58	0.0030	0.0122	n/a	n/a	n/a
Catlins FMU	Maclennan Kahuiku Sch Rd	45	0.0035	0.0150	n/a	n/a	n/a
Catlins FMU	Owaka at Katea Road	58	0.0041	0.0167	28	136.84	178.06
Catlins FMU	Tahakopa at Tahakopa	45	0.0039	0.0076	28	46.01	110.82
Dunedin & Coast FMU	Akatore Creek at A-Ck Road	43	0.0028	0.0088	32	89.72	146.67
Dunedin & Coast FMU	Kaikorai Stream Brighton Rd	57	0.0062	1.9325	31	416.37	502.82
Dunedin & Coast FMU	Leith at Dundas Street Bridge	56	0.0046	0.0259	n/a	n/a	n/a
Dunedin & Coast FMU	Lindsay’s Creek North Road Br	57	0.0062	0.0157	n/a	n/a	n/a
Dunedin & Coast FMU	Tokomairiro at Blackbridge	59	0.0090	0.1759	n/a	n/a	n/a
Dunedin & Coast FMU	Tokomairiro West Branch B	59	0.0033	0.0293	30	112.28	175.45
Dunedin & Coast FMU	Waitati at Mt Cargill Road	57	0.0035	0.0443	n/a	n/a	n/a
Dunstan Rohe	Arrow at Morven Ferry Road	46	0.0019	0.0025	23	29.87	34.36
Dunstan Rohe	Bannockburn at Lake Dunstan	58	0.0019	0.0163	n/a	n/a	n/a
Dunstan Rohe	Cardrona at Mt Barker	57	0.0022	0.0061	28	36.39	56.37
Dunstan Rohe	Clutha @ Luggate Br	56	0.0028	0.0092	n/a	n/a	n/a
Dunstan Rohe	Hawea at Camphill Bridge	58	0.0009	0.0028	n/a	n/a	n/a
Dunstan Rohe	Kawarau @ Chards Rd	56	0.0026	0.0101	n/a	n/a	n/a
Dunstan Rohe	Lindis at Ardgour Road	57	0.0022	0.0054	23	111.37	114.61
Dunstan Rohe	Lindis at Lindis Peak	57	0.0012	0.0034	n/a	n/a	n/a
Dunstan Rohe	Luggate Creek at SH6 Bridge	49	0.0013	0.0061	32	66.46	96.51
Dunstan Rohe	Mill Creek at Fish Trap	51	0.0037	0.0584	n/a	n/a	n/a
Dunstan Rohe	Nevis at Wentworth Station	46	0.0005	0.0023	n/a	n/a	n/a
Dunstan Rohe	Quartz Reef Creek at SH8	45	0.0022	0.0054	n/a	n/a	n/a
Dunstan Rohe	Roaring Meg at SH6	46	0.0014	0.0022	n/a	n/a	n/a
Dunstan Rohe	Shotover @ Bowens Peak	55	0.0017	0.0063	n/a	n/a	n/a
Dunstan Rohe	Upper Cardrona Tuohys Gully Rd	44	0.0019	0.0022	n/a	n/a	n/a
Lower Clutha Rohe	Blackcleugh Burn Rongahere Rd	42	0.0012	0.0040	30	19.10	29.81
Lower Clutha Rohe	Clutha @ Balclutha	58	0.0024	0.0126	n/a	n/a	n/a
Lower Clutha Rohe	Crookston Burn at Kelso Road	56	0.0080	0.1341	n/a	n/a	n/a
Lower Clutha Rohe	Heriot Burn at Park Hill Road	56	0.0084	0.0282	n/a	n/a	n/a
Lower Clutha Rohe	Lovells Creek at Station Road	59	0.0056	0.0371	n/a	n/a	n/a
Lower Clutha Rohe	Pomahaka at Burkes Ford	56	0.0044	0.0299	n/a	n/a	n/a
Lower Clutha Rohe	Pomahaka at Glenken	56	0.0020	0.0046	n/a	n/a	n/a
Lower Clutha Rohe	Tuapeka at 700m u/s bridge	57	0.0039	0.0304	n/a	n/a	n/a
Lower Clutha Rohe	Upper Pomahaka Aitchison R Rd	45	0.0012	0.0037	29	23.19	35.76
Lower Clutha Rohe	Waipahi at Cairns Peak	56	0.0061	0.0187	n/a	n/a	n/a
Lower Clutha Rohe	Waipahi at Waipahi	56	0.0037	0.0339	25	166.05	234.70
Lower Clutha Rohe	Wairuna at Millar Road	56	0.0171	0.0835	n/a	n/a	n/a
Lower Clutha Rohe	Waitahuna at Tweeds Bridge	59	0.0041	0.0591	29	18.65	31.23
Lower Clutha Rohe	Waiwera at Maws Farm	59	0.0085	0.1160	n/a	n/a	n/a

FMU	Site Name	NH4-N #	NH4-N Median	NH4-N Ann Max	Chla #	Chla Q83	Chla Q92
Manuherekia Rohe	Dunstan Creek at Beattie Road	58	0.0014	0.0041	28	18.79	47.50
Manuherekia Rohe	Hills Creek at SH85	45	0.0011	0.0528	n/a	n/a	n/a
Manuherekia Rohe	Manuherekia at Blackstone Hill	58	0.0014	0.0369	24	49.96	67.18
Manuherekia Rohe	Manuherekia at Galloway	58	0.0021	0.0101	29	57.07	101.87
Manuherekia Rohe	Manuherekia at Ophir	58	0.0034	0.0243	26	81.22	102.98
Manuherekia Rohe	Manuherekia downstream of Fork	47	0.0011	0.0013	n/a	n/a	n/a
Manuherekia Rohe	Poolburn at Cob Cottage	47	0.0038	0.0292	n/a	n/a	n/a
Manuherekia Rohe	Thomsons Creek at SH85	57	0.0044	0.0558	n/a	n/a	n/a
North Otago FMU	Awamoko at SH83	55	0.0045	0.1666	n/a	n/a	n/a
North Otago FMU	Kakaho Creek at SH1	33	0.0148	0.1235	n/a	n/a	n/a
North Otago FMU	Kakanui at Clifton Falls Bridge	55	0.0016	0.0192	2	80.20	80.20
North Otago FMU	Kakanui at McCones	55	0.0027	0.0102	30	283.60	464.30
North Otago FMU	Kauru at Ewings	55	0.0019	0.0067	n/a	n/a	n/a
North Otago FMU	Oamaru Creek at SH1	43	0.0173	0.1470	34	485.40	568.83
North Otago FMU	Pleasant at Patterson Road Ford	43	0.0037	0.0171	n/a	n/a	n/a
North Otago FMU	Shag at Craig Road	56	0.0025	0.0248	n/a	n/a	n/a
North Otago FMU	Shag at Goodwood Pump	55	0.0034	0.0102	32	330.61	372.25
North Otago FMU	Trotters Creek at Mathesons	55	0.0061	0.0953	n/a	n/a	n/a
North Otago FMU	Upper Shag at SH85 Culvert	46	0.0017	0.0238	n/a	n/a	n/a
North Otago FMU	Waianakarua at Browns	55	0.0020	0.0056	33	179.16	220.05
North Otago FMU	Waianakarua S Branch SH1	43	0.0027	0.0055	n/a	n/a	n/a
North Otago FMU	Waiareka Creek at Taipo Road	54	0.0081	0.3198	n/a	n/a	n/a
North Otago FMU	Waikouaiti 200m d/s DCC take	44	0.0019	0.0077	n/a	n/a	n/a
Roxburgh Rohe	Benger burn at Booths	54	0.0033	0.0085	n/a	n/a	n/a
Roxburgh Rohe	Clutha @ Millers Flat	58	0.0015	0.0035	n/a	n/a	n/a
Roxburgh Rohe	Fraser at Old Man Range	45	0.0011	0.0025	n/a	n/a	n/a
Roxburgh Rohe	Teviot at Bridge Huts Road	45	0.0009	0.0079	n/a	n/a	n/a
Taieri FMU	Contour Channel at No. 4 Br	59	0.0102	0.0910	n/a	n/a	n/a
Taieri FMU	Deep Stream at SH87	58	0.0009	0.0081	n/a	n/a	n/a
Taieri FMU	Kye Burn at SH85 Bridge	59	0.0017	0.0046	26	25.20	32.80
Taieri FMU	Meggat Burn at Berwick Road	46	0.0039	0.0220	n/a	n/a	n/a
Taieri FMU	Nenthorn at Mt Stoker Road	58	0.0016	0.0070	n/a	n/a	n/a
Taieri FMU	Silverstream at Taieri Depot	59	0.0023	0.3150	31	159.14	273.31
Taieri FMU	Silverstream at 3 Mile Hill Rd	46	0.0019	0.0030	n/a	n/a	n/a
Taieri FMU	Sutton Stream at SH87	55	0.0013	0.0070	n/a	n/a	n/a
Taieri FMU	Taieri at Allanton Bridge	57	0.0036	0.0232	n/a	n/a	n/a
Taieri FMU	Taieri at Linnburn Runs Road	58	0.0011	0.0031	n/a	n/a	n/a
Taieri FMU	Taieri at Outram	60	0.0016	0.0138	19	121.94	197.33
Taieri FMU	Taieri at Stonehenge	59	0.0015	0.0175	n/a	n/a	n/a
Taieri FMU	Taieri at Sutton	59	0.0020	0.0127	15	79.86	128.55
Taieri FMU	Taieri at Tiroiti	59	0.0024	0.0116	n/a	n/a	n/a
Taieri FMU	Taieri at Waipiata	59	0.0029	0.0268	17	19.84	26.23
Taieri FMU	Waipori at Waipori Falls	59	0.0011	0.0273	n/a	n/a	n/a
Taieri FMU	Whare Creek at W Flat Rd	46	0.0012	0.0037	n/a	n/a	n/a
Upper Lakes Rohe	12 Mile Creek at G-QT Road	44	0.0013	0.0030	29	3.96	9.43
Upper Lakes Rohe	25 Mile Creek at G-QT Road	44	0.0017	0.0076	29	23.47	31.89
Upper Lakes Rohe	Buckler Burn at G-QT Road	44	0.0017	0.0022	n/a	n/a	n/a
Upper Lakes Rohe	Bullock Creek at Dunmore St	37	0.0017	0.0019	32	198.37	322.96

FMU	*Site Name*	*NH4-N #*	*NH4-N Median*	*NH4-N Ann Max*	*Chla #*	*Chla Q83*	*Chla Q92*
Upper Lakes Rohe	Craig Burn at SH6	37	0.0017	0.0082	n/a	n/a	n/a
Upper Lakes Rohe	Dart at The Hillocks	56	0.0011	0.0039	20	1.55	6.50
Upper Lakes Rohe	Dundas Creek at Mill Flat	43	0.0015	0.0019	n/a	n/a	n/a
Upper Lakes Rohe	Greenstone at G-Station Rd	43	0.0012	0.0029	29	4.16	6.79
Upper Lakes Rohe	Horn Creek at Queenstown Bay	45	0.0061	0.1140	n/a	n/a	n/a
Upper Lakes Rohe	Invincible Creek at Rees Val Rd	43	0.0019	0.0022	n/a	n/a	n/a
Upper Lakes Rohe	Leaping Burn at W-MtA Rd	37	0.0008	0.0034	n/a	n/a	n/a
Upper Lakes Rohe	Makarora at Makarora	45	0.0014	0.0017	n/a	n/a	n/a
Upper Lakes Rohe	Matukituki at West Wanaka	50	0.0025	0.0109	24	1.03	3.79
Upper Lakes Rohe	Motatapu at W-MtA Rd	37	0.0017	0.0022	28	26.82	50.27
Upper Lakes Rohe	Ox Burn at Rees Valley Road	43	0.0017	0.0061	n/a	n/a	n/a
Upper Lakes Rohe	Precipice Creek at G-Para Rd	44	0.0017	0.0022	32	10.62	13.88
Upper Lakes Rohe	Quartz Creek at Maung Val Rd	41	0.0017	0.0128	n/a	n/a	n/a
Upper Lakes Rohe	Rees at G-Para Rd	44	0.0016	0.0039	n/a	n/a	n/a
Upper Lakes Rohe	Scott Creek at Routeburn Road	44	0.0014	0.0030	n/a	n/a	n/a
Upper Lakes Rohe	The Neck Creek at Meads Road	45	0.0015	0.0019	31	8.60	32.31
Upper Lakes Rohe	Timaru at Peter Muir Bridge	43	0.0008	0.0028	n/a	n/a	n/a
Upper Lakes Rohe	Turner Creek at Kinloch Road	44	0.0011	0.0024	29	50.64	71.76

12.4 Lakes - Summary Results Total N, Total P, Phytoplankton

Site Name	*TN TP #*	*TN Median*	*TN Ann Max*	*TP Median*	*TP Max*	*# Chla*	*Chla Median*	*Chla Ann Max*
Lake Dunstan at Clyde Dam 10m	34	0.067	0.101	0.0026	0.008	34	1.4	3.3
Lake Dunstan at Clyde Dam HYP	32	0.067	0.09	0.00205	0.023	n/a	n/a	n/a
Lake Dunstan at Cromwell Boat Club 10m	34	0.0745	0.103	0.002	0.005	34	1.3	2.9
Lake Dunstan at Cromwell Boat Club HYP	32	0.0775	0.121	0.0022	0.021	n/a	n/a	n/a
Lake Dunstan at Dead Man’s Point	58	0.073	0.11	0.002	0.0175	59	1.2	2.6
Lake Hawea North Open Water 10m	20	0.036	0.075	0.001	0.006	20	0.535	1.4
Lake Hawea North Open Water HYP	20	0.042	0.189	0.001	0.003	n/a	n/a	n/a
Lake Hawea South Open Water 10m	56	0.036	0.063	0.001	0.004	56	0.56	1.3
Lake Hawea South Open Water HYP	55	0.041	0.192	0.001	0.005	n/a	n/a	n/a
Lake Hayes at Mid Lake 10m	56	0.36	0.78	0.043	0.101	56	25	94
Lake Hayes at Mid Lake HYP	56	0.31	0.51	0.044	0.129	n/a	n/a	n/a
Lake Onslow at Boat Ramp	55	0.27	0.41	0.023	0.044	55	3.3	8.1
Lake Tuakitoto at Outlet	59	1.1	3.2	0.117	0.31	59	8	103
Lake Waihola at Waihola Mid	16	0.515	1.23	0.0455	0.143	16	9.8	27
Lake Waihola at Waihola South	16	0.7	1.85	0.063	0.28	16	16	40
Lake Wakatipu at Frankton Arm 10m	56	0.051	0.29	0.001	0.0085	56	0.65	6
Lake Wakatipu at Queenstown Bay 10m	57	0.053	0.092	0.0017	0.013	57	0.71	1.7
Lake Wakatipu North Open Water 10m	19	0.054	0.082	0.001	0.002	19	0.55	1.3
Lake Wakatipu North Open Water HYP	19	0.061	0.09	0.001	0.0031	n/a	n/a	n/a
Lake Wakatipu Open Water 10m	55	0.053	0.128	0.001	0.0375	55	0.555	1.8
Lake Wakatipu Open Water HYP	52	0.059	0.45	0.001	0.053	n/a	n/a	n/a
Lake Wanaka at Glendu Bay 10m	58	0.0555	0.099	0.001	0.003	58	0.9	2.4
Lake Wanaka at Roy's Bay 10m	58	0.0565	0.083	0.001	0.002	58	0.82	1.8
Lake Wanaka North Open Water 10m	20	0.059	0.095	0.001	0.0025	20	0.78	2
Lake Wanaka North Open Water HYP	20	0.063	0.117	0.001	0.004	n/a	n/a	n/a
Lake Wanaka Open Water 10m	58	0.0565	0.08	0.001	0.005	58	0.755	2.1
Lake Wanaka Open Water HYP	56	0.0665	0.52	0.001	0.0048	n/a	n/a	n/a

12.5 Lake - Summary Results *E. coli* and Ammonia

Site Name	*# E. coli*	*E. coli Median*	*E. coli Q95*	*E. coli G540*	*E. coli G260*	*NH4-N #*	*NH4-N Median*	*NH4-N Ann Max*
Lake Dunstan at Clyde Dam 10m	33	1	31	0.000	0.000	34	0.0015	0.0017
Lake Dunstan Cromwell Boat Club 10m	33	3	24	0.000	0.000	34	0.0016	0.0048
Lake Dunstan at Dead Man’s Point	58	3	40	0.017	0.017	59	0.0014	0.0069
Lake Hawea North Open Water 10m	18	0	1	0.000	0.000	18	0.0014	0.0015
Lake Hawea South Open Water 10m	50	0	1	0.000	0.000	51	0.0014	0.0039
Lake Hayes at Mid Lake 10m	49	1	6	0.000	0.000	48	0.0142	0.1076
Lake Hayes at Mid Lake HYP	1	1	1	0.000	0.000	n/a	n/a	n/a
Lake Onslow at Boat Ramp	54	2	60	0.000	0.000	55	0.0014	0.0065
Lake Tuakitoto at Outlet	59	58	1689	0.085	0.136	59	0.0201	0.1544
Lake Waihola at Waihola Mid	16	38	597	0.063	0.125	16	0.0025	0.0189
Lake Waihola at Waihola South	16	7	1730	0.063	0.063	16	0.0039	0.1252
Lake Wakatipu at Frankton Arm 10m	50	0	2	0.000	0.000	50	0.0014	0.0223
Lake Wakatipu at QueensT Bay 10m	50	2	13	0.000	0.000	51	0.0002	0.0007
Lake Wakatipu North Open Water 10m	17	1	1	0.000	0.000	17	0.0014	0.0015
Lake Wakatipu Open Water 10m	49	1	1	0.000	0.000	49	0.0014	0.0030
Lake Wanaka at Glendu Bay 10m	51	0	3	0.000	0.000	52	0.0015	0.0043
Lake Wanaka at Roy's Bay 10m	51	0	2	0.000	0.000	52	0.0015	0.0019
Lake Wanaka North Open Water 10m	17	0	1	0.000	0.000	18	0.0015	0.0019
Lake Wanaka Open Water 10m	51	1	2	0.000	0.000	52	0.0008	0.0028

12.6 Groundwater - Summary Results *E. coli*, Nitrate-N, Arsenic

FMU	*Bore*	*Analyte*	*#*	*Q5*	*Q20*	*Q25*	*Median*	*Q75*	*Q80*	*Q95*	*AnnMax*
Catlins	H46/0118	Arsenic	18	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.0000275
Catlins	H46/0118	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	5.6	9
Catlins	H46/0118	Nitrate	18	0.185	0.21	0.21	0.24	0.41	1.166	1.506	1.53
D & Coast	H45/0314	Arsenic	18	0.00052	0.00077	0.00083	0.0012	0.0016	0.00223	0.00414	0.0047
D & Coast	H45/0314	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
D & Coast	H45/0314	Nitrate	18	0.0005	0.0005	0.0005	0.0005	0.0022	0.0022	0.00616	0.0088
Dunstan	CB13/0159	Arsenic	6	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	F40/0025	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	F40/0045	Arsenic	19	0.00015	0.00016	0.00016	0.00018	0.00019	0.0002	0.00021	0.0002092
Dunstan	F40/0206	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	F41/0104	Arsenic	11	0.00923	0.01391	0.01402	0.0146	0.01565	0.01609	0.01785	0.0179
Dunstan	F41/0162	Arsenic	20	0.00014	0.00014	0.00015	0.00016	0.00017	0.00017	0.00018	0.0001842
Dunstan	F41/0203	Arsenic	20	0.00009	0.00013	0.00014	0.00024	0.00041	0.00047	0.00081	0.0009142
Dunstan	F41/0300	Arsenic	20	0.0009	0.00098	0.00101	0.00118	0.00142	0.00149	0.00178	0.0018421
Dunstan	F41/0437	Arsenic	17	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006
Dunstan	F41/0438	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	G40/0175	Arsenic	19	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.0000325
Dunstan	G40/0367	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	G40/0411	Arsenic	20	0.00085	0.00096	0.001	0.0011	0.00115	0.0012	0.00135	0.0015
Dunstan	G40/0415	Arsenic	18	0.00093	0.001	0.001	0.0011	0.0012	0.0012	0.00126	0.0013
Dunstan	G40/0416	Arsenic	18	0.00124	0.0014	0.0014	0.0015	0.0016	0.0016	0.0017	0.0017
Dunstan	G41/0211	Arsenic	16	0.0012	0.0013	0.0013	0.0014	0.0014	0.00143	0.00157	0.0016
Dunstan	G41/0487	Arsenic	7	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dunstan	CB13/0159	E-Coli	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F40/0025	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	2.425	4
Dunstan	F40/0045	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	4.6	7
Dunstan	F40/0206	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0104	E-Coli	11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0162	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0203	E-Coli	20	0.07696	0.17751	0.22323	0.58929	1.35607	1.59269	2.58105	2.7898423
Dunstan	F41/0300	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0437	E-Coli	17	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	F41/0438	E-Coli	39	0.00027	0.00497	0.00949	0.13311	2.75	5.4	261.75	2420
Dunstan	G40/0175	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	2.6	4
Dunstan	G40/0367	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	G40/0411	E-Coli	20	0.25	0.25	0.25	0.25	0.25	0.25	0.625	1
Dunstan	G40/0415	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	G40/0416	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	G41/0211	E-Coli	15	0.25	0.25	0.25	0.25	0.25	0.25	0.8125	1
Dunstan	G41/0487	E-Coli	7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dunstan	CB13/0159	Nitrate	6	0.26	0.267	0.27	0.275	0.29	0.293	0.3	0.3
Dunstan	F40/0025	Nitrate	20	0.36	0.395	0.4	0.52	0.725	0.845	1.075	1.19
Dunstan	F40/0045	Nitrate	19	2.1	2.23	2.325	2.9	3.2	3.34	4.295	4.7
Dunstan	F40/0206	Nitrate	20	0.665	0.72	0.735	0.79	0.87	0.875	0.94	0.94
Dunstan	F41/0104	Nitrate	11	0.00064	0.00123	0.00148	0.00425	0.09625	0.1647	0.3565	0.36
Dunstan	F41/0162	Nitrate	20	0.295	0.33	0.33	0.345	0.37	0.37	0.415	0.42
Dunstan	F41/0203	Nitrate	20	1.08	1.175	1.205	2.05	3.35	4	6.5	6.8
Dunstan	F41/0300	Nitrate	20	0.71	0.855	0.87	1.14	1.49	1.515	1.79	2
Dunstan	F41/0437	Nitrate	17	2.235	2.39	2.4	2.5	2.6	2.61	2.865	2.9

FMU	Bore	Analyte	#	Q5	Q20	Q25	Median	Q75	Q80	Q95	AnnMax
Dunstan	F41/0438	Nitrate	40	0.044	0.0625	0.0765	0.1085	0.169	0.1855	0.2875	2.6
Dunstan	G40/0175	Nitrate	19	0.8545	0.863	0.875	0.91	0.9625	0.977	1.071	1.08
Dunstan	G40/0367	Nitrate	20	0.16395	1.2825	1.44	1.595	1.73	1.75	1.98	2.1
Dunstan	G40/0411	Nitrate	20	3.35	4.2	4.3	5.25	7.75	8.2	9.4	9.9
Dunstan	G40/0415	Nitrate	18	0.02242	0.0375	0.042	0.0555	0.076	0.0778	0.244	0.33
Dunstan	G40/0416	Nitrate	18	0.288	0.36	0.36	0.435	0.49	0.49	0.576	0.58
Dunstan	G41/0211	Nitrate	16	1.073	1.104	1.12	1.145	1.19	1.193	1.321	1.36
Dunstan	G41/0487	Nitrate	7	0.28	0.289	0.2925	0.31	0.31	0.312	0.33	0.33
Lower Clutha	G44/0127	Arsenic	18	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.000035
Lower Clutha	H46/0144	Arsenic	18	0.01363	0.01633	0.0166	0.01705	0.0175	0.01759	0.01832	0.0184
Lower Clutha	G44/0127	E-Coli	18	0.11779	0.16535	0.18484	0.32631	0.59832	0.68373	9.4	13
Lower Clutha	H46/0144	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Lower Clutha	G44/0127	Nitrate	18	2.28	2.62	2.8	3.35	3.9	4.44	5.34	5.7
Lower Clutha	H46/0144	Nitrate	18	0.00002	0.00007	0.0001	0.00034	0.00162	0.00196	0.0106	0.011
Manuherekia	G41/0254	Arsenic	20	0.00024	0.00028	0.00029	0.00037	0.0005	0.00054	0.00072	0.00076
Manuherekia	G42/0123	Arsenic	20	0.00009	0.00011	0.00012	0.00018	0.00029	0.00033	0.00051	0.0005599
Manuherekia	G42/0290	Arsenic	20	0.00013	0.00015	0.00016	0.00022	0.00032	0.00035	0.00049	0.0005291
Manuherekia	G46/0152	Arsenic	20	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000975
Manuherekia	G41/0254	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	3.25	6
Manuherekia	G42/0123	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Manuherekia	G42/0290	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Manuherekia	G46/0152	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Manuherekia	G41/0254	Nitrate	20	2.95	3.4	3.6	4.1	4.55	4.65	5.55	5.8
Manuherekia	G42/0123	Nitrate	20	0.84	0.93	0.95	1.045	1.165	1.175	1.225	1.23
Manuherekia	G42/0290	Nitrate	20	1.985	2.2	2.2	2.3	2.3	2.4	2.85	2.9
Manuherekia	G46/0152	Nitrate	20	0.925	0.99	1.005	1.1	1.17	1.205	1.35	1.36
North Otago	J41/0008	Arsenic	20	0.00022	0.00023	0.00023	0.00025	0.00026	0.00027	0.00028	0.0002804
North Otago	J41/0249	Arsenic	14	0.00075	0.00079	0.00081	0.00089	0.00098	0.00101	0.00109	0.0011
North Otago	J41/0317	Arsenic	20	0.00014	0.00015	0.00016	0.00017	0.00019	0.00019	0.0002	0.0002072
North Otago	J41/0442	Arsenic	21	0.0003	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0571	Arsenic	21	0.0003	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0576	Arsenic	20	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00004	0.00005
North Otago	J41/0586	Arsenic	21	0.0003	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0762	Arsenic	15	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0764	Arsenic	18	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/0771	Arsenic	18	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J41/1403	Arsenic	8	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
North Otago	J42/0126	Arsenic	19	0.00015	0.00016	0.00017	0.00018	0.0002	0.0002	0.00022	0.000219
North Otago	J43/0006	Arsenic	18	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008
North Otago	J41/0008	E-Coli	19	0.5	0.5	0.5	0.5	0.5	1.55	21.6	27
North Otago	J41/0249	E-Coli	14	0.5	0.5	0.5	0.5	0.5	0.5	34	42
North Otago	J41/0317	E-Coli	20	0.29273	0.44049	0.50021	1	16.5	28	111.5	135
North Otago	J41/0442	E-Coli	21	0.5	0.5	0.5	0.5	0.575	1.16	2.45	3
North Otago	J41/0571	E-Coli	21	0.5	0.5	0.5	0.5	0.5	0.5	1.79	3
North Otago	J41/0576	E-Coli	20	0.5	0.5	0.5	0.5	1.5	2.5	76	115
North Otago	J41/0586	E-Coli	21	0.5	0.5	0.5	0.5	0.5	0.5	2.8	5
North Otago	J41/0762	E-Coli	14	0.5	0.5	0.5	0.5	0.5	0.5	233	291
North Otago	J41/0764	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
North Otago	J41/0771	E-Coli	17	0.25	0.25	0.25	0.25	0.25	0.25	1	1
North Otago	J41/1403	E-Coli	8	0.5	0.55	0.75	4	11	11.8	30	30
North Otago	J42/0126	E-Coli	19	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
North Otago	J43/0006	E-Coli	17	0.5	0.5	0.5	0.5	0.5	0.5	1	1

FMU	Bore	Analyte	#	Q5	Q20	Q25	Median	Q75	Q80	Q95	AnnMax
North Otago	J41/0008	Nitrate	20	17	25	25.5	26	27.5	28	29	29
North Otago	J41/0249	Nitrate	14	1.016	2.015	2.4	4.2	4.5	4.57	4.9	4.9
North Otago	J41/0317	Nitrate	20	3.95	4.45	4.75	5.75	6.4	6.5	8.5	8.6
North Otago	J41/0442	Nitrate	21	0.22585	0.418	0.4525	0.53	0.6925	0.727	1.013	1.09
North Otago	J41/0571	Nitrate	21	3.365	3.74	3.8	4.6	5.15	5.3	5.835	6
North Otago	J41/0576	Nitrate	20	5.7	5.95	6	6.4	7.55	7.65	7.85	7.9
North Otago	J41/0586	Nitrate	21	5.365	5.98	6.1	6.8	7.225	7.3	7.635	7.8
North Otago	J41/0762	Nitrate	15	0.09075	0.43	0.97	4.8	10.85	11.45	13.275	13.5
North Otago	J41/0764	Nitrate	19	1.6775	2.13	2.25	3.1	3.575	3.74	4.41	4.5
North Otago	J41/0771	Nitrate	18	9.06	10.62	10.8	11.6	13.4	13.67	15.02	15.5
North Otago	J41/1403	Nitrate	8	9.3	9.68	10.4	11.75	13.7	14.5	15.9	15.9
North Otago	J42/0126	Nitrate	19	17.725	19.2	19.2	19.7	19.975	20.7	21.55	22
North Otago	J43/0006	Nitrate	18	0.258	0.328	0.4	0.645	0.82	0.82	1.092	1.1
Roxburgh	G43/0009	Arsenic	26	0.00012	0.00013	0.00013	0.00015	0.00016	0.00016	0.0002	0.0003
Roxburgh	G43/0072	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0032	0.0059
Roxburgh	G43/0224a	Arsenic	25	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007
Roxburgh	G43/0224b	Arsenic	25	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006
Roxburgh	G43/0009	E-Coli	25	0.5	0.5	0.5	0.5	0.5	0.5	2.1	6
Roxburgh	G43/0072	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Roxburgh	G43/0224a	E-Coli	24	0.5	0.5	0.5	0.5	0.5	0.5	6.1	18
Roxburgh	G43/0224b	E-Coli	24	0.5	0.5	0.5	0.5	0.5	0.5	0.65	1
Roxburgh	G43/0009	Nitrate	26	4.24	4.47	4.5	4.75	5	5.3	5.86	6.5
Roxburgh	G43/0072	Nitrate	20	3.45	3.7	3.8	4.45	5.1	5.15	5.45	5.5
Roxburgh	G43/0224a	Nitrate	25	6.9375	7.775	7.8	8.4	10.15	10.3	10.775	11.6
Roxburgh	G43/0224b	Nitrate	25	7.5875	7.85	7.9375	8.3	8.725	8.9	9.45	9.9
Taieri	H42/0213	Arsenic	20	0.00029	0.00067	0.00081	0.002	0.00395	0.0044	0.0083	0.0096
Taieri	H42/0214	Arsenic	19	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.000075
Taieri	H43/0132	Arsenic	19	0.00019	0.00025	0.00028	0.00045	0.00084	0.00098	0.00169	0.002
Taieri	H44/0007	Arsenic	11	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.0000675
Taieri	I44/0495	Arsenic	20	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.000055
Taieri	I44/0519	Arsenic	20	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Taieri	I44/0821	Arsenic	20	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.0000275
Taieri	I44/0964	Arsenic	13	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Taieri	H42/0213	E-Coli	20	0.5	0.5	0.5	0.5	0.75	1	655.5	1300
Taieri	H42/0214	E-Coli	18	0.5	0.5	0.5	0.5	1	1	49	79
Taieri	H43/0132	E-Coli	18	0.5	0.5	0.5	0.5	0.5	0.5	380.5298	632.88303
Taieri	H44/0007	E-Coli	11	0.5	0.5	0.5	0.5	0.875	5.8	118.65	124
Taieri	I44/0495	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	11.5	22
Taieri	I44/0519	E-Coli	20	0.00201	0.00635	0.00911	0.05237	0.63403	1	34	66
Taieri	I44/0821	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Taieri	I44/0964	E-Coli	13	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Taieri	H42/0213	Nitrate	20	0.00147	0.00275	0.00325	0.01925	0.0735	0.1055	0.225	0.23
Taieri	H42/0214	Nitrate	19	3.735	4.06	4.2	4.5	5.6	6.26	7.265	7.4
Taieri	H43/0132	Nitrate	19	0.34593	0.777	0.91	1.51	1.695	1.741	4.934	7.4
Taieri	H44/0007	Nitrate	11	0.0319	0.22	0.22	0.23	0.2375	0.24	0.24	0.24
Taieri	I44/0495	Nitrate	20	0.00064	0.00151	0.00186	0.00606	0.0915	0.1465	0.38	0.38
Taieri	I44/0519	Nitrate	20	1.8	2.85	2.9	3.15	3.4	3.55	3.75	3.8
Taieri	I44/0821	Nitrate	20	5.15	5.4	5.4	5.7	5.95	6.05	6.35	6.4
Taieri	I44/0964	Nitrate	13	1.473	1.55	1.55	1.57	1.625	1.69	1.734	1.74

FMU	Bore	Analyte	#	Q5	Q20	Q25	Median	Q75	Q80	Q95	AnnMax
Upper Lakes	E41/0182	Arsenic	12	0.744	0.789	0.795	0.825	0.875	0.89	0.908	0.91
Upper Lakes	E41/0183	Arsenic	12	0.00069	0.00107	0.0011	0.0013	0.00155	0.00171	0.00333	0.0035
Upper Lakes	E41/0184	Arsenic	12	0.1602	0.1647	0.17	0.182	0.193	0.196	0.1996	0.2
Upper Lakes	E41/0185	Arsenic	12	0.00222	0.00258	0.00335	0.0053	0.0079	0.00868	0.0166	0.0171
Upper Lakes	F42/0113	Arsenic	20	0.00615	0.0077	0.00785	0.0082	0.00925	0.00965	0.0109	0.0116
Upper Lakes	E41/0182	E-Coli	12	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Upper Lakes	E41/0183	E-Coli	12	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Upper Lakes	E41/0184	E-Coli	12	0.25	0.25	0.25	0.25	0.25	0.25	0.925	1
Upper Lakes	E41/0185	E-Coli	12	0.5	0.5	0.5	0.5	0.5	0.5	4.55	5
Upper Lakes	F42/0113	E-Coli	20	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Upper Lakes	E41/0182	Nitrate	12	0.0005	0.0005	0.0005	0.0005	0.00079	0.00108	0.00182	0.0019
Upper Lakes	E41/0183	Nitrate	12	0.1089	0.1557	0.161	0.26	0.365	0.388	0.694	0.71
Upper Lakes	E41/0184	Nitrate	12	0.0005	0.0005	0.0005	0.0005	0.001	0.00113	0.00311	0.0032
Upper Lakes	E41/0185	Nitrate	12	0.381	1.056	1.55	2.25	3.75	3.91	4.18	4.2
Upper Lakes	F42/0113	Nitrate	20	0	0.00003	0.00005	0.00047	0.00575	0.00782	0.128	0.21

13 Appendix 3

13.1 State Assessment Methods

13.1.1 Handling censored values

Censored values were replaced by imputation for the purposes of calculating the compliance statistics. Left censored values (values below the detection limit(s)) were replaced with imputed values generated using ROS (Regression on Order Statistics; Helsel, 2012), following the procedure described in Larned *et al.* (2015). The ROS procedure produces estimated values for the censored data that are consistent with the distribution of the uncensored values and can accommodate multiple censoring limits. When there are insufficient non-censored data to evaluate a distribution from which to estimate values for the censored observations, censored values are replaced with half of their reported value.

Censored values above the detection limit were replaced with values estimated using a procedure based on 'survival analysis' (Helsel, 2012). A parametric distribution is fitted to the uncensored observations and then values for the censored observations are estimated by randomly sampling values larger than the censored values from the distribution. The survival analysis requires a minimum number of observations for the distribution to be fitted; hence in the case that there were fewer than 24 observations, censored values above the detection limit were replaced with 1.1* the detection limit. The supplementary file outputs provide details about whether and how imputation was conducted for each site by criteria assessment.

13.1.2 Time period for assessments

When grading sites based on NPS-FM attributes, it is generally good practice to define consistent time periods for all sites and to define the acceptable proportion of missing observations (i.e., data gaps) and how these are distributed across sample intervals so that site grades are assessed from comparable data. The time period, acceptable proportion of gaps and representation of sample intervals by observations within the time period are commonly referred to as site inclusion or filtering rules (e.g., Larned *et al.*, 2018).

The grading assessments were made for the 5-year time-period to end of June 2022. The start and end dates for this period were determined by the availability of quality assured data, reporting time periods and consideration of statistical precision of the compliance statistics used in the grading of sites. The statistical precision of the compliance statistics depends on the variability in the water quality observations and the number of observations. For a given level of variability, the precision of a compliance statistic increases with the number of observations. This is particularly important for sites that are close to a threshold defined by an attribute band because the confidence that the assessment of state is 'correct' (i.e., that the site has been correctly graded) increases with the precision of the compliance statistics (and therefore with the number of observations). As a general rule, the rate of increase in the precision of compliance statistics slows for sample sizes greater than 30 (i.e., there are diminishing returns on increasing sample size with respect to precision (and therefore confidence in the assigned grade) above this number of observations; McBride, 2005).

In this study, a period of five years represented a reasonable trade-off for most of the attributes because it yielded a sample size of 30 or more observations for many sites and attribute combinations. The five-year period for the state analyses is also consistent with national water-quality state analyses (e.g., Larned *et al.*, 2015, 2018), as well as guidance for a number of specific attributes within the NPS-FM (2020). Where no guidance was provided, a default filtering rule that required at least 30 observations in the 5-year time period was used. For annually sampled macroinvertebrate variables, which are generally less variable than physical or chemical water quality variables, the nominated minimum sample size requirement was reduced to 5.

For grading the suspended fine sediment and *E. coli* attributes, the NPS-FM requires 60 observations over 5 years. For monthly monitoring, this requires collection of all monthly observations (i.e., no missing data). All ORC records have at least one missing observation associated with the national COVID-19 lockdown in April 2020, and so no sites met this requirement for the selected time periods. For this study, the rule to require observations for 90% of months over the 5-year period (54 observations) was relaxed. Both this relaxation and default sample number are subjective choices. Therefore, within the supplementary files state assessments for all sites are provided regardless of whether they meet the filtering rules, as well as details about the number of observations and number of years with observations.

13.1.3 Calculation of water clarity

The NPS-FM suspended fine sediment attribute is based on observations of visual clarity. ORC river monitoring programme does not include visual clarity but does routinely collect turbidity observations. Franklin et al. (2020) define a relationship between median clarity and median turbidity, based on a regression of 582 sites across New Zealand as:

$$\ln(CLAR) = 1.21 - 0.72 \ln(TURB)$$

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 were calculated first, and then calculated median clarity using the above relationship in order to grade the sites against the NPS-FM suspended fine sediment attribute.

Sites operated by NIWA as part of the national monitoring network include observations of clarity, and therefore for these sites performance against the NPS-FM suspended fine sediment attribute has been evaluated with the observed (rather than modelled) clarity values.

13.1.4 pH Adjustment of Ammonia

Ammonia is toxic to aquatic animals and is directly bioavailable. When in solution, ammonia occurs in two forms: the ammonium cation (NH_4^+) and unionised ammonia (NH_3); the relative proportions of the forms are strongly dependent on pH (and temperature). Unionised ammonia is significantly more toxic to fish than ammonium, hence the total ammonia toxicity increases with increasing pH (and/or temperature) (ANZECC, 2000). Standards related to ammoniacal-N concentrations in freshwater typically require a correction to account for pH and temperature. A pH correction to NH_4-N was applied to adjust values to equivalent pH 8 values, following the methodology outlined in Hickey (2014). For pH values outside the range of the correction relationship (pH 6-9), the maximum (pH<6) and minimum (pH>9) correction ratios were applied.

13.1.5 Evaluation of compliance statistics

For compliance statistics specified and 'annual' (maximum, median, 95th percentile) in the NPS-FM, have been calculated over the entire 5-year state period.

The results from the state analysis are provided in the supplementary file: ORCGWState_072017to062022, ORCLakeState_072017to062022, ORCRiverState_072017to062022. Provided on the ORC website https://www.orc.govt.nz/plans-policies-reports/reports-and-publications/water-quality

13.2 Trend Assessment Methods

13.2.1 Sampling dates, seasons, and time periods for analyses

In trend assessments, there are several reasons why it is generally important to define the trend period and seasons and to assess whether the observations are adequately distributed over time. First, because variation in many water quality variables is associated with the time of the year or 'season', the robustness of trend assessment is likely to be diminished if the observations are biased to certain times of the year. Second, a trend assessment will always represent a time period; essentially that defined by the first and last observations. The assessment's characterisation of the change in the observations over the time period is likely to be diminished if the observations are not reasonably evenly distributed across the time period. For these reasons, important steps in the data compilation process include specifying the seasons, the time period, and ensuring adequately distributed data.

Monitoring programs are generally designed to sample with a set frequency, (e.g., monthly, quarterly). The trend analysis 'season' is generally specified to match this sampling frequency (e.g., seasons are months, bi-months, or quarters). There is therefore generally an observation for each sample interval (i.e., each season, such as month or quarter, within each year). Sampling frequency for some variables is annually. For example, annual sampling is common for biological sampling such as macro-invertebrates. In this case the 'season' is specified by the year.

Two common deviations from the prescribed sampling regime are (1) the collection of more than one observation in a sample interval (e.g., two observations within a month) and (2) a change in sampling interval within the time period. Both of these deviations occurred in the ORC datasets, particularly type (2), as there was a network wide change in sampling frequency in 2013, largely moving from bi-monthly to monthly monitoring for rivers, and from biannual to quarterly for groundwater in 2011. For type (1) deviations, the median within each sample interval was taken. For type (2) deviations, the coarser sampling interval to define seasons was used. For the part of the record with a higher frequency, the observations in each season were defined by taking the observation closest to the midpoint of the coarser season. The reason for not using the median value in this case is that it will induce a trend in variance, which will invalidate the null distribution of the test statistic (Helsel *et al.*, 2020).

The trend at all sites was characterised by the rate of change of the central tendency of the observations of each variable through time. Because water quality is constantly varying through time, the evaluated rate of change depends on the time-period over which it is assessed (e.g., Ballantine *et al.*, 2010; Larned *et al.*, 2016). Therefore, trend assessments are specific for a given period of analysis. Trend periods of 10- and 20 years were evaluated for rivers, five-, 10- and 20- years for lakes, and trend periods of five and 10 years for groundwater.

For a regional study that aims to allow robust comparison of trends between sites and to provide a synoptic assessment of trends across a whole region, such as the present study, it is important that trends are commensurate in terms of their statistical power and representativeness of the time period. In these types of studies, it is general practice to define consistent time periods (i.e., trend duration and start date) so that all sites are subjected to the same conditions (i.e., equivalent political, climate, economic conditions). It is also general practice to define the acceptable proportion of gaps and how these are distributed across sample intervals so that the reported trends are assessed from comparable data. The acceptable proportion of gaps and representation of sample intervals by observations within the time period are commonly referred to as site inclusion or filtering rules (e.g., Larned *et al.*, 2018) but this is also termed 'site screening criteria' and 'completeness criteria'.

There are no specific data requirements or filtering rules for trend assessments performed over many sites and variables such as the present study. The definition of filtering rules is complicated by a trade-off: more restrictive rules increase the robustness of the individual trend analyses but will generally exclude a larger number of sites thereby reducing spatial coverage. In general, this trade-off is also affected by the duration of trend period. Steadily increasing monitoring effort in New Zealand over the last two decades means that shorter and more recent trend periods will generally have a larger number of eligible sites.

The application of filtering rules for variables that are measured at quarterly intervals or more frequently requires two steps. First, retain sites for which observations are available for at least *X*% of the years in the time period. Second, retain sites for which observations are available for at least *Y*% of the sample intervals. For variables that are measured annually such as MCI, the filtering rules are applied by retaining sites for which values are available for at least *X*% of the years in the trend period.

In this study, we used filtering rules applied by Larned et al. (2019), which set X and Y to 80%. Further, the definition of seasons was flexible in order to maximise the number of sites that were included. If the site failed to comply with filter rule (2) when seasons were set as months, a coarsening of the data to quarterly seasons was applied and the filter rule (2) was reassessed. If the data then complied with filter rule (2), the trend results based on the course (i.e., quarterly) seasons were retained for reporting. For groundwater sites we allowed further coarsening, to preferentially biannual (a historical monitoring frequency) or to an annual 'season' if the data did not comply with the filter rule for biannual. This is because much of the historic data was sampled at a very low frequency, and it is expected that groundwater water quality is less temporally variable than surface water quality.

It is noted that the filtering rules imply a tolerance of variable levels of statistical power and temporal representativeness across the sites that were included in the analysis. In these analyses, we also included bimonths as an intermediate coarseness between months and quarters, and biannual (only for groundwater), as these are historically used sampling intervals for ORC.

The trends presented in this study were for 10- and 20-year periods ending on 30 June 2022. For groundwater and lakes, we have additionally included 5-year trend assessments to provide some information about trends at the sites that have been established in recent past, which have short records (i.e., < 10 years). We advise that some caution is applied with the interpretation of trends over such short time periods. It has been demonstrated that the shorter the time period over which a river water quality trend is assessed, the greater the level of influence of climatic variation on the assessed trend (Snelder *et al.*, 2021).

13.2.2 Handling censored values

For several water-quality variables, true values are occasionally too low or too high to be measured with precision. These measurements are called censored values. The 'detection limit' is the lowest value that can be measured by an analytical method accurately (either a laboratory measurement or a measurement made in the field) and the 'reporting limit' is the greatest value of a variable that can be measured. Water-quality datasets from New Zealand rivers and lakes often include DRP, TP and NH4N measurements that are censored because they are below detection limits, and ECOLI and CLAR measurements that are censored because they are above reporting limits.

Censored values are managed in a special way by the non-parametric trend assessment methods. It is therefore important that censored values are correctly identified in the data. Detection limits or reporting limits that have changed through the trend time period (often due to analytical changes) can induce trends that are associated with the changing precision of the measurements rather than actual changes in the variable. This possibility needs to be accounted for in the trend analysis and this is another reason that it is important that censored values are correctly identified in the data.

We applied a 'high-censor' filter in the trend assessments to minimise biases that might be introduced due to changes in detection limits through the trend assessment period. The high-censor filter identifies the highest detection limit for each water quality variable in the trend assessment period and replaces all observations below this level with the highest detection limit and identifies these as censored values. This procedure generally had limited impact on the trend assessment, with the exception of Ammoniacal Nitrogen, as there was a significant shift in the detection limit, and most of the observations were generally very small (of similar magnitude to the detection limit).

13.2.3 Seasonality assessment

For many site/variable combinations, observations vary systematically by season (e.g., by month or quarter). In cases where seasons are a major source in variability, accounting for the systematic seasonal variation should increase the statistical power of the trend assessment (i.e., increase the confidence in the estimate of direction and rate of the trend). The purpose of a seasonality assessment is to identify whether seasons explain variation in the water quality variable. If this is true, then it is appropriate to use the seasonal versions of the trend assessment procedures at the trend assessment step.

We evaluated seasonality using the Kruskall-Wallis multi-sample test for identical populations. This is a non-parametric ANOVA that determines the extent to which season explains variation in the water quality observations. Following Hirsch *et al*. (1982), we identified site/variable combinations as being seasonal based on the *p*-value from the Kruskall-Wallis test with $\alpha=0.05$. For these sites/variable combinations, subsequent trend assessments followed the 'seasonal' variants.

The choice of α is subjective and a value of 0.05 is associated with a very high level of certainty (95%) that the data exhibit a seasonal pattern. In our experience there are generally diminishing differences between the seasonal and non-seasonal trend assessments for *p*-values values larger than 0.05 (Helsel *et al*., 2020).

13.2.4 Analysis of trends

The purpose of trend assessment is to evaluate the direction (i.e., increasing or decreasing) and rate of the change in the central tendency of the observed water quality values over the period of analysis (i.e., the trend). Because the observations represent samples of the water quality over the period of analysis, there is uncertainty about the conclusions drawn from their analysis. Therefore, statistical models are used to determine the direction and rate of the trend and to evaluate the uncertainty of these determinations.

Trends were evaluated using the LWPTrends functions in the R statistical computing software. A brief description of the theoretical basis for these functions is described below.

13.2.5 Trend direction assessment

The trend direction and the confidence in the trend direction were evaluated using either the Mann Kendall assessment or the Seasonal Kendall assessment. Although the non-parametric Sen slope regression also provides information about trend direction and its confidence, the Mann Kendall assessment is recommended, rather than Sen slope regression, because the former more robustly handles censored values.

The Mann Kendall assessment requires no *a priori* assumptions about the distribution of the data but does require that the observations are randomly sampled and independent (no serial correlation) and that there is a sample size of ≥ 8. Both the Mann Kendall and Seasonal Kendall assessments are based on calculating the Kendall *S* statistic, which is explained diagrammatically in Figure 68.

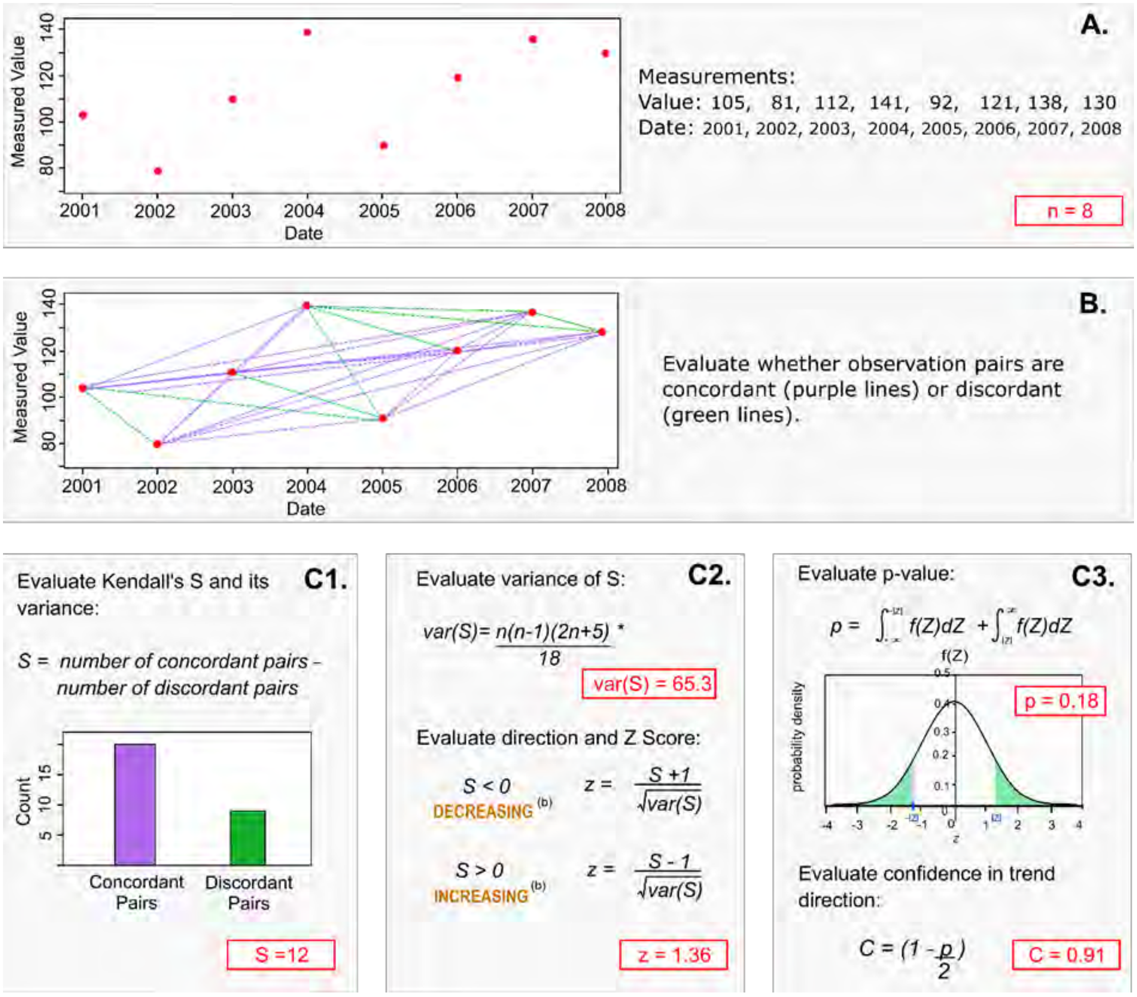

Figure 68. Pictogram of the steps taken in the trend direction assessment to calculate the Kendall S statistic and its confidence in trend direction. Notes: [a] the calculation of the variance in S has some adjustments to account for ties (numerically equal values) and censored values. Details of these adjustments can be found in (Helsel 2005, 2012). [b] There is a third alternative, where S=0. In this case C is 0.5, and the trend direction is classified as 'indeterminate'. Values of S equal to -1 or 1 will also result in a Z value of 0, a p-value of 1 and a C value of 0.5 and the trend direction is similarly classified as 'indeterminate'.

The Kendall *S* statistic is calculated by first evaluating the differences between all pairs of water quality observations (Figure 68, A and B). Positive differences are termed 'concordant' (i.e., the observations increase with increasing time) and negative differences are termed 'discordant' (i.e., the observations decrease with increasing time). The Kendall *S* statistic is the number of concordant pairs minus the number of discordant pairs (Figure 68, C1). The water quality trend direction is indicated by the sign of *S* with a positive or negative sign indicating an increasing or decreasing trend, respectively (Figure 68C2).

The seasonal version of the Kendall *S* statistic *S* is calculated in two steps. First, for each season, the *S* statistic is calculated in the same manner as shown in Figure 68 but for data pertaining to observations in each individual season. Second, *S* is the sum of values over all seasons ($S = \sum_1^n S_i$), where S_i is the number of concordant pairs minus the number of discordant pairs in the i^{th} season and n is the number of seasons. The variance of S is calculated for each season and then summed over all seasons.

The sign (i.e., + or -) of the S statistic calculated from the sample represents the best estimate of the population trend direction but is uncertain (i.e., the direction of the population trend cannot be known with certainty). A continuous measure of confidence in the assessed trend direction can be determined based on the posterior probability distribution of S, the true (i.e., population) difference in concordant and discordant pairs (Snelder *et al.*, 2022). The posterior probability distribution of S is given by a normal distribution with mean of S and variance of *var(S)*. The confidence in assessed trend direction can be evaluated as the proportion of the probability distribution that has the same sign as S.

In practice the integrals described above can be calculated by first transforming the value of $S = 0$ on the posterior probability distribution into a standard normal deviate, Z (panel C2). C is then calculated as area under the standard normal distribution to the left (Z>0) or right (Z<0) of the value of Z, using the quantile function for the normal distribution

The value C can be interpreted as the probability that the sign of the calculated value of S indicates the direction of the population trend (i.e., that the calculated trend direction is correct). The value C ranges between 0.5, indicating the sign of S is equally likely to be in the opposite direction to that indicated by the true trend, to 1, indicating complete confidence that the sign of S is the same as the true trend.

As the size of the sample (i.e., the number of observations) increases, confidence in the trend direction increases. When the sample size is very large, C can be high, even if the trend rate is very low. It is important therefore that C is interpreted correctly as the confidence in direction and not as the importance of the trend. As stated at the beginning of this section; both trend direction and the trend rate are relevant and important aspects of a trend assessment.

13.2.6 Assessment of trend rate

The method used to assess trend rate is based on non-parametric Sen slope regressions of water quality observations against time. The Sen slope estimator (SSE; Hirsch *et al.,* 1982) is the slope parameter of a non-parametric regression. SSE is calculated as the median of all possible inter-observation slopes (i.e., the difference in the measured observations divided by the time between sample dates).

The seasonal Sen slope estimator (SSSE) is calculated in two steps. First, for each season, the median of all possible inter-observation slopes is calculated in same manner as shown in Figure 69 but for data pertaining to observations in each individual season. Second, *SSSE* is the median of the seasonal values.

Uncertainty in the assessed trend rate is evaluated following a methodology outlined in Helsel and Hirsch (2002). To calculate the 100(1-α) % two-sided symmetrical confidence interval about the fitted slope parameter, the ranks of the upper and lower confidence limits are determined, and the slopes associated with these observations are applied as the confidence intervals.

The inter-observation slope cannot be definitively calculated between any combination of observations in which either one or both observations comprise censored values. Therefore, it is usual to remove the censor sign from the reported laboratory value and use just the 'raw' numeric component (i.e., <1 becomes 1) multiplied by a factor (such as 0.5 for left-censored and 1.1 for right-censored values). This ensures that in the Sen slope calculations, any left-censored observations are always treated as values that are less than their 'raw' values and right censored observations are always treated as values that are greater than their 'raw' values. The inter-observation slopes associated with the censored values are therefore imprecise (because they are calculated from the replacements). However, because the Sen slope is the median of all the inter-observation slopes, the Sen slope is unlikely to be affected by censoring when a small proportion of observations are censored. As the proportion of censored values increase, the probability that the Sen slope is affected by censoring increases. The outputs from the trend assessment provide an 'analysis note' to identify Sen Slopes where one or both of the observations associated with the median inter-observation slope is censored.

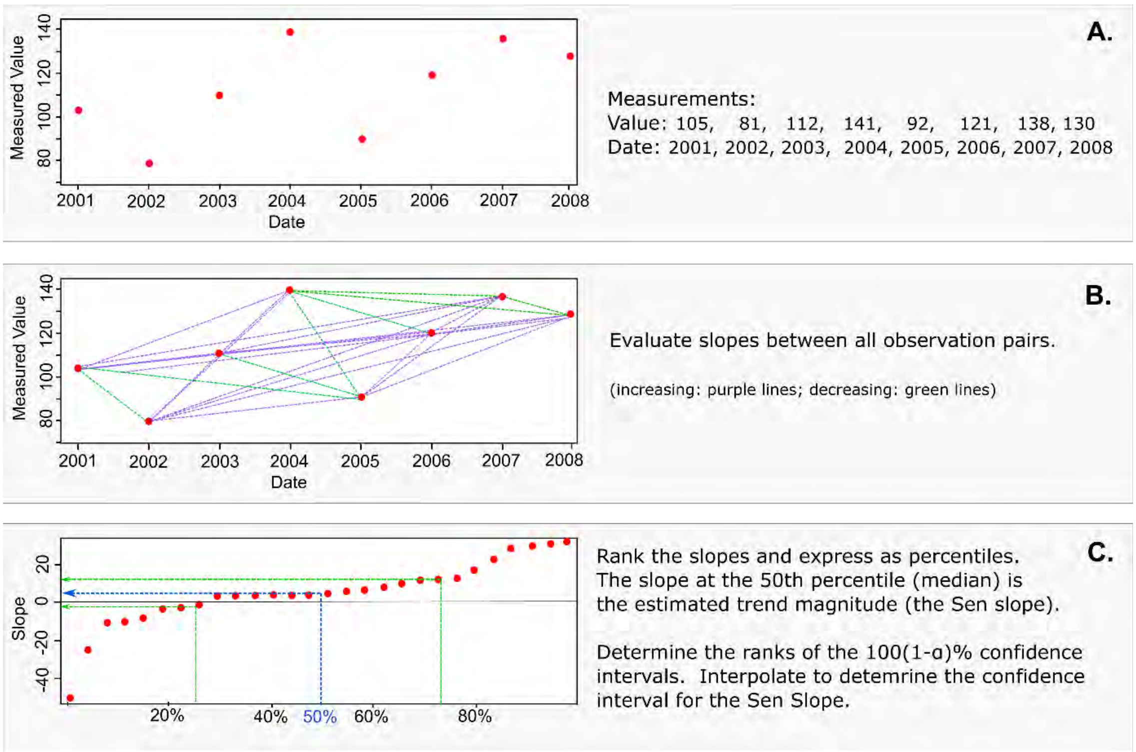

Figure 69 Pictogram of the calculation of the Sen slope, which is used to characterise trend rate.

13.2.7 Interpretation of trends

The trend assessment procedure used here facilitates a more nuanced inference than the 'yes/no' output corresponding to the chosen acceptable misclassification error rate. The confidence in direction (C) can be transformed into a continuous scale of confidence the trend was decreasing (C_d). For all trends with $S < 0$, $C_d = C$, and for all $S > 0$ a transformation is applied so that $C_d = 1\text{-}C$. 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 approach to presenting levels of confidence of the Intergovernmental Panel on Climate Change (IPCC; Stocker *et al.*, 2014) is one way of conveying the confidence of trend directions (Table 15). These same categorical levels of confidence were used to express the confidence that water quality was improving[14] for each site and variable in this report. Note, the confidence of degradation is the compliment of the confidence of improvement.

The trend for each site/variable combination was assigned a categorical level of confidence that the trend was decreasing according to its evaluated confidence. Improvement is indicated by decreasing trends for all the water quality variables in this study except for MCI, SQMCI, and ASPM (for which increasing trends indicate improvement). The aggregate proportion of sites were calculated for sites and for each variable and these values were plotted as colour coded bar charts. These charts provide a graphical representation of the proportions of improving and degrading trends at the levels of confidence indicated by the categories.

Table 15. Level of confidence categories used to convey the confidence that the trend (or step change) indicated improving water quality. The confidence categories are used by the Intergovernmental Panel on Climate Change (IPCC; Stocker et al., 2014).

Categorical level of confidence trend was decreasing	*Value of C_d (%)*
Virtually certain	0.99–1.00
Extremely likely	0.95–0.99
Very likely	0.90–0.95
Likely	0.67–0.90
About as likely as not	0.33–0.67
Unlikely	0.10–0.33
Very unlikely	0.05–0.10
Extremely unlikely	0.01–0.05
Exceptionally unlikely	0.0–0.01

Outputs from the trend analyses were also classified into four direction categories: improving, degrading, indeterminate, and not analysed. An increasing or decreasing trend category was assigned based on the sign of the S statistic from the Mann Kendall test. An indeterminate trend category was assigned when the Z score equalled zero. Trends were classified as 'not analysed' for two reasons:

1) When a large proportion of the values were censored (data has <5 non-censored values and/or <3 unique non-censored values). This arises because trend analysis is based on examining differences in the value of the variable under consideration between all pairs of sample occasions. When a value is censored, it cannot be compared with any other value and the comparison is treated as a 'tie' (i.e., there is no change in the variable between the two sample occasions). When there are many ties there is little information content in the data and a meaningful statistic cannot be calculated.
2) When there is no, or very little, variation in the data because this also results in ties. This can occur because laboratory analysis of some variables has low precision (i.e., values have few or no significant figures). In this case, many samples have the same value, and this then results in ties.

[14] Note the trend analysis outputs include a confidence of decreasing trend; the conversion of the trend confidence to improving (and its inverse, degrading) depends on whether decreasing represents improvement or degradation and varies between commonly used indicators of water quality.

13.3 LWP Output

The results from the analysis are provided in the supplementary file: ORC_River_GW_Lake_Trends_toJun2022_24Feb23.xlsx. There are worksheets for each of the water domain types (groundwater, lakes, rivers), A description of the data provided in these *sheets is provided in* Table 16

Table 16 Description of Supplementary Data: Trends

Column Name	Description
sID	Site ID
npID	Variable name
nObs	Number of observations
S	S-statistic
VarS	Variance
D	n * (n - 1)/2
tau	Kendall's tau
Z	Z-statistic
p	p-value for Mann-Kendall or Seasonal Kendall test
C	Confidence that trend direction is correct
Cd	Confidence that trend direction is decreasing
prop. censored	proportion of observations that are censored
prop.unique	proportion of observations that are unique
no.censorlevels	number of censor levels
Median	Median value for the time period
AnnualSenSlope	Annual Sen Slope (attribute units/year)
Sen_Lci	Lower confidence interval for annual sen slope
Sen_Uci	Upper confidence interval for annual sen slope
AnalysisNote	Relevant notes about the analysis
Percent.annual.change	Percent annual change in Sen slope
TrendDirection	The trend direction
Seasonal	TRUE if data is seasonal and Seasonal Kendall test performed
Freq	The sampling frequency used as seasons in the analysis (either monthly, bi-
Period	The time period of the trend assessment
EndYEar	The end year of the trend assessment
DecreasingConf	Categorical description of confidence of decreasing trend
ImprovementConf	Categorical description of confidence of improving trend

13.3.1 River data availability

Following the application of the filtering rules, the total number of sites that were included in the analyses was reduced, a summary of the site numbers that were included in the final trend assessment is presented in Table 17**.** Confidence that the trend direction indicated improving water quality, was mapped for the raw (with high censor filter) for the 10- and 20-year trend periods.

Table 17 River water quality variables, measurement units and site numbers for which 10- and 20-year trends (Raw, and Flow Adjusted FA) were analysed by this study.

Variable	Number of sites that complied with filtering rules (10-years)		Number of sites that complied with filtering rules (20-years)	
	Raw	FA	Raw	FA
Ammoniacal Nitrogen	50	32	34	18
Chlorophyll a	0	0	0	0
Dissolved Inorganic Nitrogen	0	0	0	0
Dissolved Reactive Phosphorus	50	32	33	18
E. coli	50	27	28	13
Nitrite/Nitrate Nitrogen	50	32	34	18
Total Nitrogen	50	32	33	18
Total Phosphorus	50	32	32	18
Turbidity	50	32	32	18

13.3.2 Evaluated trends

Timeseries plots of the evaluated trends are provided in the supplementary files: 10YearTrends_Rivers_hiCen02Feb23.pdf, 20YearTrends_Rivers_hiCen02Feb23.pdf.

13.4 Groundwater

13.4.1 Groundwater data availability

Following the application of the filtering rules the total number of sites that were included in the final analysis was reduced. A summary of the site numbers that were included in the final trend assessment is presented in Table 18.

Table 18 Groundwater quality variables, and site numbers that complied with the trend assessment filtering rules.

Variable	**Total number of monitoring sites**	**Number of sites that complied with filtering rules**		
		5-year	**10-year**	**20-year**
Ammoniacal Nitrogen	55	45	27	16
Arsenic Dissolved	55	45	27	0
Chloride	55	45	30	16
Dissolved Reactive Phosphorus	55	45	30	16
E-Coli MPN	55	45	18	3
Nitrate-N	55	45	27	0
Total Nitrogen	55	45	3	0
Total Phosphorus	55	45	3	0

13.4.2 Evaluated trends

Timeseries plots of the evaluated trends are provided in the supplementary files: 5YearTrends_GW_hiCen25Jan23.pdf , 10YearTrends_GW_hiCen25Jan23.pdf, 20YearTrends_GW_hiCen25Jan23.pdf.

13.5 Lakes

13.5.1 Lake Data Availability

Following the application of the filtering rules, the total number of sites that were included in the final analysis was reduced, a summary of the site numbers that were included in the final trend assessment is presented in Table 19.

Table 19 Lake water quality variables, measurement units and site numbers used in this study,

Variable	Total number of monitoring sites	Number of sites that complied with filtering rules		
		5-year	10-year	20-year
Ammoniacal Nitrogen	27	19	5	3
Chlorophyll a	26	23	3	2
Dissolved Reactive Phosphorus	27	25	5	3
E. coli	19	16	3	3
Nitrite/Nitrate Nitrogen	27	30	5	3
Secchi depth	31	18	0	0
Total Nitrogen	27	30	5	3
Total Phosphorus	27	29	4	3
Turbidity	20	9	3	3

13.5.2 Evaluated trends

Timeseries plots of the evaluated trends are provided in the supplementary files: 5YearTrends_LakesHICEN_03Mar23.pdf, 10YearTrends_LakesHICEN_03Mar23.pdf and 20YearTrends_LakesHICEN_03Mar23.pdf.