Taranaki Regional Council

AGENDA
Policy & Planning

Tuesday 30 August 2022, 10.30am

Policy and Planning Committee

30 August 2022 10:30 AM

Agenda Topic — Page

Taranaki Regional Council

AGENDA
Policy & Planning

Purpose of Policy and Planning Committee meeting

This committee attends to all matters of resource management, biosecurity and related environment policy.

Responsibilities

Prepare and review regional policy statements, plans and strategies and convene as a Hearing Committee as and when required for the hearing of submissions.

Monitor plan and policy implementation.

Develop biosecurity policy.

Advocate, as appropriate, for the Taranaki region.

Other policy initiatives.

Endorse submissions prepared in response to the policy initiatives of organisations.

Membership of Policy and Planning Committee

Councillor C L Littlewood (Chairperson)
Councillor M G Davey
Councillor D H McIntyre
Councillor E D Van Der Leden
Councillor M P Joyce (ex officio)
Councillor N W Walker (Deputy Chairperson)
Councillor M J McDonald
Councillor C S Williamson
Councillor D N MacLeod (ex officio)

Representative Members

Councillor C Young (STDC)
Councillor G Boyde (SDC)
Ms B Bigham (Iwi Representative)
Councillor S Hitchcock (NPDC)
Mr P Moeahu (Iwi Representative)
Ms L Tester (Iwi Representative)

Health and Safety Message

Emergency Procedure

In the event of an emergency, please exit through the emergency door in the committee room by the kitchen.

If you require assistance to exit please see a staff member.

Once you reach the bottom of the stairs make your way to the assembly point at the birdcage. Staff will guide you to an alternative route if necessary.

Earthquake

If there is an earthquake - drop, cover and hold where possible. Please remain where you are until further instruction is given.

MEMORANDUM
Policy & Planning

Date	30 August 2022
Subject:	**Confirmation of Minutes - 26 July 2022**
Approved by:	A D McLay, Director - Resource Management
	S J Ruru, Chief Executive
Document:	3096790

Recommendations

That the Policy and Planning Committee of the Taranaki Regional Council:

a) takes as read and confirms the minutes and resolutions of the Policy and Planning Committee of the Taranaki Regional Council held in the Taranaki Regional Council Boardroom, 47 Cloten Road, Stratford on Tuesday 26 July 2022 at 10.30am

b) notes the recommendations therein were adopted by the Taranaki Regional Council on Tuesday 9 August 2022.

Matters arsing

Appendices/Attachments

Document 3085589: Minutes Policy and Planning Committee 26 July 2022

MINUTES
Policy & Planning

Date 26 July 2022, 10.30am

Venue: Taranaki Regional Council Boardroom, 47 Cloten Road, Stratford

Document: 3085589

Members	Councillor	C L Littlewood	Committee Chairperson
	Councillor	M J McDonald	
	Councillor	D H McIntyre	
	Councillor	E D Van Der Leden	
	Councillor	M P Joyce	*ex officio zoom*
	Councillor	D N MacLeod	*ex officio zoom*
Representative Members	Councillor	C Young	South Taranaki District Council
	Councillor	G Boyde	Stratford District Council
	Ms	B Bigham	Iwi Representative *zoom*
	Ms	L Tester	Iwi Representative
	Mr	P Moeahu	Iwi Representative *zoom*
	Mr	P Muir	Federated Farmers
Attending	Councillor	D L Lean	Taranaki Regional Council
	Mr	S J Ruru	Chief Executive
	Mr	A D McLay	Director - Resource Management
	Ms	A J Matthews	Director – Environment Quality
	Mr	D R Harrison	Director – Operations *zoom*
	Mr	M J Nield	Director – Corporate Services
	Mr	C Spurdle	Planning Manager
	Mr	R Phipps	Science and Technology Manager
	Ms	J Harvey	Scientist - Groundwater
	Ms	J Allen	Consents Manager
	Mr	B Pope	Compliance Manager
	Mr	P Davidson	Team Leader Compliance
	Mr	C Wadsworth	Strategy Lead
	Ms	J Harvey	Scientist - Groundwater
	Ms	K Holland	Team Leader Communications
	Mr	C Woollin	Communications Adviser
	Miss	A Campbell	Policy Analyst
	Miss	B Mestrom	Policy Analyst
	Mr	S Ellis	Environment Services Manager
	Miss	L Davidson	Executive Assistant *zoom*

Two members of the media and two members of the public.

Councillor C L Littlewood Acknowledged sudden passing of Peter de Rungs, WITT.

Apologies Apologies were received and sustained from Councillors M G Davey, N W Walker, C S Williamson & S Hitchcock.
Littlewood/McIntyre

Notification of Late Items RMA reform update.
Te Uru Kahika – 3 Waters programme and submission.

1. Confirmation of Minutes – 7 June 2022

Resolved

That the Policy and Planning Committee of the Taranaki Regional Council:

a) takes as read and confirms the minutes and resolutions of the Policy and Planning Committee of the Taranaki Regional Council held in the Taranaki Regional Council Boardroom, 47 Cloten Road, Stratford on Tuesday 7 June 2022 at 10.30am

b) notes the recommendations therein were adopted by the Taranaki Regional Council on Tuesday 28 June 2022.

McDonald/Young

Matters arising

1.1 It was requested that Officers explore a Climate Change page on the TRC website and upload the Climate Change report from NIWA on here.

2. Essential Freshwater Implementation Review

2.1 Mr C Wadsworth, Strategy Lead, spoke to the memorandum to provide the Committee with a Freshwater implementation programme update.

2.2 The national level tool for submitting nitrogen information is not ready yet and a sector developed electronic tool will be available in August. There will also be an option for, farmers to submit their nitrogen information to Council manually.

2.3 The focus points for the final quarter of the year are:

- FW vision and the incorporation of Te Mana o Te Wai.
- Water Quality Accounting.
- Increased level of engagement with Iwi.

2.4 It was clarified that the Intensive Winter Grazing (IWG) aerial mapping exercise was recently undertaken by MfE, using satellite imagery, and represents a snap shot in time. The information was then provided to regional councils who identified which farms have IWG. Land Management Officers then visit those properties and provide advice and information to those farmers to ensure they are complying with the national environmental standard.

Recommended

That the Taranaki Regional Council:

a) receives the Memorandum on Freshwater implementation programme.

Van Der Leden/Boyde

3. Submission on the exposure draft of proposed changes to the National Policy Statement for Freshwater Management and the National environmental Standards for Freshwater

3.1 Mr C Spurdle, Planning Manager, spoke to the memorandum to seek Members' endorsement on the submission on the exposure draft of proposed changes to the National Policy Statement for Freshwater Management and the National Environmental Standards for Freshwater .

Recommended

That the Taranaki Regional Council:

a) receives the memorandum Submission on the exposure draft of proposed changes to the National Policy Statement for Freshwater Management and the National Environmental Standards for Freshwater

b) endorses the submission on the exposure drafts

c) determines that this decision be recognised not significant in terms of section 76 of the Local Government Act 2002

d) determines that it has complied with the decision-making provisions of the Local Government Act 2002 to the extent necessary in relation to this decision; and in accordance with section 79 of the Act, determines that it does not require further information, further assessment of options or further analysis of costs and benefits, or advantages and disadvantages prior to making a decision on this matter.

McDonald/Van Der Leden

5. Groundwater Quantity – State of Environment 2017 - 2020

5.1 Ms J Harvey, Scientist – Groundwater, spoke to the memorandum and gave a presentation to provide the Committee with an overview of the findings and recommendations of the report Groundwater Quantity - State of the Environment Monitoring Triennial Report 2017-2020.

5.2 It was noted that Council would like to increase the number of monitoring bores, especially within the eastern parts of Taranaki, to improve understanding of areas where there is limited data and information.

5.3 Water allocation in the region is well within current allocation limits and monitoring shows that groundwater levels are generally stable, with fluctuations the result of seasonal rainfall and pumping effects. It was noted that we are already starting to see an increase in demand for ground water and this has the potential to grow in response to pressure on surface water. However, it is not expected that this will place groundwater under significant pressure in the near future. Also, groundwater resources did not offer sufficient capacity to significantly offset surface ware abstractions.

5.4 In response to questions raised around the state of groundwater quality, it was noted that the SOE 2022 report provided an indication of the current state of ground water quality and this was generally positive. A more detailed report will be provided at the next meeting.

Recommended

That the Taranaki Regional Council:

a) receives the memorandum and technical report Groundwater Quantity - State of the Environment Monitoring Triennial Report 2017-2020 and notes the specific recommendations therein.

Young/McDonald

6. Taranaki Water Quality State Spatial Modelling

6.1 Mr R Phipps, Manager – Science and Technology, spoke to the memorandum to provide the Committee with an overview of the findings of a recent report commissioned by Taranaki Regional Council (TRC), Taranaki water quality state spatial modelling by Land Water People (LWP).

6.2 In response to questions raised around the effects of forestry activities, it was noted that there are currently no specific sites monitoring sediment in water ways in the areas where deforestation activity is occurring. Regular on-site compliance monitoring inspections are undertaken. A review of the SOE monitoring programme is now underway to assess the effectiveness and suitability of the existing network and identify any areas for improvement.

6.3 The national objectives framework was introduced and the options the Council had under that framework to establish limits was discussed.

6.4 The incorrect report was uploaded in the agenda in error. The correct report will be emailed out to Councillors.

Recommended

That the Taranaki Regional Council:

a) receives the technical report, Taranaki water quality state spatial modelling and notes that the outputs from the modelling carried will provide useful context regarding the state of water quality and ecosystem health across the region as we continue work to implement the requirements of the NPS-FM.

Boyde/Van Der Leden

7. Submission on draft National Policy for Indigenous Biodiversity

7.1 Mr C Spurdle, Planning Manager, spoke to the memorandum to seek Members' endorsement of the Councils draft submission on the Draft National Policy Statement for Indigenous Biodiversity - Exposure Draft (the Exposure Draft).

The cause of the biodiversity decline and the important need for central government leadership and support for implementing the National policy statement were discussed.

Recommended

That the Taranaki Regional Council:

a) receives the memorandum and the attached submission on the exposure draft on the National Policy Statement for Indigenous Biodiversity

b) endorses the submission on the Exposure Draft

c) determines that this decision be recognised not significant in terms of section 76 of the Local Government Act 2002

d) determines that it has complied with the decision-making provisions of the Local Government Act 2002 to the extent necessary in relation to this decision; and in accordance with section 79 of the Act, determines that it does not require further information, further assessment of options or further analysis of costs and benefits, or advantages and disadvantages prior to making a decision on this matter.

Littlewood/Joyce

8. Report on advocacy and response activities for 2020/21 and 2021/22

8.1 Mr C Wadsworth, Strategy Lead - Resource Management, spoke to the memorandum to report to the Committee on advocacy and response activities for the 2020/21 and 2021/22 years.

8.2 Members acknowledged the considerable staff effort involved in preparing submissions and their impact on decision makers.

Recommended

That the Taranaki Regional Council:

a) receives the memorandum Report on Advocacy and Response activities for 2020/21 and 2021/22

b) notes that in 2020/21 and 2021/22 the Council made a total of 31 submissions on the policy initiatives of other agencies

c) notes that senior staff were also involved in various working parties or other fora on central and local government policy development and review.

Young/Van Der Leden

9. Review of Cat Management Options Report

9.1 Mr S Ellis, Environment Services Manager spoke to the memorandum to present for Members' information the report Review of Cat Management Options following a request for feral cats to be considered for inclusion in the Pest Management Plan for Taranaki 2018.

9.2 It was noted that this report is about feral cats not domestic cats. Feral cats are increasing and causing a lot of biodiversity damage throughout the region.

9.3 Iwi were included as part of the Wild for Taranaki workshop as so were well engaged.

Recommended

That the Taranaki Regional Council:

a) receives this memorandum entitled *Review of Cat Management Options Report*

b) receives the Review of Cat Management Options Place Group Report

c) notes officers have begun preparations for a councillor workshop to review current pest management policies in early 2023.

Joyce/McIntyre

10. General Business

10.1 **RMA reform announcements**

- Mr S J Ruru gave an update on RMA Reform provided by Minister Parker at the LGNZ Conference last week.
- There will need to be a significant transition process and officials will be looking for three pilot regions to lead the spatial planning change and then extend it to other regions.
- Regional Planning Committees will be formed and will undertake development of plans. These committees will consist of a minimum of six members (one from each Council and two Iwi representatives). Can see this working well in the smaller regions but not so much in larger regions. The Committee can call for submissions.
- Each of the Councils will be able to produce a statement of community outcomes and regional councils will produce a regional environmental outcomes statement.
- David Parkers speech is now on the Beehive website for those who want to view.

10.2 **Te Uru Kahika – 3 Waters programme and submission**

- Programme is moving at speed to form entities and working through an inaugural board process.
- Te Uru Kahika made a submission on the need for the formation of regional representative groups and highlighting the need for the new water entities to link in to different regional views across the entities.
- Clear on the need to link in to planning process and spatial plans. Not just 3 waters focus with transport infrastructure, telecommunications, electricity and core infrastructure very important.
- Need to be clear on practical linkage between stormwater and flood management.

There being no further business the Committee Chairperson, Councillor C L Littlewood, declared the meeting of the Policy and Planning Committee closed at 12.23pm. The meeting closed with a karakia.

Confirmed

Policy and Planning
Chairperson: ______________________________

C L Littlewood

30 August 2022

Taranaki Regional Council

MEMORANDUM
Policy & Planning

Date	30 August 2022
Subject:	**Agenda Memorandum Freshwater Implementation Report August 2022**
Approved by:	A D McLay, Director - Resource Management
	S J Ruru, Chief Executive
Document:	3097663

Purpose

1. The purpose of this memorandum is to provide the Committee with a Freshwater implementation project update.

Recommendation

That the Taranaki Regional Council:

a) receives the update on Freshwater implementation programme.

Background

2. The Council has prepared an implementation programme of the Government's Freshwater programme. The purpose of this memorandum is to update Members on progress in implementing the project. The implementation programme has previously been presented to, and approved by, the Committee.

Financial considerations—LTP/Annual Plan

3. This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

4. This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks including, but not restricted to, the *Local Government Act 2002*, the *Resource Management Act 1991* and the *Local Government Official Information and Meetings Act 1987*.

Iwi considerations

5. This memorandum and the associated recommendations are consistent with the Council's policy for the development of Māori capacity to contribute to decision-making processes (schedule 10 of the *Local Government Act 2002*) as outlined in the adopted long-term plan and/or annual plan. Similarly, iwi involvement in adopted work programmes has been recognised in the preparation of this memorandum.

Community considerations

6. This memorandum and the associated recommendations have considered the views of the community, interested and affected parties and those views have been recognised in the preparation of this memorandum.

Legal considerations

7. This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council.

Appendices/Attachments

Document 3097587: Freshwater Implementation Report for August 2022

Taranaki Regional Council

Freshwater Implementation Project
Report to Policy & Planning Committee

30 August 2022

Document Number: 3097857

Executive Summary

Progress has continued well, with all programme areas on or slightly ahead of planned May activities.

Project Programme

Key project achievements during the last reporting period

- Specific implementation activities:
  - Iwi Planning Officers started and had first day of "hot desking" at TRC offices during the period.
  - Work progressing on baselining studies for EColi, phosphorus and sediment.
  - On-gong progress towards N-Cap national reporting system go live, planned for 29 August. Main focus of attention has been communications, internal systems for collecting and processing responses (including paper based).
  - Compliance and consents teams collaborated to process dairy effluent consents that were due for renewal – finishing 90 (of 130 total) over the period.
  - Engagement preparing for next major round, with a focus on Te Mana o te Wai and limit setting.

Key upcoming activities and milestones in the next reporting period

- Continue iwi engagement – including induction for Iwi Planners and possible Council hosting of Mauri Compass workshops.
- Continue plan drafting – however note the possible "reset" required with change in key Policy & Planning staff over the period.
- Continue phosphorus monitoring, limit setting (starting with E.Coli) and water quantity accounting work.
- Prepare for FMU Stocktakes to go live using StoryMaps (GIS system).
- General community engagement – continue preparation for next round and for set up of Social Pinpoint tool.
- Compliance programme work on stock holding/IWG progressing – somewhat impacted by staff movements.
- Prepare for go live of nitrogen reporting system – although required reporting date to be determined to make allowance for calving.
- Continue next round of hill country farm planning.

HSE Updates

Nothing significant to report

Workstream Status Summary		
Workstream	**Tracking**	**Comments/Clarifications**
Tangata whenua partnerships		• The two Council funded Iwi Planning Officers started work in early August, with their first days at Council offices mid-month. A focused induction programme has been prepared, including on FW Implementation. • Working with iwi to determine interest and possible availability for a series of Mauri Compass workshops. Looking to introduce the tool to iwi as one possible approach to greater inclusion of mātauranga māori in scientific assessments.
Policy and Planning		• On track – plan drafting continues in accordance with overall implementation targets. • Preparing for handover of key FW Implementation responsibilities to new Policy Manager and Senior Policy Analyst when current staff leave in late August/early September.
Environment Quality		• Continued investigation into natural levels of phosphorus in waterways due to flows from the National Park. Some focused additional sampling (eg. faecal source tracking) will also be conducted alongside this work. • Continued work on water quantity accounting systems – still targeting December completion.
Consents		• Revision of farm dairy effluent consent forms is progressing well, with expected go live of end of the month. • Consents team received the first application based around Te Mana o te Wai, for a large water user. Following discussions with officers, the application was sent back for more information, including a refocus to matters on the NOF hierarchy. • Working with EQ to determine how to best manage large water take applications within the NOF framework.
Compliance		• Closing out dairy consents – 40 of the 130 currently up for renewal remain to be processed. • Developing systems and processes to handle N-Cap reporting once the national system goes live (expected 29 August, with a proposed reporting date of late October). Main focus is on an appropriate, education based response in the first year.
Operations		• Aerial photography showed approximately 260 ha of intensive winter grazing in the region on approximately 160 properties. Working with Compliance to identify and engage the relevant parties. • Missed annual target of 10,000ha new farm plans – hitting 7,500ha instead. Given the disruptions of the year, this is still a good result.
Engagement		• Main focus on preparing for general community engagement and next series of SIG meetings (both September), as well as release of Social Pinpoint tool for broader community engagement. • Continued preparing communications material for staff (eg. updates on wetlands, IWG, nitrogen) and preparing for the further community and focused engagement planned for the next quarter.

Project Risk/Opportunity Management

Officers are conducting the planned annual review of the project risk register.

The revised list of top priority risks will be reported again from the October Report.

MEMORANDUM
Policy & Planning

Date 30 August 2022

Subject: **Groundwater Quality – State of Environment Monitoring 2015-2020**

Approved by: Abby Matthews, Director – Environment Quality

S J Ruru, Chief Executive

Document: 3095638

Purpose

1. The purpose of this memorandum is provide the Committee with an overview of the findings and recommendations of the report *Groundwater Quality - State of the Environment Monitoring Report 2015-2020.*
2. A copy of the technical report accompanies this memorandum, and is available via the Council's website. This item will be accompanied by a brief presentation.

Executive summary

3. Regional councils have responsibilities under the Resource Management Act (1991) to monitor the state of the environment (SEM) within their region. The Taranaki Regional Council (the Council) monitors the state and trends across the region's groundwater systems using a number of measures, including chemical and microbial water quality, groundwater levels and usage. The focus of this report is on regional groundwater quality.
4. The Council has routinely monitored groundwater quality across the region since 1994. This helps us track how groundwater quality varies across the region and to assess how its quality is changing over time. We examine where the region's groundwater systems are impacted by land use activities and how suitable groundwater is for various uses (such as drinking water). Because groundwater provides a pathway from land to surface water bodies, we also assess the risk groundwater may pose to the health of sensitive receiving environments such as rivers, streams, lakes and estuaries.
5. Council's current Groundwater Quality Monitoring Programme (GQMP) network includes a total of 32 wells and bores. These sites are sampled every three months and analysed for a number of physical and chemical indicators of water quality. For this report, analysis of state and temporal trends was conducted on GQMP site data for 12 key indicators of groundwater quality. Data collected during the five years from 2015 to 2020 were used to assess current state, with results compared to accepted levels for environmental or human health, including attribute limits set-out in the National Policy Statement for Freshwater Management (NPS-FM) and the Drinking-water Standards for

New Zealand 2018 (DWSNZ). Trends were assessed using data collected over the ten year period from 2010 to 2020.

6. Analysis of monitoring data collected over the five years to 2020 showed that indicators *Escherichia coli* bacteria (*E. coli*), nitrate nitrogen (nitrate), ammoniacal nitrogen (ammonia), iron and manganese are occasionally found at levels considered unsafe for people or stock to drink, or at levels that can make the water look or taste unpleasant.

7. People using private groundwater supplies are most at risk of drinking groundwater with *E. coli* bacteria and elevated levels of nitrate. Overall, median nitrate and *E. coli* levels in Taranaki groundwater are comparable to other regions across Aotearoa where intensive agriculture is the predominant land use. Human activities and animal and industry wastewater discharged to land locally are both common sources of bacteria and nitrate. Poorly constructed wells and bores, or those that are not adequately isolated from direct sources of contamination, or surface runoff, are more likely to display elevated levels of *E.coli*.

8. At certain concentrations, nitrate can pose a health risk to babies and breastfeeding mothers. The DWSNZ sets a maximum acceptable value (MAV) for nitrate intended to protect against these risks. There is some discussion in the science community presently around whether a more stringent MAV should be set to protect our health, although there is not yet a strong consensus in New Zealand as to whether the science supports further limits on nitrate levels in groundwater. In Taranaki, there was only one site where median levels of nitrate were found to exceed the MAV for drinking water. Median nitrate concentrations were less than half of the MAV at 27 of 32 sites monitored (84%).

9. The presence of *E. coli* is used as an indicator of the potential presence of pathogens that can make us sick. Monitoring during 2015 to 2020 showed that *E. coli* were detected on at least one occasion at 21 of the 25 sites (84%) located in aquifers most at risk from *E. coli* contamination. At a number of sites the presence of *E. coli* is related to poor well construction or wellhead protection, which allows for the ingress of overland runoff into groundwater. *E. coli* concentrations found in purpose designed monitoring wells installed following good drilling practices are consistently low. These results highlight the importance of the proper construction and maintenance of bore infrastructure, particularly well-head protection. The treatment of groundwater prior to using it for household drinking water provides additional protection.

10. The presence of iron, manganese and ammonia in groundwater is mostly due to the local geology and natural processes that occur in aquifers with low levels of oxygen. The concentration of these contaminants in water at some locations can cause the staining of plumbing fixtures, clogging of pipes or result in the taste or look of groundwater being unpleasant, making the water unsuitable for certain uses. Iron concentrations are a particularly common challenge for those utilising groundwater in Taranaki. Between 2015 and 2020, 12 of 32 monitored sites (38%) were found to have concentrations of iron and/or manganese exceeding an aesthetic or heath related standard set out in the DWSNZ. A further three sites (9%) had exceedances of the aesthetic standard for ammonia.

11. Test results show that pesticides and heavy metals are generally not an issue in the region's groundwater aquifers, although there have been isolated instances where contamination by chemical substances and herbicides/fungicides have been detected.

12. There was sufficient data available to assess trends in groundwater quality at ten of the 32 sites monitored. In most cases, individual water quality indicators at these sites have

shown little change over the last ten years, or are changing at an insignificant rate. Meaningful changes were only detected in three bores, with levels of nitrate considerably improving in one bore (10%) and deteriorating in two others (20%).

13. The Council is currently reviewing its Regional Policy Statement (RPS) and developing a new Natural Resources Plan (NRP) to cater for new guidance and thresholds for freshwater quality and health. This will include setting limits on the use of natural resources to achieve agreed community values and outcomes for freshwater.

14. Monitoring of groundwater quality in Taranaki may also need to adapt to help the Council meet rules in the new policy and plans, especially where relationships between groundwater and surface water may exist. Work is underway to review Council's wider freshwater SEM programmes with a view to establishing a network that accommodates both requirements of the NPS-FM and provides key information for decision-makers around freshwater management.

Recommendation

That the Taranaki Regional Council:

a) receives the memorandum and technical report *Groundwater Quality - State of the Environment Monitoring 2015-2020* and notes the specific recommendations therein.

Background

15. Regional councils, under Section 35(2)(a) of the Resource Management Act (RMA) 1991, must monitor the state of the environment (SEM) within their region. Monitoring and reporting on the state of the environment informs decision-making around the sustainable management of the region's natural resources and provides an understanding of the state or health of the environment overall.

16. Policies and plans, developed and enforced by the Council, aim to protect, enhance and/or maintain the quality of the region's groundwater systems by avoiding, remedying or mitigating adverse impacts on groundwater aquifers. Key policy documents include the 2010 Regional Policy Statement for Taranaki (RPS), and the 2001 Regional Freshwater Plan for Taranaki (RFWP).

17. The 2010 RPS advocates for the sustainable management of the region's groundwater quality under: Freshwater Issue 6.3 - *Maintaining groundwater flows and quality at sustainable levels*.

18. The 2001 RFWP provides polices, methodologies and rules for the management of groundwater quality under: Issue 6.4 – *Adverse effects on the environment from the taking and use of groundwater*; and, Issue 6.5 - *Adverse effects on groundwater quality from the discharge of contaminants to land and water*.

19. The Council monitors the state and trends across the region's groundwater systems using a number of measures, including physiochemical and microbial water quality variables, groundwater levels and usage. State and trend analysis of groundwater quality in the Taranaki region is usually conducted on a biennial basis. The last report was prepared in 2017 and assessed monitoring data collected between 1 July 2002 and 30 June 2016 from 35 groundwater monitoring sites (Figure 1).

20. This report provides an overview of groundwater quality state and trends in the Taranaki region based on monitoring data from 32 groundwater sites sampled between 1 July 2010 and 30 June 2020, along with discussion around the suitability of

groundwater in Taranaki for particular uses, like stock and potable supply, highlighting where groundwater contamination may pose a risk to aquatic ecosystem health.

21. The report complements the recently released report: Groundwater Quantity: State of Environment Monitoring Triennial Report 2017-2020 which discusses the allocation and use of groundwater in the region.

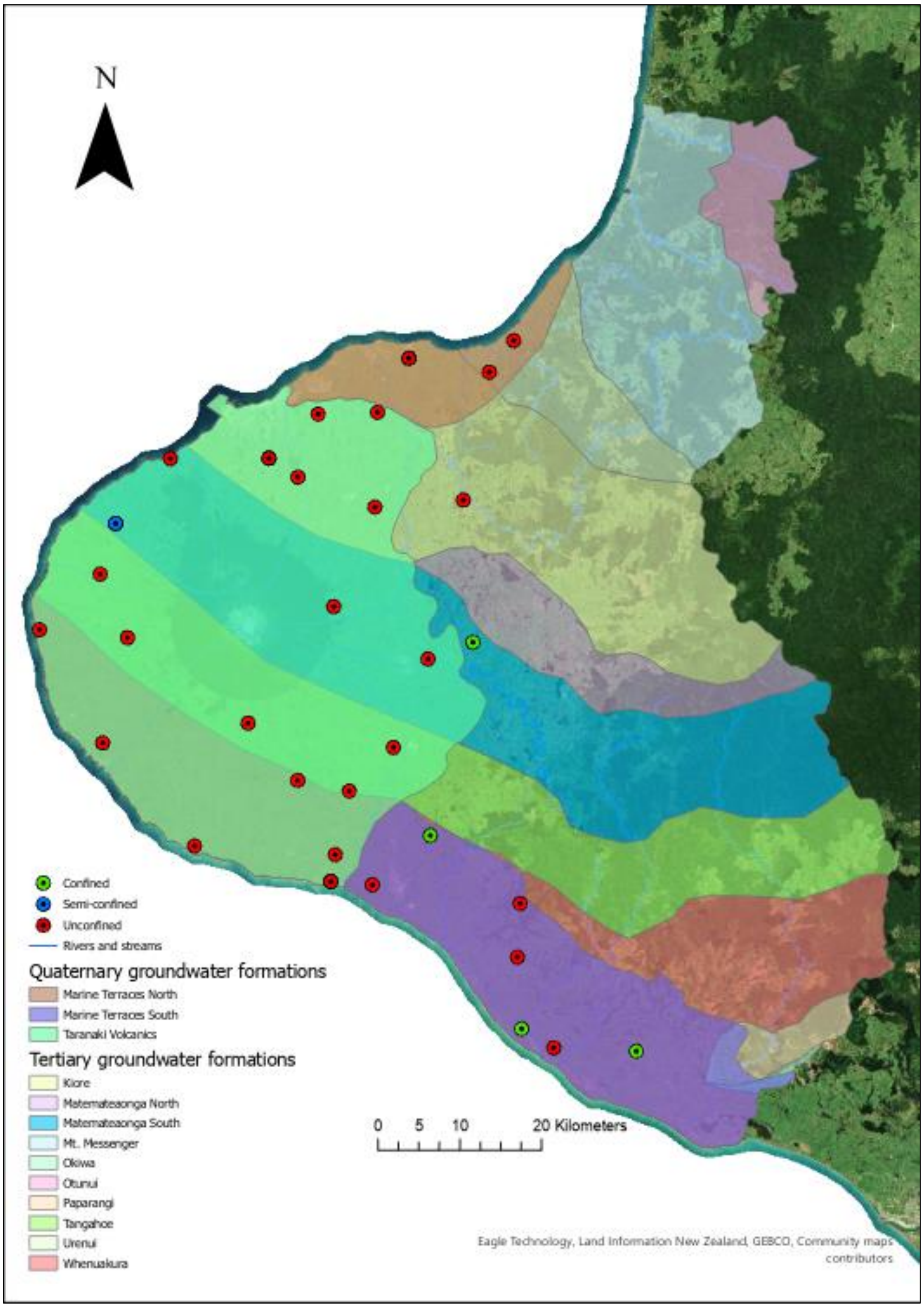


Figure 1: Locations of groundwater sites included in the GQMP

Discussion

22. The state of (and trends in) groundwater quality across Taranaki are influenced by both natural processes and human activities. Minerals, salts and contaminants can easily be dissolved into, and transported by water. Aquifers close to the Earth's surface are more at risk of contamination from land use activities given the shorter, or more direct, pathways to them. Deeper aquifers, or those separated from the Earth's surface by geological material that restrict the flow of water (an aquitard), are at less risk from surface contamination. In addition to potential contamination by activities on the land surface, the quality of groundwater can also be adversely impacted by the rocks and sediments in the aquifer through which it flows. In some instances, these natural process can also affect the suitability of groundwater for certain uses.

23. Observed concentrations of 12 key indicator variables of groundwater quality highlight patterns that can be associated with a range of drivers, such as aquifer confinement, groundwater residence time, rock/water interaction with local geology and soil, regional recharge mechanisms, redox related processes, and human influences including land use management practices. The composition of groundwater has been shown to vary in response to the occurrence and magnitude of these influences across the region, and can also change over time.

24. The mineral content of the region's deep and confined aquifers is typically greater than that of groundwater in the region's shallow and unconfined aquifers. Aquifer depth, reducing groundwater conditions and longer groundwater residence times naturally promote greater concentrations of bicarbonate, sodium, iron, manganese and ammonia in confined aquifers. Additionally, elevated levels of electrical conductivity (EC), nitrate, chloride and *E.coli* in groundwater samples from some of the region's more oxidised, unconfined aquifers suggests groundwater in Taranaki can be impacted by land use.

25. Analysis of sodium/chloride (Na:Cl) ratios in groundwater indicates the main source of recharge to regional aquifers is rainfall derived from marine evaporation. Concentrations of chloride and sodium, along with EC values, were greater in samples from GQMP sites located in coastal areas west/south-west of Taranaki Maunga through to South Taranaki. This may reflect that rainfall at the coast is richer in chloride and sodium, compared to rainfall that falls inland. Nearly two thirds of GQMP sites plot below the SWDL, suggesting that much of the region's groundwater is enriched with sodium from rock/water interactions with sodium rich source rocks.

26. An analysis of nitrate concentrations over the entire GQMP network suggests that there has been little change in groundwater nitrate levels over the last five years. There is weak statistical evidence that levels of nitrate and *E.coli* in groundwater are higher in autumn and winter, which likely reflect early seasonal rainfall leaching nutrients and bacteria more readily into unconfined aquifers. Elevated nitrate in groundwater is largely associated with the region's intensive agriculture land use.

27. Median counts of *E.coli* were above the DWSNZ (2018) MAV in seven of the 25 GQMP sites tested routinely for bacteria. However, positive counts of *E.coli* were detected on one or more sampling occasion in groundwater samples from almost all of the GQMP wells screened in unconfined aquifers. Site owners are informed when detections are made. It is likely that much of the *E.coli* contamination is due to local sources of bacteria, such as animal or human waste, which is able to make its way into the well when there is poor wellhead protection or certain construction methods have been used. There is some evidence that dug and unlined wells (as well as possibly dug or bored/augured wells in general) are slightly more at risk of bacteriological contamination than other

bore or well constructs. It is recommended that these well types, alongside poorly constructed monitoring sites in general, are replaced with drilled and screened GQMP monitoring wells in the same location. More work may also be required to understand and improve the level of wellhead security at individual GQMP sites.

28. Groundwater concentrations of nitrite, fluoride and bromide were not above their respective DWSNZ (2018) MAV or WHO (2017) thresholds. While an evaluation of the pesticide surveys undertaken by the Council and ESR show that regionally there are limited low levels of pesticide or EOCs in groundwater, these are not at a level of concern to human health. This may reflect the relatively small extent of horticulture within the region, as well as the reliance on groundwater being more prevalent in rural areas than in urban areas. Heavy metals and metalloids are not routinely tested as part of the GQMP, although the limited results available do not indicate an issue.

29. Analysis of the state of groundwater quality highlights that elevated nitrate concentrations are evident to varying degrees within the region's shallow aquifers. This is highly likely due to human influence and the effects of intensive agricultural land use. Environmentally meaningful trends in concentrations of nitrate (or NNN) were found with high confidence at only three sites, including one improving trend and two deteriorating trends. It is also noted that previous analysis of groundwater quality over a 16 year period (TRC 2017) found statistically significant and environmentally meaningful trends in groundwater concentrations of nitrate in seven GQMP sites that are still currently monitored (four improving and three worsening trends). Only groundwater concentrations of nitrate in GND0827 and GND1095 continue to show degrading and improving trends with a high level of confidence between the two reporting periods. This may suggest groundwater nitrate concentrations in all other sites have been maintained over the last ten years, or that changes are not yet able to be measured with a high level of confidence.

30. Consideration of current median values of the 12 key indicator variables alongside temporal trends analysis can provide an indication of where the quality of regional groundwater is of concern environmentally or from a drinking water standard perspective. State and temporal trend analysis of groundwater chemistry in four sites (GND0563, GND0827, GND0829 and GND2213) indicate that concentrations of select variables are changing at rates that are considered environmentally meaningful. Changes in overall hydrochemistry at GND0563 indicated the state of groundwater in this bore is no longer suitable for potable supply. Given that groundwater quality at this bore is being impacted by the deteriorating state of the bore's integrity, it is recommended that GND0563 be removed from the GQMP network.

31. Groundwater concentrations of nitrate and NNN in the remaining three bores are changing at rates that could either exceed the DWSNZ (2018) MAV for nitrate or have an impact on any receiving environments. For example, the current rate of change could see levels of NNN exceed the DWSNZ (2018) MAV for nitrate (11.3 mg/L) in just under three years at GND0829 (although, it should be noted that nitrate concentrations at this site have reduced since 2018). Meanwhile, nitrate concentrations at GND0827 have steadily degraded since the last reporting period, with the median nitrate concentration increasing from 2.41 (TRC 2017) to 3.3 mg/L.

32. Many of the data records for GQMP sites were not yet of suitable length to enable robust analysis of temporal trends. A more widespread analysis for trends will be possible as these datasets grow in coming years and this will enable a better insight into how groundwater quality is changing, and at what rate, across the region.

33. The risk that nutrient rich groundwater may pose to hydraulically connected surface water in the region, either in promoting aquatic ecosystem toxicity or the instream proliferation of nuisance plants and algae, is mostly unknown, as are the influence of localised aquifer characteristics (such as aquifer lithology, overlying soil conditions, groundwater residence times, redox in unconfined aquifers) on nutrient attenuation and reduction within the region’s unconfined aquifers.

34. Targeted investigations, such as the Waiokura Stream catchment study, have highlighted changeable redox conditions and hydrochemical links between groundwater and the Waiokura Stream. Sources of nutrients (like nitrate) in the stream were also found to be strongly associated with agricultural land use activities in the Waiokura catchment (van der Raaij and Martindale, 2016). However, these are the preliminary findings of only one study exploring localised hydraulic connections. Regionally, it is expected that some attenuation and dilution (reduction) of nutrients will occur along the groundwater flow path and within surface water.

35. Developing management policies and strategies that consider the potential contaminant contribution of groundwater to surface water may be difficult as nutrients are highly mobile in water. Many of the region’s shallow unconfined aquifers already show some degree of human impact above the NPS-FM (2020) nitrate aquatic toxicity threshold. Dry stock and dairy farming are typically attributed as sources of nutrient loading, however, in Taranaki, the intensity of these two activities has been relatively stable for some time. Moreover, the nutrient contribution from increased application of nitrogen-based fertilisers in recent times, and the impact of large scale industry in the region needs to be considered and managed appropriately. Further investigation, such as analysis of groundwater age, lag times and flow pathways would help understand where and when to expect the cumulative impacts of land use to become apparent in regional aquifers and waterways.

36. Further research into aquifer characteristics and possible hydraulic links and the fate and transport of nutrients, bacteria and other contaminants in unconfined aquifers would assist with the development of regional policies and strategies for managing land use and any impacts on groundwater. This is particularly important given the move away from pond-treated farm effluent discharges to water, in preference of discharging to land. This is a necessary step in order to reduce surface water contaminant loading however, potential impacts on groundwater quality also need to be appropriately managed to protect groundwater aquifers and receiving water bodies. Research into better understanding drivers of groundwater and surface water quality will assist with meeting national attribute objectives outlined in the NPS-FM (2020).

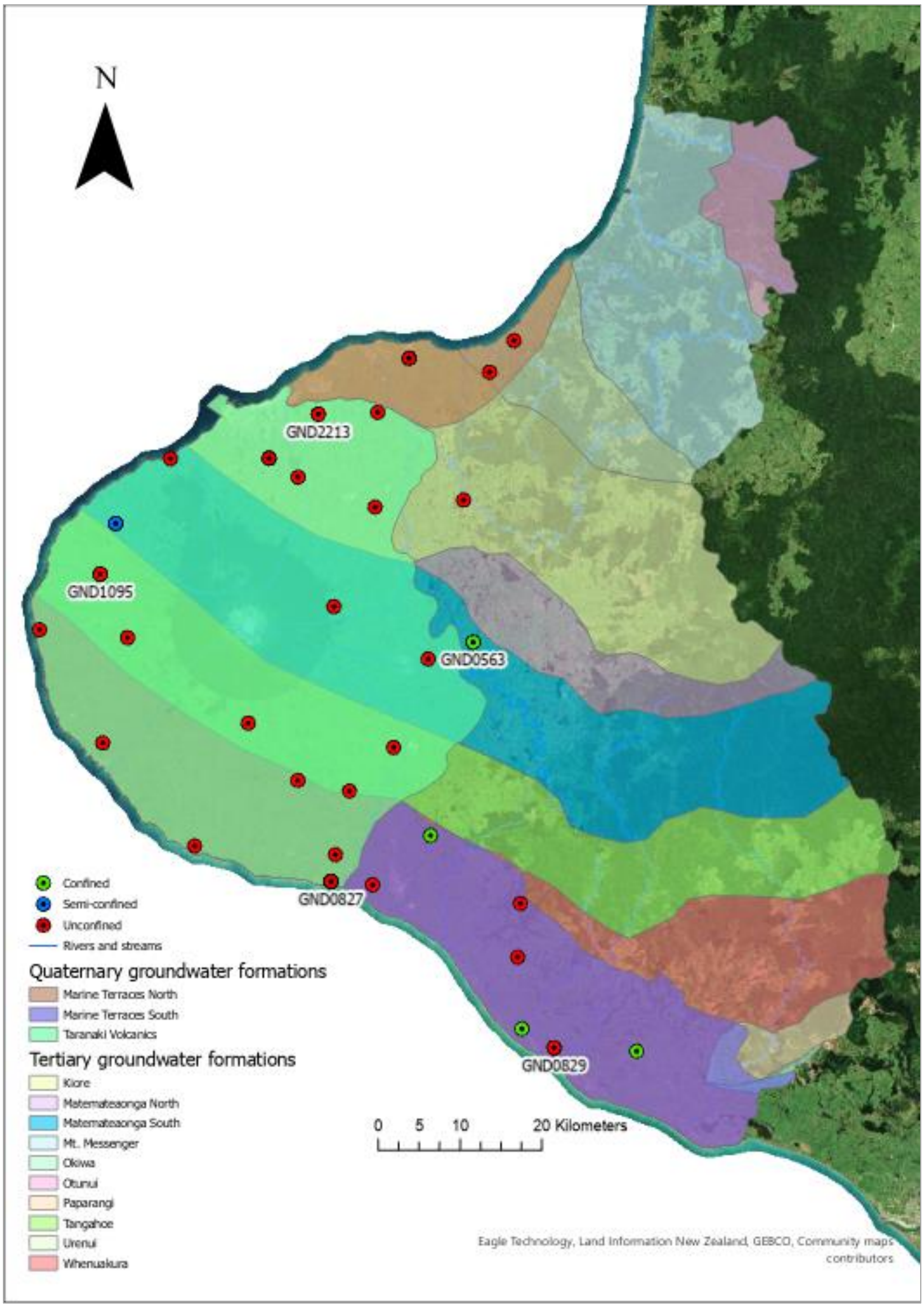


Figure 2: Locations of groundwater sites discussed above

37. The report includes six recommendations as follows:

- THAT the Ministry of Health, Taranaki District Health Board and private bore or well owners be informed of groundwater quality results from potable supply bores

- THAT the Council continues to monitor new research regarding the potential health risks associated with nitrate in drinking water and liaise with the Taranaki District Health Board in respect of any research outputs
- THAT changes to regional policy and plans are made that enable identification of all groundwater wells/bores installed in the region. Any bores or wells established historically should be registered with the Council
- THAT an analysis of groundwater data from both GQMP sites and wells/bores used in consent compliance monitoring is undertaken collectively to better understand the extent and magnitude of nutrient contamination (particularly nitrate) in regional aquifers
- THAT hydraulic connections between groundwater and surface water are investigated to aid in the attribute objective and target setting that is to be implemented in regional policy through the NPS-FM (2020)
- THAT the range of analyses currently carried out on samples from the SGWM network be extended in forthcoming sampling events to include calcium, magnesium and potassium. Routine periodic testing of heavy metals and metalloids should also be scheduled in to the GQMP.

38. Any potential modifications to Council's groundwater monitoring network will be considered as part of Council's broader state of environment monitoring network review during 2022-2023.

Financial considerations—LTP/Annual Plan

39. This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

40. This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks including, but not restricted to, the *Local Government Act 2002*, the *Resource Management Act 1991* and the *Local Government Official Information and Meetings Act 1987*.

Iwi considerations

41. This memorandum and the associated recommendations are consistent with the Council's policy for the development of Māori capacity to contribute to decision-making processes (schedule 10 of the *Local Government Act 2002*) as outlined in the adopted long-term plan and/or annual plan. Similarly, iwi involvement in adopted work programmes has been recognised in the preparation of this memorandum.

Community considerations

42. This memorandum and the associated recommendations have considered the views of the community, interested and affected parties and those views have been recognised in the preparation of this memorandum.

Legal considerations

43. This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council.

References

van der Raaij R.W., and Martindale, H. 2016. *Application of hydrochemical and isotopic methods to assess water source and contaminant pathways in the Waiokura Catchment, Taranaki, New Zealand*. Draft GNS Science Report 2016/65. 39 p.

Appendices/Attachments

Document 3097376: Groundwater Quality State of the Environment Monitoring 2015-2020 Technical Report 2022-87 (Executive summary and recommendations).

Groundwater Quality

State of the Environment Monitoring

2015-2020

Technical Report 2022-87

Working with people | caring for Taranaki

Taranaki Regional Council

Taranaki Regional Council
Private Bag 713
Stratford

ISSN: 1178-1467 (Online)
Document: 2216734 (Word)
Document: 3097376 (Pdf)
August 2022

Groundwater Quality

State of the Environment Monitoring
2015-2020

Technical Report 2022-87

Groundwater Quality

State of the Environment Monitoring 2015-2020

Technical Report 2022-87

Taranaki Regional Council
Private Bag 713
Stratford

ISSN: 1178-1467 (Online)
Document: 2216734 (Word)
Document: 3097376 (Pdf)
August 2022

Executive summary

Regional councils have responsibilities under the Resource Management Act (1991) to monitor the state of the environment (SEM) within their region. The Taranaki Regional Council (the Council) monitors the state and trends across the region's groundwater systems using a number of measures, including chemical and microbial water quality, groundwater levels and water usage. The focus of this report is on regional groundwater quality.

Minerals, salts and contaminants can easily be dissolved into, and transported by water. Aquifers close to the Earth's surface are more at risk of contamination from land use activities given the shorter, or more direct, pathways to them. Deeper aquifers, or those separated from the Earth's surface by geological material that restrict the flow of water (an aquitard), are at less risk from surface contamination although can be contaminated via poorly secured bores and wells. In addition to potential contamination by activities on the land surface, the quality of groundwater can also be adversely impacted by the rocks and sediments in the aquifer through which it flows. In some instances, these natural process can also affect the suitability of groundwater for certain uses.

The Council has routinely monitored groundwater quality across the region since 1994. We do this in order to gain a better understanding of how groundwater quality varies across the region and to assess how its quality is changing over time. We examine how our groundwater systems are being impacted by land use activities and how suitable groundwater is for various uses (such as drinking water). Because groundwater provides a pathway from land to surface water, we also assess the risk groundwater may pose to the health of sensitive environments such as streams, lakes and estuaries.

Our current Groundwater Quality Monitoring Programme (GQMP) network includes a total of 32 wells and bores. These sites are sampled every three months and analysed for a number of physical and chemical indicators of water quality. For this report, analysis of state and temporal trends was conducted on GQMP site data for 12 key indicators of groundwater quality. Data from 2015 to 2020 was used to assess current state, with results compared to accepted levels for environmental or human health, including attribute limits set-out in the National Policy Statement for Freshwater Management (NPS-FM) and the Drinking-water Standards for New Zealand 2018 (DWSNZ). Trends were assessed using data collected over the ten year period from 2010 to 2020.

Monitoring by the Council over the last five years shows *Escherichia coli* bacteria (*E. coli*), nitrate nitrogen (nitrate), ammoniacal nitrogen (ammonia), iron and manganese are occasionally found at levels considered unsafe for humans or stock to drink, or at levels that can make the water look or taste unpleasant.

People using private groundwater supplies are most at risk of drinking groundwater with *E. coli* bacteria and elevated levels of nitrate. Overall, median nitrate and *E. coli* levels in Taranaki groundwater are comparable to other regions across Aotearoa where intensive agriculture is the predominant land use. Human activities and animal and industry wastewater discharged to land locally are both common sources of bacteria and nitrate. Poorly constructed wells and bores, or those that are not adequately isolated from direct sources of contamination, or surface runoff, are more likely to display elevated levels of *E. coli*.

At certain concentrations, nitrate can pose a health risk to babies and breastfeeding mothers. The DWSNZ sets a maximum acceptable value (MAV) for nitrate intended to protect against these risks. There is some discussion in the science community presently around whether a more stringent MAV should be set to protect our health, although there is not yet a strong consensus in New Zealand as to whether the science supports further limits on nitrate levels in groundwater. In Taranaki, there was only one site where median levels of nitrate were found to exceed the MAV for drinking water. Median nitrate concentrations were less than half of the MAV at 27 of 32 sites monitored (84%).

The presence of *E. coli* is used as an indicator of the potential presence of pathogens that can make us sick. Monitoring during 2015 to 2020 showed that *E. coli* were detected on at least one occasion at 21 of the 25 sites (84%) located in aquifers most at risk from *E. coli* contamination. At a number of sites the presence of *E. coli* is related to poor bore or well construction, which allows for the ingress of overland runoff into groundwater. *E. coli* concentrations found in purpose designed monitoring wells installed following good drilling practices are consistently low. These results highlight the importance of the proper construction of bores and treating groundwater prior to using it for household drinking water.

The presence of iron, manganese and ammonia in groundwater is mostly due to the local geology and natural processes that occur in aquifers with low levels of oxygen. The concentration of these contaminants in water at some locations can cause the staining of plumbing fixtures, clogging of pipes or result in the taste or look of groundwater being unpleasant, making the water unsuitable for certain uses. Iron concentrations are a particularly common challenge for those utilising groundwater in Taranaki.

Between 2015 and 2020, 12 of 32 monitored sites (38%) were found to have concentrations of iron and/or manganese exceeding an aesthetic or heath related standard set out in the DWSNZ. A further three sites (9%) had exceedances of the aesthetic standard for ammonia.

Test results show that pesticides and heavy metals are generally not an issue in groundwater throughout Taranaki, although there have been isolated instances where contamination by chemical substances and herbicides/fungicides has been detected.

There was sufficient data available to assess trends in groundwater quality at ten of the 32 sites monitored. In most cases, individual water quality indicators at these sites have shown little change over the last ten years, or are changing at an insignificant rate. Meaningful changes were only detected in three bores, with levels of nitrate considerably improving in one bore (10%) and deteriorating in two others (20%).

The Council is currently reviewing its regional policy and plans to cater for new guidance and thresholds for freshwater quality and health. Monitoring of groundwater quality in Taranaki may also need to change to help the Council meet rules in the new policy and plans, especially where relationships between groundwater and surface water may exist.

Table of contents

List of tables

List of figures

1. Introduction

Groundwater in the Taranaki region is mostly used for stock and domestic water supply and is generally abstracted at low volumes and pumping rates. Other significant uses of groundwater include industrial purposes, community water supply, and pastoral and horticultural irrigation.

Groundwater provides base flow to rivers, streams and wetlands, or forms natural springs or seeps where it discharges at the ground's surface. Careful management of the quality and quantity of groundwater is required to protect both groundwater aquifers (from occurrences like saltwater intrusion and aquifer collapse or contamination), and surface water ecosystems dependent on groundwater.

Regional councils, under Section 35(2)(a) of the Resource Management Act (RMA) 1991, must monitor the state of the environment (SEM) within their region. Monitoring and reporting on the state of the environment informs decision-making around the sustainable management of the region's natural resources and provides an understanding of the state or health of the environment overall.

Policies and plans, developed and enforced by the Council, aim to protect, enhance and/or maintain the quality of the region's groundwater systems by avoiding, remedying or mitigating adverse impacts on groundwater aquifers. Key policy documents include the 2010 Regional Policy Statement for Taranaki (RPS), and the 2001 Regional Freshwater Plan for Taranaki (RFWP).

The 2010 RPS advocates for the sustainable management of the region's groundwater quality under: Freshwater Issue 6.3 - *Maintaining groundwater flows and quality at sustainable levels*.

The 2001 RFWP provides polices, methodologies and rules for the management of groundwater quality under: Issue 6.4 – *Adverse effects on the environment from the taking and use of groundwater*; and, Issue 6.5 - *Adverse effects on groundwater quality from the discharge of contaminants to land and water*.

Human activities that have an effect on the environment or use natural resources, are required to meet the standards and conditions outlined in regional policy and plans. If activities cannot meet these requirements, then a resource consent (permit) is required. Often discharges to the environment (either to water or to land) or water abstraction will require a resource consent from the Council under the 2001 RFWP.

The Taranaki Regional Council (the Council) monitors the state and trends across the region's groundwater systems using a number of measures, including physiochemical and microbial water quality variables, groundwater levels and usage. State and trend analysis of groundwater quality in the Taranaki region is usually conducted on a biennial basis. The last report was prepared in 2017 and assessed monitoring data collected between 1 July 2002 and 30 June 2016 from 35 groundwater monitoring sites.

This report provides an overview of groundwater quality state and trends in the Taranaki region based on monitoring data from 32 groundwater sites sampled between 1 July 2010 and 30 June 2020, along with discussion around the suitability of groundwater in Taranaki for particular uses, like stock and potable supply, highlighting where groundwater contamination may pose a risk to aquatic ecosystem health. The report complements the recently released report: Groundwater Quantity: State of Environment Monitoring Triennial Report 2017-2020 which discusses the allocation and use of groundwater in the region.

2. Groundwater quality monitoring in the Taranaki Region

Groundwater quality has been routinely monitored in the Taranaki region at a select number of sites since 1994. The Council historically sampled groundwater sites separately under the SEM Groundwater Chemical Quality and the SEM Nitrates in Shallow Groundwater monitoring programmes. In 2011, a series of external and internal reviews of the groundwater quality network initiated an amalgamation of all SEM groundwater quality programmes into a single Groundwater Quality Monitoring Programme (GQMP) in 2013. Monitoring results from sites sampled in the revised GQMP were first reported in 2017 (TRC 2017).

The GQMP has three primary objectives:

1. To characterise the state of groundwater quality at a selected number of sites across the region;
2. Enable the assessment of groundwater quality against relevant guidelines and standards; and
3. Identify spatial and temporal trends in groundwater quality arising as a result of natural and/or anthropogenic influences.

This information is used to measure how effective the Council's management practices, policies and rules are at maintaining the quality of the region's groundwater, and if environmental outcomes for groundwater quality are being achieved.

The current GQMP comprises 32 groundwater wells and bores, located throughout the Taranaki region (Figure 1). Site details are included in Appendix I. Sites were selected for GQMP largely based on location, depth and aquifer representation. Sampling is carried out at three monthly intervals, generally in March, June, September and December, with the intention of capturing seasonal variations in groundwater quality.

Sites sampled for the GQMP are classified into two subset networks for the purpose of this report. There are 24 groundwater wells which are less than 15 m in depth[1] and collectively form the shallow groundwater monitoring (SGWM) network. The Council also undertakes groundwater sampling at a further eight sites on behalf of the Institute of Geological and Nuclear Sciences (IGNS) for the National Groundwater Monitoring Programme (NGMP). These sites are a mixture of wells and bores, collectively referred to as the NGMP network.

The GQMP attempts to sample a diverse and regionally representative range of groundwater sites. However, Figure 1 illustrates that majority of GQMP monitoring sites are shallow wells located within unconfined aquifers in the Taranaki Maunga volcanic ring plain or Marine Terrace geological units, and in areas of intensive land use. The remaining five GQMP sites are deeper bores screened within the Tertiary geological formations that extend from the Eastern Hill Country, where land use is a mix of high and low intensity (grassland – low producing) land use. As such, the GQMP is more representative of groundwater quality in unconfined aquifers, i.e. those most susceptible to land use impacts.

[1] The Regional Freshwater Plan 2001 defines all bores and wells less than 20 m depth as wells and all bores and wells greater than 20 m depth as bores.

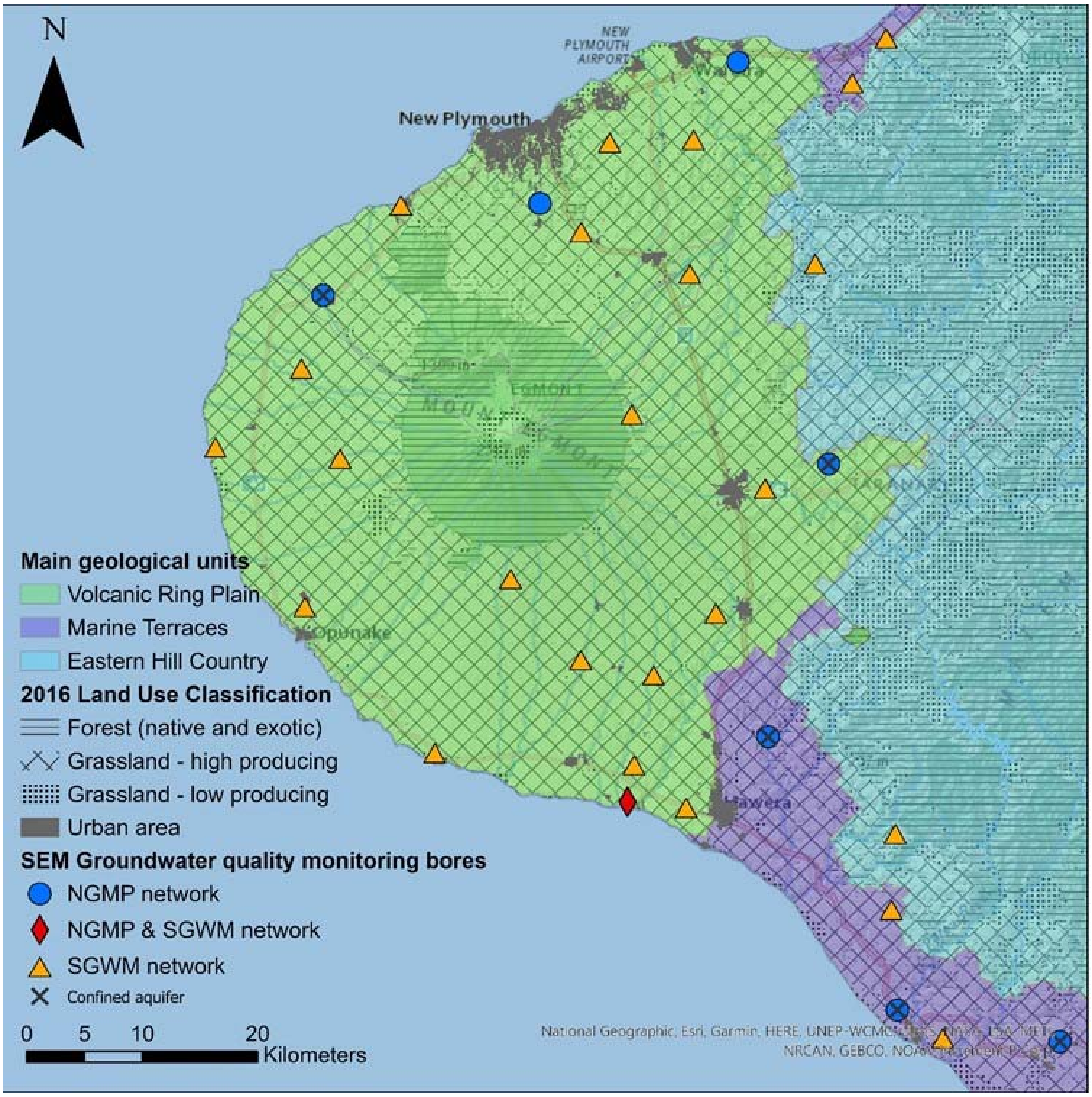


Figure 1 Location of the 32 groundwater sites monitored as part of the Taranaki Groundwater Quality network

Note: *Sub networks include the National Groundwater Monitoring Programme (NGMP) and the Shallow Groundwater Monitoring (SGWM) networks. The main geological units and land use are also detailed here.*

Wells in the SGWM network are constructed using a range of drilling methodologies. The most common method of construction is to excavate shallow wells by hand or machine (referred to as a “Dug Well”). The well is either lined with precast wide diameter concrete rings (c.900 mm to 1,200 mm in diameter) or left unlined. Other well construction methods include auger or rotary drilling rigs. Wells may or may not be lined and/or screened, within the water bearing aquifer. Bores in the NGMP network tend to be constructed by drilling deeper and screening bores within a single aquifer. However, two of the NGMP bores are open ended casing (no bore screen) (Appendix I). Figure 2 illustrates examples of the various construction types in the Taranaki region.

Figure 2 Examples of the well construction types in Taranaki

(Top left: Dug and lined well GND1098, Top right: Dug - unlined well GND1082, Bottom left: Example of internal well lining in dug well GND1095, Bottom right: drilled and screened well GND2484 (being sampled with a peristaltic pump)

2.1. Monitoring variables and methods

Groundwater quality is assessed by measuring different variables including: pH, conductivity, faecal indicator bacteria (*E. coli*), dissolved nutrients (including nitrogen and phosphorus), redox potential, and some major ions. Groundwater samples are collected in accordance with the Council's Groundwater Sampling Procedure (TRC, 2015). The rationale for monitoring select variables, together with details on variable analysis methodology is provided in Appendix II.

At present, the SGWM and NGMP networks do not test groundwater samples for the same number of variables. The NGMP network analyses for most major and minor ions, providing a general overview of hydrochemistry in the region. Meanwhile, the SGWM network tests variables that are more likely to be associated with aquifers influenced by anthropogenic activity. Table 1 provides a list of chemical analytes tested for under each groundwater monitoring network. Appendix II details changes to the testing regime since groundwater quality monitoring began in Taranaki.

Until 30 June 2018, SGWM samples were tested by the Council's onsite IANZ accredited laboratory. The SGWM programme samples are currently tested by RJ Hill Laboratories in Hamilton. Samples collected for the NGMP programme are tested by IGNS for a more comprehensive range of water quality variables (see Table 1). The results of all sample analyses are stored in the Council's LAB database.

Table 1 Routine laboratory testing and sample analysis details

Analyte	SGWM network	NGMP network
Temperature (Field)	💧	💧
pH (Field)	💧	💧
Electrical conductivity (Field)	💧	💧
Dissolved oxygen (Field)	💧	💧
pH (Lab)	💧	💧
Electrical conductivity (Lab)	💧	💧
E.coli	💧	-
Bicarbonate (as HCO_3)	💧	💧
Chloride (Cl)	💧	💧
Sodium (Na)	💧	💧
Total dissolved solids (TDS)	-	💧
Nitrate (as NO_3-N)	💧	💧
Nitrite (as NO_2-N)	💧	💧
Ammoniacal Nitrogen (NH_4)	💧	💧
Dissolved reactive phosphorus (DRP)	💧	-
Potassium (K)	-	💧
Calcium (Ca)	-	💧
Bromide (Br)	-	💧
Fluoride (F)	-	💧
Iron (Fe)	💧	💧
Magnesium (Mg)	-	💧
Manganese (Mn)	💧	💧
Silica (SiO_2)	-	💧
Sulphate (SO_4)	💧	💧
Total no. tests conducted	17	22
💧 *Indicates test is undertaken*		

2.2. Approach to data analysis

This section outlines how data were selected and analysed for state and trend in groundwater quality. Further details summarise the methods used to present data analysis, and the relevant groundwater quality guidelines that are used for comparison.

2.2.1. Water quality guidelines and national reporting

A number of water quality guidelines and thresholds were used to understand and quantify state and trends detected in regional groundwater quality, and to make comparisons with national groundwater data.

Drinking Water Standards and Guidelines

Groundwater quality sample results were compared against the Ministry of Health (MoH) 2018 Drinking-water Standard for New Zealand (DWSNZ) or, where required, to the 2017 World Health Organisation (WHO). These standards or guidelines apply to water intended for human consumption. The DWSNZ (2018) sets a health-related maximum acceptable value (MAV) or an aesthetic (opposed to health risk) guideline value (GV) for a number of water quality variables. MAVs are the concentration at which a particular variable in water will pose a significant risk to the health of a person consuming two litres of water per day over their lifetime (assumed to be 70 years). The MAV for protection against microbes uses a faecal indicator bacteria, *Escherichia coli* (*E.coli*), to indicate the potential presence of other pathogenic bacteria in drinking water.

2020 National Policy Statement for Freshwater Management (NPS-FM)

The NPS-FM (2020) requires an integrated management approach to maintain and enhance freshwater ecosystems nationally, and acknowledges groundwater as a key pathway for freshwater. As there are recognised connections between groundwater and surface water systems in Taranaki, groundwater nitrate and ammonia concentrations have been compared against the NPS-FM (2020) annual median toxicity attribute states for nitrate (2.4 mg/l) and ammonia (0.24 mg/L) national bottom lines in surface water.

Application of the NPS-FM (2020) toxicity thresholds for rivers and lakes highlights where groundwater nutrient or other contaminant inputs may pose a potential risk to ecosystem health or the promotion of proliferation of nuisance plants and algae in receiving surface water bodies. In this report a comparison of the NPS-FM (2020) toxicity attribute states to groundwater quality has been provided to identify potential areas where groundwater nutrient levels may pose a risk to surface water ecosystems. In undertaking this assessment, it should be recognised that groundwater contributions to surface water are subject to sub-surface and instream attenuation processes and dilution (reducing the concentration of nutrients prior to and during discharge to surface water). However, further investigation is required to understand groundwater/surface water flow pathways, and their relationship to the fate and transport of nutrients in groundwater within the region.

2000 Australia and New Zealand Environment and Conservation Council (ANZECC) Water Quality Guidelines

Groundwater results were compared to ANZECC (2000) guideline's trigger values (TV) for aquatic toxicity or for stock drinking water quality for select variables. Comparisons were made to signal where groundwater may not be suitable for livestock to drink, and where groundwater discharges to surface water may have adverse ecological impacts on aquatic ecosystems. Note: these comparisons assume that flow in the surface water is comprised entirely of groundwater, not taking into account likely dilution.

Natural verses human induced concentrations of nitrate-nitrogen groundwater

Close et al. (2001) determined groundwater in New Zealand rarely has natural nitrate concentrations above 1 mg/L, while Daughney and Reeves (2005) concluded that nitrate concentrations above 1.6 mg/L are 'probably' due to human influence. Daughney and Reeves (2005) and Madison & Brunett (1985) further concluded, with high confidence, that groundwater concentrations of nitrate above 3 mg/L – 3.5 mg/L "are almost certainly indicative of human impact".

As the NPS-FM (2020) annual median nitrate toxicity attribute is <2.4 mg/L, this report will display where groundwater is not impacted (<1 mg/L) and is impacted by low levels of nitrate contamination (1 mg/L - <2.4 mg/L). However, where groundwater concentrations of nitrate are above 2.4 mg/L, the reader can infer these concentrations are most likely due to human influence.

2.2.2. Data used in this report

Data used to analyse the state and trends in groundwater quality across the Taranaki region has been collected over the period 1 July 2010 to 30 June 2020. During this period, some monitoring sites have been removed or replaced from the sampling network due to poor well or bore integrity or access issues. However, data from these sites may still be included in analysis where there is sufficient data.

Although the SWGM programme and NGMP test for 17 and 22 groundwater quality parameters respectively, descriptive statistics (state) and trend analysis have been calculated for 12 key indicators of human impact or natural groundwater chemistry, and/or where they are associated with a human/ecological health risk (Moreau et al 2016 and MfE 2019). Table 2 provides explanation for variable inclusion in groundwater state and trend data analysis.

In addition to the standard testing regime, a selection of shallow wells are sampled on a four yearly basis for the National Pesticides Survey. The survey is coordinated by the Institute of Environmental Science and Research (ESR). The Council has been participating in the survey since it began in 1990. The last survey took place in 2018 and results reported in Section 4.9. The next survey is scheduled to take place in 2022. In addition to the ESR National Pesticides Surveys, the Council independently tested groundwater samples from 30 wells for pesticides in 1995.

2.2.3. Data checks, processing and presentation

Groundwater quality samples are collected as per Council protocols[2] and to national groundwater sampling protocols (MfE 2006). This ensures that data collected from field measurements or returned from Hill or IGNS laboratories is entered correctly into the Council's LAB database.

For quality assurance purposes, duplicate samples from up to 10% of all groundwater sites sampled for this programme were submitted to an accredited external laboratory for comparative analysis. Results from this quality check show consistently good agreement between original and duplicates sample results. Further quality control checks of both laboratory and field data are carried out following each sampling round. These checks are intended to identify any results that differ significantly from the expected values at a sampling site. Any outliers are flagged and checked to ascertain if they are a representative result, or are a result due to sampling collection, analysis or data entry error. Box and whisker plots were generated in R and follow Turkey style as explained in Figure 3.

[2] Council Procedure 44 internal document #31364121

Table 2 Key variables used to summarise the current state and trends of groundwater quality in the Taranaki region (Source: Moreau et al 2016 and MfE 2019)

Variable	Explanation for inclusion as a key variable	DWSNZ (2008) MAV (Health protection)	DWSNZ (2008) GV (Aesthetic protection)	ANZECC (2000) TV (Stock drinking water)	ANZECC (2000) TV (Aquatic toxicity)	NPS-FM (2020) (Aquatic toxicity)	Other
Electrical conductivity (EC)	EC values are useful in providing an indication of spatial and temporal variations in groundwater composition due to changes in natural processes, recharge sources, or human activities like over abstraction, saltwater intrusion or land use.	-	1,000 mg/L	2,000-2,500 mg/L	-	-	-
Bicarbonate (HCO_3)	Bicarbonate is a major anion species, present in groundwater due to several geochemical processes, including: interactions between the soil zone and atmospheric water and carbon dioxide, mineral dissolution and redox processes. Bicarbonate can also be a potential indicator of intensive land use impact where fertiliser is applied to land (Rosen, 2001).	-	-	-	-	-	-
Chloride (Cl)	Chloride is relatively unaffected by geochemical processes which makes it a good indicator of general groundwater quality. The primary source of chloride in groundwater is marine sourced rainfall recharge to an aquifer. However, saltwater intrusion and land use activities, such as wastewater and effluent discharges, can contribute chloride to groundwater.	-	250 mg/L	-	-	-	-
Sodium (Na)	Sources of sodium in groundwater include marine derived rainfall recharge, geochemical processes and weathering of sodium bearing rock within an aquifer. Sodium can also be indicative of groundwater contamination from industrial, agricultural and domestic sources.	-	200 mg/L	-	-	-	-
Iron (Fe)	Iron is only soluble in groundwater under oxygen depleted conditions. Its presence can aid the interpretation of ammonia and nitrate concentrations. Taranaki is dominated by volcanic geology so iron commonly occurs in regional groundwater.	-	0.2 mg/L	-	-	-	-
Fluoride (F)	Fluorine is a common component of many minerals in the Earth's crust. Therefore, fluoride can occur naturally in groundwater, sometimes at levels above those recommended for protection of human and stock health.	1.5 mg/L	-	2 mg/L	-	-	-
Bromide (Br)	Bromide is naturally abundant in sea water (≥65 mg/L) and as bromine the Earth's crust. Elevated concentrations of bromide in freshwater may be due to saltwater intrusion or contamination from fire retardants, pesticides and herbicides.	-	-	-	-	-	Adults: 6 mg/L Children ≤10 Kg: 2 mg/L (WHO, 2017)
Manganese (Mn)	Similar to iron, manganese is only soluble in oxygen depleted groundwater and can aid the interpretation of ammonia and nitrate concentrations. Manganese can naturally be found in Taranaki aquifers given the region's dominant volcanic geology.	0.4 mg/L,	0.04 mg/L	-	1.9 mg/L	-	-
Nitrite nitrogen (Nitrite)	Consumption of groundwater with excessive concentrations of nitrite can adversely affect human and stock health.	0.06 mg/L	-	30 mg/L	-	-	-
Nitrate nitrogen (Nitrate)	Nitrate contamination can indicate impact from anthropogenic activity such as intensive land use and is a national indicator of groundwater quality.	11.3 mg/L	-	-	-	Annual median: 2.4 mg/L 95th percentile: 3.5 mg/L	-
Ammoniacal nitrogen (Ammonia)	Ammonia usually exists in oxygen depleted groundwater as the reduced form of nitrogen (compared to the oxidised form nitrate). Conversely, ammonia can be transformed to nitrate in oxygen rich groundwater. Ammonia can indicate the occurrence of nitrogen contamination in groundwater where naturally reduced aquifer conditions may convert nitrate to ammonia. Contaminant sources can include fertiliser, effluent, landfill and industrial discharges to land and/or groundwater. The decomposition and reduction of naturally occurring organic matter within an aquifer can also contribute ammonia to groundwater.	-	1.5 mg/L	-	-	Annual median: 0.24 mg/L 95th percentile: 0.4 mg/L	-
Escherichia coli (*E. coli*)	*E. coli* is a species of bacteria lives in the lower intestine of warm-blooded organisms. Its presence in groundwater indicates faecal matter contamination within an aquifer and the potential presence of other pathogenic bacteria, protozoa and/or viruses.	<1 cfu/100mL	-	100 cfu/100mL (median)	-	-	-

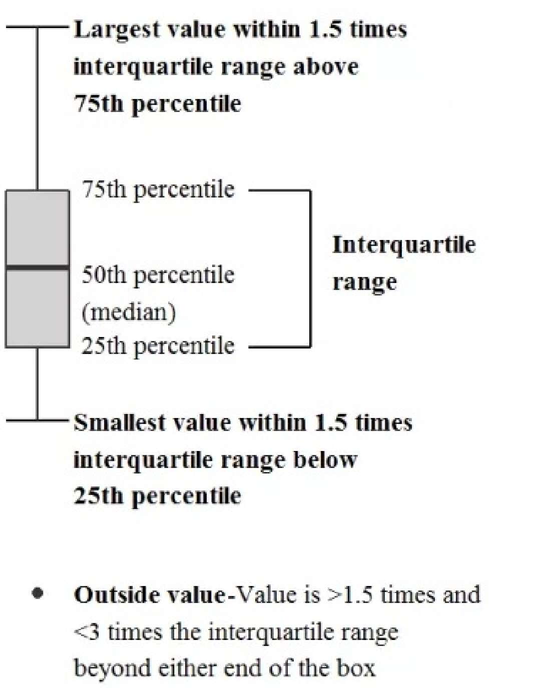


Figure 3 Summary statistics defined by Turkey boxplots used to report on the State of Groundwater Quality measurements

Note: *In order to present median and quartiles values graphically on boxplot, values that were below detection limits were set at the most common detection limit threshold (opposed to the most conservative value). Therefore, any values below these detection limits should not be directly interpreted.*

2.2.4. Summary statistics and current state analysis

Summary statistics have been calculated using the last five years of monitoring data (1 July 2015 to 30 June 2020) when there is at least 75% data coverage over the time period (i.e. data from at least 15 of the scheduled 20 samplings is available). Where this criteria has not been satisfied, summary statistics based on the last two years of monitoring are presented. These two-year summaries are indicative only and are denoted as such in the reported summary tables. Commentary on the state of groundwater quality is based on data for 12 key indicator variables as outlined in Section 2.2.2.

Wherever possible, censored data has been handled using the NADA package in R software (vers. 1.6-1.1; Lopaka Lee, 2020). Left censored data has been replaced with imputed values using regression on order statistics (ROS). This method fits a distribution to the non-censored values in the data record and uses the resulting model to impute replacement values for the censored data.

Summary statistics have been evaluated using the following methods:

- Where there is no censored data in the dataset, regular summary statistics have been calculated.
- Where the dataset consists of less than 70% censored data, ROS has been used to evaluate data below the censor limit. Depending on the proportion of censored data, this may affect percentile and median assessments. The minimum has been reported as equal to the lowest censor limit.
- Where the dataset consists of 70% or greater censored data, there is insufficient non-censored data to robustly perform a ROS evaluation. In these cases, regular summary statistics have been calculated to give an indication of results at the site. The minimum and median statistics have been reported as equal to the lowest censor limit.

2.2.5. Temporal trends analysis

Trend analysis has been undertaken for the 12 key variables sampled outlined in Section 2.2.2. Trend analysis has been carried out using the LWP-Trends library R package (version 1901), developed by Land Water People Ltd. (Snelder and Fraser, 2019). The methods employed have the primary purpose of establishing the direction and rate of any trend, along with a measure of the uncertainty in the result. Trend analysis is undertaken using the last 10 years of monitoring data (1 July 2010 to 30 June 2020) when the following criteria have been satisfied:

- There is at least 75% data coverage over the time period (data from at least 30 of the 40 scheduled samplings is available).
- The dataset consists of less than 70% censored data.

As a first step in the trend analysis, a visual inspection of the raw time-series data is undertaken, giving a view of the proportion and temporal distribution of censored data. A Kruskal-Wallis test (using a threshold of $\alpha=0.05$) is then employed to determine whether there is seasonality in the data.

Depending on the result of the seasonality test, a non-parametric Mann-Kendall or seasonal Kendall test is used to determine the direction of a monotonic trend through the time-series data. Trend rate, and the confidence in trend rate, are evaluated using Sen-slope regression of observations against time. This is a non-parametric regression procedure, where the Sen-slope estimate (SSE) is taken as the median of all possible inter-observation slopes (Hirsch et al. 1982). Where there is more than one observation within one season, the median of the observations is used in SSE assessments. In calculating the Kendall S statistic, censored data are dealt with as robustly as possible, following the methods of Helsel (2011), this allows inter-observation increases and decreases to be identified whenever possible (Snelder and Fraser, 2019). In calculating the SSE, censored data are replaced by a value 0.5x the highest common censor limit. While this biases inter-observation slopes associated with censored data, in most cases with a small proportion of censored data, the median slope will be unaffected.

Usually, when the SSE is affected by censored data this indicates that the trend rate is smaller than can be detected. Trends noted as being affected by censored data are critically analysed to assess if the resulting statistics are meaningful or not. In a small number of cases, trend assessment is not carried out due to there being insufficient unique data. This occurs when there are <5 non-censored data, or if there are <4 unique non-censored values.

In this report, the assessment of confidence in trend direction moves away from the traditional null hypothesis significance testing (NHST) approach used in previous reports, and instead follows the recommended credible interval assessment method of McBride (2019). Using this method, the reported trend direction (from the Kendall S statistic), is accompanied by the associated confidence in that trend direction being true. Confidence levels are categorised as in Table 3.

Table 3 Confidence categories for trend direction results

Trend Category	Confidence in direction
Very likely improving	90-100%
Likely improving	66–90%
Indeterminate	50-66%
Likely degrading	66–90%
Very likely degrading	90-100%

It is noted that the trend analysis methods implemented above are constrained to identifying a monotonic (single direction) trend through any time-series. In many cases, however, environmental data is not monotonic, with a change of conditions or individual events resulting in changes of behaviour at monitoring sites. To account for this, a Loess curve has been overlaid on trend-analysis plots to allow for a qualitative assessment of any non-monotonic trends, and further investigation into the possible cause of any change of behaviour.

Furthermore, it is important that while a trend direction is always reported this needs to be considered alongside the given confidence in that direction assessment, and the absolute and relative scale of the trend. Here, the SSE is used as a measure of absolute rate of change in a variable, while the percent annual change is calculated as ratio of the SSE to the median level of the variable at the site.

The term 'environmentally meaningful' used in this report defines where variable concentrations or levels over the ten year monitoring period have been shown to be changing, not only within a high degree of confidence, but at a rate that is significantly altering the quality of the groundwater at a particular location. Note, changes in groundwater quality can have both an overall positive or negative impact on a receiving environment or a resource, such as potable water supplies.

There are no groundwater quality guidelines which outline acceptable rates of change for individual variables. However, analysis of national groundwater quality data by Daughney and Reeves (2006), and Daughney and Randall (2009) suggests rates of change which are less than ±2% and ±5% per year, for major and minor elements respectively, are slow and may reflect natural processes. These suggested rates of change have been used in consideration of temporal trends in this report. However, all trends reported here were also evaluated for environmentally meaningfulness individually by collectively considering median values (from analysis of state), data range and distribution, and the rates of change. Daughney and Reeves (2006) further indicated that an absolute rate of change greater than ±0.1 mg/L nitrate in groundwater was most likely due to human influence and is included in this report as a measure of an environmentally meaningful trend.

3. Overview of groundwater in the Taranaki

This section provides an overview of factors influencing regional groundwater in Taranaki. Factors include both natural processes, such as geology and recharge mechanism, and pressures from human influence. Significant consented activities, with the potential to impact on groundwater quality, are also summarised.

3.1. Regional hydrogeology and groundwater systems

The majority of the unconfined aquifer systems in the region are located within the volcanic ring plain and the Marine Terrace deposits. Collectively, much of the region's groundwater abstraction occurs within these unconfined aquifers. Unconfined, semi confined and confined aquifers are located in the Eastern Hill Country, or at depth beneath the volcanic ring plain and marine terraces. Although groundwater abstraction occurs to a lesser extent in semi confined and confined aquifers, yields from regional confined aquifer systems can be considerable, particularly from the Whenuakura and Matemateaonga Formations. Figure 4 illustrates the distribution and complexity of the major geological units of Taranaki, which contain the region's predominant aquifer systems:

- Taranaki Volcanics formation aquifer
- Marine Terrace formation aquifer
- Whenuakura formation aquifer
- Matemateaonga formation aquifer

Generally, regional aquifers are recharged by rainfall infiltration. Limited investigations of aquifers in the Eastern Hill Country suggests surface water recharge to groundwater can occur in the region, see Section 3.2.1(a). However, this has not been explored extensively in the wider region. A number of spring-fed streams originate within the Te Papakura o Taranaki and at lower elevations across the ring plain. It is documented that many rivers on the ring plain derive up to 80% of their base-flow from within Te Papakura o Taranaki (TRC 1996). Regionally, groundwater flow paths generally radiate out from Taranaki Maunga (Mount Taranaki) or from the Eastern Hill Country towards the coast. However, the complex geology of the Taranaki region does create localised flow paths in some areas, Figure 4 details the cross-sections of regional geological conditions and intersections.

The Taranaki region receives regular and high volumes of rainfall throughout the year, due to the region's exposure to the prevailing westerly winds. Westerly winds push air, rich with water vapour from the Tasman Sea, over the dominant mountain topography. Rainfall volumes increase rapidly with elevation away from the coast and in the Eastern Hill Country, as the air is forced to drop moisture in order rise to greater elevations. The high rainfall volumes across Taranaki generally ensure rainfall surpluses are available to regularly recharge the region's aquifers, particularly where groundwater recharge zones are located in elevated areas of Taranaki Maunga or the Eastern Hill Country. For more information on rainfall and climate variability in the Taranaki region, refer to the latest SEM Groundwater Quantity report (TRC 2022).

3.1.1. Taranaki Volcanics Formation

Eruptions and lahars from Taranaki Maunga, during the Quaternary Period, have deposited volcanic material from the coastal boundary in the west, to the Taranaki Basin Tertiary deposits in the north and north-east. While a number of volcanic debris avalanche deposits, from the periodic collapse of Taranaki Maunga, dominate lithologies to the west and south of Taranaki (Roverato et al 2014). The area is bounded to the north and south by Quaternary Marine Terrace deposits, and is often described as the volcanic ring plain. Volcanic deposits comprise both coarse material (sands, breccia and agglomerates) and fine material (clay, tuff and ash), which create irregular rock sequences and hydrogeological conditions (Taylor and Evans, 1999). Subsequently, a complex system of unconfined, perched and semi confined aquifers exist within the volcanic deposits and are collectively known as the Taranaki Volcanics Formation aquifer.

The water table within the Taranaki Volcanics aquifer is typically encountered between 1 to 10 m below ground level, although there can be seasonal variations of up to 5 m. Groundwater flow generally reflects surface topography, and flows radially out from Taranaki Maunga. The Taranaki Volcanics aquifer is recharged mainly by rainfall infiltration, with possible contributions from stream and river bed leakage. Groundwater discharges at numerous puna wai (springs) and provides baseflow to the many rivers and streams that traverse the ring plain. Yield from the unconfined Taranaki Volcanics aquifer is generally low (0.5 L/s to <3 L/s), while confined volcanic aquifers beneath the Kaitake Ranges, New Plymouth, Okato and Kapuni may yield higher volumes (8 L/s to 20 L/s).

3.1.2. Marine Terrace Formations

Marine Terrace deposits occur in coastal areas south of Hawera (overlying the Whenuakura formation), and north of New Plymouth. Basal units comprise marine sands, often with conglomerate or shell layers, and progressively grade into terrestrial sediments (e.g. peat) with localised iron pans towards the surface. Formation of the Marine Terraces is attributed to sea level fluctuations and progressive uplift at the coastal areas. Lithological units within the Marine Terrace deposits range up to about 40 m in thickness, and can contain multiple unconfined aquifers.

The water table within the Marine Terrace aquifers generally lies between 1 to 15 m below ground level, while groundwater flow is generally a subtle reflection of surface topography towards the coast. Marine Terrace aquifers are unconfined and primarily recharged by rainfall infiltration. Groundwater composition and quality are highly variable, while yield can vary (0.3 L/s to <4 L/s) dependent on well or bore location and construction methods.

3.1.3. Tertiary Sedimentary Formations

There are nine Tertiary sedimentary formations recognised in the region, all of which dominate various areas throughout the Eastern Hill Country. The Otunui and Mount Messenger formations are fully exposed in the north of the region, while the remaining seven formations are exposed but continue beneath the Taranaki Volcanics and Marine Terrace formations. All formations tilt gently from the Eastern Hill Country towards the southwest of the region with groundwater flow generally following the same line out to sea.

Little is known about groundwater use in the Otunui and Mt. Messenger formations, while the Urenui Formation is regarded as an aquitard with no groundwater. In all other formations, shallow wells and bores draw from both the low yielding unconfined aquifers, and from the deeper more productive confined aquifers. High yields have been reported at bores drawing from confined aquifers in the Kiore Formation at Bell Block (35 L/s), Matemateaonga Formation at Kapuni and Eltham (7-20 L/s), and in the Whenuakura Formation at Pātea and Waverley (8-10 L/s).

Aquifers in the Whenuakura and Matemateaonga formations generally provide higher yields than the region’s shallow unconfined aquifers, and have the greatest volume of groundwater abstraction in the region. Recharge to these aquifers is not well understood. However, limited environmental isotope measurements suggest that recharge may occur through overlying unconfined volcanic and marine terrace deposits, and where the formations are exposed at the surface in the Eastern Hill Country (TRC 1996). Due to depth and confinement, aquifer systems within the Whenuakura and Matemateaonga formations are less susceptible to contamination from land use, and may exist under artesian conditions.

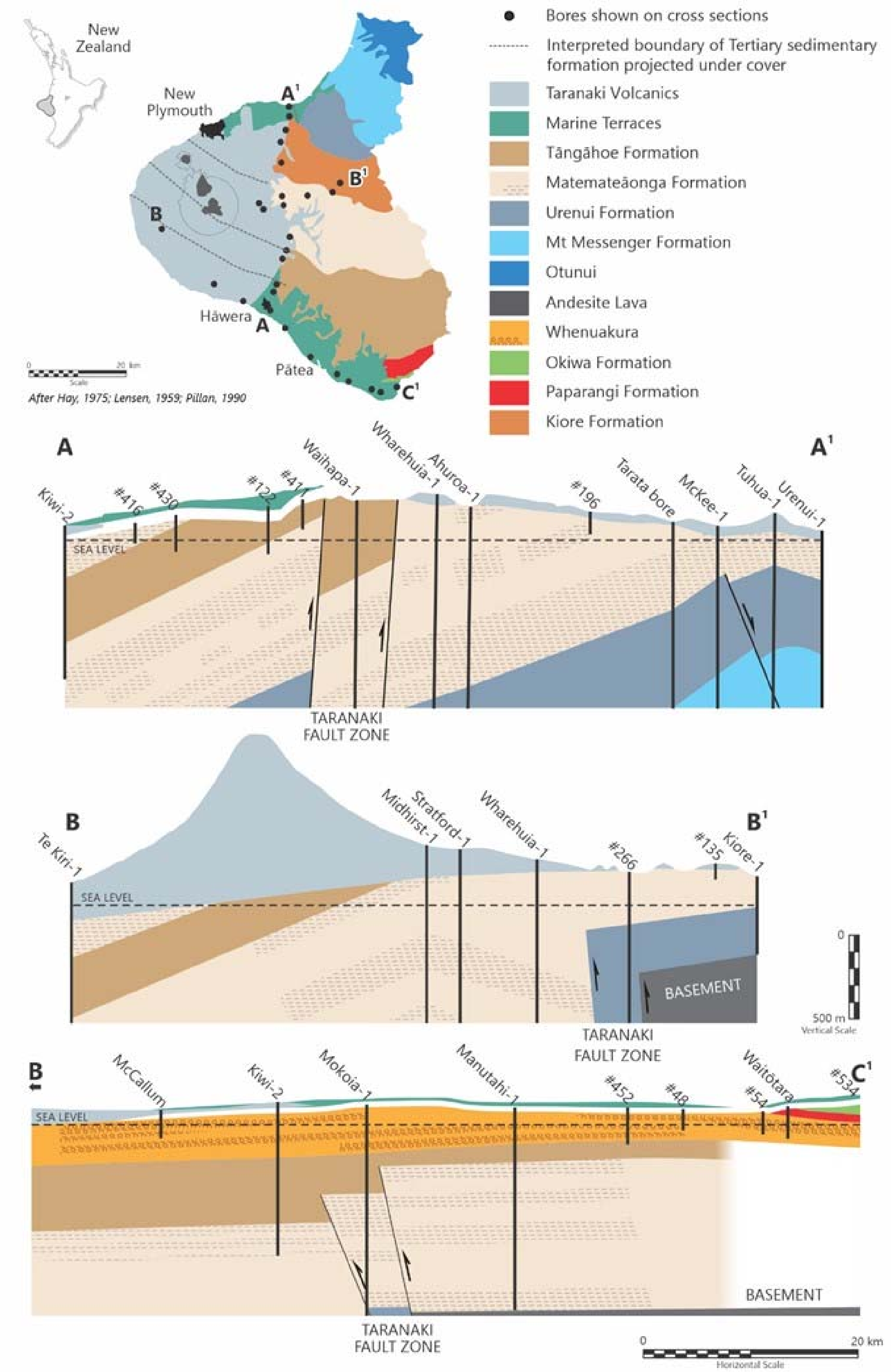


Figure 4 Distribution of the main geological units which form the major aquifer systems in the Taranaki region (Source: Brown 2013 and TRC 1996)

3.1.4. The influence of regional soil characteristics on hydrology

The properties of soil overlying aquifer recharge areas are an important consideration when ascertaining likely areas of rainfall infiltration and hydrochemical influences. Soils in the Taranaki region can broadly be categorised into four groups based on location (See Appendix III). The north and south-eastern slopes of Mount Taranaki are dominated by rapidly free-draining Typic Orthic Allophanic soils (e.g. Egmont Loam) derived from andesitic tephra eruptions. Debris avalanche deposits, from the periodic collapse of Taranaki Maunga on the western slopes, form stony and poorly drained Gley Allophanic soils on the western slopes. Shallow, erosion prone Orthic Brown soils, formed from uplifted tertiary marine sediments such as mud, silt and sand stones, dominate the Eastern Hill Country. Meanwhile, free draining Sandy Brown and Recent soils occupy patches of the region's coastal areas, especially south of Hawera through to Waitotara. However, localised iron pans impede drainage in some areas. (Manaaki Whenua 2020, Molloy 1998, TRC 1996). See Figure 5 for soil drainage classifications overlying regional aquifer recharge areas.

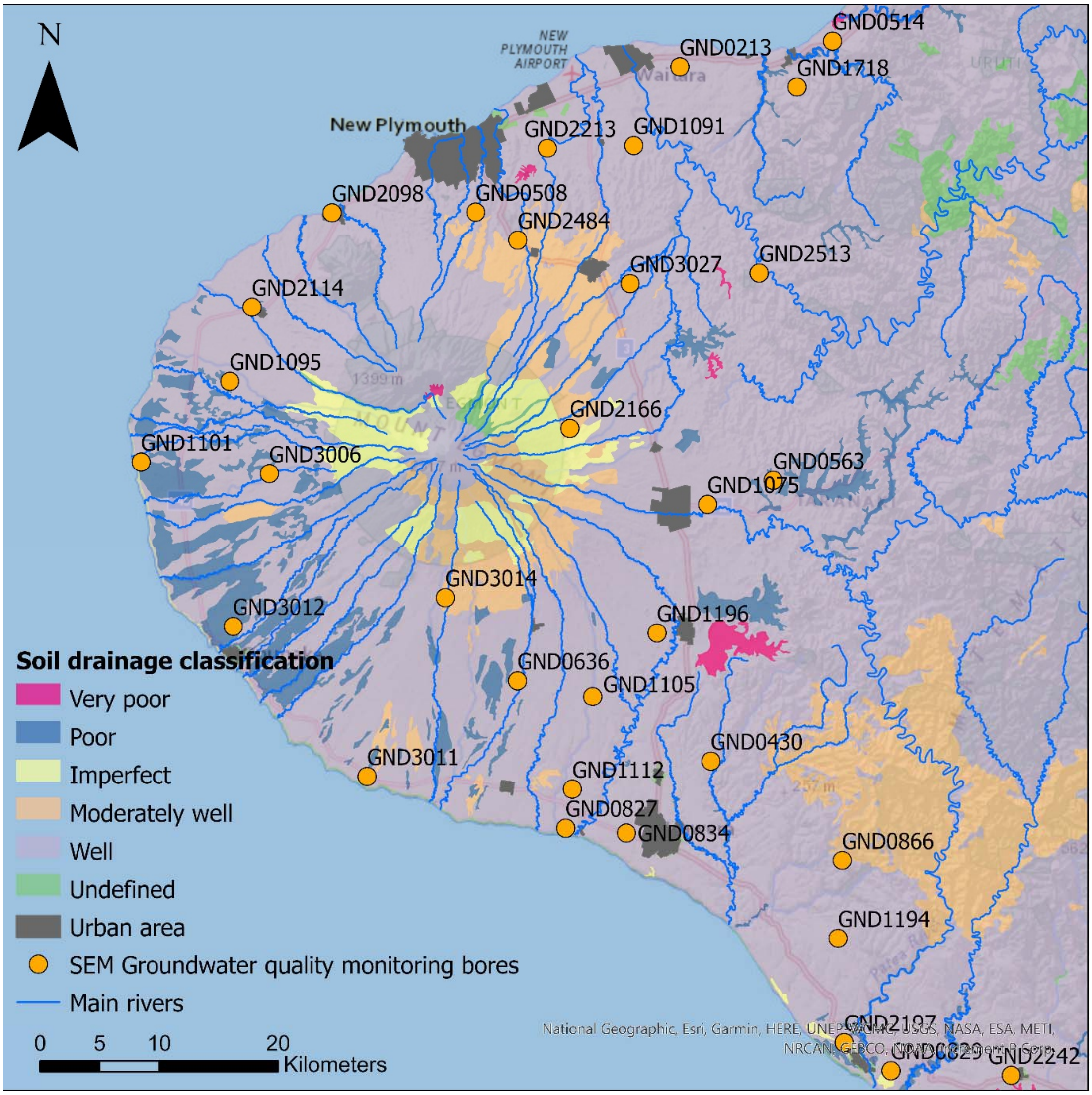


Figure 5 Soil drainage classification for the Taranaki region (Source: Landcare Research NZ 2000)

Soils in the ring plain area are highly productive for the growth of pasture or other crop types, while hill country soils support sheep and beef farming, and forestry (Molloy 1998). In general due to their marine or volcanic origins, regional soils have a great tendency to retain phosphorus within the soil profile where it is not available for plant growth. Further to this, soils in Taranaki are similar to most New Zealand soil in being slightly acidic (except on the coastal terraces about Hawera to Waverley and within debris avalanche deposits to the west of Taranaki Maunga), with low levels of potassium, sulphur, available phosphorus and nitrogen. To maintain or increase levels of soil productivity, lime and fertilisers have been applied to land to neutralise soil acidity and supplement soil nutrient and trace elements levels (Gillingham 2008, Manaaki Whenua 2020, Molloy 1998 and Fertiliser Association 2021).

3.2. Influences on groundwater quality

Given water is a very good solvent, minerals, salts and contaminants can easily be dissolved into, and transported by water. Aquifer geology, water residence time within an aquifer and land use activities in the recharge zone can all cause variation in the chemical composition of groundwater between aquifers or even spatially within the same aquifer.

3.2.1. Natural processes

Natural processes such as recharge mechanisms, interactions between water, rock and soil, and residence time directly influence the chemical composition of groundwater. Environmental conditions of the aquifer (like presence or absence of oxygen in groundwater) can encourage natural hydrochemical and microbial interactions, which further influence groundwater quality.

3.2.1.1. Aquifer recharge

Rainfall that seeps from the land’s surface, or river water that flows through the river bed to replenish an aquifer is known as recharge. While predominantly a naturally occurring process, recharge can also occur as a result of human activities such as irrigation or wastewater injection. The area where recharge occurs is called the recharge zone. Groundwater within a well or bore may have entered the aquifer via a recharge zone that is nearby, or many kilometres away, see Figure 6.

Unconfined aquifer systems in the region are predominantly recharged by infiltration of local rainfall. The volume of aquifer recharge can vary with changes in rainfall and evapotranspiration, and as a result of differing land use and vegetation cover, soils and geology. Most rainfall in Taranaki occurs during late autumn and winter through to early spring. Consequently, recharge rates peak over these periods. Lower rainfall volumes over summer, result in reduced recharge rates and lower groundwater levels.

Seepage, from rivers and streams, also contribute to aquifer recharge. Water in the Whenuakura River and groundwater samples from the Whenuakura aquifer at Waverley are chemically similar, suggesting that the Whenuakura River provides significant recharge to confined aquifers in South Taranaki (TRC, 1992). The Pātea River may also provide significant recharge to the Whenuakura aquifer, particularly where the formation is exposed at the surface in the Eastern Hill Country (Taylor and Evans, 1999). The contribution of surface water systems to aquifer recharge varies with changes in river flow and as a result of local geology.

3.2.1.2. Groundwater residence time

In general, the further along a flow path, or the slower the groundwater flow rate, the older and more reduced (oxygen depleted) the groundwater is likely to be, see Figure 6. Groundwater closer to the point of recharge or within an aquifer with greater transmissivity is typically younger and more oxidised (oxygen rich). Groundwater age/residence time and concentration of dissolved oxygen can also depend on where groundwater discharge or abstraction of an aquifer occurs.

Age dating of groundwater abstracted from the Taranaki Volcanics aquifer using tritium isotopes indicated that the water is generally less than 2 years old (TRC, 2008). This suggests the groundwater is either young or recently recharged. In contrast, age dating analysis by Taylor and Evans (1999) indicated that Whenuakura and Matemateaonga aquifer systems contain very old water, in some instances over tens of thousands of years old.

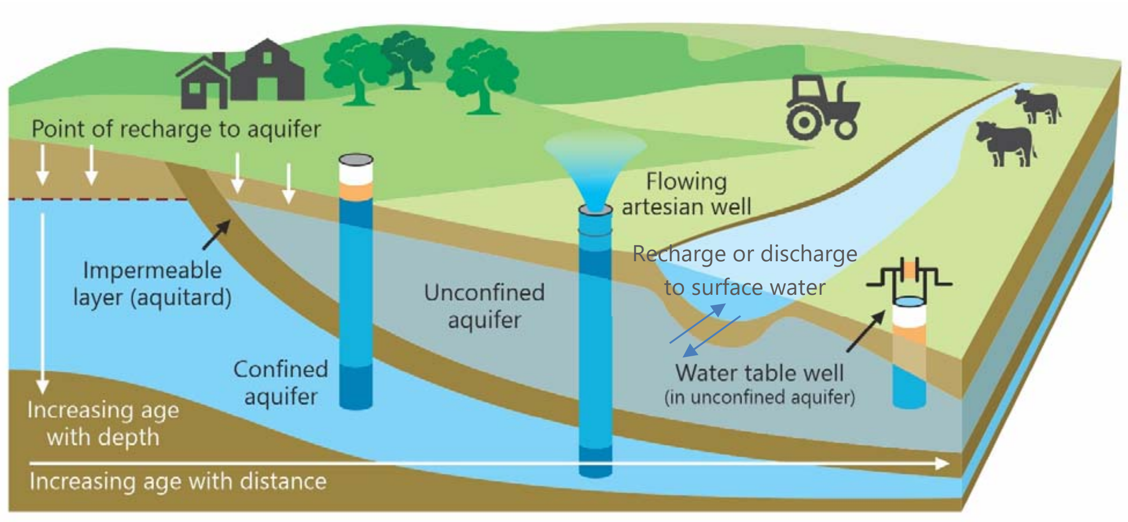


Figure 6 An overview of aquifer types, recharge mechanisms, groundwater flow paths and residence times (Source: modified from Environment Canada)

Note: *In the unconfined aquifer, groundwater is pumped to the Earth's surface. However, pressure in the confined aquifer can cause groundwater to flow to the surface without the use of a pump (flowing artesian well).*

3.2.1.3. Rock-water interaction

As water moves through aquifers, it interacts with soils and rock, dissolving ions (such as calcium, magnesium, bicarbonate or iron) from salts and minerals. Some soil and rock types dissolve into water more easily than others, which can give groundwater chemical characteristics that are unique to individual aquifers or specific types of aquifers.

The degree of rock-water interaction occurring within an aquifer is a function of groundwater recharge mechanisms, aquifer confinement and residence times. Concentrations of ions generally increase as contact time between aquifer lithologies and groundwater increases. Highly transmissive or recently recharged aquifers (usually unconfined) typically have lower concentrations of dissolved ions, reflecting less rock-water interaction. However, these aquifers may be more susceptible to surface contamination from land use activities, see Section 3.2.2.

Aquifers with low transmissivities, increasing confinement and groundwater residence times, tend to have greater concentrations of dissolved ions. Increases in depth, confinement and age can lead to groundwater becoming more saline in nature as it evolves to be more like seawater (Chebotarev 1955). Therefore, the hydrochemical signature of groundwater can provide an indication of groundwater age and aquifer characteristics.

The influence of water-rock interactions is apparent in groundwater quality data collected by the Council. Elevated concentrations of iron and manganese in the region's shallower volcanic aquifers is influenced by the weathering of volcanic rock. Both the Marine Terraces and Taranaki Volcanic formations typically reflect a water type that is sodium chloride/calcium chloride in nature. Variable concentrations of carbonate minerals (e.g. magnesium bicarbonate or sodium bicarbonate) are more typical of groundwater in the region's deeper confined aquifers, within sedimentary rock sequences like the Matemateaonga and Whenuakura formations (TRC 1996).

3.2.1.4. Geochemical and biogeochemical processes

The chemical composition of groundwater can be significantly influenced by geochemical and biogeochemical processes. Geochemical processes include the formation of carbonic acid in the soil profile, due to interactions between organic matter in the soil and atmospheric water and carbon dioxide. The carbonic acid can then migrate into the underlying aquifer, lowering groundwater pH values in the water body. Biogeochemical processes include interactions between components that are non-living (soil, rock, air and water) and living (plants, animals, fungi and bacteria).

Redox reactions are the most common biogeochemical processes influencing the composition and concentration of ions within groundwater. Redox (reduction/oxidation) is the transfer of electrons between ions which are derived from groundwater interactions with surrounding aquifer lithology. An ion becomes 'oxidised' when it donates electrons (resulting in a loss of energy), and 'reduced' when it receives electrons (resulting in an energy gain). Bacteria in groundwater encourage redox reactions to harness the energy which is released. Bacteria prefer to use dissolved oxygen as an electron receiver as it provides the most energy gain. However, where dissolved oxygen is absent or becomes depleted, bacteria will utilise other electron receivers in successive order of preference, from dissolved oxygen, nitrate, manganese, iron, sulphate to carbon dioxide.

Reduced forms of some chemical species are more soluble in water than their oxidised forms and can result in the natural accumulation of manganese, iron, sulphide, methane and arsenic in oxygen poor groundwater (Daughney & Wall 2007). Denitrification refers to the biologically driven redox reaction where nitrate is reduced to nitrogen. Stages of the denitrification cycle can also include the reduction of nitrate to ammoniacal nitrogen within an aquifer. This can be important when considering the nitrate attenuation capacity of an aquifer underlying land use activities with the potential to leach nitrate.

A 2016 investigation by the Council and Lincoln Agritech, (Strenger and Clague 2016) into the redox state of groundwater in the GQMP sites, indicated that oxic groundwater was most prevalent in wells located in the shallow unconfined aquifers SGWM network. However, it should be noted that the SEM monitoring network is dominated by wells located within unconfined aquifers. There were six SGWM network wells that were drawing primarily anoxic groundwater, which suggests denitrification and attenuation is taking place in some areas of the region's unconfined aquifers. Groundwater was generally classified as anoxic within the region's confined aquifers. A small number of sites display variability in their redox state, some of which is seasonal.

3.2.2. Anthropogenic influences on groundwater quality

Contaminants arising as a result of anthropogenic (human) activities have the potential to adversely impact groundwater quality across both urban and rural settings. Contaminant sources with the potential to adversely affect groundwater quality can be divided into two broad groups; point and non-point source (diffuse).

Point sources pollution describes situations where a contaminant is directly discharged from a specific point or location. Point source pollutants in groundwater are usually found in a plume that has the highest concentrations of the pollutant nearest the contaminant source. Contaminant concentrations will generally decrease with distance from the point source. Point source discharges can include those from septic tanks, leaking effluent treatment ponds, underground storage tanks and pipelines.

Diffuse pollution is the accumulation of contaminants within the environment from an activity, or a range of activities, rather than being from a single specific point. Diffuse pollution is characterised by its occurrence across a large area, as opposed to the plume effect associated with point source discharges. It is often difficult to trace the exact origin or fate of contaminants generated through diffuse processes due to their cumulative nature, and the impact of soil, geology and groundwater flow on contaminant attenuation and distribution. Consequently, the management of diffuse pollution is challenging.

Diffuse pollution arises as a result of land use activities. Given its predominance across Taranaki, agricultural land use constitutes the region's greatest potential source of diffuse contaminants. These include the contaminants from animal excreta and land application of fertiliser and effluent. Specific contaminants associated with agricultural land use with the potential to adversely impact groundwater quality include nutrients, primarily in the form of nitrate, and faecal bacteria. Land use effects, and specifically those associated with agricultural land use, are discussed further below.

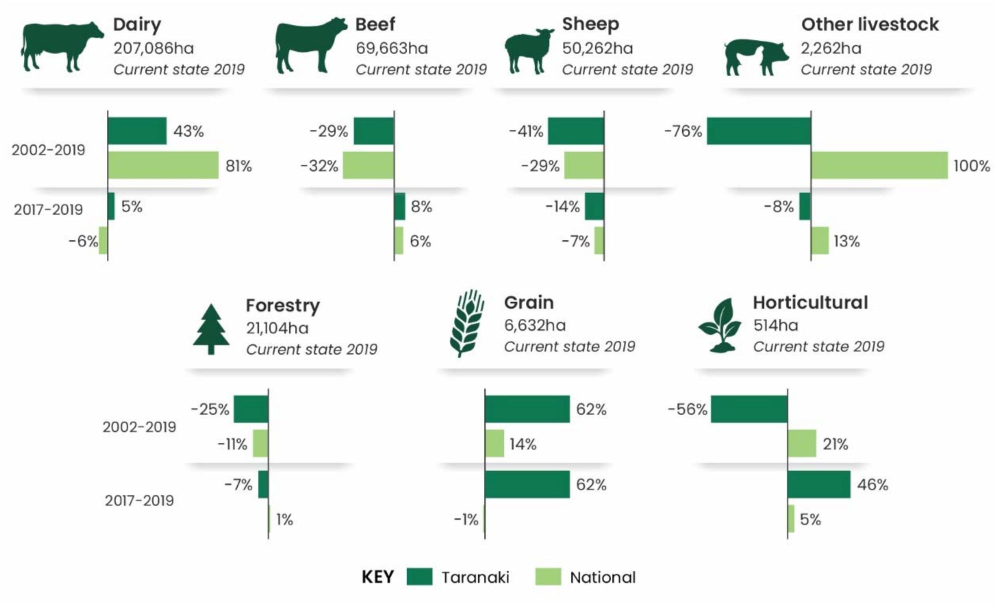
3.2.2.1. Land use effects

Around half of the Taranaki land area is used for agriculture and horticulture. Dairy farming remains the predominant land use, accounting for 207,086 ha, or 58% of land used for primary production in 2019. The area utilised for dairying across Taranaki has increased by 62,095 ha (43%) since 2002, primarily through conversion from dairy support or extensive sheep and beef pastoral farming. Much of this change occurred prior to 2012, and has slowed considerably in recent years. While there is some dairy farming in the lower hill country, most occurs on the ring plain of Taranaki Maunga and on the marine terraces in northern and southern coastal areas.

Sheep and beef farming occurs mainly on the steeper, less fertile slopes of the Taranaki eastern hill country. Land used for sheep and beef farming in Taranaki has reduced by 35,389 ha (-41%) and 28,901 ha (-29%) respectively since 2002. The decline in the area used for sheep farming has continued in recent years, reducing by 8,128 (-14%) since 2017, however the beef farming area has increased by 5,376 (8%) over the same period. These trends generally follow those seen elsewhere in New Zealand.

Horticulture and grain production accounts for just 7,146 ha (2%) of the total area used for agricultural and horticultural production in Taranaki, with less than 1% in horticultural land use. However, this is increasing. Between 2017 and 2019 the area in grain production grew by 2,540 ha (62%), and horticultural land use by 162ha (46%).

As of 2019, there were about 587,000 dairy cattle in Taranaki, up 4% (24,000 cows) from 1990. Nationally, the total dairy herd increased 82% over the same period. However, from 2014 to 2019, dairy cattle numbers remained steady in Taranaki, while nationally there was a 7% decline. As of 2020, the average stocking rate for dairy cattle in Taranaki was 2.78 cows/ha, in-line with the average stocking rate across North Island dairy farms. While cow numbers and associated stocking rates have been relatively stable in Taranaki over recent decades, the amount of milk solids being produced has increased by approximately 35% since 2000 (LIC, 2000, 2020) This increase in production is likely due to a range of factors, including improved herd management practice, breeding and genetics, but also supported by higher farm inputs in the form of fertilisers and supplementary feeds.



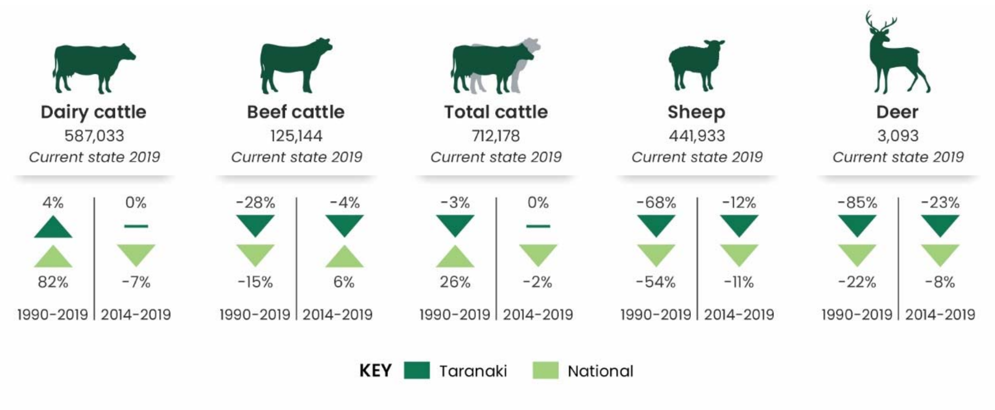


Figure 7 Changes in land use (top) and livestock numbers (bottom) in Taranaki over time

4. State of groundwater quality

Descriptive statistics were derived for the 12 key indicators to assess the state of groundwater quality in the region. Table 4 provides a summary of descriptive statistics for nine key indicators based on data collected over the last five or two years from GQMP sites. Note that the two year summary statistics are provided for indicative purposes only, and robust analytical conclusions should not be made based on this data.

Median concentrations for nitrite nitrogen, fluoride and bromide in groundwater were generally below their respective laboratory detection limits, or were well below DWSNZ (2018) or WHO (2017) MAVs. They have therefore not been included in Table 4 or reported on specifically in this section. These variables are still commented on in the following section on temporal trend analysis.

4.1. Electrical conductivity (EC)

Electrical conductivity is a general indicator of changes in groundwater composition. These changes could be the result of natural processes or human activities, including seawater intrusion or land use. Typical EC values in freshwater range from 300 μS/cm to 800 μS/cm (Hem 1985).

EC values can also be used to approximate concentrations of total dissolved solids (TDS) using the formula TDS (mg/L) = k x EC (μS/cm), k is the ratio of TDS/EC with a typical value of and k = 0.55 (HEM 1985). The DWSNZ (2018) GV taste threshold for TDS of 1,000 mg/L. While the ANZECC (2000) stock water TDS threshold is 2,000-2,500 mg/L to prevent decline in stock productivity.

Median electrical conductivity measurements across the region ranged from 66 μS/cm (GND2166) to 696 μS/cm (GND2513), (Table 4). No approximated median value exceeded the DWSNZ (2018) GV of 1,000 mg/L or ANZECC (2000) stock water threshold of 2,000-2,500 mg/L for TDS.

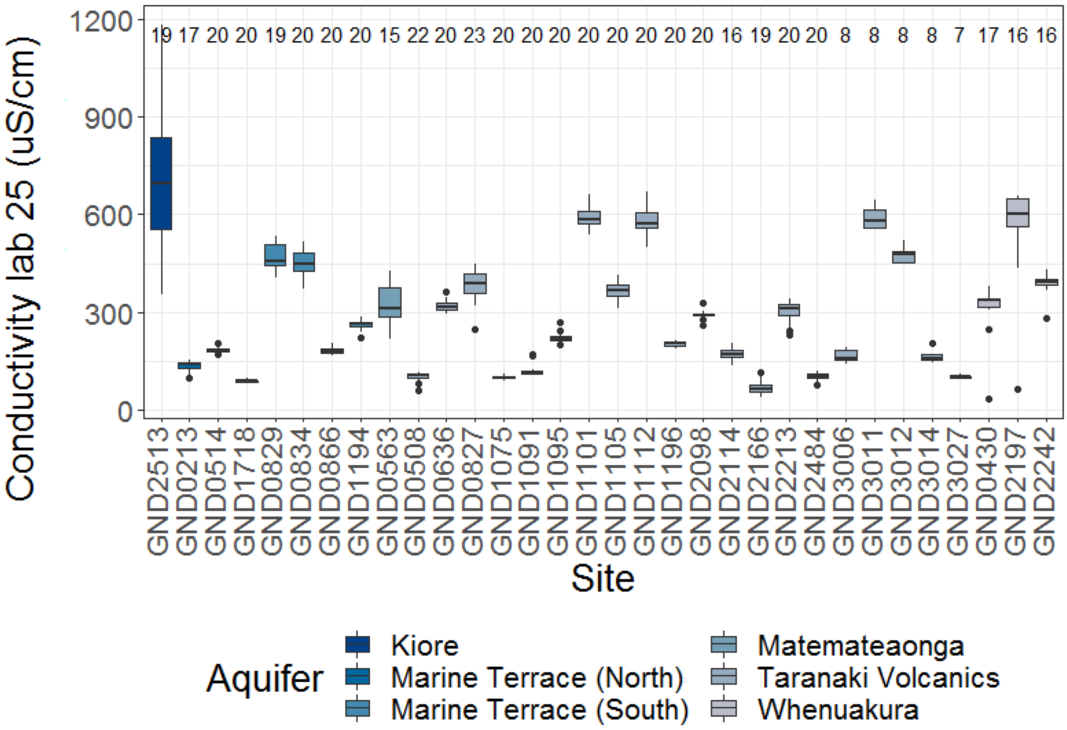


Figure 8 Electrical conductivity values recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020. Bores are grouped by aquifer.

Table 4 Summary statistics calculated based on data from nine key variables measured quarterly in 32 GQMP sites in the Taranaki region between 1 July 2015 and 30 June 2020

Note: *Statistical analysis methods outlined in Section 2.2.4. The range here is defined as the 5th and 95th percentile. Median values which are greater than DWSNZ (2018) MAVs are shown in bold font. Where % censored value is greater than 70%, the minimum and medium values stated are the detection limit.*

Site	Aquifer	Conductivity (µS/cm)				Nitrate nitrogen (mg/L)				Ammoniacal nitrogen (mg/L)				Dissolved iron (mg/L)				Dissolved manganese (mg/L)			
		Median	Range	n	% censored	Median	Range	N	% censored	Median	Range	n	% censored	Median	Range	n	% censored	Median	Range	n	% censored
Kiore																					
GND2513	Unconfined	696	441 - 995	19	0	0.003	0.001 - 0.017	19	37	2.10	0.901 - 2.56	19	0	2.62	0.16 - 10.39	19	0	**0.480**	0.090 - 0.705	19	5
Marine Terrance (North)																					
GND0213	Unconfined	143	107 - 152	17	0	0.740	0.637 - 1.05	19	0	0.006	0 - 0.044	19	37	<0.01	<0.01 - 0.04	19	74	0.001	0.00 - 0.011	19	42
GND0514	Unconfined	186	179 - 200	20	0	4.55	3.20 - 5.94	20	0	<0.004	<0.003 - 0.010	20	85	<0.03	<0.02 - <0.03	20	100	<0.01	<0.01 - 0.01	20	95
GND1718	Unconfined	90	84 - 96	20	0	0.910	0.599 - 1.38	20	0	<0.003	<0.003 - 0.010	20	95	<0.03	<0.02 - <0.03	20	100	<0.01	<0.01 - <0.01	20	100
Marine Terrance (South)																					
GND0829	Unconfined	456	418 - 530	19	0	9.70	7.34 - 11.22	19	0	<0.008	<0.003 - 0.010	19	84	<0.03	<0.02 - 0.03	19	95	<0.01	<0.01 - <0.01	19	100
GND0834	Unconfined	447	399 - 494	20	0	1.47	0.591 - 3.18	20	0	<0.007	<0.003 - 0.010	20	90	<0.03	<0.02 - <0.03	20	100	<0.01	<0.01 - <0.01	20	100
GND0866	Unconfined	180	170 - 205	20	0	3.35	2.42 - 4.06	20	0	<0.004	<0.003 - 0.010	20	95	<0.03	<0.02 - 0.07	20	75	0.003	0.001 - 0.009	20	55
GND1194	Unconfined	265	223 - 277	20	0	2.29	1.15 - 3.28	20	0	<0.007	<0.003 - 0.011	20	85	<0.03	<0.02 - <0.03	20	100	<0.01	<0.01 - <0.01	20	100
Matemateaonga																					
GND0563	Confined	312	252 - 404	15	0	0.010	0.010 - 0.010	3	67	5.02	4.72 - 5.76	3	0	7.10	5.66 - 8.72	3	0	0.23	0.203 - 0.257	3	0
Taranaki Volcanics																					
GND0508	Unconfined	106	84 - 115	22	0	0.505	0.276 - 1.06	24	0	<0.003	<0.002 - 0.006	24	71	<0.01	<0.01 - 0.03	24	75	0.003	0.001 - 0.009	24	25
GND0636	Unconfined	315	301 - 363	20	0	7.01	6.19 - 8.07	20	0	<0.007	<0.003 - 0.010	20	80	<0.03	<0.02 - 0.03	20	90	0.010	0.00 - 0.010	20	70
GND0827	Unconfined	387	322 - 441	23	0	3.30	2.31 - 5.46	23	0	<0.006	<0.003 - 0.022	23	74	0.03	0.01 - 0.17	23	9	0.002	0.001 - 0.008	23	13
GND1075	Unconfined	101	93 - 111	20	0	0.840	0.420 - 2.24	20	0	0.003	0.000 - 0.045	20	60	<0.03	<0.02 - 0.20	18	94	0.001	0.00 - 0.018	19	58
GND1091	Unconfined	117	110 - 167	20	0	2.13	1.96 - 2.69	20	0	<0.003	<0.003 - 0.010	20	95	<0.03	<0.02 - <0.03	20	100	0.001	0.001 – 0.001	20	55
GND1095	Unconfined	218	201 - 247	20	0	1.74	1.37 - 2.31	20	0	<0.005	<0.003 - 0.010	20	85	<0.03	<0.02 - <0.03	20	100	0.002	0.00 - 0.007	20	60
GND1101	Unconfined	583	544 - 653	20	0	8.11	6.94 - 12.11	20	0	<0.004	<0.003 - 0.011	20	85	<0.03	<0.02 - 0.07	20	85	0.004	0.001 - 0.014	20	45
GND1105	Unconfined	368	314 - 407	20	0	10.65	7.92 - 16.21	20	0	<0.007	<0.003 - 0.014	20	80	<0.03	<0.02 - <0.03	20	100	<0.01	<0.01 - 0.01	20	85
GND1112	Unconfined	574	521 - 636	20	0	**24.00**	19.74 - 29.01	20	0	<0.007	<0.003 - 0.011	20	90	<0.03	<0.02 - <0.03	20	100	<0.01	<0.01 - 0.01	20	90
GND1196	Unconfined	204	192 - 213	20	0	3.20	2.79 - 3.63	20	0	<0.009	<0.003 - 0.011	20	75	<0.03	<0.02 - 0.10	20	90	<0.01	<0.01 - 0.01	20	90
GND2098	Unconfined	293	276 - 305	20	0	2.13	1.62 - 2.31	20	0	0.006	0.002 - 0.019	20	60	<0.03	<0.02 - 0.06	20	80	0.030	0.020 - 0.077	20	0
GND2166	Unconfined	66	44 - 111	19	0	1.41	0.386 - 3.32	18	0	<0.010	<0.003 - 0.011	18	83	<0.03	<0.02 - 0.03	18	94	0.012	0.006 - 0.037	18	11
GND2213	Unconfined	314	242 - 334	20	0	1.97	1.56 - 2.43	20	0	<0.010	<0.003 - 0.020	20	85	<0.03	<0.02 - 0.03	20	95	0.002	0.001 - 0.011	20	45
GND2484	Unconfined	106	86 - 113	20	0	0.260	0.164 - 0.362	20	0	<0.006	<0.003 - 0.010	20	90	<0.03	<0.02 - 0.04	20	80	0.001	0.001 – 0.001	20	55
GND3006	Unconfined	158	145 - 190	8	0	2.90	2.54 - 3.30	8	0	<0.010	<0.010 - <0.010	8	100	<0.02	<0.02 - 0.02	8	88	0.00	0.00 – 0.001	8	50
GND3011	Unconfined	580	557 - 635	8	0	0.003	0.000 - 0.117	8	50	0.029	0.016 - 0.046	8	0	4.55	0.77 - 9.12	8	0	0.092	0.075 - 0.280	8	0
GND3012	Unconfined	480	451 - 509	8	0	0.002	0.000 - 0.064	8	50	0.595	0.443 - 0.673	8	0	10.80	8.85 - 13.48	8	0	**0.595**	0.560 - 0.979	8	0
GND3014	Unconfined	161	148 - 193	8	0	2.05	1.77 - 2.43	8	0	<0.010	<0.010 - <0.010	8	100	<0.02	<0.02 - 0.02	8	88	0.008	0.002 - 0.218	8	0
GND3027	Unconfined	102	96 - 110	7	0	0.340	0.285 - 0.513	7	0	<0.010	<0.010 - 0.011	7	71	<0.02	<0.02 - <0.02	7	100	0.009	0.005 - 0.028	7	0
GND2114	Confined	173	140 - 199	16	0	0.004	0.000 - 0.436	18	56	0.481	0.273 - 0.522	18	0	1.15	0.02 - 2.26	18	6	**0.74**	0.009 - 2.200	18	0
Whenuakura																					
GND0430	Confined	337	205 - 360	17	0	0.010	0.001 - 0.279	19	37	0.444	0.146 - 0.503	19	0	0.04	0.02 - 0.06	19	0	0.009	0.007 - 0.098	19	0
GND2197	Confined	601	344 - 657	16	0	0.005	0.001 - 0.050	18	67	2.30	2.06 - 2.80	18	0	0.01	0.00 - 0.01	18	28	0.002	0.002 – 0.003	18	6
GND2242	Confined	394	345 - 420	16	0	<0.010	<0.003 - 0.027	18	78	0.740	0.706 - 0.822	18	0	0.01	0.00 - 0.02	18	44	0.002	0.001 - 0.010	18	6

Table 4 Summary statistics calculated based on data from nine key variables measured quarterly in 32 GQMP sites in the Taranaki region between 1 July 2015 and 30 June 2020

Note: *Statistical analysis methods outlined in Section2.2.4. The range here is defined as the 5th and 95th percentile. Median values which are greater than DWSNZ (2018) MAVs are shown in bold font. Where % censored value is greater than 70%, the minimum and medium values stated are the detection limit.*

Site	Aquifer	Bicarbonate (mg/L)				Chloride (mg/L)				Dissolved sodium (mg/L)				*E.coli* (MPN/100mL)			
		Median	Range	n	% censored	Median	Range	n	% censored	Median	Range	n	% censored	Median	Range	n	% censored
Kiore																	
GND2513	Unconfined	500	374 - 590	8	0	27.0	19.1 - 31.9	8	0	193.5	136.2 – 243.0	8	0	**9**	<1 - 112	16	44
Marine Terrace (North)																	
GND0213	Unconfined	42	37 - 46	19	0	18.2	17.3 - 18.6	19	0	13.6	13.0 - 14.4	19	0	Not tested			
GND0514	Unconfined	27	19 - 34	8	0	27.0	26.0 – 28.0	8	0	13.7	13.4 - 14.3	8	0	**1**	<1 - 29	20	50
GND1718	Unconfined	26	24 - 29	7	0	9.1	8.1 - 9.5	8	0	8.6	7.9 - 8.8	8	0	<1	<1 - 39	20	80
Marine Terrace (South)																	
GND0829	Unconfined	104	100 - 109	8	0	46.5	44.3 - 61.8	8	0	41.0	39 - 47.6	8	0	<1	<1 - 6	19	63
GND0834	Unconfined	83	72 - 89	8	0	58.0	48.9 - 68.5	8	0	50.0	45.7 - 53.3	8	0	<1	<1 - 14	20	75
GND0866	Unconfined	35	33 - 35	8	0	22.0	21.0 - 23.3	8	0	23.0	22.0 - 25.6	8	0	<1	<1 - 1	20	90
GND1194	Unconfined	94	84 - 97	8	0	16.8	15.4 - 18.9	8	0	16.9	16.6 - 17.8	8	0	<1	<1 - 1	20	85
Matemateaonga																	
GND0563	Confined	218	214 - 232	3	0	10.2	10.1 - 10.4	3	0	32.0	31.1 - 36.5	3	0	Not tested			
Taranaki Volcanics																	
GND0508	Unconfined	26	24 - 29	19	0	13.0	11.5 - 15.2	19	0	7.5	6.6 – 8.0	19	0	Not tested			
GND0636	Unconfined	50	44 - 52	8	0	34.0	31.0 - 42.8	8	0	24.0	22.4 - 26.3	8	0	<1	<1 - 2	20	80
GND0827	Unconfined	73	62 - 79	21	0	50.0	44.0 – 61.0	21	0	45.0	38.0 – 51.0	21	0	**3**	<1 - 80	19	26
GND1075	Unconfined	32	27 - 35	8	0	6.2	5.4 - 7.3	8	0	5.7	5.2 - 6.3	8	0	<1	<1 - 12	20	80
GND1091	Unconfined	22	20 - 25	8	0	16.4	15.5 - 16.6	8	0	9.4	8.6 - 9.6	8	0	<1	<1 - <1	20	100
GND1095	Unconfined	64	60 - 88	8	0	19.3	18.7 - 19.7	8	0	18.1	16.2 - 20.5	8	0	**1**	<1 - 20	20	45
GND1101	Unconfined	78	69 - 81	8	0	96.0	83.4 – 102.0	8	0	66.5	60.0 - 74.7	8	0	**1**	<1 – 2,543	20	70
GND1105	Unconfined	58	50 - 64	8	0	41.0	36.0 - 44.3	8	0	24.0	22.4 - 24.6	8	0	**2**	<1 - 62	20	50
GND1112	Unconfined	42	40 - 46	8	0	88.5	83.0 – 91.0	8	0	42.0	38.4 – 43.0	8	0	**1**	<1 - 7	20	70
GND1196	Unconfined	52	51 - 58	8	0	20.0	19.0 - 21.6	8	0	20.0	18.3 – 20.0	8	0	<1	<1 - 1	20	90
GND2098	Unconfined	84	83 - 85	8	0	35.0	34.0 - 36.6	8	0	33.0	30.4 - 33.6	8	0	<1	<1 - 261	20	65
GND2166	Unconfined	11	7 - 20	8	0	8.4	3.7 - 18.4	8	0	5.3	3.0 - 9.1	8	0	<1	<1 - 26	18	72
GND2213	Unconfined	116	97 - 126	8	0	28.0	27.0 – 29.0	8	0	29.0	27.4 – 31.0	8	0	<1	<1 - 5	20	80
GND2484	Unconfined	44	37 - 46	8	0	7.1	6.6 - 7.5	8	0	9.9	8.5 - 10.5	8	0	<1	<1 - 2	20	95
GND3006	Unconfined	38	33 - 41	8	0	16.4	15.6 - 19.6	8	0	11.8	11.1 - 13.8	8	0	<1	<1 - <1	8	100
GND3011	Unconfined	88	84 - 100	8	0	69.0	64.3 – 70.0	8	0	70.0	69.0 - 74.3	8	0	<1	<1 - 4	8	75
GND3012	Unconfined	172	168 - 186	8	0	42.5	39.7 - 44.6	8	0	58.0	55.3 - 66.6	8	0	<1	<1 - 14	8	88
GND3014	Unconfined	40	38 - 52	8	0	18.2	16.4 - 21.9	8	0	11.6	10.7 - 15.6	8	0	<1	<1 - <1	8	100
GND3027	Unconfined	39	38 - 43	7	0	5.8	5.4 - 6.4	7	0	6.3	6.2 – 8.0	7	0	<1	<1 - <1	7	100
GND2114	Confined	70	35 - 77	18	0	20.0	19.7 - 21.1	18	0	15.1	14.3 - 15.7	18	0	Not tested			
Whenuakura																	
GND0430	Unconfined	167	161 - 172	19	0	24.0	23.0 – 25.0	19	0	22	21.9 - 23.1	19	0	Not tested			
GND2197	Unconfined	326	299 - 351	18	0	34.0	33.0 – 35.0	18	0	130	117.7 - 140.3	18	0	Not tested			
GND2242	Unconfined	176	171 - 183	18	0	30.0	29.0 – 30.0	18	0	24	23.9 – 25.0	18	0	Not tested			

The lowest median EC values (<100 µS/cm) were detected in groundwater samples from GND2166 and GND1718 (Table 4). GND2166 is a 3.5 m deep well located just outside of Te Papakura o Taranaki where the unconfined Taranaki Volcanics aquifer is likely recharged by recent rainfall on Taranaki Maunga. GND1718 is an 11 m deep well screened in an unconfined Marine Terraces (North) aquifer, recharged by coastal rainfall and surrounded by a mix of high and low producing grassland.

The highest EC values, both median and 95th percentile, were detected in GND2513. This site also had the largest inter-percentile range of 554 µS/cm (Table 4). GND2513 is a 5 m deep well screened in the shallow unconfined Kiore aquifer. The well was installed in 2015, as part of a joint investigation by Lincoln Agritech and the Council (Stenger and Clague 2015), to study the anoxic conditions which had been identified at a nearby former GQMP site (GND1080). These conditions were considered unusual as anoxic environments are more typical of deeper confined aquifers where oxygen is limited. It is likely the anoxic aquifer environment at this location more readily promotes the dissolution of ions from the surrounding aquifer geology, and favours the denitrification and attenuation of nitrogen as ammonia. This is reflected in high EC values and concentrations of other key variables (such as ammonia, bicarbonate, iron, manganese and sodium) noted in groundwater samples from GND2513.

Box plot summaries of EC values recorded at each GQMP site are displayed In Figure 8 with sites grouped by aquifer. EC values recorded in bores screened in confined aquifers, like Whenuakura and Matemateaonga, were often not much greater than EC values recorded in wells screened in unconfined aquifers, such as Marine Terraces and Taranaki Volcanics. However, this may simply reflect that while the drivers of EC may differ between unconfined and confined, both natural processes and human activities may be equally as strong in influencing EC values. EC values in the groundwater of the Marine Terrace (North) unconfined aquifers appears to be comparatively lower than groundwater in most other aquifers (Figure 9).

Drivers of EC values detected in the remaining GQMP sites appear to vary with geographic location, recharge mechanisms, land use influence and aquifer confinement (Figure 9). Groundwater samples from GQMP sites situated in the coastal areas west/south-west of Taranaki Maunga through to South Taranaki (including south of Kaponga) generally had greater median EC values (301 µS/cm - ≤650 µS/cm), than inland sites and sites located in northern and eastern parts of the region.

The greater EC values noted in coastal aquifers may reflect the fact that rainfall at the coast is richer in chloride and sodium ions, compared to rainfall that falls inland. However, aquifer lithology in this area is dominated by volcanic debris avalanche deposits and poorly drained soils (see Section 3.1.4), or marine derived formations and/or soils rich in marine derived salts. The less transmissive nature of these formations can promote extended rock/water interactions and ion enrichment of groundwater in both unconfined and confined aquifers. This is possibly the reason for high EC values noted in GND3011, GND3012 and GND2197, as discussed in Section 4.3. Land use contributions may also drive EC values in these areas as well, such as at GND1101 and GND1112, where elevated nitrate concentrations are also observed (Sections 4.3 and 4.6).

The fresh to moderately-freshwater EC values (0 µS/cm - ≤300 µS/cm) of inland GQMP sites (i.e. midway between Taranaki Maunga and boundary of the Volcanic Ring Plain), and sites located in the northern and eastern parts of the region, suggest that recharge to these aquifers is relatively recent. Analysis of groundwater Na:Cl ratios (Section 4.3) further suggests that groundwater is recharged by recent rainfall derived from marine origins. However, land use and/or natural rock-water interactions can still elevate EC values in these aquifers.

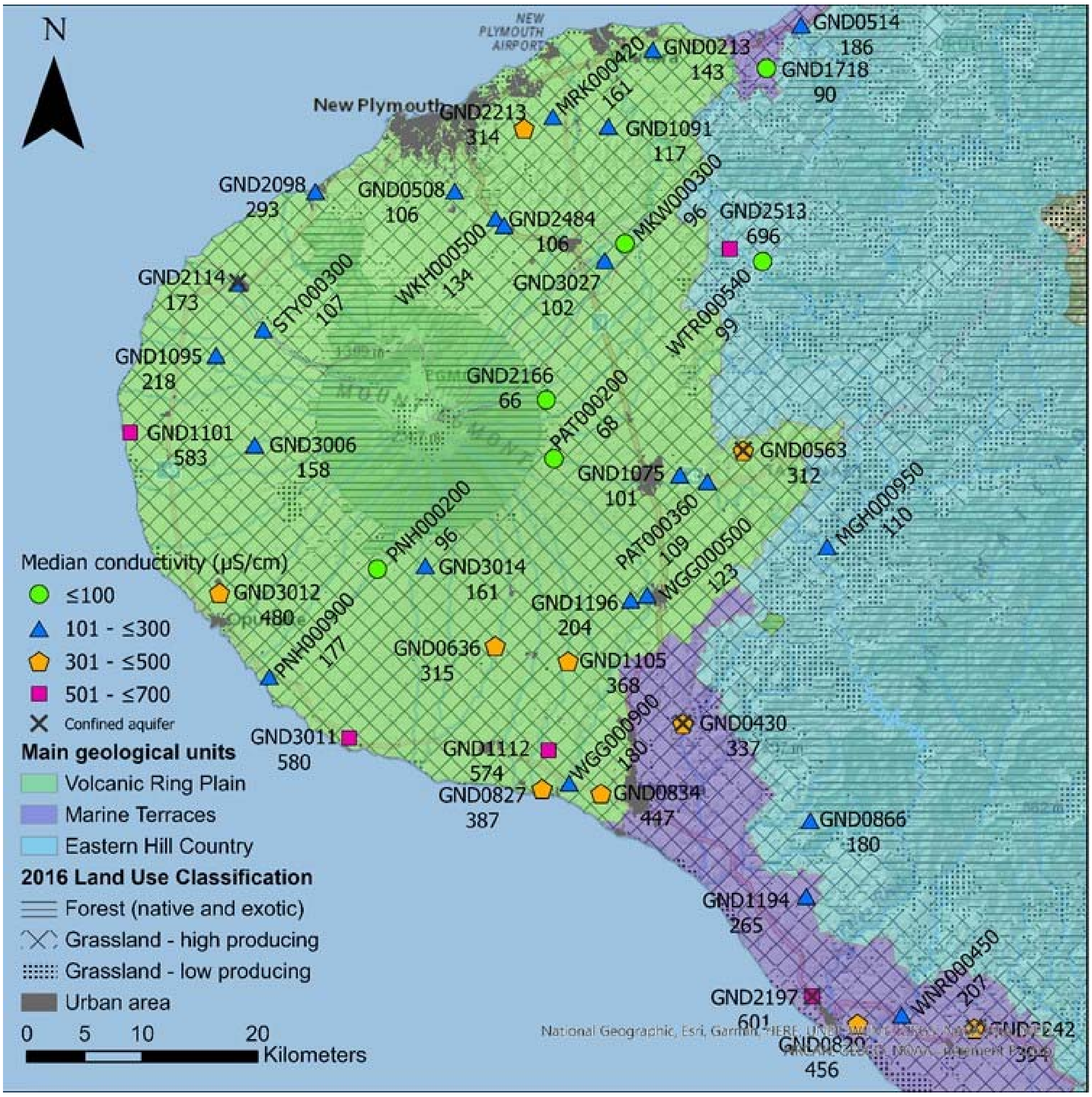


Figure 9 Median electrical conductivity (EC) values recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020

Note: *Groundwater sites are denoted by prefix GND. Median EC values, recorded at 15 surface water sites between 01 July 1995 and 30 June 2019, reported on in the 2019 SEM freshwater physicochemical report have been included for comparison. Calculated median values are recorded under their respective well or bore name.*

The strength of hydraulic connections between surface water and groundwater in the north and east of the region is unclear. Often groundwater from unconfined aquifers in these areas have median EC values within the range of median EC values of nearby rivers (TRC 2020) (Figure 9). This suggests some links between these aquifers and the region's larger river systems. However, it may be that the EC of these aquifers simply reflect where lower residence times and short flow paths provide less opportunity for ions from contamination or natural processes to build-up in groundwater. In contrast, aquifers closer to the coast, may have longer flow paths and groundwater residence times.

4.1.1. Summary

- EC values can be used to estimate TDS in groundwater samples. No approximated TDS median value exceeded the DWSNZ (2018) GV of 1,000 mg/L or ANZECC (2000) stock water threshold of 2,000-2,500 mg/L for TDS.

- Median groundwater EC measurements (State) ranged from 66 µS/cm to 696 µS/cm. The lowest median EC value was detected in an unconfined GQMP site very close to Te Papakura o Taranaki. While the highest median EC value was noted in a site in the Eastern Hill Country, which is sampled to monitor the unusual anoxic groundwater conditions of the local shallow unconfined aquifer.
- EC values in groundwater at GQMP sites can be influenced by one or more drivers such as, marine derived rainfall recharge, soil drainage conditions, aquifer confinement, sodium enrichment from aquifer geology and land use in the recharge zone.
- Groundwater EC values are generally greater in the coastal areas west/south-west of Taranaki Maunga through to South Taranaki (including south of Kaponga) when compared to groundwater EC values from inland GQMP sites and sites located in northern and eastern parts of the region.

4.2. Bicarbonate (HCO_3)

Median concentrations of bicarbonate ranged from 11 mg/L (GND2166) to 500 mg/L (GND2513), (Table 4 and Figure 10).

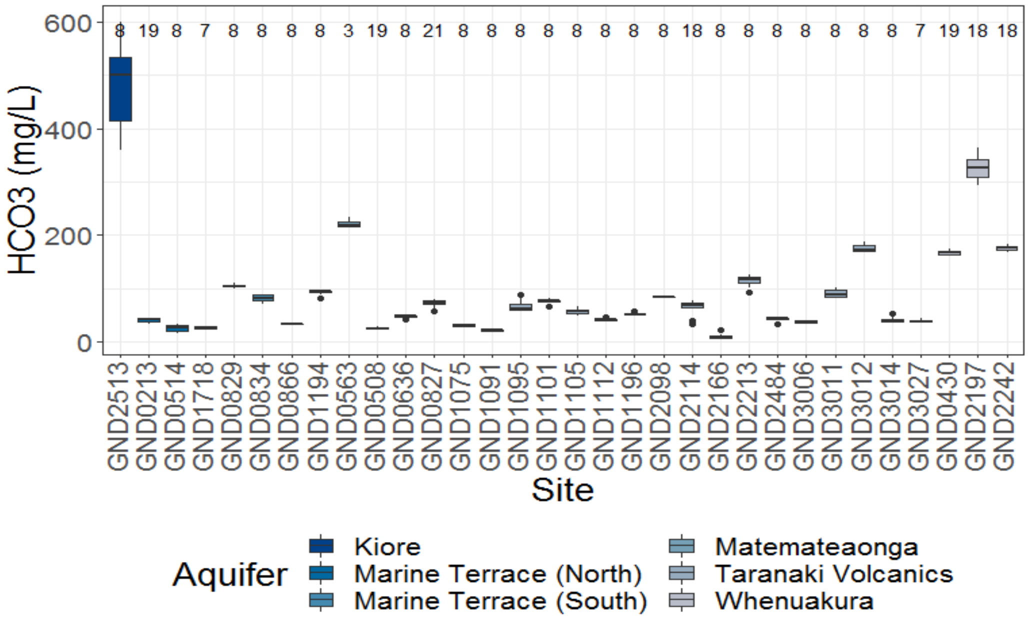


Figure 10 Comparison of bicarbonate concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020. Sites are grouped by aquifer

Bicarbonate concentrations were the highest in sites screened in unconfined and confined aquifers within the Kiore, Matemateaonga and Whenuakura aquifers. Here, bicarbonate concentrations most likely reflect oxygen poor conditions and longer residence times which promote carbonate enrichment of groundwater. GND3012 and GND2213, which are screened <11 m deep within unconfined aquifers of the Taranaki Volcanics Formation, also had notably high bicarbonate concentrations. It is likely that bicarbonate concentrations at GND2213 are driven by land use activities. While GND3012 may reflect where groundwater is influenced by localised reducing aquifer conditions arising from poor soil drainage (Figure 5) and a dominance of volcanic debris avalanche deposits. Sites screened in shallow and unconfined Marine Terrace (South) aquifers often had moderate concentrations of bicarbonate. This is most likely due to natural interactions between groundwater and the rich carbonate source rocks that comprise these aquifers.

Similar to EC, in GND2166 Bicarbonate concentrations reflect a transmissive unconfined aquifer which is rapidly recharged by fresh rainfall and has little rock/water interactions or influence from human activity. Bicarbonate concentrations in GND2513 are due to naturally oxygen poor conditions of the local unconfined aquifer that promote redox driven rock/water interactions.

Spatially, groundwater samples from GQMP sites situated in the coastal areas west/south-west of Taranaki Maunga through to South Taranaki generally had greater bicarbonate concentrations (51 mg/L - ≤500 mg/L), than inland sites and sites located in northern and eastern parts of the region (≤50 mg/L). While often the coastal and southern sites appeared to be more impacted by land use (as discussed in Section 4.6), it is more likely that bicarbonate concentrations in these aquifers are driven by carbonate rich lithology and/or aquifers with potentially lower transmissivities and longer residence times.

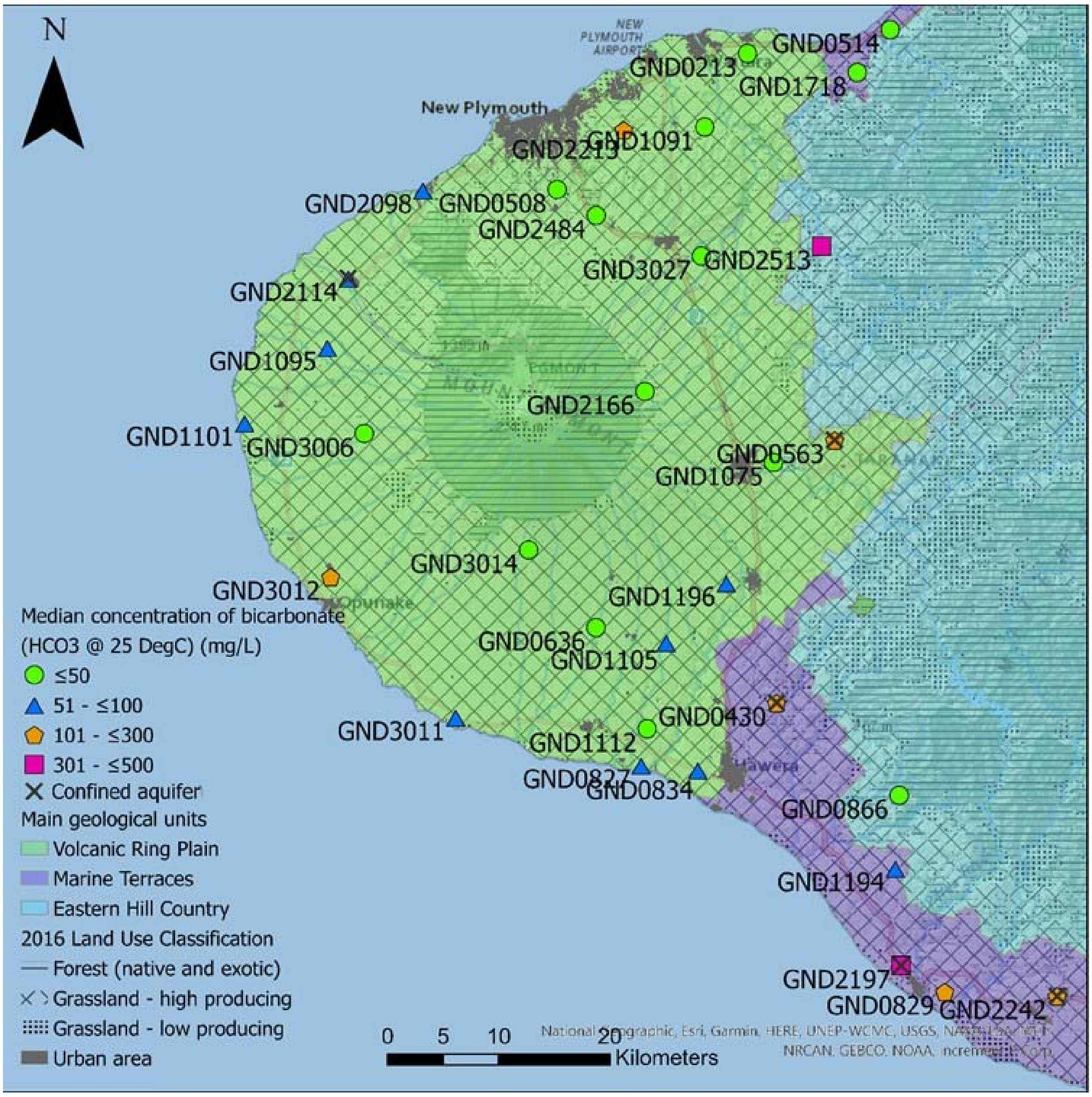


Figure 11 Median bicarbonate concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020

4.2.1. Summary

- Median concentrations of bicarbonate ranged from 11 mg/L to 500 mg/L.

- The lowest median bicarbonate concentration was detected in a sitevery close to Te Papakura o Taranaki and reflects an unconfined aquifer which is rapidly recharged by rainfall. The highest median bicarbonate concentrations was detected in a shallow well in the Eastern Hill Country, which is sampled to monitor the unusual anoxic groundwater conditions of the local unconfined aquifer.
- Bicarbonate concentrations appear to be greater in the coastal areas west/south-west of Taranaki Maunga through to South Taranaki, and notably in the Marine Terrace (South), Kiore, Whenuakura and Matemateaonga Formations. Bicarbonate concentrations in these aquifers are driven by carbonate rich lithology and/or aquifers with potentially lower transmissivities and longer residence times.

4.3. Chloride (Cl) and sodium (Na)

Chloride and sodium are considered together in this section as the relative ratio of sodium to chloride in a sample can be used to differentiate the source of salinity in groundwater. Median concentrations of chloride ranged from 5.8 mg/L (GND3027) to 96 mg/L (GND1101), while median concentrations of sodium ranged from 5.3 mg/L (GND2166) to 193.5 mg/L (GND2513) (Table 4, Figure 12). Groundwater samples from GND2513 periodically exceeded the DWSNZ (2018) GV for sodium (200 mg/L).

There appear to be no patterns in chloride and sodium concentrations associated with particular aquifers. However, geographically, chloride and sodium concentrations appear to be greater in GQMP sites located in coastal areas west/south-west of Taranaki Maunga through to South Taranaki. Meanwhile, sites located inland close to Taranaki Maunga, and in the northern and eastern parts of the region, tended to have lower concentrations of chloride and sodium. This is similar to spatial patterns noted for EC and bicarbonate levels, and the combination of drivers such as; proximity to the marine environment and natural processes influenced by aquifer lithology and transmissivity, are most likely the same.

Seawater has an approximate ratio of sodium to chloride (in mg/L) of 0.55. When plotted, this linear ratio is referred to as the seawater dilution line (SWDL). This ratio can also be reflected in rainwater when the rainwater is derived from seawater evaporation. However, in such a case, the absolute concentration of each ion in the rainwater is orders of magnitude lower than that in seawater. If salinity in groundwater is derived from marine sourced rainfall recharge, the Na:Cl ratio will be similar to that found in seawater (0.55), and will plot along the SWDL. Deviations away from this ratio indicate additional inputs of either ion from geochemical processes within the groundwater system or from human activities.

The relative ratios of sodium to chloride at all 32 GQMP sites sampled over the last five years are plotted in Figure 13. Ratios are derived from median concentrations of sodium and chloride. Figure 13 indicates 11 GQMP sites have Na:Cl ratios that plot close to the SWDL, i.e. the Na:Cl ratios at these sites are +/-0.2 within the Na:Cl ratio of seawater (0.55). GND1101 and GND2166, which had the highest and lowest median concentrations of chloride and sodium respectively, fall within this group. Rainfall at the coast is more likely to have higher levels of chloride, and GND1101 is strongly influenced by its proximity to the coast near Rahotu. However, land use may also contribute to the chloride and sodium values noted at this site, as discussed in Section 4.6. Meanwhile, GND2166, located at the foot of Taranaki Maunga, represents a site where rainfall may still be of marine origin, but concentrations of chloride and sodium are diluted due to the site's distance inland.

It is likely that much of the rainfall recharge to regional aquifers is sourced from seawater given the coastal location of Taranaki. However, as nearly two thirds of GQMP sites plot below the SWDL (Figure 13), it appears much of the region's groundwater is enriched with sodium. This is most likely due to natural processes, like rock/water interaction with sodium rich source rocks, which actively occurs within both

confined and unconfined aquifers. Sites GND3027 and GND2513, which had the lowest and highest median concentrations of both chloride and sodium respectively, fall within this group and show the extent of sodium enrichment within different aquifers. While groundwater at GND3027 is very fresh, with low concentrations of both chloride and sodium, levels of sodium are greater than chloride indicating sodium enrichment is occurring in this aquifer. As noted in the results of previous sections, groundwater at GND2513 represents an unconfined aquifer with unique reducing conditions.

GND1112 and GND0514 plot slightly above the SWDL, suggesting localised chloride enrichment of groundwater in Taranaki Volcanics aquifers. Na:Cl ratios at both sites fall within +/- 0.2 of the seawater Na:Cl ratio (0.55), indicating marine derived rainfall recharge is likely to be a strong source of chloride in groundwater. However, nitrate concentrations in both sites suggests land use is having an impact on groundwater quality (see Section 4.6) and may also be contributing to groundwater concentrations of chloride in these aquifers.

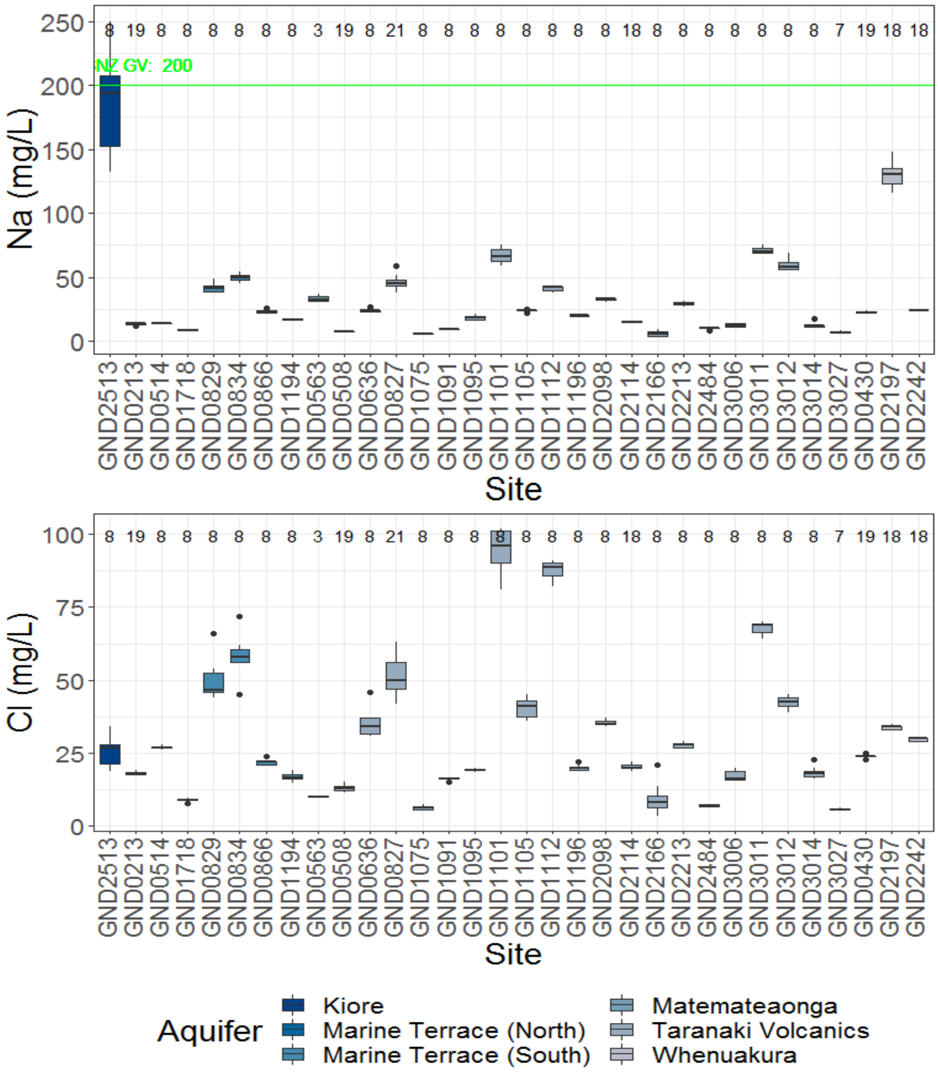


Figure 12 Comparison of sodium and chloride concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020 (Sites are grouped by aquifer)

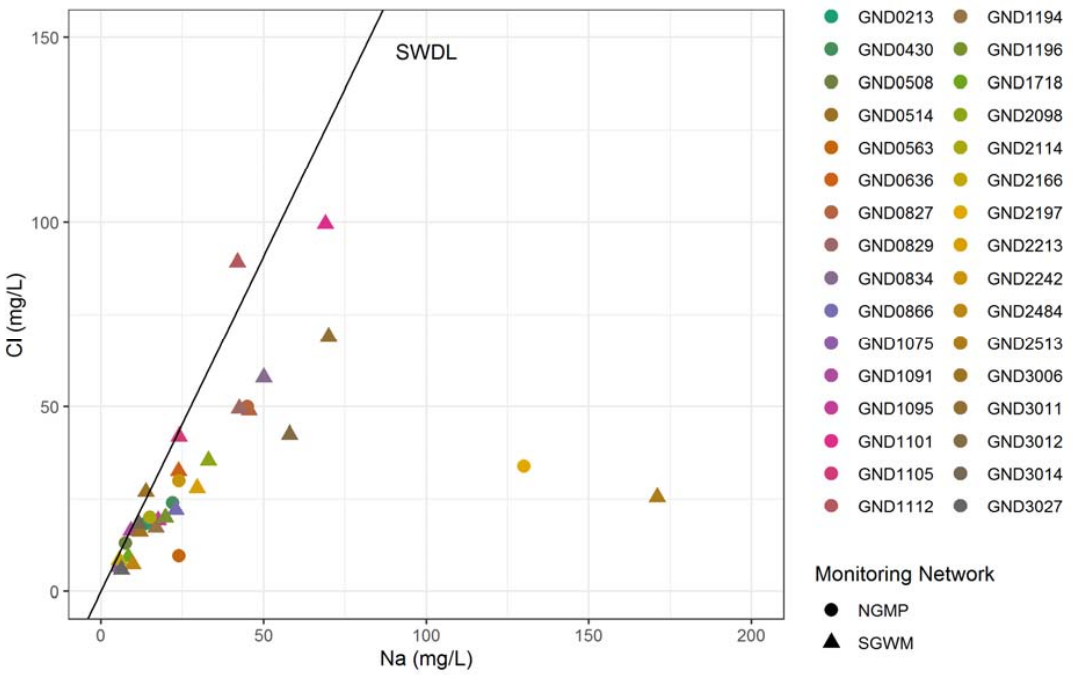


Figure 13 Sodium to chloride ratios of groundwater samples from 32 individual GQMP sites plotted against the seawater dilution line (SWDL)

Note: *Ratios are derived from median concentrations of sodium and chloride recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020. The SWDL represents the approximate ratio of sodium to chloride in seawater (0.55).*

4.3.1. Summary

- Median concentrations of chloride ranged from 5.8 mg/L to 96 mg/L, while median concentrations of sodium ranged from 5.3 mg/L to 193.5 mg/L.
- Chloride and sodium concentrations appear to be greater in GQMP sites located in coastal areas west/south-west of Taranaki Maunga through to South Taranaki. This could be due to a combination of factors like proximity to the marine environment, aquifer geology and natural processes.
- GQMP sites located inland close to Taranaki Maunga, and in the northern and eastern parts of the region tended to have lower concentrations of chloride and sodium. This reflects where fresh rainfall, derived from marine sources, recharges many of the region's aquifers.
- Sodium concentrations at one site periodically exceeded the sodium DWSNZ (2018) GV value of 200 mg/L. This site is sampled to monitor the unusual anoxic groundwater conditions of the local unconfined aquifer.
- In general, rainfall recharge is sourced from seawater and accounts for much of the chloride and sodium measured in regional aquifers. However, as nearly two thirds of GQMP sites plot below the SWDL, it appears much of the region's groundwater is enriched with sodium.
- Sodium enrichment of groundwater is likely due to natural processes, like rock/water interaction with sodium rich source rocks, which actively occurs within both confined and unconfined aquifers.

4.4. Iron (Fe) and manganese (Mn)

While there is no statistical correlation between iron and manganese, elevated concentrations of both variables tend to coincide in groundwater from oxygen poor aquifers. Manganese dissolves out first into groundwater under reducing conditions, despite iron being the more abundant ion in most rock types

(Rosen 2001). For these reasons, concentrations of iron and manganese are evaluated together in this section.

Median concentrations of iron ranged from detection limit (lab dependant: <0.01 mg/L to <0.03 mg/L) in multiple sites, to 10.8 mg/L (GND3012). Similarly, median concentrations of manganese from detection limit (<0.0005mg/L to <0.01 mg/L) in multiple sites, to 0.74 mg/L (GND2114) (Table 4).

Table 5 The 11 GQMP sites in which groundwater samples were above the DWSNZ (2018) GV and/or MAV for iron (Fe) and/or manganese (Mn) on one or more sampling occasions between 1 July 2015 and 30 June 2020

Note: *Table shows where iron and manganese were both above GV and/or MAV thresholds in six of the 11 sites.*

Site name	Sites above the DWSNZ (2018) Fe GV <0.2 mg/L (Staining of laundry & sanitary ware)	Sites above the DWSNZ (2018) Mn GV <0.04 mg/L (Staining of laundry & sanitary ware)	Sites above the DWSNZ (2018) Mn MAV <0.4 mg/L (Health significance)	Comment
GND0563	✓	✓		Groundwater quality affected by adjustments to bore depth and sedimentation issues as noted in previous results sections.
GND1075	✓	✓		Although well screened in an unconfined aquifer, localised conditions may favour low level natural dissolution of Fe and Mn from volcanic source rocks.
GND2513	✓		✓	Well screened in an unusually high reducing aquifer environment which promotes dissolution of Fe and Mn.
GND2114	✓		✓	Fe and Mn concentrations may reflect reducing conditions of a semi-confined/confined aquifer.
GND3011	✓	✓		Although well screened in an unconfined aquifer, localised conditions may favour natural dissolution of Fe and Mn from volcanic source rocks.
GND3012	✓		✓	Although well screened in an unconfined aquifer, localised anoxic conditions may favour natural dissolution of Fe and Mn from volcanic source rocks.
GND0827	✓			Individual sample shows a one off spike in iron.
GND430			✓	Mn concentrations may reflect the confined reducing aquifer conditions about this bore.
GND2098		✓		Although bores are screened in an unconfined aquifer, localised conditions may favour low level natural dissolution of Fe and Mn from volcanic source rocks.
GND2166		✓		
GND3014		✓		

The DWSNZ (2018) GVs iron and manganese, and the MAV for manganese was exceeded at 11 individual GQMP sites on one or more sampling occasions. Table 5 lists the 11 sites against the respective DWSNZ (2018) thresholds which they were above, and shows where both iron and manganese concentrations were elevated at the same six sites. Only GND0827 is used as a potable water supply, and in which case only GV for iron was exceeded. GND0563 historically was used as a potable water supply but levels of iron and manganese have made it unusable for this purpose. All other sites are either used for monitoring purposes only, or for stock or industrial use.

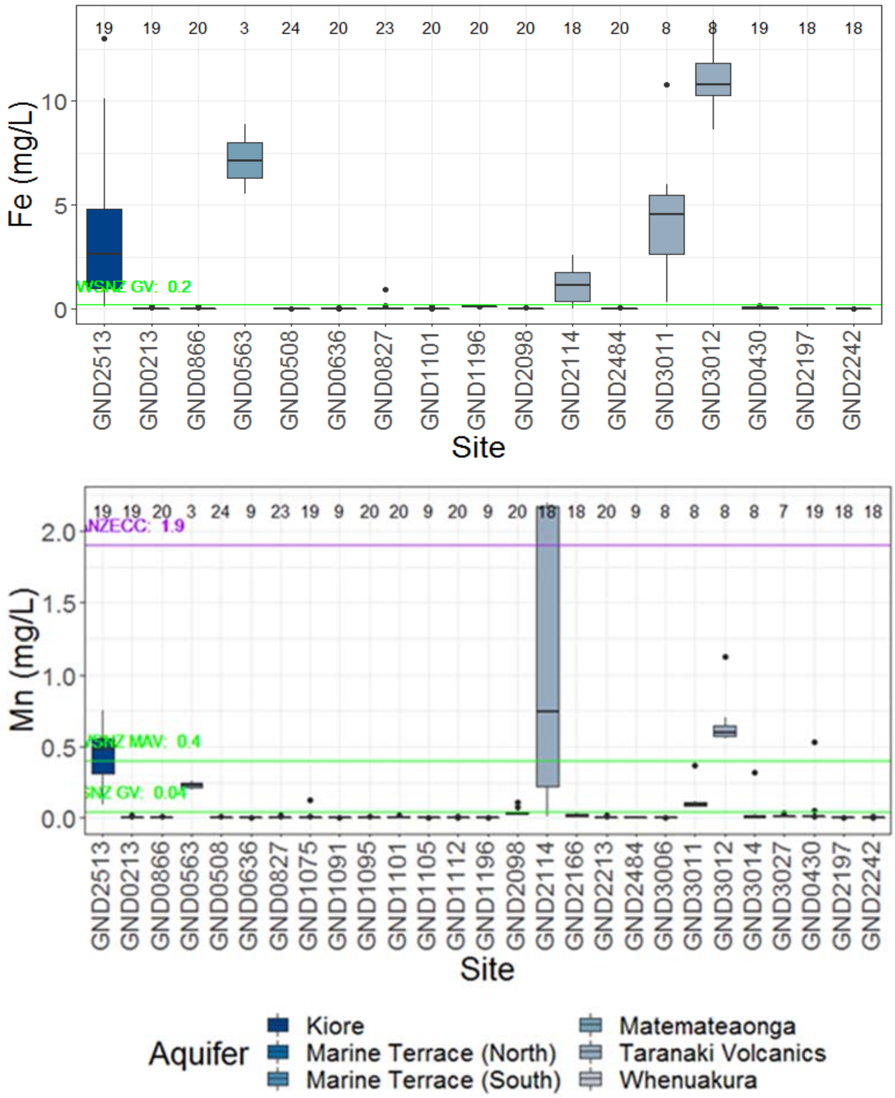


Figure 14 Comparison of iron and manganese concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020. Sites are grouped by aquifer

Note: *Boxplots are only shown where site datasets contained >1 non-censored measurement*

Concentrations of manganese in groundwater samples from GND2114 were also periodically above the ANZECC (2000) toxicity TV of 1.9 mg/L (see Figure 14). GND2114 is 41.9 m deep bore and is the only GQMP site screened within a confined Taranaki Volcanics aquifer. The bore, located <60 m from the Kaihihi Stream in Okato, has both fresh and evolving groundwater quality signatures. Low EC values and an Na:Cl ratio of 0.76, which is just outside the +/- 0.2 range of saltwater Na:Cl ratio (0.55), suggests recharge to this point of the aquifer is relatively recent. However, moderate concentrations of HCO_3, ammonia, iron and manganese indicate aquifer conditions favour some degree of dissolution of ions from surrounding source rock. It may be that GND2114 represents groundwater moving from an unconfined to a semi-confined aquifer, rather than groundwater typical of a purely confined aquifer.

Box plot summaries of iron and manganese concentrations recorded at each GQMP site are displayed in Figure 14, with sites grouped by aquifer. Iron and manganese are most likely to be present together in groundwater from aquifers within the Taranaki Volcanics Formation. It is likely iron and manganese are naturally present in groundwater from these aquifers due to the volcanic geology of Taranaki, which can be rich in both ions. Meanwhile, the anoxic conditions, encountered in the region's confined aquifers and about GND2513, promote the natural dissolution of both ions. Poor soil drainage about wells GND3011 and GND3012 may also provide the oxygen poor conditions required to actively dissolve iron and manganese into local aquifers, see Figure 5.

4.4.1. Summary

- Median concentrations of iron and manganese ranged from detection limit, in many of the 32 GQMP sites, to 10.8 mg/L and 0.74 mg/L respectively.
- Groundwater samples exceeded the DWSNZ (2018) GVs for iron (<0.2 mg/L) and manganese (<0.04 mg/L) at seven and six sites respectively, on one or more sampling occasions. Only one site is used as a potable water supply, and in which case only GV for iron was exceeded.
- Groundwater samples exceeded the DWSNZ (2018) MAV for manganese (0.4 mg/L) at four sites on one or more sampling occasions. However, exceedances were not detected in GQMP sites used for potable supply.
- Concentrations of manganese in groundwater samples from one site were also periodically above the ANZECC (2000) toxicity TV of 1.9 mg/L.
- Elevated concentrations of iron and manganese generally occur in tandem.
- The volcanic geology of Taranaki Volcanics Formation can be rich in iron and manganese. Concentrations of both ions are commonly detected in groundwater from aquifers within this formation, usually at low levels.
- Redox processes in anoxic groundwater systems can naturally increase dissolved concentrations of both iron and manganese in groundwater. Elevated concentrations of both ions are typically seen in the region's confined aquifers, and at a site well known for its unusual anoxic unconfined aquifer.

4.5. Ammoniacal nitrogen (NH_4-N)

Median concentrations of ammoniacal nitrogen (ammonia) ranged from below detection limit in multiple sites (lab dependant, ranges from <0.0003 mg/L to <0.01 mg/L) to 5.02 mg/L (GND0563), see Table 4. As noted in previous sections, the groundwater quality at GND0563 has been impacted by bore integrity issues, apparent since 2011 onwards, and adjustments made to bore depth. This is most likely the driver of the highly elevated ammonia concentrations at this bore.

Median concentrations of ammonia in three GQMP sites (GND0563, GND2197 and GND2513) exceeded the DWSNZ (2018) GV of 1.5 mg/L. Only one of these sites, GND2197, is currently used as a potable water supply. Median ammonia concentrations were above the NPS-FM (2020) annual median to protect against ammonia toxicity in freshwater ecosystems (0.24 mg/L) in a further four sites; GND0430, GND2114, GND2242 and GND3012, see Figure 15.

Box plot summaries of ammonia concentrations recorded at each GQMP site are displayed in Figure 15, with sites grouped by aquifer. While there are no spatial patterns for ammonia in the region, generally elevated concentrations of ammonia were detected in groundwater samples from bores screened in confined aquifers within the Taranaki Volcanics, Matemateaonga and Whenuakura Formations. The exception to this is wells GND2513 and GND3012, which have both been noted on in previous sections as being influenced by unusual localised anoxic conditions in an unconfined aquifer.

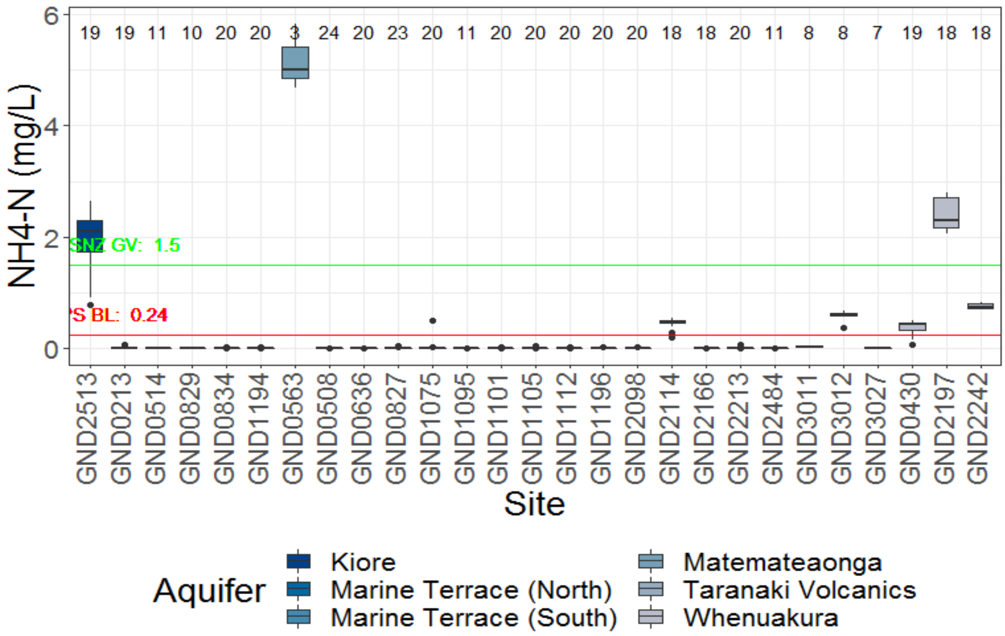


Figure 15 Comparison of ammoniacal nitrogen concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020 (Sites are grouped by aquifer)

Note: *Boxplots are only shown where site datasets contained >1 non-censored measurement*

A plot of individual ammonia concentrations against their respective nitrate concentrations for all 32 GQMP highlights where low levels ammonia and nitrate were present together in unconfined aquifers (Figure 15). While the plot generally supports the understanding that ammonia persists over nitrate in reduced environments typical of confined aquifers, some sites screened in unconfined aquifers also show signs of oxygen poor conditions. GND2098 and GND3011, alongside the seven aforementioned GQMP sites with elevated ammonia concentrations, have also been identified as displaying other redox sensitive parameters, as discussed in previous results sections (i.e. bicarbonate, sodium, iron and manganese). Meanwhile in other sites, such as GND0827 and GND1105, the presence of ammonia alongside elevated nitrate concentrations suggests ammonia may be present in the aquifer due to land use impacts, and/or occurs where aquifer conditions are occasionally oxygen poor.

A comparison of ammonia to nitrate concentrations also highlights where confined aquifer conditions may not always be oxygen poor. For example, the periodicity of nitrate concentrations >1 mg/L in GND2114 suggests groundwater, at times, may be sufficiently oxygenated to maintain nitrogen in the form of nitrate nitrogen over ammonia. It may also suggest that land use is the source of nitrogen to this aquifer and that GND2114 represents conditions of a semi-confined rather than confined aquifer.

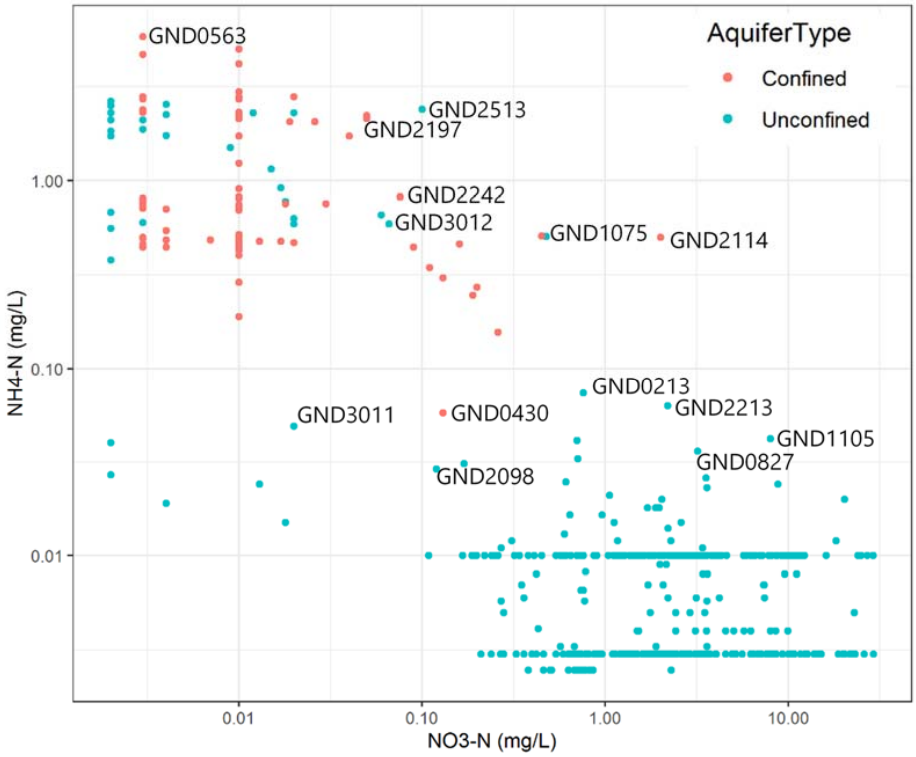


Figure 16 Ammoniacal nitrogen and nitrate nitrogen concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020

4.5.1. Summary

- Median concentrations of ammoniacal nitrogen (ammonia) ranged from below detection limit in multiple sites to 5.02 mg/L. The highest median concentration of ammonia was detected in a bore in which the hydrochemistry is most likely affected by adjustments to bore depth and on-going sedimentation issues.
- Concentrations of ammonia in three GQMP sites exceeded the DWSNZ (2018) GV of 1.5 mg/L, on one or more sampling occasions. Only one of these sites is currently used as a potable water supply.
- In seven sites median ammonia concentrations were above the annual median set in NPS-FM (2020), to protect against ammonia toxicity in freshwater ecosystems (0.24 mg/L).
- Observed concentrations of ammoniacal nitrogen are generally dictated by the oxidation state of the groundwater.
- Higher concentrations of ammoniacal nitrogen are generally found in deeper aquifers across Taranaki, or in areas of the region where shallow groundwater is highly reducing.
- Ammoniacal nitrogen can be present in groundwater as a result of land use inputs and/or naturally occurring processes.

4.6. Nitrate (NO_3-N)

Median concentrations of nitrate nitrogen (nitrate) ranged from below detection limit (lab dependant, <0.001 mg/L to <0.002 mg/L) in multiple sites, to 24 mg/L in GND1112 (Table 4, Figure 17). Box plot summaries of nitrate concentrations recorded at each GQMP site are displayed in Figure 17, with sites grouped by aquifer.

Only one site, GND1112, had a median nitrate concentration above the DWSNZ (2108) MAV of 11.3 mg/L. This site also recorded a maximum groundwater nitrate concentration of 29.2 mg/L, and was noted in the previous reporting period (TRC 2017) for exceeding the MAV, along with one other bore (GND1101). GND1112 is a 12.2 m deep large diameter unlined well, screened within an unconfined Taranaki Volcanics aquifer between Hawera and Manaia, and has been noted in previous sections for very high concentrations of chloride and sodium at ratios which tracked close to Na:Cl ratio in seawater, but with evidence of chloride enrichment.

In addition to GND1112, nitrate concentrations in four further GQMP sites were also above the DWSNZ (2108) MAV of 11.3 mg/L on one or more sampling occasions (GND0827, GND0829, GND1101 and GND1105, see Figure 17). All four of these sites are located within South Taranaki, with ND0829, GND1101 and GND1105 historically noted for highly elevated levels of nitrate in groundwater (TRC 2017). Of the four sites, the highest maximum concentration of nitrate was recorded in a groundwater sample from GND1105 (18.2 mg/L). GND0827, GND0829, GND1105 and GND1112 are all used for stock and/or domestic supplies. Well owners are advised of these results. Analysis of state also indicated that median nitrate concentrations in 27 of the 32 GQMP sites were ≤50% of the MAV.

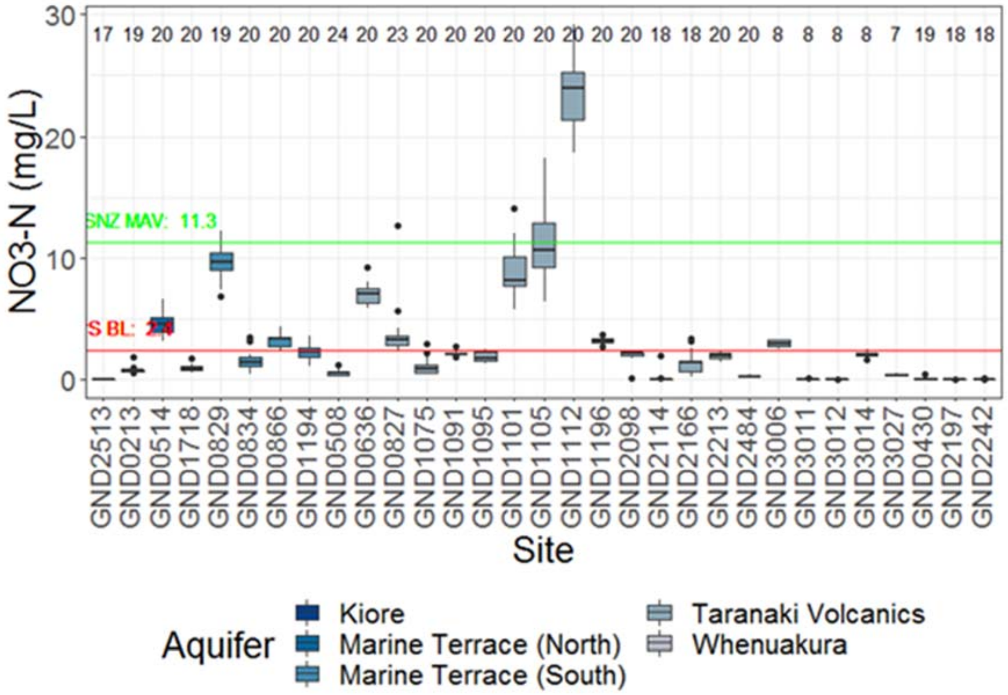


Figure 17 Comparison of nitrate nitrogen concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020. Sites are grouped by aquifer

Note: *Boxplots are only shown where site datasets contained >1 non-censored measurement*

In a total of 10 GQMP sites, median nitrate concentrations were above the annual median stipulated in the NPS-FM (2020) for protecting against nitrate toxicity in river aquatic ecosystems (2.4 mg/L). In addition, groundwater samples from nine sites were periodically above this toxicity threshold (Figure 17). While this highlights that nitrogen is elevated in groundwater in some areas, further work is required to identify the fate and transport of nitrogen-enriched groundwater to receiving waterbodies where these thresholds apply.

Based only on data collected from the 32 GQMP sites over the last five year, median concentrations of nitrate in groundwater were mapped to check for any spatial patterns in groundwater nitrate concentrations across the region (Figure 18). Figure 18 shows that nitrate concentrations are generally low in all of the Region's confined aquifers. However as demonstrated in Section 4.5, nitrogen generally persists in confined aquifers in the form of ammonia rather than nitrate, due to oxygen poor conditions. In contrast, groundwater concentrations of nitrate are most evident in GQMP sites screened in unconfined Taranaki Volcanics and Marine Terrace aquifers, which underlie high producing grassland.

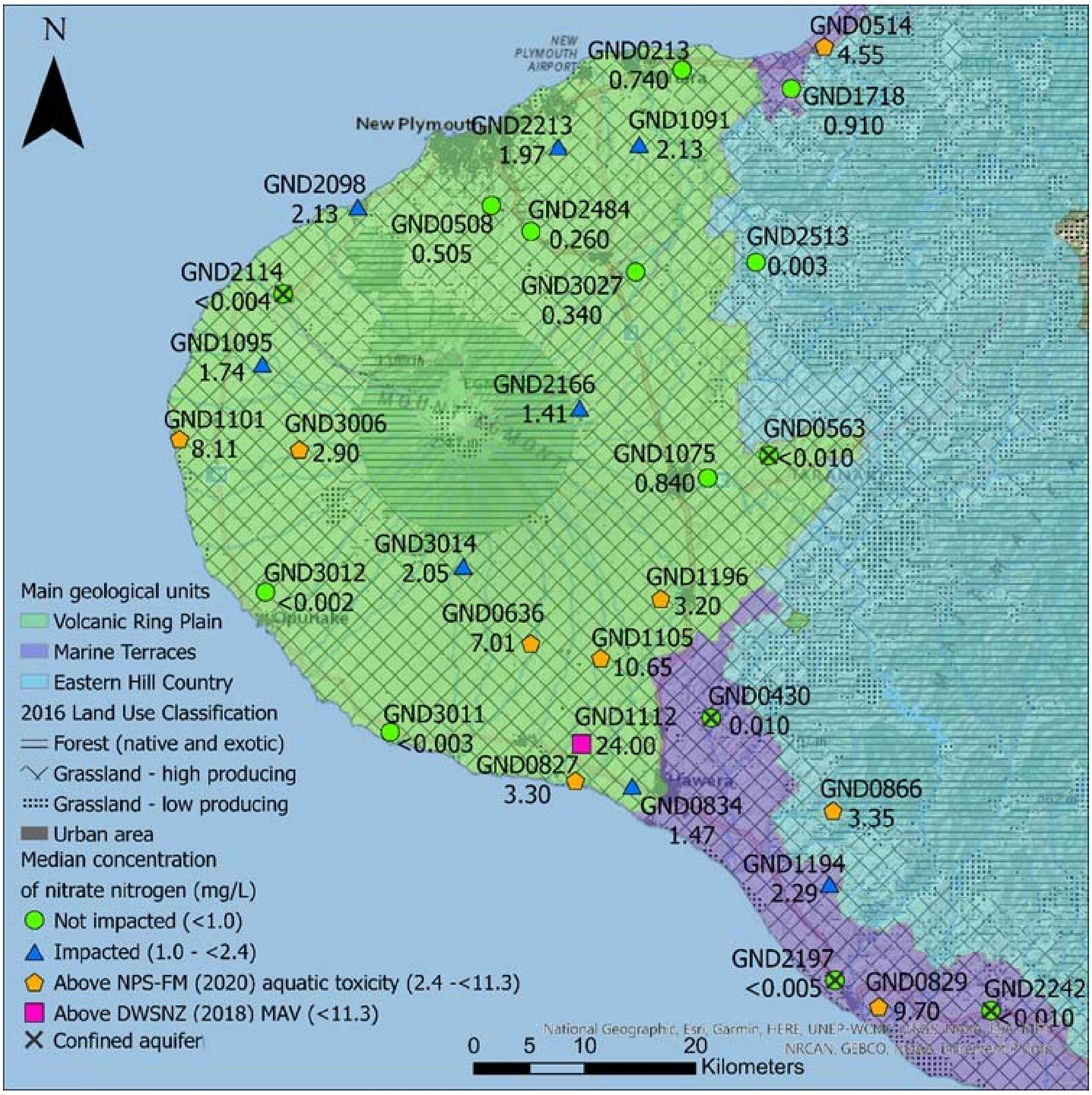


Figure 18 Median nitrate nitrogen concentrations recorded at 32 GQMP sites between 1 July 2015 and 30 June 2020

Elevated concentrations of nitrate are evident in an area of South Taranaki, which extends from Kaponga to Eltham and down towards the coast to Manaia and Hawera. This area includes GND0636, GND0827, GND1105, GND1196 and GND1112, which are noted for levels of nitrate routinely above the DWSNZ (2018) MAV for nitrate or the NPS-FM (2020) aquatic toxicity threshold. Intensive agriculture is the predominant land use in this area.

Elsewhere in Taranaki, spatial patterns suggest nitrate contamination is more prevalent in unconfined aquifers in the coastal areas west/south-west of Taranaki Maunga through to South Taranaki (including south of Kaponga). Groundwater samples which detected concentrations of nitrate above the DWSNZ

(2018) MAV and the NPS-FM (2020) aquatic toxicity threshold for nitrate were all generally collected from GQMP sites within this area (Figure 18).

Although spatial patterns in groundwater nitrate contamination can be linked to intensive agricultural land use or particular industries near to recharge zones for GQMP sites, these patterns were also similar to the spatial patterns noted for EC values, bicarbonate, sodium and chloride concentrations in the region's unconfined aquifers. This suggests groundwater nitrate concentrations in west and south Taranaki may also be driven by poor soil draining conditions and volcanic avalanche deposits, which create irregular hydrogeological conditions. Subsequently, these aquifers may have lower transmissivities, which in turn accumulate and retain nitrate within groundwater for longer periods.

While much of the land in northern and eastern areas of Taranaki has also historically been used for agriculture and industry, the unconfined aquifers in these areas tend to have soil and geological conditions that may favour higher aquifer transmissivities and have hydraulic connection to nearby rivers or waterways. Therefore, groundwater recharge, either from rainfall or surface water, is more effective at diluting or flushing out nitrate concentrations within an aquifer. However, further research is required to understand the influence of localised aquifer geology on groundwater chemistry, and if hydraulic connections between groundwater and surface water exist in these areas.

4.6.1. Variation and seasonality in groundwater concentrations of nitrate

The nitrate results from all 32 GQMP sites were collated for the last ten monitoring years (1 July 2010 to 30 June 2020) to look at the variation in groundwater concentrations of nitrate annually. Groundwater concentrations of nitrate from individual sites were normalised against their respective median nitrate values in order to allow a full network analysis.

Figure 19 indicates that the annual distribution of nitrate concentrations in regional aquifers has not notably varied over the last six monitoring years. Nor does any particular monitoring year show a peak in groundwater concentrations of nitrate. This suggests that nitrate levels in regional aquifers may be relatively stable.

Temporal trend analysis of nitrate concentrations in groundwater did not indicate seasonality in any individual GQMP sites, see Section 5. However, when the last ten years of nitrate data from the entire GQMP network were normalised and analysed together, seasonality was weakly evident. A Kruskal Wallis test was used to compare the distributions of groundwater concentrations of nitrate between four seasons (spring, summer, autumn and winter), and showed some evidence (i.e. $p < 0.05$) of a difference between the seasons. A subsequent Dunn's test suggested that (at a network scale) groundwater concentrations of nitrate are higher in winter compared to autumn and summer (Appendix IV). It is noted that this analysis is based on limited data; further investigation would be necessary to understand seasonality in relation to the fate and transport of nitrogen in groundwater.

During summer months rainfall volumes are generally low, resulting in limited soil drainage and groundwater recharge. Plant uptake of nitrogen also decreases during this period. As a result, nitrate can accumulate in the soil profile and in the unsaturated zone overlying the seasonal water table. As rainfall volumes increase during late autumn and winter, the excess of water drains through the soil profile and recharges aquifers, transporting stored nitrate from the soil profile into the groundwater system. As a result, marginal peaks in groundwater concentrations of nitrate may be observed during winter.

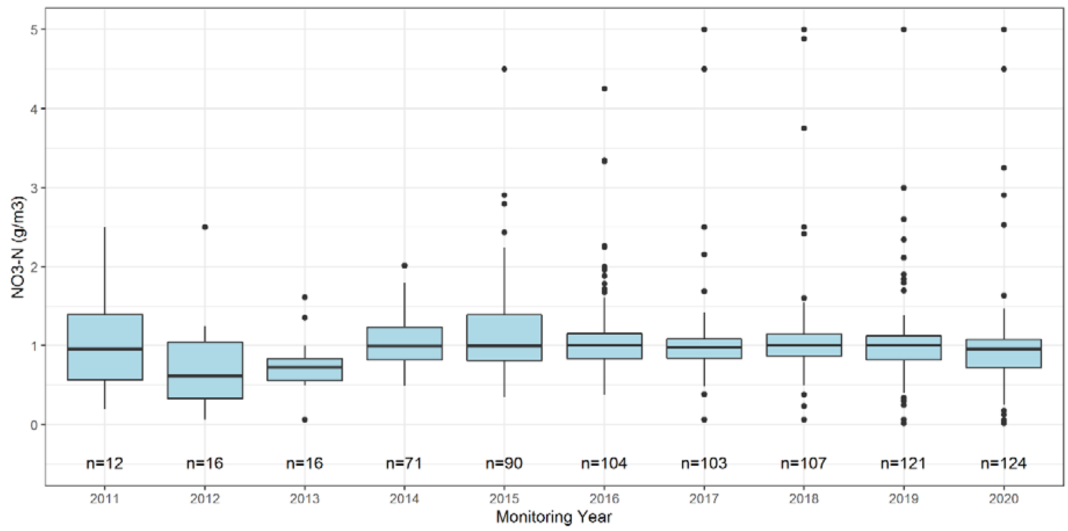


Figure 19 Boxplots showing the range of groundwater concentrations of nitrate nitrogen from 32 GQMP sites for individual monitoring years between 1 July 2010 and 30 June 2020

Note: *Data has been normalised against intra-site medians. The plot has been truncated at 5 mg/L NO_3-N for ease of interpretation. Omitted data generally reflects where the median absolute concentration of nitrate for a particular site is very low, thus accentuating slightly higher absolute concentrations at that site. In addition, given the limited data available for years 2011 to 2013 these years have not been considered or incorporated in discussion.*

4.6.2. Summary

- Median concentrations of nitrate nitrogen (nitrate) ranged from below detection limit, in multiple sites, to 24 mg/L.
- Median nitrate concentration in one GQMP site exceed the DWSNZ (2018) MAV of 11.3 mg/L. However, nitrate concentrations in groundwater samples from a further four sites were above the same MAV on one or more sampling occasions. Four of these sites are used for stock and/or domestic water supply. Owners are advised of any exceedances recorded.
- Median nitrate concentrations in 27 of the 32 GQMP sites were ≤50% of the MAV.
- Median nitrate concentrations were above the NPS-FM (2020) annual median (2.4 mg/L), to protect against nitrate toxicity in freshwater ecosystems in rivers, in a total of 10 GQMP sites. In addition, groundwater samples from a further 9 sites were periodically above this toxicity threshold. Further work is required to understand the fate and transport of nitrate in groundwater and the potential impacts on receiving waterbodies.
- Groundwater concentrations of nitrate are generally greater in the coastal areas west/south-west of Taranaki Maunga through to South Taranaki (including south of Kaponga and Eltham), when compared to nitrate levels in groundwater sampled from inland GQMP sites and sites located northern and eastern parts of the region.
- Elevated concentrations of nitrate are evident in an area of South Taranaki, which extends from Kaponga to Eltham and down towards the coast to Manaia and Hawera. This is most likely due to intensive agricultural land use within this area.
- In other areas of Taranaki, leaching of nitrogen from activities associated with intensive agricultural land use are most likely the main source of nitrate in regional aquifers.
- There is some evidence that nitrate concentrations are greater during winter compared to autumn and summer.

4.7. *Escherichia coli* (*E. coli*)

Groundwater samples from all SWGM sites are tested for *E. coli* bacterium to assess the bacteriological state of groundwater. Groundwater samples from NGMP sites are not sampled for *E. coli* as these sites are predominantly screened within confined aquifers, which are less likely to be infiltrated by surface water containing these types of indicator bacteria.

Median counts of *E. coli* ranged from below detection limit in multiple sites (<1 MPN/100 mL) to 9 MPN/L100 mL (GND2513). Median counts of *E. coli* were above the DWSNZ (2018) MAV of <1 MPN/100 mL in seven of the 25 SWGM sites sampled (Table 4). Groundwater from five of these seven sites is used for stock and/or domestic supply. Overall, *E. coli* was detected in groundwater samples on one or more sampling occasion, in 21 of the 25 routinely tested sites (Figure 20).

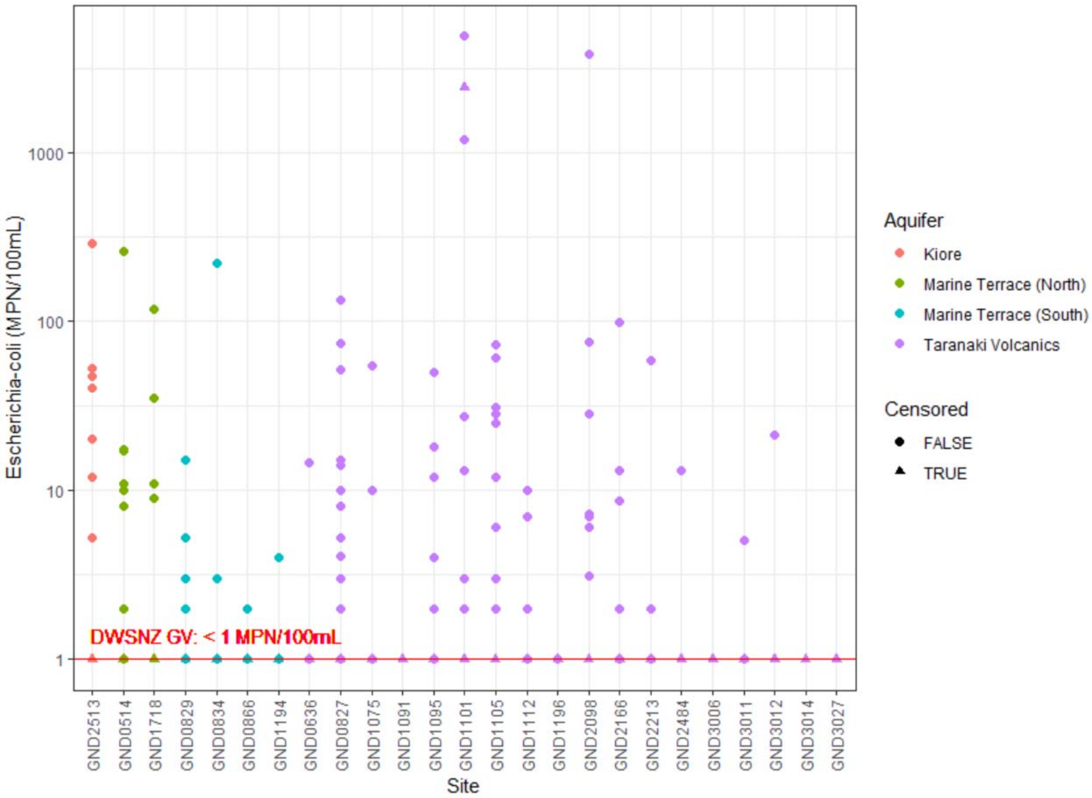


Figure 20 Counts of *Escherichia coli* (*E.coli*) detected in groundwater samples from 25 GQMP sites sampled between 1 July 2015 and 30 June 2020

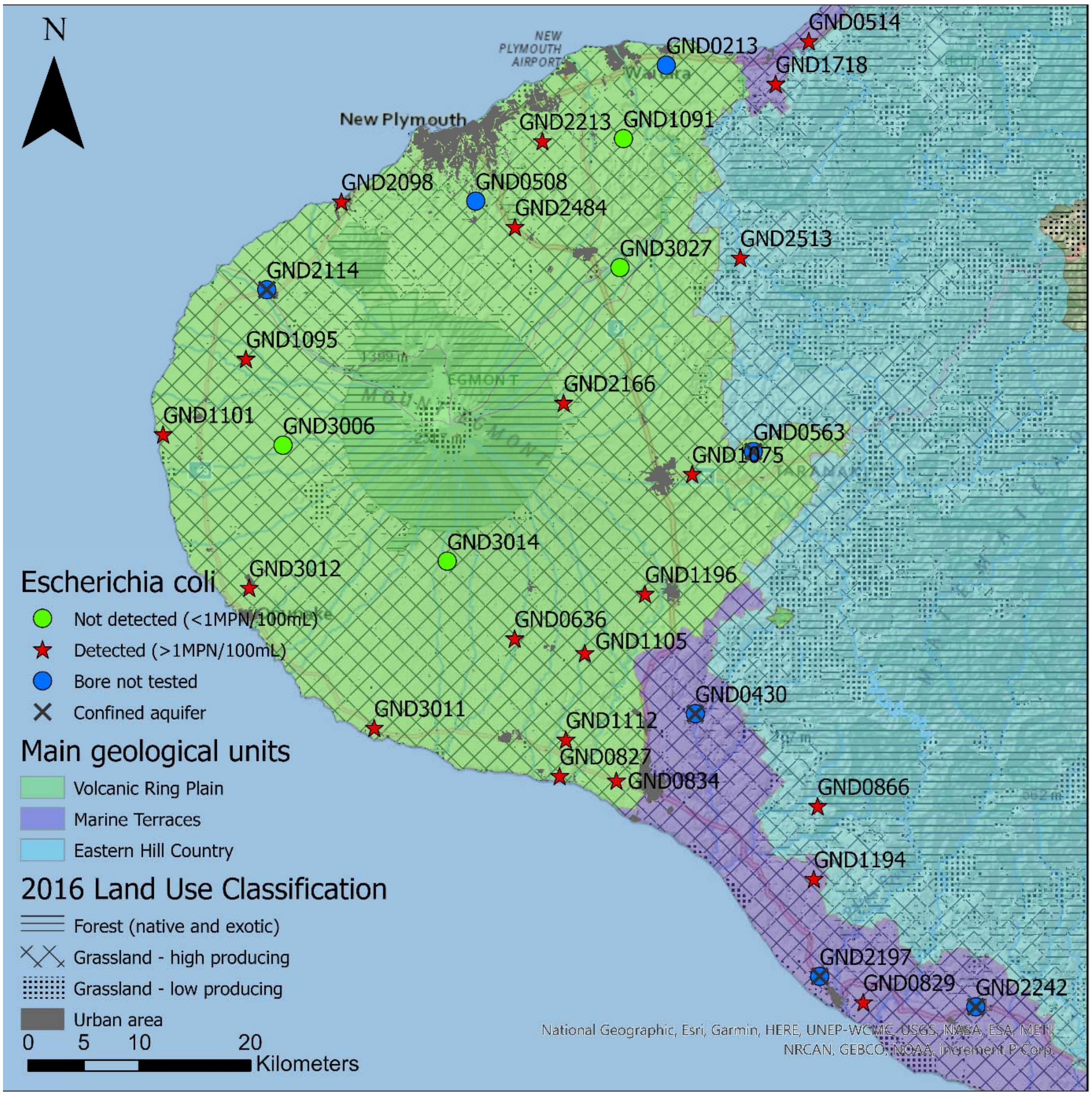


Figure 21 Location of positive counts of *Escherichia coli* (*E.coli*) detected in groundwater samples from 32 GQMP sites tested between 1 July 2015 and 30 June 2020

4.7.1. Relationship between bore or well construction type and counts of *E.coli* in groundwater

Further analysis was conducted to examine the relationship between bore or well construction types within the GQMP network and occurrence of *E.coli* contamination of groundwater using GQMP data collected over the last ten years.

Results show that *E.coli* contamination of groundwater occurs more often in monitoring sites that are dug and unlined (Table 6). Typically these sites have large diameters and are constructed to depths less than 15 m deep. A total of 52% of groundwater samples from dug and unlined wells had a positive count of *E.coli* (i.e. ≥1 MPN/100 mL). A higher proportion of groundwater samples from dug-unlined wells also detected counts of *E.coli* >1 MPN/100 mL compared to other bore or well types (Table 6). These findings were supported by the results of Dunn's tests which were carried out on all combinations of bore or well constructs and showed evidence (i.e. $p<0.05$) that wells which are dug and unlined were most at risk of *E.coli* contamination (see Appendix V for further details). These types of wells have no subsurface barriers (such as overlying aquitards or structural lining within the well itself) which prevent the potential infiltration of bacterial laden surface water into a bore or well via the soil profile and/or shallow water table.

Table 6 Percentage of samples with positive and elevated counts of *Escherichia coli* (*E.coli*) in groundwater by different construction type

Note: *Samples included were taken from 25 GQMP sites routinely for E.coli between 1 July 2010 and 30 June 2020. One construction type (drilled – open ended casing) is not represented within the subset of sites sampled for E.coli. % samples with elevated counts of E.coli are a subset of the % samples with positive counts of E.coli.*

Construction type	n of sites	n of samples tested for *E.coli*	% samples with positive counts of *E.coli* (i.e. ≥1 MPN/100 mL)	% samples with elevated counts of *E.coli* (i.e. >1 MPN/100 mL)
Bored or augured – lined	1	24	8	4
Bored or augured - unlined	4	122	26	18
Drilled - screened	12	214	20	14
Dug - lined	6	189	29	20
Dug - unlined	3	97	52	38

Bores and wells[3] that are dug and lined, or bored/augured and unlined may also be somewhat vulnerable to *E.coli* contamination (Table 6). While a total of 29% and 26% of all groundwater samples collected from dug–lined and bored/augured-unlined wells respectively had positive counts of *E.coli*. The results of Dunn's test did not find evidence that these two construction types were more at risk from bacteriological contamination than any other constructs (Appendix IV). *E.coli* contamination may be a slight risk in dug-lined, or bored/augured-unlined wells as these wells also have large diameters and are constructed to depths which are generally less than 15 m deep.

It should be noted that some *E.coli* contamination is apparent in all sites regardless of construction type (Table 6). Therefore, it cannot be ruled out that groundwater *E.coli* contamination may reflect the level of bore or wellhead security at individual sites, rather than being related to construction type (i.e. how successfully the bore or wellhead prevents surface water from directly entering the bore or well). A greater understanding of bore or wellhead security at individual sites in the GQMP is required to better correlate relationships between construction types and the level of *E.coli* contamination of groundwater. A greater number of sites may also need to be sampled to increase representation of certain construction types. It is clear the more recently installed wells, which were designed specifically for monitoring purposes and installed following good drilling practice have had significantly less detections of *E. coli* than at other sites (e.g. GND3006, GND3011, GND3012, GND3014 and GND3027).

4.7.2. Seasonality in groundwater counts of *E.coli*

Temporal trend analysis of *E.coli* counts in groundwater did not indicate seasonality in any individual GQMP site (Section 5). However, when the last ten years of *E.coli* data across the entire GQMP network were grouped by quarterly season, A Kruskal Wallis test showed weak evidence of seasonality (i.e. $p < 0.05$).

---

[3] The Freshwater Plan 2001 defines all wells and bores of less than 20 m in depth as wells and all wells and bores of greater than 20 m in depth as bores.

Consequent Dunn's tests between all paired combinations of seasons showed evidence that counts of *E.coli* in groundwater are greater in autumn and, to a lesser extent, in summer, compared to counts detected in winter and spring (Appendix IV).

4.7.3. Summary

- Median counts of *E. coli* ranged from below detection limit in multiple sites, to 9 MPN/100 mL,
- Over the last five years, median counts of *E. coli* were above the DWSNZ (2018) MAV (<1 MPN/100 mL) in seven of the 25 GQMP sites which are routinely tested for bacteria. However, in total, positive counts of *E. coli* were detected on one or more sampling occasion in groundwater samples from 21 sites. Of the 21 sites which detected positive counts of *E.coli*, 13 are used for stock and/or domestic supply.
- There is some evidence of a relationship between well construction type and frequency and magnitude of *E.coli* counts detected. It is likely that wells which are dug or bored/augured have more pathways for surface water intrusion, resulting in increased risk of bacteriological contamination.
- The adequacy of bore or wellhead protection of GQMP sites and the influence of regional meteorological characteristics needs to be further investigated.

4.8. Nitrite nitrate (NO_2-N), fluoride and bromide

Nitrite nitrogen (nitrite), fluoride and bromide were included in key variable analysis, as all three variables have associated DWSNZ (2018) or WHO (2017) MAVs. Analysis showed that median concentrations for all three of these variables are either below their respective laboratory detection limits, or the DWSNZ (2018) or WHO (2017) MAVs. They are most likely present in groundwater at low levels due to natural processes. It should be noted that nitrite is tested only in groundwater samples from SGWM wells, while fluoride and bromide are only tested for under the NGMP.

4.9. Pesticides and emerging organic contaminants

Regional groundwater bores/wells which were selected for inclusion in the ESR National Pesticide Survey were generally located within areas of horticulture (both commercial and private gardens) and intensive agriculture (dairy). On two separate sampling occasions, groundwater samples from a well within an area used for land farming, and from a well located at a waste water treatment plant (WWTP), were also included in the ESR survey. In 1995, the Council undertook an independent survey of pesticides in regional groundwater. Sites for this study were also located in areas where groundwater was considered vulnerable to pesticide contamination.

Results of regional testing for pesticides in groundwater show that pesticides were not often detected in the sites sampled. Over the length of the ESR pesticide surveys, pesticides have only been detected in groundwater on three sampling occasions, including twice from the same well. In these cases, however, concentrations of the pesticides detected have been below the DWSNZ (2018) pesticide MAVs (Table 7).

The Council's independent survey of pesticides in 1995 detected the presence of pesticides in one groundwater sample from a single well. The pesticide levels in this groundwater sample, tested in 1995, were below MAVs, or were at levels considered not to be a risk to human health at the time.

In the 2018 survey of pesticides by ESR, samples were also tested for "emerging organic contaminants" (EOCs) which included chemicals associated with or derived from caffeine, artificial sweeteners, some medications, skin-care products and packaging. Of the eight wells tested, samples from five showed traces of EOC compounds which were similar to levels detected nationally (Close and Humphries 2019).

Table 7 Pesticides detected in select sites sampled between 1990 and 2018 by ESR for the national survey of pesticides in groundwater, and as part of targeted groundwater investigations conducted by TRC

Site	Depth (m)	Location	Land use	Year			
				1994	1995	1998	2018
GND0810	3.6	Lepperton	Garden nursery	Simazine 0.2 mg/L (MAV 2 ppb)		Simazine 0.03 ppb	
GND2515	6.9	New Plymouth	Dairy near golf course & WWTP				Terbuthylazine 0.029 ppb (MAV 0.08 ppb)
GND0508* **Presumed monitoring well*	8.6	Carrington Road near New Plymouth city outskirts	Dairy		Metalaxyl 2.4 ppb (p.MAV 100 ppb) Simazine 0.1 ppb		

5. Temporal trends in groundwater quality

Temporal trend analysis of groundwater quality across the Taranaki Region has been undertaken on data collected from the 32 GQMP sites between 1 July 2010 and 30 June 2020.

Each of the 12 key groundwater quality variables were checked for temporal trends, using the methods outlined in Section 2.2.5. In addition, total oxidised nitrogen (NNN) data was analysed for trends over the last ten years. This is because groundwater samples from SGWM sites were not routinely tested for nitrate before October 2013, whereas these samples were regularly tested for NNN. NNN is the total of nitrite nitrogen (nitrite) and nitrate nitrogen (nitrate), of which nitrate is the most chemically stable form. As nitrite is not often present in groundwater, unless under strong redox conditions or gross contamination, it can be assumed most of the nitrogen in NNN takes the form of nitrate.

5.1. Trend results

Following quality control, 52 site-variable time series were found to have sufficient data for trend analysis. The resulting trend analysis spans across ten GQMP sites, and 11 of the 12 key indicator variables measured. Table 8 summarises the results of these temporal trend analyses.

The results of the trend analysis carried out found improvements were very likely for 15 site-variable time series, with a further 17 found very likely to be degrading.

The results of the statistical temporal trend analysis were critically analysed in order to identify any misleading results, and determine those trends that are environmentally meaningful (as defined in Section 2.2.5). Given the nature of the trend methods used, statistical results need to be reviewed with respect to their context when:

- There has been a change laboratory detection limits over the monitoring period, or there are a large number of censored values within a dataset;
- The concentrations for a variable are very small. In these cases small deviations from these low levels over time can result in a high percent annual change, giving the appearance of a temporal and/or environmentally meaningful trend;
- The examined dataset consists of few unique values with a very small range. In these cases, changes recorded by temporal trends analysis are likely within the level of measurement uncertainty and are not truly indicative of groundwater quality changes; and
- There has been a change of behaviour/conditions at the site within the monitoring period, which biases the assessed monotonic trend.

Examination of trend results falling into the first three of the above cases showed that variable concentrations/levels were being maintained rather than changing over time. Overall, only eight of the trends detected over the network were considered to be environmentally meaningful. As the majority of temporal trends detected were mostly at four of the ten sites, temporal changes in groundwater quality have been considered by bore or well.

Table 8 Summary of statistical temporal trend analyses performed on data collected from GQMP sites between 1 July 2010 and 30 June 2020

Note: *State Median values are based on five years of data in Table 4. Analysis performed on 12 key indicator variables on groundwater quality. NNN refers to total oxidised nitrogen, ammonia = ammoniacal nitrogen and nitrate = nitrate nitrogen*

Site	Measure	n	Proportion censored values	State Median	Median Sen Slope (units/year)	% annual change	Trend Category	Confidence in reported direction (%)
GND0430	Iron	40	0.20	0.040	0.003	9.9	Very Likely Degrading	100
	Bromide	40	0.07	0.090	0.002	2.6	Likely Degrading	86
	Chloride	40	0.0	24.0	0	0	Likely Degrading	76
	Conductivity	34	0	337.2	2.6	0.8	Likely Degrading	88
	Fluoride	40	0.03	0.080	0	0	Likely Degrading	69
	Manganese	40	0.03	0.009	0	0	Indeterminate	56
	Ammonia	32	0	0.444	0	0	Indeterminate	56
	Nitrate	40	0.38	0.010	-0.002	-2.7	Likely Improving	77
	Bicarbonate	40	0	167.0	-0.432	-0.3	Very Likely Improving	97
	Sodium	40	0	22.0	0	0	Very Likely Improving	100
GND0508	Chloride	40	0	13.0	0.161	1.3	Very Likely Degrading	99
	Conductivity	36	0	106.0	0.029	0.0	Indeterminate	52
	Bromide	39	0.15	0.040	0	0	Likely Improving	76
	Sodium	40	0	7.5	-0.033	-0.4	Likely Improving	86
	Bicarbonate	39	0	26.0	-0.316	-1.2	Very Likely Improving	100
	Manganese	41	0.39	0.003	0	-11.5	Very Likely Improving	98
	Ammonia	39	0.51	0.003	-0.001	-19.2	Very Likely Improving	100
	Nitrate	40	0	0.505	-0.014	-2.7	Very Likely Improving	91
GND0563	Bromide	33	0.15	0.060	0.002	4.1	Very Likely Degrading	99
	Conductivity	32	0	312.1	8.2	2.7	Very Likely Degrading	98
	Fluoride	33	0	0.630	0.031	14.4	Very Likely Degrading	100
	Iron	33	0.03	7.1	0.275	53.3	Very Likely Degrading	100
	Bicarbonate	33	0	218.0	2.3	1.2	Very Likely Degrading	99
	Manganese	33	0.15	0.230	0.011	22.6	Very Likely Degrading	100
	Sodium	33	0	32.0	0.560	2.4	Very Likely Degrading	98
	Chloride	33	0	10.2	-0.006	-0.1	Likely Improving	67
GND0827	Iron	41	0.42	0.030	0.001	6.8	Very Likely Degrading	98
	Bicarbonate	40	0	73.00	2.0	2.9	Very Likely Degrading	100
	Nitrate	41	0	3.3	0.185	6.0	Very Likely Degrading	100
	Conductivity	39	0	387.1	0.484	0.1	Indeterminate	54
	Manganese	41	0.36	0.002	0	-3.3	Likely Improving	75

Site	Measure	n	Proportion censored values	State Median	Median Sen Slope (units/year)	% annual change	Trend Category	Confidence in reported direction (%)
	Bromide	40	0.03	0.180	-0.007	-3.2	Very Likely Improving	99
	Chloride	40	0	50.0	-1.1	-2.0	Very Likely Improving	100
	Fluoride	40	0	0.120	-0.004	-3.1	Very Likely Improving	97
	Sodium	40	0	45.0	-0.379	-0.8	Very Likely Improving	97
	Ammonia	38	0.60	0.006	0	-1.1	Very Likely Improving	99
GND0829	Conductivity	32	0	456.5	3.9	0.9	Very Likely Degrading	94
	NNN	32	0	9.7	0.570	6.4	Very Likely Degrading	100
	E.coli	32	0.62	0.228	0	0	Very Likely Improving	94
GND1075	Conductivity	33	0	100.8	0.412	0.4	Likely Degrading	87
	NNN	33	0	0.840	0.030	3.4	Likely Degrading	85
	Ammonia	33	0.52	0.003	0	0	Likely Improving	87
GND1091	Conductivity	33	0	116.5	1.8	1.6	Very Likely Degrading	100
	NNN	33	0	2.1	0.019	0.9	Likely Degrading	86
GND1095	Conductivity	33	0	218.5	2.5	1.2	Very Likely Degrading	100
	E.coli	33	0.48	1.0	0	0	Indeterminate	66
	NNN	33	0	1.7	-0.043	-2.1	Very Likely Improving	91
GND1101	*E.coli*	33	0.70	1.0	0	0	Indeterminate	58
	NNN	33	0	8.1	-0.164	-1.7	Likely Improving	87
	Conductivity	33	0	583.0	-8.5	-1.4	Very Likely Improving	92
GND2213	Conductivity	33	0	313.9	9.4	3.1	Very Likely Degrading	98
	NNN	33	0	2.0	-0.103	-5.2	Very Likely Improving	100

GND0430 is a 234.6 m deep bore located within a confined Whenuakura Formation aquifer. Temporal trend analysis detected trends in ten variables at this site, three of which were found with a high level of confidence (iron, bicarbonate and sodium). In general, the temporal trends detected in variables were indicative of natural processes (i.e. the rate of change for major and minor variables were less than ±2% or ±5% per year respectively). Examination of trend plots for GND0430 suggests the slight changes in the hydrochemical signatures observed at this bore are within cyclic fluctuations or are being maintained by natural processes.

Of the eight temporal trends detected in the key variables measured at GND0563, seven trends were found with high confidence. Trends for bicarbonate, fluoride, iron and manganese were considered environmentally meaningful. However, these trends have been induced by ongoing bore integrity issues and multiple depth modifications at the bore. Located with the confined Matemateaonga Formation, bore GND0563 was originally an open-ended (no bore screen) 77 m deep bore. Due to increasing sediment infiltration into the bore, apparent since 2011 (TRC 2107), the bore was backfilled to 26 m sometime during 2018. While this resolved sedimentation issues temporarily, increases in iron concentrations made the bore water unusable, both in the dairy shed and as a drinking water supply. Subsequently, the bore was deepened again to 50 m. However, this has not reinstated the former quality of groundwater abstracted from the bore, and sedimentation continues to be a problem.

Statistical analysis of data from GND0508 detected trends in eight key variables, with five trends being detected with high confidence. However, review of trend plots for GND0508 indicate temporal trend analysis was heavily influenced by the very low concentrations/levels of variables present in the groundwater. Long term monitoring suggests groundwater quality is being maintained, with the very small number of measured parameters falling below any threshold of concern. GND0508 is a 14 m deep well within an unconfined Taranaki Volcanics aquifer, with groundwater quality that is likely influence by localised rainfall patterns (TRC 2021). Changing rainfall patterns may be reflected in small changes noted in chloride levels at the well.

GND0827 is an 8 m deep unlined large diameter well, within an unconfined Taranaki Volcanics aquifer. Trends were detected in ten monitored groundwater quality variables at this site, with eight of the trends found with high confidence. Concentrations of nitrate and bicarbonate at GND0827 were found to be very likely degrading. These trends are considered environmentally meaningful and show some evidence of land use impact on the local aquifer (Table 8). This is expected given the well's location in an area of intensively farmed land. A review of the time series data for the remaining eight variables indicate that in most instances, variable concentrations are very low and much of the recorded change occurred early in the data record. This has led to the statistical trend analysis categorising variables as very likely improving or likely improving. In the case of iron, the dataset has been heavily influenced by changing detection limits. Despite these influences, the very likely improving trends for ammonia, bromide, chloride, fluoride and manganese, while albeit very small improvements, suggest either land use management around GND0827 have improved or there has been a gradual change in source of groundwater to the well.

A total of 14 improving or degrading trends suggest that groundwater levels of EC, *E.coli*, ammonia, and NNN are changing in the remaining six wells (GND0829, GND1075, GND1091, GND1095, GND1101 and GND2213). All six wells are large diameter dug - lined or bored/augured – unlined wells, are screened shallower than 11 m deep and are located in unconfined Taranaki Volcanics or Marine Terraces (South) aquifers. Trends detected in these wells generally reflect where changing groundwater quality is likely due to land use, as all wells are located in areas of intensively farmed land. Of the nine trends that were found with high confidence, only two, for groundwater concentrations of NNN in wells GND0829 and GND2213, were considered environmentally meaningful.

Temporal trend analysis indicated groundwater EC and NNN concentrations have increased over the last ten years at wells GND0829, GND1075 and GND1091. However, it should be noted that EC and NNN levels for GND0829 and GND1091 either peaked early in the monitoring period and now appear to be improving, or have stabilised later in the monitoring period, respectively. Further to this, counts of *E.coli* in GND0829 have decreased in recent years to below detection limits (<1 cfu/100 mL). This may be due to improvements to wellhead security at the site.

EC levels at wells GND1095 and GND2213 were found to be very likely degrading (increasing), while concentrations of NNN at both sites are very likely improving. A review of the time series data indicates a small but steady increase in EC levels over time in GND1095, while concentrations of NNN have gone through a low within the last ten years and appear to be increasing again. In GND2213 which is located less than 50m from a tributary of the Mangaoraka Stream, EC values appear to have increased and stabilised at a new level from 2014 onwards. Over the last 10 years NNN levels at the site have improved to levels more typical of un-impacted groundwater.

At well GND1101, EC levels and NNN concentrations were found to be very likely improving and likely improving respectively. Past reporting on groundwater quality trends (TRC 2017) had also noted an improving trend in nitrate (assumed to be NNN).

Trend analysis of *E.coli* levels at GND1095 and GND1101 suggest that generally counts of *E.coli* are being maintained below or at MAV. Meanwhile, the likely improving trend found in concentrations of ammonia at well GND1075 is very low in magnitude and is impacted by a large proportion of censored values in the time series, indicating that ammonia levels at the site are being maintained at low concentrations.

Trend plots are included in Appendix V.

6. Discussion

The state and trends of groundwater quality across Taranaki is influenced by both natural processes and human activities. Observed concentrations of 12 key indicator variables of groundwater quality highlight patterns that can be associated with a range of drivers, such as aquifer confinement, groundwater residence time, rock/water interaction with local geology and soil, regional recharge mechanisms, redox related processes, and human influences including land use management practices. The composition of groundwater has been shown to vary in response to the occurrence and magnitude of these influences across the region, and can also change over time.

6.1. State of regional groundwater quality

Analysis of GQMP data collected between 1 July 2015 and 30 June 2020 indicates variability in the composition and quality of groundwater across the region's aquifers. The region's shallow unconfined aquifers are generally more oxidised and their proximity to land surface means that they display greater impacts from land use activities. Deeper, older water contained in confined aquifers is generally more chemically evolved, and more influenced by natural processes than human induced factors.

The mineral content of the region's deep and confined aquifers is typically greater than that of groundwater in the region's shallow and unconfined aquifers. Aquifer depth, reducing groundwater conditions and longer groundwater residence times naturally promote greater concentrations of bicarbonate, sodium, iron, manganese and ammonia in confined aquifers. Additionally, elevated levels of EC, nitrate, chloride and *E.coli* in groundwater samples from some of the region's more oxidised, unconfined aquifers suggests groundwater in Taranaki can be impacted by land use.

Reducing conditions have been shown to exist in some soil profiles above unconfined aquifers, and within unconfined aquifers. Examples include the Kiore aquifer, and Taranaki Volcanics aquifer about GND3012. Here, the groundwater chemistry reflects the conditions of an oxygen-poor confined aquifer despite being unconfined. Reducing conditions may assist with the removal of nitrate from groundwater in unconfined aquifers by promoting denitrification. Conversely, the alternating presence of ammonia and nitrate in groundwater samples from bores screened in confined aquifers, as seen in GND2114, suggests land use may contribute to the presence of nitrogen, in the form of ammonia, in confined groundwater aquifers.

Analysis of Na:Cl ratios in groundwater indicates the main source of recharge to regional aquifers is rainfall derived from marine evaporation. Concentrations of chloride and sodium, along with EC values, were greater in samples from GQMP sites located in coastal areas west/south-west of Taranaki Maunga through to South Taranaki. This may reflect that rainfall at the coast is richer in chloride and sodium, compared to rainfall that falls inland. Nearly two thirds of GQMP sites plot below the SWDL, suggesting that much of the region's groundwater is enriched with sodium from rock/water interactions with sodium rich source rocks.

Spatially, levels of bicarbonate, EC, sodium, chloride and nitrate in groundwater tended to be greater in GQMP sites located west/south-west of Taranaki Maunga through to South Taranaki. Unconfined aquifers west/south-west of Taranaki Maunga within the volcanic ring plan appear to be geologically influenced by volcanic avalanche deposits, which create irregular hydrogeological conditions (Roverato et al 2014). In contrast the Marine Terraces (South) formations in South Taranaki are more likely to contain marine derived carbonate rich geological sequences. These geological units are more likely to display lower groundwater transmissivities, longer residence times and have fewer hydraulic connections to surface water. Subsequently, these characteristics promote natural processes such as the sodium and bicarbonate enrichment of groundwater, and may allow for the accumulation of nitrate in groundwater at levels above drinking water and ecological thresholds.

Recorded levels of bicarbonate, EC, sodium, chloride and nitrate are comparatively lower in aquifers in the east and north of the region. Here, unconfined aquifers are influenced by lahar deposits (Roverato et al

2014), which are thought to support higher transmissivities, shorter groundwater residence times and have more hydraulic connections to surface water. This would potentially enable regular flushing or dilution of variables like nitrate, and limit natural mineral enrichment of groundwater.

As natural concentrations of nitrate in New Zealand are rarely considered to be above 1 mg/L (Close et al. 2001), it is clear that many of the regional unconfined aquifers show some degree of human impact. Further to this, median groundwater concentrations of nitrate in 10 GQMP sites are above the NPS-FM (2020) bottom line for aquatic toxicity of an annual median of 2.4 mg/L. In addition to this, groundwater samples from a further nine sites were periodically above the NPS-FM (2020) bottom line on individual sampling occasions. Note that this is an indicative comparison only, as the NPS-FM attribute is defined as a one-year median of monthly data, while the median for groundwater quality in this report is based on five years of quarterly data. While seven GQMP sites had median groundwater concentrations of ammonia were above NPS-FM ammonia aquatic toxicity threshold for receiving surface waterbodies (0.24 mg/L), these sites were screened in confined aquifers or were influenced by unusual localised anoxic conditions in an unconfined aquifer and are unlikely to impact surface water.

An analysis of nitrate concentrations over the entire GQMP network suggests that there has been little change in groundwater nitrate levels over the last five years. There is weak evidence that levels of nitrate and *E.coli* in groundwater are higher in winter and autumn, respectively, which likely reflect early seasonal rainfall leaching nutrients and bacteria more readily into unconfined aquifers. Elevated nitrate in groundwater is largely associated with intensive agriculture land use.

6.1.1. Suitability of groundwater for potable water supply

Groundwater in Taranaki can be considered suitable for stock water supply in most wells/bores, with no or minimal treatment. However, groundwater will generally require treatment if it is to be used for potable supply.

Comparison of median concentrations of key indicator variables against their respective DWSNZ (2018) MAVs or GVs, show that iron, manganese, sodium and ammonia are above one or more of these thresholds in a total of 15 (47%) GQMP sites. The presence of these variables in groundwater, found both in confined aquifers and unconfined aquifers with oxygen poor conditions, are most likely due to natural processes influenced by reducing environments and longer groundwater residence times. Often, elevated concentrations of iron, manganese, sodium and ammonia were detected in the same seven GQMP sites. Of these, two are used for domestic or potable supply, and these only had groundwater concentrations of iron and ammonia above their respective GVs.

The median concentration of nitrate was above the DWSNZ (2018) MAV in only one GQMP wells, however, nitrate levels in this well were regularly more than double the MAV of 11.3 mg/L. In addition, groundwater samples from a further four sites had nitrate concentrations above the MAV on one or more sampling occasion. Groundwater from all five wells are used for stock and/or domestic supplies. Well owners are advised of these results. Overall, median nitrate concentrations in 27 of the 32 GQMP sites were ≤50% of the MAV.

There is some discussion in the science community presently around whether a more stringent maximum acceptable value (MAV) for nitrate should be set to protect human health, although there is not yet a strong consensus in New Zealand as to whether the science supports further limits on nitrate levels in groundwater.

Median counts of *E.coli* were above the DWSNZ (2018) MAV in seven of the 25 GQMP sites tested routinely for bacteria. However, positive counts of *E.coli* were detected on one or more sampling occasion in groundwater samples from almost all of the GQMP wells screened in unconfined aquifers. Site owners are informed when detections are made. It is likely that much of the *E.coli* contamination is due to local sources of bacteria, such as animal or human effluent, which is able to make its way into the well or bore when there is poor bore or wellhead protection or certain construction methods have been used. There is some evidence that dug and unlined wells (as well as possibly dug or bored/augured wells in general) are slightly more at risk of bacteriological contamination than other bore or well constructs. It is recommended that these well types, alongside poorly constructed monitoring sites in general, are replaced with drilled and screened GQMP monitoring wells in the same location. More work may also be required to understand and improve the level of bore or wellhead security at individual GQMP sites.

Groundwater concentrations of nitrite, fluoride and bromide were not above their respective DWSNZ (2018) MAV or WHO (2017) thresholds. While an evaluation of the pesticide surveys undertaken by the Council and ESR show that regionally there are limited low levels of pesticide or EOCs in groundwater, these are not at a level of concern to human health. This may reflect the relatively small extent of horticulture within the region, as well as the reliance of groundwater being more prevalent in rural areas than in urban areas. Heavy metals and metalloids are not routinely tested as part of the GQMP, although the limited results available do not indicate an issue.

6.2. Temporal trends in groundwater quality

Improving or degrading trends were found with high confidence in 32 site-variable time series (Section 2.2.5). There was a nearly even split between trends that showed groundwater quality was very likely improving (15 trends) and very likely degrading (17 trends) in regional aquifers. Only eight trends overall were considered environmentally meaningful.

In general, the results of the undertaken trend analyses suggest that natural processes (like rock/water interactions or rainfall patterns) have driven small scale hydrochemical changes across a number of key indicator variables in regional aquifers over the last 10 years. Such variables include bicarbonate, bromide, chloride, fluoride, iron and manganese. Meanwhile, anthropogenic influences appear to be a stronger driver of temporal trends for a select few regional groundwater quality variables (EC, *E.coli*, nitrate and NNN). In general, the reported trends are consistent with those from the previous reporting period (TRC 2017), although updated trend reporting methods and terminologies have been used in this report.

Bore integrity issues at GND0563 appear to have caused a number of changes to groundwater quality at this location, with trends in four groundwater quality variables at this bore considered to be environmentally meaningful. However, given that the groundwater quality trends at GND0563 reflect where an unscreened bore has led to a deterioration in down-hole conditions due to sedimentation, and does not represent groundwater quality of the Matemateaonga aquifer, it is recommended that GND0563 is removed from the GQMP and NGMP networks.

Analysis of the state of groundwater quality highlights that elevated nitrate concentrations are evident to varying degrees within the region's shallow aquifers. This is highly likely due to human influence and the effects of intensive agricultural land use. Environmentally meaningful trends in concentrations of nitrate (or NNN) were found with high confidence at only three sites, including one improving trend and two deteriorating trends. It is also noted that previous analysis of groundwater quality over a 16 year period (TRC 2017) found statistically significant and environmentally meaningful trends in groundwater concentrations of nitrate in seven GQMP sites that are still currently monitored (four improving and three worsening trends). Only groundwater concentrations of nitrate in GND0827 and GND1095 continue to show degrading and improving trends with a high level of confidence between the two reporting periods. This may suggest groundwater nitrate concentrations in all other sites are being maintained over the last ten years, or that changes are not yet able to be measured with a high level of confidence.

6.3. National context

Median values for nitrate and *E.coli* in Taranaki groundwater are comparable to those found nationally and are similar to those in other regions of New Zealand dominated by agricultural land use. Levels of *E.coli* and nitrate in Taranaki groundwater are proportionately less likely to exceed MAVs than sites surveyed nationally.

Comparison of temporal trends suggests changes in groundwater quality are more influenced by anthropogenic activities than natural processes, both at a regional and national scale.

Monitoring results from the GQMP were compared against figures from two national groundwater quality reports. Both reports are based on groundwater quality data collected from regional councils for SEM reporting, and from the NGMP database (Moreau et al 2016, and MfE and StatsNZ 2019). It is noted that both national reports cover different analysis periods than used in this report, however, the analysis methods used between regional and national reporting are similar and results are considered comparable.

Moreau et al (2016) determined the overall median groundwater concentration of nitrate in Taranaki to be 2.3 mg/L, which was the third highest in New Zealand behind Canterbury (3.2 mg/L) and Southland (4.9 mg/L), and marginally ahead of Waikato (2.2 mg/L). These regions are all known for their large agricultural sectors.

Table 9 The number of sites surveyed nationally and regionally in which median values of *E.coli* and nitrate nitrogen exceed national drinking water standards, alongside overall median values calculated for the same variables

Note: *n= the total number of sites assessed for each variable*

DWSNZ (2018) MAV	No. of sites nationally where median exceeds MAV From: MfE & StatsNZ (2014-2018)	No. of sites regionally where median exceeds MAV (TRC 2015–2020)	Overall national median From: IGNS (2005–2014)	Overall regional median (TRC 2015–2020)
E.coli (<1 cfu/100 mL)	68% (n=364)	33.3% (n=24)	<1 cfu/100 mL	<1 cfu/100 mL
Nitrate-nitrogen (<11.3 mg/L)	19% (n=433)	3.1% (n=32)	1.5 mg/L	1.85 mg/L

6.4. Overall assessment of regional groundwater quality

Consideration of current median values of the 12 key indicator variables alongside temporal trends analysis can provide an indication of where the quality of regional groundwater is of concern environmentally or from a drinking water standard perspective. State and temporal trend analysis of groundwater chemistry in four sites (GND0563, GND0827, GND0829 and GND2213) indicate that concentrations of select variables are changing at rates that are considered environmentally meaningful. However, only changes in overall hydrochemistry at GND0563 indicated the state of groundwater in this bore is no longer suitable for potable supply. Given that groundwater quality at this bore is being impacted by the deteriorating state of the bore’s integrity, it is recommended that GND0563 be removed from the GQMP network.

Groundwater concentrations of nitrate and NNN in the remaining three bores are changing at rates that could either exceed the DWSNZ (2018) MAV for nitrate or have an impact on any receiving environments. For example, the current rate of change could see levels of NNN exceed the DWSNZ (2018) MAV for nitrate (11.3 mg/L) in just under three years at GND0829 (although, it should be noted that nitrate concentrations at this site have reduced since 2018). Meanwhile, nitrate concentrations at GND0827 have steadily degraded since the last reporting period, with the median nitrate concentration increasing from 2.41 (TRC 2017) to 3.3 mg/L.

Many of the data records for GQMP sites were not yet of suitable length to enable robust analysis for temporal trends. A more widespread analysis for trends will be possible as these datasets grow in coming years and this will enable a better insight into how groundwater quality is changing, and at what rate, across the region.

The risk that nutrient rich groundwater may pose to hydraulically connected surface water in the region, either in promoting aquatic ecosystem toxicity or the instream proliferation of nuisance plants and algae, is mostly unknown, as are the influence of localised aquifer characteristics (such as aquifer lithology, overlying soil conditions, groundwater residence times, redox in unconfined aquifers) on nutrient attenuation and reduction within the region's unconfined aquifers.

Targeted investigations, such as the Waiokura Stream catchment study, have highlighted changeable redox conditions and hydrochemical links between groundwater and the Waiokura Stream. Sources of nutrients (like nitrate) in the stream were also found to be strongly associated with agricultural land use activities in the Waiokura catchment (van der Raaij and Martindale 2016). However, these are the preliminary findings of only one study exploring localised hydraulic connections. Regionally, it is expected that some attenuation and dilution of nutrients will occur along the groundwater flow path and within surface water.

Developing management policies and strategies that consider the potential contaminant contribution of groundwater to surface water may be difficult as nutrients are highly mobile in water. Many of the regional unconfined aquifers already show some degree of human impact above the NPS-FM (2020) nitrate aquatic toxicity threshold. Dry stock and dairy farming are typically attributed as sources of nutrient loading, however, in Taranaki, the intensity of these two activities has been relatively stable for some time. Moreover, the nutrient contribution from increased application of nitrogen-based fertilisers in recent times, and the impact of large scale industry in the region needs to be considered and managed appropriately. Analysis of groundwater age would help understand where and when to expect the cumulative impacts of land use to become apparent in regional aquifers and waterways.

Further research into aquifer characteristics and possible hydraulic links and the fate and transport of nutrients, bacteria and other contaminants in the Taranaki unconfined aquifers can help with developing regional policies and strategies for managing nitrate (and other contaminants) in groundwater. This is especially important, as in recent years there has been a move away from discharges to water in preference of discharge to land overlying regional aquifers. Such a move has been made in order to improve surface water quality, however the subsequent environmental impact on groundwater quality is as yet unknown. Such research will in turn assist with meeting national attribute objectives outlined in the NPS-FM (2020).

7. Conclusion

The results of monitoring by the Council over the last five years shows indicators like *Escherichia coli* bacteria (*E. coli*), nitrate nitrogen (nitrate), ammoniacal nitrogen (ammonia), iron and manganese are occasionally found at levels considered unsafe for humans or stock to drink, or at levels that can make the water look or taste unpleasant.

People using private groundwater supplies are most at risk of drinking groundwater with *E. coli* bacteria and elevated levels of nitrate. Overall, median nitrate and *E. coli* levels in Taranaki groundwater are comparable to other regions across Aotearoa where intensive agriculture is the predominant land use. Human activities and animal and industry wastewater discharged to land locally are both common sources of bacteria and nitrate. Poorly constructed wells and bores, or those that are not adequately isolated from direct sources of contamination, or surface runoff, are more likely to display elevated levels of *E.coli*.

At certain concentrations, nitrate can pose a health risk to babies and breastfeeding mothers. The DWSNZ sets a maximum acceptable value (MAV) for nitrate intended to protect against these risks. There is some discussion in the science community presently around whether a more stringent MAV should be set to protect our health, although there is not yet a strong consensus in New Zealand as to whether the science supports further limits on nitrate levels in groundwater. In Taranaki, there was only one site where median levels of nitrate were found to exceed the MAV for drinking water. Median nitrate concentrations were less than half of the MAV at 27 of 32 sites monitored (84%).

The presence of *E. coli* is used as an indicator of the potential presence of pathogens that can make us sick. Monitoring during 2015 to 2020 showed that *E. coli* were detected on at least one occasion at 21 of the 25 sites (84%) located in aquifers most at risk from *E. coli* contamination. At a number of sites the presence of *E. coli* is related to poor bore or well construction, which allows for the ingress of overland runoff into groundwater supplies. *E. coli* concentrations found in purpose designed monitoring wells installed following good drilling practices are consistently low. These results highlight the importance of the proper construction of wells/bores and treating groundwater prior to using it for household drinking water.

The presence of iron, manganese and ammonia in groundwater is mostly due to the local geology and natural processes that occur in aquifers with low levels of oxygen. The concentration of these contaminants in water at some locations can cause the staining of plumbing fixtures, clogging of pipes or result in the taste or look of groundwater being unpleasant, making the water unsuitable for certain uses. Iron concentrations are a particularly common challenge for those utilising groundwater supplies in Taranaki.

Between 2015 to 2020, 12 of 32 monitored sites (38%) were found to have concentrations of iron and/or manganese exceeding an aesthetic or heath related standard set out in the DWSNZ. A further three sites (9%) had exceedances of the aesthetic standard for ammonia.

Test results show that pesticides and heavy metals are generally not an issue in our groundwater, although there have been isolated instances where contamination by chemical substances and herbicides/fungicides has been detected.

Temporal trend analysis of GQMP data collected over a ten year period (2010 to 2020) was conducted on 52 data sets from 10 GQMP sites covering 11 of the 12 key indicator variables. A total of eight environmentally meaningful trends were identified through the analysis. Four of these were related to site GND0563 and are likely related to physical changes made to the bore and its rapidly declining structural integrity. It is recommended that this bore is removed from the GQMP. The remaining four meaningful trends detected in levels of nitrate/NNN and bicarbonate indicate groundwater quality is deteriorating at two sites and improving at one site. Overall, trend analysis found few environmentally meaningful trends at sites where sufficient monitoring data was available for analysis. This suggests groundwater quality across the region is generally stable. In some instances, however, this means that concentrations of contaminants, like nitrate, are being maintained at levels above national drinking water standards or aquatic ecosystem toxicity thresholds.

Comparisons between temporal trend analyses conducted on regional and national data sets indicated that changes in groundwater quality are more likely to be driven by land use or human influence, rather than natural processes at regional and national scales.

7.1. Recommendations

1. THAT the Ministry of Health, Taranaki District Health Board and private bore or well owners be informed of groundwater quality results from potable supply bores;
2. THAT the Council continues to monitor new research regarding the potential health risks associated with nitrate in drinking water and liaise with the Taranaki District Health Board in respect of any research outputs;
3. THAT changes to regional policy and plans are made that enable identification of all groundwater wells/bores installed in the region. Any bores or wells established historically should be registered with the Council.
4. THAT an analysis of groundwater data from both GQMP sites and wells/bores used in consent compliance monitoring is undertaken collectively to better understand the extent and magnitude of nutrient contamination (particularly nitrate) in regional aquifers;
5. THAT hydraulic connections between groundwater and surface water are investigated to aid in the attribute objective and target setting that is to be implemented in regional policy through the NPS-FM (2020); and
6. THAT the range of analyses currently carried out on samples from the SGWM network be extended in forthcoming sampling events to include calcium, magnesium and potassium. Routine periodic testing of heavy metals and metalloids should also be scheduled in to the GQMP.

Glossary of common terms and abbreviations

The following abbreviations and terms may be used within this report:

Anisotropic	Different physical properties in all directions.
Anoxic	Water that is depleted of dissolved oxygen.
Aerobic	Water containing oxygen or a related process requiring oxygen.
ANZECC	Australia and New Zealand Environment and Conservation Council Water Quality Guidelines (2000)
Aquifer	A permeable water-bearing geological formation through which water moves under natural conditions and which yields water to wells at a sufficient rate to be a practical source of water supply.
Bore	Bore means a hole drilled into the ground and completed for the abstraction of water or hydrocarbons to a depth of greater than 20 metres below the ground surface.
Censored data	Any data for which the precise value is partially unknown. For the purpose of this report censored data relates to a sampling result returned below the analysing laboratories limit of detection for that test (i.e. a nitrate result of <0.001 mg/L).
Confined aquifer	When an impermeable formation, such as clay, overlies an aquifer so that air and water are no longer in contact and the pressure is no longer equal to atmospheric pressure. Water in a well will stand at a different level to the water table.
Denitrification	A microbially facilitated process of nitrate reduction.
DO	Dissolved oxygen.
DWSNZ	Drinking Water Standards for New Zealand 2005 (Revised 2018).
E.coli	Escherichia coli, an indicator of the possible presence of faecal material and pathological micro-organisms. Usually expressed as colony forming units per 100 millilitre sample.
Effluent	Liquid waste including slurries.
Electrical conductivity	Conductivity, an indication of the level of dissolved salts in a sample, usually measured at 20°C and expressed in mS/m.
GQMP	Groundwater quality monitoring programme.
GV	Guideline Value (taken from DWSNZ).
Heterogeneity	The quality or state being diverse in physical character or content.
Heterogeneous	See Heterogeneity.
IANZ	International Accreditation New Zealand.
Infiltration	The seepage of water into soil or rock.
Intervention	Action/s taken by Council to instruct or direct actions be taken to avoid or reduce the likelihood of an incident occurring.
Leaching	The loss of mineral and/or organic solutes through percolation.
Lithology	The general physical characteristics of a rock or the rocks in a particular area.
MAV	Maximum Acceptable Value (taken from DWSNZ).
mS/m	Millisiemens per metre.
µS/cm	Microsiemens per centimetre

NGMP	National Groundwater Monitoring Programme.
NH_4	Ammonium, normally expressed in terms of the mass of nitrogen (N).
NO_3	Nitrate, normally expressed in terms of the mass of nitrogen (N).
Objective	A statement of a desired and specific environmental outcome.
Oxic	Water in which dissolved oxygen is present.
Oxidation state	See Redox.
pH	A numerical system for measuring acidity in solutions, with 7 as neutral. Numbers lower than 7 are increasingly acidic and higher than 7 are increasingly alkaline. The scale is logarithmic i.e. a change of 1 represents a ten-fold change in strength. For example, a pH of 4 is ten times more acidic than a pH of 5.
Policy	A specific statement that guides or directs decision making. A policy indicates a commitment to a general course of action in working towards the achievement of an objective.
Purging	The removal of groundwater from a well or bore prior to obtaining a sample.
Recharge	The addition of water from other sources to an aquifer, e.g., seepage from rivers, percolation of rainfall.
Redox	Redox (reduction-oxidation) reactions include all chemical reactions in which atoms have their oxidation state changed; in general, redox reactions involve the transfer of electrons between species. Oxidation is the loss of electrons or an increase in oxidation state by a molecule, atom, or ion. Reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom, or ion.
Reduction processes	See Redox.
Residence time	The amount of time water is present within an aquifer between recharge and discharge.
Resource consent	Refer Section 87 of the RMA. Resource consents include land use consents (refer Sections 9 and 13 of the RMA), coastal permits (Sections 12, 14 and 15), water permits (Section 14) and discharge permits (Section 15).
RFWP	Regional Freshwater Plan for Taranaki (2001).
RMA	Resource Management Act 1991 and including all subsequent amendments.
SEM	State of the Environment
SGWM	Shallow groundwater monitoring.
Transmissivity	Transmissivity is a measurement of the rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient.
Unconfined aquifer	Groundwater which is freely connected to the atmosphere and which is free to rise and fall in the saturated zone, or water of an unconfined aquifer, or water under water table conditions.
Water table	The upper level of an underground surface in which the soil or rocks are permanently saturated with water.
Well	A hole dug, augured or drilled, tapping the water-table or springs to a depth of 20 m or less below the ground surface.
Yield	The volume of water per unit of time able to be abstracted from a bore or well.

Bibliography and references

Ballantine, D.J., and Davies-Colley, R.J., (2009). Water quality trends at NRWQN sites for the period 1989-2007. NIWA client report (HAM2009-26). Prepared for Ministry for the Environment, March 2009.

Britannica, The Editors of Encyclopaedia. "Biogeochemical cycle". Encyclopedia Britannica., (2020). https://www.britannica.com/science/biogeochemical-cycle [Accessed July 2021].

Brown, K.B., (2013). Stocktake and assessment of Taranaki Groundwater Resources. Report prepared by Geosearch Limited for Taranaki Regional Council.

Burgess, A.C., and Davis, E.B., (1966). Soil fertility problems of Taranaki. New Zealand Grasslands Publication 1966.

Chebotarev II., (1995). Metaporphism of natural water in the crust of weathering Geochim. Cosmochim. Acta. 8 (pp. 22-28).

Close M., and Humphries, B., (2019). National Survey of Pesticides and Emerging Organic Contaminants (EOCs) in Groundwater 2018. Client report CSC19016. Institute of Environmental Science and Research.

Daughney, C.J., and Reeves, R.R., (2005). Definition of hydrochemical facies in the New Zealand National Groundwater Monitoring Programme. Journal of Hydrology (NZ) 44(2). pp 105-130.

Daughney, C.J., and Reeves, R.R., (2006). Analysis of long-term trends in New Zealand's groundwater quality based on data from the National Groundwater Monitoring Programme. Journal of Hydrology New Zealand 45: 41-62.

Daughney, C.J., and Wall, M., (2007). Groundwater quality in New Zealand: State and Trends 1995-2006. GNS Science Consultancy Report 2007/23 prepared for the Ministry for the Environment.

Environment Canada., (2021). Groundwater. https://www.canada.ca/en/environment-climate-change/services/water-overview/sources/groundwater.html [Accessed June 2019].

Fertiliser Association NZ., (2018). Fertiliser use in NZ: http://www.fertiliser.org.nz/Site/about/fertiliser_use_in_nz.aspx. [Accessed March 2021].

Gillingham, A., (2008). 'Soils and regional land use - Central and western North Island', Te Ara - the Encyclopaedia of New Zealand, http://www.TeAra.govt.nz/en/soils-and-regional-land-use/page-4 [Accessed March 2021].

Helsel, D.R., (2011). Statistics for censored environmental data using Minitab and R (Vol. 77). John Wiley & Sons.

Helsel D.R., and Hirsch R.M., (1992). Statistical methods in water resources. Studies in Environmental Science, Vol. 49. Elsevier, Amsterdam.

Hirsch, R.M., Slack, J.R., and Smith, R.A., (1982). Techniques of trend analysis for monthly water quality data. Water resources research, 18(1), pp.107-121.

Hem, D., (1985). Study and Interpretation the Chemical of Natural of Characteristics Natural Water. 3rd edition USGS Water Supply Paper 2254 66-69 US Govt Printing Office Washington DC.

Jowett, I., (2018). Review of minimum flows and water allocation in Taranaki. Jowett Consulting Ltd. chlorideient Report: IJ1702. July 2018.

Livestock Improvement Corporation Limited (LIC) and Dairy NZ Limited., (2000). New Zealand Dairy Statistics 1999-2000. LIC, Hamilton and Dairy NZ, Hamilton. https://www.lic.co.nz/about/dairy-statistics [Accessed December 2020].

Livestock Improvement Corporation Limited (LIC) and Dairy NZ Limited., (2010). New Zealand Dairy Statistics 2009-10. LIC, Hamilton and Dairy NZ, Hamilton. https://www.lic.co.nz/about/dairy-statistics [Accessed December 2020].

Livestock Improvement Corporation Limited (LIC) and Dairy NZ Limited., (2020). New Zealand Dairy Statistics 2019-20. LIC, Hamilton and Dairy NZ, Hamilton. https://www.lic.co.nz/about/dairy-statistics [Accessed December 2020].

Manaaki Whenua Landcare Research., (2000). Land Resource Inventory of Taranaki 2000.

Manaaki Whenua Landcare Research., (2020). The New Zealand Soils Map Viewer https://doi.org/10.26060/9vfz-hw43 [Accessed December 2020].

McBride, G.B., (2019). Has water quality improved or been maintained? A quantitative assessment procedure. Journal of Environmental Quality, 48(2). https://doi.org/10.2134/jeq2018.03.0101

McMahon, P.B., and Chapelle, F.H., (2008). Redox Processes and Water Quality of Selected Principal Aquifer Systems. *Ground Water*. [online] 46 (2), 259-271. Available from: https://oh.water.usgs.gov/tanc/pubs/McMahon-ground-water-april_2008 [Accessed August 2017].

Ministry for the Environment., (2006). A national protocol for the state of the environment groundwater sampling in New Zealand. Ministry for the Environment. Wellington.

Ministry for the Environment. 2009. Water Quality in Selected Dairy Farming Catchments: A baseline to support future water-quality trend assessments. Wellington: Ministry for the Environment.

Ministry for the Environment., (2016): Land-use and Carbon Analysis System: Satellite imagery interpretation guide for land-use classes (2nd edition) 2016 Update. Ministry for the Environment. Wellington.

Ministry for the Environment., (2014). National policy statement for freshwater management 2014. Gazetted 4 July 2014. Ministry for the Environment, Wellington.

Ministry for the Environment & Statistics NZ., (2019). New Zealand's Environmental Reporting Series: Environment Aotearoa 2019 Summary. Publication number: ME 1417. Published in April 2019 by Ministry for the Environment and Stats NZ. Available from www.mfe.govt.nz and www.stats.govt.nz

Ministry of Health., (2018). Drinking-water Standards for New Zealand 2005 (Revised 2018). Ministry of Health, Wellington.

Molloy, L., (1998). Soils in the New Zealand Landscape – the living mantle, 2nd Edition. New Zealand Society of Soil Science c-/- Department of Soil Science, Lincoln University. New Zealand.

Moreau, M., Reidi, M.A., and Aurisch, K., (2016). Update of national Groundwater Quality Indicators: State and trends 2005-2014. GNS Science Consultancy Report 2015/107. 42p.

National Institute of Atmosphere and Water., (2021). https://niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/land-use/agriculture/dry-stock/activities [Accessed June 2021].

Neal, C., Neal, M., Hughes, S., Wickham, H., Hill, L., and Harman, S., (2007). Bromine and bromide in rainfall, cloud, stream and groundwater in the Plynlimon area of mid-Wales. Hydrology and Earth System Sciences Discussions, European Geosciences Union, 2007, 11 (1), pp.301-312.

Pattle Delamore Partners., (2011). Audit of Taranaki Regional Council State of the Environment Groundwater Programmes. Report prepared for Taranaki Regional Council.

Pattle Delamore Partners., (2011). New Zealand Guidelines for the Monitoring and Management of Sea Water Intrusion Risk on Groundwater. Report prepared for Envirolink Project 420-NRLC50

Rosen, M.R., (2001). Hydrochemistry of New Zealand's aquifers. In Rosen MR. and White PA. (EDs). Groundwaters of New Zealand (pp. 77-110). New Zealand Hydrological Society, Wellington.

Roverato, M., Cronin, S., Procter, J., and Capra, L., (2014). Textural features as indicators of debris avalanche transport and emplacement, Taranaki volcano. Geological Society of America Bulletin. 127. 3-18. 10.1130/B30946.1.

Rusydi, A.F., (2018). IOP Conf. Ser.: Earth Environ. Sci. 118 012019. https://iopscience.iop.org/article/10.1088/1755-1315/118/1/012019 [Accessed July 2021].

Schullehner, J., Hansen B., Thygesen, M., Pedersen, C.B., and Sigsgaard, T., (2018). Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study. International Journal of Cancer. 2018; 143(1):73-79. https://doi.org/10.1002/ijc.31306

Sherris, A.R., Baiocchi, M., Fendorf, S., Luby, S.P., Yang, W., Shaw, G.M., (2021). Nitrate in Drinking Water during Pregnancy and Spontaneous Preterm Birth: A Retrospective Within-Mother Analysis in California. Environmental Health Perspectives. 2021; 129(5):057001. https://doi.org/10.1289/EHP8205

Smedley, P.L., and Kinniburgh, D.G., (2002). A review of the source, behaviour and distribution of arsenic in natural waters. Applied Geochemistry, 17: 517-568.

Snelder, T., and Fraser, C., (2018). Aggregating trend data for environmental reporting. LWP Client Report 2018-01.

Snelder, T., and Fraser, C., (2019). LWP-Trends library Version 1901: LWPTrends_v2101.r. Tools for analysing water quality trends. Land Water People Ltd Report, p35. Christchurch New Zealand. Note – this tool is constantly updated.

Statistics New Zealand., (2020). Infoshare https://www.stats.govt.nz/tools/stats-infoshare [Accessed December 2020].

Stenger, R., and Clague, J., (2016). Investigations of redox gradients in shallow groundwater systems: Monitoring results July 2015 - April 2016. Report 1046-2-6. Report prepared by Lincoln Agritech Limited for Taranaki Regional Council.

South Taranaki District Council, (2018). Waste Assessment. https://www.southtaranaki.com/repository/libraries/id:27mlbegko1cxbyf94es5/hierarchy/Documents/Plans%2C%20strategies%20and%20reports/Waste%20Management%20and%20MInimisation%20Plan/2018%20South%20Taranaki%20District%20Council%20Waste%20Assessment.pdf

Taranaki Regional Council., (1992). South Taranaki Groundwater Survey and Management Policies. ISSN: 0114-8184, Taranaki Regional Council, Stratford, November 1992.

Taranaki Regional Council., (1996). Groundwater Resources of The Taranaki Region. Taranaki Regional Council, Stratford, August 1996.

Taranaki Regional Council., (2008). Groundwater Chemical Quality. State of the Environment Monitoring 1994-2007. Technical Report 2017-45. Taranaki Regional Council, Stratford, October 2017.

Taranaki Regional Council., (2015): Taranaki as one. State of the Environment Report 2015. Taranaki Regional Council, Stratford, June 2015.

Taranaki Regional Council., (2015): Procedure for Groundwater Sampling [Procedure 44]. Taranaki Regional Council, Stratford, October 2015.

Taranaki Regional Council., (2017): Taranaki Regional Council requirements for good farm management Available from: www.trc.govt.nz. Taranaki Regional Council, Stratford, March 2017.

Taranaki Regional Council., (2017). Groundwater Chemical Quality. State of the Environment Monitoring 2016-2017. Technical Report 2008-58. Taranaki Regional Council, Stratford, October 2008.

Taranaki Regional Council., (2020). Freshwater Physicochemical Programme State of the Environment Monitoring Annual Report 2018-2019. Technical Report 2019-98. Taranaki Regional Council, Stratford, October 2020.

Taranaki Regional Council., (2022): Groundwater Quantity State of the Environment Monitoring Triennial Report 2017-2020. Available from: www.trc.govt.nz. Taranaki Regional Council, Stratford, July 2022.

Taylor, C.B., and Evans, C.M., (1999). Isotopic indicators for groundwater hydrology in Taranaki, New Zealand. Journal of Hydrology (NZ) 38(2). pp 237-270.

van der Raaij R.W., and Martindale, H., (2016). Application of hydrochemical and isotopic methods to assess water source and contaminant pathways in the Waiokura Catchment, Taranaki, New Zealand, DRAFT GNS Science Report 2016/65. 39 p.

World Health Organisation., (2017). Guidelines for Drinking-water Quality: fourth edition incorporating the first Addendum. Geneva: World Health Organization; 2017. License: CC BY-NC-SA 3.0 IGO.

Younger, P.L., (2007). Groundwater in the environment: an introduction. Blackwell. London 2008. ISBN 1-4051-2143-2.

Appendix I

Monitoring site details

Site	Easting	Northing	Area	Date drilled	Depth (m)	Diameter (mm)	Screened depth (m BGL)	Construction method	Usage	Aquifer	Aquifer type	Date monitoring began	Programme
GND0213	1711187	5682097	Motunui	18/12/1982	21.7	76.2	17.6 - 20.6	Drilled - screened	Monitoring	Marine Terrace (North)	Unconfined	23/09/2015	NGMP
GND0430	1713802	5623656	Hawera	05/11/1992	234.6	150	54.0 - 234.0	Drilled - open ended casing	Stock	Whenuakura	Confined	13/12/1994	NGMP
GND0508	1694021	5669859	New Plymouth	29/05/2003	14	50	8.0 -14.0	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	13/12/1994	NGMP
GND0514	1724029	5684247	Urenui	14/07/1987	4.2	1200	0.5 - 4.2	Dug - lined	Stock & domestic	Marine Terrace (North)	Unconfined	22/10/2014	SGWM
GND0563	1719027	5647305	Toko	06/01/1995	77.7	100	72.7 - 77.7	Drilled - open ended casing	Domestic	Matemateaonga	Confined	26/09/1995	NGMP
GND0636	1697543	5630420	Kaponga	28/09/1994	6.5	50	-	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	21/10/2013	SGWM
GND0827	1701591	5618033	Hawera	Unknown	8	1500	-	Dug - unlined	Domestic	Taranaki Volcanics	Unconfined	13/12/1994 (NGMP) 09/01/2002 (SGWM)	NGMP & SGWM
GND0829	1728941	5597650	Patea	Unknown	5.2	1000	-	Bored or augered - unlined	Stock & domestic	Marine Terrace (South)	Unconfined	24/01/2002	SGWM
GND0834	1706701	5617616	Hawera	Unknown	7	1500	-	Bored or augered - unlined	Domestic	Marine Terrace (South)	Unconfined	09/01/2002	SGWM
GND0866	1724829	5615319	Manutahi	Unknown	7	1000	-	Bored or augered - lined	Stock & domestic	Marine Terrace (South)	Unconfined	29/04/2001	SGWM

Site	Easting	Northing	Area	Date drilled	Depth (m)	Diameter (mm)	Screened depth (m BGL)	Construction method	Usage	Aquifer	Aquifer type	Date monitoring began	Programme
GND1075	1713523	5645279	Stratford	Unknown	7	-	-	Dug - lined	Stock & domestic	Taranaki Volcanics	Unconfined	14/05/2001	SGWM
GND1091	1707330	5675479	Lepperton	Unknown	7.5	1500	-	Dug - lined	Stock & domestic	Taranaki Volcanics	Unconfined	17/05/2001	SGWM
GND1095	1673342	5655645	Okato	01/01/1945	7.5	1000	-	Dug - lined	Unused	Taranaki Volcanics	Unconfined	21/05/2001	SGWM
GND1101	1665886	5648848	Rahotu	Unknown	5.5	1000	-	Dug - lined	Stock	Taranaki Volcanics	Unconfined	22/05/2001	SGWM
GND1105	1703856	5629095	Hawera	Unknown	7.2	1200	-	Unknown	Domestic	Taranaki Volcanics	Unconfined	23/05/2001	SGWM
GND1112	1702153	5621304	Hawera	Unknown	12.2	1000	-	Dug - unlined	Stock & domestic	Taranaki Volcanics	Unconfined	24/05/2001	SGWM
GND1194	1724486	5608758	Manutahi	01/01/1930	7.02	1000	-	Dug - lined	Domestic	Marine Terrace (South)	Unconfined	23/01/2002	SGWM
GND1196	1709272	5634442	Eltham	10/01/2002	8.5	50	2.4 - 8.4	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	15/11/2013	SGWM
GND1718	1721048	5680386	Urenui	01/12/2004	11	1000	-	Bored or augered - unlined	Domestic	Marine Terrace (North)	Unconfined	27/01/2015	SGWM
GND2098	1681945	5669803	Oakura	03/09/2008	13.5	50	7.5 - 12.0	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	14/10/2014	SGWM
GND2114	1675221	5661873	Okato	09/08/2009	41.9	150	34.4 - 41.9	Drilled - screened	Industrial	Taranaki Volcanics	Confined	07/12/2015	NGMP
GND2166	1701952	5651677	Inglewood	23/12/2009	3.5	50	-	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	30/01/2015	SGWM
GND2197	1725006	5599997	Patea	01/04/2011	144.2	220	96.5 - 141.5	Drilled - screened	Public supply	Whenuakura	Confined	08/12/2015	NGMP
GND2213	1700043	5675241	Lepperton	Unknown	10.7	1200	-	Bored or augered - unlined	Domestic	Taranaki Volcanics	Unconfined	01/08/2011	SGWM

Site	Easting	Northing	Area	Date drilled	Depth (m)	Diameter (mm)	Screened depth (m BGL)	Construction method	Usage	Aquifer	Aquifer type	Date monitoring began	Programme
GND2242	1739058	5597248	Waverley	24/01/2012	171.3	276	129.2 - 168.2	Drilled - screened	Public supply	Whenuakura	Confined	08/12/2015	NGMP
GND2484	1697570	5667514	New Plymouth	01/01/2008	8.3	50	2.3 - 6.3	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	22/10/2014	SGWM
GND2513	1717861	5664741	Huinga (Toko)	18/05/2015	5	50	1.0 - 5.0	Drilled - screened	Monitoring	Kiore	Unconfined	31/07/2015	SGWM
GND3006	1676679	5647875	Rahotu	26/03/2018	8	50	2.0 - 8.0	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	26/06/2018	SGWM
GND3011	1684896	5622370	Otakeho/ Oeo	29/08/2018	13.5	50	10.0 - 13.0	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	21/09/2018	SGWM
GND3012	1673639	5634990	Opunake	27/08/2018	10.5	50	7.0 - 10.0	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	20/09/2018	SGWM
GND3014	1691470	5637406	Opunake/Makaka	10/09/2018	12.5	50	9.0 - 12.0	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	21/09/2018	SGWM
GND3027	1707018	5663862	Inglewood	26/11/2018	11.6	50	8.1 - 11.1	Drilled - screened	Monitoring	Taranaki Volcanics	Unconfined	11/12/2018	SGWM

Appendix II

Water quality variables and analytical methods

Appendix Two: Water quality variables and analytical methods

Groundwater samples are obtained from all SGWM and NGMP network bores on a quarterly basis, generally during the months of September, December, March and June. Sampling is undertaken in accordance with the Council's Groundwater Sampling Procedure (TRC, 2015).

If direct access to the well or bore is possible, groundwater is purged using a low-flow peristaltic or pneumatic bladder pump to remove any standing water within the bore. Groundwater is pumped from the bore and monitored continuously as it passes through a flow-cell housing a multi parameter field chemistry meter. Groundwater samples are taken when field parameters such as temperature, pH, electrical conductivity and dissolved oxygen stabilised within set criteria (See Figure 1A). These practises are employed to make sure that the groundwater sample collected is representative of the surrounding aquifer.

A number of bores in the SEM Groundwater Quality programme are regularly used by private bore owners for example: irrigation and domestic supply bores. This means 'fresh' groundwater is continuously drawn into the bore from the aquifer and stabilisation of field parameters can occur rapidly. When direct access to the bore is not available, samples are obtained from the nearest available tap or hose. If the bore is in regular use, water will be run for a short period of time and field chemistry measurements taken when obtaining the sample. If not in regular use, a purge will be attempted and field chemistry monitored for stabilisation. When stabilised, the sample is obtained.

Groundwater samples collected for the NGMP are collected in a range of unfiltered, filtered and acid preserved sample bottles provided by GNS Science. Groundwater samples collected for the SGWM programme are collected in unpreserved sample bottles. All samples are chilled to between 4ºC - 8ºC during storage and transport to the laboratory for analysis. Samples requiring microbial analysis are delivered to the laboratory within 12 hours of being taken.

Figure 1A Groundwater bore GND0508 is continuously monitored while purged of standing water using a peristaltic pump purging. Groundwater sample is collected when field parameters are stabilised

Rational for physico-chemcial and microbiological variables measured in the Council's SEM Groundwater Quality programme are outlined in in Table 4A below. Between 2002 and June 2018, groundwater samples collected for the SGWM programme were tested by the Council's IANZ accredited laboratory, Stratford, Taranaki. From June 2018, these samples were sent RJ Hill Laboratories in Hamilton for analysis. Groundwater samples collected for the NGMP were sent the IGNS Laboratory in Wairakei, Taupo for analysis. Analytical methods and detection limits for each laboratory are showing in Table 5A to Table 8A.

Table A4 Core physico-chemical and microbiological water quality variables in the SEM GQMP

Variable type	Variable	Explanation	Monitoring history
Bacteria	*Escherichia coli (E.coli)*	*E. coli* can indicate pollution due to faecal matter and the presence of potentially harmful pathogens in groundwater. The Ministry for the Environment uses E. coli as a national indicator of groundwater quality.	*E. coli* tested under SGWM programme since July 2006. Not currently tested un NGMP.
Major ions	Total & Dissolved sodium (Na) Dissolved potassium (K) Dissolved calcium (Ca) Dissolved magnesium (Mg) Chloride (Cl) Sulphate (SO4) Total alkalinity	Concentrations of major ions can give an indication of the chemical composition of the water, the origins of groundwater, water residence time in the aquifer and the extent of rock/water interaction. Concentrations of major ions can also be indicative of groundwater contamination from industrial, agricultural and domestic sources.	All major ions except total alkalinity tested under the NGMP since 1994. Cl tested under SGWM programme since March 2018. Total Na tested between March 2018 & Sept 2019, switched to Dissolved Na in Dec 2019. SO4 and Total Alkalinity tested since July 2017 and June 2018 respectively. K and Ca currently not tested for under SGWM.
Nutrients	Nitrite-nitrate nitrogen (NNN or TON) Nitrate nitrogen (NO_3-N) Nitrite nitrogen (NO_2-N) Ammoniacal nitrogen (NH_4-N) Dissolved reactive phosphorus (DRP)	Dissolved concentrations of nutrients can indicate impact from anthropogenic activity such as intensive land use or industrial discharges. Nitrate nitrogen (nitrate) represents the oxidised form of nitrogen. Elevated concentrations of nitrate can have an adverse effect on human health and can be harmful to aquatic life. Nitrate is a national indicator of groundwater quality. Ammoniacal nitrogen (ammonia) usually exists under oxygen-poor conditions and represents the reduced form of nitrogen. Therefore, ammonia can be used as an indicator of contamination in the absence of nitrate. Natural sources of DRP in groundwater can sometimes occur due to rock/water interactions within an aquifer. However, this typically occurs in anoxic environments. Human sources of DRP are derived from intensive land use practices, and from effluent and industrial discharges.	Nutrients tested under the NGMP since 1994 with the exception of DRP which is irregularly test for. NH_4-N and NNN inconsistently tested under the SGWM programme since 2002, regularly tested since 2013. NO_3-N and NO_2-N regularly tested for since Oct 2013. DRP testing began in March 2018.
Metals	Dissolved iron (Fe) Dissolved manganese (Mn)	Trace metals are usually present in groundwater at low concentrations - elevated concentrations can suggest contamination of groundwater. Elevated concentrations of dissolved lead and manganese can adversely affect human health.	Trace elements tested under NGMP since 1996. Not currently tested under SGWM.

Variable type	Variable	Explanation	Monitoring history
Trace elements	Bromide (Br) Fluoride (F)	Bromide naturally occurs in water but can suggest contamination from wastewater and agricultural run off. The DWSNZ (2005) MAV for fluoride is set to protect against potential dental fluorosis. Elevated concentrations of dissolved boron can have adversely affect human health.	Trace elements tested under NGMP since 1996. Not currently tested under SGWM.
Other	Temperature (Temp) pH Electrical conductivity (EC) Dissolved oxygen (DO) Redox potential Dissolved reactive Silica (SiO_2)	Temperature measured in the field to identify when the bore is purged and water samples can be collected for analysis. Water with a low pH can have a high plumbosolvency. It is measured in the field to identify when the bore is purged and water samples can be collected for analysis. Electrical conductivity can provide a measure of total dissolved solids. Measured in the field to identify when the bore is purged and water samples can be collected for analysis. Dissolved oxygen (DO) can indicate whether groundwater is under reduced or oxidised conditions. DO is measured in the field to identify when the bore is purged and water samples can be collected for analysis. Redox potential is a measure of how oxygen rich (oxic) or oxygen poor (anoxic) the environment within an aquifer is. Can be used to map contamination plumes and understand where natural aquifer conditions encourage denitrification in groundwater. Can help interpret the extent of rock/water interaction.	Field measurements of temp, pH, EC and DO may have been tested for under the NGMP since 1994. However, this hasn't been recorded by TRC or NGMP until 2002. Records are patchy until 2013. Lab measurements of Temp, pH, EC and DO have been tested since 1994, but not always recorded. SiO_2 tested under NGMP since 1994. Lab EC & pH, and Field Temp tested under SWGM programme since Jan 2001. Field pH, EC, DO tested SWGM Oct 2013. SiO_2 tested under SWGM between Oct 2013 to June 2016 and redox potential since Oct 2014.
Calculations	Total dissolved solids (TDS) Bicarbonate (as HCO3) Carbonate (as CaCO3	Can help interpret the extent of rock/water interaction.	HCO_3, TDS calculated for NGMP since 1994. $CaCO_3$ tested intermittently. HCO_3, added to SGWM March 2018.

Table 5A RJ Hill Laboratory analytical methods and detection limits used in the SEM GQMP (Shallow Groundwater Monitoring network from June 2018)

Variable	Method	Detection limit
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-
Total Digestion	Nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-
pH	pH meter. APHA 4500-H+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (modified for Alkalinity <20) 23rd ed. 2017.	1.0 g/m^3 as $CaCO^3$
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 23rd ed. 2017.	1.0 g/m^3 at 25°C
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 23rd ed. 2017.	0.1 mS/m
Filtration for dissolved metals analysis	Sample filtration through 0.45µm membrane filter and preservation with nitric acid. APHA 3030 B 23rd ed. 2017.	-
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.02 g/m^3
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.0005 g/m^3
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.05 g/m^3
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.02 g/m^3
Total Sodium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.021 g/m^3
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3
Total Ammoniacal-N	Phenol/hypochlorite colourimetry. Flow injection analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH3 H (modified) 23rd ed. 2017.	0.010 g/m^3
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I (modified) 23rd ed. 2017.	0.002 g/m^3
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House	0.0010 g/m^3
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO3- I (modified) 23rd ed. 2017.	0.002 g/m^3
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23rd ed. 2017.	0.004 g/m^3
Reactive Silica	Filtered sample. Heteropoly blue colorimetry. Discrete analyser. APHA 4500-SiO2 F modified from flow injection analysis) 23rd ed. 2017.	0.10 g/m^3 as SiO_2
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3
Escherichia coli	MPN count using Colilert , Incubated at 35°C for 24 hours. APHA 9223 B 23rd ed. 2017.	1 MPN / 100mL
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, MUG Confirmation. APHA 9222 G 23rd ed. 2017.	1 cfu / 100mL

Table 6A Taranaki Regional Council analytical methods and detection limits used in SEM GQMP (Shallow Groundwater Monitoring network prior to June 2018)

Variable	TRC Lab method code	Method	Detection limit
Filtration	Sample processing	Sample filtration through 0.45µm membrane filter.	-
pH	Method 8.1.2: pH (PH-1)	(1) Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (Part 4500-H+B) (2) Physical and Chemical Methods for Water Quality Analysis, Water and Soil Miscel. Publication No. 38, 1982	0.1 pH Units
Total Alkalinity	Method 8.3.1: Alkalinity - Titrimetric, pH 4.5 (ALKT-1)	(1) Standards Methods, 22nd Edition 2012, APHA-AWWA-WEF (Part 2320B) (2) ASTM, Part 31, 1980 `Water'	1.0 g/m^3 as $CaCO_3$
Electrical Conductivity (EC)	Method 8.1.1: Conductivity (CONDY-1	(1) Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (Part 2510B) (2) Instrument Manual for Orion conductivity meter.	0.1 mS/m
Dissolved Iron	Method 8.5.1: Dissolved and Recoverable Metals (FED-1)	Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (3030F.3B, 3111B, 3111D)	0.03 g/m^3
Dissolved Manganese	Method 8.5.1: Dissolved and Recoverable Metals (MND-1)	Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (3030F.3B, 3111B, 3111D)	0.01 g/m^3
Dissolved Sodium	Method 8.5.2: Sodium and Potassium –AE (NA-4, K-4)	(1) Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (3500-NaB, 3500-K) (2) Water Research Vol 17, No 11	0.06 g/m^3
Total Sodium		Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.021 g/m^3
Chloride	Method 8.3.2 A: Chloride -Ferric Thiocyanate Colorimetry (CL-1)	Annual Book of ASTM Standards, Part 31 `Water', Standard D512, Method C (1980)	0.2 g/m^3
Total Ammoniacal-N	Method 8.4.1: Ammonia (NH4-1)	Physical and Chemical Methods for Water Quality Analysis - Water and Soil Miscel. Publication No. 38, 1982	0.003 g/m^3
Nitrite-N	Method 8.4.2 A: Nitrite (NO2-1)	Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (4500-NO2-B)	0.001 g/m^3
Nitrate-N	NO3-5	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House	0.001 g/m^3
Nitrate-N + Nitrite-N	Method 8.4.2 C: Nitrate - Hydrazine Reduction (NNN-5)	Standard methods, 22nd Edition 2012 APHA-AWWA-WEF (part 4500-NO3 - H)	0.01 g/m^3
Dissolved Reactive Phosphorus	Method 8.4.5: Reactive Dissolved Phosphorus (DRP-1)	Physical and Chemical Methods for Water Quality Analysis, Water and Soil Miscellaneous Publication No. 38, 1982	0.003 g/m^3
Reactive Silica	Silica -Molybdosilicate Colorimetric SIDR-1, SITD-1)	Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (Part 4500-SiO2 C)	1.0 g/m^3 as SiO_2
Sulphate	Method 8.3.8: Sulphate – Turbidimetric (SO4-1)	(1) Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (4500-SO42-E) (2) Department of Transportation, California Test 417, 1999.	0.5 g/m^3
Escherichia coli	Method 7.4: E. coli MF procedure (ECOL-1)	(1) Test Methods for Escherichia coli and Enterococci in Water by the Membrane Filter Procedure, USEPA, 1985 (2) Standard Methods, 22nd Edition 2012, APHA-AWWA-WEF (Part 9213D)	1 cfu / 100mL

Table 7A Institute of Geological & Nuclear Sciences analytical methods and detection limits used in the National Groundwater Monitoring Programme

Variable	Method	Detection limit
Alkalinity (as HCO3)	Auto titration method APHA 2320 - B 22nd Edition 2012	5 mg/L
Ammonia (as filterable NH3)	Flow Injection Analyser APHA 4500 NH3-H 22nd Edition 2012	0.003 mg/L
Barium	ICP-OES APHA 3120-B 22nd Edition 2012	0.001 mg/L
Bicarbonate (total)	HCO3 Titration Method ASTM Standards D513-82 Vol.11.01 of 1988	20 mg/L
Boron	ICP-OES APHA 3120-B 22nd Edition 2012	0.1 mg/L
Bromide	Ion Chromatography APHA 4110-B 22nd Edition 2012	0.02 mg/L
Calcium	ICP-OES APHA 3120-B 22nd Edition 2012	0.01 mg/L
Chloride	Ion Chromatography APHA 4110-B 22nd Edition 2012	0.05 mg/L
Conductivity	Conductivity Meter APHA 2510 B 22nd Edition 2012	1.0 µS/cm
Fluoride	Ion Chromatography APHA 4110-B 22nd Edition 2012	0.02 mg/L
Iron	ICP-OES APHA 3120-B22nd Edition 2012	0.01 mg/L
Magnesium	ICP-OES APHA 3120-B 22nd Edition 2012	0.01 mg/L
Manganese	ICP-OES APHA 3120-B 22nd Edition 2012	0.005 mg/L
Nitrate Nitrogen	Flow Injection Analyser QuickChem 8500 Series 2 Method	0.002 mg/L
Nitrite Nitrogen	Flow Injection Analyser QuickChem 8500 Series 2 Method	0.002 mg/L
pH	Electrometric Method APHA 4500-H+ B 22nd Edition 2012	-
Dissolved reactive phosphorus	Flow Injection Analyser APHA 4500-P G (modified) 22nd Edition 2012	0.002 mg/l
Potassium	ICP-OES APHA 3120-B 22nd Edition 2012	0.11 mg/L
Silica (SiO2)	ICP-OES APHA 3120-B 22nd Edition 2012	0.05 mg/L
Sodium	ICP-OES APHA 3120-B 22nd Edition 2012	0.02 mg/L
Sulphate	Ion Chromatography APHA 4110-B 22nd Edition 2012	0.03 mg/L
Total dissolved solids	By calculation	

Table 8A Taranaki Regional Council field analytical methods and detection limits used in the SEM GQMP

(Source: https://www.ysi.com/proplus)

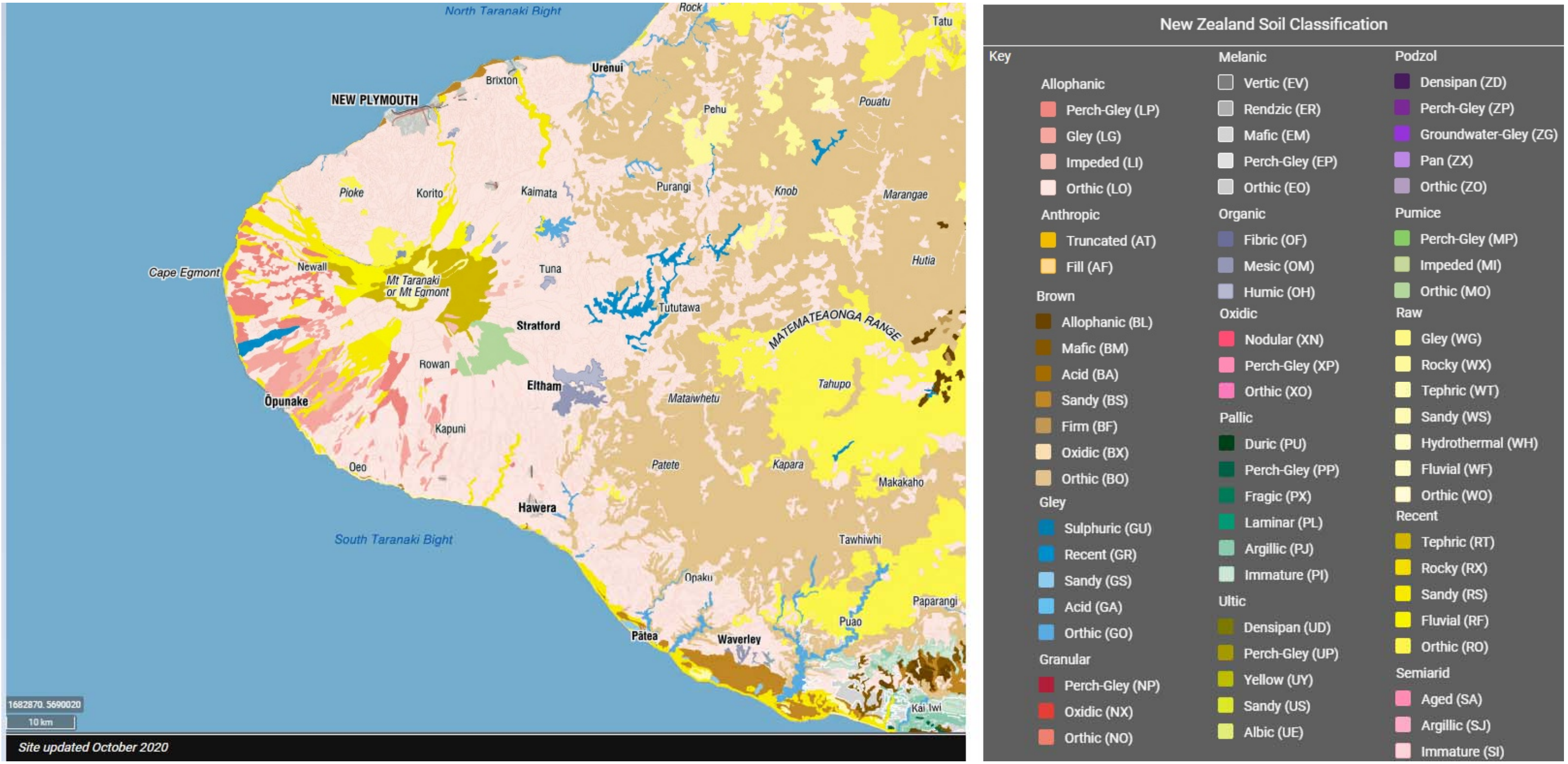
Variable	Method	Detection limit
Redox potential mV	YSI Pro Plus	0.1 mV
Acidity pH units	YSI Pro Plus	0.01 pH units
Temperature Deg. C	YSI Pro Plus	0.1 C
Oxygen mg/L	YSI Pro Plus	0.01 mg/L
Electrical conductivity uS/cm@25ºC (based on range 50.01 – 200mS/cm)	YSI Pro Plus	0.1 mS/cm

Appendix III

New Zealand Soil Classification Map

Appendix Three: New Zealand Soil Classification Map

Manaaki Whenua - Landcare Research 2020. The New Zealand Soils Map Viewer.
Soil Map View is built and operated by the Informatics and Soils and Landscapes teams at Manaaki Whenua (Landcare)
https://doi.org/10.26060/9vfz-hw43 https://soils-maps.landcareresearch.co.nz/#maps



Appendix IV

Additional analysis of select variables using Kruskal-Wallis and Dunn's tests

Appendix Five: Additional analysis of select variables using Kruskal-Wallis and Dunn's tests

Seasonality in groundwater concentrations of nitrate nitrogen

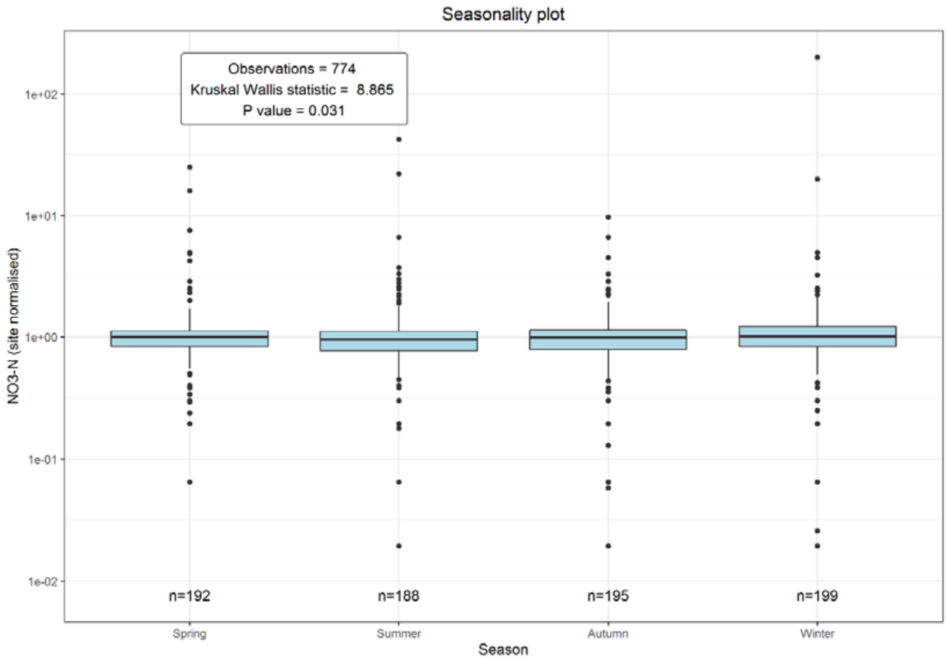


Figure 3A Boxplots showing seasonal differences in groundwater concentrations of nitrate nitrogen based on data from 32 SEM GQMP bores collected between 01 July 2010 and 30 June 2020

Table 12A The distribution (expressed as percentiles) of nitrate nitrogen concentrations in groundwater between four seasons. Based on data from 32 SEM GQMP bores collected between 01 July 2010 and 30 June 2020

Season	n	10th	25th	median	75th	90th
Spring	192	0.66	0.83	1	1.13	1.41
Summer	188	0.55	0.77	0.95	1.11	1.4
Autumn	195	0.51	0.79	0.98	1.14	1.5
Winter	199	0.53	0.83	1.01	1.23	1.79

Table 13A Results of Dunn's tests investigating seasonal differences in groundwater concentrations of nitrate nitrogen. Based on data from 32 SEM GQMP bores collected between 01 July 2010 and 30 June 2020

Comparison	Z	*p* unadjusted	*p* adjusted
Autumn - Spring	-0.691	0.49	0.49
Autumn - Summer	0.801	0.423	0.846
Spring - Summer	1.48	0.138	0.553
Autumn - Winter	-2.07	0.038	0.191
Spring - Winter	-1.37	0.17	0.511
Summer - Winter	-2.86	0.004	0.025

Relationship between bore construction type and counts of *Escherichia coli* (*E.coli*) in groundwater

Table 14A Results of Dunn's tests investigating possible relationships between types of bore constructs and the detection of positive counts of *Escherichia coli (E.coli)* in groundwater. Based on data from 32 SEM GQMP bores collected between 01 July 2010 and 30 June 2020

Comparison	Z	*p* unadjusted	*p* adjusted
Bored/augured-lined – Bored/augured-unlined	-1.59	0.113	0.563
Bored/augured-lined - Drilled-screened	-1.29	0.198	0.594
Bored/augured-unlined - Drilled-screened	0.680	0.496	0.993
Bored/augured-lined - Dug-lined	-1.96	0.050	0.298
Bored/augured-unlined - Dug-lined	-0.612	0.540	0.540
Drilled-screened - Dug-lined	-1.49	0.137	0.550
Bored/augured-lined - Dug-unlined	-3.68	0.000	0.002
Bored/augured-unlined - Dug-unlined	-3.56	0.000	0.003
Drilled-screened - Dug-unlined	-4.59	0.000	0.000
Dug-lined - Dug-unlined	-3.31	0.001	0.007

Seasonality in groundwater counts of *Escherichia coli (E.coli)*

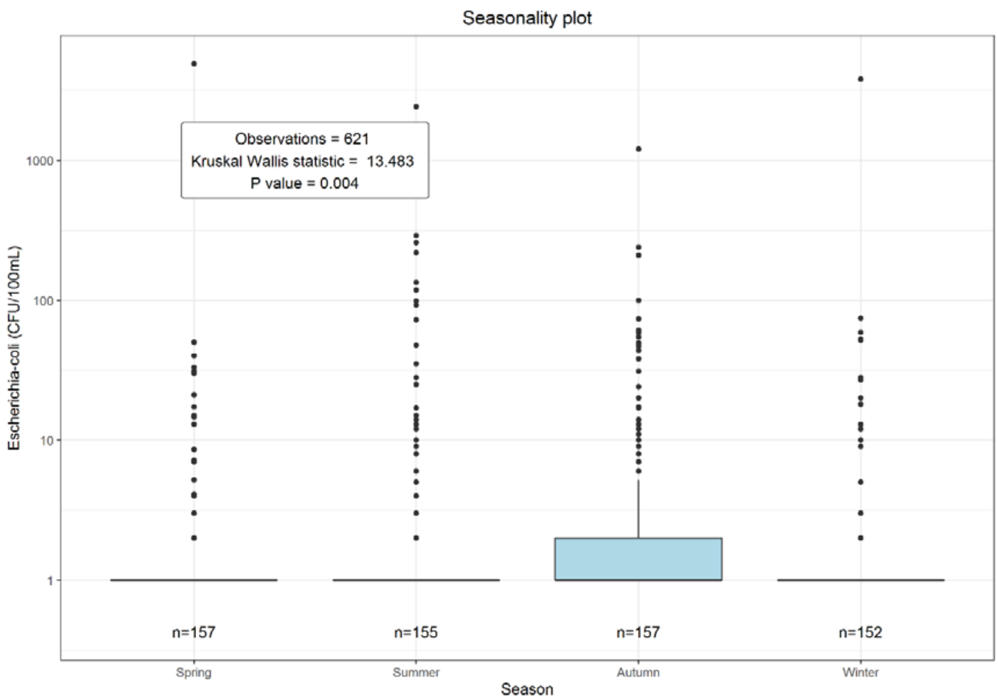


Figure 4A Boxplots showing seasonal differences in groundwater counts of *Escherichia coli* (*E.coli*) based on data from 32 SEM GQMP bores collected between 01 July 2010 and 30 June 2020

Table 15A The distribution (expressed as percentiles) of *Escherichia coli* (*E.coli*) counts in groundwater between four seasons. Based on data from 32 SEM GQMP bores collected between 01 July 2010 and 30 June 2020

Season	n	% samples with positive counts of *E.coli* (i.e. ≥1 MPN/100 mL)	% samples with elevated counts of *E.coli* (i.e. >1 MPN/100 mL)	10th	25th	median	75th	90th
Spring	157	21.66	14.65	1	1	1	1	4.54
Summer	155	33.55	23.87	1	1	1	1	13.60
Autumn	157	39.49	28.66	1	1	1	2	17.12
Winter	152	19.74	15.13	1	1	1	1	4.80

Table 16A Results of Dunn's tests investigating seasonal differences in groundwater counts of *Escherichia coli* (*E.coli*). Based on data from 32 SEM GQMP bores collected between 01 July 2010 and 30 June 2020

Comparison	Z	*p* unadjusted	*p* adjusted
Autumn - Spring	3.06	0.002	0.013
Autumn - Summer	0.976	0.329	0.658
Spring - Summer	-2.07	0.038	0.154
Autumn - Winter	2.92	0.003	0.017
Spring - Winter	-0.108	0.914	0.914
Summer - Winter	1.95	0.052	0.155

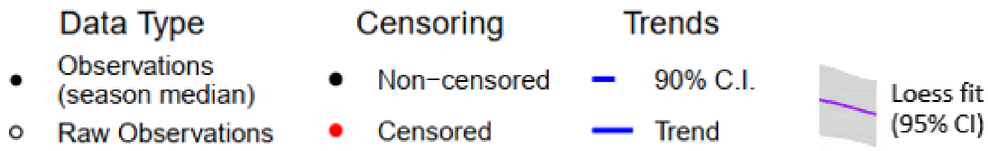
Appendix V

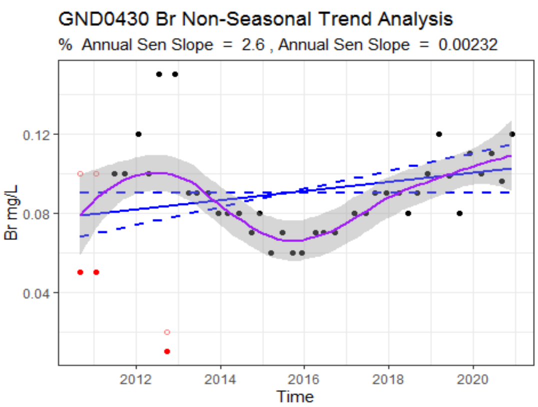
Temporal trend plots for GQMP data

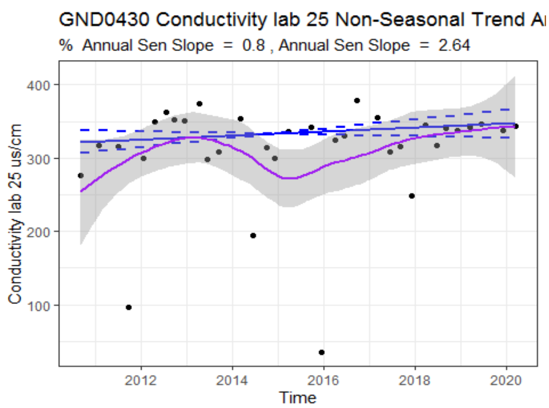
Appendix Five – Temporal trend plots for SEM GQMP data

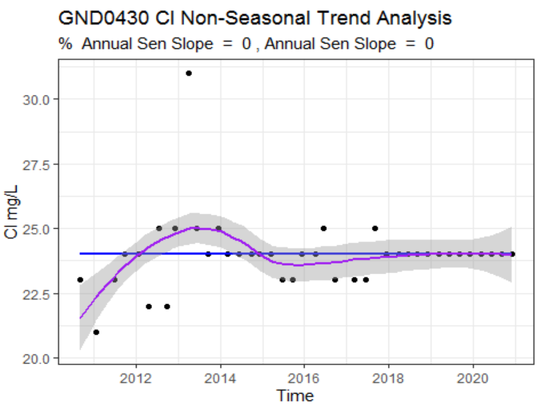
Ten year trend analysis is undertaken on groundwater data collected over the TRC SGWM and NGMP networks when there is 75% data coverage over the last ten years (minimum 30 of 40 samples taken), and when there is less than 70% raw censored data.

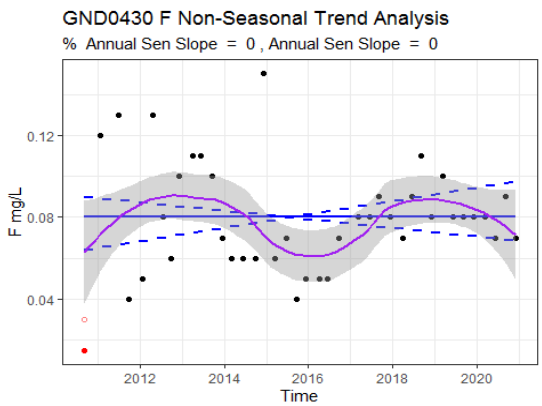
Legend for all plots:

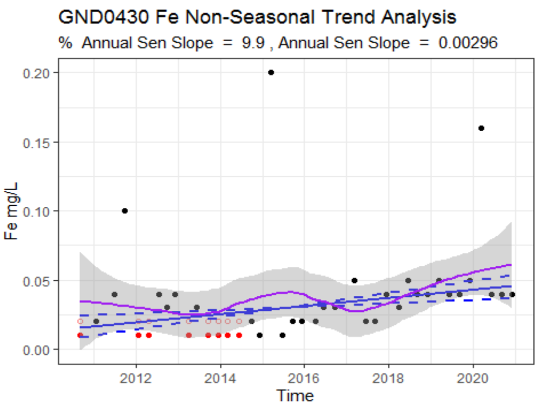


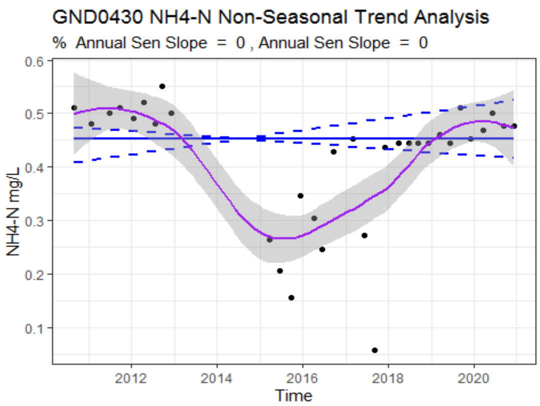


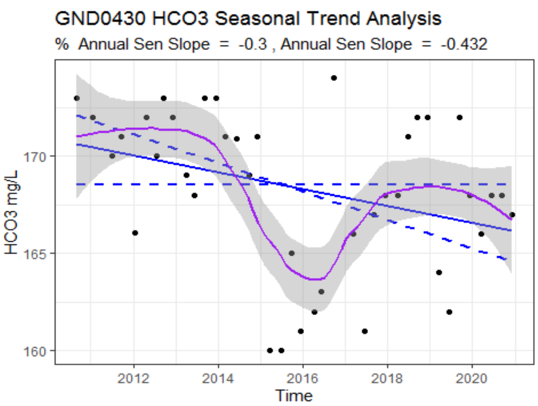


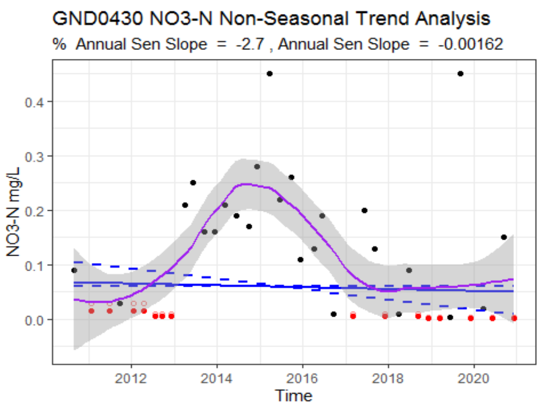


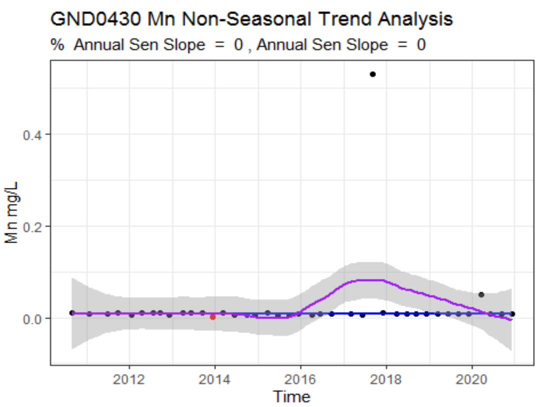


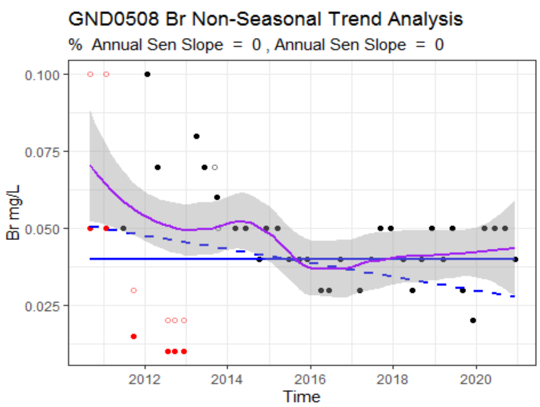

GND0430 Fe Non-Seasonal Trend Analysis
% Annual Sen Slope = 9.9 , Annual Sen Slope = 0.00296
Fe mg/L
0.20
0.15
0.10
0.05
0.00
2012
2014
2016
2018
2020
Time

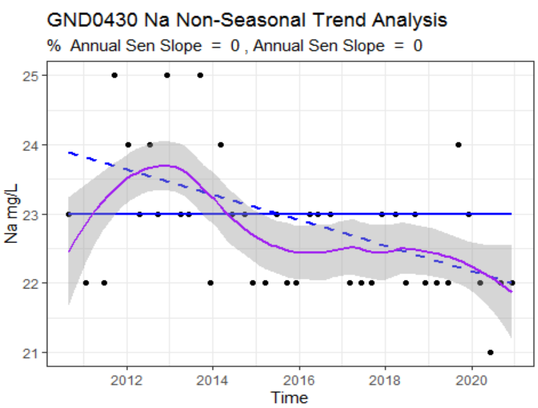

GND0430 NH4-N Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
NH4-N mg/L
0.6
0.5
0.4
0.3
0.2
0.1
2012
2014
2016
2018
2020
Time

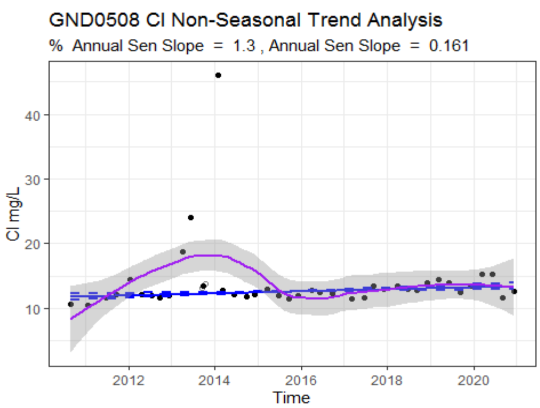

GND0430 HCO3 Seasonal Trend Analysis
% Annual Sen Slope = -0.3 , Annual Sen Slope = -0.432
HCO3 mg/L
170
165
160
2012
2014
2016
2018
2020
Time

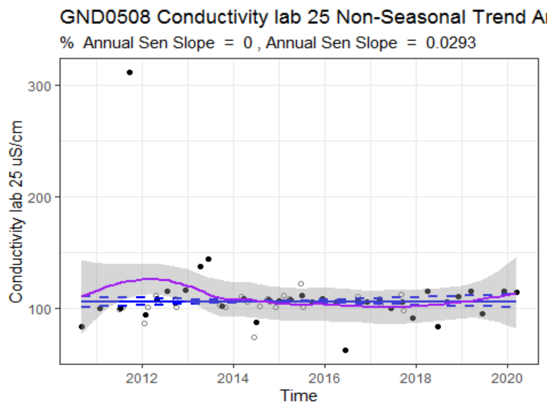

GND0430 NO3-N Non-Seasonal Trend Analysis
% Annual Sen Slope = -2.7 , Annual Sen Slope = -0.00162
NO3-N mg/L
0.4
0.3
0.2
0.1
0.0
2012
2014
2016
2018
2020
Time

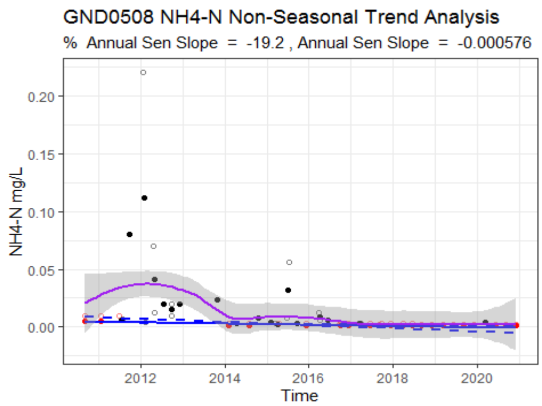

GND0430 Mn Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
Mn mg/L
0.4
0.2
0.0
2012
2014
2016
2018
2020
Time

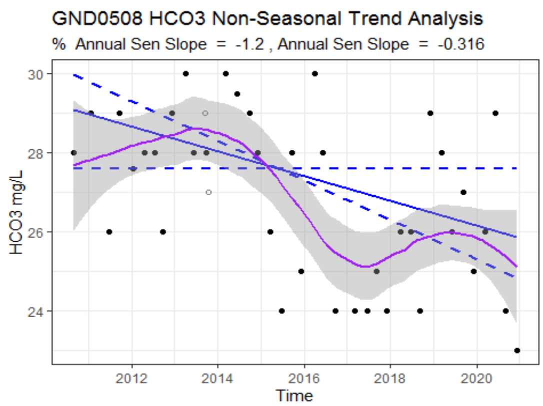

GND0508 Br Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
Br mg/L
0.100
0.075
0.050
0.025
2012
2014
2016
2018
2020
Time

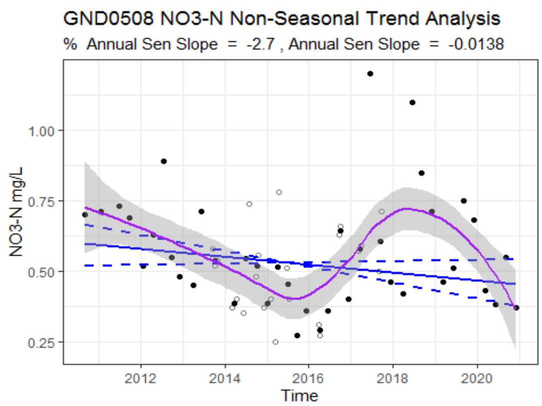

GND0430 Na Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
Na mg/L
25
24
23
22
21
2012
2014
2016
2018
2020
Time

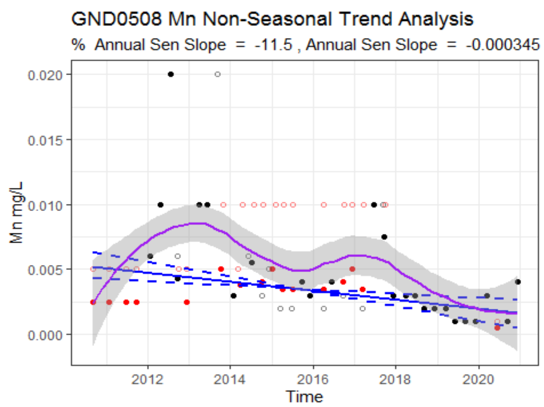

GND0508 Cl Non-Seasonal Trend Analysis
% Annual Sen Slope = 1.3 , Annual Sen Slope = 0.161
Cl mg/L
40
30
20
10
2012
2014
2016
2018
2020
Time

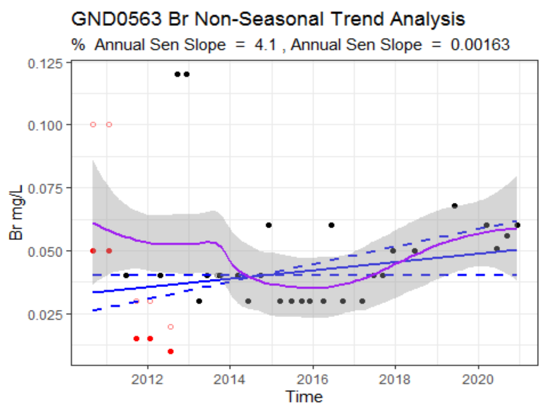

GND0508 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = 0 , Annual Sen Slope = 0.0293
Conductivity lab 25 uS/cm
100
200
300
2012
2014
2016
2018
2020
Time

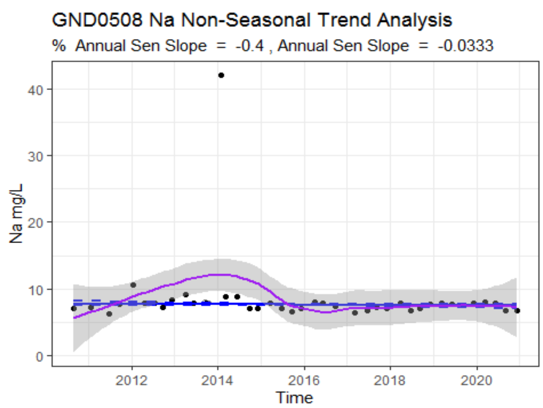

GND0508 NH4-N Non-Seasonal Trend Analysis
% Annual Sen Slope = -19.2 , Annual Sen Slope = -0.000576
NH4-N mg/L
0.00
0.05
0.10
0.15
0.20
2012
2014
2016
2018
2020
Time

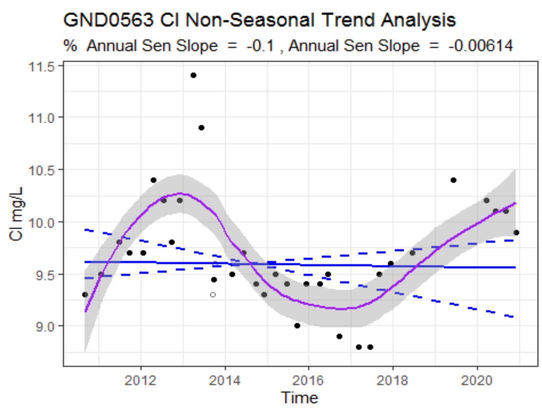

GND0508 HCO3 Non-Seasonal Trend Analysis
% Annual Sen Slope = -1.2 , Annual Sen Slope = -0.316
HCO3 mg/L
24
26
28
30
2012
2014
2016
2018
2020
Time

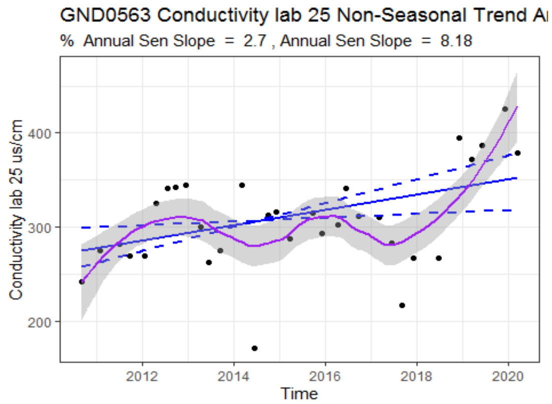

GND0508 NO3-N Non-Seasonal Trend Analysis
% Annual Sen Slope = -2.7 , Annual Sen Slope = -0.0138
NO3-N mg/L
0.25
0.50
0.75
1.00
2012
2014
2016
2018
2020
Time

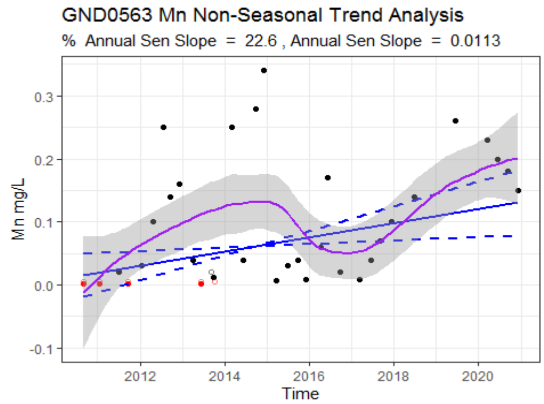

GND0508 Mn Non-Seasonal Trend Analysis
% Annual Sen Slope = -11.5 , Annual Sen Slope = -0.000345
Mn mg/L
0.000
0.005
0.010
0.015
0.020
2012
2014
2016
2018
2020
Time

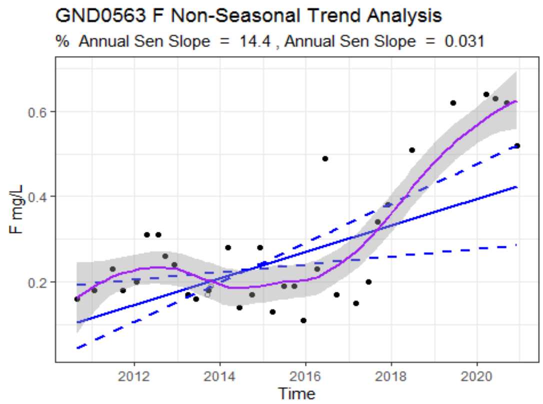

GND0563 Br Non-Seasonal Trend Analysis
% Annual Sen Slope = 4.1 , Annual Sen Slope = 0.00163
Br mg/L
0.025
0.050
0.075
0.100
0.125
2012
2014
2016
2018
2020
Time


GND0508 Na Non-Seasonal Trend Analysis
% Annual Sen Slope = -0.4 , Annual Sen Slope = -0.0333
Na mg/L
0
10
20
30
40
2012
2014
2016
2018
2020
Time

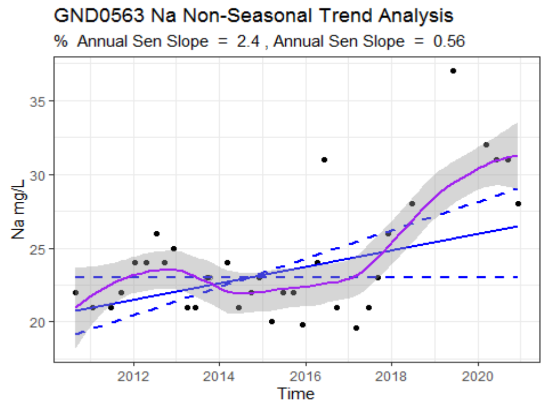

GND0563 Cl Non-Seasonal Trend Analysis
% Annual Sen Slope = -0.1 , Annual Sen Slope = -0.00614
Cl mg/L
9.0
9.5
10.0
10.5
11.0
11.5
2012
2014
2016
2018
2020
Time

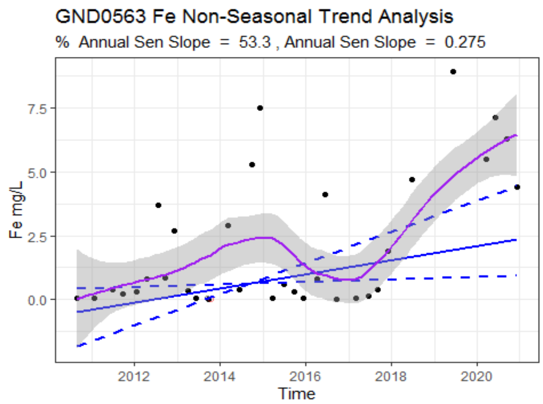

GND0563 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = 2.7 , Annual Sen Slope = 8.18
Conductivity lab 25 us/cm
200
300
400
2012
2014
2016
2018
2020
Time

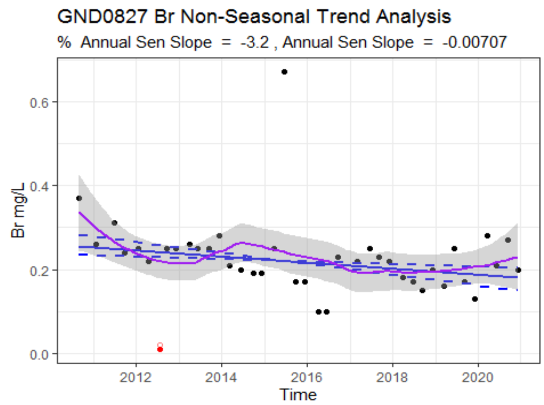

GND0563 Mn Non-Seasonal Trend Analysis
% Annual Sen Slope = 22.6 , Annual Sen Slope = 0.0113
Mn mg/L
-0.1
0.0
0.1
0.2
0.3
2012
2014
2016
2018
2020
Time

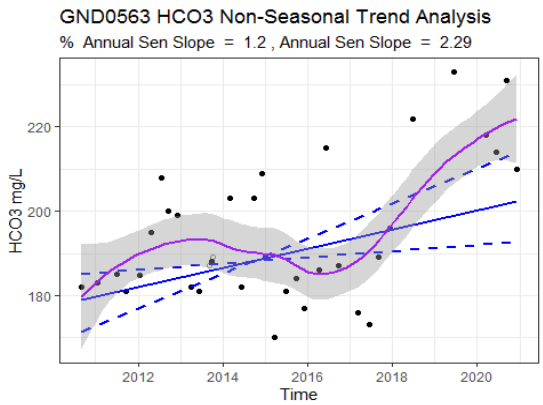

GND0563 F Non-Seasonal Trend Analysis
% Annual Sen Slope = 14.4 , Annual Sen Slope = 0.031
F mg/L
0.2
0.4
0.6
2012
2014
2016
2018
2020
Time

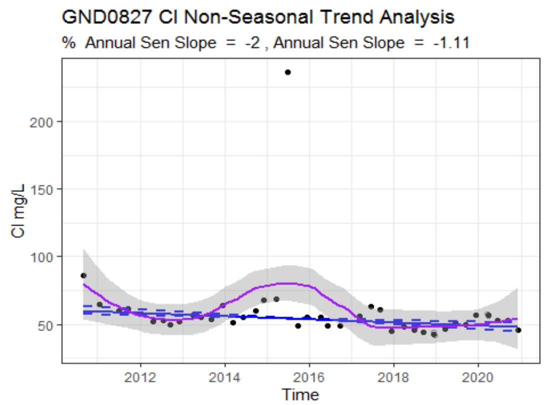
8

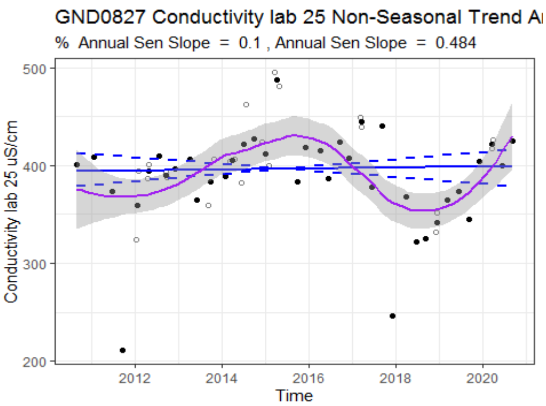

GND0563 Na Non-Seasonal Trend Analysis
% Annual Sen Slope = 2.4 , Annual Sen Slope = 0.56
Na mg/L
20
25
30
35
2012
2014
2016
2018
2020
Time

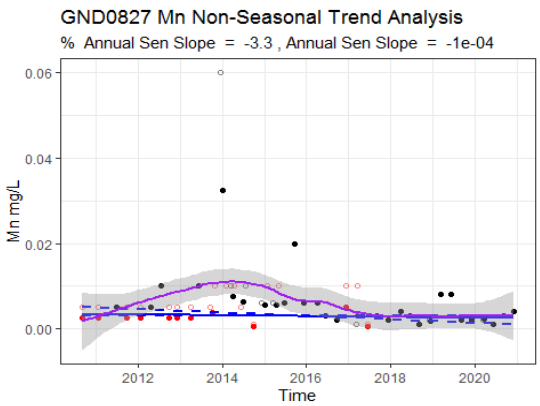

GND0563 Fe Non-Seasonal Trend Analysis
% Annual Sen Slope = 53.3 , Annual Sen Slope = 0.275
Fe mg/L
0.0
2.5
5.0
7.5
2012
2014
2016
2018
2020
Time

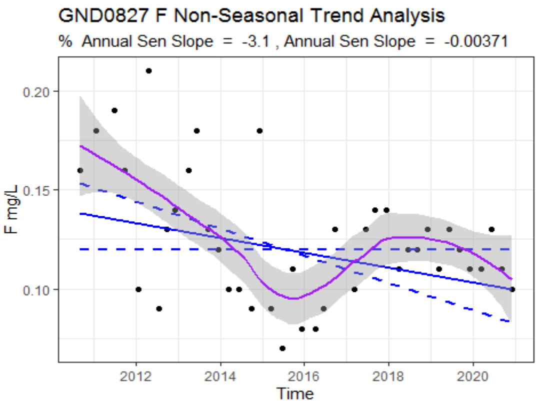

GND0827 Br Non-Seasonal Trend Analysis
% Annual Sen Slope = -3.2 , Annual Sen Slope = -0.00707
Br mg/L
0.0
0.2
0.4
0.6
2012
2014
2016
2018
2020
Time

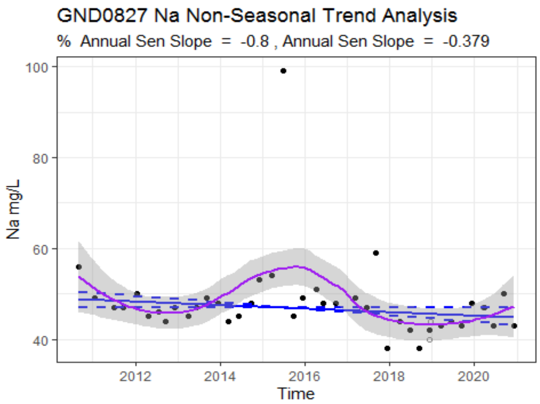

GND0563 HCO3 Non-Seasonal Trend Analysis
% Annual Sen Slope = 1.2 , Annual Sen Slope = 2.29
HCO3 mg/L
180
200
220
2012
2014
2016
2018
2020
Time

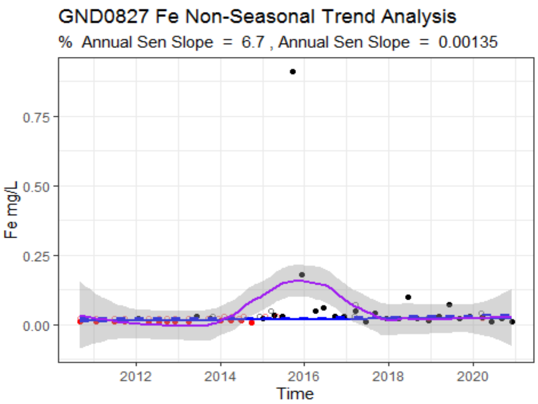

GND0827 Cl Non-Seasonal Trend Analysis
% Annual Sen Slope = -2 , Annual Sen Slope = -1.11
Cl mg/L
50
100
150
200
2012
2014
2016
2018
2020
Time

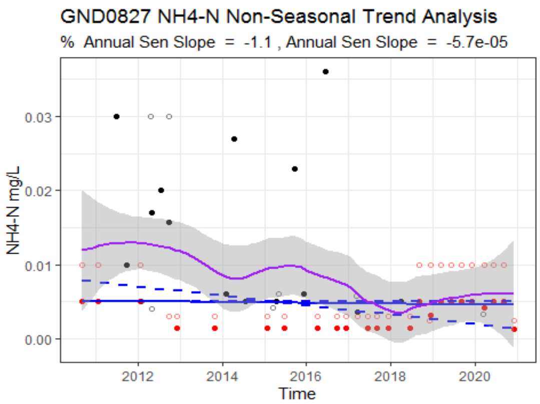

GND0827 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = 0.1 , Annual Sen Slope = 0.484
Conductivity lab 25 uS/cm
500
400
300
200
2012
2014
2016
2018
2020
Time

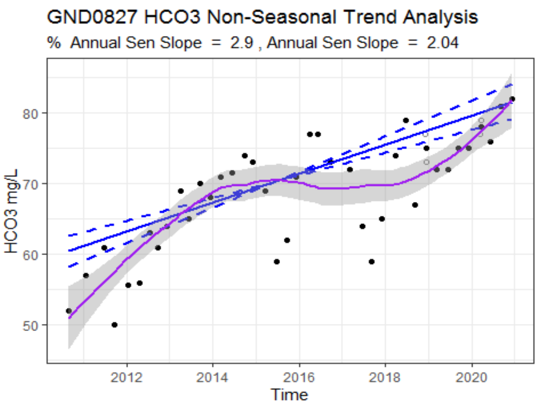

GND0827 Mn Non-Seasonal Trend Analysis
% Annual Sen Slope = -3.3 , Annual Sen Slope = -1e-04
Mn mg/L
0.06
0.04
0.02
0.00
2012
2014
2016
2018
2020
Time

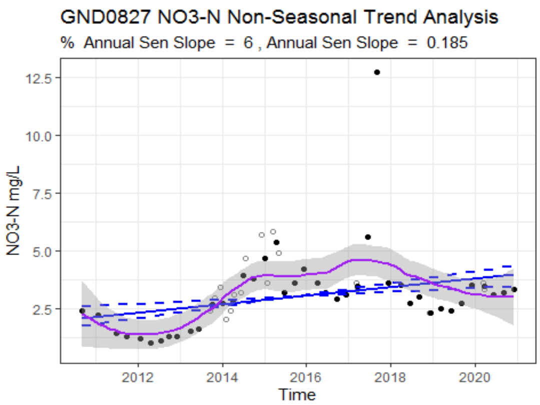

GND0827 F Non-Seasonal Trend Analysis
% Annual Sen Slope = -3.1 , Annual Sen Slope = -0.00371
F mg/L
0.20
0.15
0.10
2012
2014
2016
2018
2020
Time

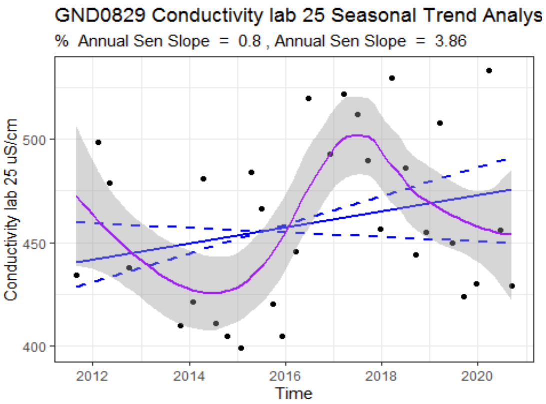

GND0827 Na Non-Seasonal Trend Analysis
% Annual Sen Slope = -0.8 , Annual Sen Slope = -0.379
Na mg/L
100
80
60
40
2012
2014
2016
2018
2020
Time

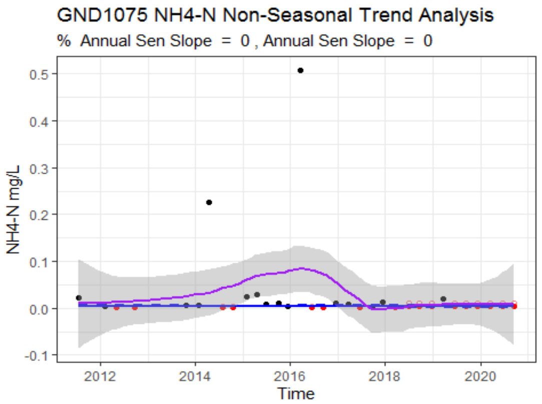

GND0827 Fe Non-Seasonal Trend Analysis
% Annual Sen Slope = 6.7 , Annual Sen Slope = 0.00135
Fe mg/L
0.75
0.50
0.25
0.00
2012
2014
2016
2018
2020
Time

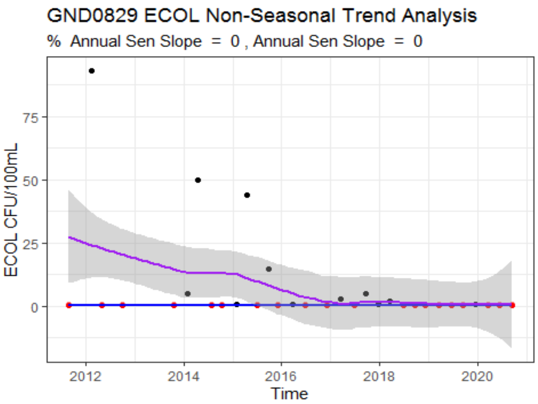

GND0827 NH4-N Non-Seasonal Trend Analysis
% Annual Sen Slope = -1.1 , Annual Sen Slope = -5.7e-05
NH4-N mg/L
0.03
0.02
0.01
0.00
2012
2014
2016
2018
2020
Time

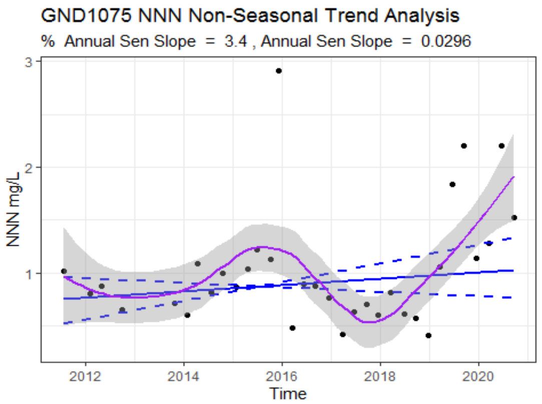

GND0827 HCO3 Non-Seasonal Trend Analysis
% Annual Sen Slope = 2.9 , Annual Sen Slope = 2.04
HCO3 mg/L
80
70
60
50
2012
2014
2016
2018
2020
Time

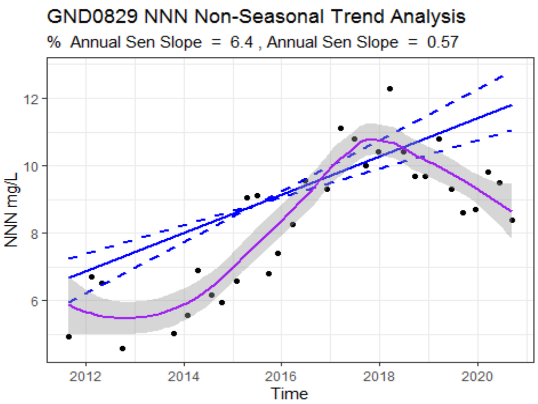

GND0827 NO3-N Non-Seasonal Trend Analysis
% Annual Sen Slope = 6 , Annual Sen Slope = 0.185
NO3-N mg/L
12.5
10.0
7.5
5.0
2.5
2012
2014
2016
2018
2020
Time

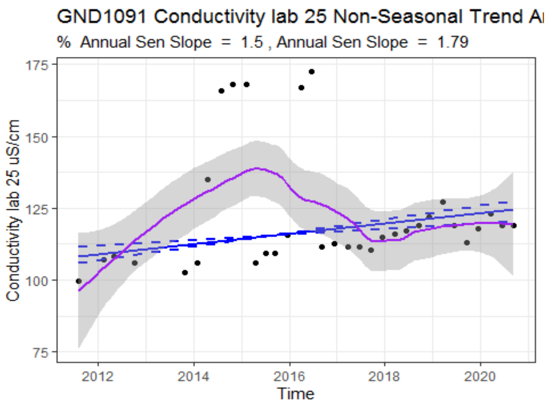

GND0829 Conductivity lab 25 Seasonal Trend Analys
% Annual Sen Slope = 0.8 , Annual Sen Slope = 3.86
Conductivity lab 25 uS/cm
Time

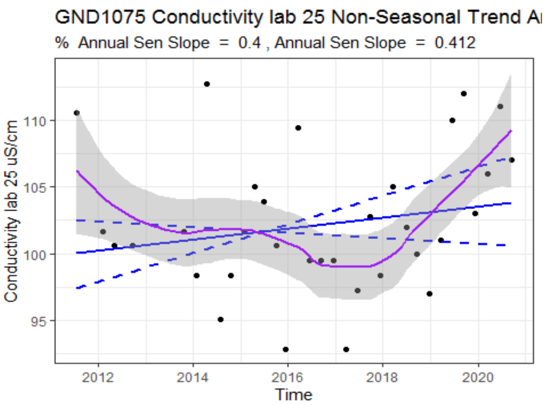

GND1075 NH4-N Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
NH4-N mg/L
Time

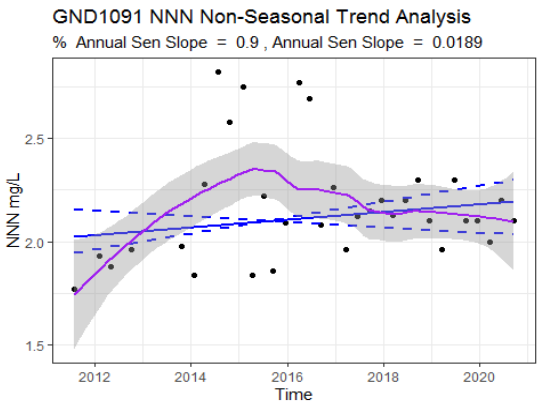

GND0829 ECOL Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
ECOL CFU/100mL
Time

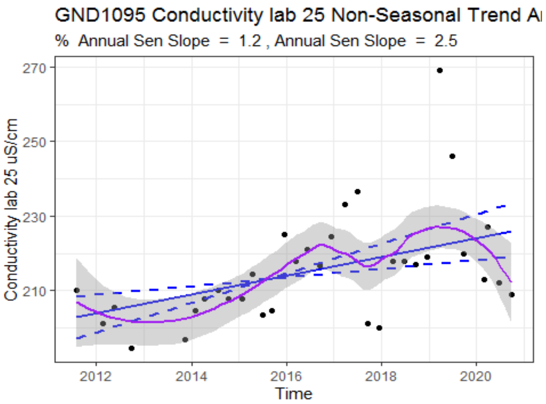

GND1075 NNN Non-Seasonal Trend Analysis
% Annual Sen Slope = 3.4 , Annual Sen Slope = 0.0296
NNN mg/L
Time

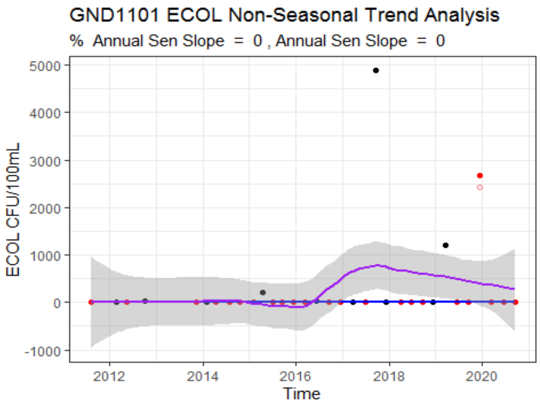

GND0829 NNN Non-Seasonal Trend Analysis
% Annual Sen Slope = 6.4 , Annual Sen Slope = 0.57
NNN mg/L
Time

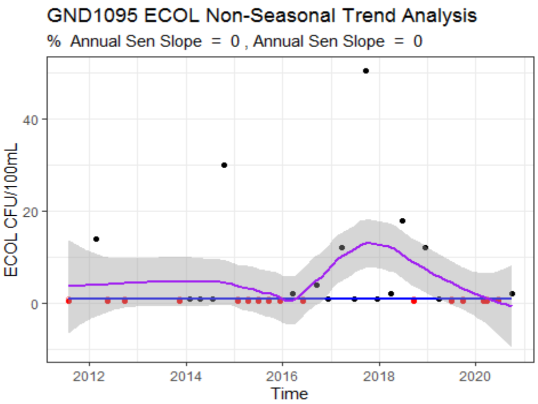

GND1091 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = 1.5 , Annual Sen Slope = 1.79
Conductivity lab 25 uS/cm
Time

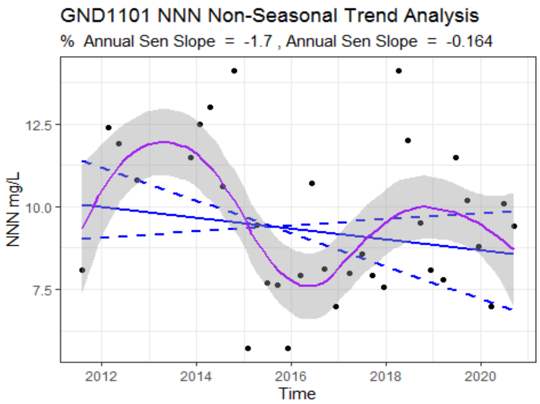

GND1075 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = 0.4 , Annual Sen Slope = 0.412
Conductivity lab 25 uS/cm
Time

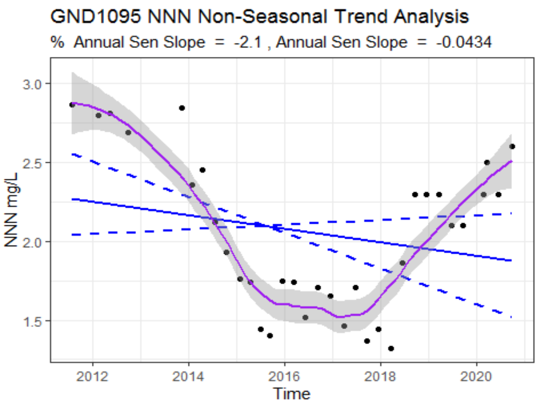

GND1091 NNN Non-Seasonal Trend Analysis
% Annual Sen Slope = 0.9 , Annual Sen Slope = 0.0189
NNN mg/L
Time

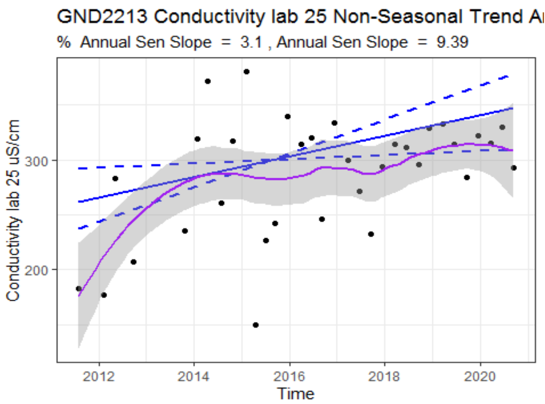

GND1095 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = 1.2 , Annual Sen Slope = 2.5
Conductivity lab 25 uS/cm
Time

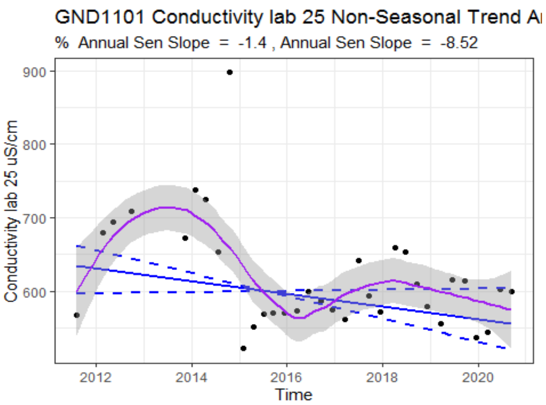

GND1101 ECOL Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
ECOL CFU/100mL
Time

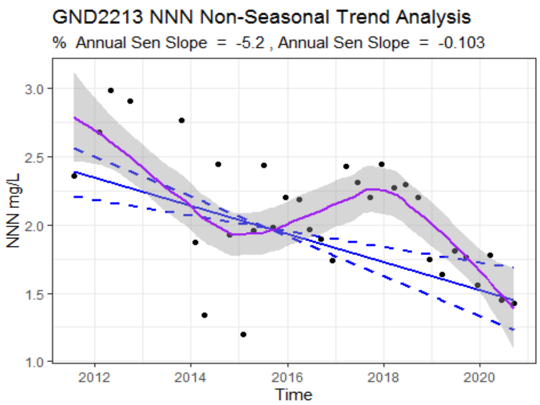

GND1095 ECOL Non-Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
ECOL CFU/100mL
Time


GND1101 NNN Non-Seasonal Trend Analysis
% Annual Sen Slope = -1.7 , Annual Sen Slope = -0.164
NNN mg/L
Time


GND1095 NNN Non-Seasonal Trend Analysis
% Annual Sen Slope = -2.1 , Annual Sen Slope = -0.0434
NNN mg/L
Time


GND2213 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = 3.1 , Annual Sen Slope = 9.39
Conductivity lab 25 uS/cm
Time


GND1101 Conductivity lab 25 Non-Seasonal Trend A
% Annual Sen Slope = -1.4 , Annual Sen Slope = -8.52
Conductivity lab 25 uS/cm
Time


GND2213 NNN Non-Seasonal Trend Analysis
% Annual Sen Slope = -5.2 , Annual Sen Slope = -0.103
NNN mg/L
Time

Taranaki Regional Council

MEMORANDUM
Policy & Planning

Date	30 August 2022
Subject:	**Assessment of *Escherichia coli* (*E. Coli*) load reductions required to achieve freshwater objectives in the rivers of the Taranaki region**
Approved by:	AJ Matthews, Director - Environment Quality S J Ruru, Chief Executive
Document:	3093454

Purpose

1. The purpose of this memorandum is to provide the Committee with an overview of the findings of a recent report commissioned by the Council, A*ssessment of Escherichia coli load reductions required to achieve freshwater objectives in the rivers of the Taranaki region* by Land Water People (LWP).

Executive summary

2. The *National Policy Statement for Freshwater Management 2020* (NPS-FM) requires that every regional council, in consultation with its community, develop a plan for maintaining or improving the state of freshwater in the region.
3. The National Objectives Framework (NOF), contained within the NPS-FM, directs councils and communities to set values and desired environmental outcomes (objectives) for the state of fresh water bodies in their regions. Action plans and limits on resource use must then be established to achieve these agreed outcomes. Progress against identified values and objectives is assessed by monitoring and reporting against a range of measures on the state of a river or lake, referred to as attributes.
4. The NOF sets out a grading system used to describe the state of each attribute against set criteria. The grading system ranges from band A (best state) to band D or E (worst state). For most attributes, the NOF sets a 'national bottom line' that represents the minimum standard that must be achieved.
5. In rivers, *Escherichia coli* (*E. coli)* is the NOF attribute used to assess whether the compulsory value of 'human contact' is provided for. *E. coli* is a bacterium found in the gut of warm-blooded animals. It is present in high concentrations within faecal matter and indicates the potential presence of other bacteria and pathogens in water.
6. The NOF attribute for human contact uses *E. coli* concentrations to predict the risk of infection to those persons potentially ingesting water during water based activities.

Within *E. coli* band A, the average risk of infection to swimmers (based on a random exposure on a random day, including swimming during high flows) is estimated at 1%, while band D represents a risk of >7%. This value is often referred to as 'swimmability' however, while the human contact value encompasses swimming, it is also intended to provide for a range of other water-based activities and is also linked to other values such as mahinga kai.

7. In 2017, the Government set a national target of making 90% of New Zealand's large rivers and lakes swimmable by 2040. It set an interim target of 80% swimmable by 2030. Swimmable is defined as being band C or higher under the NOF attribute for *E. coli*; the target applies to large rivers – those classified as order four or above, and lakes with a perimeter of 1.5 km or more.
8. At the time the national targets were developed, a modelling taskforce estimated that around 39% of Taranaki rivers (by river length) and 97% of lakes met the required standard for swimmability. It was also estimated that interventions already underway in Taranaki to reduce bacterial contamination in Taranaki waterways, specifically Council's riparian programme and the diversion of dairy shed effluent to land, could result in around 67% of large rivers swimmable by 2030. The national modelling did not provide any estimates for projected improvements for lakes.
9. The Council argued that the modelling was overly optimistic in regard to the likely impact of current interventions in reducing *E. coli* concentrations. Council subsequently set a regional target of 50-55% of large rivers and 97% of lakes being swimmable by 2030. It is important to note that these targets were established prior to the release of the NPS-FM 2020 and are subject to change based on community engagement through Council's NPS-FM Freshwater Implementation Programme.
10. Meeting swimmability standards and targets is going to be a significant challenge for the Taranaki region. Data from our monitoring networks presented in the recently published *Our Place: State of Environment 2022* report, and the results of the spatial water quality modelling presented at the 26 July 2022 Policy and Planning Committee meeting, both highlight the scale of this challenge.
11. To better understand this challenge, the Council recently commissioned LWP to calculate estimates of *E. coli* loads in our rivers and the reductions in loads required to achieve various freshwater objectives. The objectives used for *E. coli* concentrations in this assessment were derived from the NOF attribute for *E. coli* (i.e. the different NOF attribute bands).
12. The underlying analysis undertaken by LWP utilised several models that describe concentrations and loads of *E. coli* in the rivers across Taranaki. These models were built from TRC's monthly river state of environment monitoring (SoE) data, supplemented by SoE data collected at sites in the Manawatū-Whanganui and Waikato regions. A total of up to 95 sites were used in the modelling, each with at least 10 years of available data.
13. The report provided by LWP describes the modelling methods and results, including estimates of the magnitude of *E. coli* load reductions required to meet freshwater objectives across each of the proposed Freshwater Management Units (FMUs) for Taranaki and the region as a whole. The report also describes in detail the uncertainty associated with the estimates generated.
14. The results of the analysis illustrate that reductions in *E. coli* loads of approximately 60 to 90% will be required to achieve freshwater objectives in Taranaki rivers. The study presents the results as best estimates (of required load reduction) and the 90%

confidence interval for these estimates. The broad-scale patterns in the estimated *E. coli* load reductions provide a reliable indication of the relative differences between locations, although there is considerable uncertainty in these estimates. It is unlikely that these uncertainties can be significantly reduced in the short to medium term (i.e., in less than 5 to 10 years) because, among other factors, the modelling is dependent on the collection of long-term water quality monitoring data.

15. The report does not consider what kinds of limits on resource use might be used to achieve load reductions, how limits might be implemented, over what timeframes and what, if any, implications this may have for other values and outcomes. These will be matters for the Council, tangata whenua and our community to consider as we work through the NOF limit setting process.

16. The report highlights that decision-making will ultimately need to be made in the face of uncertainty about the magnitude of load reductions required to achieve community outcomes, and uncertainty around the efficacy of mitigations and interventions. Uncertainty is an unavoidable aspect of modelling; models are based on simplifications of reality and, in this case, informed by limited data. That said, the NPS-FM is clear that councils must use the best information available and take all practicable steps to reduce uncertainty. Decision-making cannot be delayed on the basis of incomplete data and information, or uncertainty about the robustness of this information.

17. Alongside other sources of information, including Council's recently published *Our Place: State of Environment 2022* report, the outputs from this modelling will provide useful context regarding *E. coli* loads in our waterways, and the magnitude of reductions required to achieve freshwater objectives, as we continue work to implement the requirements of the NPS-FM.

18. A next logical step is to consider what actions could reduce *E. coli* loads and then predict how effective these might be, both individually and in combination, in terms of contribution to the percentage load reductions required. There are various possible approaches to this step and officers are currently seeking advice and guidance around options available, with a view to identifying an approach that is fit for Council’s intended purpose, resources and timeframe.

Recommendation

That the Taranaki Regional Council:

a) receives the technical report, A*ssessment of Escherichia coli load reductions required to achieve freshwater objectives in the rivers of the Taranaki region* and notes that the outputs will provide useful context as we continue work to implement the requirements of the NPS-FM.

Background

19. As part of the *Essential Freshwater* reform programme, the Government gazetted the NPS-FM in September 2020. A significant component of the NPS-FM is the National Objectives Framework (NOF). The NOF requires councils to work with tangata whenua and the community to identify values and desired outcomes (objectives) for freshwater. At a minimum, the NPS-FM requires that the four compulsory values of ecosystem health, human contact, threatened species and mahinga kai be provided for.

20. The value of human contact refers to the extent to which a Freshwater Management Unit (FMU) or part of an FMU supports people being able to connect with the water through

a range of activities such as swimming, waka use, boating, fishing, mahinga kai, and water skiing, in a range of different flows or levels.

21. The NOF identifies two key measures for primary contact: *E. coli* in rivers and lakes (as an indicator of possible infection with Campylobacter), and planktonic cyanobacteria (potentially toxic algae) in lakes. Council is in the process of developing a lakes monitoring programme to align with NPS-FM requirements and provide baseline information around the current state of the region's lakes. The relevant attribute for rivers for the purposes of limit setting is *E. coli* concentrations in water. As such, the focus of LWP's modelling was the current state and load reductions required to achieve different *E. coli* attribute states in the region's rivers.

22. The NOF requires that Councils monitor and report on progress in terms of maintaining or enhancing freshwater to achieve these values and agreed objectives. The NOF sets out a grading system used to describe the state of each attribute against set criteria. The grading system ranges from band A (best state) to band E (worst state). For *E.coli*, four different measures are calculated to determine the overall state (Table 1).

Table 1: *National Objectives Framework E. coli attribute criteria (Appendix 2A) which requires limits to be set on resource use to provide for the NPS-FM value for human contact.*

Value	Human contact			
Freshwater body type	Lakes and rivers			
Attribute unit	*E. coli*/100 mL (number of E. coli per hundred millilitres)			
Attribute band and description	**Numeric attribute state**			
Description of risk of Campylobacter infection (based on E. coli indicator)	% exceedances over 540/100 mL	% exceedances over 260/100 mL	Median concentration /100 mL	95th percentile of *E. coli*/100 mL
A (Blue) For at least half the time, the estimated risk is <1 in 1,000 (0.1% risk). The predicted average infection risk is 1%.	<5%	<20%	≤130	≤540
B (Green) For at least half the time, the estimated risk is <1 in 1,000 (0.1% risk). The predicted average infection risk is 2%	5-10%	20-30%	≤130	≤1000
C (Yellow) For at least half the time, the estimated risk is <1 in 1,000 (0.1% risk). The predicted average infection risk is 3%.	10-20%	20-34%	≤130	≤1200
D (Orange) 20-30% of the time the estimated risk is ≥50 in 1,000 (>5% risk). The predicted average infection risk is >3%.	20-30%	>34%	>130	>1200
E (Red) For more than 30% of the time the estimated risk is ≥50 in 1,000 (>5% risk). The predicted average infection risk is >7%.	>30%	>50%	>260	>1200

Attribute state should be determined by using a minimum of 60 samples over a maximum of 5 years, collected on a regular basis regardless of weather and flow conditions. However, where a sample has been missed due to adverse weather or error, attribute state may be determined using samples over a longer timeframe.

Attribute state must be determined by satisfying all numeric attribute states. The predicted average infection risk is the overall average infection to swimmers based on a random exposure on a random day, ignoring any possibility of not swimming during high flows or when a surveillance advisory is in place (assuming that the *E. coli* concentration follows a lognormal distribution). Actual risk will generally be less if a person does not swim during high flows.

23. Only two of 15 regionally monitored sites achieved national swimmability standards (achieved band C) over the five year period from 2015 to 2020, as reported in *Our Place: Taranaki State of Environment 2022* (Figure 1). The analysis also showed that *E. coli* concentrations have increased at 70% of monitored sites over the last 10 years (Figure 2).

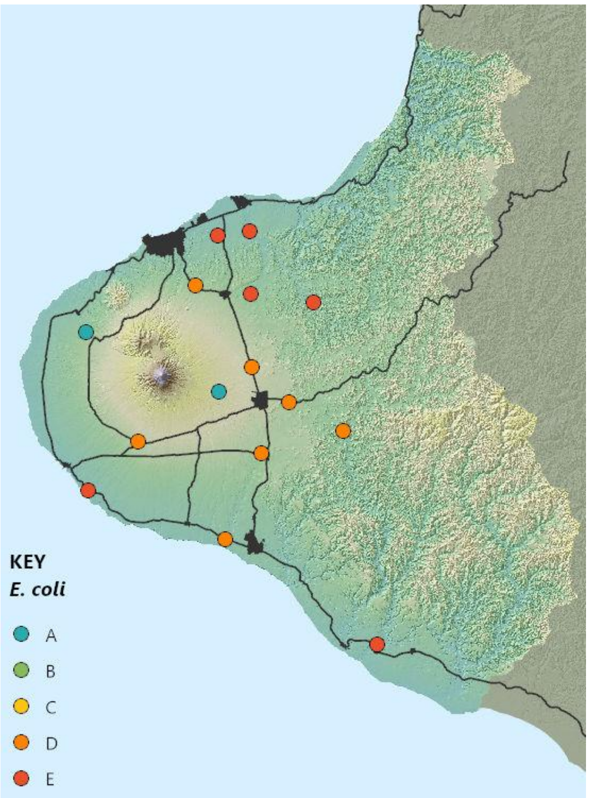


Figure 1: *The current state of E. coli at monitored sites, as assessed against the respective NOF attribute bands.*

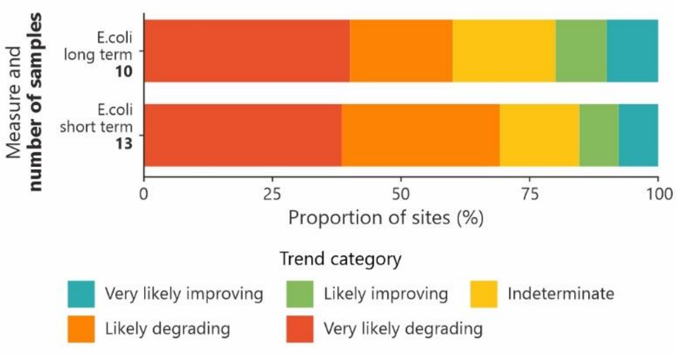


Figure 2: *Summary of trends in E. coli concentrations at monitored sites over both short (10 year) and long-term (25 year) time periods.*

24. For most attributes, the NOF sets a 'national bottom line' that represents the minimum standard that must be achieved. While it does not specifically set a 'national bottom line' for *E. coli* for the purposes of limit setting, where one or more of the values of the four statistics exceed band C, the Council will need to undertake action to reduce the length of specified rivers and lakes in the band E (red) and band D (orange) categories, and

increase the length of specified rivers and lakes in the band C (yellow), band B (green) and band A (blue) categories.

25. Spatial water quality modelling undertaken by LWP (2022a) and reported to Council's Policy and Planning Committee on 26 July 2022, presented the current state of *E.coli* as defined by the NOF. Maps showing the spatial distribution of current state for each of the four *E.coli* numeric attribute states is shown in Figure 3.

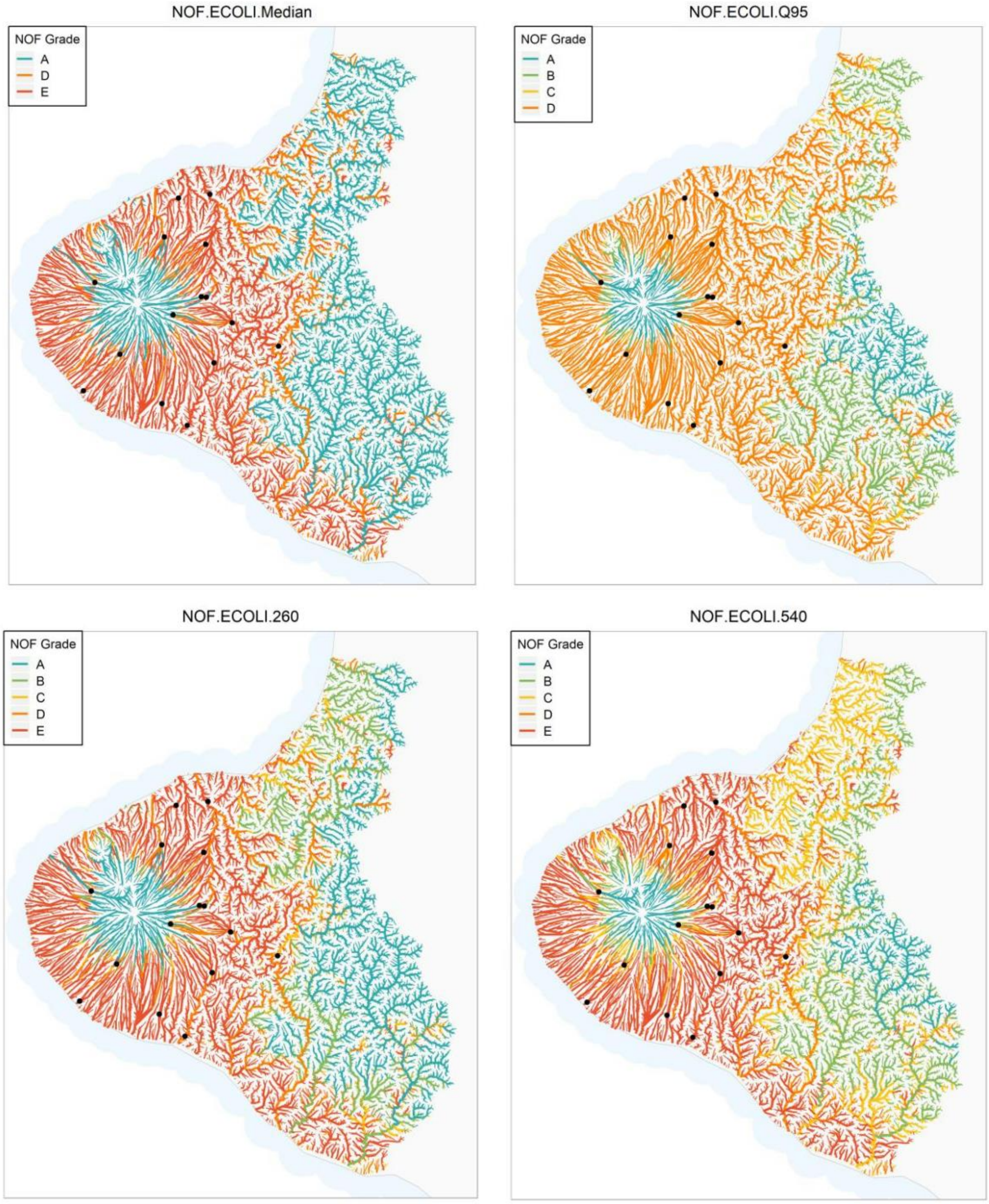


Figure 3: *Predictions of spatially modelled NOF grades for the E. coli attribute: percentage of exceedances over 260/100mL (top left); percentage of exceedances over 540/100mL (top right); median/100mL (bottom left); and 95th percentile/100mL (bottom right). Source: LWP, 2022a.*

National and Regional Swimmability Targets

26. In 2017, the government set national target of 80% of large rivers swimmable by 2030 and 90% by 2040. Swimmable is defined as being band C or higher under the NOF attribute for *E. coli*.

27. At the time the national targets were developed, a modelling taskforce estimated that only 39% of Taranaki rivers met the required standard for swimmability (MfE, 2018). They also estimated that interventions already underway in Taranaki to reduce bacterial contamination in our waterways, specifically our riparian programme and the diversion of dairy shed effluent to land, would result in 67% of waterways being swimmable by 2030.

28. The Council argued that the modelling was overly optimistic with regard to the likely impact of current interventions in reducing *E. coli* concentrations and subsequently set a regional target of 50-55% of large rivers being swimmable by 2030.

29. To provide a more complete picture of the current state of *E. coli* in Taranaki, the Council recently commissioned LWP to undertake further analysis to quantify the loads of *E. coli* being transported in Taranaki waterways and the corresponding load reductions required to achieve various NOF attribute states.

30. The report A*ssessment of Escherichia coli load reductions required to achieve freshwater objectives in the rivers of the Taranaki region* by LWP describes the current estimates of *E. coli* loads across all river reaches in Taranaki. The work also estimates the load reductions required to meet various freshwater objectives and details the uncertainty associated with the estimates generated.

Discussion

31. This report by LWP describes *E. coli* load reductions required to achieve options for freshwater objectives for human contact in rivers in the Taranaki region. Estimates of the magnitude of the load reductions and how these vary across the region are provided for each of the *E. coli* attribute criteria (bands) described in Table 1 (above).

32. The underlying analysis utilised several models that describe concentrations and loads of *E. coli* in the rivers across the study area. These models were built from Council's monthly river state of environment monitoring (SoE) data supplemented by state of the environment monitoring data collected at sites in the adjacent Manawatū-Whanganui and Waikato regions. A total of up to 95 sites were used in the modelling.

33. The modelling provides estimated load reductions for the region's river network to achieve different attribute criteria (band A, B or C). The report summarises reductions required for the entire river network (regionally consistent approach), as well as load reductions required for the six proposed Freshwater Management Units (FMUs), as proportions of current *E. coli* load.

Regionally consistent approach

34. An estimate of the region's length of river segments falling within each of the five NOF attribute states is provide in Table 2. As with any modelling, there is uncertainty in these estimates and the 90% confidence intervals for these estimates are very wide. For example, the best estimate of the proportion of segments that are in the A band is 4% but the 90% confidence intervals extend from 1% to 14%.

Table 2. *Proportion of all river segments (%) predicted to be in each attribute band. Source: LWP, 2022.*

Attribute band	Best estimate	5% confidence limit	95% confidence limit
A	4	1	14
B	13	6	23
C	5	2	10
D	29	20	38
E	48	37	61

35. Overall, the proportion of Taranaki rivers of stream order >3 currently suitable for primary contact (i.e. falling within band A, B or C) is estimated at 20%, with the lower and upper bounds defined by 12% and 40%, respectively.

36. This is consistent with, but at the upper end of, the previous estimate of 39% of these large rivers in Taranaki being suitable for primary contact as reported by MfE in 2018. Differences between these estimates are likely due to differences in the modelling; the modelling undertaken by this study being region-specific whereas the MfE study used a model of national extent.

Freshwater Management Unit based approach

37. As a potential alternative approach to having spatially uniform objectives for *E. coli* across proposed FMUs, a spatially variable approach to objectives was also tested by LWP. This approach was based on dividing the region's rivers into three management classes defined as mountain, hill and lowland rivers, with corresponding objectives of A, B and C band, respectively.

38. Spatial variation in objectives can be justified for each type of river based on both what is reasonable relative to each type under natural conditions and community expectations. This approach acknowledges that lowland rivers will be most impacted by upstream land use activities and are in the poorest current state. Therefore targeting band C in these rivers may be a reasonable management objective and would still represent a significant improvement in state. On the other hand, mountain sourced rivers are likely to be achieve a higher state under natural conditions and communities are likely to have higher expectations in relation to their condition.

39. Estimates of *E. coli* loads and load reduction requirements were generated using complex statistical modelling methods. These include the random forest models generated previously by LWP as part of their spatial water quality modelling exercise for Taranaki. A summary of the methods used in the analysis is presented in Figure 4 and further information can be found in the appended report.

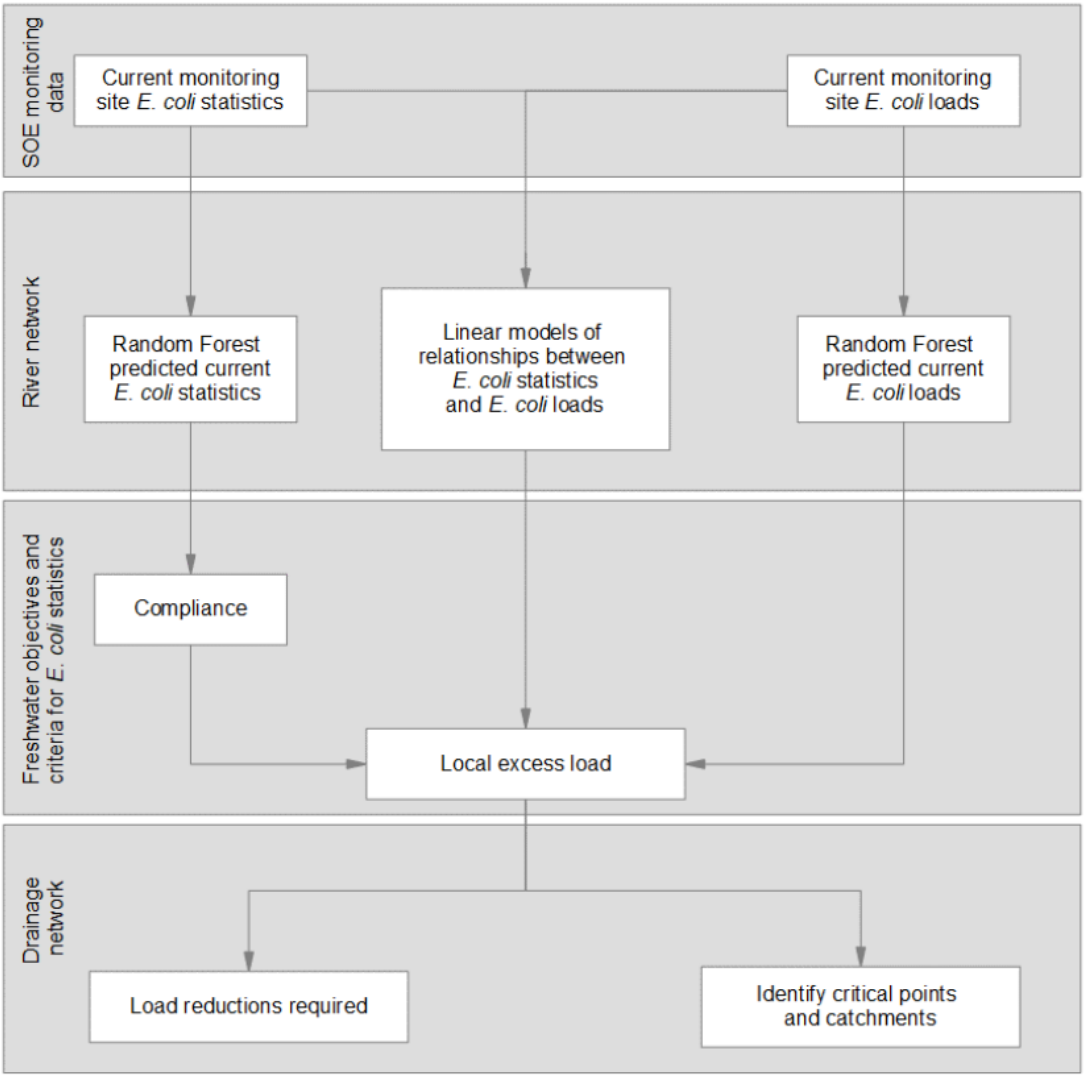


Figure 4: *Summary of methods used to calculate E. coli loads and load reductions requirements in this assessment.*

40. The results of the analysis illustrate that reductions in *E. coli* loads of approximately 60 to 90% will be required to achieve freshwater objectives in Taranaki (Table 3). The best estimates generated for load reductions required were always less for band C settings compared to band B, and likewise for band B compared to band A. However, the 90% confidence intervals for the four sets of potential objectives overlap in all cases.

Table 3: *The reductions in E. coli loads required to meet freshwater objectives in each proposed FMU for Taranaki and a spatially variable approach. The load reductions are shown as proportion of current loads (%). The first value in each column is the best estimate, with values in parentheses being the lower and upper bounds of the 90% confidence interval.*

Proposed FMU	Load reduction required (%) to meet: NOF C band	Load reduction required (%) to meet: NOF B band	Load reduction required (%) to meet: NOF A band	Spatially variable
Coastal Terraces	75 (68 - 82)	80 (71 - 87)	88 (84 - 91)	76 (67 - 84)
Northern Hill Country	67 (50 - 83)	72 (60 - 83)	83 (76 - 89)	65 (48 - 82)
Patea	80 (58 - 97)	84 (68 - 98)	91 (77 - 98)	80 (56 - 97)
Southern Hill Country	76 (62 - 88)	82 (73 - 89)	89 (83 - 93)	77 (65 - 88)
Volcanic Ring Plain	81 (76 - 86)	85 (80 - 87)	91 (88 - 93)	82 (77 - 86)
Waitara	80 (61 - 98)	82 (67 - 94)	89 (80 - 95)	83 (69 - 96)
Regional average	80 (72 - 88)	83 (78 - 89)	90 (87 - 92)	81 (75 - 87)

Modelling and uncertainty

41. The uncertainty of the assessments was quantified using a Monte Carlo analysis, by making 100 ‘realisations’ of the calculations. The study presents the results as best estimates (of required load reduction) and the 90% confidence interval for these estimates. The broad-scale patterns in the estimated *E. coli* load reductions provide a reliable indication of the relative differences between locations. However, there is considerable uncertainty associated with the absolute values of the *E. coli* load reductions and these become larger as the spatial scale over which the reductions are evaluated is reduced.

42. It is unlikely that these uncertainties in the modelling can be significantly reduced in the short to medium term (i.e., in less than 5 to 10 years) because, among other factors, the modelling is dependent on the collection of long-term water quality monitoring data.

43. The report does not consider what kinds of limits on resource use might be used to achieve load reductions, how limits might be implemented, over what timeframes and with what implications for other values. These will be matters for the Council, tangata whenua and our community to consider.

44. Decision-making will ultimately need to be made in the face of uncertainty about the magnitude of load reductions needed. Uncertainty is an unavoidable aspect of modelling work as it is based on simplifications of reality and because it is informed by limited data.

45. The NPS-FM is clear that councils must use the best information available and take all practicable steps to reduce uncertainty. Decision-making cannot be delayed on the basis of incomplete data and information, or uncertainty about the robustness of this information. This includes using the best available information to determine the baseline state of freshwater attributes in rivers and lakes throughout the region.

46. Alongside other sources of information, including Council's recently published State of Environment 2022 report, the outputs from modelling will provide useful context regarding *E. coli* loads in our waterways, and the magnitude of reductions required to achieve freshwater objectives, as we continue work to implement the requirements of the NPS-FM.

Next steps

47. Meeting swimmability standards is going to be a significant challenge for the Taranaki region. The setting of targets for swimmability and the associated limits and actions required to achieve those targets are likely to be a prominent issues as we continue work with our community to develop a new regional plan that gives effect to the NPS-FM.

48. A next logical step is to consider what actions could reduce *E. coli* loads and then predict how effective these might be, both individually and in combination, in terms of contribution to the percentage load reductions required. There are various possible approaches to this step and officers are currently seeking advice and guidance around options available, with a view to identifying an approach that is fit for Council's intended purpose, resources and timeframe.

49. A further action will be to establish agreed actions to reduce *E. coli* concentrations at identified primary contact sites (popular swim spots) during the summer bathing season, an additional requirement of the NPS-FM.

Financial considerations—LTP/Annual Plan

50. This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

51. This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks including, but not restricted to, the *Local Government Act 2002*, the *Resource Management Act 1991* and the *Local Government Official Information and Meetings Act 1987*.

Iwi considerations

52. Alongside other sources of data, information and knowledge relating to the state of our environment, the outputs from this report will help inform discussions with iwi and hapū, as we jointly work through implementation of the NPS-FM.

53. This memorandum and the associated recommendations are consistent with the Council's policy for the development of Māori capacity to contribute to decision-making processes (schedule 10 of the *Local Government Act 2002*) as outlined in the adopted long-term plan and/or annual plan. Similarly, iwi involvement in adopted work programmes has been recognised in the preparation of this memorandum.

Community considerations

54. This memorandum and the associated recommendations have considered the views of the community, interested and affected parties and those views have been recognised in the preparation of this memorandum.

Legal considerations

55. This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council.

References

Snelder T and Fraser C. 2022a. *Assessment of Escherichia coli load reductions required to achieve freshwater objectives in the rivers of the Taranaki region*. LWP Client report prepared for Taranaki Regional Council, June 2022.

Fraser C. 2022b. *Taranaki water quality state spatial modelling*. LWP Client report prepared for Taranaki Regional Council, February 2022.

Appendices/Attachments

Document 3088248: *Assessment of Escherichia coli load reductions required to achieve freshwater objectives in the rivers of the Taranaki region.*

LWP
landwaterpeople

Assessment of *Escherichia coli* Load Reductions Required to Achieve Freshwater Objectives in the Rivers of the Taranaki Region

June 2022

Prepared By:

Ton Snelder

Caroline Fraser

For any information regarding this report please contact:

Ton Snelder

Phone: 027 575 8888
Email: ton@lwp.nz
LWP Ltd
PO Box 70
Lyttelton 8092

LWP Client Report Number: 2022-01
Report Date: June 2022

Quality Assurance Statement

Version	Reviewed By	
Final	Simon Harris	

Table of Contents

Figures

Tables

Executive Summary

This report describes *Escherichia coli* (*E. coli*) load reductions predicted to be needed to achieve options for freshwater objectives for human contact (FWOs) in rivers in the Taranaki region. The analysis does not consider how the *E. coli* load reductions would be achieved. The analysis aims to inform the Taranaki Regional Council (TRC) about the magnitude of the load reductions needed for each option and how these vary across the region.

The study area includes all of Taranaki. The underlying analysis utilised several models that describe concentrations and loads of *E. coli* in the rivers across the study area. These models were built from TRC's monthly river state of environment monitoring (SoE) data supplemented by state of the environment monitoring data collected at sites in the adjacent Manawatū-Whanganui and Waikato regions. A total of up to 95 sites were used in the modelling. The concentrations and loads were combined with criteria associated with FWOs. The necessary load reductions required to achieve desired FWOs were calculated.

The FWOs were based on *E. coli* numeric attribute states (bands A, B or C) that are defined by the National Objective Framework (NOF) (National Policy Statement for Freshwater Management 2020 (NPS-FM). Four sets of potential options for FWOs were included in the assessment. The first three sets of FWOs simply assigned the A, B and C NOF band, uniformly to all parts of the river network. The fourth set of FWOs were spatially variable with different FWOs, specified as NOF bands applying to a proposed classification of the region's rivers into management classes defined as Mountain, Hill and Lowland rivers.

Like all assessments of this type, the predicted load reductions required are subject to uncertainty. The uncertainty of the assessments was quantified using a Monte Carlo analysis, by making 100 'realisations' of the calculations. Each realisation was perturbed by a random error that reflected the statistical error (i.e., uncertainty) associated with the modelled concentrations and loads. The study presents the results as best estimates (of required load reduction) and the 90% confidence interval for these estimates. The broad-scale patterns in the estimated *E. coli* load reductions provide a reliable indication of the relative differences between locations. However, there is considerable uncertainty associated with the absolute values of the *E. coli* load reductions and these become larger as the spatial scale over which the reductions are evaluated is reduced. It is unlikely that these uncertainties can be significantly reduced in the short to medium term (i.e., in less than 5 to 10 years) because, among other factors, the modelling is dependent on the collection of long-term water quality monitoring data.

The assessed load reductions required for the six proposed Freshwater Management Units (FMUs) and the whole region are shown in Table A below as proportions of current *E. coli* load. The best estimate for the load reductions was always less for the C band settings compared to the B band and for the B band compared to the A band. However, the 90% confidence intervals for the four sets of FWOs overlap in all cases. This indicates that the study is unable to discriminate appreciable differences in the amount of effort (i.e., the reduction in *E. coli* loads required) to achieve all four sets of FWOs. This is because the models have considerable uncertainty and the concentrations and corresponding loads that separate the four sets of FWOs are similar, relative to this uncertainty.

Table A. the load reductions required for individual FMUs and the whole region for the four sets of FWOs. The load reductions are shown as proportion of current load (%). The first value in each column is the best estimate, which is the mean value over the 100 Monte Carlo realisations. The values in parentheses are the lower and upper bounds of the 90% confidence interval.

FMU	C band	B band	A band	Spatially variable
Coastal Terraces	75 (68 - 82)	80 (71 - 87)	88 (84 - 91)	76 (67 - 84)
Northern Hill Country	67 (50 - 83)	72 (60 - 83)	83 (76 - 89)	65 (48 - 82)
Patea	80 (58 - 97)	84 (68 - 98)	91 (77 - 98)	80 (56 - 97)
Southern Hill Country	76 (62 - 88)	82 (73 - 89)	89 (83 - 93)	77 (65 - 88)
Volcanic Ringplain	81 (76 - 86)	85 (80 - 87)	91 (88 - 93)	82 (77 - 86)
Waitara	80 (61 - 98)	82 (67 - 94)	89 (80 - 95)	83 (69 - 96)
Total	80 (72 - 88)	83 (78 - 89)	90 (87 - 92)	81 (75 - 87)

The NPS-FM requires regional councils to set limits on resource use to achieve environmental outcomes (e.g., FWOs). This report helps inform Taranaki Regional Council's process of setting limits by assessing the approximate magnitude of the *E. coli* load reductions needed to achieve several options for FWOs, with a quantified level of uncertainty associated with each option. The results of this study are comprehensive (i.e., covering the whole region) and consistent (i.e., using information with comparable levels of precision in all locations) but resolution is low because the underlying modelling has high uncertainty.

This report does not consider what kinds of limits on resource might be used to achieve any load reductions, how such limits might be implemented, over what timeframes and with what implications for other values. The NPS-FM requires regional councils to have regard to these and other things when making decisions on setting limits. This report shows that these decisions will ultimately need to be made in the face of uncertainty about the magnitude of load reductions needed.

1 Introduction

This report describes an assessment of *Escherichia coli* (*E. coli*) load reductions required to achieve options for numeric objectives in the rivers of Taranaki. The purpose is to inform the Taranaki Regional Council (TRC) about where potential objectives are currently being achieved and not achieved. Where objectives are not being achieved, the report describes the size of the gap between current *E. coli* loads and loads that would allow the objectives to be achieved.

The analysis described in this report does not consider how the *E. coli* load reductions would be achieved. The current report therefore only aims to inform the TRC about the magnitude of the required load reductions, how these vary across the region, and aims to establish a framework for future scenario testing of methods that might be employed to reduce loads. The various objectives presented in this report are options. It is assumed that objectives will remain options until the testing of methods to achieve the reductions has been completed.

The analysis methodology is based on similar studies that assessed national-scale nitrogen load reduction requirements (MFE, 2019; Snelder *et al.*, 2020) and regional scale nutrient reductions (nitrogen and phosphorus) in the Southland region (Snelder, 2021). However, the current analysis involved some modifications to methods used by these earlier studies to represent the Taranaki region in greater detail, and to assess load reductions for *E. coli* rather than nutrients. Those modifications had also been applied in previous studies that assessed *E. coli* load reduction requirements for rivers in the Southland and Otago regions (Snelder and Fraser, 2021a; b) To keep the current report simple, the methods are described only in broad terms and the reader is referred to MFE (2019) and Snelder *et al.* (2020) for the details of the methodology. The exceptions to this are descriptions of details of the method where these pertain to modifications made for the current study.

2 Methods

2.1 Overview

Conceptually, this study represents *E. coli* loads being generated in catchments and transported to downstream river and stream receiving environments by the drainage network (Figure 1). The loads of *E. coli* (i.e., *E. coli* organisms per year) arriving at each receiving environment determine the distribution of *E. coli* concentrations through time and therefore the risk to human health (MFE and MoH, 2003). Acceptable risks to human health are defined by levels of four statistics (i.e., criteria) that describe the distribution of *E. coli* values at a site. These statistics are the annual median and 95th percentile concentrations (Median, Q95), and the proportion of samples for which concentration thresholds of 260 and 540 *E. coli* 100mL^{-1} are exceeded (G260, G540). These statistics are used because they are the basis for the *E. coli* attribute states in the National Objectives Framework (NOF) appended to the National Policy Statement – Freshwater NPS-FM; NZ Government (2017, 2020). Where one or more of the values of the four statistics exceed a defined criterion, there is a requirement to reduce the current load of *E. coli*. The four statistics are also the basis for national targets to increase the proportions of large rivers that are suitable for primary contact (i.e., that are C band state or better), as set out in Appendix 3 of the NPS-FM (NZ Government, 2017, 2020).

This study's calculations were based on a spatial framework that represents the drainage network (i.e., streams and rivers) and associated catchments. Calculations were performed for every segment of the network, which represent river receiving environments.

The calculation of load reductions required were based on statistical models fitted to *E. coli* data obtained from 95 river state of environment (SOE) monitoring sites in the Taranaki and neighbouring Manawatū-Whanganui and Waikato regions. Sites in the Manawatū-Whanganui and Waikato regions were used to supplement the dataset because there were only 11 Taranaki sites with sufficient data for modelling purposes. The details of the sites used are provided in Sections 2.3, 2.4 and 2.5.

The analyses are shown schematically in Figure 1. Initially, observations made at each SOE monitoring site were used to calculate the current values of four *E. coli* statistics and to calculate current annual loads of *E. coli* (i.e., number of organisms) per year. In addition, linear regression models were used to relate the observed values of the *E. coli* statistics at each SOE monitoring site with the associated *E. coli* loads (expressed as yields by dividing by the catchment area of each SOE monitoring site).

The four statistics and the loads were used as training data in spatial models. The spatial models were used to predict the current value for the four statistics and the current *E. coli* loads for every segment of the river network (i.e., every stream and river receiving environment) within the study area.

The criteria to achieve four sets of options for FWOs in river receiving environments are defined in terms of four statistics representing *E. coli* concentrations. Compliance with FWOs was assessed for each segment of the river network by comparing these criteria with the associated predicted value. In addition, the linear models relating *E. coli* statistics and loads were used to calculate the maximum allowable load (MAL), which is the load that will ensure the four *E. coli* statistics do not exceed their associated criteria at each segment. For segments that are non-compliant (i.e., the estimated current value of one or more of the *E. coli* statistics exceeds the criteria), the local excess load was calculated as the current load minus the MAL. The local excess load is the amount by which the current load at each segment would need to be reduced to achieve the FWO.

The load reduction required differs from the local excess load in that it considers the excess load of all upstream receiving environments. Thus, a point in the network may have a local excess load of zero but, if it is situated downstream of receiving environments that have local excess loads, it will have a load reduction required that that reflects a reconciliation of those upstream local excess loads. The load reduction required can be expressed in absolute terms as a load of organisms per year (*E. coli* yr^{-1}), as a yield (organisms per catchment area per year; *E. coli* ha^{-1} yr^{-1}) and as a proportion of the current load of *E. coli* (%).

Critical points and catchments were identified by first identifying critical points in each sea-draining catchment in the study area. For every point in the drainage network there is a critical point, which is the downstream segment that has the highest ratio of current load to MAL. The catchment upstream of the critical point is a critical point catchment and has a load reduction required, which is the local excess load at the critical point. The critical catchment load reduction required is expressed as a yield (i.e., number of *E. coli* organisms per catchment area; *E. coli* ha^{-1} yr^{-1}) or as a percentage of current *E. coli* load (%). The critical catchment load reduction required indicates the spatially averaged reduction rate that would be required over the entire area of the critical point catchment to reduce the load sufficiently to allow FWO to be achieved across the entire catchment. Sea-draining catchments can have one critical point (the most downstream receiving environment) or multiple critical points, which include the most downstream receiving environment and other sub-catchments. Critical catchments can have a catchment load reduction required of zero when the current load is less than the MAL or have positive values when the current load exceeds the MAL.

It should be kept in mind that a critical catchment load reduction required represents a load reduction for the whole critical catchment. If the catchment includes areas of natural land cover and that is not subject to human use, and the methods for load reduction are restricted to mitigation actions associated with land use, the required load reduction from productive land would need to be higher than the reported value.

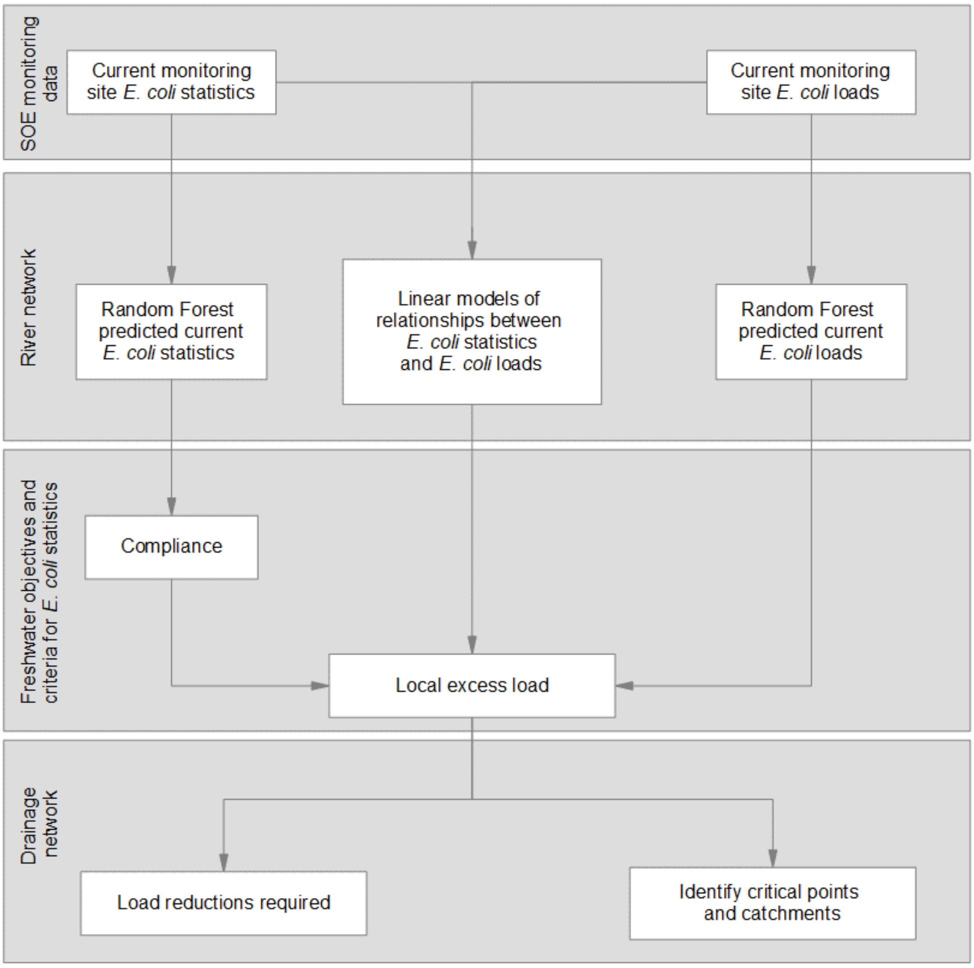


Figure 1. Schematic diagram of the assessment of E. coli load reductions required to achieve freshwater objectives.

The following sections describe the various components of the analysis shown in Figure 1 in more detail.

2.2 Spatial framework

The study area comprised the Taranaki region (Figure 2). The drainage network and river receiving environments were represented by the GIS-based digital drainage network, which underlies the River Environment Classification (REC version 2.4; Snelder and Biggs, 2002).

This is the same drainage network that was the spatial framework used by Snelder (2020). The digital network was derived from 1:50,000 scale contour maps and represented the rivers within the study area as 16,625 segments bounded by upstream and downstream confluences, each of which is associated with a sub-catchment (Figure 2). The terminal segments of the river network (i.e., the most downstream points in each drainage network that discharges to the ocean) were identified.

The results of the load reductions required analyses can be reported at any spatial scale from individual receiving environments (i.e., river segments, Figure 2), to freshwater management units (FMUs; Figure 3) and the whole study area.

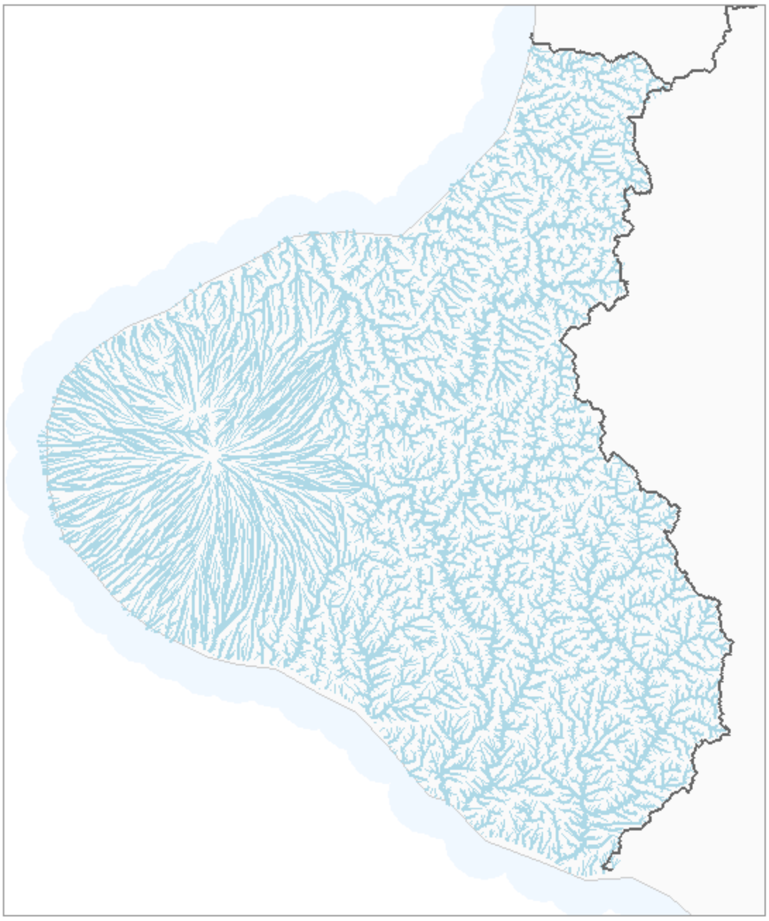


Figure 2. The digital network within the study area that provided the spatial framework for the analysis.

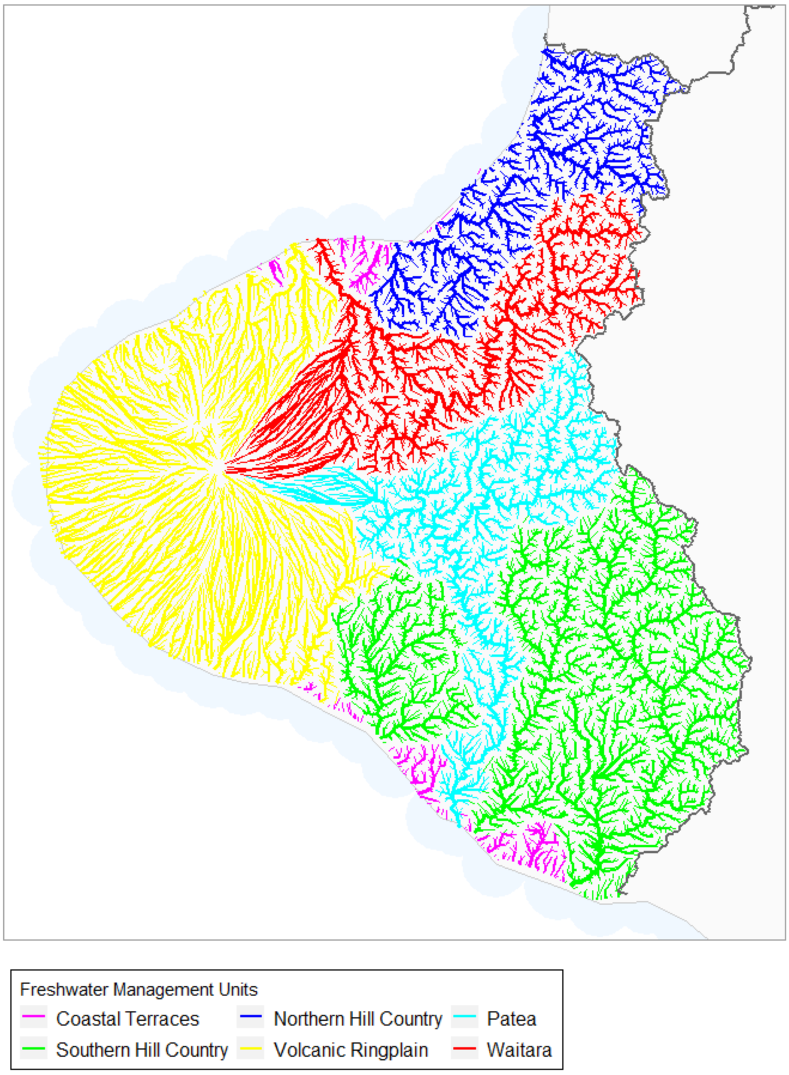


Figure 3. Proposed freshwater management units (FMUs) for Taranaki used for summarising the results of the analysis.

2.3 *E. coli* criteria and predicted current *E. coli* statistics

The NOF defines five levels of environmental quality (termed "attribute states" in the NPS-FM) denoted A, B, C, D and E. The five attribute states are linked to threshold criteria for the four *E. coli* statistics shown in Table 1. The attribute states are associated with low (A) to high (E) concentrations of *E. coli*, which are linked to low to high risk of infection by microbiological pathogens for humans contacting the water. Each of the four criteria defined by Table 1 must be satisfied (i.e., the value of each statistic representing the state of a river receiving environment must be lower than the criteria) for that receiving environment to be in that attribute state. Thus, if one or more criteria cannot be satisfied in an attribute state, a lower attribute state applies.

The national targets to increase the proportions of large rivers that are suitable for primary contact are linked to NOF attribute states. The NPS-FM defines rivers as suitable for primary contact if they are in NOF attributes states A, B or C and large rivers are defined by network segments of a stream order of ≥4 as defined by the REC. In Taranaki, river segments of stream order of ≥4 have a minimum catchment area of 6.8 km^2 and approximately 75% of them have mean flows >1 $m^3 s^{-1}$.

Table 1. Criteria used to define the E. coli freshwater attribute states.

Criteria	**Attribute state**				
	A	**B**	**C**	**D**	**E**
Median *E. coli*/ 100ml^{-1} (Q50)	<130	130	130	260	>260
95th Percentile *E. coli* 100ml^{-1} (Q95)	<540	1000	1200	1200	>1200
Proportion of exceedances over 260 *E. coli* 100ml^{-1} (G260)	<0.2	0.3	0.34	0.5	>0.5
Proportion of exceedances over 540 *E. coli* 100ml^{-1} (G540)	<0.05	0.1	0.2	0.3	>0.3

The analysis described below was based on values of four NOF *E. coli* statistics (Table 1) that were predicted for all segments of the drainage network using spatial statistical regression modelling. The statistical modelling to predict the values of the four *E. coli* statistics for every network segment commenced by calculating each of the four statistics shown in Table 1 for 95 SOE monitoring sites located in the Taranaki, Manawatū-Whanganui and Waikato regions. *E. coli* had been measured at each site on a monthly basis for the five-year period ending 30 June 2020 (Figure 4). The statistic values were calculated from the monitoring data for each site. The site values of each statistic were used as response variables in four regression models (one for each statistic) that were based on several similar national and regional studies (e.g., Whitehead, 2018) and the studies on which the current analysis was based (MFE, 2019; Snelder *et al.*, 2020).

For each *E. coli* statistic (i.e., Median, Q95 G260, G540), a random forest (RF) regression model was fitted to the observed monitoring site values using predictor variables that describe various aspects of each site's catchment including the climate, topography, geology and land cover. In addition, this study included five predictors that quantified the density of pastoral livestock in 2017 to indicate land use intensity. These predictors were based on publicly available information describing the density of pastoral livestock (https://statisticsnz.shinyapps.io/livestock_numbers/). These predictors improve the discrimination of catchment land use intensity compared to previous studies, that have only had access to descriptions of the proportion of catchment occupied by different land cover categories (e.g., (Larned *et al.*, 2018). The densities of four livestock types (dairy, beef, sheep and deer) in each catchment were standardised using 'stock unit (SU) equivalents', a commonly used measure of the metabolic demand of New Zealand's livestock (Parker, 1998). Stock unit equivalents that were applied to dairy, beef, sheep and deer were 8, 6.9, 1.35, and 2.3, respectively. These values represent adjustments to the original equivalents of Parker (1998), to account for increasing animal size and productivity since 1998 (Snelder *et al.*, 2021). The five predictors express land use intensity as the total stock units, and the stock units by each of the four livestock types, divided by catchment area (i.e., SU ha^{-1}).

The site Median and Q95 values were $\log_{10}$ transformed to improve model performance (Whitehead, 2018). A logit transformation was applied before fitting the model for G260 and G540 values. A logit transformation is defined as:

$$logit = log\left(\frac{x}{1-x}\right) \qquad \text{Equation 1}$$

where x are the site G260 and G540 values, which are in the range 0 to 1. The logit transformed values range between $-\infty$ and $+\infty$. In a previous study, Snelder (2018) showed that transformation of the G260 and G540 statistics did not improve the performance of the RF models but did improve their ability to discriminate variation in small values of the statistics.

The fitted models were combined with a database of predictor variables for every network segment in the region and used to predict the current (i.e., 2020) values of the four statistics for all segments. Model predictions were back-transformed and, in the case of the log transformed statistics (Median and Q95) corrected for re-transformation bias as described by (Duan, 1983).

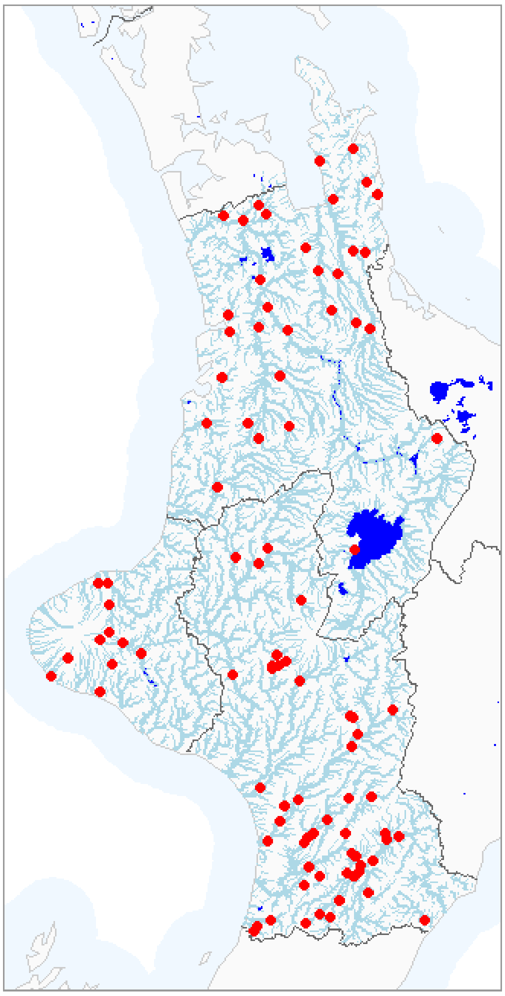


Figure 4. Locations of the 95 river SOE monitoring sites used to fit the RF E. coli concentration and yield models.

The performance of the models and the uncertainty of the predictions were evaluated using three measures: regression R^2, Nash-Sutcliffe efficiency (NSE), and bias. The regression R^2 value is the coefficient of determination derived from a regression of the observations against the predictions. The R^2 value indicates the proportion of the total variance explained by the model, but is not a complete description of model performance (Piñeiro *et al.*, 2008). NSE indicates how closely the observations coincide with predictions (Nash and Sutcliffe, 1970). NSE values range from $-\infty$ to 1. An NSE of 1 corresponds to a perfect match between predictions and the observations. An NSE of 0 indicates the model is only as accurate as the mean of the observed data, and values less than 0 indicate the model predictions are less accurate than using the mean of the observed data. Bias measures the average tendency of the predicted values to be larger or smaller than the observed values. Optimal bias is zero, positive values indicate underestimation bias and negative values indicate overestimation bias (Piñeiro *et al.*, 2008). The normalization associated with R^2 and NSE allows the performance of the models of the four *E. coli* statistics to be directly compared. Model predictions were evaluated against two performance measures (R^2 and NSE) following the criteria proposed by Moriasi et al. (2015), outlined in Table 2.

Bias was quantified by the root mean square deviation (RMSD). RMSD is the mean deviation of the predicted values from their corresponding observations and is therefore a measure of the characteristic model uncertainty (Piñeiro *et al.*, 2008).

Table 2: Performance ratings for statistics used in this study. The performance ratings are from Moriasi et al. *(2015).*

Performance Rating	R^2	NSE
Very good	$R^2 \geq 0.70$	NSE > 0.65
Good	$0.60 < R^2 \leq 0.70$	0.50 < NSE ≤ 0.65
Satisfactory	$0.30 < R^2 \leq 0.60$	0.35 < NSE ≤ 0.50
Unsatisfactory	$R^2 < 0.30$	NSE ≤ 0.35

For the statistics Median and Q95, model predictions require back transformation from the original $\log_{10}$ space to the original units (*E. coli* 100 mL^{-1}) using Equation 2.

$$Prediction = CF \times 10^{[log_{10}(x) - bias]} \qquad \text{Equation 2}$$

where x represents the untransformed prediction (in $\log_{10}$ space) from the model and CF is a factor to correct for retransformation bias (Duan, 1983).

For the statistics G260 and G540 the model predictions require back transformation from the original logit space to the using Equation 3.

$$Prediction = \frac{e^{x-bias}}{1+e^{x-bias}} \qquad \text{Equation 3}$$

where x represents the untransformed prediction (in logit space) from the model.

2.4 Estimated current river *E. coli* loads

Estimates of current loads of *E. coli* for all segments of the drainage network were made using river water quality monitoring data from river water quality SOE monitoring sites in the Taranaki, Manawatū-Whanganui and Waikato regions (Figure 4) and statistical regression modelling in two steps. Loads were calculated for 95 sites that met minimum data requirements for the 10-year period ending December 2020. The sites were required to have: (1) 60 or more observations; (2) observations in 8 of the 10 years; and (3) observations in 80% of the quarters. Data and methods for load calculation are described in Appendix A. Load calculations were based on mean daily flows for each monitoring site that were either derived from flow recorders, or, within the Taranaki region, based on extrapolation of monthly gauged sites provided by TRC staff. The load calculation method estimated the mean annual load but accounted for trends in the concentration data so that the final load estimates pertain to 2020. The loads were expressed as yields by dividing by the catchment area (*E. coli* ha^{-1} yr^{-1}). The 95 sites poorly represented rivers draining high rainfall parts of the Taranaki region (i.e., alpine headwater areas) but well represented rivers along a gradient in the proportion of the upstream catchment occupied by pastoral land use (Figure 4).

The second step used the same statistical regression modelling approach as for concentrations to fit random forest models to calculated monitoring site yields. The site yield values were $\log_{10}$ transformed to improve model performance (Snelder, 2018).

The fitted models were combined with a database of predictor variables for every network segment in the Taranaki region and used to predict current yields of *E. coli*. Model predictions were back-transformed using Equation 2, which includes correcting for re-transformation bias based on the method of Duan (1983). The load model predictions were evaluated following the same criteria used for the concentration predictions (Table 2).

2.5 Linear models describing *E. coli* yield as function of attribute statistics

We fitted models describing the relationship between the *E. coli* yield (i.e., the load divided by the catchment area) and each of the four attribute statistics, using data from 33 sites (Figure 5), which included 11 Taranaki sites and a selection of “close” sites in the Manawatū-Whangaui and Waikato regions. We assumed that the relationships between attribute statistics and *E. coli* yield are influenced by a range of factors including the environmental character of catchments and river size. Therefore, we selected “close” sites from the neighbouring regions based on geographic proximity and similarity in river mean flow magnitude. We assumed that these “close” sites are a reasonable sample that represent the relationships between attribute statistics and *E. coli* yield in the Taranaki region. The sample included 17 sites for the Manawatū-Whangaui region from catchments west of the Manawatū River (excluding sites with mean flows greater than 1.5 times the largest estimated mean flow in the Taranaki region), and five sites from the Waikato region, located in the upper portions of the Waipa River (upstream of Pirongia) and west coast draining catchments (south of Kawhia).

The *E. coli* statistics for the sites were for the period ending 31 December 2020. Because the loads pertained to the end of 2020, they were representative of the 5-year period ending December 2020 that the *E. coli* statistics were calculated from. The models describing the relationships between the four attribute statistics and *E. coli* yield were linear regressions with appropriate transformations applied to linearise the modelled relationships. We log (base 10) transformed both the yield and the statistic values prior to fitting the models pertaining to the median and Q95 statistics. We logit (base 10) transformed the yield values and logit transformed the statistic values for the models pertaining to the G260 and G540 statistics.

The uncertainties of these models were evaluated using a leave-one-out cross validation process to obtain a set of independent predictions of the yields at each site. These independent predictions were then combined with the observed yields and the model statistics shown in Table 2 were used to describe the performance of the four separate models. Note that because the linear models were fitted to the $\log_{10}$ transformed values of the yield, the outputs obtained from the models were back-transformed (by raising to the power of 10) and corrected for re-transformation bias as described by (Duan, 1983).

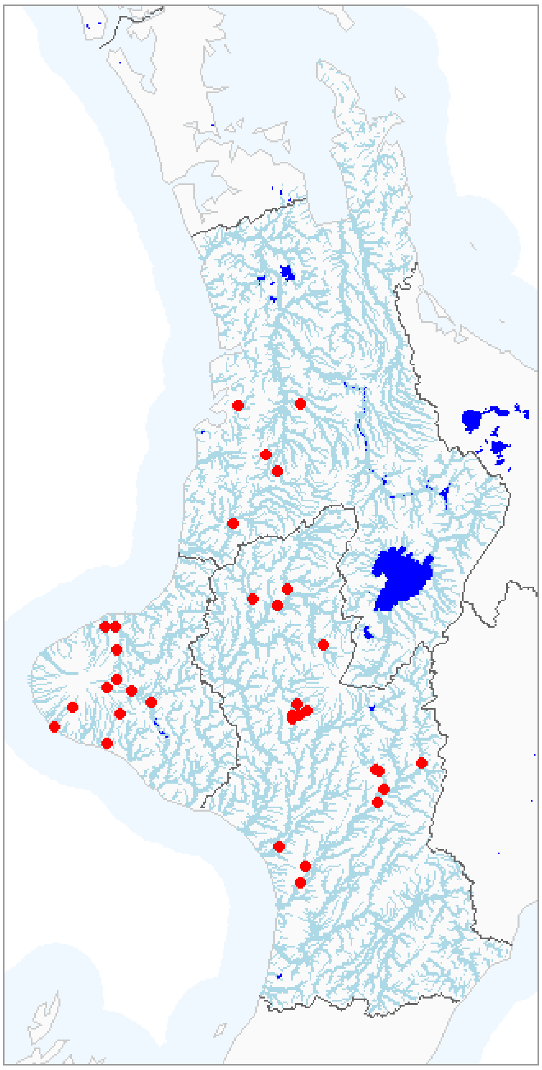


Figure 5. Locations of the 33 river SOE monitoring sites used to fit the linear models describing E. coli yield as function of attribute statistics. The fitting dataset included 11 sites in the Taranaki region, 17 sites from the Manawatū-Whangaui region and five sites from the Waikato region.

2.6 Current state and compliance

We undertook the analyses that follow for four sets of possible objectives that were defined using the NPS-FM *E. coli* attribute states. These sets of objectives are options that could be adopted and therefore the analyses indicate the impact of choosing each option in terms of the load reductions required were that option to be adopted. Options 1, 2 and 3 assumed spatially uniform objectives defined by the A, B and C bands (Table 1), respectively for all rivers in the region. Option 4 allowed the objectives (defined as bands A, B or C) to vary across the Taranaki region according to river classes that are discussed in Section 2.9. The remainder of the section describes how the predicted current values of the four *E. coli* statistics were compared with the objectives nominated under options 1, 2, 3 and 4, to assess the current attribute state and compliance (step 3 of the analysis described in Figure 1).

The current attribute state and compliance were assessed for each river segment in three steps. First, based on its nominated objective and associated attribute state (i.e., band), each segment was assigned a criterion for each statistic based on Table 1. Second, for each segment, the current attribute state was assessed by comparing the predicted values of the four statistics to the band criteria provided in Table 1. The current attribute state was based on the statistic that produced the lowest band. For example, if the Median, Q95 and G540 were assigned to the B band but the G260 was assigned to the C band, the attribute state of the segment was assessed as C. Third, the assessed attribute state was compared to the nominated objective. If the assessed attribute state was the same or better than the objective, the segment was compliant, otherwise it was considered noncompliant.

The predicted current values of the four *E. coli* statistics were also used to determine the proportion of large rivers that are currently suitable for primary contact. This assessment was performed by calculating the proportion of segments with stream order of >3 for which the predicted current attribute state was A, B or C. It is noted that the proportion of segments that are unsuitable is the complement of the proportion that are suitable (i.e., 1 – proportion suitable). The proportion suitable for primary contact was calculated for the region. This was done to enable comparison of the results for the whole Taranaki region with a previously reported estimate of the current proportion of large rivers suitable for primary contact in Taranaki (i.e., 39%; MFE 2018) and also to compare with the national targets laid out in the NPSFM (i.e., 80% by 2030 and 90% no later than 2040).

2.7 Load reductions required and critical catchments

The *E. coli* load reduction required to bring all segments into a compliant state was calculated in three steps (steps 3, 4 and 5; Figure 1). At step 3, for all noncompliant segments and each *E. coli* statistic, the *E. coli* yield corresponding to the criteria was estimated using the linear models describing the *E. coli* yield as a function of the four attribute statistics (section 2.5). Then, for each segment, the largest percentage reduction across all non-compliant *E. coli* statistics was found. The maximum allowable load (MAL) was evaluated as this largest percentage reduction applied to the predicted current *E. coli* load (i.e., predicted using the random forest model). The local excess load is then evaluated as the current load minus the MAL. For example, if the segment FWO was the A attribute state, the Q50 criteria would be 130 *E. coli* 100ml^{-1} (Table 1). The *E. coli* yield corresponding to a Q50 of 130 *E. coli* 100ml^{-1} would be estimated using the linear model to be 120 giga *E. coli* ha^{-1} yr^{-1} (see Figure 10). Then, the *E. coli* yield corresponding to the predicted current value of the statistic would be estimated from the linear models. If the predicted current Q50 value was 200 *E. coli* 100ml^{-1}, the corresponding *E. coli* yield would be estimated from the linear model as 173 giga *E. coli* ha^{-1} yr^{-1} (see Figure 10). The difference between the estimated current yield and the estimated yield to achieve the criteria can then be expressed as a percentage reduction, i.e., 31% ([173-120]/173). If the predicted current *E. coli* load were 200 giga *E. coli* ha^{-1} yr^{-1} the MAL would be evaluated as 138 giga *E. coli* yr^{-1} (i.e., [100 – 31%] x 200). The local excess load would be evaluated as 200 - 138 = 62 giga *E. coli* ha^{-1} yr^{-1}.

The load reduction required (Figure 1) was calculated by traversing the digital drainage network in the downstream direction. At all upstream-most segments, the load reduction required was defined to be the local excess load. Then, beginning at the upstream-most segments, the load reduction required was compared to the local excess load of the next segment downstream. If the local excess load at the next downstream segment was less than the load reduction required of the upstream segment, the load reduction required of the downstream segment was updated to be the load reduction required of the upstream segment. If the reverse applied, the local excess load of the downstream segment was updated to be its local load reduction required. The load reduction required therefore took a positive value (*E. coli* yr^{-1}) at any segment in the catchment for which there was a local excess load at that, or any upstream, segment. In this study, we evaluated the load reduction required in relative terms (i.e., by dividing all local excess loads by their respective estimated current loads). This was because the estimated current load sometimes decreased in the downstream direction due to changing catchment characteristics (in the downstream direction). The use of the relative measure of the maximum of the upstream local excess loads ensured that we did not have load reductions required that exceeded the estimated current load at any segment. Summaries of the load reductions required as mass per year (*E. coli* yr^{-1}) were produced for the proposed FMUs (Figure 3) and the whole study area. These summaries were evaluated by summing excess loads over all terminal segments (i.e., network of segments intersecting the coastline) of the summary area.

Finally, critical points and catchments (Figure 1) were identified as follows. The terminal segment of every sea-draining catchment (the river mouth) was defined as a critical point and the ratio of the current load to MAL at that point was noted. A ratio of the current load to MAL greater than one indicates non-compliance and the larger this value is, the greater the extent to which the current load exceeds the MAL. From the terminal segment, the ratio of the current load to MAL at successive upstream river segments were obtained. At each segment, the ratio was compared with the ratio for the downstream critical point. If the ratio of the current load to MAL at the segment was greater than that of the downstream critical point, the segment was defined as a critical point and the load reduction required for the catchment upstream of this point is the local excess load of this segment. If the ratio of the current load to MAL at the segment is less than that of the downstream critical point the critical point is unchanged. The process continues upstream to the catchment headwaters. Maps indicating the load reductions required were produced for critical point catchments as yields by dividing by the upstream catchment area (*E. coli* ha^{-1} yr^{-1}) or as proportions of the current load (%). More details of the process of defining critical points and catchments are provided by Snelder *et al.* (2020)[1]. To map the critical catchment load reduction required, the quantity is expressed as a percentage of current *E. coli* load or as a yield (i.e., number of *E. coli* organisms per catchment area; *E. coli* ha^{-1} yr^{-1}).

2.8 Estimation of uncertainties

Our analysis was based on nine statistical models (i.e., random forest models to predict current values of the four *E. coli* statistics, random forest models to predict the current *E. coli* yield, and four linear regression models describing *E. coli* yield as function of four *E. coli* statistics). These models were all associated with uncertainties. The uncertainty of each model was quantified by its RMSD values (Table 2). These random errors propagate to all the assessments produced in this study including the assessments of current state and compliance, and the assessment of the load reduction required.

[1] Snelder et al. (2020) based the identification of critical points on excess loads, which were expressed as the ratio of the current load to the maximum allowable load.

We inspected the residual errors for each of the models. There was no apparent geographic pattern in these errors and the pattern of errors was not explained by catchment characteristics. All models incorporated data pertaining to the 33 sites that were used to fit the linear models (Figure 5). We expected that the residual errors associated with these 33 sites for each model would be correlated to a degree with the errors of the other eight models. We used the correlation matrix derived from the nine sets of model errors to describe the relationship between all pairs of model errors. We assumed that this correlation structure represents the correlation in the uncertainties when the models were combined in the assessment process.

We applied the same simple Monte Carlo analysis approach as Snelder *et al.* (2020) to estimate uncertainties in our assessments based on 100 'realisations' of our calculations in four steps. First, for a realisation (r), predictions made with all models were perturbed by a random error. Random errors were obtained by generating random normal deviates (ε_r) and applying these to predictions made using the models. When the response variables in the models were log (base 10) transformed the perturbed prediction for a realisation was derived as follows.

$$Prediction_r = CF \times 10^{[log_{10}(x) - bias + \varepsilon_r \times RMSD]}$$ Equation 4

When the response variables in the models were logit transformed (i.e., the models of current values of G260 and G540) the perturbed prediction for a realisation was derived as follows.

$$Prediction_r = \frac{e^{x - bias + \varepsilon_r \times RMSD}}{(1+e^{x - bias + \varepsilon_r \times RMSD})}$$ Equation 5

Random normal deviates representing errors for each model (ε_r) were drawn from a multi-variate distribution with the same correlation structure as that between the observed errors. Because a concentration or load at any point in a catchment is spatially dependent on corresponding values at all other points in the catchment's drainage network, the values of the random normal deviates were held constant for each realisation within the river network representing a sea-draining catchment but differed randomly between sea-draining catchments.

At the second step, for each realisation we stored the perturbed predicted values of the four *E. coli* statistics, current load and load reduction required. At the third step, we repeated the procedure described above for each realisation. At the fourth step, we used the distribution of values of the four *E. coli* statistics, current load and load reduction required obtained from the 100 realisations to provide a best estimate and the uncertainty of the assessments. The uncertainty of the assessments of compliance and whether the segment was suitable for contact recreation were quantified by estimating the probability that each segment was compliant or suitable across the 100 realisations. Segment compliance and suitability for contact recreation was therefore assessed as a value between one (100% confident the segment is compliant or suitable) to zero (100% confident the segment is non-compliant or not suitable). For the current state and load reduction required assessments, the best estimate was represented by the mean value from the distribution of values. Where the mean value was negative, the load reduction requirement was taken to be zero. The uncertainty of these two assessments was quantified by their 90% confidence intervals.

2.9 Freshwater objectives settings

2.9.1 Management classes

To proceed with the analysis, it is necessary to nominate FWOs in terms of a band (A, B, C, D or E) for all river receiving environments (represented by network segments) in the study area. The same FWOs can be applied uniformly over all network segments or spatially variable FWOs can be defined. Some regional councils use environmental classification systems such as the River Environment Classification (REC; Snelder and Biggs, 2002) to subdivide receiving environments into groups for which differing objectives can be justified. The REC can be used, for example, to differentiate river types on the basis that they are dominated by mountain, hill, and lowland Source-of-flow classes. Spatial variation in objectives can be justified for each type of river based on both what is reasonable relative to each type under natural conditions and community expectations. For example, in the Southland and Canterbury regions, objectives for a variety of river attributes (e.g., periphyton biomass, visual clarity and human health) vary according to management classes that are defined by REC Source-of-flow classes. In general, natural water quality and public expectations for water quality are highest for mountain Source-of-flow class followed by Hill and then Lowland classes.

The REC has already classified all segments of the river network in the Taranaki region into three Source-of-flow classes (Mountain, Hill, Lowland; Figure 6). In this study, we nominally used these classes to demonstrate and assess the impact of an option for spatially variable FWOs (i.e., FWOs were independently set for each river management class).

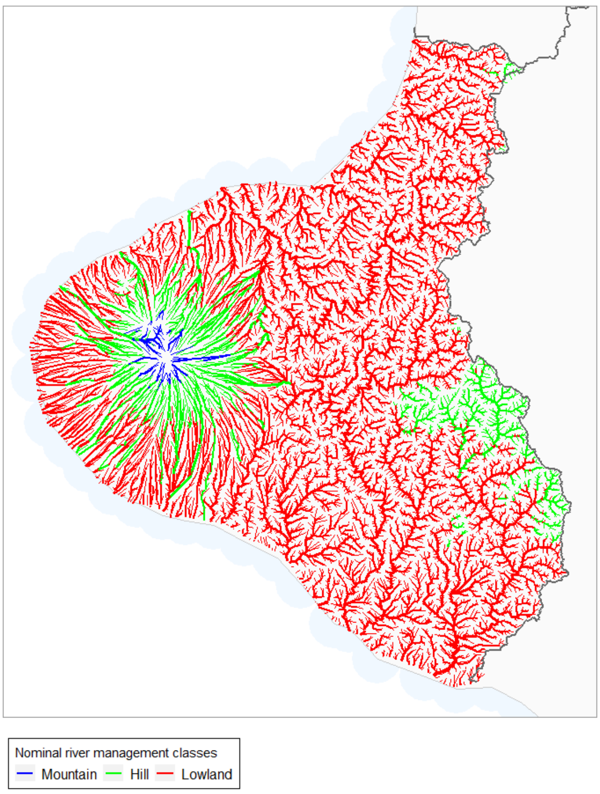


Figure 6. Map of the distribution of the nominal river management classes based on REC Source-of-flow classes.

2.9.2 Objectives

Because FWOs can be applied uniformly or by the nominated management class, there were many potential spatial configurations of FWO. To make the analyses and presentation of results manageable, we nominated four sets of FWOs for which load reduction assessments were made. The first three sets of FWOs simply assigned the A, B and C NOF band, uniformly to all segments. Therefore, these FWOs did not vary spatially, and the objectives are consistent across all segments. The fourth set of FWOs were spatially variable with the NOF band varying by the nominated river management classes shown in Figure 6 and with NOF bands for each class as shown in Table 3.

Table 3. Nominated NOF bands of the river management classes for the spatially variable FWOs. Note that the river management classes are nominal and are based on REC Source-of-flow classes shown in Figure 6.

Management class	NOF Band
Mountain	A
Hill	B
Lowland	C

3 Results

3.1 Performance of random forest *E. coli* statistics models

The random forest models of the four *E. coli* statistics had ‘good’ performance (Table 4), based on the criteria of Moriasi *et al.* (2015; Table 2). The mapped predictions for all four statistics had similar coarse-scale spatial patterns, with relatively high values in low-elevation areas of Taranaki and low values in high elevation areas (Figure 7). These patterns were consistent with expectations and reflect the influence of increasing proportions of catchment occupied by agricultural and other intensive land uses.

Table 4. Performance of random forest models of the four E. coli statistics; Median, Q95, G260 and G540. Median and Q95E. coli ha^{-1} yr^{-1}. G260 and G540.The overall performance rating is based on the criteria of Moriasi et al. (2015) shown in Table 2.

Statistic	N	R^2	NSE	BIAS	RMSD	Performance rating
Median	95	0.61	0.59	0.00	0.24	Good
Q95	95	0.61	0.61	-0.01	0.26	Good
G260	95	0.61	0.61	-0.03	0.78	Good
G540	95	0.65	0.65	-0.01	0.62	Good

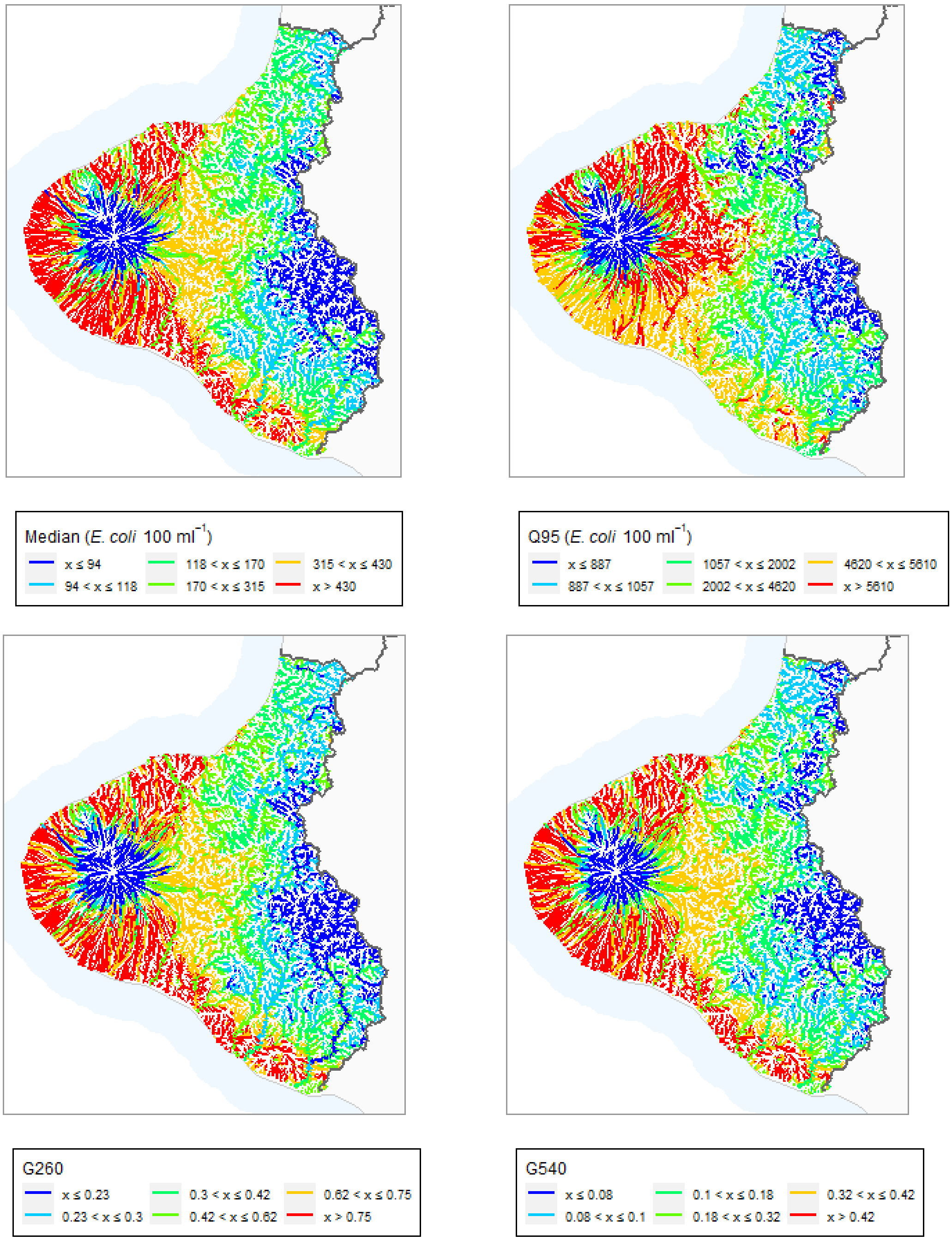


Figure 7. Predicted patterns of the current value of the four E. coli statistics. Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.2 Calculated *E. coli* current yields and performance of the random forest spatial model

Calculated current *E. coli* yields at the 95 SOE sites varied over three orders of magnitude from a value of 1.3 giga *E. coli* ha^{-1} yr^{-1} to 2,650 giga *E. coli* ha^{-1} yr^{-1}. In general, the uncertainty of the calculated current *E. coli* yields was high, and the 95% confidence interval could extend over more than an order of magnitude (Figure 8). The high uncertainties are attributable to the variability of *E. coli* concentration data from which the current *E. coli* yields are calculated. While there is often a significant positive association between flow and *E. coli* concentration, there is also generally increasing variation in concentrations at high flows. In addition, there were generally few samples at high flows (see Appendix A for examples). These two limitations lead to large uncertainties in loads because these are product of concentration and flow (see Appendix A for examples). We used an independent load calculation method to verify the calculated loads, which indicated the loads were reasonable (see Appendix A for details).

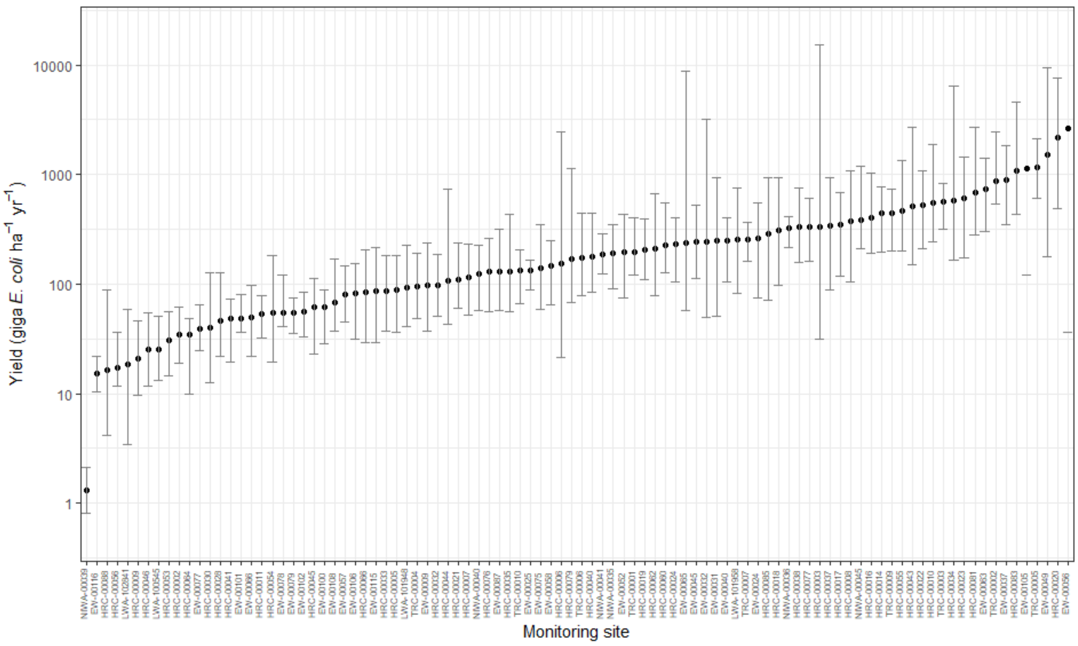


Figure 8. Cumulative frequency distribution of calculated site E. coli yields. The error bars show the 95% confidence interval of the estimated yield at each site.

The random forest models of *E. coli* annual yield had 'unsatisfactory' performance (Table 5), based on the rating criteria of Moriasi *et al.*, 2015; Table 2. We do not interpret an "unsatisfactory" performance rating to mean the model should not be used, rather we interpret this as indicating that the model's predictions have high uncertainty. The model performance could not be improved but relevant information about the impact of the quality of the model is provided by the uncertainty of the study's assessments.

The mapped predictions of annual yield of *E. coli* had similar coarse-scale spatial patterns as the *E. coli* statistics with relatively high values in low-elevation coastal areas of Taranaki and generally lower values in higher elevation and inland areas (Figure 9). These patterns were consistent with expectations and reflect the increasing concentration of *E. coli* in association with increasing proportions of catchments occupied by agricultural land use. Model diagnostics indicated that *E. coli* annual yield was positively related to the proportion of catchment associated with pastoral land use but also to catchment elevation, slope, temperature and rainfall.

Table 5. Performance of the random forest models of E. coli annual yield.E. coli ha^{-1} yr^{-1}. The overall performance rating is based on the criteria of Moriasi et al. (2015) shown in Table 2.

Variable	N	R^2	NSE	BIAS	RMSD	Performance rating
E. coli yield	95	0.25	0.25	-0.02	0.43	Unsatisfactory

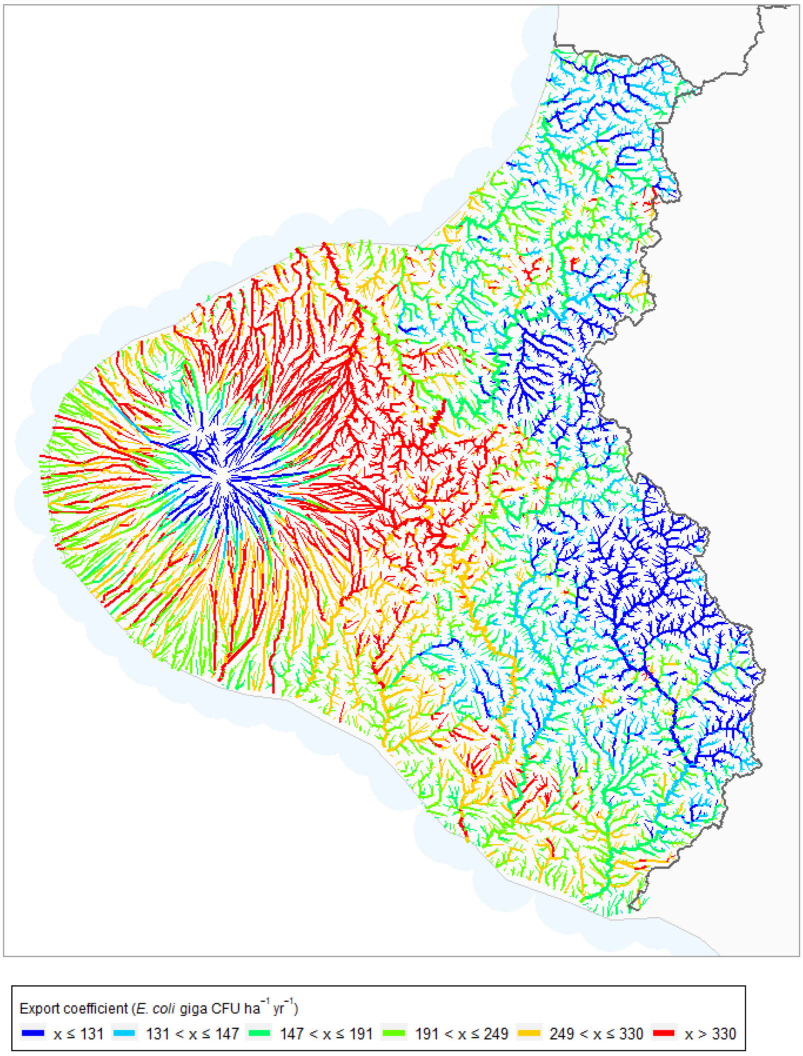


Figure 9. Predicted patterns of the current E. coli loads (as yields giga (10^9) E. coli ha^{-1} yr^{-1}). Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.3 Performance of the linear models of *E. coli* yield as function of attribute statistics

With appropriate transformation, *E. coli* yield was linearly related to the four *E. coli* attribute statistics (Figure 10, Table 9). The linear models that incorporated the median, G260 and G540 had satisfactory performance as indicated by the criteria of Moriasi *et al.* (2015; Table 2) and low bias (Table 6). The linear model that incorporated the Q95 had 'unsatisfactory' performance based on the criteria of Moriasi *et al.* (2015; Table 2).

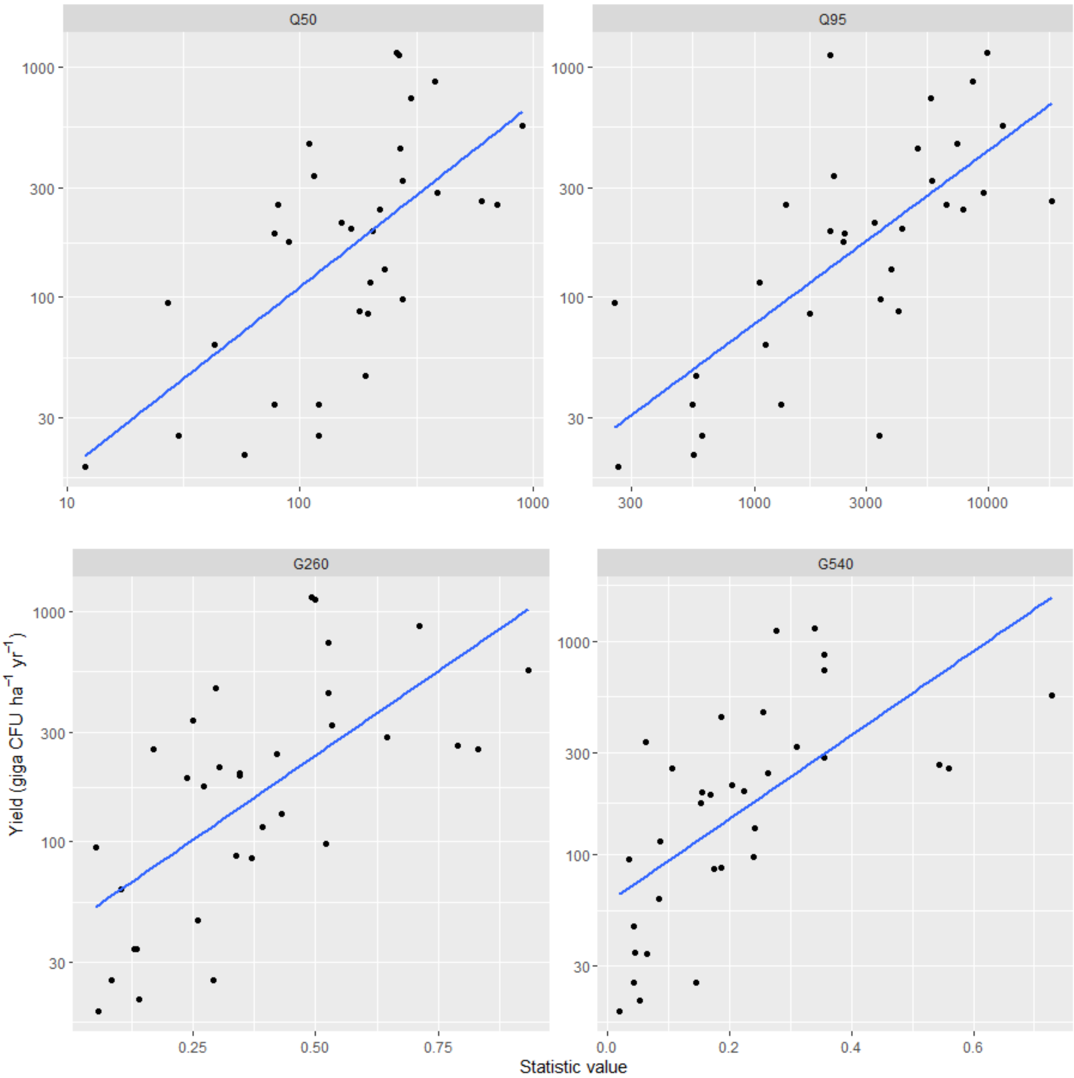


Figure 10. Linear relationships between E. coli yield and the four E. coli statistics. The black points represent the yield and E. coli statistic for the 32 sites and the blue line indicates the fitted linear regression. Note that on these plots and the fitted models, yield was log (base 10) transformed, the Median and Q95 values were log (base 10) transformed and the G260 and G540 values were logit transformed.

Table 6. Performance of the linear models describing E. coli yield as function of the four E. coli attribute statistics; Q50 (i.e., median), Q95, G260 and G540. The transformation indicated was applied to the statistic. In all cases the model response (i.e., E. coli yield) was log_{10} transformed. The overall performance rating is based on the criteria of Moriasi et al. (2015) shown in Table 2.

Statistic	N	R^2	NSE	BIAS	RMSD	Transformation	Performance rating
Q50	33	0.35	0.35	0.00	0.40	Log_{10}	Satisfactory
Q95	33	0.19	0.11	-0.02	0.47	Log_{10}	Unsatisfactory
G260	33	0.37	0.37	-0.01	0.40	Logit	Satisfactory
G540	33	0.47	0.47	0.00	0.36	Logit	Satisfactory

3.4 Correlation of model errors

The model errors were strongly correlated (Pearson correlation coefficient > 0.6) between all pairs of models that were used to predict current values of the *E. coli* statistics (Table 7). Correlations between the model errors associated with the *E. coli* statistics and the *E. coli* loads were low (*r* < 0.4). The model errors were strongly correlated (*r* > 0.6) between all pairs of the linear regression models that were used to describe the relationships between the *E. coli* statistics and loads (as yields). Correlations between the RF and linear regression models were low (*r* < 0.2). The correlation structure shown in Table 7 was used to generate random normal deviates (ε_r) for each model in the Monte Carlo analysis.

Table 7. Correlation of errors between all pairs of models used in the analysis. The table is a lower triangular matrix showing the correlations between all pairs of model errors for the 35 sites that were common to all models (Figure 5). RF indicates random forest models and LM indicates linear regression models.

Model	LM Median	LM Q95	LM G260	LM G540	RF Median	RF Q95	RF G260	RF G540
LM Q95	0.76							
LM G260	0.95	0.8						
LM G540	0.87	0.83	0.93					
RF Median	-0.14	0.16	-0.11	0				
RF Q95	0.04	-0.01	-0.05	-0.12	0.64			
RF G260	-0.09	0.06	-0.2	-0.1	0.86	0.77		
RF G540	-0.04	-0.01	-0.17	-0.26	0.65	0.83	0.82	
RF Load	0.7	0.72	0.7	0.79	0.39	0.31	0.38	0.19

3.5 Current state

The measured current state for the 11 SOE monitoring sites in the Taranaki region is shown in Table 8 in terms of NOF swimming grades by nominated management classes. These results indicate that poor attribute grades (i.e., D and E) occur at 10 of the 11 SOE sites in the Taranaki region. In addition, Table 8 indicates that the SOE sites provide some representation of rivers in the Hill and Lowland management classes but that there are no sites in the Mountain management class.

Table 8. Measured current state as numbers of SOE monitoring sites in each NOF overall swimming grade by management class. The value in parentheses is the proportion of total sites (%).

NOF Swimming grade	Number of sites by nominal management class		
	Mountain	Hill	Lowland
A	0	1 (9)	0
B	0	0	0
C	0	0	0
D	0	1 (9)	3 (27)
E	0	1 (9)	5 (45)

The best estimate of the proportions of the region's river network segments in the five NOF attribute states are shown in Table 9. The 90% confidence intervals for these estimates are very wide. For example, the best estimate of the proportion of segments that are in the A band is 4% but the 90% confidence intervals extend from 1% to 14% (Table 9). This large uncertainty reflects the, at best good, performance of the models used to predict the *E. coli* statistics (Table 4). This uncertainty is also indicated by the maps of the estimated probability of network segments belonging to the five NOF swimming grades (Figure 11). Over much of the network, the probability of segments being in a specific NOF attribute band was less than 50% indicating low certainty about the true state (Figure 11).

Table 9. Proportion of all segments (%) predicted to be in each attribute band. Note that results by proposed FMU are tabulated in Appendix B.

Attribute band	Best estimate	5% confidence limit	95% confidence limit
A	4	1	14
B	13	6	23
C	5	2	10
D	29	20	38
E	48	37	61

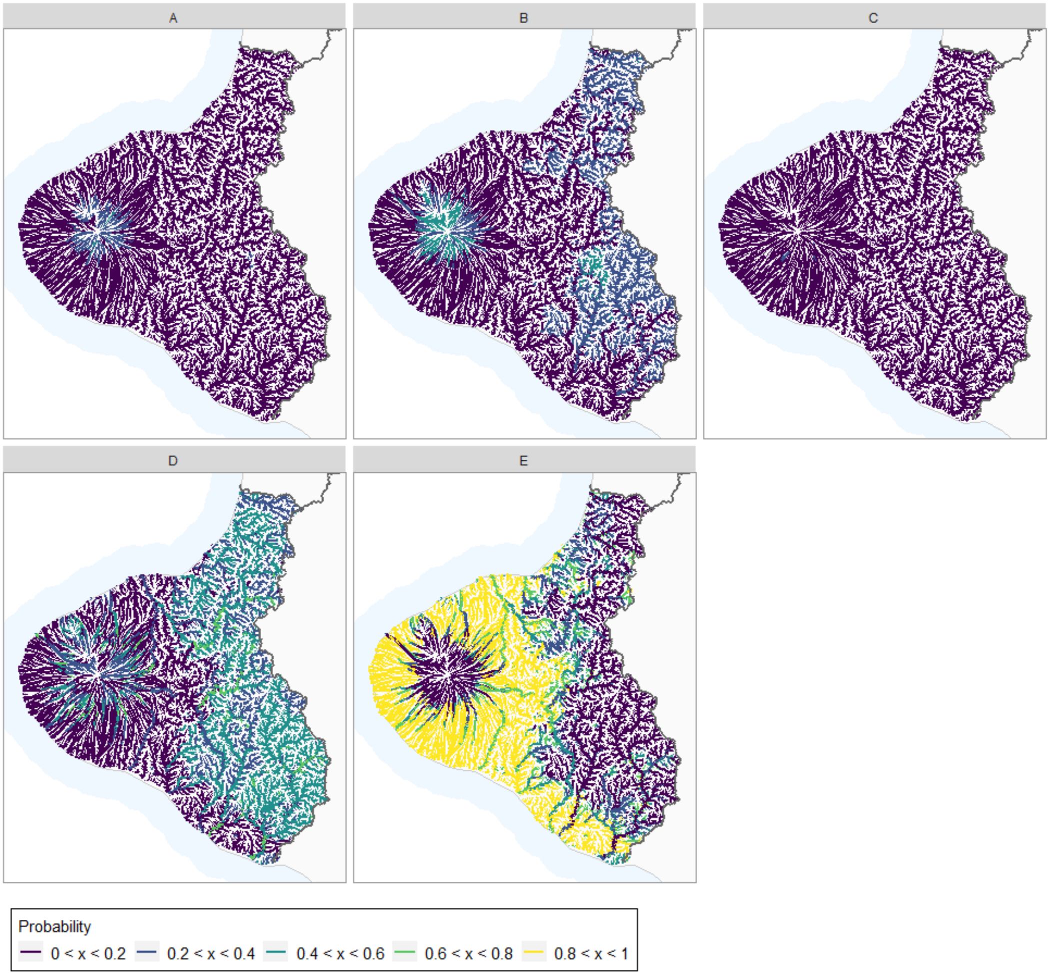


Figure 11. Estimated probability of network segments belonging the indicated NOF swimming grade or poorer.

The best estimate of the proportion of the Region's river segments of stream order >3 that are currently suitable for primary contact (i.e., NOF attributes states A, B or C) is 20%. There is high uncertainty associated with this estimate. The 90% confidence interval extends from 7% to 39%. This uncertainty is also indicated by a map of the estimated probability that network segments are currently suitable for primary contact (Figure 12). The map indicates that segments that have the highest probability of being suitable for primary contact are in headwater catchments. The main-stem rivers (i.e., stream order >3) traversing lowland areas have low probability (i.e., <20%) of being suitable, which is equivalent to high probability (i.e., >80%) of being unsuitable.

Our estimate that 20% of river segments of stream order >3 being are currently suitable for primary contact is smaller than a previous estimate of 39% of these large rivers being suitable for primary contact in Taranaki reported in MFE (2018). Differences between these estimates are likely due to differences in the modelling; the modelling undertaken by this study being region-specific whereas the MFE (2018) study used a model of national extent.

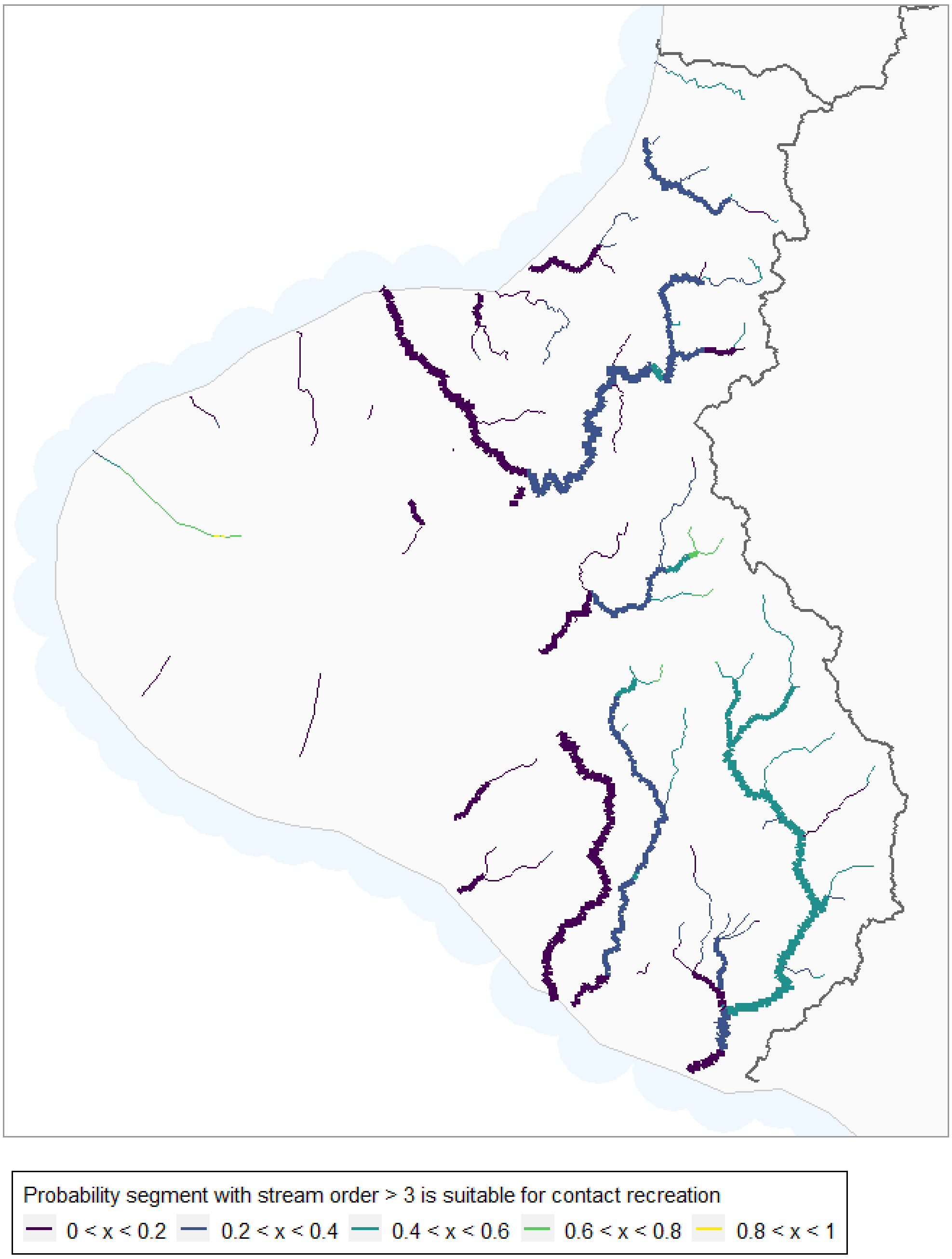


Figure 12. Estimated probability that network segments with stream order >3 are suitable for primary contact recreation.

3.6 Assessment of C band option

3.6.1 Compliance

The estimated probability that values of the four *E. coli* statistics are compliant with the C band was greater than 0.6 for 29%, 22%, 31% and 49% of segments for the Median, Q95, G260 and G540, respectively (Figure 13). The estimated probability that all statistics complied with the C band was greater than 0.6 for 7% of segments (Figure 14). The probability of compliance was greatest for segments in the headwater areas of the individual catchments, and particularly in the higher elevation parts of the region. The probability of compliance was lowest for segments in the low elevation parts of the region that have high proportions of catchment in pastoral land cover. This was consistent with the predicted pattern in the current values of all four *E. coli* statistics shown in Figure 7 and the *E. coli* yields shown in Figure 9.

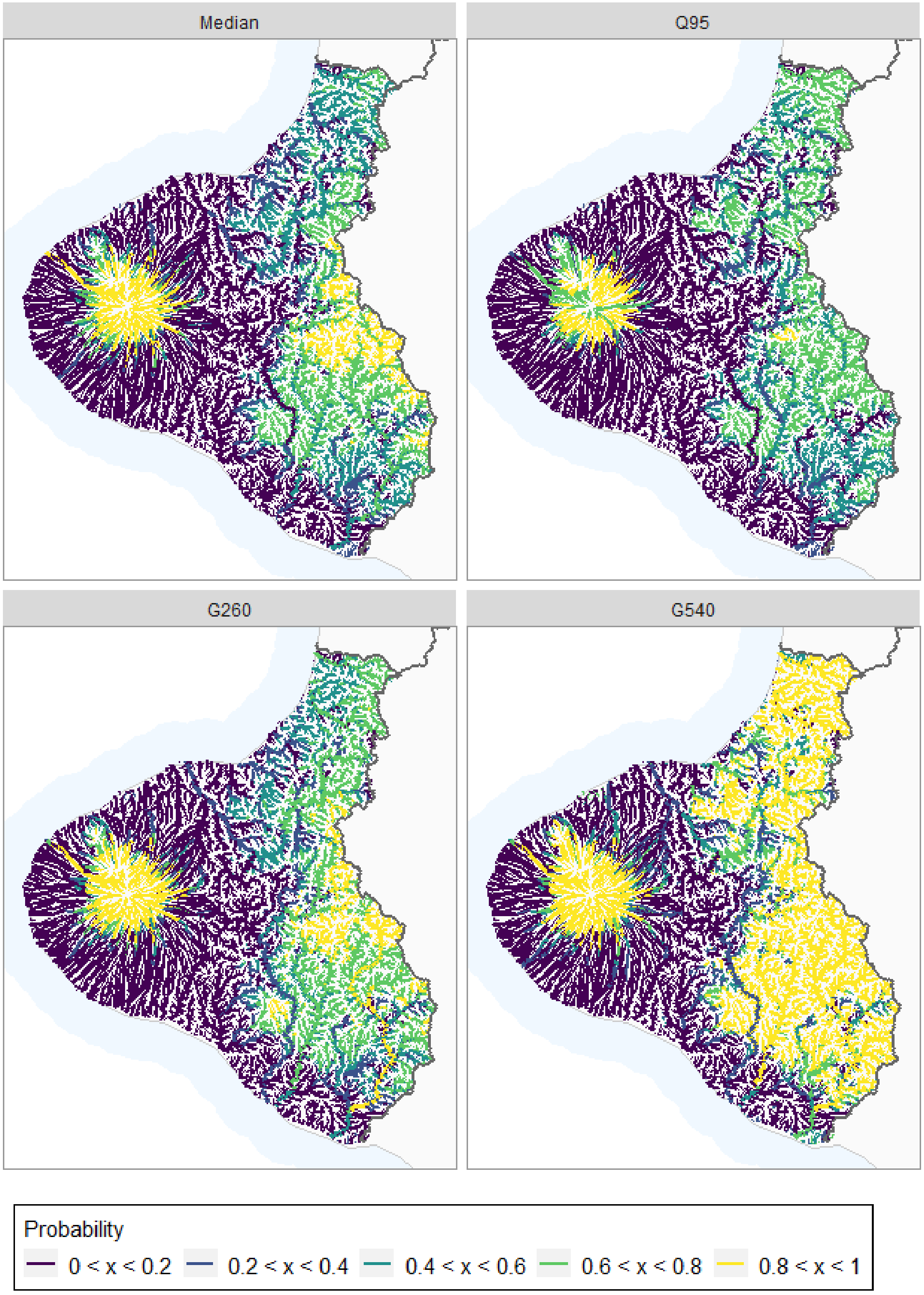


Figure 13. Probability of compliance with the criteria for each of the four E. coli statistics when the FWO is the C band. Each map represents the probability that segments achieve the criteria for the E. coli statistic that is associated with C band.

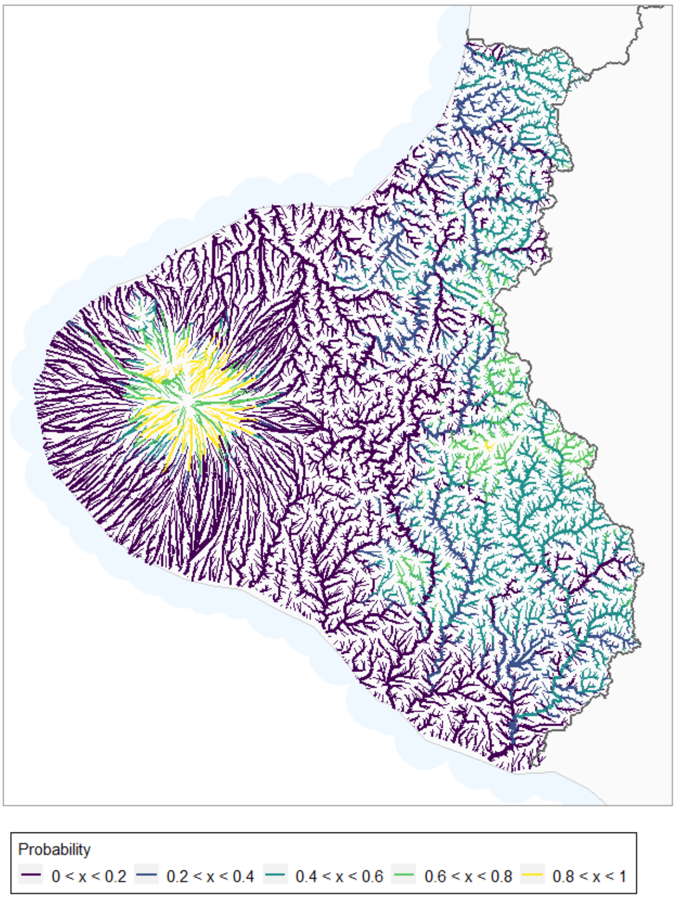


Figure 14. Probability of compliance when the FWO is the C band. This map represents the overall probability that segments achieve the C band.

3.6.2 Local excess loads

The local excess load is the amount by which the current *E. coli* load at a river segment would need to be reduced to achieve the objective for that receiving environment. For the C band, the best estimate of the local excess *E. coli* load local was zero for 2% of segments, exceeded 20 giga *E. coli* ha^{-1} yr^{-1} for 65% of river segments, and exceeded 100 giga *E. coli* ha^{-1} yr^{-1} for 44% of river segments (Figure 15). Note that the 20 and 100 giga *E. coli* ha^{-1} yr^{-1} are nominal breakpoints for communication purposes and correspond to the legend thresholds on Figure 15.

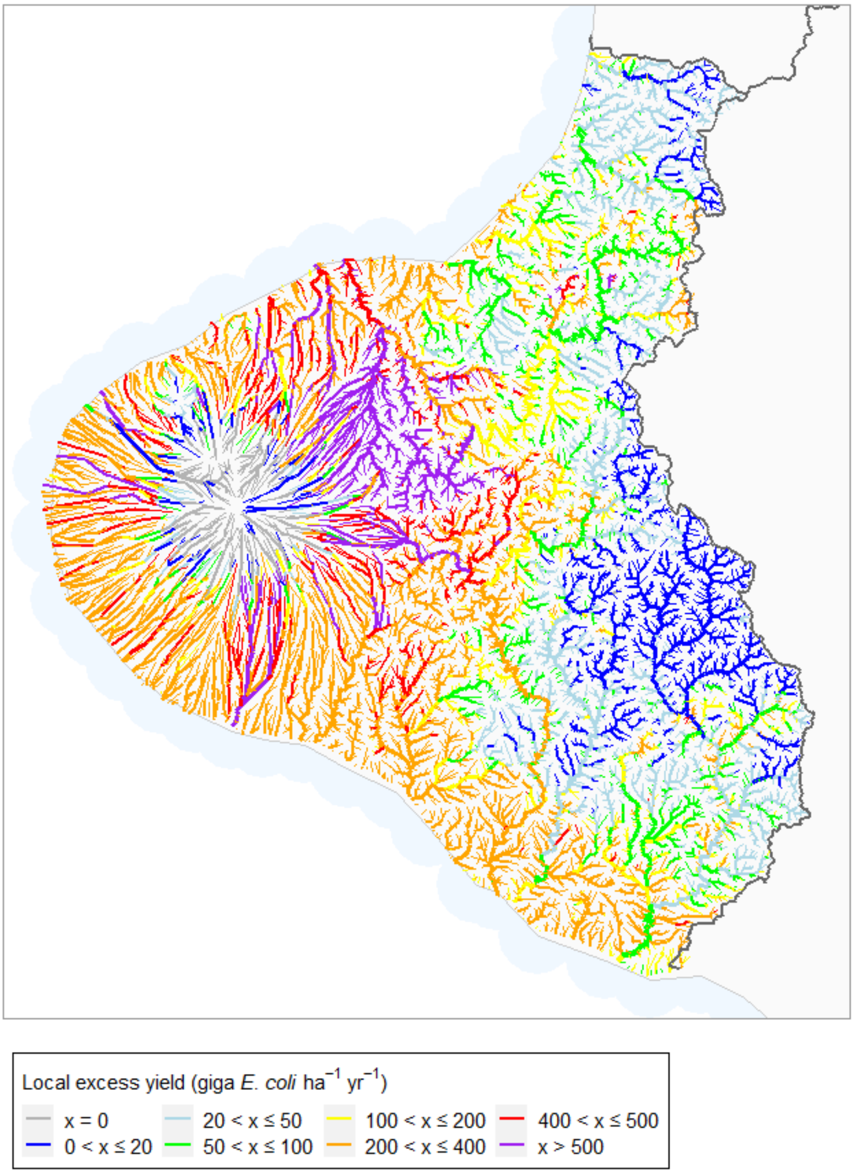


Figure 15. Local excess E. coli loads when the FWO is the C band. Note that the breakpoints for the local excess yield in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.6.3 Critical point catchment load reductions required

The load reduction required for critical point catchments is defined as the minimum load reduction that ensures the loads for all receiving environments in the critical catchment do not exceed the MAL (and therefore all FWOs in the catchment are achieved). The load reductions required therefore differ from the local excess loads in that they consider all river segments in a critical point catchment. The load reductions required for the C band FWO are expressed below as yields (i.e., *E. coli* ha^{-1} yr^{-1}), and as a percentage of the current load.

The load reductions required by the C band FWO for critical point catchments are shown on Figure 16 and Figure 17. Critical point catchment *E. coli* load reduction requirements of greater 100 giga *E. coli* ha^{-1} yr^{-1} occupied 85% of the study area (Figure 16). Critical point catchment *E. coli* load reduction requirements of greater than 200 giga *E. coli* ha^{-1} yr^{-1} occupied 69% of the study area (Figure 16). The comparison of load reductions expressed as yields (*E. coli* ha^{-1} yr^{-1}) with those expressed as proportion of current load (%) indicates that reduction requirements in catchments with low yield reductions (e.g., much of the Northern Hill Country and Southern Hill Country FMUs) are nevertheless appreciable (i.e., >20%) in relative terms. Critical point catchments with *E. coli* load reductions of greater than 30% occupied 87% of the study area and critical point catchments with *E. coli* load reductions of greater than 60% occupied 50% of the study area (Figure 17).

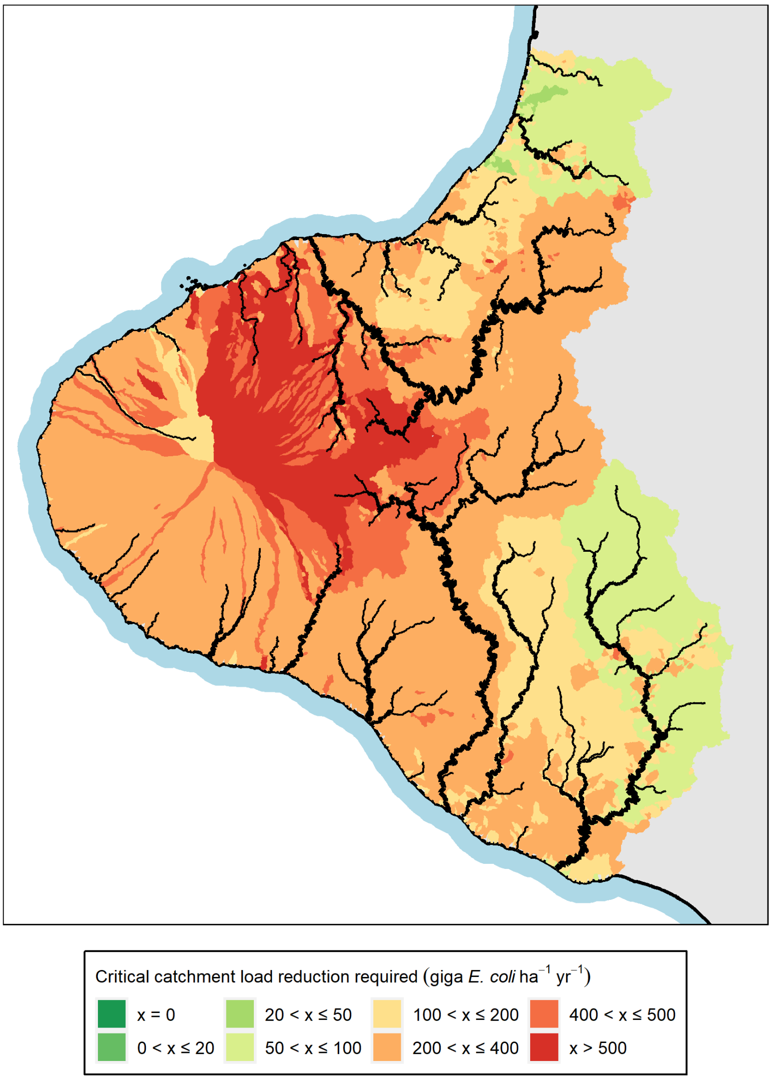


Figure 16. The E. coli load reduction required, expressed as yields, for critical point catchments when the FWO is the C band. The critical point catchment colours indicate the mean E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

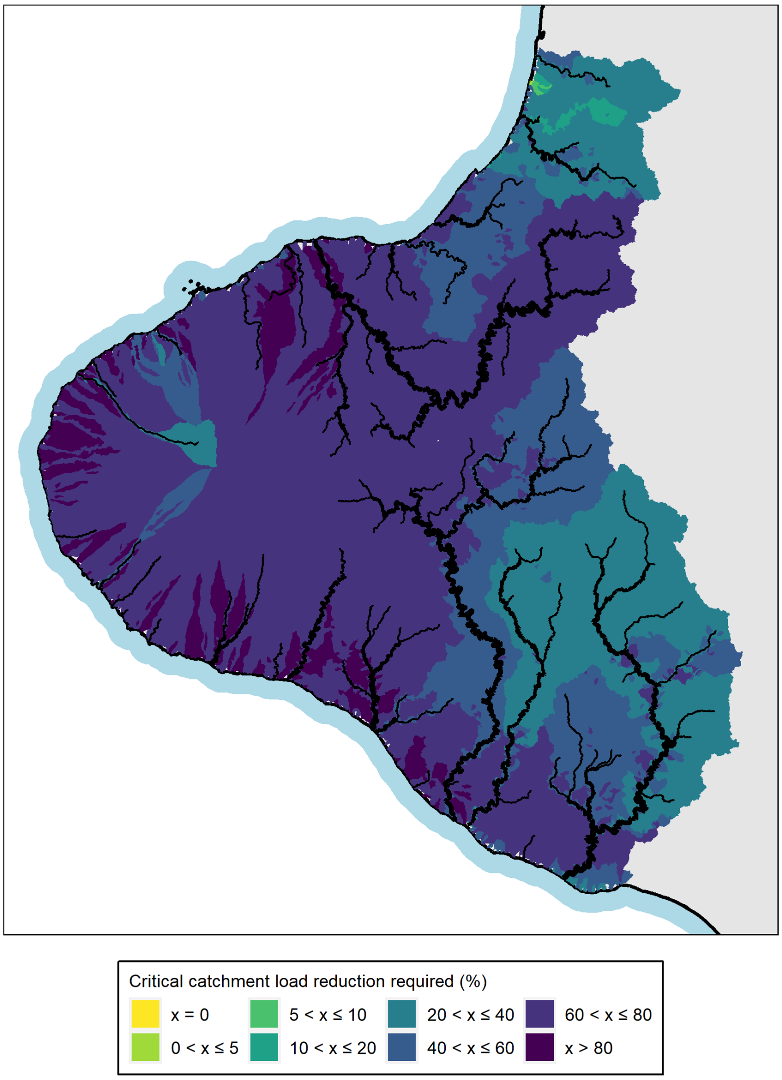


Figure 17. The E. coli load reduction required, expressed as proportion of the current load (%), for critical point catchments when the FWO is the C band. The critical point catchment colours indicate the E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

3.6.4 Proposed FMU and regional load reductions required

The load reduction required when the FWO is the C band for each proposed FMU and for whole region are shown in Table 10. For the Taranaki region, the best estimate of total *E. coli* load reductions required was 249 peta *E. coli* yr^{-1}, which represents 80% of the current load. The *E. coli* load reductions required were lowest, relative to current loads (<80%), in the Coastal Terraces FMU, Northern Hill Country and Southern Hill Country FMUs. The *E. coli* load reductions required were highest, relative to current loads (>80%) in the Volcanic Ringplain FMU.

Table 10. Current load and load reduction required for E. coli by proposed FMU and for the Taranaki region when the FWO is the C band. Note that loads are expressed in absolute terms in units of E. coli organisms per year (peta E. coli yr^{-1}) and as a proportion of current load (%). The first value in each column is the best estimate, which is the mean value over the 100 Monte Carlo realisations. The values in parentheses are the lower and upper bounds of the 90% confidence interval.

FMU	**Total load (peta *E. coli* yr^{-1})**	**Load reduction required (peta *E. coli* yr^{-1})**	**Load reduction required (%)**
Coastal Terraces	12 (7 - 19)	9 (5 - 15)	75 (68 - 82)
Northern Hill Country	19 (9 - 35)	13 (5 - 25)	67 (50 - 83)
Patea	57 (10 - 192)	48 (8 - 168)	80 (58 - 97)
Southern Hill Country	77 (21 - 167)	60 (15 - 139)	76 (62 - 88)
Volcanic Ringplain	103 (71 - 143)	84 (55 - 117)	81 (76 - 86)
Waitara	87 (10 - 283)	74 (7 - 269)	80 (61 - 98)
Total	308 (190 - 645)	249 (144 - 561)	80 (72 - 88)

3.7 Assessment of B band option

3.7.1 Compliance

The estimated probability that values of the four *E. coli* statistics are compliant with the B band was greater than 0.6 for 36%, 19%, 27% and 28% of segments for the Median, Q95, G260 and G540, respectively (Figure 18). The estimated probability that all statistics complied with the B band was greater than 0.6 for 3% of segments (Figure 19).

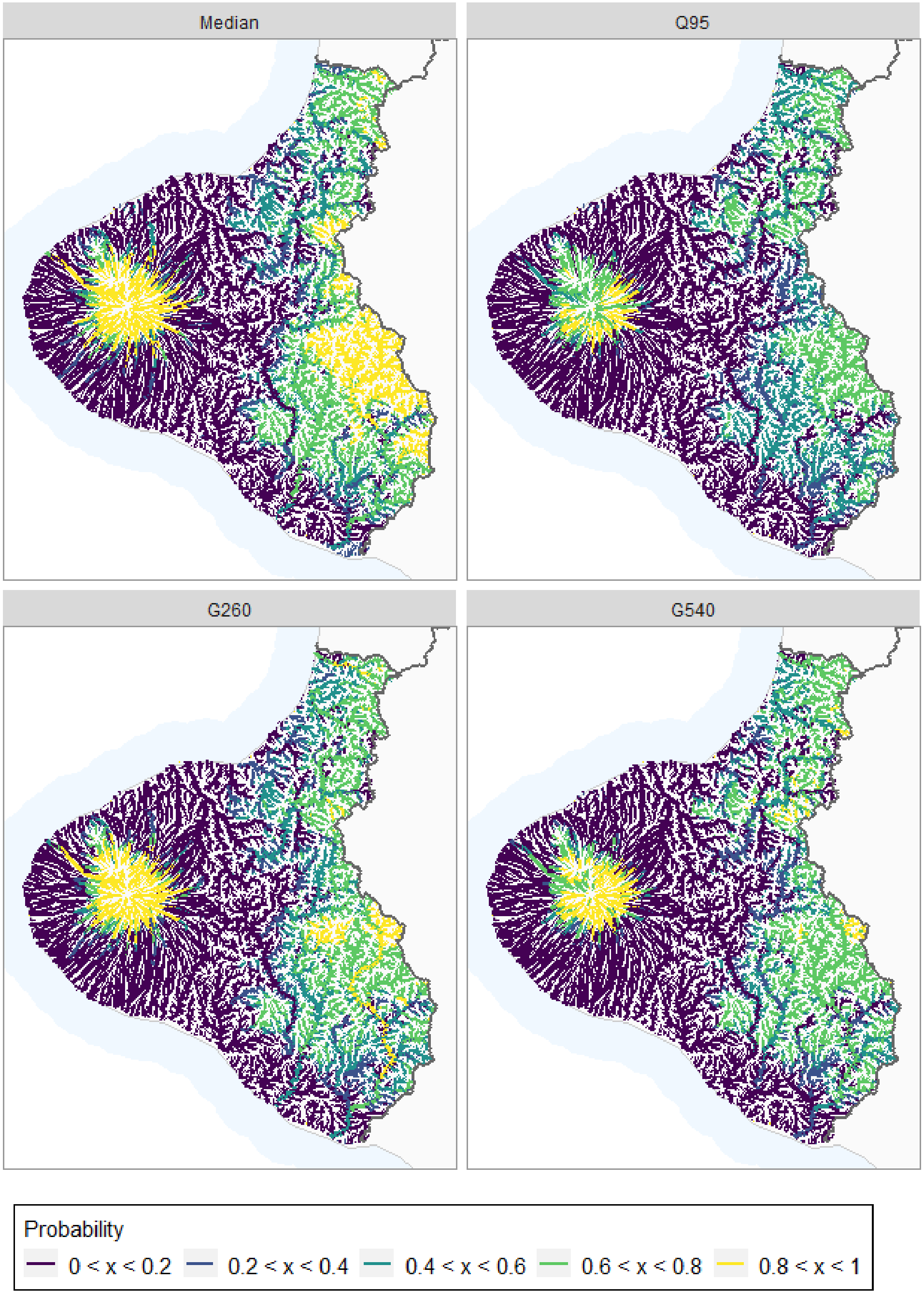


Figure 18. Probability of compliance with the criteria for each of the four E. coli statistics when the FWO is the B band. Each map represents the probability that segments achieve the criteria for the E. coli statistic that is associated with B band.

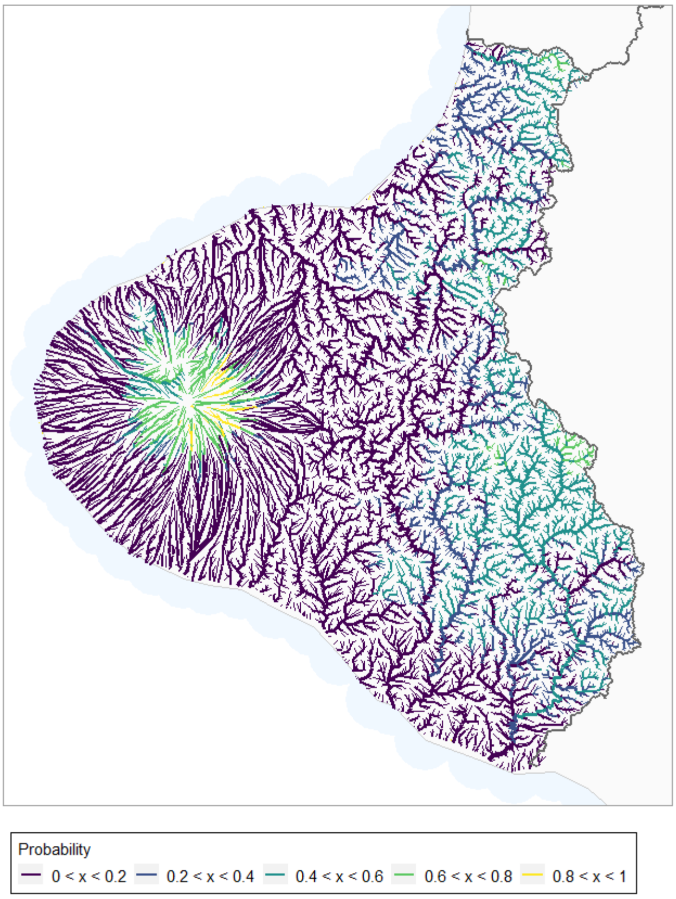


Figure 19. Probability of compliance when the FWO is the B band. This map represents the overall probability that segments achieve the B band.

3.7.2 Local excess loads

The local excess load is the amount by which the current *E. coli* load at a river segment would need to be reduced to achieve the objective for that receiving environment. For the B band, the best estimate of the local excess *E. coli* load local was zero for 1.1% of segments and exceeded 20 giga *E. coli* ha^{-1} yr^{-1} for 67% of river segments and exceeded 100 giga *E. coli* ha^{-1} yr^{-1} for 44% of river segments (Figure 20).

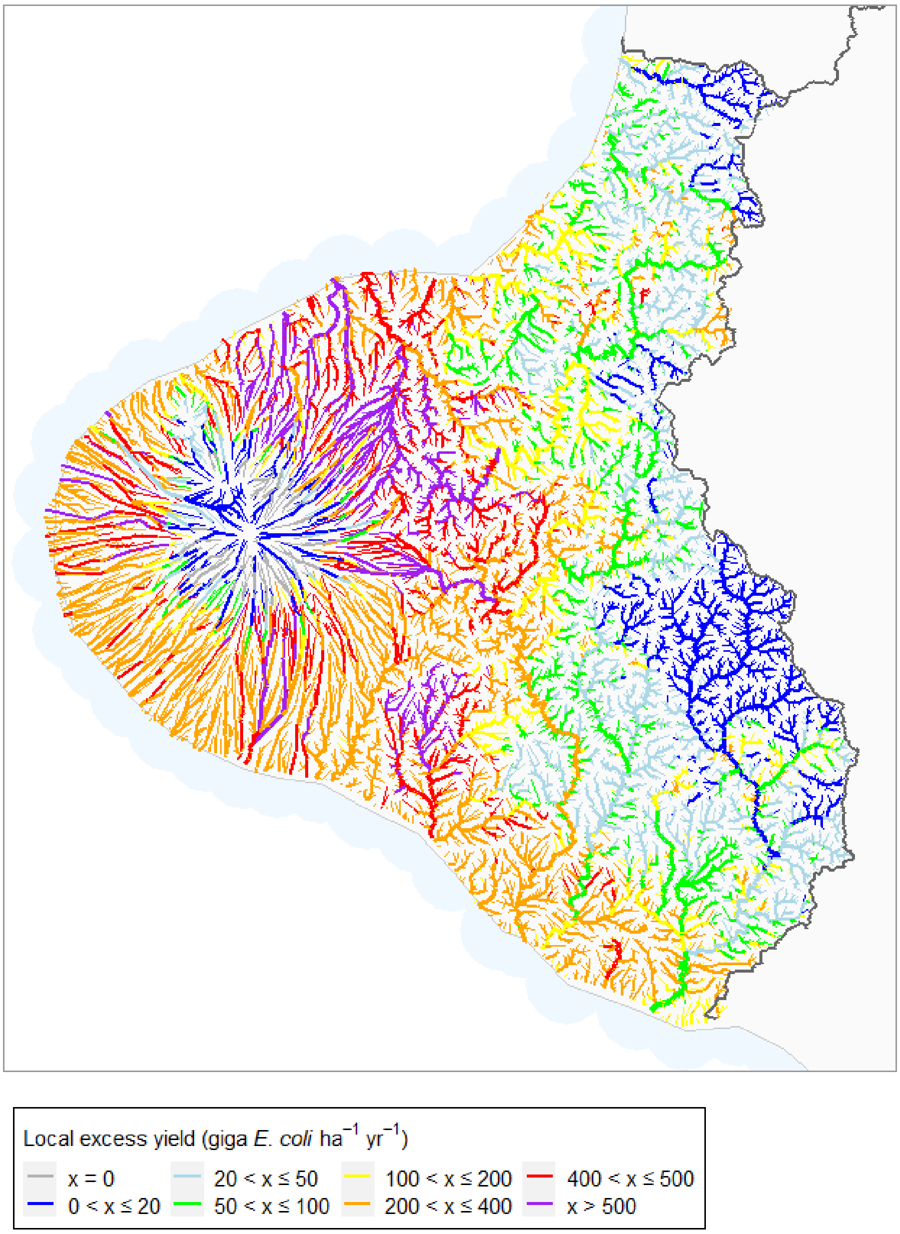


Figure 20. Local excess E. coli loads when the FWO is the B band. Note that the breakpoints for the local excess yield in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.7.3 Critical point catchment load reductions required

The load reductions required by the B band FWO for critical point catchments are shown on Figure 21 and Figure 22. Critical point catchment *E. coli* load reduction requirements of greater 100 giga *E. coli* ha^{-1} yr^{-1} occupied 85% of the study area (Figure 21). Critical point catchment *E. coli* load reduction requirements of greater than 200 giga *E. coli* ha^{-1} yr^{-1} occupied 71% of the study area (Figure 21). The comparison of load reductions expressed as yields (*E. coli* ha^{-1} yr^{-1}) with those expressed as proportion of current load (%) indicates that reduction requirements in catchments with low yield reductions (e.g., much of the Northern Hill Country and Southern Hill Country FMUs) are nevertheless appreciable (i.e., >20%) in relative terms. Critical point catchments with *E. coli* load reductions of greater than 30% occupied 95% of the study area and critical point catchments with *E. coli* load reductions of greater than 60% occupied 71% of the study area (Figure 22).

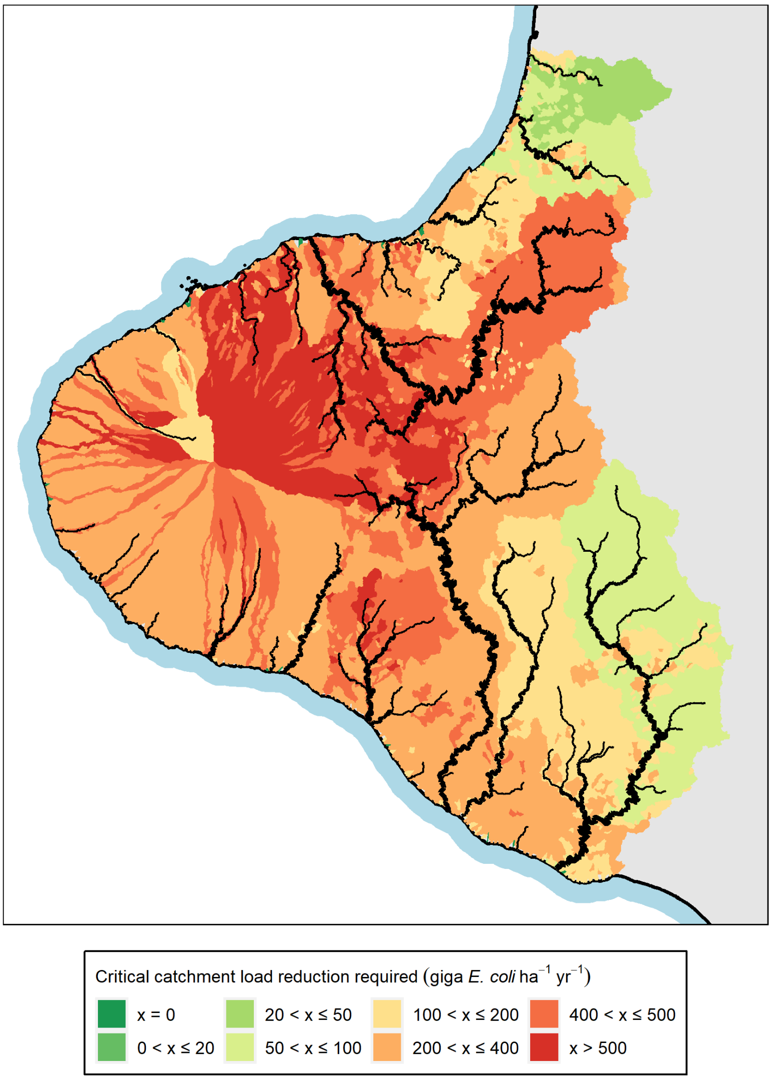


Figure 21. The E. coli load reduction required, expressed as yields, for critical point catchments when the FWO is the B band. The critical point catchment colours indicate the mean E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

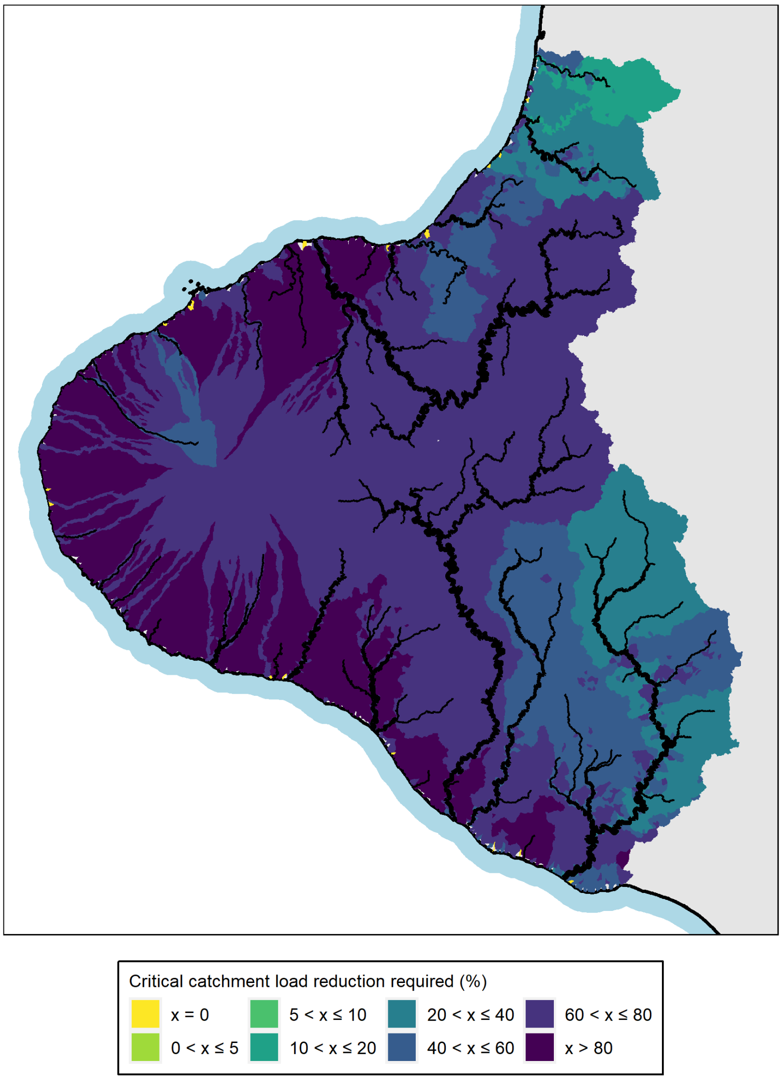


Figure 22. The E. coli load reduction required, expressed as proportion of the current load (%), for critical point catchments when the FWO is the B band. The critical point catchment colours indicate the E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

3.7.4 Proposed FMU and regional load reductions required

The load reduction required when the FWO is the B band for each FMU and for whole region are shown in Table 11. For the Taranaki region as a whole, the best estimate of total *E. coli* load reduction required was 262 peta *E. coli* yr^{-1}, which represents 84% of the current load. The *E. coli* load reductions required were highest, relative to current loads (>80%), in the all FMUs except the Northern Hill Country FMU.

Table 11. Current load and load reduction required for E. coli by proposed FMU and for the Taranaki region when the FWO is the B band. Note that loads are expressed in absolute terms in units of E. coli organisms per year (peta E. coli yr^{-1}) and as a proportion of current load (%). The first value in each column is the best estimate, which is the mean value over the 100 Monte Carlo realisations. The values in parentheses are the lower and upper bounds of the 90% confidence interval.

FMU	Total load (peta *E. coli* yr^{-1})	Load reduction required (peta *E. coli* yr^{-1})	Load reduction required (%)
Coastal Terraces	13 (7 - 26)	10 (6 - 21)	80 (71 - 87)
Northern Hill Country	18 (9 - 35)	13 (6 - 27)	72 (60 - 83)
Patea	52 (7 - 174)	45 (5 - 157)	84 (68 - 98)
Southern Hill Country	69 (25 - 135)	57 (20 - 116)	82 (73 - 89)
Volcanic Ringplain	102 (71 - 138)	86 (57 - 119)	85 (80 - 87)
Waitara	76 (12 - 201)	65 (9 - 174)	82 (67 - 94)
Total	299 (204 - 529)	253 (163 - 470)	83 (78 - 89)

3.8 Assessment of A band option

3.8.1 Compliance

The estimated probability that values of the four *E. coli* statistics are compliant with the A band was greater than 0.6 for 32%, 0%, 4% and 0% of segments for the Median, Q95, G260 and G540, respectively (Figure 23). The estimated probability that all statistics complied with the A band was greater than 0.6 for 0% of segments (Figure 24).

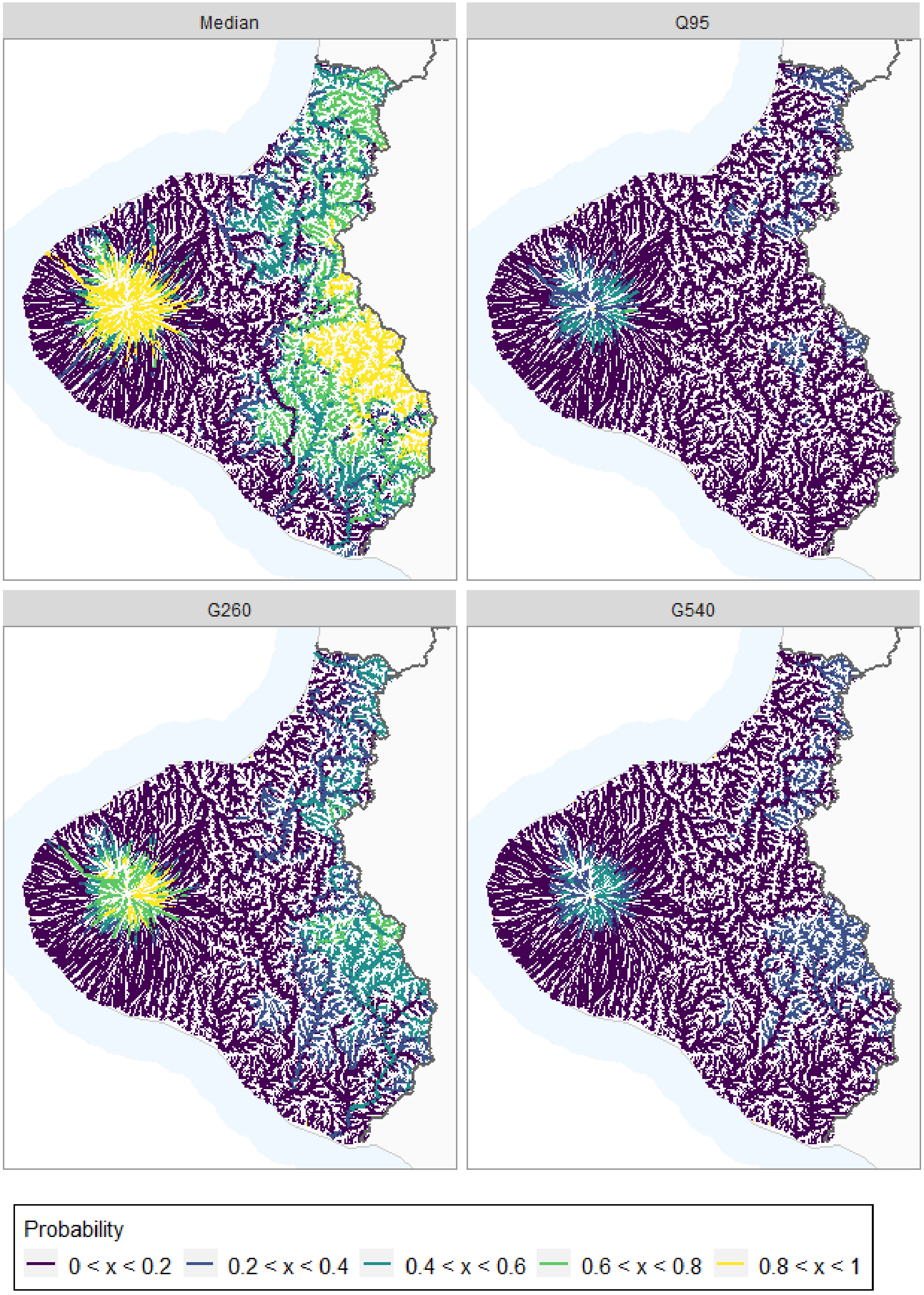


Figure 23. Probability of compliance with the criteria for each of the four E. coli statistics when the FWO is the A band. Each map represents the probability that segments achieve the criteria for the E. coli statistic that is associated with A band.

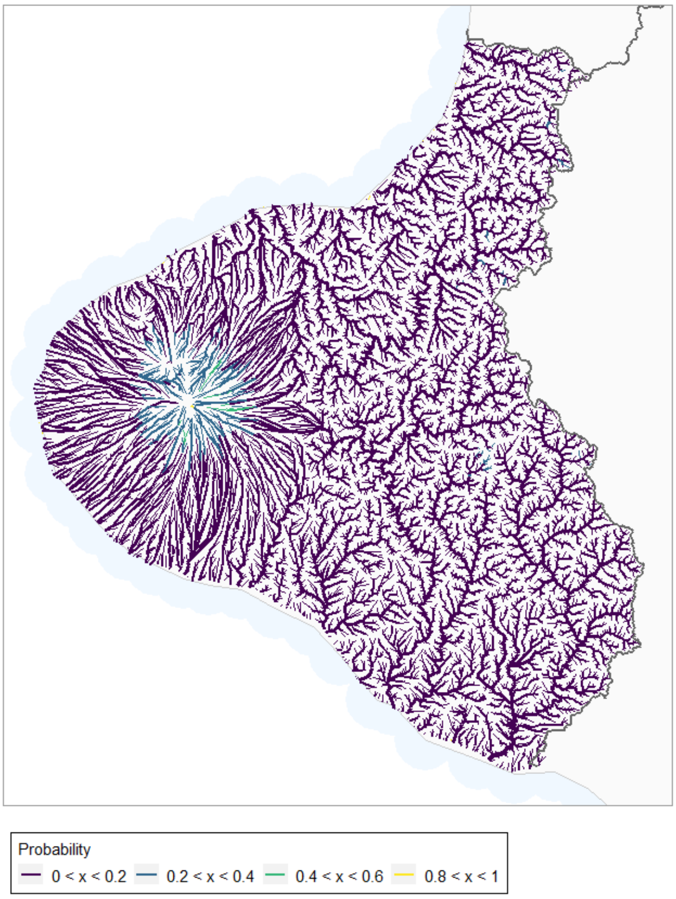


Figure 24. Probability of compliance when the FWO is the A band. This map represents the overall probability that segments achieve the A band.

3.8.2 Local excess loads

For the A band, no segments had a best estimate of the local excess *E. coli* load local of zero (Figure 25). The load reductions exceeded 20 giga *E. coli* ha^{-1} yr^{-1} for 95% of river segments and exceeded 100 giga *E. coli* ha^{-1} yr^{-1} for 48% of river segments (Figure 25).

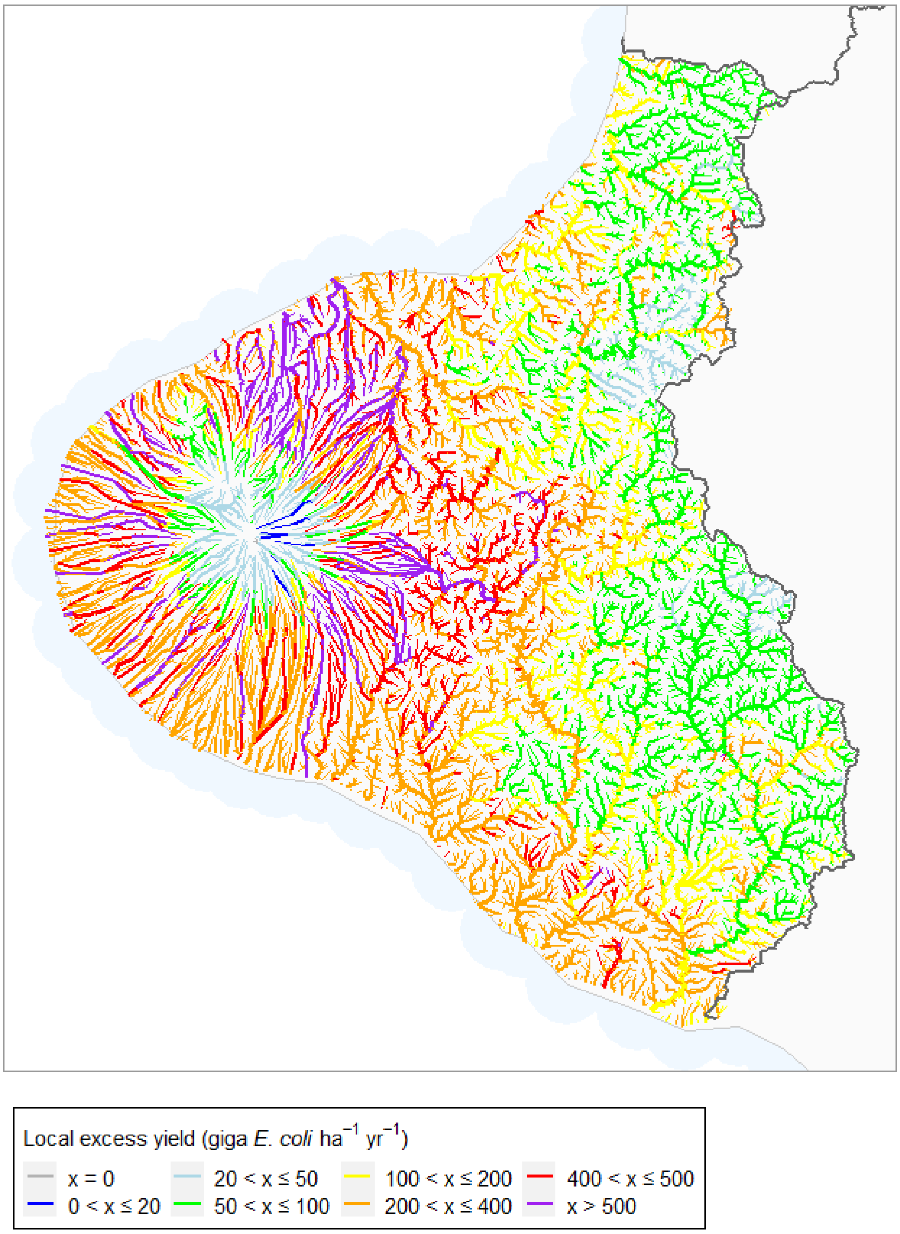


Figure 25. Local excess E. coli loads when the FWO is the A band. Note that the breakpoints for the local excess yield in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.8.3 Critical point catchment load reductions required

The load reductions required by the A band FWO for critical point catchments are shown on Figure 26 and Figure 27. Critical point catchment *E. coli* load reduction requirements of greater 100 giga *E. coli* ha^{-1} yr^{-1} occupied 98% of the study area (Figure 21). Critical point catchment *E. coli* load reduction requirements of greater than 200 giga *E. coli* ha^{-1} yr^{-1} occupied 84% of the study area (Figure 27). Critical point catchments with *E. coli* load reductions of greater than 30% occupied 100% of the study area and critical point catchments with *E. coli* load reductions of greater than 60% occupied 95% of the study area (Figure 27).

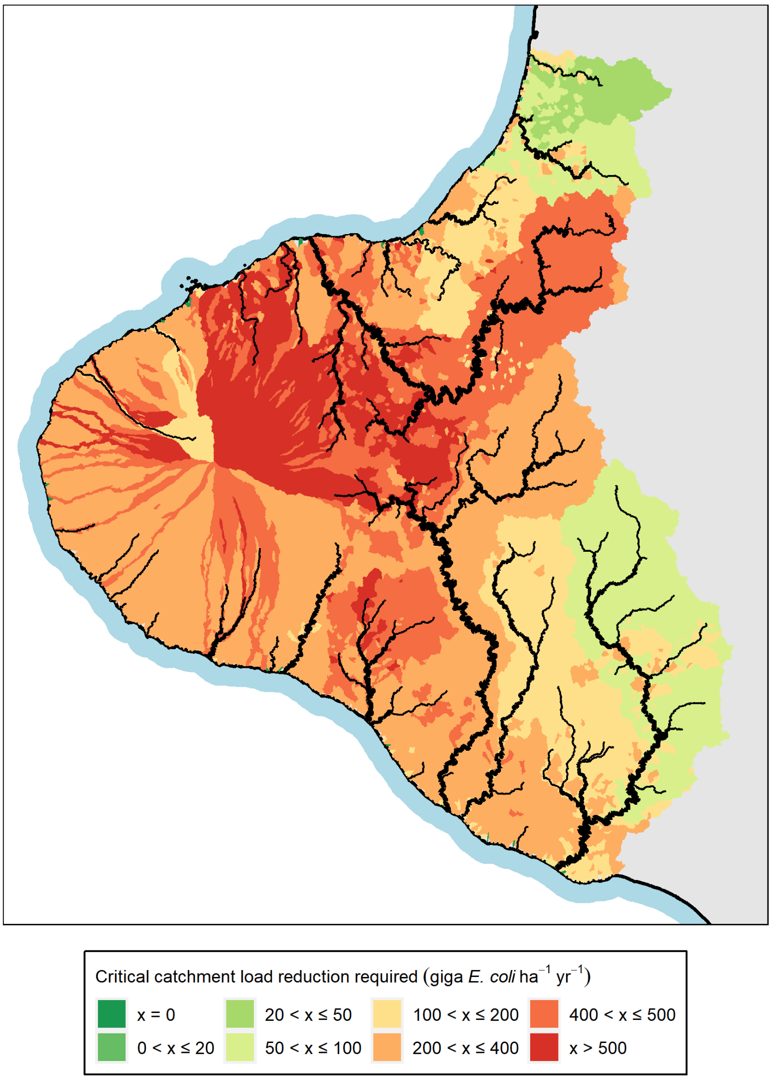


Figure 26. The E. coli load reduction required, expressed as yields, for critical point catchments when the FWO is the A band. The critical point catchment colours indicate the mean E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

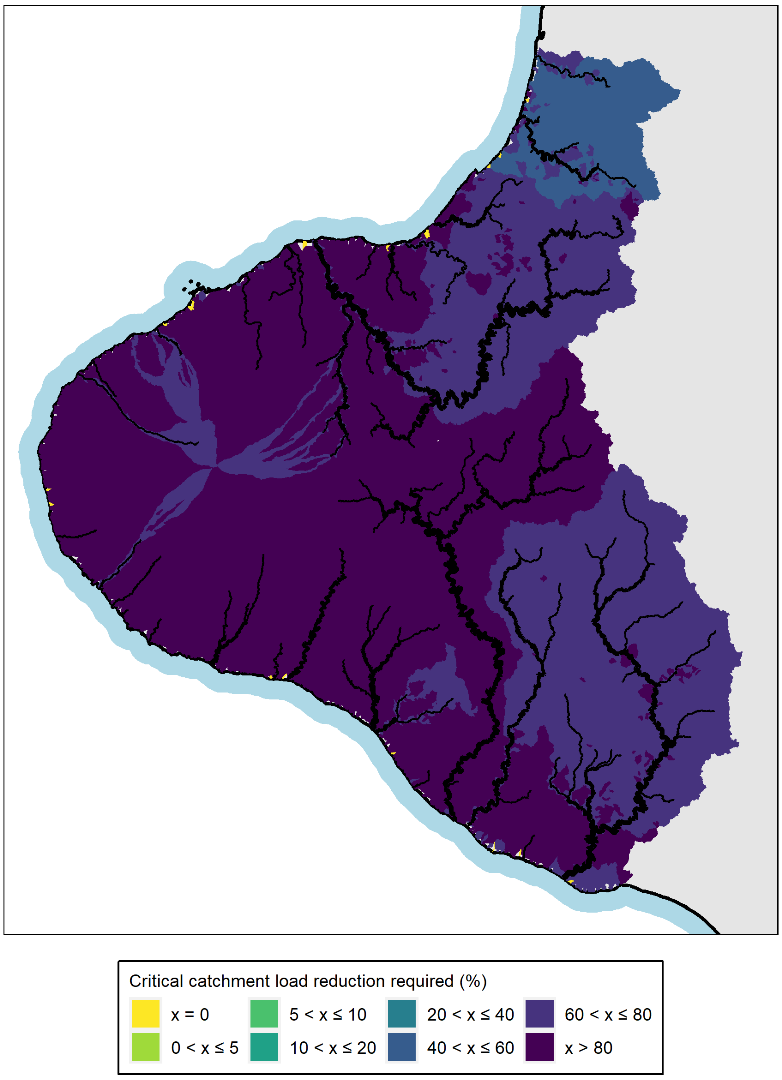


Figure 27. The E. coli load reduction required, expressed as proportion of the current load (%), for critical point catchments when the FWO is the A band. The critical point catchment colours indicate the E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

3.8.4 Proposed FMU and regional load reductions required

The load reduction required when the FWO is the A band for each proposed FMU and for whole region are shown in Table 12. For the Taranaki region as a whole, the best estimate of total *E. coli* load reduction required was 270 peta *E. coli* yr^{-1}, which represents 90% of the current load. The *E. coli* load reductions required were highest, relative to current loads (≥90%), in the Patea FMU and Volcanic Ringplain FMU. The *E. coli* load reductions required were lowest, relative to current loads (83%) in the Northern Hill Country FMU.

Table 12. Current load and load reduction required for E. coli by proposed FMU and for the Taranaki region when the FWO is the A band. Note that loads are expressed in absolute terms in units of E. coli organisms per year (peta E. coli yr^{-1}) and as a proportion of current load (%). The first value in each column is the best estimate, which is the mean value over the 100 Monte Carlo realisations. The values in parentheses are the lower and upper bounds of the 90% confidence interval.

FMU	Total load (peta *E. coli* yr^{-1})	Load reduction required (peta *E. coli* yr^{-1})	Load reduction required (%)
Coastal Terraces	12 (7 - 21)	10 (6 - 19)	88 (84 - 91)
Northern Hill Country	18 (9 - 35)	15 (7 - 29)	83 (76 - 89)
Patea	48 (7 - 123)	44 (7 - 110)	91 (77 - 98)
Southern Hill Country	68 (25 - 147)	61 (21 - 134)	89 (83 - 93)
Volcanic Ringplain	105 (73 - 152)	95 (64 - 138)	91 (88 - 93)
Waitara	54 (11 - 145)	48 (9 - 128)	89 (80 - 95)
Total	300 (189 - 437)	270 (169 - 412)	90 (87 - 92)

3.9 Assessment of spatially variable option

3.9.1 Compliance

The estimated probability that values of the four *E. coli* statistics are compliant with the spatially variable FWOs was greater than 0.6 for 29%, 26%, 30% and 46% of segments for the Median, Q95, G260 and G540, respectively (Figure 28). The estimated probability that all statistics complied with the spatially variable FWOs was greater than 0.6 for 7% of segments (Figure 29).

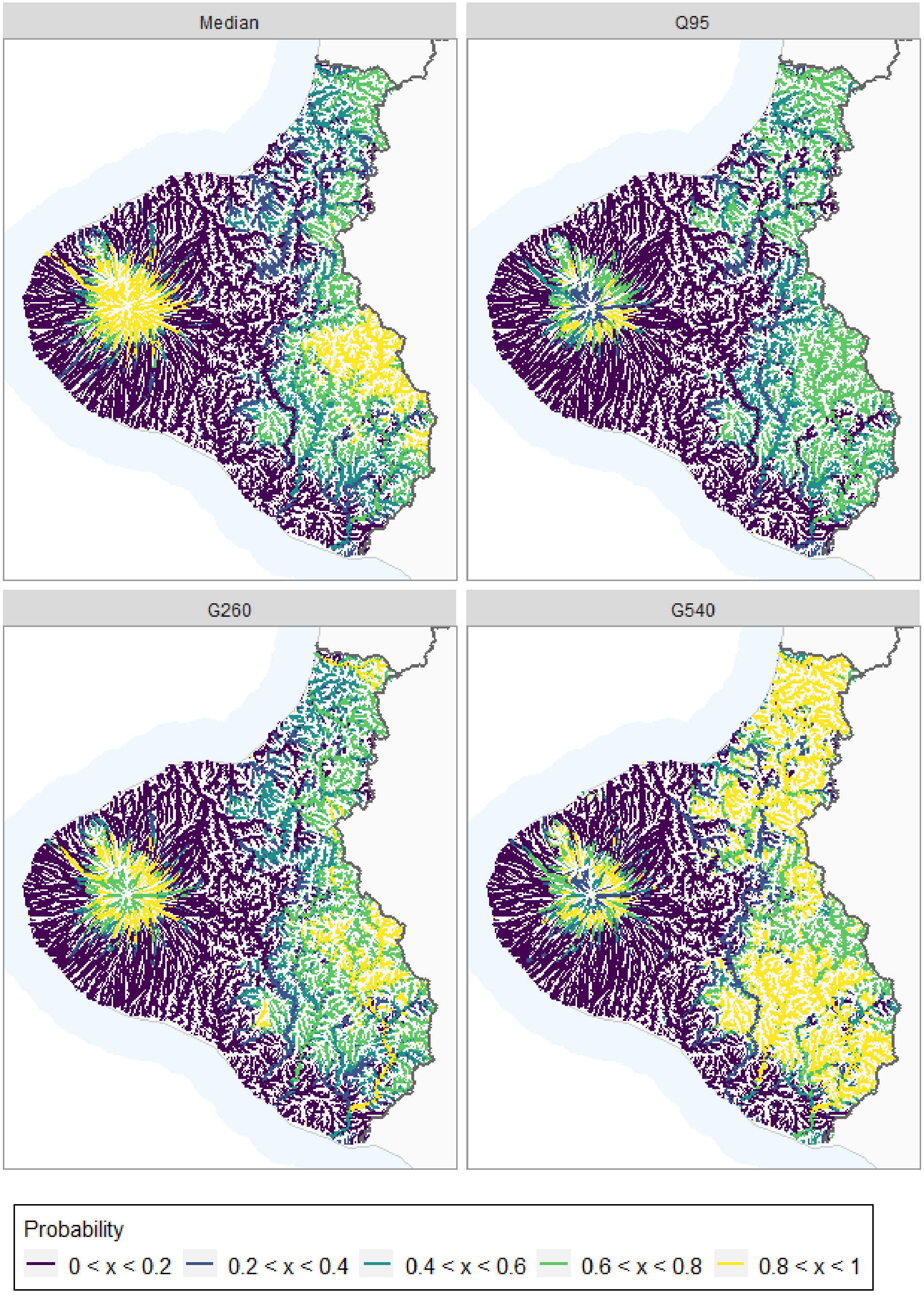


Figure 28. Probability of compliance with the criteria for each of the four E. coli statistics when the FWOs are spatially variable. Each map represents the probability that segments achieve the criteria for the E. coli statistic that is associated with the spatially variable FWOs.

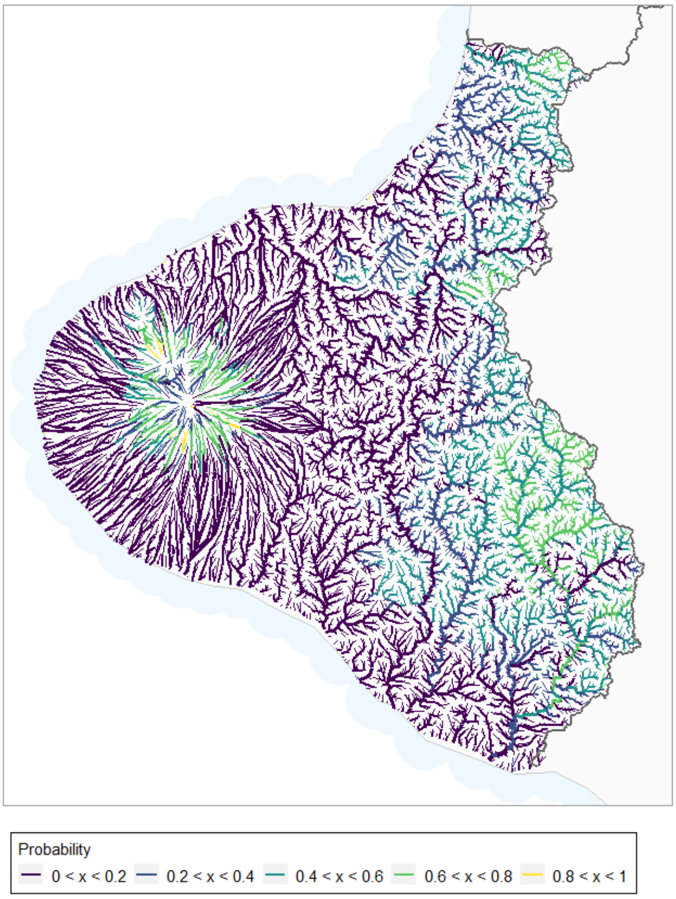


Figure 29. Probability of compliance with the spatially variable FWOs. This map represents the overall probability that segments achieve the spatially variable FWOs.

3.9.2 Local excess loads

For the spatially variable FWOs, the best estimate of the local excess *E. coli* load local was zero for 0% of segments, exceeded 20 giga *E. coli* ha^{-1} yr^{-1} for 64% of river segments and exceeded 100 giga *E. coli* ha^{-1} yr^{-1} for 41% of river segments (Figure 30).

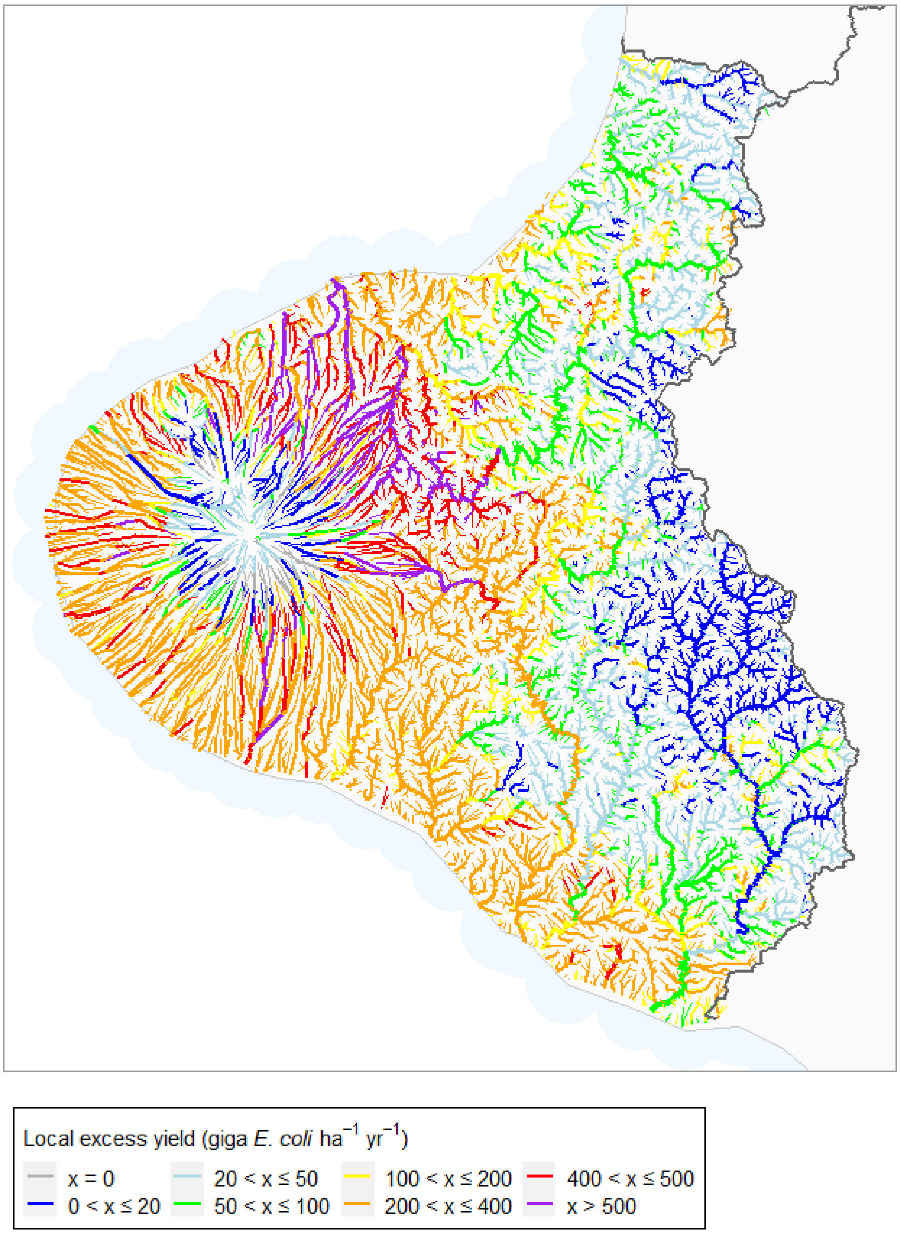


Figure 30. Local excess E. coli loads when the FWO are spatially variable. Note that the breakpoints for the local excess yield in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.9.3 Critical point catchment load reductions required

The load reductions required for the spatially variable FWOs are expressed below as yields (i.e., *E. coli* ha^{-1} yr^{-1}) and as a percentage of the current load. The load reductions required by the spatially variable FWOs for critical point catchments are shown on Figure 31 and Figure 32. Critical point catchment *E. coli* load reduction requirements of greater 100 giga *E. coli* ha^{-}

[1] yr^{-1} occupied 85% of the study area (Figure 31). Critical point catchment *E. coli* load reduction requirements of greater 200 giga *E. coli* ha^{-1} yr^{-1} occupied 69% of the study area (Figure 31). Critical point catchments with *E. coli* load reductions of greater than 30% occupied 87% of the study area and critical point catchments with *E. coli* load reductions of greater than 60% occupied 57% of the study area (Figure 32).

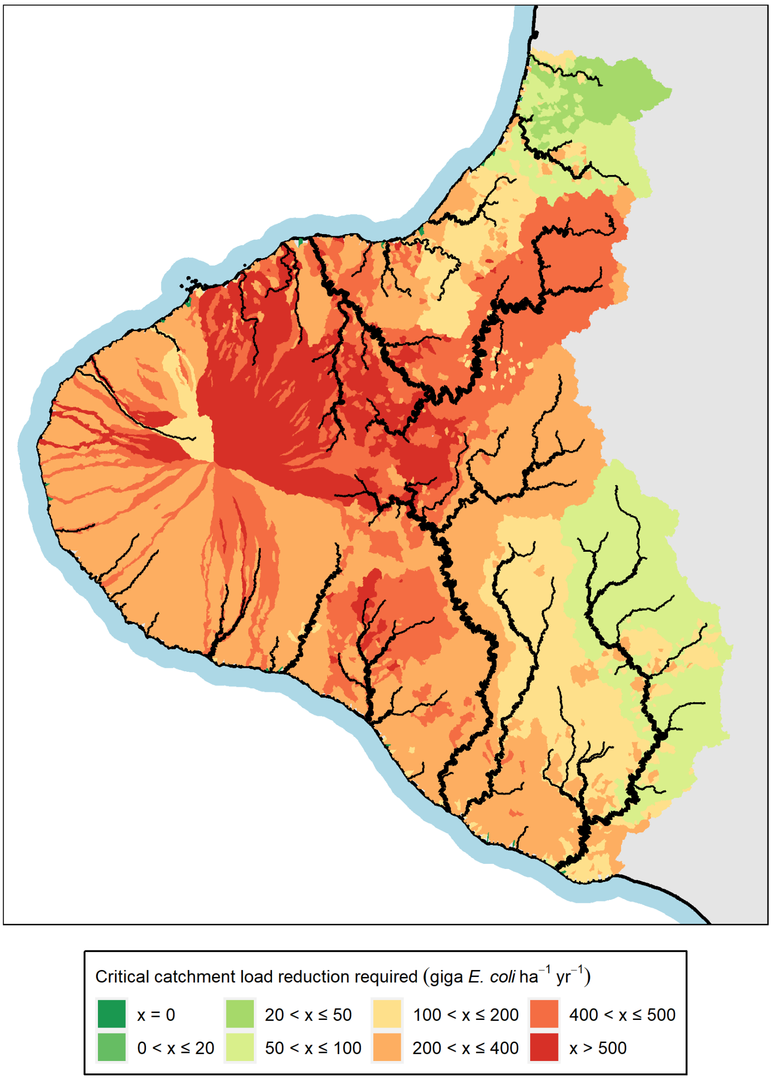


Figure 31. The E. coli load reduction required, expressed as yields, for critical point catchments when the FWOs are spatially variable. The critical point catchment colours indicate the mean E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

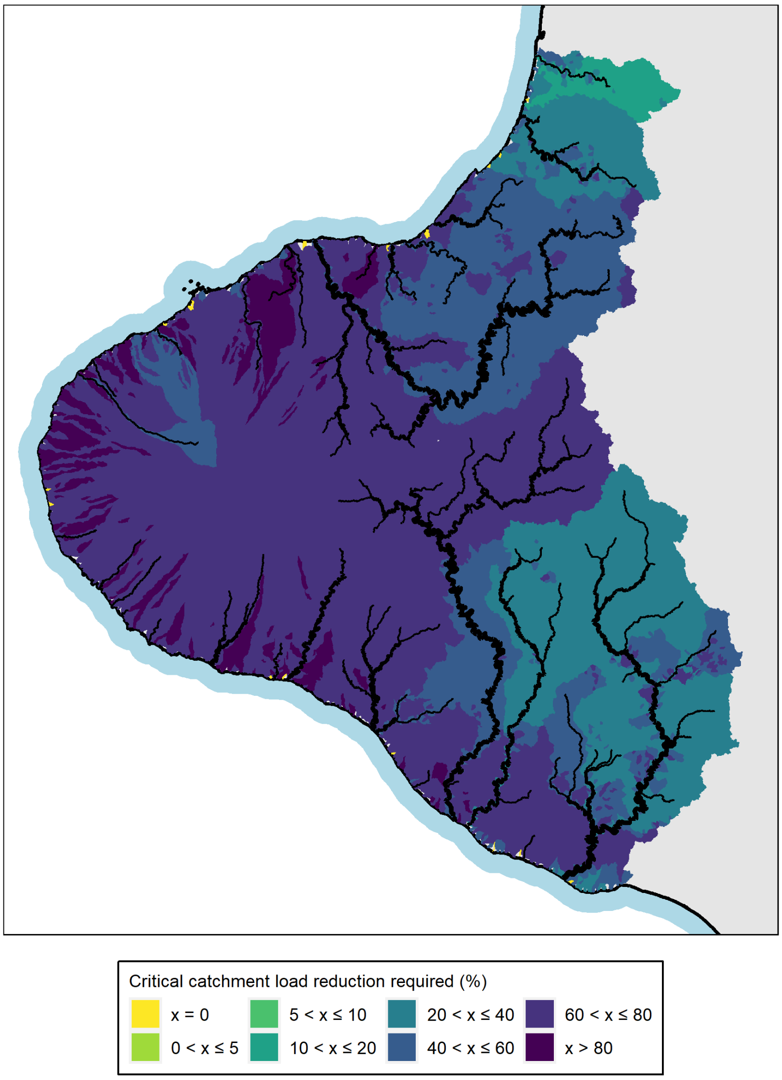


Figure 32. The E. coli load reduction required, expressed as proportion of the current load (%), for critical point catchments when the FWOs are spatially variable. The critical point catchment colours indicate the E. coli load reductions required to allow all FWOs be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

3.9.4 Proposed FMU and regional load reductions required

The load reduction required when the FWOs are spatially variable for each proposed FMU and for whole region are shown in Table 13. For the Taranaki region as a whole, the best estimate of total *E. coli* load reductions required was 238 peta *E. coli* yr^{-1}, which represents 81% of the current load. The *E. coli* load reductions required were highest, relative to current loads (>80%), in the Volcanic Ringplain and Waitara FMUs. The *E. coli* load reductions required were lowest, relative to current loads (<70%) in the Northern Hill Country FMU.

Table 13. Current load and load reduction required for E. coli by proposed FMU and for the Taranaki region when the FWOs are spatially variable. Note that loads are expressed in absolute terms in units of E. coli organisms per year (peta E. coli yr^{-1}) and as a proportion of current load (%). The first value in each column is the best estimate, which is the mean value over the 100 Monte Carlo realisations. The values in parentheses are the lower and upper bounds of the 90% confidence interval.

FMU	**Total load (peta *E. coli* yr^{-1})**	**Load reduction required (peta *E. coli* yr^{-1})**	**Load reduction required (%)**
Coastal Terraces	12 (7 - 20)	9 (5 - 17)	76 (67 - 84)
Northern Hill Country	18 (8 - 40)	12 (5 - 28)	65 (48 - 82)
Patea	49 (8 - 120)	41 (7 - 117)	80 (56 - 97)
Southern Hill Country	65 (26 - 139)	51 (18 - 116)	77 (65 - 88)
Volcanic Ringplain	101 (68 - 143)	83 (54 - 122)	82 (77 - 86)
Waitara	74 (8 - 268)	63 (6 - 202)	83 (69 - 96)
Total	292 (196 - 531)	238 (155 - 421)	81 (75 - 87)

3.10 Comparison between FWO settings

A comparison of the *E. coli* load reductions required by the four sets of FWOs for the proposed FMUs and the whole region is shown in Figure 33. The best estimate for the load reductions is always less for the C band settings compared to the B band and for the B band compared to the A band. However, the 90% confidence intervals for the four sets of FWOs are generally overlapping. This indicates that the study is generally unable to discriminate appreciable differences in the amount of effort (i.e., the reduction in *E. coli* loads required) to achieve all four sets of FWOs. This is because the models have considerable uncertainty and the concentrations and corresponding loads that separate the four sets of FWOs are similar, relative to this uncertainty.

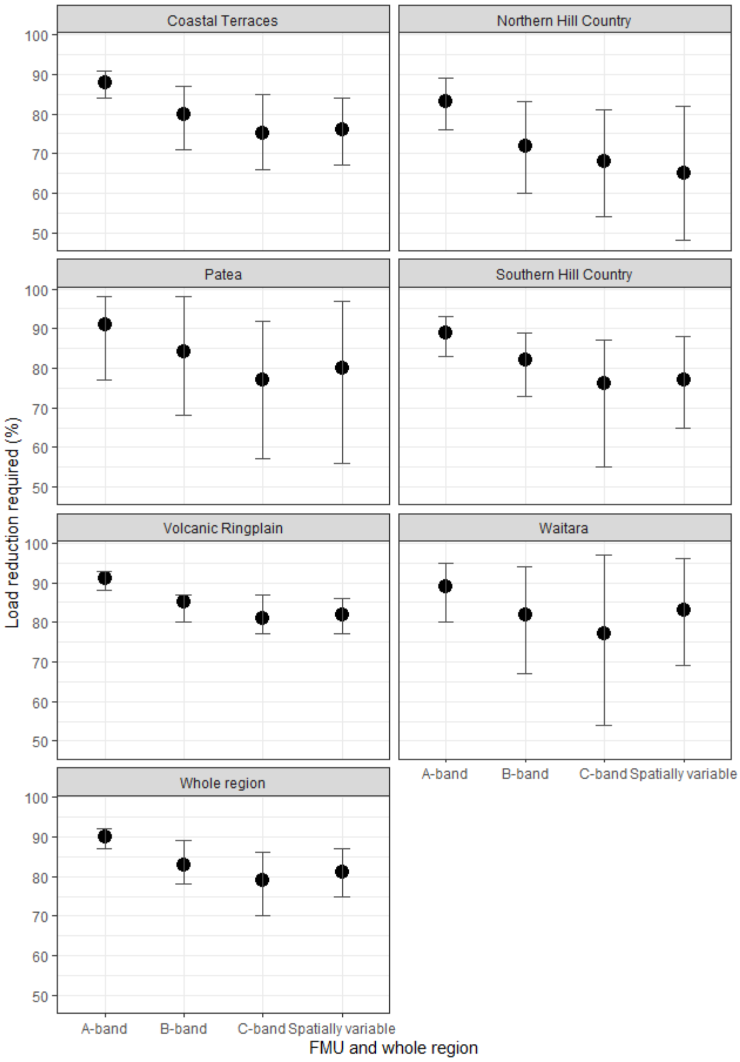


Figure 33. Comparison of the load reductions required for individual proposed FMUs and the whole region for the four sets of FWOs. The load reductions are shown as proportion of current load (%). The point represents is the best estimate, which is the mean value over the 100 Monte Carlo realisations. The error bars indicate the lower and upper bounds of the 90% confidence interval.

4 Discussion and conclusions

4.1 Load reductions required

This report has predicted *E. coli* load reductions needed to achieve options for freshwater objectives (FWO) for human health in rivers in the Taranaki region. The options for FWOs are defined in terms of NOF attribute bands for all river receiving environments (represented by network segments) in the region. Four sets of FWO options were nominated and are referred to as the A, B and C band options and the spatially variable option. The A, B and C band options represent uniform adoption of the A, B or C *E. coli* attribute state as defined by the NPS-FM. The spatially variable option proposes differing NOF *E. coli* attribute states by a nominal classification of Taranaki's rivers into Mountain, Hill, Lowland, management classes that were derived based on the REC.

For the whole study area and the C band option, which is the minimum state deemed suitable for primary contact in the national targets laid out in Appendix 3 of the NPSFM, the best estimate of the *E. coli* load reductions required at the regional level was 249 peta *E. coli* yr^{-1}, which represents a best estimate of 80% of the current loads. For the whole study area and the A band option, the *E. coli* load reductions required at the regional level was estimated to be 270 peta *E. coli* yr^{-1}, which represents 90% of the current loads. The difference in the percentage load reduction for both the whole study area and the FMUs were always consistent with expectations, that is, reductions were always less for the C band option than the A band option (Figure 33). The large load reduction for the A band option reflects the stringency of the FWOs. However, the 90% confidence intervals for all sets of load reduction estimates were strongly overlapping. This indicates that, from a practical perspective, the reduction in *E. coli* loads required to achieve all sets of FWO options are not significantly different.

4.2 Comparison with previous studies and national targets

This study also provided an estimate that 20% of the large rivers (i.e., those with stream order >3) across the whole region are currently suitable for primary contact according to the NPSFM Appendix 3 criteria (i.e., in attribute state C or better). The 90% confidence interval for this estimate is wide, with the lower and upper bounds defined by 12% and 40%, respectively. The estimate by this study is therefore consistent with, but at the upper end of, the previous estimate of 39% of these large rivers in Taranaki being suitable for primary contact as reported in MFE (2018). It is noteworthy that all sets of FWO options assessed in this study lead to 100% of rivers being suitable for primary contact (i.e., better than C band). These options represent a considerably greater increase in swimmable rivers than the 26% increase (to 65% swimmable) associated with committed work in the rural area of Taranaki reported by (MFE, 2018).

4.3 Uncertainties

Uncertainty is an unavoidable aspect of this study because it is based on simplifications of reality and because it has been informed by limited data. The study estimated the statistical uncertainty of the *E. coli* load reduction estimates that are associated with two key components of the analyses: the modelled regional river *E. coli* statistics and loads (see Sections 3.1 and 3.2). The statistical uncertainty of these models is associated with the imprecision of the *E. coli* statistics calculated for each site due to high sample variability and the inability of the random forest models to perfectly predict the statistics and loads observed at water quality monitoring sites; the error associated with these predictions is quantified by the model RMSD values (Table 4 and Table 5). A Monte Carlo analysis was used to combine the above model uncertainties and to make assessments of the uncertainty of several characteristics and quantities.

The *E. coli* load estimates for the SOE sites that informed this study have high uncertainty (Figure 8). These site-level load uncertainties were not explicitly represented in the Monte Carlo analysis. Each site's load estimate is evaluated with a model of the relationship between flow and *E. coli* concentration that also incorporates the influence of season and trends in the concentrations (see Appendix A for details). These models are therefore accounting for several processes that influence variation in *E. coli* concentrations. In general, there is a positive association between *E. coli* concentration and flow (i.e., concentrations increased with increasing flow). However, it is likely (and often evident from the observations) that other processes contribute to variation in *E. coli* concentrations over time, such as inputs from point sources. In general, we expect a negative association between *E. coli* concentration and flow for that component of the load that is contributed by point sources because increasing flow rates would dilute a constant discharge. This means it is likely there are mixed signals with respect to the relationship between *E. coli* concentration and flow at a site. These mixed signals are not represented by our load calculation method and will contribute to the large uncertainties associated with the site load estimates. Disentangling these signals and representing these processes in the calculation of loads would require significant investment in data and research.

The Monte Carlo analysis recognises and is based on the uncertainties associated with the nine individual models that are used in the assessment. We have presented the results of the analyses differently depending on the assessed characteristics. In general, the mean of results obtained from 100 Monte Carlo realisations was used to represent the best estimate of any quantity. For example, we provide a best estimate of the proportion of network segments in each of the five NOF attribute bands (Table 9). We also use the 90% confidence interval for our estimates of these proportions to indicate the uncertainty of these estimates. The lower and upper confidence limits can be interpreted as the values for which we are 95% confident the proportions are not lower than or greater than. The estimated load reductions required for the region and the FMUs have followed this same approach with a best estimate and 90% confidence intervals (e.g., Table 10 and Table 12). We have presented maps showing compliance with criteria associated with the FWOs (e.g., Figure 14). These maps show the estimated probability that segments comply with the criteria. We note that the distributions of load reductions over the 100 realisations (and mean and 90% confidence intervals) derived by the analyses can be obtained for each of the 16,625 segments represented in the analysis. These data are not presented in this report but are available as supplementary files.

An important conclusion from the analysis of uncertainty is that we are 95% confident that *E. coli* load reductions are required to achieve all sets of FWO options for the whole region. This is because the lower bound of the 90% confidence interval for load reduction required is greater than zero for all sets of FWOs (**Error! Reference source not found.**). Similarly, we are 95% confident that *E. coli* load reductions are required to achieve all sets of FWO options in all FMUs.

There are sources of uncertainty that this study has not accounted for. A key uncertainty is the source of *E. coli* at any point in the river network. An underlying implicit assumption in this study is that *E. coli* concentrations at any point are the outcome of load and that this load is attributable to contributions from all land in the upstream catchment. This is not necessarily true, concentrations at a location may be more strongly influenced by immediate local sources than contributions from upstream. Local sources may be from local land areas, point sources, or may be associated with transfer of *E. coli* from the river bed, particularly during high flow events (Wilkinson *et al.*, 2011). The assumption that *E. coli* loads at any point are the outcome of contributions from all land in the upstream catchment is manifested in our analysis by the additive reconciliation of local load reductions in the downstream direction at step 4 of the analysis to obtain the load reduction required at every point in the drainage network. This analysis is based on an assumption that any reduction upstream of a location contributes to the load reduction necessary at that location. This assumption would be violated if local contributions were important determinants of concentrations and loads at a point. The existence of these processes is not well understood or represented by our analysis and are therefore sources of additional uncertainty associated with the estimation of load reduction required.

The uncertainties described in this study indicate that the best estimates and maps are appropriately considered as indicative of the regional-scale patterns of compliance and *E. coli* load reductions required. The broad scale patterns provide a reliable indication of the relative differences in compliance and load reductions required between locations. However, there is considerable uncertainty associated with the absolute values of the *E. coli* load reductions required and these become larger as the spatial scale over which the reductions are evaluated is reduced. It is unlikely that these uncertainties can be significantly reduced in the short to medium term (i.e., in less than 5 to 10 years) because, among other factors, the modelling is dependent on the collection of long-term water quality monitoring data.

4.4 Informing decision-making on limits

The NPS-FM requires regional councils to set limits on resource use to achieve environmental outcomes (e.g., FWOs). This report helps inform Taranaki Regional Council’s process of setting limits by assessing the approximate magnitude of the *E. coli* load reductions needed to achieve several options for FWOs, with a quantified level of uncertainty associated with each option. However, this report does not consider what kinds of limits on resource might be used to achieve any load reductions, how such limits might be implemented, over what timeframes and with what implications for other values. The NPS-FM requires regional councils to have regard to these and other things when making decisions on setting limits. This report shows that these decisions will ultimately need to be made in the face of uncertainty about the magnitude of load reductions needed.

Acknowledgements

We thank Regan Phipps of TRC for assistance with obtaining all data used in this study. We also thank Abby Mathews, Lizzie Ingham, Jeremy Wilkinson and Darin Sutherland for thorough review of the draft report.

References

Cohn, T.A., 2005. Estimating Contaminant Loads in Rivers: An Application of Adjusted Maximum Likelihood to Type 1 Censored Data. Water Resources Research 41.

Cohn, T.A., D.L. Caulder, E.J. Gilroy, L.D. Zynjuk, and R.M. Summers, 1992. The Validity of a Simple Statistical Model for Estimating Fluvial Constituent Loads: An Empirical Study Involving Nutrient Loads Entering Chesapeake Bay. Water Resources Research 28:2353–2363.

Cohn, T.A., L.L. Delong, E.J. Gilroy, R.M. Hirsch, and D.K. Wells, 1989. Estimating Constituent Loads. Water Resources Research 25:937–942.

Duan, N., 1983. Smearing Estimate: A Nonparametric Retransformation Method. Journal of the American Statistical Association 78:605–610.

Efron, B., 1981. Nonparametric Estimates of Standard Error: The Jackknife, the Bootstrap and Other Methods. Biometrika 68:589–599.

Hirsch, R.M., 2014. Large Biases in Regression-Based Constituent Flux Estimates: Causes and Diagnostic Tools. JAWRA Journal of the American Water Resources Association 50:1401–1424.

Hirsch, R.M., S.A. Archfield, and L.A. De Cicco, 2015. A Bootstrap Method for Estimating Uncertainty of Water Quality Trends. Environmental Modelling & Software 73:148–166.

Hirsch, R.M., D.L. Moyer, and S.A. Archfield, 2010. Weighted Regressions on Time, Discharge, and Season (WRTDS), with an Application to Chesapeake Bay River Inputs 1. JAWRA Journal of the American Water Resources Association 46:857–880.

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

MFE, 2018. Regional Information for Setting Draft Targets for Swimmable Lakes and Rivers. Ministry for the Environment, Wellington, New Zealand.

MFE, 2019. Essential Freshwater: Impact of Existing Periphyton and Proposed Dissolved Inorganic Nitrogen Bottom Lines. Ministry for the Environment & Statistics NZ, Wellington, New Zealand.

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

Moriasi, D.N., M.W. Gitau, N. Pai, and P. Daggupati, 2015. Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. Transactions of the ASABE 58:1763–1785.

Nash, J.E. and J.V. Sutcliffe, 1970. River Flow Forecasting through Conceptual Models Part I—A Discussion of Principles. Journal of Hydrology 10:282–290.

NZ Government, 2017. National Policy Statement for Freshwater Management 2014 (Amended 2017).

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

Parker, W.J., 1998. Standardisation between Livestock Classes: The Use and Misuse of the Stock Unit System. Proceedings of the Conference New Zealand Grassland Association., pp. 243–248.

Piñeiro, G., S. Perelman, J. Guerschman, and J. Paruelo, 2008. How to Evaluate Models: Observed vs. Predicted or Predicted vs. Observed? Ecological Modelling 216:316–322.

Snelder, T., 2018. Assessment of Recent Reductions in E. Coli and Sediment in Rivers of the Manawatū-Whanganui Region. LWP Ltd, Christchurch, New Zealand.

Snelder, T., 2021. Assessment of Nutrient Load Reductions to Achieve Freshwater Objectives in the Rivers, Lakes and Estuaries of Southland. To Inform the Southland Regional Forum Process. LWP Client Report, LWP Ltd, Christchurch, New Zealand.

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

Snelder, T. and C. Fraser, 2021a. Assessment of Escherichia Coli Load Reductions to Achieve Draft Freshwater Objectives in the Rivers of Southland Murihiku. To Inform the Southland Regional Forum Process. LWP Client Report, LWP Ltd, Christchurch, New Zealand.

Snelder, T. and C. Fraser, 2021b. Assessment of Escherichia Coli Load Reductions to Achieve Freshwater Objectives in the Rivers of Otago. LWP Client Report, LWP Ltd, Christchurch, New Zealand.

Snelder, T.H., C. Fraser, S.T. Larned, R. Monaghan, S. de Malmanche, and A. Whitehead, 2021. Attribution of River Water-Quality Trends to Agricultural Land Use and Climate Variability in New Zealand. Marine and Freshwater Research.

Snelder, T.H., A.L. Whitehead, C. Fraser, S.T. Larned, and M. Schallenberg, 2020. Nitrogen Loads to New Zealand Aquatic Receiving Environments: Comparison with Regulatory Criteria. New Zealand Journal of Marine and Freshwater Research 54:527–550.

Whitehead, A., 2018. Spatial Modelling of River Water-Quality State,. Incorporating Monitoring Data from 2013 to 2017. NIWA Client Report, NIWA, Christchurch, New Zealand.

Wilkinson, R.J., L.A. McKergow, R.J. Davies-Colley, D.J. Ballantine, and R.G. Young, 2011. Modelling Storm-Event E. Coli Pulses from the Motueka and Sherry Rivers in the South Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 45:369–393.

Appendix A Calculation of *E. coli* loads at monitoring sites

A1 Water quality data

We obtained *E. coli* monitoring data for nine river SOE monitoring sites where flow was also measured or estimated from the TRC database, and from NIWA for two NRWQN sites within the Taranaki region. We also obtained *E. coli* monitoring data from 59 and 33 sites where flow was also measured in the Manawatu-Whanganui region by Horizons Regional Council (HRC) and the Waikato region by the Waikato Regional Council (WRC). Observations of *E. coli* were generally made at all SOE sites on a monthly basis. These sites had variable start and end dates and total numbers of observations. However, site numbers listed above all met the minimum data requirements that, for the 10-year period ending 2021, they had: (1) 60 or more observations; (2) observations in 8 of the 10 years; and (3) observations in 80% of the quarters.

A2 Flow Data

We obtained observed daily timeseries of flow at 99 monitoring sites from the three regional councils (i.e., TRC, HRC and WRC) and NIWA. In addition, we obtained modelled daily flow timeseries from TRC for four sites in the Taranaki region where monthly flow gauging is performed and daily flow timeseries were estimated by TRC hydrologists based on correlations with nearby catchments.

Start years for the flow records ranged from 1959 to 2011. Sites within the Taranaki region had between 27 and 48 years of flow record. All but 15 sites had more than 15 years of daily flow observations, with a median of 30 years of flow data across all sites.

A3 Load calculations

Calculation of *E. coli* loads at monitoring sites generally comprise two steps: (1) the generation of a series of flow and concentration pairs representing 'unit loads' and (2) the summation of the unit loads over time to obtain the total load. In practice step 1 precedes step two but in the explanation that follows, we describe step 2 first.

If flow and concentration observations were available for each day, the export coefficient, (the mean annual load, standardised by the upstream catchment area) would be the summation of the daily flows multiplied by their corresponding concentrations:

$$L = \frac{K}{A_c N} \sum_{j=1}^{N} C_j Q_j \qquad \text{(Equation A1)}$$

where L: mean annual export coefficient (giga *E. coli* yr^{-1} ha^{-1}), A_c: catchment area, ha, K: units conversion factor, C_j: *E. coli* concentration for each day in period of record (*E. coli* 100 ml^{-1}, Q_j: daily mean flow for each day in period of record (m^3 s^{-1}), and N: number of days in period of record.

In this summation, the individual products represent unit loads. Because concentration data are generally only available for infrequent days (i.e., generally in this study, monthly observations), unit loads can only be calculated for these days. However, flow is generally observed continuously, or the distribution of flows can be estimated for locations without continuous flow data, and there are often relationships between concentration and flow, time and/or season. Rating curves exploit these relationships by deriving a relationship between the sampled nutrient concentrations (c_i) and simultaneous observations of flow (q_i). Depending on the approach, relationships between concentration and time and season may be included in the rating curve. This rating curve is then used to generate a series of flow and concentration pairs (i.e., to represent Q_j *and* C_j in Equation A1) for each day of the entire sampling period (i.e., step 1 of the calculation method; Cohn *et al.*, 1989). The estimated flow and concentration pairs are then multiplied to estimate unit loads, and these are then summed and transformed by K, N and A_c to estimate mean annual export coefficients (i.e., step 2 of the calculation method; Equation A1).

There are a variety of approaches to defining rating curves. Identifying the most appropriate approach to defining the rating curve requires careful inspection of the available data for each site and contaminant. The details of the approaches and the examination of the data are described below in Section A3.3.

For each site, we calculated the load for each contaminant using three commonly used and recommended methods that are based on different types of rating curves, which we refer to as the the flow stratification method, the seven-parameter (L7) rating method and the five-parameter (L5) rating method. We expressed all *E. coli* loads as annual export coefficients (i.e., for giga *E. coli* yr^{-1} ha^{-1}) by dividing the annual load (*E. coli* yr^{-1}) by the catchment area (ha). Loads were estimated for an evaluation date of 31/12/2019 (rather than a long term mean load).

A3.1 Methods for defining rating curves

A3.1.1 L7 model

Two regression model approaches to defining rating curves of Cohn *et al.* (1989, 1992) and Cohn (2005) are commonly used to calculated loads. The regression models relate the log of concentration to the sum of three explanatory variables: discharge, time, and season. The L7 model is based on seven fitted parameters given by:

$$ln(\widehat{C_i}) = \beta_1 + \beta_2\left[ln(q_i) - \overline{(ln(q))}\right] + \beta_3\left[ln(q_i) - \overline{(ln(q))}\right]^2 + \beta_4(t_i - \bar{T}) + \beta_5(t_i - \bar{T})^2 + \beta_6 sin(2\pi t_i) + \beta_7 cos(2\pi t_i) \quad \text{Equation A2}$$

where, *i* is the index for the concentration observations, $\beta_{1,2,..7}$: regression coefficients, t_i: time in decimal years, $\bar{T}$: mean value of time in decimal years, $\overline{(ln(q))}$ mean of the natural log of discharge on the sampled days, and $\widehat{C_i}$: is the estimated i^{th} concentration.

The coefficients are estimated from the sample data by linear regression, and when the resulting fitted model is significant ($p < 0.05$), it is then used to estimate the concentration on each day in the sample period, $ln(\widehat{C_j})$. The resulting estimates of $ln(\widehat{C_j})$ are back-transformed (by exponentiation) to concentration units. Because the models are fitted to the log transformed concentrations the back-transformed predictions were corrected for retransformation bias. We used the smearing estimate of Duan (1983) as a correction factor (S):

$$S = \frac{1}{n}\sum_{i=1}^{n} e^{\widehat{\varepsilon_i}} \quad \text{Equation A3}$$

where, $\hat{\varepsilon}$ are the residuals of the regression models, and *n* is the number of flow-concentration observations. The smearing estimate assumes that the residuals are homoscedastic and therefore the correction factor is applicable over the full range of the predictions.

The average annual load is then calculated by combining the flow and estimated concentration time series:

$$L = \frac{KS}{A_c N} \sum_{j=1}^{N} \hat{C}_j Q_j$$ Equation A1b

If the fitted model is not significant, $\widehat{C_j}$ is replaced by the mean concentration and S is unity.

To provide an estimate of the load at a specific date, (i.e., t^{est} = 1/3/2004) a transformation is performed so that the year components of all dates (t_j) are shifted such that all transformed dates lie within a one-year period centred on the proposed observation date (i.e., *Y*=1/9/2003 to 31/8/2004). For example, flow at time *t*=13/6/2007 would have a new date of *Y* =13/6/2004, and a flow at time *t*=12/11/1998 would have a new date of *Y*=12/11/2003.

$$ln\left(\widehat{C_j^Y}\right) = \beta_1 + \beta_2\left[ln(q_j) - \overline{(ln(q))}\right] + \beta_3\left[ln(q_j) - \overline{(ln(q))}\right]^2 + \beta_4(Y_j - \bar{T}) + \beta_5(Y_j - \bar{T})^2 + \beta_6 sin(2\pi Y_j) + \beta_7 cos(2\pi Y_j)$$ Equation A2a

where $\widehat{C_j^Y}$ is the estimated j^{th} concentration for the estimation year, and Y_j is the transformed date of the i^{th} observation, and all other variables are as per Equation A3. The regression coefficients ($\beta_{1,2,..7}$) are those derived from fitting Equation A2 to the observation dataset. It follows that the estimated load for the year of interest can be calculated by:

$$L^Y = \frac{KS}{A_c N} \sum_{j=1}^{N} \hat{C}_j^Y Q_j$$ Equation A1c

A3.1.2 L5 Model

The L5 model is the same as L7 model except that two quadratic terms are eliminated:

$$ln(\widehat{C_i}) = \beta_1 + \beta_2(ln(q_i)) + \beta_3(t_i) + \beta_4 sin(2\pi t_i) + \beta_5 cos(2\pi t_i)$$ Equation A4

The five parameters are estimated, and loads are calculated in the same manner as the L7 model. Following the approach outlined for the L7 model, the L5 model can be adjusted when used for prediction to provide estimates for a selected load estimation date:

$$ln\left(\widehat{C_j^Y}\right) = \beta_1 + \beta_2[ln(q_j)] + +\beta_4(Y_j - \bar{T}) + +\beta_6 sin(2\pi Y_j) + \beta_7 cos(2\pi Y_j)$$ Equation A4a

A3.1.3 Flow stratification

For TRC sites where L5 and L7 models showed unrealistic models, we employed a flow stratification approach to defining rating curves. This approach is based on a non-parametric rating curve, which is defined by evaluating the average concentration within equal increments of the flow probability distribution (flow 'bins'). We used ten equal time-based categories (flow decile bins), defined using flow distribution statistics and then calculated mean concentrations within each bin. This non-parametric rating curve can then be used to estimate *E. coli* concentrations, $\hat{C}$, for all days with flow observations. At step 2, the export coefficient is calculated following equation (1a), providing an estimate of average annual export coefficient over the observation time period.

$$L = \frac{K}{A_c N} \sum_{j=1}^{N} \hat{C}_j Q_j$$ (Equation A1d)

where $\widehat{C}_j$ is calculated mean concentration associated with the flow quantile bin of the flow Q_j., and all other variables are as per equation A1.

A3.2 Precision of load estimates

The statistical precision of a sample statistic, in this study the mean annual load, is the amount by which it can be expected to fluctuate from the population parameter it is estimating due to sample error. In this study, the precision represents the repeatability of the estimated load if it was re-estimated using the same method under the same conditions. Precision is characterised by the standard deviation of the sample statistic, commonly referred to as the standard error. We evaluated the standard error of each load estimate by bootstrap resampling (Efron, 1981). For each load estimate we constructed 100 resamples of the concentration data (of equal size to the observed dataset), each of which was obtained by random sampling with replacement from the original dataset. Using each of these datasets, we recalculated the site load and estimated the 95% confidence intervals, using the boot r package.

A3.3 Identifying a best load estimate

We developed an expert judgement-based methodology to evaluate the 'best' rating curve approach for each site and used this to make a 'best' load estimate. We did this by inspecting summaries of the flow-concentration-time (Q-C-T) data and model diagnostic information and performance measures pertaining to the rating curves. Data availability and sampling distribution with season, time and flow were also considered in this assessment. All sites had L5 and L7 models fitted. Where these models were considered to provide unrealistic representations of the observed data, the load estimates were either excluded (for EW and HRC sites), or a flow stratification model was fitted and assessed for suitability. In the final model selection, ten sites were excluded and one TRC site was represented with a flow stratification model. All diagnostic plots for SOE sites in Taranaki are provided in the supplementary file TRC Load model diagnostic plots and explanation.pdf.

A4 Verification of loads

Load estimation involves subjective decisions, such as the choice of method. We sought to verify our load estimates (i.e., demonstrate they were reasonable) by calculating them using an alternative method. We undertook the validation of our *E. coli* load estimates by applying a new sophisticated load estimation method called Weighted Regressions on Time, Discharge, and Season (WRTDS; Hirsch et al., 2015, 2010). The WRTDS method is complex and is not explained here. However, it can be understood as a form of regression modelling that fits a relationship to concentration based on time and flow. WRTDS is more flexible than the methods we used to calculate the loads and allows for changes in the underlying relationships over time. WRTDS is also more resistant to bias than the load calculation methods that we used, although not entirely immune (Hirsch, 2014). WRTDS is "unsupervised" in the sense that the loads are calculated without requiring any judgements by the analyst, whereas the "rating curves" methods used by this study required expert judgement to select an appropriate model at each site.

We calculated *E. coli* loads at each site using WRTDS with the same input data described above. Calculations were performed with the Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval: R package (Hirsch *et al.*, 2015). The outputs of the EGRET package are numerous and complicated. We obtained from the output the flow normalised flux (*E. coli* day^{-1}) for 2020. Flow normalised flux is a representation of flux that integrates over the probability distribution of discharge in order to remove the effect of year-to-year variation in discharge. It is therefore consistent with the approach we used to calculate loads which integrated unit loads over the entire flow time series. Using the flux estimate for 2020 was consistent with our load estimates which pertain to 2020. We converted the flux to the units of E. coli yields used by this study (giga *E. coli* ha^{-1} yr^{-1}) by dividing by catchment area of the water quality stations and multiplying by the appropriate unit conversion factor.

It should be noted that there are many methods of load calculation that differ in how the underlying relationships are represented in subtle ways. Many studies have documented differences in loads calculated from the same data but using different methods and it is often shown these differences can be large (e.g., Cohn, 2005; Johnes, 2007; Preston et al., 1989; Quilbé et al., 2006; Snelder et al., 2017). Therefore, differences between our loads and those estimated by WRTDS are expected. Notwithstanding this, the plot shown in Figure 34 indicates strong correspondence between the two sets of loads. The majority of the 95% confidence intervals estimated by this study intersect the one-to-one line indicating that the two sets of estimates are consistent. Our conclusion is that the loads calculated and used in this study are reasonable and are the best estimates that we could produce, given the data.

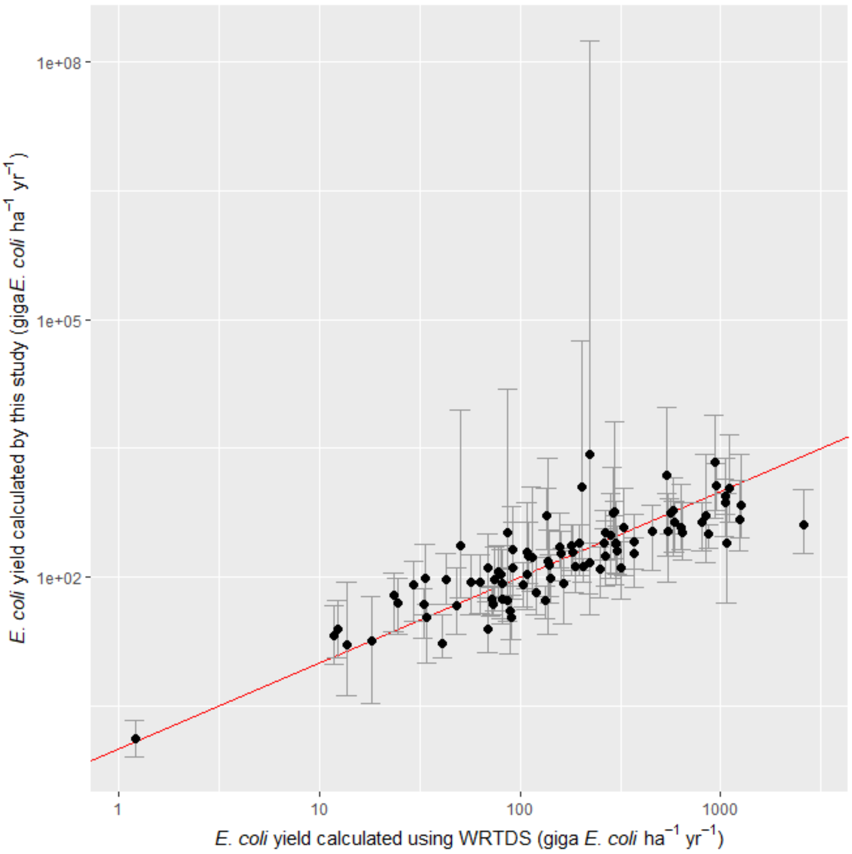


Figure 34. Comparison of E. coli loads (expressed as yields) calculated by this study (y-axis) with loads calculated using WRTDS. The error bars show the 95% confidence intervals estimated by this study. The red line indicates perfect correspondence (one-to-one).

Appendix B Proportions of segments predicted to be in each attribute band by reporting catchment and management class.

Table 14. Proportion of segments (%) predicted to be in each attribute band by reporting catchment.

Reporting catchment	Attribute band	Best estimate	5% confidence limit	95% confidence limit
Coastal Terraces	A	0	0	0
Coastal Terraces	B	0	0	1
Coastal Terraces	C	0	0	1
Coastal Terraces	D	4	1	12
Coastal Terraces	E	95	87	98
Northern Hill Country	A	6	0	20
Northern Hill Country	B	18	2	38
Northern Hill Country	C	8	1	22
Northern Hill Country	D	37	19	56
Northern Hill Country	E	31	15	56
Patea	A	3	0	26
Patea	B	11	0	35
Patea	C	7	0	21
Patea	D	31	5	54
Patea	E	49	2	95
Southern Hill Country	A	7	0	34
Southern Hill Country	B	18	0	43
Southern Hill Country	C	9	0	25
Southern Hill Country	D	36	16	67
Southern Hill Country	E	31	18	49
Volcanic Ringplain	A	4	1	7
Volcanic Ringplain	B	6	4	9
Volcanic Ringplain	C	2	1	4
Volcanic Ringplain	D	11	8	19
Volcanic Ringplain	E	76	67	80
Waitara	A	5	0	28
Waitara	B	12	0	31
Waitara	C	5	0	20
Waitara	D	33	15	57
Waitara	E	45	3	83

Taranaki Regional Council

MEMORANDUM
Policy & Planning

Date 30 August 2022

Subject: High Court decision on Proposed Otago Regional Policy Statement

Approved by: A D McLay, Director - Resource Management

S J Ruru, Chief Executive

Document: 3096632

Purpose

1. The purpose of this memorandum is to update Members on the recent High Court decision on the *Proposed Otago Regional Policy Statement* (PORPS) and its implications for the Taranaki Regional Council's (TRC) plan reviews under the *Resource Management Act 1991* (RMA).

Executive summary

2. In 2020, the Government amended the RMA to include a new streamlined planning process for regional policy statements and regional plans giving effect to the *National Policy Statement for Freshwater Management 2020* (NPS-FM).
3. The freshwater planning process has more limited rights of appeal in comparison with other planning processes under Schedule I of the RMA.
4. On 26 June 2021, in a first-of-its-kind move, the Otago Regional Council notified the whole of its PORPS as a freshwater planning instrument.
5. It was Otago Regional Council's view that everything has a connection and therefore relates to freshwater. They determined that adopting this interpretation is necessary to achieve integrated management of all natural resources and in accordance with the concept of Te Mana o te Wai and ki uta ki tai.
6. Locally, Otago Regional Council's determination was supported by iwi. However, it was challenged by a number of district councils, Forest and Bird, Port Otago, Oceana Gold, and two major forestry companies.
7. On 21 September 2021, the Council brought proceedings in the High Court in Dunedin under the *Declaratory Judgments Act 1908* to determine whether the PORPS is a freshwater planning instrument, in terms of section 80A of the RMA, to test its decision and provide surety for the remainder of the review process.
8. The High Court hearing was held on the 8th and 9th February 2022 with the Judge releasing his ruling on 22 July 2022.

9. In brief, the High Court ruled that:
   - the Otago Regional Council's determination, that the whole of its proposed regional policy statement was a freshwater planning instrument, was in error;
   - only those parts of the proposed regional statement that relate **directly** to the maintenance or enhancement of freshwater quality or quantity can be treated as parts of a freshwater planning instrument; and
   - Otago Regional Council must re-notify those parts of the proposed regional statement, which are to be treated as a freshwater planning instrument and begin again the freshwater planning process as to those parts.
10. This is a much narrower interpretation than most pundits would have expected and has significant implications for all regional councils.
11. For councils reviewing their regional policy statement and regional plans to give effect to the NPS-FM (including this Council) the High Court's decision is legally correct but still disappointing. First, councils must now run two separate potentially disjointed public planning processes and the risk of added administrative complexity and inefficiencies that process will entail. Second, there is a significant risk that the two separate planning processes will result in decisions that make or reduce integrated management.
12. Officers will need be factoring in the consequences of the High Court's decision and taking it into account as it develops the *Proposed Natural Resources Plan for Taranaki*.

Recommendations

That the Taranaki Regional Council:

a) receives the memorandum titled *High Court decision on Proposed Otago Regional Policy Statement*

b) notes the limiting nature of the High Court's decision that only freshwater matters related to quality and quantity can be consider to be a planning instrument under section 80A of the RMA

c) notes that the Court's decision means that the public process of the Council's *Proposed Natural Resources Plan* will involve two public processes run in conjunction with each other

d) determines that this decision be recognised as not significant in terms of section 76 of the *Local Government Act 2002*

e) determines that it has complied with the decision-making provisions of the *Local Government Act 2002* to the extent necessary in relation to this decision; and in accordance with section 79 of the Act, determines that it does not require further information, further assessment of options or further analysis of costs and benefits, or advantages and disadvantages prior to making a decision on this matter.

Background

13. Regional policy statements are a legislative instrument under the RMA. Section 59 of the RMA provides that the purpose of regional policy statements is to achieve the purpose of the Act by providing an overview of the resource management issues of the region and policies and methods to achieve integrated management of the natural and physical resources of the whole region. They must integrate national direction in the regional context, and give integrated direction to regional and district plans.

14. Section 60 of the RMA provides that at all times for every region there will be a regional policy statement prepared by the regional council in the manner set out in Schedule 1.
15. The current RPS for the Taranaki region was made operative in 2010 and as Members are aware, the Council has commenced a review of its RPS as part of the development of a *Proposed Natural Resources Plan for Taranaki* (that also includes the review of the regional freshwater, soil and air plans).
16. In 2020, the Government amended the RMA. The amendments included a new Section 80A with a streamlined planning process for the regional policy statements and regional plans.
17. The purpose of the new process was to set up a framework to expedite the public process involving provisions giving effect to NPS-FM and, amongst other things, included reduced rights of appeal. Appeal rights are restricted compared to the standard plan-making process. Avenues for appeal depend on whether the regional council accepts or rejects the panel's recommendation. Where a council accepts the panel's recommendation, a person who submitted on that matter can appeal to the High Court on a point of law followed by an appeal to the Court of Appeal only. Where a council rejects the panel's recommendation, a merit appeal is available to the Environment Court by a person whose submission covered that particular matter.
18. Section 80A of the RMA requires that all "*freshwater planning instruments*" undergo the freshwater planning process. A freshwater planning instrument includes a proposed regional policy statement that gives effect to any national policy statement for freshwater management or that relates to freshwater (other than for the purpose of giving effect to any national policy statement for freshwater management).
19. Section 80A(3) reads:

    "(3) A regional council must prepare a freshwater planning instrument in accordance with Subpart 4 of Part 5 and Part 4 of Schedule 1. However, if the council is satisfied that only part of the instrument relates to freshwater, the council must—

    (a) prepare that part in accordance with this subpart and Part 4 of Schedule 1; and

    (b) prepare the parts that do not relate to freshwater in accordance with Part 1 of Schedule 1 or, if applicable, subpart 5 of this Part."
20. The issue for regional council's is whether they can run one public process or need to run two public processes for regional policy statements and/or combined plans that cover domains other than freshwater? The complexities and inefficiencies of running two public planning processes for a single document are obvious.

High Court proceedings on the PORPS

21. On 26 June 2021, the Otago Regional Council notified the whole of its PORPS as a freshwater planning instrument. In a first-of-its-kind move, the Council decided its proposed regional policy statement was the kind of planning document that suited a new, streamlined, freshwater planning process introduced through changes to the RMA in 2020. Otago Regional Council considered it nonsensical to try to separate freshwater from the wider environment and run two separate public processes. A view that this Council's officers also share.
22. As noted at the time, the Otago Regional Council made this determination to achieve integrated management of all natural resources and in accordance with the concepts of Te Mana o te Wai and ki uta ki tai encapsulated in the NPS-FM. While the Council's

determination was supported by iwi, it was challenged by a number of district councils, Forest and Bird, Port Otago, Oceana Gold and two major forestry companies.

23. On 21 September 2021, the Council brought proceedings in the High Court in Dunedin under the *Declaratory Judgments Act 1908* to determine whether the PORPS is a freshwater planning instrument in terms of section 80A of the RMA. In so doing, it was hoping to test its decision, make sure its assumptions and interpretation were correct, and provide surety for the remainder of the review process.

24. The High Court hearing was held on 8 and 9 February 2022 with the Judge releasing his ruling on 22 July 2022.

High Court's decision

25. In brief, the High Court has ruled that Otago Regional Council had used too broad a definition of "*relates to freshwater*" when it said its entire regional statement was appropriate for the new process.

26. Key findings are that:
    - the Otago Regional Council's determination, that the whole of its proposed regional policy statement was a freshwater planning instrument, was in error;
    - the Otago Regional Council must now reconsider the proposed regional policy statement and decide which parts of it do relate to freshwater in the way the legislation requires for those parts to be subject to the freshwater planning process; and
    - the Otago Regional Council must then re-notify those parts of the proposed regional statement which are to be treated as a freshwater planning instrument and begin again the freshwater planning process as to those parts.

27. In its decision, the Court ruled that, with the 2020 amendment to RMA, Parliament contemplated there would be dual planning processes as to matters that the Otago Regional Council had to deal with in its PORPS. That is, only those matters that "*…relate to freshwater*" would be subject to the freshwater planning process.

28. In his judgment, Judge Nation ruled that only those parts of the proposed regional statement that relate directly to **the maintenance or enhancement of freshwater quality** or **quantity** can be treated as parts of a freshwater planning instrument.

29. The decision above, involves a much more narrower interpretation than most pundits would have expected.

Implications for this Council

30. The decision has significant implications for all councils reviewing regional policy statements or developing combined plans.

31. Otago Regional Council must now re-notify those parts of its proposed regional statement, which do not comply with the Council's ruling (notwithstanding the great number of submissions received on those parts). Those parts will be subject to the standard Schedule 1planning process provided by the RMA with existing rights of appeal to the Environment Court.

32. For this Council, at least we are forewarned when it comes to our decisions on how we run the freshwater planning process.

33. For the *Proposed Natural Resources Plan*, which includes the reviews of the Regional Policy Statement and the freshwater, soil and air plans, two public processes will need to be run simultaneously under Schedule 1 – the freshwater planning process and the standard planning process.
34. The decision follows the letter of the law but is a problem of the Government's own making. It runs counter to the Government's own NPS-FM, which encourages integrated 'mountains to the sea' approaches.' This Council when submitting on amendments to the RMA in 2020 warned of the dangers and missed opportunities of limiting the proposed planning process to freshwater matters only. The Government chose to ignore this.
35. Now instead of having a simpler and more streamlined public approach we have the worst of situations in needing to run two separate and potentially disjointed submission and hearing processes. Submissions will be considered and recommendations will be made at hearing with little or poor line-of-sight (through no fault of the hearing commissioners) on what is happening in the other process (on sometimes related matters).
36. The running of two Schedule 1 processes is likely to impose significant and unnecessary added administrative complexity and inefficiencies to the development of the *Proposed Natural Resources Plan*. Of more concern, is the significant risk that the two separate planning process will result in decisions that derogate from integrated management.
37. Officers will need be factoring in the consequences of the High Court's decision and taking it into account as it develops the *Proposed Natural Resources Plan*.

Financial considerations—LTP/Annual Plan

38. This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

39. This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks including, but not restricted to, the *Local Government Act 2002*, the *Resource Management Act 1991* and the *Local Government Official Information and Meetings Act 1987.*

Iwi considerations

40. This memorandum and the associated recommendations are consistent with the Council's policy for the development of Māori capacity to contribute to decision-making processes (schedule 10 of the *Local Government Act 2002*) as outlined in the adopted long-term plan and/or annual plan.
41. A review of iwi management plans shows that the High Court's decision is likely to be a disappointment to tangata whenua, as Council seeks to work with iwi and hapu to achieve integrated management of all natural resources and to give effect to concepts of Te Mana o te Wai and ki uta ki tai.

Community considerations

42. This memorandum and the associated recommendations have considered the views of the community, interested and affected parties and those views have been recognised in the preparation of this memorandum.

Legal considerations

43. This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council including consideration of the *National Policy Statement for Freshwater Management 2020*.

MEMORANDUM
Policy & Planning

Date 30 August 2022

Subject: **Submission in Support of Temporary Fishing Closure in Taranaki**

Approved by: A D McLay, Director - Resource Management

S J Ruru, Chief Executive

Document: 3097608

Purpose

1. The purpose of this memorandum is to seek feedback and endorsement from Members of the proposed submission on a request from Taranaki iwi for a temporary fishing closure on the Taranaki coast.

Executive summary

2. As Members were advised at the April 2022 meeting of this Committee, there is considerable concern amongst Ngāruahine and Taranaki iwi at the impact of recreational fishing on shellfish stocks along the Taranaki coast. Iwi had placed a rāhui on harvest of seafood on much of the coast, initially from July 2021, but over an extended area from early 2022. They were however concerned to find ways to increase the impact of that rāhui in order to give the shellfish stocks a better chance to return to sustainable levels.
3. In recent months, the two iwi have made an application to Fisheries New Zealand for the imposition of a temporary closure of the Taranaki coast to certain fishing activities. Fisheries New Zealand notified Council of that application, made pursuant to the provisions of s 186A of the Fisheries Act 1996, in mid-August 2022.
4. A submission has been prepared supporting the application by Taranaki iwi, and calling for Fisheries New Zealand to undertake monitoring to provide greater knowledge and visibility of the impact of the closure. The draft submission is presented to Members with this Memorandum, for consideration and approval.

Recommendations

That the Taranaki Regional Council:

a) receives this memorandum Submission in Support of Temporary Fishing Closure in Taranaki

b) adopts (alternatively amends) the submission.

c) determines that this decision be recognised as not significant terms of section 76 of the *Local Government Act 2002*

d) determines that it has complied with the decision-making provisions of the *Local Government Act 2002* to the extent necessary in relation to this decision; and in accordance with section 79 of the Act, determines that it does not require further information, further assessment of options or further analysis of costs and benefits, or advantages and disadvantages prior to making a decision on this matter.

Discussion

5. The April meeting of this Committee received a paper describing concerns the Ngāruahine and Taranaki iwi held about the long-term sustainability of shellfish stocks that prompted them to declare a rāhui on harvesting those species. That paper also discussed some of the options under the Fisheries Act 1996 to give greater legal effect to that rāhui, as well as Council's options, within its jurisdiction and responsibilities, to support that rāhui.
6. That paper is attached to this Memorandum, for Members information.
7. Also at that meeting, members of Ngāruahine and Taranaki iwi addressed the Committee to express their concerns and to detail some of the actions that they were considering taking. Chief amongst those actions was making an application under s 186A of the Fisheries Act for a temporary fishing closure along the Taranaki coast.
8. Taranaki iwi filed that request for a temporary closure with Fisheries New Zealand in August 2022. (Ngāruahine iwi are still discussing the possibility of making an application with their hapū.) Council was advised of the application and invited to make a submission on the request in a letter received from dated 11 August 2022.
9. In light of the matters raised in the April meeting paper and the discussions that ensued in that meeting, both amongst Members and with the iwi members present, a submission has been prepared in support of the proposed temporary closure.
10. The brief submission, a copy of which is attached to this paper, included a recommendation that Fisheries New Zealand include monitoring conditions in the proposed closure.
11. This recommendation, prepared under advice from Environment Quality staff, was to gather information that could give a greater understanding of the effectiveness of the closure. That information could both support any future requests for fisheries closures along the Taranaki coast, as well as providing Council with information that could enable it to take actions that complimented Fisheries New Zealand's management of sustainable fish stocks in the Taranaki region.

Financial considerations—LTP/Annual Plan

12. This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

13. This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks

including, but not restricted to, the *Local Government Act 2002*, the *Resource Management Act 1991* and the *Local Government Official Information and Meetings Act 1987*.

Iwi considerations

14. This memorandum and the associated recommendations are consistent with the Council's policy for the development of Māori capacity to contribute to decision-making processes (schedule 10 of the *Local Government Act 2002*) as outlined in the adopted long-term plan and/or annual plan. Similarly, iwi involvement in adopted work programmes has been recognised in the preparation of this memorandum.

Community considerations

15. This memorandum and the associated recommendations have considered the views of the community, interested and affected parties and those views have been recognised in the preparation of this memorandum.

Legal considerations

16. This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council.

Appendices/Attachments

Document 3097605: Submission on Proposed Temporary Fishing Closure in Taranaki

Document 3021992: Responsibilities for kaimoana management and cultural practices

Taranaki Regional Council

20 August 2022
Document: 3097605

Spatial Planning and Allocations
Fisheries Management
Fisheries New Zealand
P O Box 2526
Wellington 6140

Dear Sir/Madam

Submission on Proposed Temporary Fishing Closure in Taranaki

Taranaki Regional Council ("Council") thanks Fisheries New Zealand ("Fisheries") for the opportunity to provide feedback on the application by Taranaki iwi for a two year fishing closure on the Taranaki coast.

Council is the primary local government agency with responsibility for managing the effects of the use of the coastal marine area. This responsibility, which includes protecting indigenous biodiversity, is complimentary to Fisheries' responsibilities to manage the sustainable use of fisheries resources.

Council conducts monitoring of the coastal marine area as part of its State of the Environment monitoring annual science programme. The monitoring focuses on the intertidal ecology of rocky shore habitats, but the survey design does not provide a representative assessment of populations of key recreational shellfish species such as pāua and kina, within the proposed closure area. However, the programme has highlighted some matters that are relevant to this proposed fishing closure. In particular, Council has found considerable habitat disturbance around those areas that are heavily fished, likely from people overturning rocks (and leaving them upturned) when searching for shellfish. This disturbance can have an on-going impact on the viability of the intertidal communities in those areas.

Additionally, in May 2022, Council's Policy and Planning Committee considered a paper on options that the Council had to contribute to managing the concerns raised about the health of pāua stocks in Taranaki. The Committee heard oral submissions on the same topic from representatives of Ngāruahine and Taranaki on their interpretation of the situation and their concerns. Both iwi also described their current consideration of making an application under s 186A of the Fisheries Act 1996.

47 Cloten Road · Private Bag 713 · Stratford 4352 · New Zealand
T: 06 765 7127 · F: 06 765 5097 · E: info@trc.govt.nz · www.trc.govt.nz
www.facebook.com/TaranakiRegionalCouncil twitter.com/TaranakiRC
Please quote our document number in your reply

Against this background, and subject to the comments in the next paragraph, Council wishes to indicate its full support for a proposed two year fishing closure of the area from the Herekawe Stream to the Raoa Stream in order to promote the regeneration of pāua stocks.

As a component of this closure, Council would strongly encourage Fisheries to facilitate the development and implementation of an extensive programme of monitoring the population and distribution of the key target species. That monitoring would provide information on the effectiveness of such a closure that could be used to support any future closures that may be needed/requested. It would also provide useful information to Council that could inform our activities in the coastal marine area which could, ultimately, further support Fisheries' goals of sustainable management of fish species. The Council is open to discussing potential options for monitoring the effectiveness of the closure, based on our local knowledge and experience.

Council thanks Fisheries for their consideration of this submission and looks forward to working collaboratively with them in supporting the health of the Taranaki coastal environment.

Yours faithfully

S J Ruru
Chief Executive

Taranaki Regional Council

MEMORANDUM
Policy & Planning

Date	26 April 2022
Subject:	**Responsibilities for kaimoana management and cultural practices**
Approved by:	A D McLay, Director - Resource Management
	S J Ruru, Chief Executive
Document:	3021992

Purpose

1. The purpose of this memorandum is to outline which agencies manage kaimoana, the current state of the resource, and options for improved management.
2. This item arises from Members' interest at the last committee meeting.

Executive summary

3. Hapū and kaitiaki of Ngāruahine and Taranaki Iwi have established rāhui along part of the western Taranaki coastline and will present to the Committee about their concerns.
4. Rāhui in this instance is a traditional cultural practice to restrict or prohibit an activity or access to an area in order to protect, preserve and allow for the recovery of a resource.
5. Increased pressure has occurred from people learning about kaimoana resources on social media and coming to the region to gather pāua and other kaimoana shellfish stocks. Hapū have placed rāhui on the affected reef areas because of the serious concerns they have, on the long-term sustainability of the pāua and the other kaimoana shellfish stocks.
6. With support from Ngāruahine and Taranaki Iwi, discussions between the hapū and Ministry for Primary Industries (MPI) officials have sought support from the Minister for the rāhui, by way of a temporary closure under section 186A of the *Fisheries Act 1996*. Under this legislation MPI have the primary responsibility for kaimoana management and work closely with tangata whenua.
7. Taranaki Regional Council ('TRC' or the 'Council') regulatory oversight of the coastal marine area (CMA) is through the Regional Coastal Plan. The Plan has jurisdiction out to the twelve nautical mile limit, and takes into account the impacts of activities in this area. Monitoring of those effects and surveys such as the State of the Environment monitoring of the rocky shore assist the Council to keep track of what is occurring in the coastal marine area. The Courts have determined that Councils can have objectives, policies and rules to protect indigenous biodiversity (including kaimoana); however,

there is no clear business case for pursuing this approach at this time noting that the Council cannot impinge on MPI Fisheries Act responsibilities.

Recommendations

That the Taranaki Regional Council:

a) receives this memo entitled *Responsibilities for kaimoana management and cultural practices*

b) notes the rāhui by the hapū to protect, preserve and allow for the kaimoana resource to recover

c) notes the Fisheries Act is the most appropriate statute to apply to kaimoana management

d) notes that once an application is made for a temporary closure, under the Fisheries Act, the Council will consider making a submission;

e) determines that this decision be recognised as not significant in terms of section 76 of the *Local Government Act 2002*

f) determines that it has complied with the decision-making provisions of the *Local Government Act 2002* to the extent necessary in relation to this decision; and in accordance with section 79 of the Act, determines that it does not require further information, further assessment of options or further analysis of costs and benefits, or advantages and disadvantages prior to making a decision on this matter.

Background

8. Jack Davey, Kaitiaki for Nga hapū o Orimupiko Marae, Fran Davey and Mahara Okeroa will address the Committee on the state of kaimoana and actions to protect it.

9. As a result of the increased pressure by people gathering pāua and other kaimoana shellfish stocks, the hapū have placed rāhui on the affected reef areas because of the serious concerns they have, on the long-term sustainability of the pāua and the other kaimoana shellfish stocks. The increased pressure is thought to arise from interest generated on social media.

10. Rāhui in this instance is a traditional practice to restrict or prohibit an activity or access to an area in order to protect, preserve and allow for the recovery of a resource.

11. Ngāti Haua, a hapū of Ngāruahine, placed a rāhui in their coastal rohe on all species and access in July 2021. This rāhui remains in place.

12. In January this year kaumātua of the hapū of Ngāruahine placed a rāhui prohibiting the harvesting of species such as pāua along the coastline from the Taungatara Stream to the Waihi Stream.

13. On 9 January, at a public meeting at the Oaonui hall, and on behalf of Nga hapū o Orimupiko Marae, it was unanimously agreed to place a rāhui from Waiwiri Bay (just south of the Oaonui Production Station) to the Rāhuitoetoe Stream (approximately 5km south of Opunake). The rāhui is in place until 31 July 2022.

14. With support from Ngāruahine and Taranaki Iwi, discussions between the hapū and Ministry for Primary Industries (MPI) officials have commenced seeking support from the Minister for the rāhui, by way of a temporary closure under section 186A of the *Fisheries Act 1996*.

Kaimoana Management

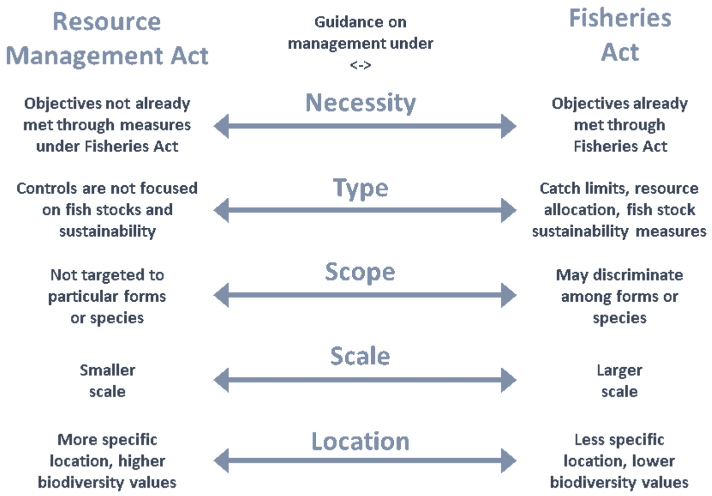
15. Under the Fisheries Act, MPI are responsible for managing kaimoana and have regulations in place that are monitored by fisheries officers.
16. A zoom meeting was held with ministry officials, on 13 April, and the following was noted:
    a) compliance monitoring in the region is extremely challenging given the multiple access points to the coast
    b) the public have very high service delivery expectations and the fisheries section has tight Government budgets
    c) storms and associated high sand movement periods have significant negative effects on kaimoana
    d) regulatory performance in the last 2 years has been greatly impacted by covid-19 lockdowns
    e) there are three fisheries officers (an increase from two several years ago); four honorary (voluntary) officers, about to increase to nine; monitoring programmes that involve bringing an extra five fisheries officers (forming four, two person teams) during the extreme low tides and working with the Police and Department of Conservation staff; fisheries officers also undertake monitoring under other low tides; enforcement action being undertaken involving giving warnings, issuing infringement fines ($250-$500), and prosecutions; also able to seize vehicles of those in serious non-compliance; in the last 6 months there were approximately 650 inspections and seventy-one (71) offences identified resulting in thirty-seven (37) warnings, thirty (30) infringement notices and four (4) prosecutions
    f) some monitoring of kaimoana stocks in the region over the years
    g) since the rāhui there has been less kaimoana gathering and pressure on the resource
    h) self-policing regimes, involving tangata whenua and the community, have proven to be successful elsewhere in NZ
    i) two year temporary closure mechanisms, reside in the Fisheries legislation, and allow a resource to recover and can be extended. The Minister of Fisheries makes the decision
    j) fisheries officers wanted to positively work with the Council and others to protect kaimoana resources.
17. The Taranaki Regional Council has environmental responsibilities for the coastal marine area (CMA) through the Regional Coastal Plan prepared under the *Resource Management Act 1991*. The Plan has jurisdiction out to the twelve nautical mile sea limit and has objectives, policies and rules for activities such as discharges, disturbance, deposition, structures and extractions.

Motiti decision

18. The Motiti decision refers to a recent ruling by the Court of Appeal on Bay of Plenty's review of their coastal plan. The Court of Appeal has determined that councils can have objectives, policies and rules to manage the taking of indigenous biodiversity (including kaimoana). The counter argument was that fishery management was solely the responsibility of the Ministry of Primary Industries.

19. Key to the Court's decision is that the Fisheries Act is concerned with sustainable utilisation of fisheries resources (and only to the extent appropriate to secure future stocks does it require decision makers to protect the aquatic environment) while the Resource Management Act (RMA) is concerned with protecting indigenous biodiversity, which has a much broader application. The Courts have determined that regional councils can control fishing and fisheries resources in the exercise of its section 30 functions.

20. The Court of Appeal outlined five indicators to provide guidance when considering whether a control could be implemented under the RMA in a way that does not act for fisheries management purposes.



21. For Bay of Plenty, the ruling has resulted in the identification of three protection areas surrounding reef systems around Motiti Island with new rules prohibiting the taking of all plants and animals (including fish and shellfish). The outcome has been controversial with some tangata whenua saying that their views were not represented in the process or decision.

22. The effect of this ruling is still being grappled with by regional councils who, until now, had seen fishery management as 'out of scope'. While this approach could technically be pursued, there are many implications.

23. First, is there a business case for Taranaki? Council would need to review the five indicators above to determine whether there was a need to manage the resource under the RMA (rather than Fisheries Act). Only then would Council consider a plan change to the Proposed Coastal Plan under the RMA (which is still proceeding with Environment Court Appeals). The results of any Plan change would be uncertain, costly and potentially out of step with what might be sought by iwi.

24. In addition, to pursue this approach would ultimately take decision-making and self-determination out of the hands of iwi for whom there is an appropriate process already in place under section 186A of the Fisheries Act. This could potentially impinge upon their role and right to act as kaitiaki.

25. Previously tangata whenua have approached the Council about concerns about kaimoana depletion and the Council has advocated for measures to protection resources, including increasing compliance monitoring capacity and increasing penalties for non-compliance.

Discussion

26. The media coverage and the results of engagement with tangata whenua, show the overfishing effects on the kaimoana shellfish stocks to a point where kaitiaki and kaumātua have had to place rāhui in order to protect and allow the recovery of these taonga for future generations. However, recognition and the understanding of rāhui across the wider community has not always been supported which has caused some tension. To ease that situation and gather wider support, hapū have printed and are distributing pamphlets and notices of the rāhui and contact details for those who wish to know more.
27. The implementation of a Fisheries Act section 186A temporary closure for up to two years would give statutory support for the rāhui. This process involves a formal iwi request, an opportunity for public submissions, and a decision by the Minister of Fisheries. The temporary closure is essentially monitored by fisheries officers and tangata whenua can also be involved.
28. A closure would provide time for the kaitiaki, kaumātua, hapū and the iwi to consider the effects and recovery of the taonga and what else may need to be completed.
29. The Regional Council has been monitoring a number of sites along the coast for many years. There are six sites that are surveyed twice a year. The survey design captures a representative sample of the rocky shore community at mid-shore height. Unfortunately, this tidal height means the survey do not often encounter pāua. However, the surveys provide a good overall picture of reef health, as well as an insight into how this relates to habitat and environmental factors such as natural sand movement. A number of significant sand burial events have been recorded over the years. But none have been recorded at the Manihi Road site, possibly because it is south of the Stony (Hangatahua) River and its high sediment input to the coastal marine area.
30. Council staff have expertise in monitoring the coastal marine area that may be able to be shared and enhanced by engagement with tangata whenua.
31. MPI fisheries officers do not seem to have a high public profile in the Taranaki community and could increase this and build some long-standing relationships, particularly with tangata whenua. More resources to effectively monitor the fisheries regulations would also be beneficial.

Financial considerations—LTP/Annual Plan

32. This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

33. This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks including, but not restricted to, the *Local Government Act 2002*, the *Resource Management Act 1991* and the *Local Government Official Information and Meetings Act 1987*.

Iwi considerations

34. This memorandum and the associated recommendations are consistent with the Council's policy for the development of Māori capacity to contribute to decision-making processes (schedule 10 of the *Local Government Act 2002*) as outlined in the adopted long-term plan and/or annual plan. Similarly, iwi involvement in adopted work programmes has been recognised in the preparation of this memorandum.
35. Iwi and hapū consulted as part of developing this memorandum have been acknowledged above.

Community considerations

36. This memorandum and the associated recommendations have considered the views of the community, interested and affected parties and those views have been recognised in the preparation of this memorandum.

Legal considerations

37. This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council.

AGENDA
Policy & Planning

Date 31 August 2022

Subject: Pest pathway programmes underway

Approved by: D Harrison, Director - Operations

S J Ruru, Chief Executive

Document: 3096471

Purpose

1. The purpose of this memorandum is to brief Members' on a new project with the Council partnering with the Ministry for Primary Industries (MPI) to increase awareness of biosecurity risks and pathways into Taranaki.

Executive summary

2. Council has jointly funded a programme with Ministry for Primary Industries (MPI) focusing on new to region pests and pest pathways.
3. This builds on current programmes such as the "Check Clean Dry" summer freshwater biosecurity programme with additional government funding supporting Te Kāhui o Rauru to undertake some of this work in south Taranaki.
4. Through our programmes, Hornwort has been identified in Lake Herengawe near Waverly. Council is currently working with landowners, Ngā Rauru and key partners to determine control options.
5. An early outcome of our increased media campaign has been the recent discovery of an infestation of Alligator weed near Waitara.
6. A delimiting survey is planned to assess the feasibility and then costs of any control operation.

Recommendations

That the Taranaki Regional Council:

a) receives this Memorandum *Pest pathway programmes underway*

b) notes Alligator weed has now been discovered in Taranaki with a delimiting survey now planned before control options can be assessed.

Background

7. In 2020, Council commissioned a report identifying high-risk pests and potential pathways for pest species in neighbouring regions but not yet found in Taranaki.
8. In late 2020, MPI approached Council, iwi and community interest groups to gauge interest in collaborating on a regional biosecurity initiative similar to Tauranga Moana Biosecurity Capital (refer https://tmbiosecurity.co.nz).
9. Progress on this initiative was initially delayed due to Covid and resourcing limitations within iwi and community groups. However, Council and MPI have now commenced a project that it expects can be adapted to better include iwi, community groups and industry with an interest in biosecurity into a much wider programme.
10. Council and MPI have agreed to co-fund a full time position on a two-year trial, primarily to develop and implement a biosecurity advocacy programme targeting pest pathways and high risk industries.
11. This builds on programmes already undertaken by council such as Weedbusters and Check Clean Dry (CCD).

Biosecurity Advocacy Programme

12. Council and MPI staff have finalised an operational work programme that includes:
    - Development and implementation of biosecurity advocacy programme
    - Working with industry including the port, roading contractors, nurseries and transport operators to help develop biosecurity policies for their operations
    - Trialling increased iwi involvement in biosecurity within their rohe
    - Continuing regular freshwater pest control programmes including Check Clean Dry
    - Local coordination of small incursion response programmes were appropriate.

Early success

13. As part of Council's contract with MPI, Council has engaged Te Kāhui o Rauru to undertake a freshwater advocacy programme within the Ngā Rauru rohe in South Taranaki. This work and has proven extremely valuable working with the local community to stop the spread of pests and advocating for the management of Hornwort in Lake Herengawe and is additional to the normal CCD summer programme.
14. Hornwort is a fresh water weed that can choke waterways and crowd out native species. It is widespread in Lake Rotorangi with current programmes aiming to educate lake users on the risks of spreading the pest to other waterways.
15. Council discovered the Hornwort was well establish in Lake Herengawe through CCD surveys and have been working with landowners, the Department of Conservation and Land Information New Zealand (LINZ) on control options.
16. The programmes increased use of social media focusing on pest/biosecurity risks to Taranaki have led to the discovery of Alligator weed in coastal dunes near the Waiongana river mouth.
17. The area is part privately owned, part public conservation estate and is a key bird breeding area with Banded dotterel and Caspian tern present. The area a Key Native Ecosystem and has an active council Biodiversity Plan.

18. Like Hornwort, Alligator weed also forms dense mats clogging waterways but can also survive in pasture and tolerates salt water Alligator weed does not seed in New Zealand but can spread by even the smallest fragment. Alligator weed is currently well established in other regions including both our neighbours.
19. In discussions with key experts, officers believe that the Alligator weed has travelled down the coast as a fragment and been washed up on a high/storm tide.
20. Officers have commenced the development of an incursion plan starting with a delimitating survey to determine how widespread it is along the coast. Waikato Regional Council and NIWA are supporting us with their expertise.
21. Control options for aquatic pests are limited and expensive and may require funding over and above current budgets. Council will be updated on next steps following the delimiting survey in November as this is the best time to spot infestations.

Next steps with the programme

22. In the coming month, Council will be undertaking increased education and publicly activities, including increasing media coverage and holding public workshops on pest risks. Key businesses will also be approached to develop biosecurity programmes.
23. The Council's summer CCD programme will start in November and we are hopeful that funding to continue to work with Te Kāhui o Rauru will also be approved by MPI.

Financial considerations—LTP/Annual Plan

24. This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

25. This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks including, but not restricted to, the *Local Government Act 2002*, the *Resource Management Act 1991* and the *Local Government Official Information and Meetings Act 1987*.

Iwi considerations

26. This memorandum and the associated recommendations are consistent with the Council's policy for the development of Māori capacity to contribute to decision-making processes (schedule 10 of the *Local Government Act 2002*) as outlined in the adopted long-term plan and/or annual plan. Iwi involvement in adopted work programmes has currently only involved Ngā Rauru, MPI with support from Council have taken the lead in approaching all Taranaki iwi regarding any expansion of the programme.

Community considerations

27. This memorandum and the associated recommendations have considered the views of the community, interested and affected parties and those views have been recognised in the preparation of this memorandum.

Legal considerations

28. This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council.

Appendices/Attachments

Document 3097426: hornwort info sheet

Document 3097425: alligator weed info sheet

Hornwort

Ceratophyllum demersum

www.weedbusters.org.nz

Family
Ceratophyllaceae (hornwort)

Also known as
Hornweed, coontail, lakeweed

Where is it originally from?
Asia, Africa, Australia, Malaysia, and North America

What does it look like?
Submerged, free-floating or anchored perennial that grows in water up to 16m deep. No roots are present, and it is usually lightly anchored by buried stems and leaves. Stems (30-150 cm long) are floating or submerged, branched, stiff and brittle. Thin dark green leaves (1-4 cm long) in whorls of 7-12 are densely crowded at the stem tip, increasingly spaced down the stem, and equally forked once or twice into stiff tapering segments with teeth on the outer edge. Produces minute green or white flowers, but is not known to fruit in New Zealand.

Photo: Rohan Wells

Are there any similar species?
Myriophyllum species have feathery not forked leaves, and their leaves are not stiff.

Why is it weedy?
New plants can form from each piece of the easily broken stems. Rapidly invades water of varying clarity, temperature, light and nutrient level, and dense growth habit crowds out native species. There are no native plants of a similar height to compete with it.

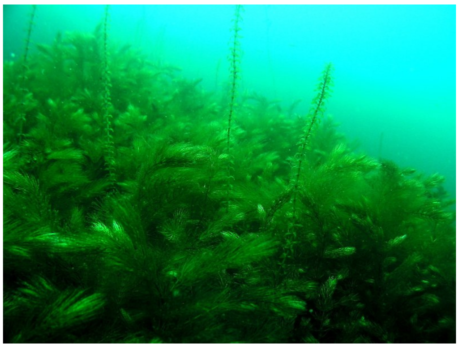


Photo: Rohan Wells

How does it spread?
Fragments are spread within catchments by the flow of the water. New catchments are infested when fragments are transported by contaminated boats and trailers (and occasionally motor cooling water), eel nets, diggers, and people liberating fish.

What damage does it do?
Forms dense beds, shades out smaller native species and prevents them establishing. It can contribute to blockages of waterways and flooding. Rotting vegetation stagnates water, killing fauna and flora. Threatens most submerged plant communities.

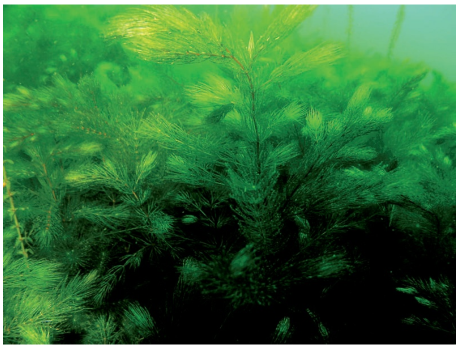


Photo: NIWA

Which habitats is it likely to invade?
Still or slow-moving waterbodies and lagoons. It could potential establish throughout New Zealand.

What can I do to get rid of it?
Report all sites to your regional council or local Department of Conservation office.

Alligator weed

Alternanthera philoxeroides

www.weedbusters.org.nz

Family
Amaranthaceae (amaranth)

Where is it originally from?
South America

What does it look like?
Perennial aquatic or terrestrial herb with long, fibrous roots. Pink, soft, hollow stems (<10 m long) root at nodes, creep along ground, or float on water with tips standing upright and forming dense stands or rafts. Dark green, waxy leaves (3-13 x 1-4 cm) are opposite. Clusters (1-2 cm diameter) of white clover-like flowers appear from December to February but no seed is produced in New Zealand.

Photo: Trevor James

Are there any similar species?
Mukunu-wenna (*Alternanthera sessilis*), nahui (*Alternanthera denticulate*), *Ludwigia* species, and willow weed all look similar.

Why is it weedy?
Rapidly forms dense mats over water and margins, with roots down to 2 m deep. Stem sections break and root readily. Tolerant of 30% sea water, high temperatures, high pollutant levels, grazing, and other damage, but intolerant of frost.

Photo: Carolyn Lewis

How does it spread?
Reproduces from stem sections only. Water flow, contaminated diggers, soil movement, dumped vegetation, machinery, eel nets, livestock, boats and trailers all spread fragments into new catchments, pastures, cropping land, waste places and drains. Also potentially spread by ethnic groups mistaking alligator weed for mukunu-wenna (*Alternanthera sessilis*), which they use as a vegetable.

What damage does it do?
Replaces most other herbaceous species on water and dry land, causes silt accumulation, obstructs water usage, and causes flooding. Rotting vegetation degrades habitats for aquatic fauna and flora.

Photo: Carolyn Lewis

Which habitats is it likely to invade?
Freshwater and moderately brackish sites, estuaries, damp habitats, dune lakes and hollows and wetlands, and can also grow in dry pastures, crops and urban areas.

What can I do to get rid of it?
Report all sites to your regional council.
1. Dig out small patches: either dispose of all pieces at a refuse transfer station, or dry them out and burn them - don't leave pieces of alligator weed on the top of soil or attempt to compost them as each piece can regrow.
2. Spray terrestrial sites (spring to autumn): glyphosate (20ml/L) or metsulfuron-methyl 600g/kg (5g/10L). Use penetrant in all herbicide mixes.
3. Spray aquatic sites (spring to autumn): glyphosate (20ml/L + penetrant).
4. Weedmat: cover site for 6-12 months to keep out light, checking edges for creeping stems.

What can I do to stop it coming back?
Excluding stock from infested areas, lowering the light levels and nutrient runoff by planting along waterways can help in the ongoing management of alligator weed sites. As stems potentially resprout at every node, regular checking of sites after control efforts is essential. There are biocontrol agents available for alligator weed growing over water - contact your regional council to see if this option is suitable for your site.

Whakataka te hau

Karakia to open and close meetings

Whakataka te hau ki te uru	Cease the winds from the west
Whakataka te hau ki tonga	Cease the winds from the south
Kia mākinakina ki uta	Let the breeze blow over the land
Kia mātaratara ki tai	Let the breeze blow over the ocean
Kia hī ake ana te atakura	Let the red-tipped dawn come with a sharpened air
He tio, he huka, he hauhu	A touch of frost, a promise of glorious day
Tūturu o whiti whakamaua kia tina.	Let there be certainty
Tina!	Secure it!
Hui ē! Tāiki ē!	Draw together! Affirm!

Nau mai e ngā hua

Karakia for kai

Nau mai e ngā hua	Welcome the gifts of food
o te wao	from the sacred forests
o te ngakina	from the cultivated gardens
o te wai tai	from the sea
o te wai Māori	from the fresh waters
Nā Tāne	The food of Tāne
Nā Rongo	of Rongo
Nā Tangaroa	of Tangaroa
Nā Maru	of Maru
Ko Ranginui e tū iho nei	I acknowledge Ranginui above and
Ko Papatūānuku e takoto ake nei	Papatūānuku below
Tūturu o whiti whakamaua kia	Let there be certainty
tina	Secure it!
Tina! Hui e! Taiki e!	Draw together! Affirm!

AGENDA AUTHORISATION

Agenda for the Policy and Planning Committee meeting held on Tuesday 30 August 2022.

Confirmed:

24 Aug, 2022 1:08:35 PM GMT+12

A D McLay

Director Resource Management

Approved:

24 Aug, 2022 2:22:44 PM GMT+12

S J Ruru

Chief Executive