Otago Regional Council

State of the Environment

Groundwater Quality in Otago

Otago Regional Council

Private Bag 1954, Dunedin 9054

70 Stafford Street, Dunedin 9016

Phone 03 474 0827

www.orc.govt.nz

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Report prepared by: Amir Levy, Marc Ettema (Groundwater Scientists), Xiaofeng Lu (Scientist - Hydrology)

Reviewed By: Jens Rekker (Senior Scientist - Catchment Modelling)

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Executive Summary

This report summarises the results from Otago Regional Council (ORC)'s groundwater quality State of the Environment (SoE) monitoring programme which monitors groundwater quality across the region. The aims of the programme include data provision and assessment of groundwater quality/quantity in Otago, understanding groundwater flow and associated surface water ecosystems, assessing the impacts of land use and the effectiveness of resource management policies, and environmental reporting in accordance with the Resource Management Act (RMA).

Groundwater is an important resource in Otago and is used across the region for drinking, irrigation, industry and stock water supply. In addition to that, groundwater discharge significantly impacts stream flow, water quality, and ecology in various catchments across the region (e.g. the Kakanui-Kauru, Shag). In contrast to the extensive gravel aquifers found in some New Zealand regions (e.g. the Canterbury Plains, Hawke's Bay) most of Otago's aquifers are small and are situated in a variety of geological settings (e.g. disconnected river valley basins associated with glacial outwash or moraine deposits, limestone, fractured rock).

The groundwater quality SoE monitoring network currently consists of 55 monitoring bores, situated on both public and private land with varying degrees of borehead security. The bores are located across Otago's five Freshwater Management Units (FMU). However, their distribution is uneven, with the Catlins and Dunedin & Coast FMUs having only one monitoring bore each. Furthermore, some of the aquifers in the region are currently not monitored. This report assesses groundwater quality results from the start of monitoring in each currently active SoE bore to the end December 2019. Groundwater quality in the SoE bores is monitored quarterly for microbiological parameters, major ion geochemistry, and metals concentrations. The sampling follows the National Environmental Monitoring Standards [NEMS] (2019) and the samples are analysed in an accredited laboratory.

This report summarises the state of groundwater quality in Otago in relation to drinking water quality. This is assessed by comparing groundwater E. coli, dissolved arsenic, and nitrate concentrations against the Drinking Water Standards for NZ (DWSNZ) thresholds. The E. coli data indicates that potential faecal contamination is a significant water quality issue across Otago, with exceedances of the DWSNZ Maximum Acceptable Value (MAV) of <1MPN/100mL detected in 75% of the bores in the region at a point during the monitoring period. Exceedances were detected in each of Otago's FMU/rohes. However, it is important to note that the data includes the full monitoring period for each bore and that some of these reported exceedances are potentially due to changing laboratories.

The proportion of E. coli exceedance across Otago (75%) is similar to that of the Clutha, North Otago and Taieri FMUs. However, a wider variability was observed within the different rohes of the Clutha FMU, with higher proportions (and contamination risk) than the regional one measured in the Manuherekia and Lower Clutha rohes. Conversely, the proportion of exceedance in the Upper Lakes rohe was lower, whilst that of the Dunstan rohe was similar to the regional. An assessment of E. coli exceedance and bore depth shows that the highest proportion of E. coli exceedance was in bores shallower than 10m (92%) and the lowest (40%) in bores deeper than 60m.

The E. Coli data indicate that groundwater and bores in Otago are vulnerable to faecal contamination. However, elevated E. Coli can also be a local issue and is strongly dependent on bore security, hence, the SoE data does not present a complete mapping of this risk. Nevertheless, it is strongly recommended that bore owners/groundwater users ensure adequate borehead security (to prevent contaminant entry into the aquifer) and regularly test their groundwater for indicator bacteria. This is particularly important after periods of heavy rainfall. If E. Coli is detected, water should be boiled or disinfected.

Arsenic is a toxic, though naturally occurring, element, present at low concentrations in soil, water, plants, animals and food. Chronic exposure to elevated arsenic can lead to a range of cancers. Arsenic in groundwater can originate from anthropogenic (e.g. sheep dips, treated timber posts) and geological sources (e.g. schist lithology, reduced peat deposits, and volcanic rocks). The spatial distribution of maximum arsenic concentrations in Otago groundwater shows that concentrations exceeded the MAV in only seven SoE monitoring bores, five of which are in the Upper Clutha/Wakatipu Basin area, which are underlain by schist lithology known to contain arsenic. No arsenic above the MAV was detected in any bores in the North Otago, Dunedin & Coast, or Catlins FMUs. Nevertheless, due to the abundance of arsenic-containing schist lithology, particularly in the Upper Clutha, and the high spatial variability of arsenic in groundwater, it is strongly recommended that bore owners regularly test their bore water for arsenic in an accredited laboratory.

Nitrate (NO_3-N) is a dissolved, inorganic form of nitrogen (N), a key nutrient required for the growth of plants and algae. Excess nitrate can adversely impact water quality (e.g. eutrophication) and cause health concerns. Groundwater nitrate concentration data shows that none of the aquifers in Otago has a median nitrate concentration above the DWSNZ MAV of 11.3mg/L. However, it did highlight a variable degree of nitrate contamination in relation to the MAV, with the median concentration in some aquifers, particularly in North Otago and the Lower Clutha, closer to the MAV. Conversely, the median nitrate concentrations in many aquifers are much lower.

The report also assessed the potential impacts of groundwater nutrient concentrations (nitrate nitrogen, Dissolved Reactive Phosphorus (DRP), and ammoniacal nitrogen (ammonia) on surface water quality. This was done by comparing groundwater nutrient concentrations in shallow bores with surface water limits from regional (Regional Plan: Water [RPW] Schedule 15 limits for receiving water bodies) and national (National Policy Statement for Freshwater Management [NPS-FM]) standards for surface water quality. However, It is important to note that these standards do not include limits for groundwater, hence, this approach solely provides an overview. The results show that most groundwater nitrate and DRP concentrations exceed the surface water limits. Conversely, most ammonia concentrations were below the limit. However, that these standards (i.e. the RPW limits and NPS-FM bands) are for surface water, hence this comparison only provides a guideline/screening exercise rather than a direct assessment.

The groundwater quality assessment for each FMU/aquifer shows that, similar to surface water, groundwater quality across the region is also highly variable. The results from the Clutha FMU show a high variability, with good groundwater quality in some rohe (i.e. the Upper Lakes, Dunstan) and degraded quality in others, particularly the Lower Clutha. The main issues in this FMU are elevated E. coli and dissolved arsenic concentrations in some bores, with elevated nutrient concentrations also common. The results from the Upper Lakes and Dunstan rohes generally show compliance with the DWSNZ, although elevated E. coli counts were measured in some bores. Elevated dissolved arsenic concentrations were also measured in some bores, although their source is likely to be geological, i.e. the prevalent schist lithology. Nutrient concentrations are generally below the DWSNZ for nitrates. High DRP and nitrate concentrations were measured in Kingston and Glenorchy, likely due to high septic tanks density, shallow bores, and poor borehead security. These can potentially adversely impact water quality in Lake Wakatipu, although groundwater (and nutrient) fluxes into the Lake are likely to be substantially lower than the surface water inflows. Groundwater quality in the Manuherekia rohe is generally fair although E. coli exceedances were measured in most bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherekia Alluvium Aquifer and Manuherekia Claybound Aquifer monitoring bores generally near the low intensity landuse reference value (<2.5mg/L). However, an increasing trend has been observed in the Manuherekia Groundwater Management Zone (GWMZ) monitoring bore, where concentrations exceed ½ of the MAV. No elevated arsenic concentrations were measured in any of the monitoring bores in the rohe. In relation to potential impacts on ecosystem health, the results from the shallow monitoring bores show that nitrate and DRP concentrations exceed the RPW limits. This suggests that groundwater-surface water interaction in this area can adversely impact surface water quality. Groundwater quality results from the Lower Clutha rohe indicate some water quality issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. One of the bores in the Inch Clutha gravel aquifer also has elevated arsenic concentrations above the MAV. The results also show issues with elevated nutrient concentrations, some of which are due to shallow, poorly-secured monitoring bores. These results also support the reported poor surface water quality results from this area (ORC, 2017).

Groundwater results from the Taieri FMU indicate potential risk for faecal contamination, with E. coli exceedance measured in all three of the FMU’s aquifers. The pattern of nitrate concentrations is mixed, with elevated concentrations over ½ of the MAV in some bores whilst concentrations in others are within the low intensity landuse reference conditions. The assessment against surface water quality indicates potential issues, with several exceedances of the Schedule 15 nutrient limits. It is likely that some of these elevated results are due to monitoring bores being shallow, insecure, and located near dairy farms and/or septic tanks. Nevertheless, these can potentially adversely impact surface water quality.

The results from the North Otago FMU indicate significant water groundwater quality issues, particularly regarding E. coli exceedances and elevated nitrate concentrations, which are the highest in the region. Nitrate concentrations in monitoring bores in the North Otago Volcanic Aquifer (NOVA) and Kakanui-Kauru aquifers substantially exceed the 11.3mg/L MAV, with concentrations in some bores exceeding 32.2mg/L (though the bores are not used for drinking). Nitrate concentrations in some bores in the Lower Waitaki aquifer are over ½ of the DWSNZ MAV. Potential faecal contamination is also a concern, with elevated E. coli measured in some bores in each of the aquifers within the FMU. The results indicate potential adverse impacts on surface water quality, with elevated nutrient concentrations substantially exceeding the RPW and NPS-FM limits, and this FMU having the region's most degraded groundwater quality. Due to the strong groundwater-surface water interaction in many North Otago catchments, it is imperative to understand the groundwater and surface water interactions in this FMU.

There are several recommendations in light of this report. These include:

- Ensure bore owners practice good bore security to prevent contaminant migration to bores. This includes improving ORC's regulatory and education regimes regarding this.
- Publishing the SoE groundwater quality monitoring results online with suitable symbology that clearly indicates when parameters exceed the DWSNZ MAVs.
- Review the legislation and management of known high risk activities to water quality in areas of poor groundwater quality.

- Embark on a programme to replace existing unsuitable SoE bores with new dedicated ones. It is recommended that new bores will be placed based on their representation of the different FMU/aquifers. These should be located on public land to ensure long term access. It is also recommended to have an ongoing maintenance programme for the bores, where they are pumped, surveyed, and the head security is confirmed on a regular basis.

1. Introduction

The Otago region covers an area of approximately 32,000km^2, with its boundary stretching from the Waitaki River in the north to Brothers Point in the south and inland to Lake Wakatipu and the Haast and Lindis Passes. The Otago landscape varies greatly in climate, land use and topography. It includes the Southern Alps and alpine lakes; dry central areas with tussock, grassland and tors; dramatic coastlines around the Catlins and Otago Peninsula; extensive high country stations; and lowland pasture in the western part of the region. The character of the region's groundwater and surface water bodies is also highly diverse, reflecting the region's variation in environmental conditions and land use.

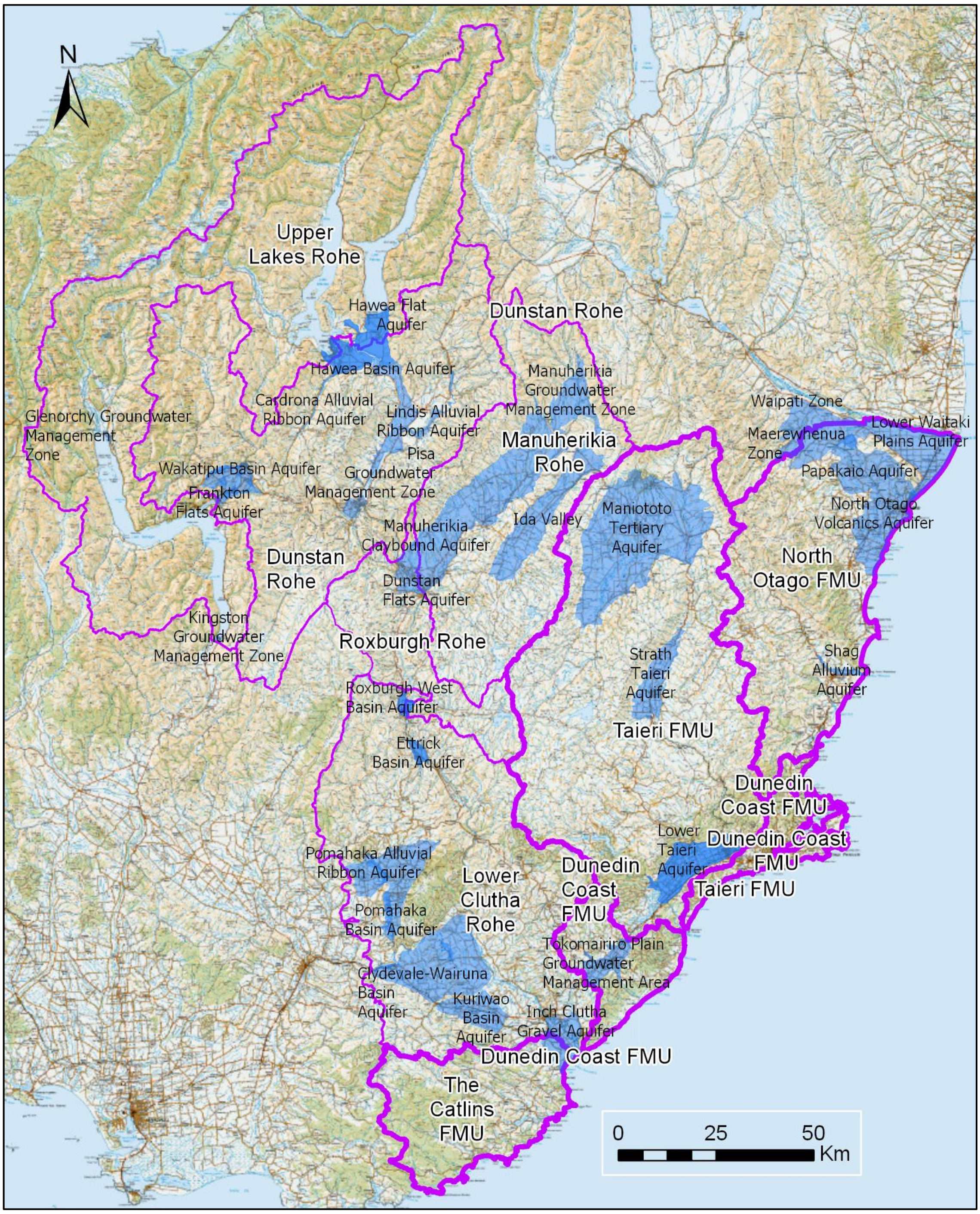
The main Clutha /Mata-Au River drains most of the Otago region, with a catchment area of around 21,000km^2. The river is mainly fed by outflows from the large Wanaka, Hawea, and Wakatipu alpine lakes, which provide 75% of the flow at Balclutha. In addition to the lakes, the Clutha catchment also receives flow from other large rivers: the Kawarau, Cardrona, Lindis, Shotover, Fraser, Nevis, Manuherekia, Teviot, Pomahaka, Waitahuna and Waiwera.

The Taieri River catchment is the second largest in Otago, with an area of 5,060km^2. The Taieri rises in the uplands of Central Otago and meanders around the Rock and Pillar block mountain range before passing through a gorge. It then flows through the Taieri Plain, where it joins the Lake Waipori and Waihola catchments and become tidal before emptying into the sea at Taieri Mouth.

Other significant catchments are located in North Otago, which include the Kakanui, Shag, and Waitaki Rivers. These rise in high country and pass through mainly dry downlands. There is also the Tokomairiro River, which flows through Milton and drains rolling hill country situated between the Taieri and Clutha catchments. Rivers in the southern part of Otago, particularly in the Catlins area, emerge from wetter, and often forested, hills (Otago Regional Council [ORC], 2017a). The catchments in Otago are grouped into five Freshwater Management Units (FMU), Figure 1.

- Clutha Mata-Au FMU (sub divided into five *Rohe*):
    - Upper Lakes
    - Dunstan
    - Manuherekia
    - Roxburgh
    - Lower Clutha
- North Otago FMU
- Taieri FMU
- Dunedin & Coast FMU
- The Catlins FMU

Figure 1: Location of Otago's Freshwater Management Units (FMU) and rohe (delineated in purple) and aquifers (in blue).



The environmental context in which Otago's water bodies exist is characterised by a wide variability in precipitation, from high rainfall in the Southern Alps, to very low rainfall and high evaporation in the rain-shadows resulting in semi-arid central Otago valleys. Despite the large water volumes in the region, distinct parts of Otago are among the driest in New Zealand, with several rivers and tributaries characterised as "water-short". These include the Lindis, Manuherekia, Taieri, Kakanui, and the Shag (ORC, 2004). Due to this high variability, groundwater forms an important part of Otago's hydrology and water resources.

Groundwater is used across the Otago region for drinking, frost-protection, irrigation, industry and stock water supply. In addition to that, groundwater discharges significantly impacts stream flow, water quality, and ecology in various streams across the region (e.g. the Kakanui-Kauru, or the Shag). However, overlying land uses may also impact groundwater quality and levels. Monitoring the state and trends of groundwater quality and quantity is therefore important for informing resource management policy and assessing its effectiveness.

The Otago Regional Council (ORC) operates a long term State of Environment (SoE) programme for monitoring groundwater quality and levels across the region. The monitoring of groundwater quality and levels is conducted for various purposes which include:

- Understanding groundwater and associated surface water ecosystems,
- Assessing the impacts land use on groundwater,
- Determining the suitability of groundwater for specific uses (e.g. drinking water, irrigation, and stock watering),
- Assessing the effectiveness of resource management policies.

The information is also used for reporting under to the obligations in s35 of the Resource Management Act (1991). The aims of the SoE monitoring are:

- Collecting baseline information regarding groundwater quality/levels
- Providing a continuous record to allow detection of state and trends in groundwater levels and quality
- Assess the impact of land use (e.g. irrigation, farming) and policy changes on groundwater levels and quality.

The groundwater SoE monitoring network currently includes 76 bores, which are located across Otago's five FMUs. The bores are located on both private land and public land, particularly public road reserves. Groundwater levels are currently monitored continuously in 34 bores using pressure transducers that record bore water level every 15 minutes. Groundwater quality is assessed by collecting quarterly grab samples from 55 bores and their analysis in an accredited laboratory. The samples are analysed for microbiological (Escherichia Coli, [E. Coli]) and geochemical (major anions and cations, metals) parameters (Appendix 1). In addition to that, water level and physicochemical parameters (temperature, pH, Electrical Conductivity, Dissolved Oxygen) are also measured in the bore as part of the sample collection procedure. The sampling protocols follow the National Environmental Monitoring Standards for groundwater sampling, measurement, processing, and data archiving (NEMS, 2019).

This report summarises the SoE groundwater quality results by referring to relevant drinking water and water quality standards for ecosystem health. It provides a regional summary of groundwater quality parameters followed by a more detailed analysis at the FMU/rohe and aquifer levels. Section 2 briefly describes Otago's groundwater resources and main uses. Section 3 describes the SoE groundwater quality monitoring network, the methodology for collecting groundwater samples, and their analysis. Section 4 provides the groundwater quality monitoring results at the regional, FMU/rohe, and aquifer scales. A discussion of the results and recommendations are provided in Section 5.

2. Groundwater resources in Otago

Groundwater is used across the Otago region for drinking, irrigation, industry, and stock water supply. In addition to that, groundwater discharge also significantly impacts stream flow, water quality, and ecology in various streams across the region (e.g. the Kakanui-Kauru, Shag). However, in contrast to the extensive aquifers located in other New Zealand regions (such as Canterbury and Hawke's Bay), the aquifers in Otago are generally small. Otago aquifers were identified within various geological settings, mainly disconnected basins that are associated with glacial outwash or moraine deposits in river valleys (i.e. alluvial/fluvial depositional environments), that can contain multiple aquifers, depending on the environment in which they were formed. The geological strata where aquifers were identified within the Otago region include:

- Quaternary outwash and recent alluvial gravel (unconfined aquifers)
- Tertiary units of varying properties (normally confined/semi-confined aquifers)
- Claybound alluvial gravels and sediments in higher and therefore older terrace settings (unconfined aquifers)
- Volcanic deposits
- Other units (limestone, fractured schist, and basal quartz conglomerates)

Although groundwater is present within the substrata of most localities within Otago, there are limited areas where bores can sustain a reliable supply of water (Heller, 2001). Within these restricted areas, bores can provide economically significant water.

3. Groundwater monitoring methodology

The groundwater quality network consists of 54 bores, whose depths range between 3.3m (bore no. J42/0762) and 90m (J41/0249). However, the details on each bore for many SoE bores lack information such as screen depth or interval (only available for 18 bores), and lithological logs (geological description of the bore), only available for 33 bores. The location of the monitoring bores within each FMU are shown on Figure 1. Details of the SoE monitoring bores are provided in Appendix 1.

The earliest available data is from August 1985 (bore J41/0249), with other bores in North Otago (J41/0008 and J41/0317) also being monitored for over 25 years. The sampling frequency varied during the monitoring periods, becoming quarterly since March 2011. The parameters for analysis and the laboratory have also changed over time, with Hill Laboratories (Hill) in Christchurch providing the analysis since December 2017. Some of the monitoring bores were also disused and replaced over the course of the monitoring period.

The monitoring bores are situated on both private and public land and there is a wide variability in borehead condition and security. Bores recently installed by ORC usually benefit from substantially higher construction standards and security, Figure 2. SOE monitoring bores located in public land are desirable since losing access for sampling due to permission not continuing has been the main cause for the loss of monitoring at particular bores. Conversely, many of the private bores suffer from very poor borehead security and other practices that increase the risk for contaminant migration into the aquifer and compromising sample integrity (i.e. livestock access to the borehead, storage of chemicals near the bore, access difficulties, pumps continuously running). An example of purpose-drilled monitoring bores is provided in Figure 2.

Figure 2: Examples of suitable, secure, purpose-drilled monitoring bores. Note the sealed concrete pad surrounding the bore head, raised casing above ground level, and the lockable cap.

The SoE monitoring programme samples and analyses groundwater for microbiological (Escherichia Coli, [E. Coli]), cations and metals (e.g. dissolved arsenic, iron, calcium, magnesium) major anions (e.g. sulphate, bicarbonate, chloride), and nutrients (Nitrate Nitrogen, Dissolved Reactive Phosphorus, Ammoniacal Nitrogen). The full list of parameters and analytical methods is provided in Appendix 2.

The ORC SoE groundwater sampling follows the National Environmental Monitoring Standards (NEMS, 2019) methodology. This method obtains a representative sample by purging[1] a minimum of three well volumes prior to the sample collection. The volume is calculated using the bore depth and the Static Water Level (SWL) in the bore, which is measured using a dip meter upon arrival on site. In addition to that, groundwater physicochemical parameters (pH, temperature, Dissolved Oxygen [DO], and Electrical Conductivity [EC]) are monitored during the purging using a handheld YSI probe in order to ensure their stability, which indicates that the bore is adequately purged. After a minimum of three volumes are purged and the parameters are observed to stabilise, the sample is then collected in bottles supplied by the laboratory. The equipment used for sampling is washed in representative water at least three times in order to prevent cross contamination between sites. The samples are stored in a dark, chilled bin and couriered to Hill Laboratory at the end of the sample day. The results are then coded based on the NEMS (2019) Quality Codes and digitally recorded in Hilltop Sampler. The main parameters analysed for ORC's groundwater SoE monitoring and the laboratory analytical Limits of Detection (LoD) are shown in Table 1. The LoD is provided by Hill Laboratories.

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[1] In effect, pumping and discarding bore water

Table 1: Analytical Limit of Detection for SoE groundwater quality parameters

Parameter	Limit of Detection (LoD)
Microbiology	
Escherichia coli	1 MPN/100mL
Anions	
Bicarbonate Alkalinity	1.0g/m^3 as $CaCO_3$
Carbonate Alkalinity	1.0g/m^3 as $CaCO_3$
Total Alkalinity	1.0g/m^3 as $CaCO_3$
Total Hardness	1.0g/m^3 as $CaCO_3$
Hydroxide Alkalinity	1.0g/m^3 as $CaCO_3$
Chloride	0.5g/m^3
Fluoride	0.05g/m^3
Sulphate	0.5g/m^3
Cations & metals	
Dissolved Arsenic	0.0010g/m^3
Dissolved Cadmium	0.00005g/m^3
Dissolved Calcium	0.05g/m^3
Dissolved Chromium	0.0005g/m^3
Dissolved Iron	0.02g/m^3
Dissolved Magnesium	0.02g/m^3
Dissolved Manganese	0.0005g/m^3
Dissolved Potassium	0.05g/m^3
Dissolved Sodium	0.02g/m^3
Approx. Total Dissolved Salts	2g/m^3
Nutrients	
Total Nitrogen	0.010g/m^3
Total Ammoniacal-N	0.005g/m^3
Nitrite-N Trace	0.0010g/m^3
Nitrate-N	0.0010g/m^3
Nitrate-N + Nitrite-N (NNN) Trace	0.0010g/m^3
Total Organic Nitrogen (TON), trace level	0.012g/m^3
Dissolved Reactive Phosphorus (trace)	0.0010g/m^3
Total Phosphorus	0.004g/m^3

4. Monitoring results

This section assesses the SoE groundwater quality monitoring results in relation to drinking water quality and ecosystem health. Drinking water quality is assessed against the New Zealand Drinking Water Standards [DWSNZ] (Ministry of Health [MoH], 2005 revised 2018), with a focus on Escherichia Coli (E. coli), dissolved arsenic, and nitrate nitrogen, all determinants that have manifested concentrations of health concern in past groundwater monitoring. The report also assesses ecosystem health using groundwater nutrient concentrations for nitrate nitrogen (nitrate), ammoniacal nitrogen (ammonia), and Dissolved Reactive Phosphorus [DRP]). These concentrations are assessed against regional and national water quality standards for ecosystem health (i.e. nuisance plant/algal growth and toxicity). The results cover the period between the start of monitoring in each active SoE bore (i.e. a monitoring bore that is currently being sampled) and the end of the 2019 calendar year.

This section follows the following structure:

- Section 4.1 describes the monitoring parameters and the standards against which they are assessed followed by a regional overview of groundwater quality in Otago.
- Sections 4.2 – 4.5 describes groundwater quality results in the different FMUs/rohes and aquifers across Otago.
- In addition to the groundwater quality results, each section also includes a brief description of the monitored aquifers and SoE bores within the different FMUs.

4.1 Regional overview of groundwater quality

4.1.1 Drinking Water Standards

4.1.1.1 Escherichia Coli (E. Coli)

Groundwater can be compared to the drinking water standards for New Zealand with reasonable justification. In rural communities without reticulated water, groundwater is the primary and preferred drinking / domestic water source. Shallow groundwater is consumed by people across significant areas of Otago often without water treatment or regular monitoring for potential contaminants. Therefore, considering the regional SoE groundwater analysis results in the context of drinking water standards relates to the same magnitude of concentrations that humans would be exposed to from bore, well or spring water supplies.

While groundwater is less vulnerable to contamination by potentially pathogenic microorganisms than surface water, groundwater may still manifest instances of microorganism occurrence. Faecal bacteria contamination in (drinking) water can originate from livestock, wastewater discharges, effluent application, and stormwater discharge, with contamination risk increasing following heavy rainfall. Escherichia Coli (E. Coli) is used as the indicator organism for bacterial compliance testing for the DWSNZ, where its presence suggests contamination of drinking water by faecal material and pathogenic microorganisms. The DWSNZ Maximum Acceptable Value (MAV) for E. Coli is <1 MPN (Most Probable Number)/100mL. Although any measurement above and including this value exceeds the DWSNZ MAV, a single exceedance is not always a reliable indication for contamination risk status, as groundwater quality can vary temporally. This report therefore assesses the percentage of exceedances above the MAV for each FMU and aquifer, following a similar approach to Environment Canterbury [ECan] (2018). The calculated percentage exceedance of the MAV for each SoE bore (i.e. the number of exceedances divided by the total number of samples from each bore) are shown on

Figure 3. Bores delineated in blue and light green suggest low risk, with no exceedances and <5% exceedance, respectively. Bores delineated in yellow are at a higher risk (5-50% exceedances) and may not be suitable for drinking water without treatment. Bores delineated in red are at the highest risk, with >50% of the samples exceeding the DWSNZ MAV.

The percentage of bores in each exceedance category for the Otago region and the number of bores for each category for the different FMUs and rohe are provided in

Figure 4 and Figure 5, respectively. This indicates that E. coli was detected in 75% of the bores in the region at **a point** during the monitoring period and that E. Coli exceedances were detected in each of Otago's FMU/rohes,

Figure 4. Again, it is important to note that the data includes the **full** monitoring period for each bore. It is also important to note that the results between October 2014 and June 2017, which read <1.6MPN/100mL, were analysed by a different laboratory (i.e. Water Care), hence, these results are potentially related to a higher Limit of Detection rather than an exceedance. Nevertheless, this report took a conservative approach which considers the results of <1.6MPN/100mL as exceedances.

Figure 3: Percentage exceedance of the E. Coli MAV for each bore. The map also shows Otago's FMUs and rohe (in purple) and aquifers (teal). The aquifer names are shown in Figure 1.

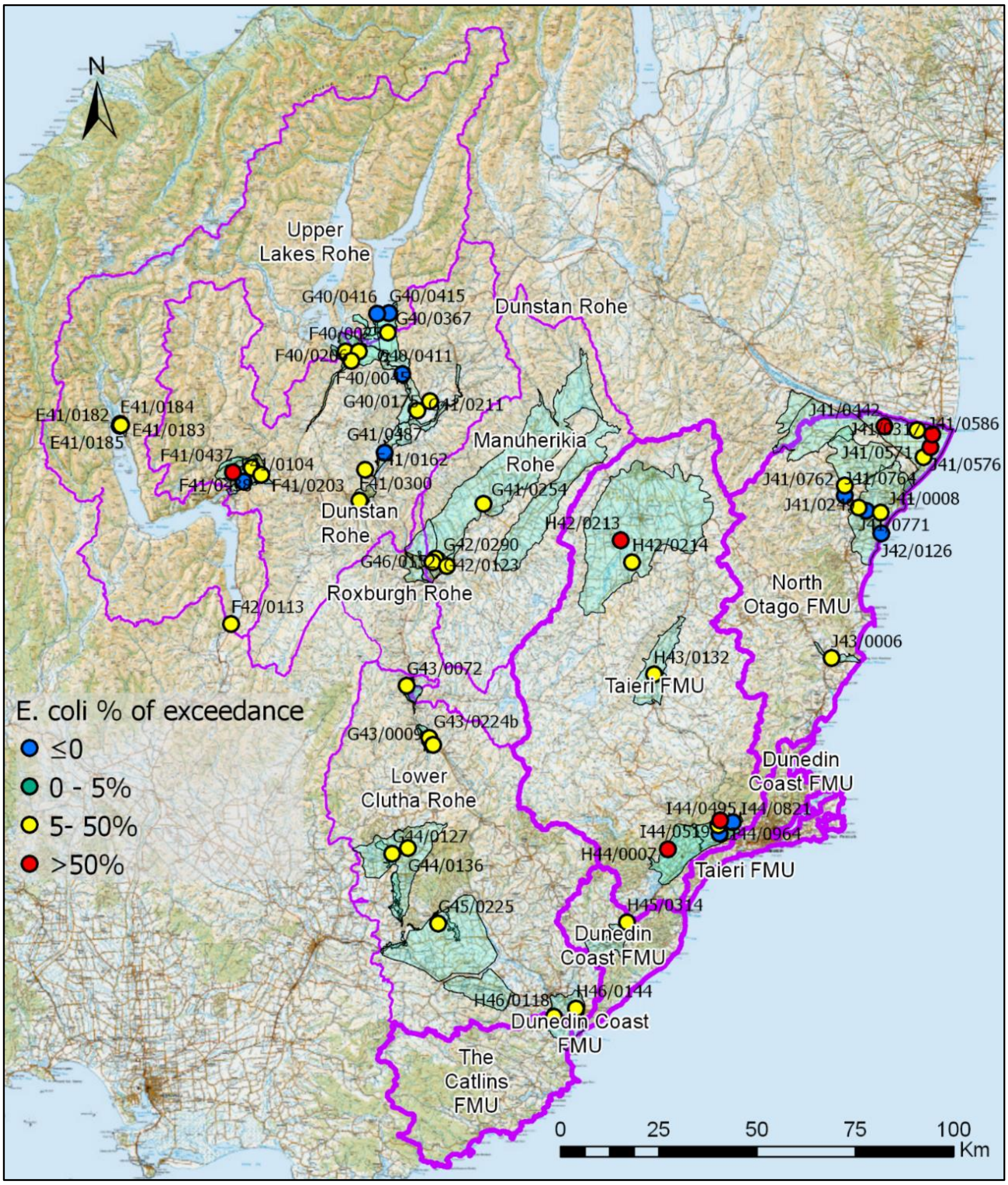
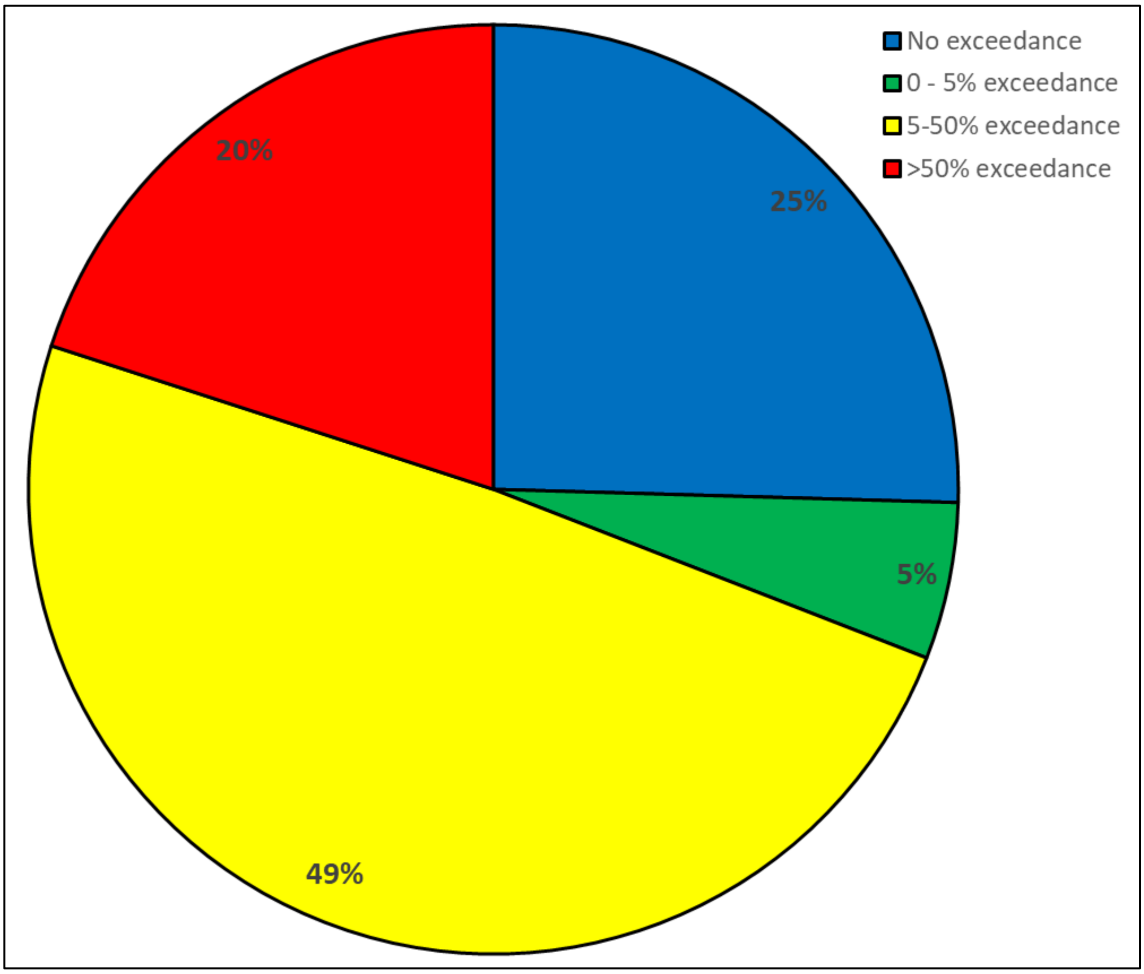


Figure 4: Percentage of bores in each of the exceedance categories (i.e. percentage of the samples that exceeded the MAV) for the whole Otago region

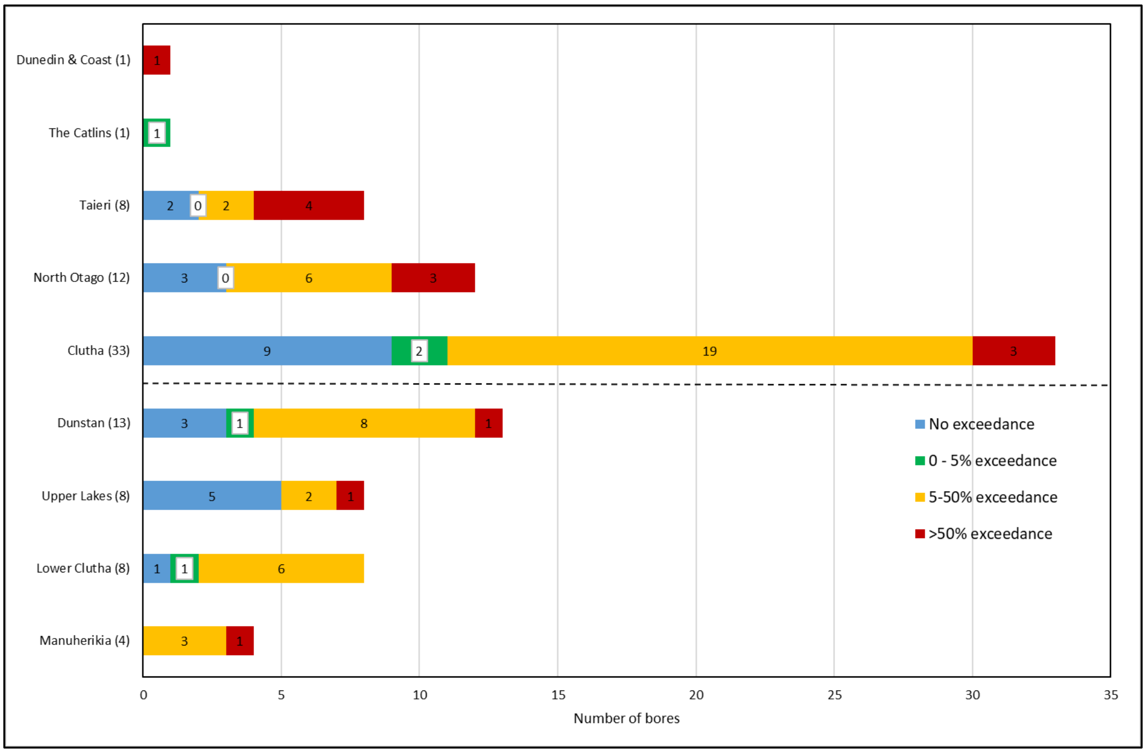


The exceedance data for the different FMU/rohe is shown in Figure 5. This indicates that the proportion of regional exceedance (75%) is similar to that of the Clutha, North Otago and Taieri FMUs. However, a wider variability was observed within the different rohes of the Clutha FMU. The exceedance percentage in the Dunstan rohe (77%) was similar to the regional one, whereas the exceedance percentage in the Upper Lakes rohe (38%) was lower than the regional. Conversely, the exceedance percentage in the Lower Clutha (88%) and Manuherekia (100%) were higher than the regional one, indicating a higher contamination risk in these rohes. The Catlins FMU have exceedance in <5% of the samples and the Dunedin & Coast FMU having exceedances >50% of the samples. However, there is only one SoE monitoring bore in each of these FMUs, hence the data is highly skewed.

The E. Coli monitoring data indicates that potential faecal contamination is a serious water quality issue across the Otago region. However, despite the wide spread of E. Coli exceedance across the region (

Figure 4), it is also important to note that elevated E. Coli can be a local issue and is strongly dependent on bore security, hence, the SoE monitoring data does not present a complete mapping of this risk. It is also important to note that the analysis provided summarises all the available data to December 2019, hence, it does not look at whether E. Coli exceedances have changed over time. It also only addresses the exceedance/no exceedance criteria, regardless of the measured E. Coli count.

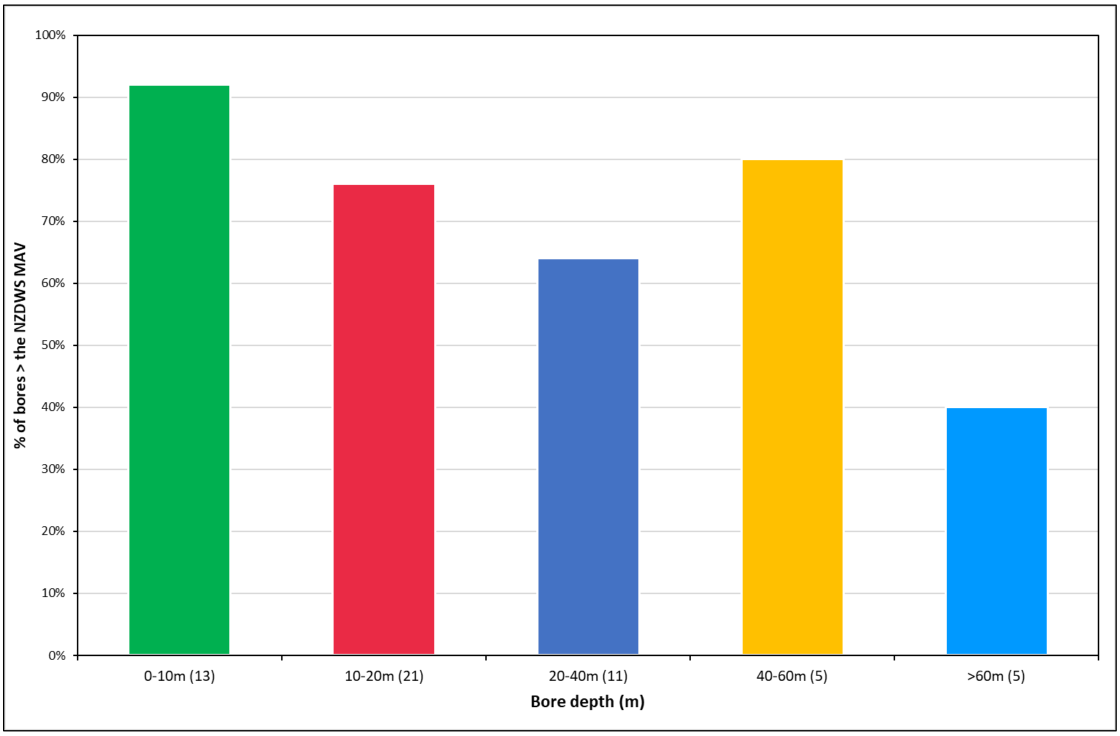
Figure 5: Summary of E. Coli exceedance per FMU and rohe. The number of monitoring bores in each FMU/rohe is shown in brackets. Data below the dashed line shows the rohes of the Clutha FMU.



In addition to the spatial distribution of E. Coli exceedance, the percentage of exceedance and bore depth was also analysed, Figure 6. This was analysed due to the relationship between bore depth and faecal bacteria, which enter groundwater from the surface and is filtered out or dies off over time as it travels through the aquifer and its overlying strata. Hence, deeper bores are usually at a lower risk of contamination (MoH, 2017; 2018).

The data for Otago shows that the highest proportion of detections was in bores shallower than 10m (92%) and the lowest in bores deeper than 60m (40%). The proportion of detection in bores of intermediate depth was 76% for bores between 10-20m deep and 64% for bores between 20-40m, Figure 6. Although most of the data supports the hypothesis of lower E. Coli with increasing bore depth, the proportion of exceedances in bores 40-60m deep was higher than the proportions of exceedance at the shallower depths between 10 and 40m. This can be potentially attributed to the small number of bores in this deeper category (40-60m). Nevertheless, the relatively high percentage of E. Coli exceedances, measured even in the deeper bores, clearly indicate that faecal contamination of groundwater in Otago is a risk at every bore depth.

Figure 6: percentage of E. Coli M



AV exceedance for different bore depths. The number of bores in each category is shown in brackets.

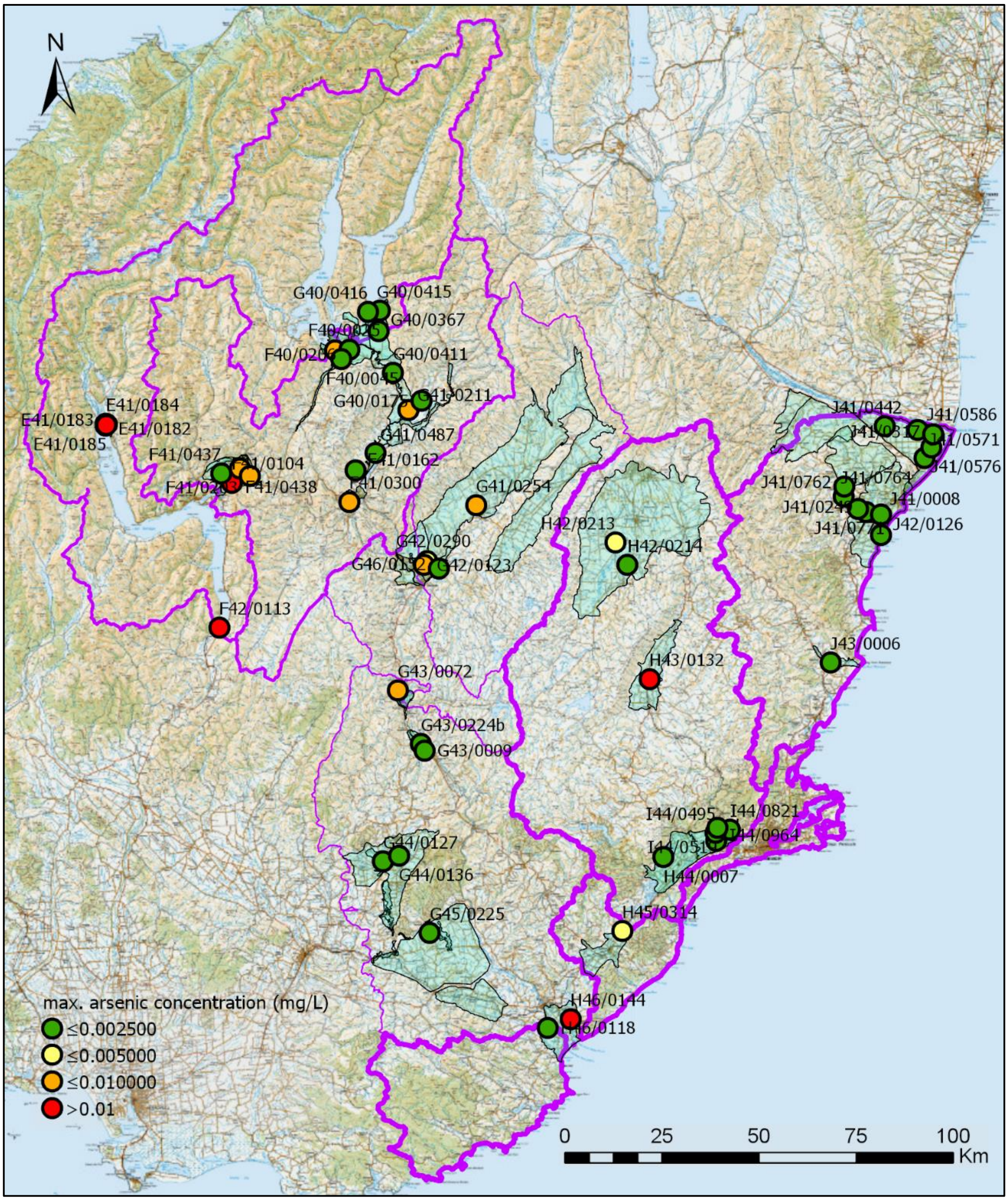
In summary, despite the aforementioned limits of the SoE monitoring data, the E coli results indicate that groundwater and bores in Otago are vulnerable to faecal contamination, regardless of location and/or bore depth. In order to lower this risk, it is strongly recommended that bore owners ensure adequate borehead security to prevent contaminant entry into the aquifer through the borehead. Further information regarding bore security can be found in the following link: https://www.orc.govt.nz/media/5634/bore-brochure.pdf . It is also recommended that groundwater used for drinking is regularly tested in an accredited laboratory, with testing being particularly important after periods of heavy rainfall. If E. Coli is detected, water should be boiled or disinfected (MoH, 2018).

4.1.1.2 Dissolved arsenic

Arsenic is a toxic, though naturally occurring, element, present at low levels in soil, water, plants, animals and food. Arsenic in groundwater can originate from either anthropogenic or natural sources. The former includes economic activities such as sheep dips and treated timber posts. The latter includes geology such as reduced peat deposits alongside volcanic rocks (e.g. Piper and Kim, 2006) and schist rocks, with the latter being particularly prevalent in Otago due to its abundance (Bloomberg *et al*., 2019). In addition to geological factors and activities that use or formerly used arsenic, dissolved arsenic concentrations in groundwater are also controlled by geochemical oxidation/reduction conditions plus water level fluctuations. Exposure to elevated arsenic can lead to a range of cancers, with bladder or lung cancer being the most common, and other non-cancer effects (Piper and Kim, 2006). The DWSNZ MAV for arsenic is 0.01mg/L (equivalent to 10 µg/L), based on a lifetime excess bladder or lung cancer risk (MoH, 2018).

The prevalence of arsenic in Otago groundwater was determined by computing the maximum value from each bore, followed by further scrutiny of any results above the MAV. The maximum arsenic concentrations in the SoE monitoring bores are shown in Figure 7.

Figure 7: Maximum dissolved arsenic concentrations. The map also shows Otago's FMUs and rohe (in purple) and aquifers (teal) . The aquifer names are shown in Figure 1.



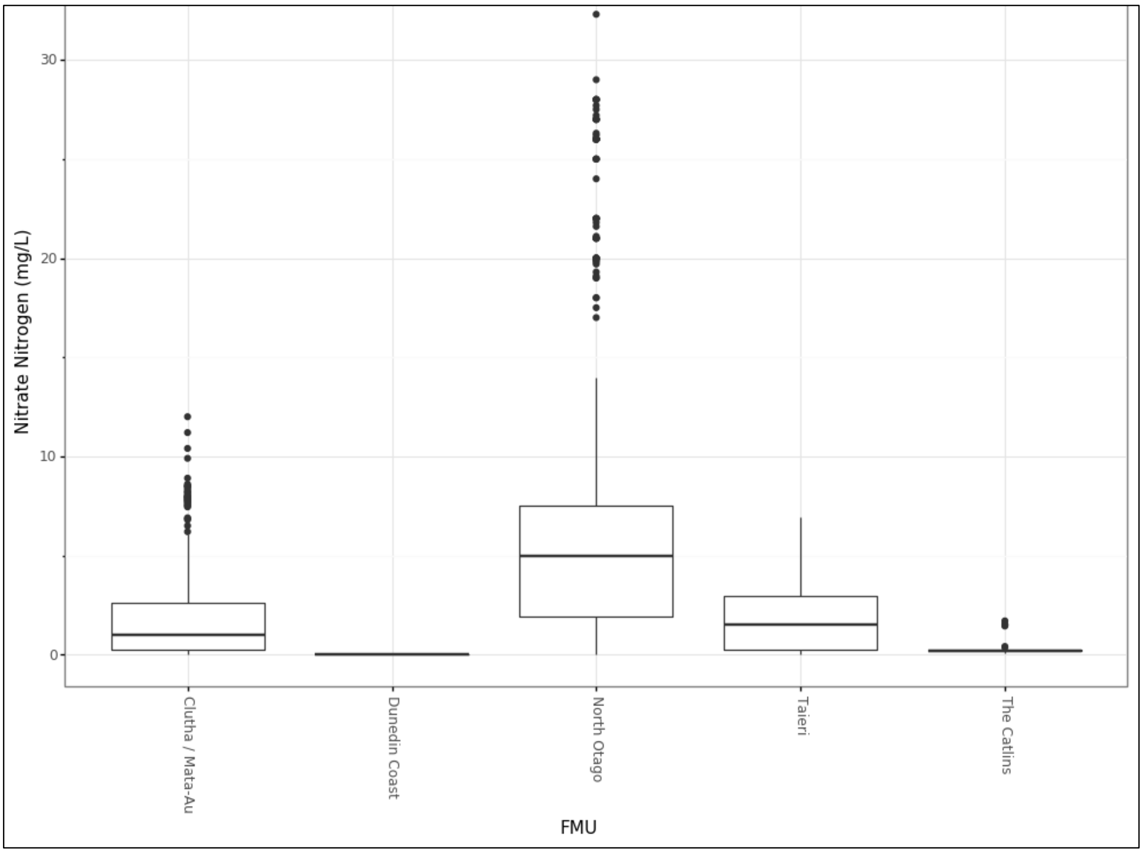
The spatial distribution of maximum arsenic concentrations shows that exceedances of the MAV were only measured in seven SOE monitoring bores across Otago. Of these, five are located in the Upper Clutha/Wakatipu Basin area (i.e. the Glenorchy Groundwater Management Zone (GWMZ), Kingston GWMZ, and the Wakatipu Basin Ladies Mile aquifer). These areas are underlain by schist lithology, known to contain arsenic which is common in groundwater of the Wanaka/Queenstown/Central Otago areas (Bloomberg *et al.*, 2019). The other two bores with elevated arsenic concentrations are located in the Strath Taieri (H43/0132) and the Inch Clutha (H46/0144) aquifers. The Strath Taieri bore had only one exceedance of the MAV in March 2009, with all other samples being two to three orders of magnitude lower the MAV. It is therefore may be an outlier result related to sampling or analytical errors. The bore in the Inch Clutha aquifer has persistently elevated arsenic concentrations although the source is unknown, potentially attributable to peat deposit geochemistry in the delta. The bore is not used for drinking water. No arsenic above the MAV was detected in any bores in the North Otago, Dunedin & Coast, or Catlins FMUs, Figure 7. Nevertheless, due to the abundance of arsenic containing schist lithology, particularly in the Upper Clutha, and high spatial variability of arsenic in groundwater, it is strongly recommended that bore owners regularly test their bore water in an accredited laboratory. As arsenic concentrations can be impacted by fluctuations in groundwater levels (e.g. MoH, 2018), it is further recommended that testing is also conducted during different seasons.

4.1.1.3 Nitrate nitrogen

Nitrate (NO_3-N) is a dissolved, inorganic form of nitrogen (N), a key nutrient required for the growth of plants and algae. Dissolved nitrogen is the most readily available nutrient for uptake by plants, hence it is an important source of fertiliser. However, excess nitrate can adversely impact water quality and also lead to health concerns. The primary health concern regarding nitrate in drinking water is the formation of methemoglobinemia, or “blue baby syndrome”, which impedes oxygen transport around the body in infants (MoH, 2017). The DWSNZ MAV for nitrate nitrogen is 11.3mg/L – N. Using groundwater dating techniques, the baseline nitrate concentration for natural groundwater (i.e. groundwater unimpacted by anthropogenic activity) in New Zealand was identified at around 0.25mg/L NO_3-N. The threshold for groundwater impacted by low intensity agriculture is between 0.25 and 2.5mg/L mg/L NO_3-N. Groundwater with nitrate concentrations >2.5mg/L NO_3-N are considered impacted by high intensity agriculture (Morgenstern and Daughney, 2012).

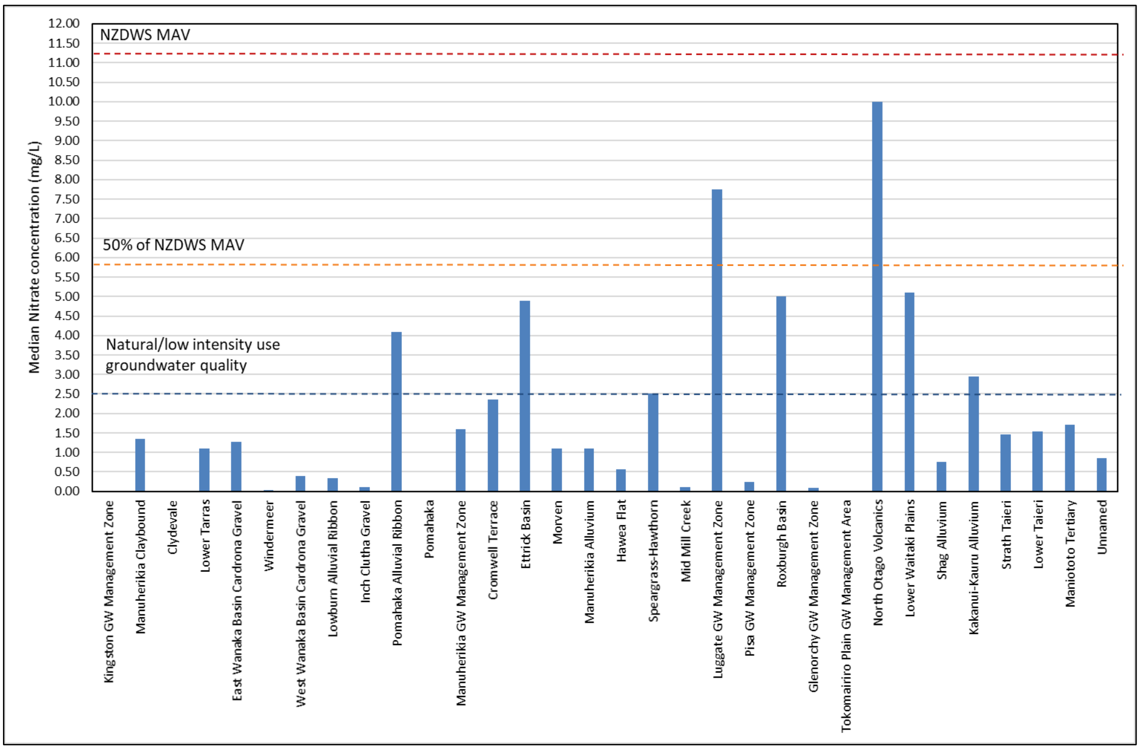
Nitrate concentrations from Otago’s FMUs are shown in Figure 8. This shows that the North Otago FMU has the highest median groundwater concentrations, with many samples exceeding the DWSNZ MAV of 11.3mg/L. The median nitrate concentrations in the Clutha (0.99mg/L) and Taieri (1.5mg/L) FMUs are similar, with their values emplaced within the threshold for low intensity landuse (Daughney and Morgenstern, 2012). However, the Clutha FMU also has a relatively large number of outliers. Median nitrate concentrations in the Dunedin & Coast and the Catlins FMUs are lower than the threshold for natural groundwater (0.25mg/L, Daughney and Morgenstern, 2012) although the Catlins FMU has several outliers. However, the results from these two FMU are skewed due to each only has one SoE monitoring bore. The aforementioned low nitrate concentrations can also be attributed to denitrification, which is a function of reduction-oxidation reactions. However, denitrification potential is beyond the scope of this report.

Figure 8: Nitrate concentrations from the Otago FMUs



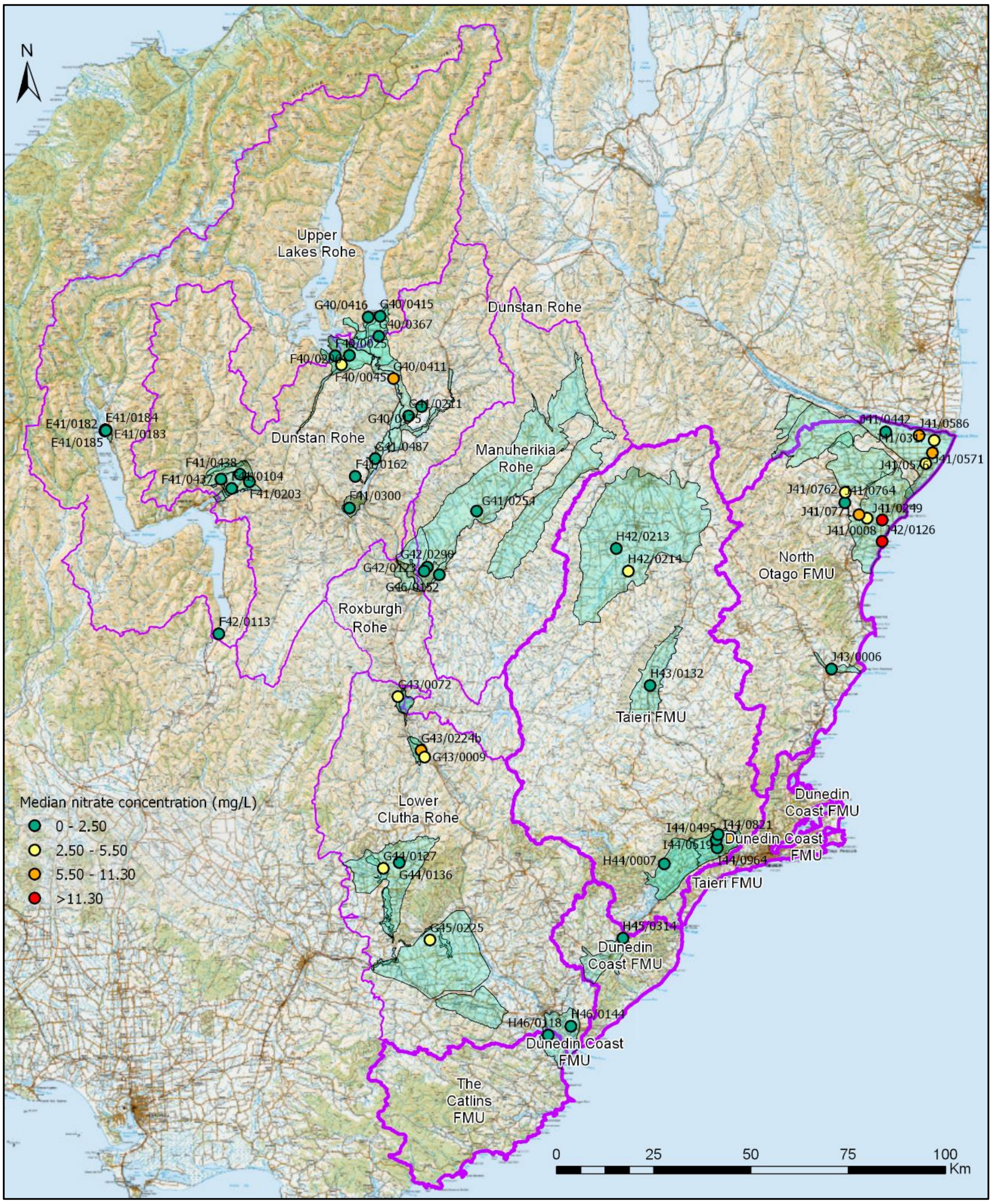
The median nitrate concentrations for the different Otago aquifers are shown in Figure 9. This indicates that there are no aquifers with a median value that exceeds the DWSNZ MAV. However, the median nitrate concentration in the North Otago Volcanic Aquifer (NOVA) and the Luggate GWMZ exceeds 50% of the MAV. There are also aquifers where the median groundwater concentration is above the natural/low intensity use baseline, notably in the Lower Clutha (Pomahaka Alluvial Aquifer, Ettrick Basin, and Roxburgh Basin) and North Otago (Lower Waitaki Plains and the Kakanui-Kauru Alluvium Aquifers). These results, in addition to the aforementioned high median concentration in the NOVA, highlight the elevated nitrate concerns in the North Otago FMU.

Figure 9: Median nitrate concentrations for Otago aquifers



In addition to the assessment of aquifer median concentration, specific bores with elevated nitrate were also considered, Figure 10. An analysis of maximum nitrate concentration indicates that concentrations elevated above the MAV were measured in several bores. Four of these bores are in the North Otago FMU (J41/0008 [located in the NOVA] and J42/0126, J42/0126, and J41/0771 [in the Kakanui-Kauru Alluvial Aquifer]). The remaining bore is in the Pomahaka Alluvial Ribbon Aquifer in the Lower Clutha rohe (G45/0225). These results, in addition to the aforementioned high median concentration in the NOVA, highlight the elevated nitrate concerns in the North Otago and the Lower Clutha.

Figure 10: Median groundwater nitrate concentrations in Otago SoE bores. The map also shows Otago's FMUs and rohe (in purple) and aquifers (teal) . The aquifer names are shown in Figure 1

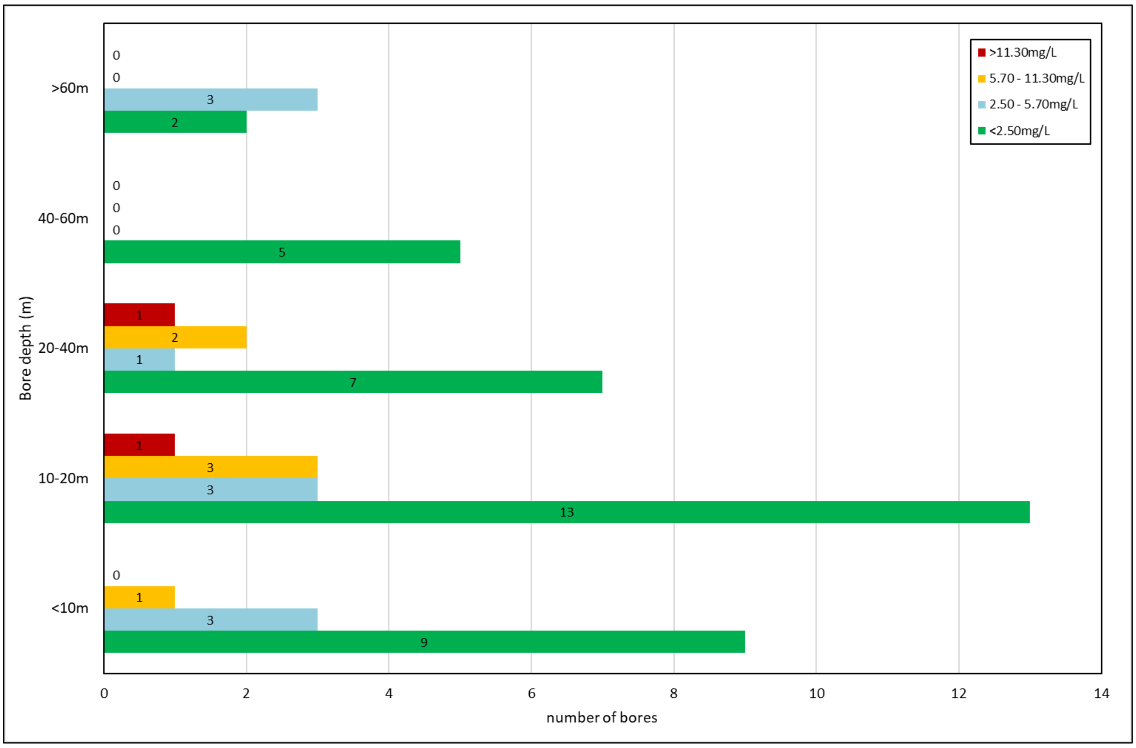


In addition to the spatial analysis of nitrate concentrations, median concentrations were also assessed against bore depth, Figure 11. The concentration was banded according to the proportion of the DWSNZ MAV (11.3mg/L):

- Natural/low intensity land use concentration (<2.50mg/L);
- ½ of the MAV (2.50 – 5.50mg/L);
- ½ MAV - MAV (5.50 – 11.30mg/L); and
- Concentrations above the MAV (>11.30mg/L).

The data shows that the median concentrations in over 50% of the samples for most depth categories are at or below the natural concentration/low intensity landuse baseline. It also shows that the deeper bores have lower nitrate concentrations, with the highest nitrate concentrations in bores >40m deep lower than ½ of the MAV. However, the relationship between bore depth and median nitrate concentrations is not very clear, with bores at depths between 10 and 40m having higher median nitrate concentrations and higher number of bores with elevated concentrations than the shallowest bores (<10m deep). These are likely due to differences in geology, land use practice, and bore security between the different sites.

Figure 11: Analysis of median nitrate concentration and bore depth



In summary, groundwater nitrate concentration data shows that none of the aquifers in Otago has a median nitrate concentration above the DWSNZ MAV. However, it has also highlighted a variable degree of nitrate contamination in relation to the MAV, with concentrations in some aquifers, notably in North Otago and the Lower Clutha, approaching the MAV. Conversely, the median nitrate concentrations in many aquifers suggest low impact from landuse. The variability was also illustrated on the analysis of nitrate concentration versus bore depth, with bores between 10 and 40m having the highest median concentrations. This may be related to variability in geology, landuse, and bore security between the different sites.

4.1.2 Ecosystem health

4.1.2.1 Overview

In addition to assessing groundwater quality against the DWSNZ (Section 4.1.1), groundwater quality also impacts surface water quality and ecosystem health, particularly for groundwater-fed surface water systems. The main impacts are stimulation of periphyton growth and toxicity in surface water ecosystems, which are caused by elevated groundwater concentration of nutrients (nitrate nitrogen, Dissolved Reactive Phosphorus [DRP], and ammoniacal nitrogen [ammonia]). Nitrite-nitrate nitrogen (NNN, which is mainly composed of nitrate) and DRP are dissolved inorganic forms of the nutrients nitrogen (N) and phosphorus (P), which are the two key nutrients required for the growth of aquatic plants and algae. Although there are numerous other forms of N and P, these dissolved forms are most readily available for uptake by plants, hence they are the most relevant for assessing nuisance growth in rivers. The terms Total Nitrogen (TN) and Total Phosphorus (TP) refer to the summed total of all forms of N and P in a sample and are more relevant when assessing lake water quality. Additionally, nitrate and ammonia at sufficiently elevated concentrations also have toxic effects on aquatic biota, with this effect independent of their significance as plant nutrients (ORC, 2017).

This was done using nitrate, DRP, and ammonia concentrations from shallow SoE bores (<20m depth), following a similar approach to ECan (2018). The details of the bores are provided in the relevant sections of the report. These nutrient concentrations were then compared against the limits in Schedule 15 of ORC’s Regional Plan: Water (2004) and standards in the National Policy Statement for Freshwater Management [NPS-FM] (Ministry for the Environment [MfE], 2017). However, although groundwater nutrient loads undoubtedly affect surface water bodies, the mixing and dilution of inflowing nutrient loads from groundwater with surface water profoundly changes the resultant nutrient concentrations, which can also change due to biological transformations. These processes weaken the linkage between groundwater-measured nutrient concentrations and the concentrations to which aquatic ecosystems are exposed. It is acknowledged that Schedule 15 and the NPS-FM, including the NOF bands were developed for surface water and therefore are not an entirely appropriate set of ecosystem health guidelines with which to assess groundwater. But, there has yet to be a set guideline developed for groundwater with ecosystem health objectives, hence, in the absence of groundwater-specific water quality guidelines, this report has made reference to both surface water ecosystem health criteria. It is also important to note some of the limitations of this comparison:

- Nutrient concentrations in groundwater are generally higher than those in surface water, for which the standards apply
- Surface water quality standards are assessed against various statistics for nutrient concentration (i.e. median, 80th and 95th percentiles). These assessments also depend on variables such as flow thresholds (i.e. samples collected at or below median flow) and river type classification which are not directly comparable with the SoE groundwater quality samples.

Due to all these factors, this assessment provides an overview, rather than a direct comparison, of the potential impacts of groundwater quality on surface water ecosystems.

4.1.2.2 Otago Water Plan Schedule 15

The ORC Regional Plan: Water (RPW) Rural Water Quality plan change (PC6A) was approved in March 2014 and provided measures for controlling contaminants and sediment coming off rural properties into waterways from runoff, leaching, and drains. Schedule 15 of the RPW lists the contaminant concentration limits and targets for good quality surface water in Otago, as required by the NPS-FM (MfE, 2020). The limits are provided in Table 15.2 of the Water Plan, a copy of which is shown in Table 2. The location of the bores (in relation to the groups) is shown in Figure 12.

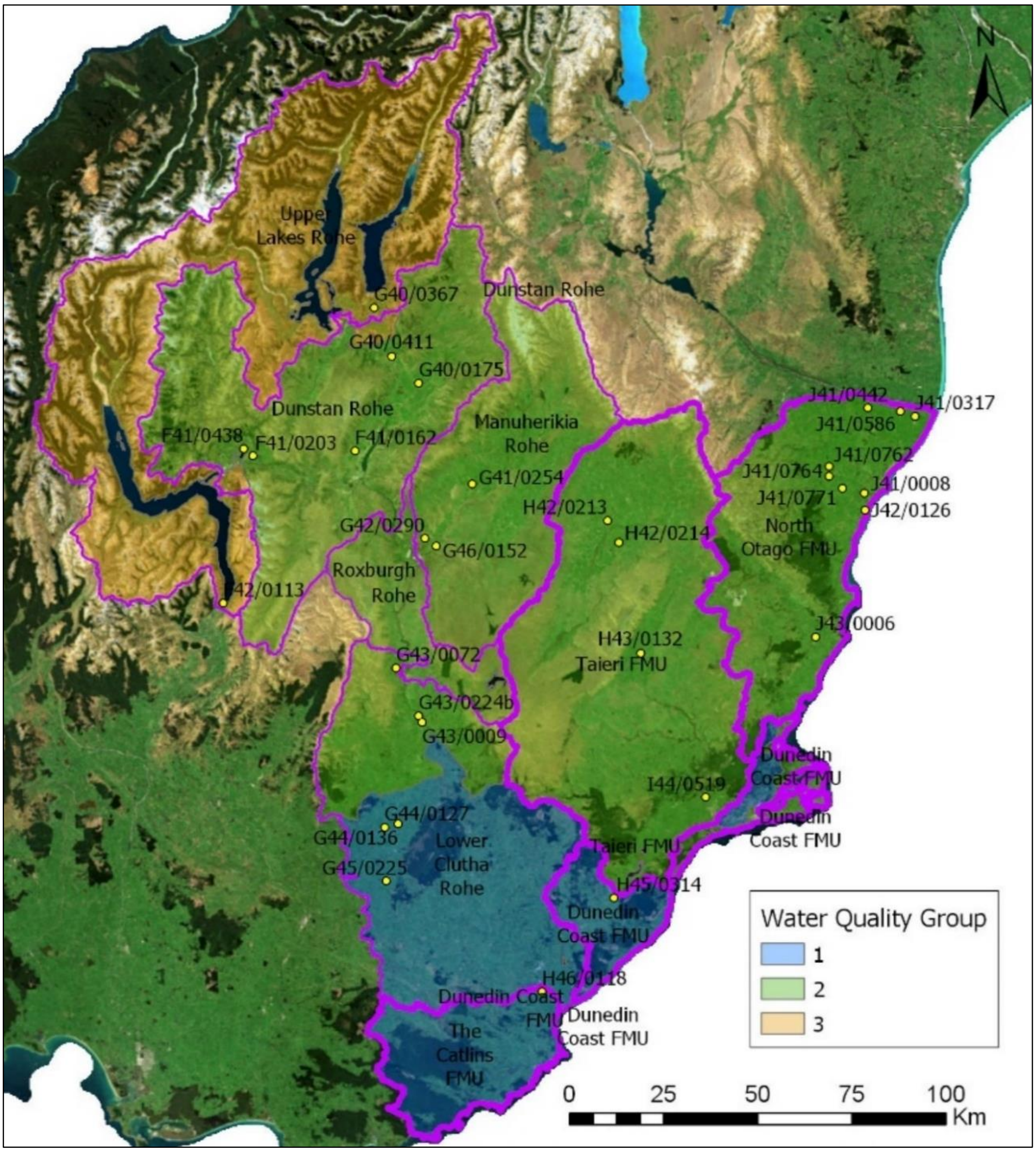
Many of the guideline values for Schedule 15 were obtained from the Australia New Zealand Environmental Conservation Council (ANZECC, 2000, revised 2018) and general water quality guidelines. Environmental guidelines can be used to describe the general state of a natural resource even though these guidelines may not be directly applicable in a regulatory context. The ANZECC (2000, 2018) guidelines are used to indicate “baseline” (unaffected) or “pseudo-baseline” (lightly impacted) conditions for catchments. The trigger values are based on water quality conditions collected from sites at NIWA’s National River Water Quality Monitoring Network [NRWQMN] (Davies-Colley, 2000). The trigger values relate to the 80th-20th percentile values for the data range obtained from the NRWQMN. The numerical limits provided in Schedule 15 (Table 2) were partly based on the ANZECC (2000) guidelines. These limits are based on nutrient thresholds for periphyton growth. However, in contrast to ANZECC’s approach of using the median values at all flows, the Schedule 15 limits are based on the 80th percentile when flows are at or below median flow for the reference flow site.

The ANZECC (2000) guidelines distinguish between lowland and upland rivers. The guidelines were updated in 2018, where the thresholds under the revised version relate to the River Environment Classification (REC), which account for a range of natural factors that influence water quality such as climate, topography, and geology (McDowell *et al*., 2013). The location of the SoE bores in relation to the receiving water groups in Schedule 15 is shown in Figure 12.

Table 2: Receiving water numerical standards by surface water catchment group (based on the five year 80th percentile when flows are at or below median flow.

Schedule 15[3]	NNN (mg/L)	DRP (mg/L)	NH_4-N (mg/L)	*E. coli* (CFU/100 ml)	Turbidity NTU	TN (mg/L)	TP (mg/L)
Group 1	0.444	0.026	0.10	260	5		
Group 2	0.075	0.010	0.10	260	5		
Group 3	0.075	0.005	0.01	50	3		
Group 4			0.10	126	5	0.55	0.033
Group 5			0.01	10	3	0.10	0.005

Figure 12: Location of shallow monitoring bores and their groups under Schedule 15



The assessment of nutrient concentrations from shallow SoE bores against the Schedule 15 limits are shown in Table 3. The results indicate poor compliance with the Schedule 15 limits for nitrate and DRP, with nitrate concentrations in two bores out of five in Group 1 substantially exceeding the 80th percentile nitrate limit of 0.444mg/L. The DRP results also showed poor compliance, with three bores out of five exceeding the Schedule 15 limit of 0.026mg/L. Conversely, the limits for ammonia, of 0.10mg/L, were not exceeded in any of the bores. Poor compliance results were also observed in Group 2, with nitrate concentrations in all bores exceeding the RPW limit of 0.075mg/L. DRP compliance was also poor, with 80th percentile DRP concentration in only three out of 23 bores below the RPW limit of 0.010mg/L. Similar to Group 1, the compliance with the ammonia limits were better, with concentrations in only two bores exceeding the RPW limit of 0.01mg/L. There were only two bores located in Group 3. The compliance results for this group show that DRP concentrations in both bores exceeded the RPW limits. The results for nitrate and ammonia show that concentrations in one bore were above the RPW limits whilst those in the other were below. Further details are provided in the individual FMU sections.

Table 3: 80th percentile values for Schedule 15 water quality variables. The orange cells show where the 80th percentile exceeds the Schedule 15 limit.

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Clutha	Lower Clutha	Inch Clutha	0.282	0.270	0.013
G44/0127	Clutha	Lower Clutha	Pomahaka Alluvial	5.020	0.015	0.010
G44/0136	Clutha	Lower Clutha	Pomahaka	0.050	0.099	0.016
H45/0314	Dunedin & Coast		Tokomairiro	0.006	0.152	0.072
G43/0224b	Clutha	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G42/0290	Clutha	Manuherekia	Manuherekia Claybound	2.460	0.020	0.010
J41/0008	N. Otago		NOVA	27.660	0.057	0.010
J41/0317	N. Otago		Lower Waitaki	5.800	0.032	0.010
J43/0006	N. Otago		Shag	1.116	0.011	0.010
G40/0175	Clutha	Dunstan	Tarras	0.938	0.018	0.010
F41/0162	Clutha	Dunstan	Lowburn	0.410	0.008	0.010
I44/0519	Taieri		Lower Taieri	2.900	0.006	0.102
G41/0254	Clutha	Manuherekia	Manuherekia	3.100	0.017	0.010
J42/0126	N. Otago		Kakanui (township)	21.600	0.026	0.010
G43/0009	Clutha	Lower Clutha	Ettrick	4.960	0.013	0.010
F41/0203	Clutha	Dunstan	Morven Ferry (Wakatipu)	3.200	0.005	0.010
J41/0762	N. Otago		Kakanui	4.940	0.011	0.016
J41/0764	N. Otago		Kakanui	3.400	0.011	0.006
Kakanui bore 10	N. Otago		Kakanui	11.000	0.010	0.012
G46/0152	Clutha	Manuherekia	Manuherekia Alluvium	1.216	0.027	0.005
H42/0213	Taieri		Maniototo Tertiary	0.109	0.143	0.386
H42/0214	Taieri		Maniototo Tertiary	4.320	0.047	0.007
F41/0438	Clutha	Dunstan	Lake Hayes	0.212	0.004	0.012

J41/0442	N. Otago		Lower Waitaki	1.072	0.005	0.005
J41/0586	N. Otago		Lower Waitaki	7.280	0.009	0.005
G40/0411	Clutha	Dunstan	Luggate	8.340	0.005	0.006
G43/0072	Clutha	Lower Clutha	Roxburgh	5.320	0.010	0.011
H43/0132	Taieri		Strath Taieri	1.600	0.048	0.010
Group 3 Sched. 15 limit (mg/L)				**0.075**	**0.005**	**0.01**
F42/0113	Clutha	Upper Lakes	Kingston	0.156	0.100	0.282
G40/0367	Clutha	Upper Lakes	Hawea Flat	1.642	0.007	0.006

4.1.2.3 National Policy Statement for Freshwater Management (NPS-FM [2017])

The NPS-FM came into effect in August 2014. It includes a National Objectives Framework (NOF) aimed at providing “an approach to establish freshwater objectives and national values and any other values that:

a) Is nationally consistent
b) Recognises regional and local circumstances (Objective CA1).

The NPS-FM was amended in 2017 and again in 2020. The NOF includes various tables of attribute and targets, where water quality parameters are categorised in Bands A-D (with Band A representing the highest water quality and D being the lowest). These attributes are taken from the proposed NPS-FM (2019) amendments, Table 4. The NOF attributes include “National Bottom Lines” – thresholds of poor water quality attributes that good management should prevent waterways from reaching, i.e. the minimum water quality level that all water bodies must achieve. The bottom line is the boundary between bands C and D, with results in Band D situated below the national bottom line. However, it is important to note that the NPS-FM’s nitrate and ammonia concentrations thresholds are for protecting ecosystem health and life supporting capacity against toxicity effects, which substantially exceed the nutrient concentrations which stimulate algal growth and eutrophication effects (on which the ANZECC/RPW Schedule 15 limits are based). Due to these different issues (i.e. periphyton growth versus toxicity) the RPW limits are substantially more stringent than the NPS-FM (i.e. sites can be emplaced in Band A under the NPS-FM and fail to comply with the Schedule 15 limits).

Table 4: NPS-FM attributes and NOF bands for nitrate, DRP, and ammonia (from MfE, 2020)

Nitrate (Toxicity) Note: This attribute measures the toxic effects of nitrate, not the trophic state. Where other attributes measure trophic state, for example periphyton, freshwater objectives, limits and/or methods for those attributes will be more stringent.		
Band & Description	**Annual Median (mg/L)**	**Annual 95th percentile**
A High conservation value system. Unlikely to be effects even on sensitive species.	≤1.0	≤1.5
B Some growth effect on up to 5% of species.	>1.0 and ≤2.4	>1.5 and ≤3.5
National Bottom Line	**2.40**	**3.50**
C Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.	>2.4 and ≤6.9	>3.5 and ≤9.8
D Impacts on growth of multiple species, and starts approaching acute impact level (i.e. risk of death) for sensitive species at higher concentrations (>20 mg/L).	>6.9	>9.8
DRP Numeric attribute state must be derived from the rolling median of monthly monitoring over five years.		
A Ecological communities and ecosystem processes are similar to those of natural reference conditions. No adverse effects attributable to DRP enrichment are expected.	≤ 0.006	≤ 0.021
B Ecological communities are slightly impacted by minor DRP elevation above natural reference conditions. If other conditions also favour eutrophication, sensitive ecosystems may experience additional algal and plant growth, loss of sensitive macroinvertebrate taxa, and higher respiration and decay rates.	> 0.006 and ≤0.010	> 0.021 and ≤0.030
C Ecological communities are impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate & fish taxa, and high rates of respiration and decay.	> 0.010 and ≤ 0.018	> 0.030 and ≤ 0.054
D Ecological communities impacted by substantial DRP elevation above natural reference conditions. In combination with other conditions favouring eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia are lost.	>0.018	>0.054
Ammonia (toxicity) Numeric attribute state is based on pH 8 and temperature of 20°C. Compliance with the numeric attribute states should be undertaken after pH adjustment		

	Annual Median (mg/L)	Annual Maximum (mg/L)
A 99% species protection level: No observed effect on any species tested	≤0.03	≤0.05
B 95% species protection level: Starts impacting occasionally on the 5% most sensitive species	>0.03 and ≤0.24	>0.05 and ≤0.40
National Bottom Line	**0.24**	**0.40**
C 80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)	>0.24 and ≤1.30	>0.40 and ≤2.20
D Starts approaching acute impact level (i.e. risk of death) for sensitive species.	>1.30	>2.20

4.2 The Clutha FMU

4.2.1 Background information

The Clutha/Mata-Au is the largest FMU in Otago and encompasses the catchment of the Clutha/ Mata-Au River. The Clutha/Mata-Au River originates in the headwaters of lakes Wakatipu, Wanaka and Hawea and drains much of the Otago region with a total catchment area of 21,022 km^2. The Clutha/Mata-Au is the second longest river in New Zealand and the longest river in the South Island, flowing for a total distance of 322 km from its uppermost point in the headwaters of the Makarora River to its mouth downstream of Balclutha. The Clutha River has a mean annual flow of 575 m^3/s, with 75% of the total flow measured at Balclutha comes from the combined outflows of lakes Wakatipu, Wanaka and Hawea (Ozanne, 2012a).

The Upper Clutha reporting region encapsulates the following catchments (from upstream to downstream by confluence): the Makarora (area of 745 km^2), Matukituki (801 km^2), Hunter (1473 km^2), Cardrona (347 km^2), Luggate Creek (123 km^2), Lindis (1039 km^2), Dart (631 km^2), Rees (405 km^2), Shotover (1091 km^2) and Mill Creek (14 km^2). The iconic Southern Great Lakes of Wakatipu, Wanaka and Hawea are central to the region. Of these larger lakes, Wanaka and Wakatipu are not impounded by dams whilst Hawea is regulated. The Clutha and its principal tributary, the Kawarau River, pass through gorges, two of which are dammed for hydro-electricity generation forming lakes Dunstan and Roxburgh. The headwaters of the catchment are predominantly located in rugged, steep terrain with the highest point, Mt. Aspiring, reaching 3,027m. Numerous headwater streams such as the Dart and Matukituki Rivers originate along the eastern boundary of the Southern Alps and are fed by permanent glaciers (ORC, 2017).

The Clutha FMU and catchment is divided into five rohes: the headwaters of Lakes Wakatipu, Wanaka and Hawea in the north (Upper Lakes rohe), the Upper Clutha River catchment (Dunstan Rohe), the Manuherekia Rohe, the Clutha catchment between the Clyde and Roxburgh Dams (Roxburgh Rohe) and the area between Roxburgh Dam and the Clutha mouth (Lower Clutha Rohe). The FMU also includes the catchments for major tributaries of the Clutha such as the Pomahaka and the Manuherekia Rivers. The main land use in the central part is horticulture/viticulture. The southern part is dominated by sheep/beef and dairy farming (ORC, 2017).

4.2.2 Summary of groundwater quality results

The median results for the DWSNZ and ecosystem health parameters from the Clutha FMU are summarised in Table 5. The compliance with the RPW Schedule 15 and NPS-FM for the Clutha FMU are provided in Table 6 and Table 7. Groundwater quality results from the Clutha FMU show a large variability, with good groundwater quality in some rohe (i.e. the Upper Lakes, Dunstan) and potentially degraded quality in others, particularly the Lower Clutha. The main issues are elevated E. coli and dissolved arsenic concentrations in some bores, with elevated nutrient concentrations also common in many bores.

The results from the Upper Lakes and Dunstan rohes generally show compliance with the DWSNZ, although elevated E. coli were measured in some bores. Elevated dissolved arsenic concentrations were also measured in some bores, while their source is likely to be the prevalent schist lithology, i.e. geological, rather than anthropogenic. Nutrient concentrations are generally below the DWSNZ for nitrate. However, nutrient concentration usually exceeds the RPW and NPS limits, with particularly high DRP and nitrate concentrations in Kingston and Glenorchy. The elevated nutrient concentrations in these rapidly developing areas are likely due to high septic tanks density, shallow bores, and poor borehead security. These can potentially adversely impact water quality in the northern/southern arm of Lake Wakatipu, although groundwater (and nutrient) fluxes into the Lake are likely to be substantially lower than the surface water inflows.

Groundwater quality in the Manuherekia rohe is generally fair although E. coli exceedances were measured in most monitoring bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherekia Alluvium Aquifer and Manuherekia Claybound Aquifer monitoring bores generally near the reference conditions for low intensity landuse, i.e. <2.5mg/L (Daughney and Morgenstern, 2012). However, an increasing trend has been observed in the Manuherekia GWMZ monitoring bore, where concentrations exceed ½ of the MAV for nitrate. No elevated arsenic concentrations were measured in any of the monitoring bores in the rohe. In relation to potential impacts on ecosystem health, the results from the shallow monitoring bores suggest elevated nitrate and DRP, with concentrations exceeding the Schedule 15 limits and DRP concentrations for the Manuherekia Alluvium bore below the National Bottom Line. This suggests that interaction of groundwater from these aquifers with surface water could adversely impact surface water quality in the absence of significant dilution of inflowing groundwater.

Groundwater quality results from the Lower Clutha rohe indicate some issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. One of the bores in the Inch Clutha gravel aquifer also has elevated arsenic concentrations above the MAV. The results also show issues with elevated nutrient concentrations, some of which are due to shallow monitoring bores and poor bore security. These results also support the reported poor surface water quality results from this area (ORC, 2017).

Table 5: median results for DWSNZ/ecosystem health parameters for the Clutha FMU

Arsenic Dissolved (mg/L)	0.001
E-Coli MPN (MPN/100mL)	0.500
Total Nitrogen (mg/L)	1.080
Nitrate Nitrogen (mg/L)	0.990
Ammoniacal Nitrogen (mg/L)	0.005
Dissolved Reactive Phosphorus (mg/L)	0.008

Table 6: NPS-FM NOF comparison results for the Clutha FMU

		Nitrate concentration		**NOF Band**	
Bore no.	Rohe	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
F41/0203	Dunstan	1.1	5.9	B	C
G40/0175	Dunstan	0.86	1.0395	A	A
F41/0162	Dunstan	0.33	0.47	A	A
F41/0438	Dunstan	0.113	0.2805	A	A
G40/0411	Dunstan	7.75	9.45	D	C
G44/0127	Lower Clutha	4.1	5.9455	C	C
G44/0136	Lower Clutha	0.005	0.05	A	A
G43/0009	Lower Clutha	4.6	5.52	C	C
G43/0224b	Lower Clutha	7.9	8.66	D	C

		DRP		**NOF Band**	
Bore number	**Rohe**	**Median (mg/L)**	**95th percentile (mg/L)**	**Median**	**95th percentile**
F41/0203	Dunstan	0.0025	0.0066	A	A
G40/0175	Dunstan	0.014	0.02195	C	B
F41/0162	Dunstan	0.00325	0.01095	A	A
F41/0438	Dunstan	0.002	0.005	A	A
G40/0411	Dunstan	0.023	0.006	D	A
G44/0127	Lower Clutha	0.011	0.0325	C	C
G44/0136	Lower Clutha	0.019	0.1146	D	D
G43/0009	Lower Clutha	0.009	0.0198	B	A
G43/0224b	Lower Clutha	0.002	0.03195	A	C
G43/0072	Lower Clutha	0.006	0.012	B	A
G42/0290	Manuherekia	0.017	0.024	C	B
G41/0254	Manuherekia	0.014	0.021	C	B
G46/0152	Manuherekia	0.0235	0.02905	D	B
F42/0113	Upper Lakes	0.0875	0.11	D	D
G40/0367	Upper Lakes	0.0048	0.0079	A	A
G43/0072	Lower Clutha	5	5.5	C	C
G42/0290	Manuherekia	2.3	2.6	B	B
G41/0254	Manuherekia	1.6	4.4	B	C
G46/0152	Manuherekia	1.1	1.341	B	A
F42/0113	Upper Lakes	0.005	0.097	A	A
G40/0367	Upper Lakes	1.4	1.853	B	B
		Ammoniacal nitrogen	**NOF Band**		
Bore number	**Rohe**	**median (mg/L)**	**Max (mg/L)**	**Median -**	**Max.**
F41/0203	Dunstan	0.005	0.1	A	B
G40/0175	Dunstan	0.005	0.018	A	A
F41/0162	Dunstan	0.005	0.021	A	A
F41/0438	Dunstan	0.0025	0.074	A	B
G40/0411	Dunstan	0.0025	0.073	A	B
G44/0127	Lower Clutha	0.005	0.056	A	B
G44/0136	Lower Clutha	0.012	0.023	A	A

G43/0009	Lower Clutha	0.005	0.38	A	B
G43/0224b	Lower Clutha	0.0025	0.062	A	B
G43/0072	Lower Clutha	0.0025	0.113	A	B
G42/0290	Manuherekia	0.005	0.13	A	B
G41/0254	Manuherekia	0.005	0.01	A	A
G46/0152	Manuherekia	0.0025	0.017	A	A
F42/0113	Upper Lakes	0.255	0.36	C	B
G40/0367	Upper Lakes	0.0025	0.44	A	C

Table 7: Schedule 15 comparison results for the Clutha FMU for 80th percentile for nitrate, DRP, and ammonia

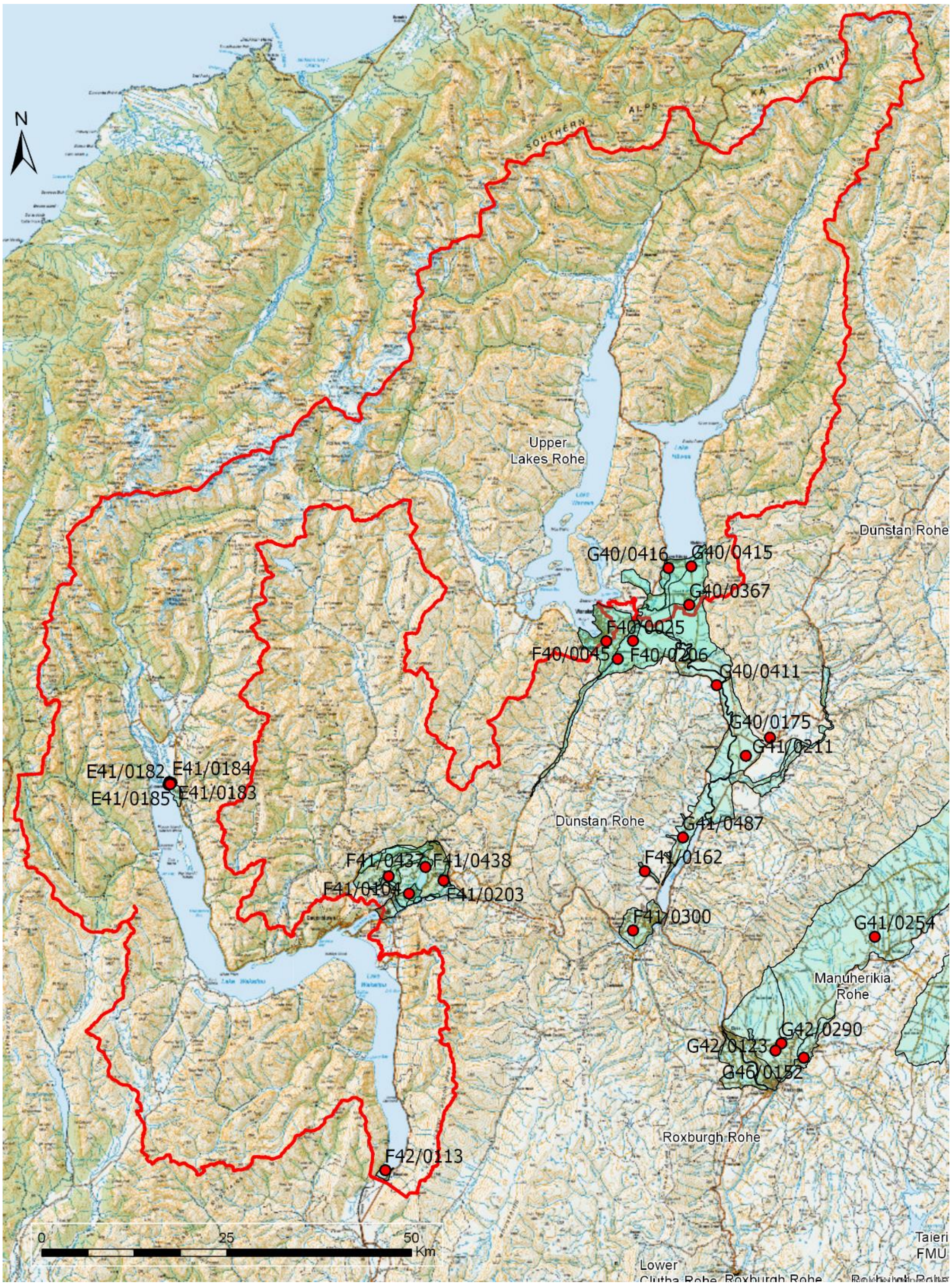
Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 1 Sched. 15 limit (mg/L)	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Lower Clutha	Inch Clutha	0.282	0.270	0.013
G44/0127	Lower Clutha	Pomahaka Alluvial	5.020	0.015	0.010
G44/0136	Lower Clutha	Pomahaka	0.050	0.099	0.016
G43/0224b	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)			**0.075**	**0.010**	**0.100**
G42/0290	Manuherekia	Manuherekia Claybound	2.460	0.020	0.010
G40/0175	Dunstan	Tarras	0.938	0.018	0.010
F41/0162	Dunstan	Lowburn	0.410	0.008	0.010
G41/0254	Manuherekia	Manuherekia	3.100	0.017	0.010
G43/0009	Lower Clutha	Ettrick	4.960	0.013	0.010
F41/0203	Dunstan	Morven Ferry (Wakatipu)	3.200	0.005	0.010
G46/0152	Manuherekia	Manuherekia Alluvium	1.216	0.027	0.005
F41/0438	Dunstan	Lake Hayes	0.212	0.004	0.012
G40/0411	Dunstan	Luggate	8.340	0.0246	0.006
G43/0072	Lower Clutha	Roxburgh	5.320	0.010	0.011
Group 3 Sched. 15 limit			**0.075**	**0.005**	**0.01**
F42/0113	Upper Lakes	Kingston	0.050	0.100	0.282
G40/0367	Upper Lakes	Upper Lakes	1.642	0.007	0.006

4.2.3 The Upper Lakes Rohe

The Upper Clutha region covers an area of around 11,970km^2, which represents around 57% of the Clutha catchment. Around 85% of the region is composed of steep terrain typical of the mountain ranges which surround the lakes. The River Environment Classification (REC) framework indicates that the rohe contains a broad range of river types, of which a significant total length is classified as cool/wet (mean annual rainfall of 500-1,000mm/year) or cool/extremely wet (mean annual rainfall >1,500mm). The Upper Clutha rohe contains the highest percentage of these high yielding river types in Otago. Additional significant river types within the Upper Clutha include glacial-fed and lake-fed rivers. The predominant land cover throughout the Upper Clutha is native vegetation followed by low producing grassland. A high proportion of the native cover in the upper catchments of the large lakes experiences high to very high rainfall and snowfall, providing high volume of exceptional quality water from pristine catchments which feed the lakes (ORC, 2017).

The Upper Lakes Rohe includes 12 SoE monitoring bores in three aquifers/GWMZ: Hawea Flat, Kingston, and Glenorchy (Figure 13). These areas experience rapid expansion and urban development which are likely to increase the pressure on groundwater quality/quantity in these areas.

Figure 13: Location of the Upper Lakes Rohe (red outline), aquifers (teal) and SoE monitoring bores (red dots). Aquifer names are shown in Figure 1.



The assessment of groundwater quality data from the Upper Lakes bores against the DWSNZ generally suggests good water quality, although some local issues are also identified. These include substantial exceedances of the dissolved arsenic MAV in both Glenorchy and Kingston and some E. coli exceedances in these GWMZ, although the E. coli counts were relatively low. In contrast to that, the bores in Hawea did not exceed the E. Coli, dissolved arsenic, or nitrate nitrogen MAVs. The elevated arsenic concentrations in Glenorchy and Kingston are likely due to the prevalent schist lithology. The E. coli exceedances are likely due to the high density of septic tanks in the townships and potentially to poor borehead security and/or shallow bores. Despite of these results, none of the monitoring bores is used for drinking. Furthermore, Glenorchy is served by a reticulated town supply, hence the use of groundwater, and the associated potential risk, is lower.

Table 8: Median concentrations for DWSNZ/ecosystem health parameters for the Upper Lakes rohe

Aquifer	Ammoniacal Nitrogen (mg/L)	Arsenic Dissolved (mg/L)	Dissolved Reactive Phosphorus (mg/L)	E-Coli MPN (MPN/100mL)	Nitrate Nitrogen (mg/L)
Glenorchy GW Management Zone	0.203	0.089	0.002	0.500	0.080
Hawea Flat	0.003	0.001	0.006	0.500	0.570
Kingston GW Management Zone	0.255	0.010	0.088	0.500	0.005

Groundwater quality results from the Upper Lakes rohe were then assessed for ecosystem health impacts based on the methodology described in section 4.1.2. Two of the bores in the Upper Lakes FMU are shallower than the 20m threshold for ecosystem health assessment. These bores are located in the Kingston GWMZ (F42/0113) and Hawea Flat (G40/0367). The bores are located in Group 3 of Schedule 15, with the Kingston and Glenorchy bores also located very close to Lake Wakatipu, which is in Group 5. The 80th percentile values for the bores and their compliance with Schedule 15 are provided in Table 9. Although the bores in the Glenorchy GWMZ are also shallower than 20m, their monitoring only began in October 2019, hence, their results were not assessed. Nevertheless, the available data still provides some useful insights.

The results show that the 80th percentile for DRP in both bores exceeded the Schedule 15 limits for Group 3 (Table 9). Nitrate concentrations in Hawea Flat substantially exceeded the limit although ammonia was below it. The results from Kingston were also calculated for the 80th percentile for Total Nitrogen (TN), and Total Phosphorus (TP), which are used in lake water quality assessment. The TN and TP concentrations substantially exceed the limits for Group 5 (Table 9). This is likely due to the high density of septic tanks in the settlement. These elevated nutrient concentrations can potentially adversely impact the water quality in Lake Wakatipu. However, this impact on the lake is unknown due to lack of monitoring in these parts of the lake. It is also likely that groundwater flow contributions are much lower than surface water, hence potential nutrient contribution from groundwater flow will be diluted by the higher volumes of surface water.

Table 9: Upper Lakes rohe 80th percentile concentrations (mg/L) for water quality variables and comparison with Schedule 15 limits

Bore number		**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
	Sched. 15 Group 3 limit (mg/L)	**0.075**	**0.005**	**0.01**
F42/0113	Kingston	0.050	0.100	0.282
G40/0367	Hawea Flat	1.642	0.007	0.006
		Total Nitrogen	**Total Phosphorus**	
	Group 5 limit (mg/L)	**0.10**	**0.005**	
F42/0113	Kingston	0.4	0.092	

Nutrient concentrations in the shallow bores were then assessed against the NPS-FM NOF. It is important to note that the NOF nitrate and ammonia attributes focus on ecosystem health and life supporting capacity by providing protection against toxicity impacts, whilst the Schedule 15 limits are based on periphyton growth which are more stringent. Therefore, as the NPS-FM NOF limits substantially exceed those of the RPW and the ANZECC (2000, 2018), sites can be placed in the “A” NOF band and fail to comply with the RPW limits.

The summary of NOF compliance for the Upper Clutha rohe is provided in Table 10. For nitrate, the bore in the Kingston GWMZ is within Band A for both median and 95th percentiles. For a site classified in Band A there are “unlikely to be [toxicity] effects even for sensitive species (MfE, 2020)”, indicating that at the current concentration there is a high level of protection against nitrate toxicity. The Hawea Flat bore (G40/0367) nitrate concentration is emplaced in Band B for both the median and 95th percentile. This band reflects an environment that may have “some growth effect on up to 5% of species”, which provides a good level of protection with some minor effects on growth rate of the most sensitive species (Hickey, 2013).

The assessment against the ammonia NOF bands indicate potential ecosystem issues, with the median and maximum concentrations in Kingston classified in Bands C and B, respectively. Band C provides protection for 80% of species, starting to impact regularly on the 20% of most sensitive species (MfE, 2020). The concentrations in the Hawea Flat bore are in Band A for the median and C for the maximum. Both the A and B bands provide a good level of protection against toxicity effects and in the case of nitrate, it is highly unlikely that there would be any chronic toxicity effects on aquatic species present at these sites. However, the ammonia concentrations in Hawea Flat indicate a potential concern.

The DRP concentrations indicate serious potential issues in Kingston, with both median and the 95th percentile in Band D, where ecological communities are impacted by substantial DRP concentrations, elevated above natural reference conditions. In addition to other conditions that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia is lost (MfE, 2020). Regarding the NOF standard for lakes, which is assessed using median Total Phosphorus concentration. The median TP concentration for the Kingston bore is 0.0895mg/L, equivalent to 89.5mg/m^3. This will emplace the site substantially below the TP National Bottom Line of >50mg/m^3 (MfE, 2020). Again, these impacts are currently unknown and are likely to be diluted due to the relatively small proportion of groundwater contribution to the lake (in comparison to surface water).

Table 10: NPS-FM NOF comparison for the Upper Clutha rohe

	Nitrate		**NOF Band**	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
F42/0113	0.005	0.097	A	A
G40/0367	1.4	1.853	B	B
	DRP		**NOF Band**	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
F42/0113	0.0875	0.11	D	D
G40/0367	0.0048	0.0079	A	A
	Ammoniacal nitrogen		**NOF Band**	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
F42/0113	0.255	0.36	C	B
G40/0367	0.0025	0.44	A	C

4.2.3.1 The Hawea Basin

4.2.3.1.1 Aquifer information

The Hawea Basin aquifer consists of unconsolidated deposits of fluvial (i.e. gravels) and glacial (moraine and till) origin. The unconsolidated strata overlie low permeability basement strata with an estimated thickness of between 50 and >100m thick (Heller, 2003).

The basin was divided into several separate domains based on topography and surface water boundaries. Groundwater flow in the aquifer is driven by seepage from Lake Hawea alongside runoff and land surface recharge. The overall groundwater flow direction in the aquifer is to the southwest, with groundwater eventually discharging into the Clutha River, to which the aquifer is well connected. The depth to groundwater varies across the aquifer, with shallower depths in the northern Hawea Flats (5-10m) and increasing depth to the south (>20m deep), where the area is dominated by terraces (ORC, 2012b).

The main groundwater use in the area is irrigation with water also being used for domestic and stock water supply. In addition to these uses, groundwater is also important for the two regionally-significant wetlands at Campbells Reserve and Butterfield wetland. Bores in the Hawea Flats area are shallow, hence their supply can be vulnerable to over abstraction and contamination. There is a proposed limit to abstraction volume from the aquifer in order to protect the wetlands and shallow bores in the area (ORC, 2012b). The Hawea basin was considered as a high priority area for risk from septic tank leachate (high development) although some of it is on a reticulated supply.

4.2.3.1.2 Groundwater quality monitoring results

There are three monitoring bores within the Hawea Basin aquifer. A summary of the bore information is provided in Table 11. The monitoring of the bores only began in 2016.

Bore G40/0367 (150mm diameter) was drilled in June 2014. It is located at Loach Road, Hawea, at NZTM E1305561 N5047533. The bore depth is 17.1m. The bore log describes fine/coarse sand with some silt to 8m underlain by coarse gravel with some sand/silt to 14m. There is then coarse sand with some gravel to 16.5m underlain by fine sand to the bore bottom at 17.1m. The bore is screened within the bottom sand layer, at a depth of 16.6 to 17.1m. The Static Water Level (SWL) in the bore ranges between approximately 12.15 and 13.42m below Measuring Point (MP).

Bore G40/0415 (250mm diameter) was drilled in October 2016. The bore is located at Gladstone Road, Hawea, at NZTM E1305860 N5052754. The total bore depth is 30.07m. The bore log describes moist silt to 4.8m underlain by silty gravel to 10.3m. There is then sandy gravel with some silt to the bottom of the bore at 30.9m. The bore is screened at a depth of between 27.0 and 30.0m, within the bottom sandy gravel horizon. The SWL in the bore ranges between 23.05m and 27.35m below MP.

Bore G40/0416 (200mm diameter) was drilled in October 2017. The bore is located on Domain Road, Hawea, NZTM E1302748 N5052499. The total bore depth is 30.5m. The bore log describes sandy gravel with some silt to 6.5m underlain by a large boulder to 10.3m. There is then sandy gravel with minor silt to 17.2m underlain by sandy silt and gravel to 23.2m. There is then silty gravel to the bottom of the bore at 30.5m. The bore is screened at a depth of between 27.65 and 30.5m, within the bottom silty gravel horizon. The SWL in the bore ranges between 24.51 and 27.10m below MP.

These logs suggest that the bores in this area abstract from an unconfined/semi confined sandy gravel/sand aquifer, with finer overlying layers (e.g. silt/silty gravel/silty sands) that potentially provide a degree of confinement. The bores are screened within sandy/silty gravel and sand horizons. These logs also illustrate the heterogeneity of the deposits in the area.

Table 11: summary of monitoring bore information for the Hawea Basin

Bore Number	Depth (m)	Diameter (mm)	Easting NZTM	Northing NZTM	Screen Top (m)	Screen bottom (m)	Bore log available
G40/0367	17.1	150	1305561	5047533	16.6	17.1	Yes

G40/0415	30.07	250	1305860	5052754	27.0	30.0	Yes
G40/0416	30.5	200	1302748	5052499	27.65	30.5	Yes

Groundwater E. coli, dissolved arsenic, nitrate, and ammonia concentrations in the Hawea basin are provided in Figure 14,

Figure 15, Figure 16, and

Figure 17. There were no E. Coli, dissolved arsenic, or nitrate nitrogen measurements which exceeded the DWSNZ MAV in any of the bores. The highest nitrate concentrations were measured in bore G40/0367, ranging between approximately 0.5 and 2.0mg/L. There appears to be a seasonal fluctuation in nitrate concentrations, with concentrations falling in summer and increasing in winter. Concentrations in the other bores are lower and less variable temporally, with the lowest concentrations measured in bore no. G40/0415.

Figure 14: Groundwater dissolved arsenic concentration for the Hawea Basin

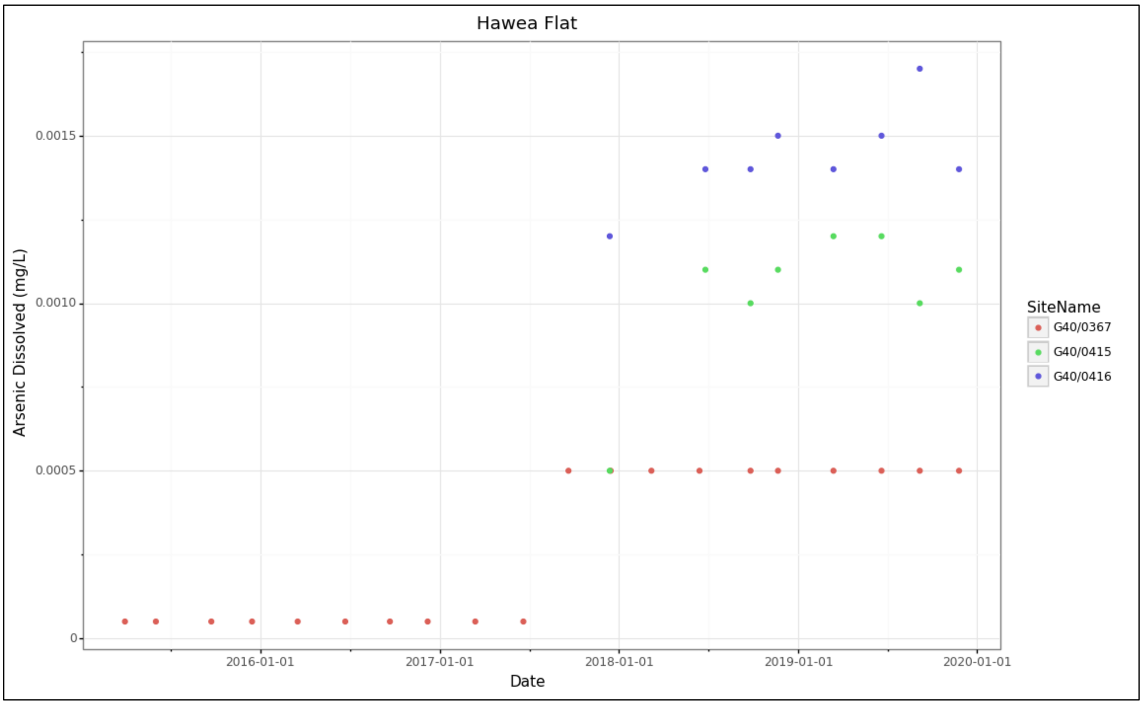


Figure 15: Groundwater nitrate concentration for the Hawea Basin

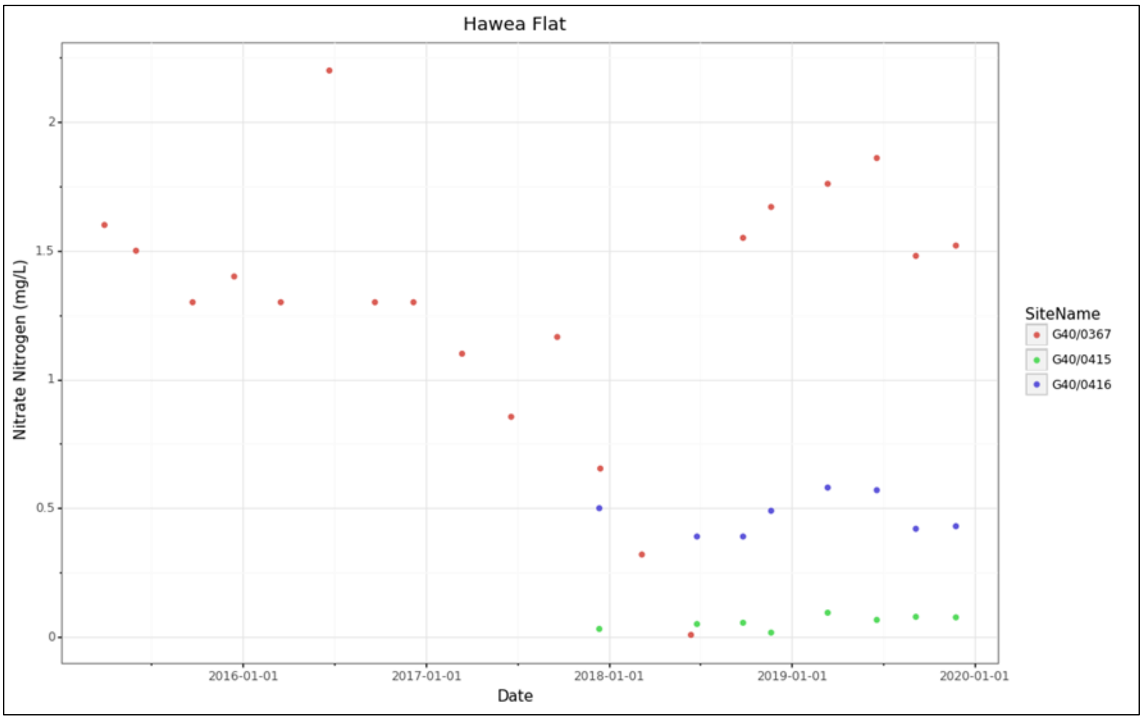


Figure 16: Groundwater E. coli count for the Hawea Basin

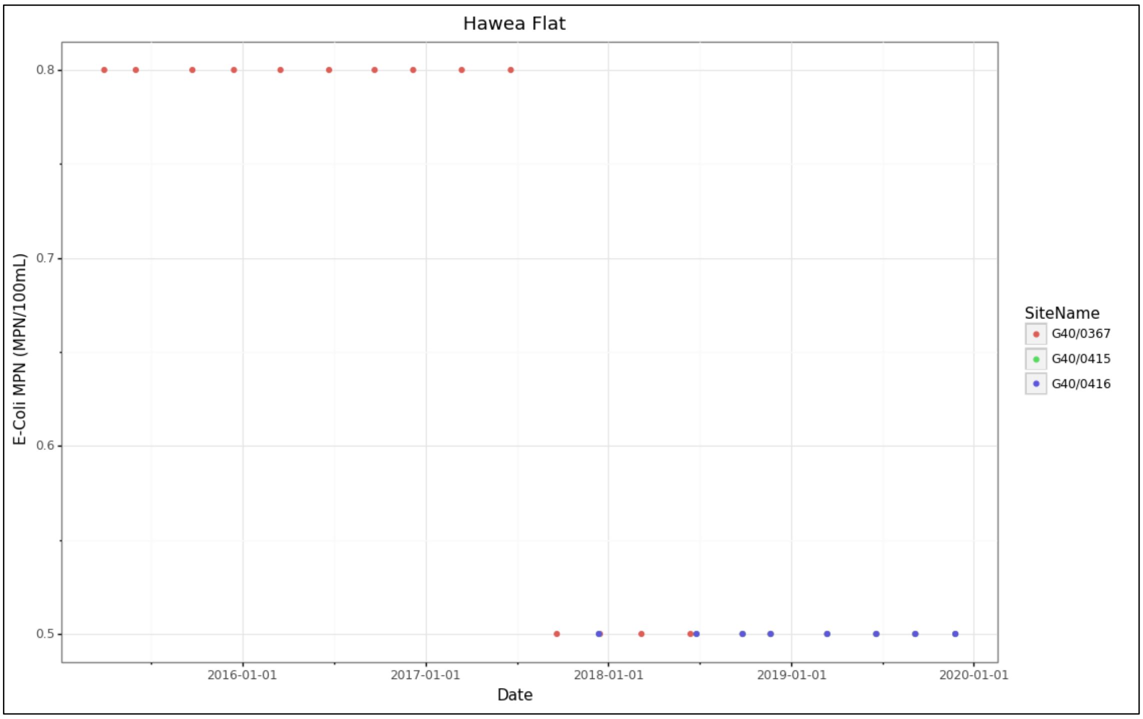
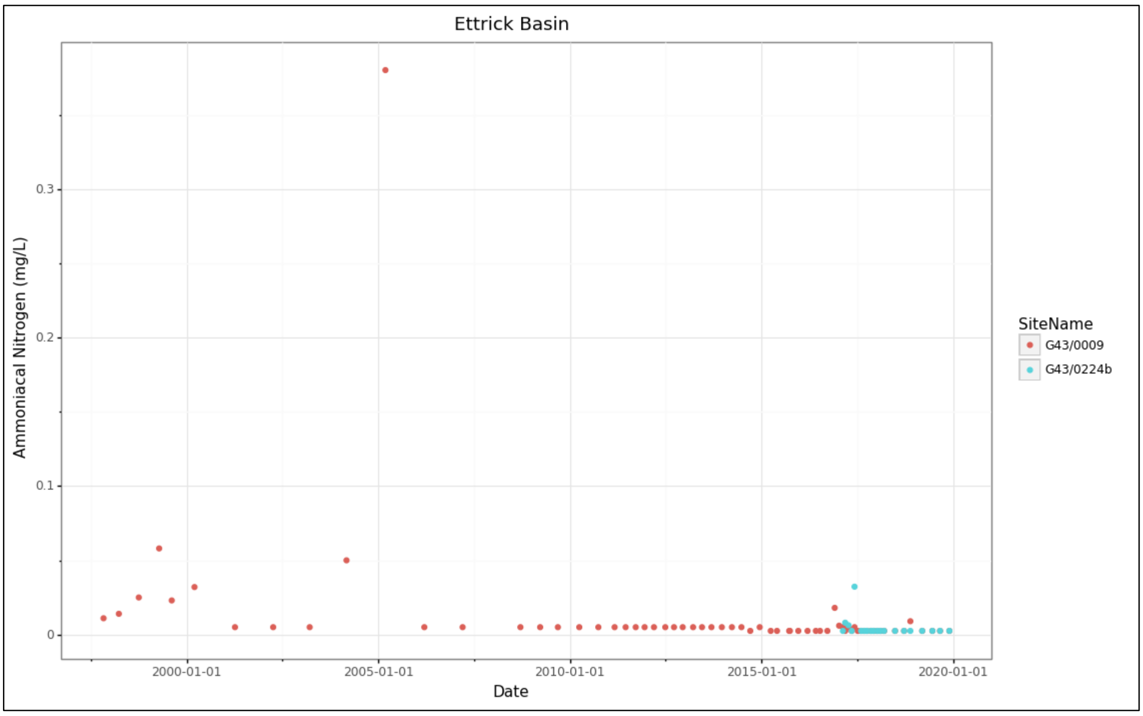


Figure 17: Groundwater Ammonia concentrations for the Hawea Basin

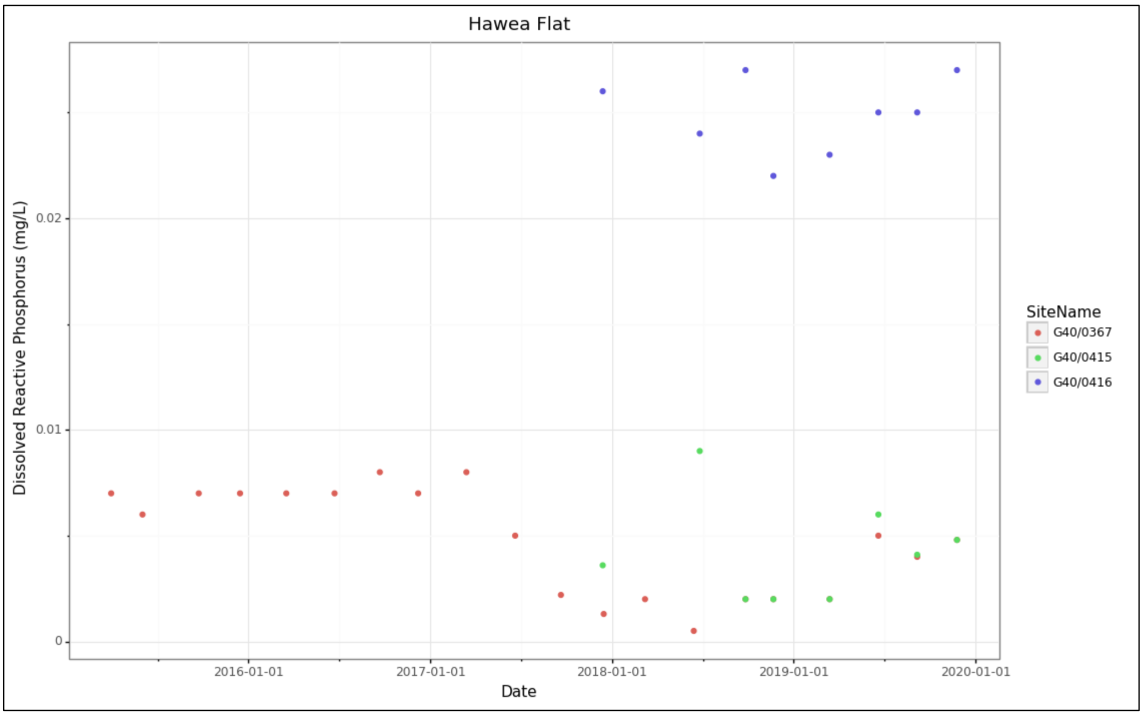


Regarding ecosystem health, bore No. G40/0367 is the only one shallower than 20m. The Hawea Flat area is located in Group 3 of Schedule 15. The comparison of the 80th percentile against the Schedule 15 limits is shown in Table 12, where concentrations that exceed the limits are in orange. The results show that the 80th percentile for ammonia was below the limit. However, nitrate concentrations (1.642mg/L) substantially exceeded the Schedule 15 limit of 0.075mg/L whilst the DRP concentration of 0.007mg/L slightly exceeded the limit (Figure 18).

Table 12: Hawea Basin 80th percentile concentrations (mg/L) for water quality variables and comparison with Schedule 15 limits

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 3 Sched. 15 limit				**0.075**	**0.005**	**0.01**
G40/0367	Clutha	Upper Lakes	Upper Lakes	1.642	0.007	0.006

Figure 18: Groundwater DRP concentration for the Hawea Basin



4.2.3.2 Kingston Groundwater Management Zone

4.2.3.2.1 Aquifer information

Kingston is situated at the southern end of Lake Wakatipu, around 40km south of Queenstown. The area is underlain by glacial moraine deposits and post glacial alluvial fan and lake shore deposits. The Kingston Stream alluvial fan extends to the lake shore on the southeastern side of the township and several unnamed streams drain the western margin. The Eyre Mountains, situated on the west side of the lake and the Hector Mountains, on the east side, are composed of schist.

The area has been substantially impacted by glacial and post glacial activity. Geomorphological evidence such as substantial preserved river channels situated south of the town, which are now swamp filled, indicates that Lake Wakatipu catchment drained southwards, down the Mataura River, during the last glaciation. These former higher lake shores are indicated by relics of 1-2m high terraces, located within the township, that are aligned parallel with the modern lake shore.

Following a glacial or post glacial lake level high, the receding lake appears to have dropped in stages. In Kingston, and across the Wakatipu deltas, this recession left a gently sloping profile with several low lakeward-sloping terraces. This process has also left a succession of generally low permeability till deposits overlain by better sorted gravelly sand alluvium and lake shore gravels of variable thickness (around 1-3m) which forms the resultant shallow aquifer system (ORC, 1997a).

4.2.3.2.2. Groundwater quality monitoring

There is only one SoE monitoring bore in the Kingston GWMZ, no. F42/0113 (75mm diameter). The bore is situated at Cornwall Street NZTM E1264431 N4971121, approximately 40m south of the shore of Lake Wakatipu. The bore is very shallow (4.4m). There is no information regarding the screen depth in the bore and a log is not available. The SWL in the bore ranges between approximately 0.83 and 1.45m below MP. The bore is solely used for groundwater monitoring. However, due to its shallow depth, poor security, and proximity to the lake it is inadequate for monitoring and should be replaced as soon as practically possible.

The assessment of groundwater quality in the Kingston GWMZ against the DWSNZ is shown in Figure 19,

Figure 20, Figure 21, and Figure 22. The DRP concentrations are shown in Figure 23. The bore previously had high arsenic concentration above the DWSNZ MAV of 0.01mg/L, with maximum concentrations of around 0.017mg/L. Although the concentrations seem to fall, some of the results still exceed the MAV (Figure 19). These exceedances are likely due to the prevalent schist lithology in this area.

The E. Coli data shows that 35% of the samples exceeded the DWSNZ MAV. However, the measured E. Coli count was generally low, with a maximum of 6MPN/100mL (March 2013). The E. coli exceedances are potentially due to the high density of septic tanks in the township, the bore's shallow depth, and poor borehead security. Furthermore, most of the exceedances were <1.6MPN/100mL and were reported between September 2014 and June 2017, when the analysis was performed by Water Care. Apart from that, the only exceedance was 6 MPN/100mL in March 2013 (

Figure 20). Nitrate concentrations in the bore are low, ranging between 0.001 and 0.57mg/L, substantially below the DWSNZ MAV of 11.3mg/L NO_3-N.

Figure 19: Groundwater dissolved arsenic concentration in the Kingston GWMZ

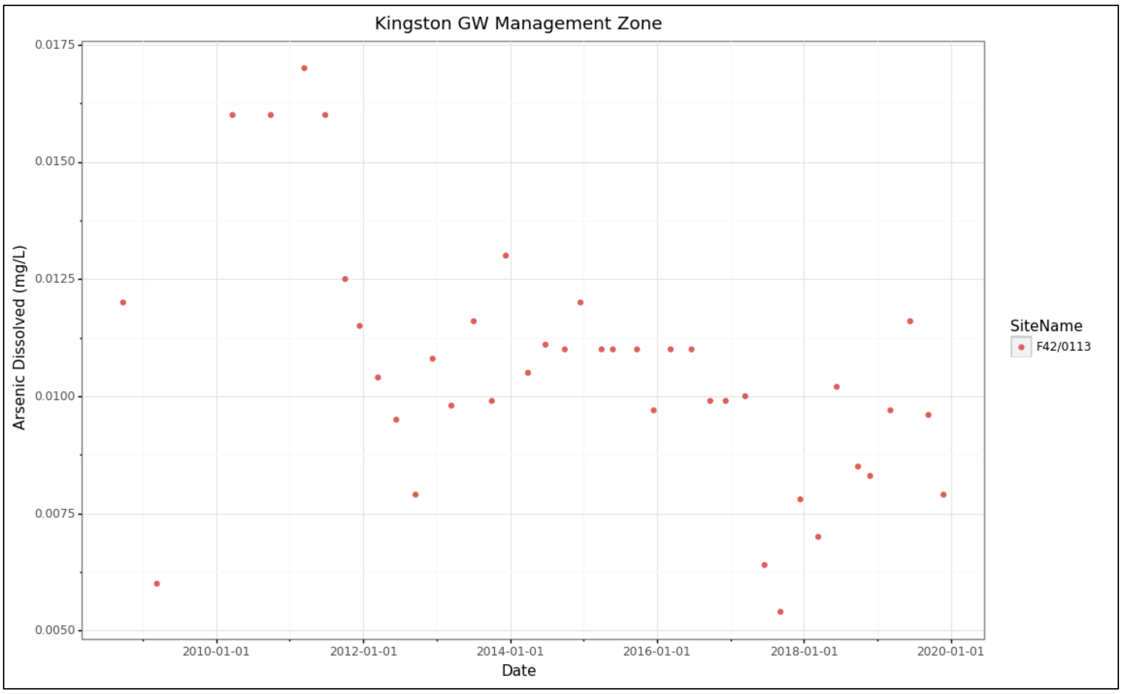


Figure 20: Groundwater E. coli counting in the Kingston GWMZ

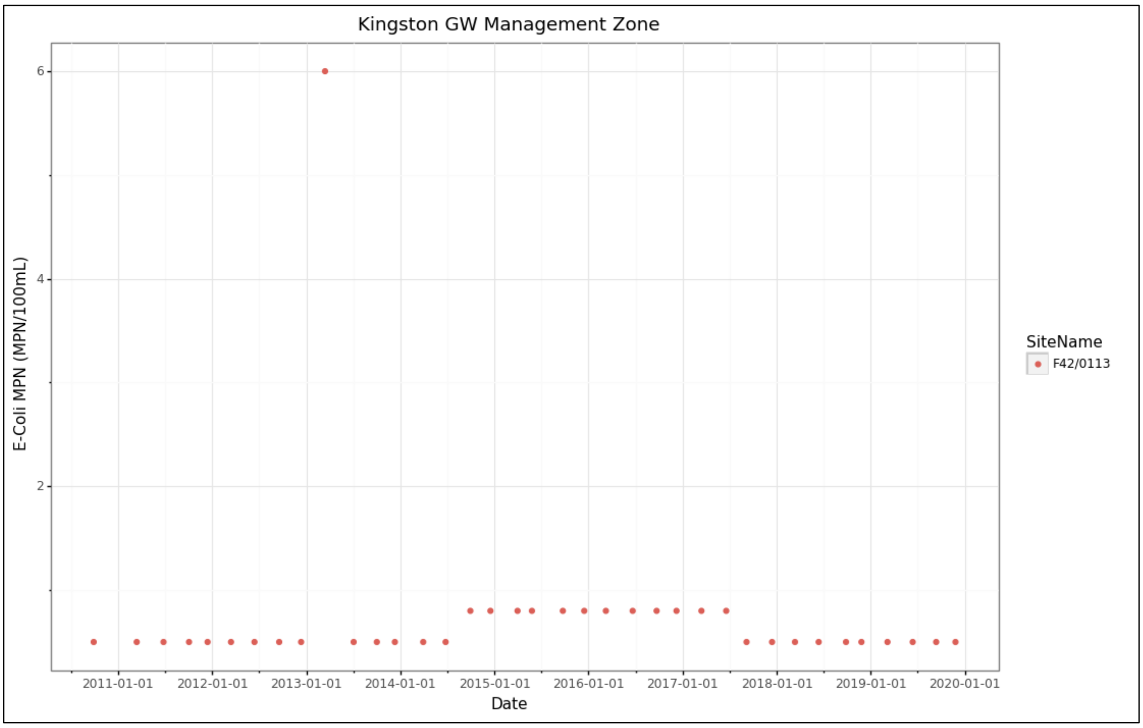


Figure 21: Groundwater nitrate concentration in the Kingston GWMZ

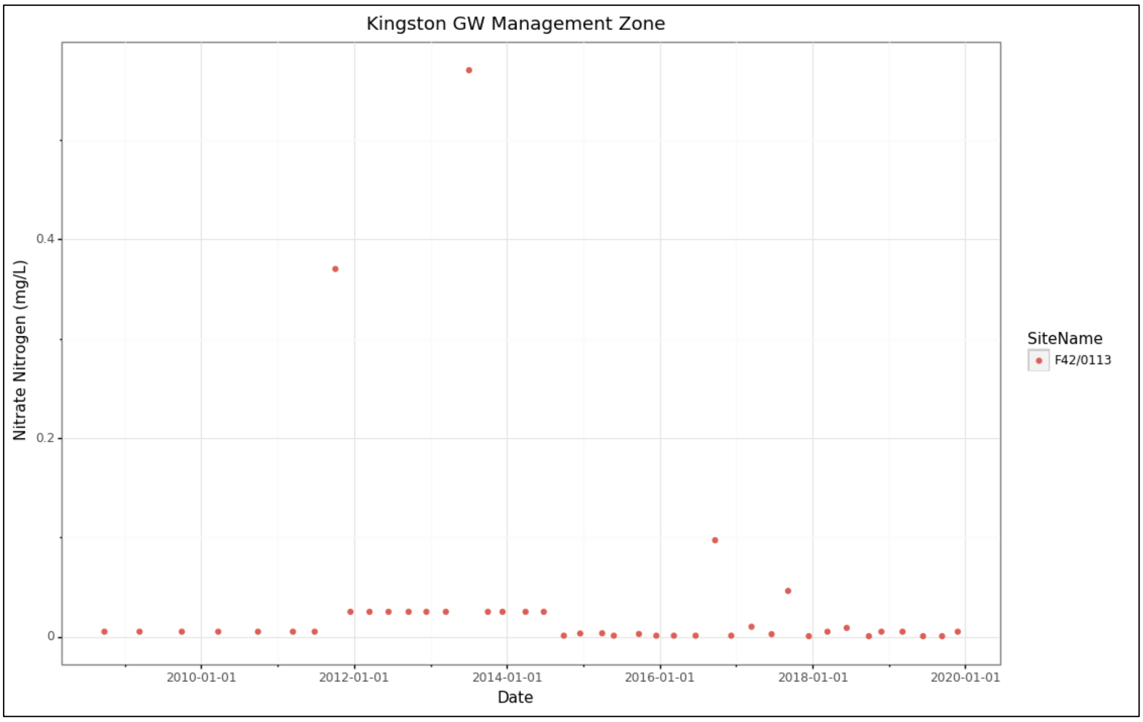


Figure 22: Groundwater ammonia concentration in the Kingston GWMZ

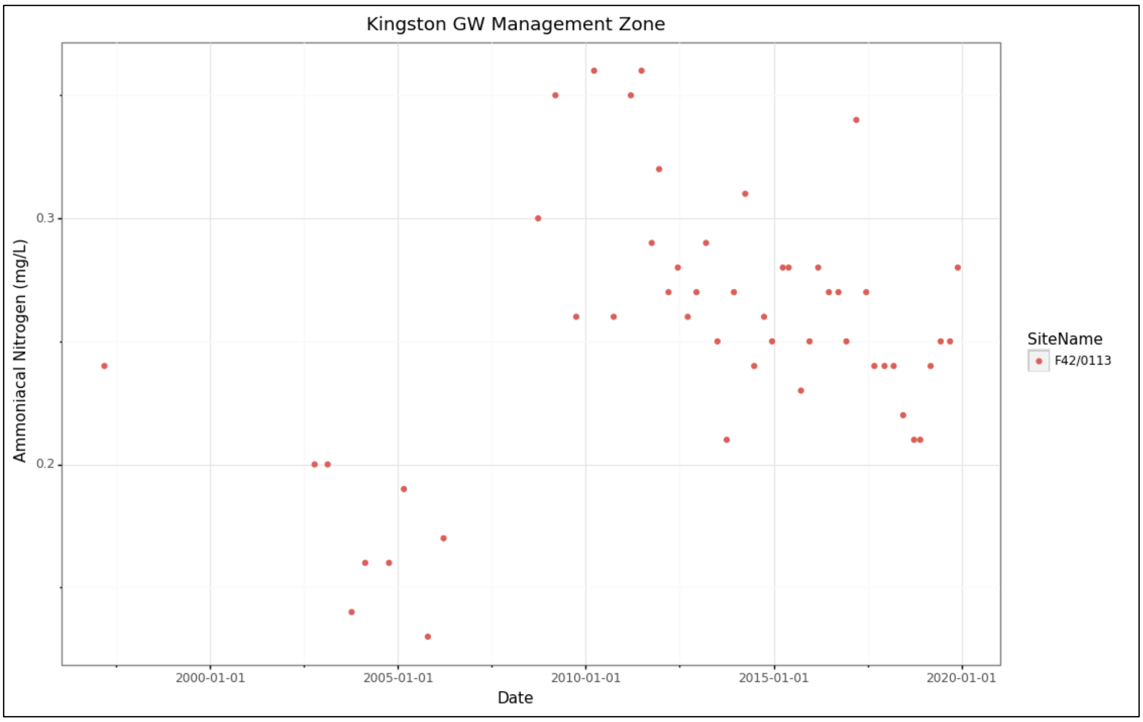
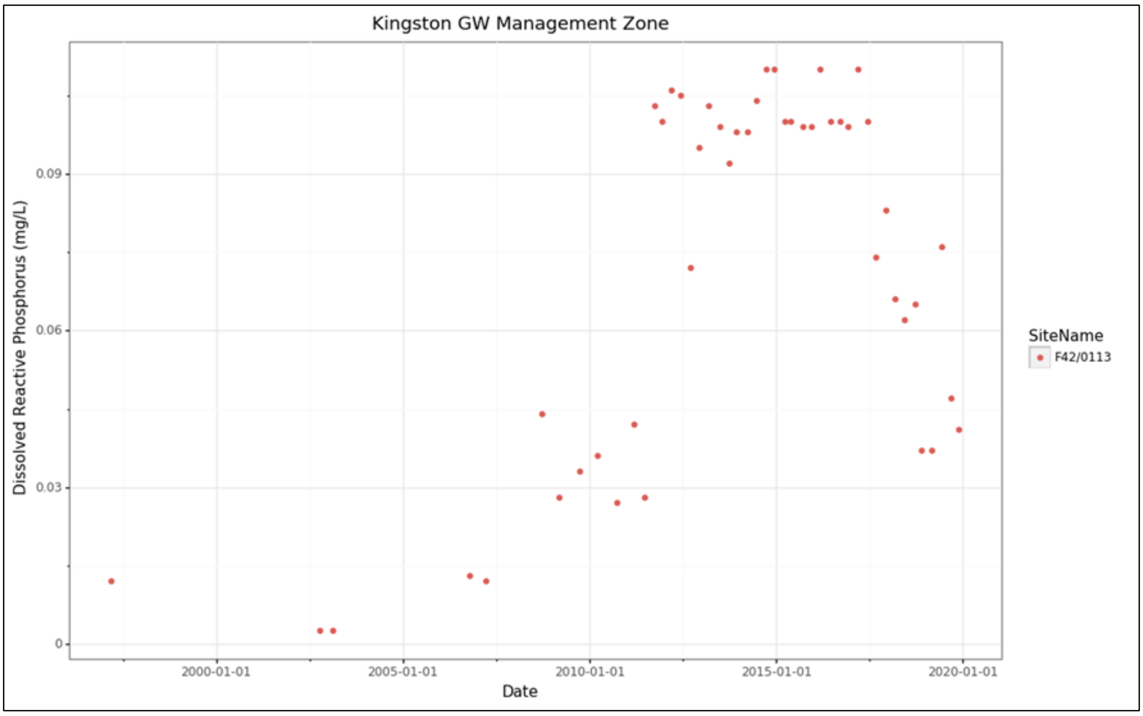


Figure 23: Groundwater DRP concentration in the Kingston GWMZ



Groundwater quality from the Kingston SoE bore was also assessed against Schedule 15 of the RPW and NPS-FM, Table 13. The bore is located in Group 3 of Schedule 15, and is also very close to the southern end of Lake Wakatipu, which is in Group 5. The data indicates that groundwater quality can adversely impact the lake, with the 80th percentile for DRP and ammonia substantially exceeding the Schedule 15 limits for both Groups 3. Due to the proximity to Lake Wakatipu, the 80th percentile for Total Nitrogen (TN) and Total Phosphorus (TP) were also assessed. TN has only been monitored continuously since September 2017, and the 80th percentile is 0.384mg/L, which substantially exceeds the Schedule 15 limit of 0.10mg/L. The data also shows that most of the TN is sourced from ammonia and Total Organic Nitrogen, as the nitrate concentration is low. Total Phosphorus has also been monitored since September 2017, with an 80th percentile concentration of 0.0912mg/L, which substantially exceed the Schedule 15 limit of 0.005mg/L. This indicates that groundwater discharge from the Kingston GWMZ into the lake can adversely impact its water quality. It is likely that the elevated ammonia and DRP concentrations are due to the high density of septic tanks, the bore's shallow depth and its location at the end of the flow path.

Table 13: Kingston GWMZ 80th percentile nutrient concentration comparison against the Schedule 15 limits for of nitrate, DRP, and ammonia concentrations. Values in orange exceed the threshold.

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 3 Sched. 15 limit				**0.075**	**0.005**	**0.01**
F42/0113	Clutha	Upper Lakes	Kingston	0.050	0.100	0.282

4.2.3.3. Glenorchy

4.2.3.3.1 Aquifer information

The township of Glenorchy is situated at the northern end of Lake Wakatipu. It is bordered by Lake Wakatipu to the west, old river terraces at the foot of the Richardson Mountains to the east, the Glenorchy Lagoon and Dart/Rees River delta to the north and the Buckler Burn to the south. The delta comprises of alluvial sands, mud flats, mires, and ponds which include a Department of Conservation (DoC) reserve. The area is also surrounded by schist mountains to the west and east. The mountains contain the mineral scheelite (Ca_2WO_4) which was formerly mined in the catchment.

The town is located on low terraced flats that gradually slope towards the lake. It is partly underlain by peaty soil and sandy gravel. Deposits in the area have high angle bedding surface that dip towards the lake, typical of sub-aqueous fan delta slope deposits. There are also well exposed, high terrace deposits underlain by remains of the Buckler Burn gravel delta which propagated into the lake during early post-glacial periods. The alluvial deposits are mainly composed of sandy gravels with low proportion of fines. (ORC, 1997b).

Some groundwater and surface water quality samples were collected during a study in 1996. The geochemistry results have identified strong connection between surface water of the

Buckler Burn and the aquifer. It also showed low faecal concentration counts and nitrogen concentrations, the highest being 3.6mg/L NO_3^-. This sample was collected in the holiday park and potentially reflects contamination from septic tank, fertiliser, or animal waste. (ORC, 1997b).

More recent investigations by E3Scientific Limited [E3S] (2018) have refined the conceptual groundwater model for Glenorchy, which highlights the area's complex hydrology. Monitoring showed that groundwater flows from the north, east and south underneath the township towards Lake Wakatipu. Sources of groundwater recharge include the Lagoon/Rees River (groundwater flow to the southwest towards the Jetty and Harbour), rainfall that flows off the Richardson Mountains (water flows west towards the Lake) and the Buckler Burn (flow to the northwest towards the Lake).

The model suggests that oxygen-rich surface water to the north (the Lagoon and its outflow into the Rees) has mixed redox status due to bio-geochemical processes involving organic matter. This water then becomes oxygen-depleted as it flows beneath the township, where septic tanks provide additional organic inputs that geochemically reduce iron oxides and sulphates. This highly reduced iron-rich groundwater discharges into the lake near the Jetty, where significant deposition of iron has been observed (E3S, 2018). Further evidence for the reducing conditions is provided by high dissolved arsenic groundwater concentrations in bore E41/0182, which is situated near the jetty. The flow from the south/east (Buckler Burn) is similar although the groundwater conditions are less reducing, hence, nitrate and sulphate concentrations are higher and iron concentration is lower. This was attributed to the increased depth to groundwater and the lower density of septic tanks in the southern half of the town, which lowers the leaching of organic material to the groundwater. On site wastewater management in Glenorchy (i.e. septic tanks) will initially impact groundwater beneath the township then Lake Wakatipu, which serves as the receiving environment. However, as the reticulated town water supply is sourced from groundwater upgradient of the township, the main risk from this wastewater management in terms of exposure is through recreational use of the lake (E3S, 2018).

4.2.3.3.2 Groundwater quality

Due to the rapid development that is experienced in Glenorchy and the high number of septic tanks, it was recommended as a high priority for groundwater monitoring (PDP, 2017). SoE groundwater monitoring by ORC began in October 2019 using the four piezometers drilled by E3S for their investigation on behalf of Queenstown Lakes District Council (QLDC). A map of the piezometers is provided in Figure 24 and the bore details are provided in Table 14. The piezometers were given ORC numbers using the ORC database. However, for clarity, the map also shows the piezometers' E3S (2018) original names (P1-P4). As sampling in Glenorchy only began in October 2019 the data is not sufficiently long for analysis. However, the results still provide very useful insight.

Figure 24: Location of SoE monitoring bores in Glenorchy (red dots)

Table 14: Details of monitoring bores in Glenorchy

Bore number	Depth (m)	Diam. (mm)	Easting	Northing	Screen Top (m)	Screen Bottom (m)	Log available	SWL (m below MP)
E41/0182 (P1)	10.1	25	1235134	5023214	2.10	10.10	Yes	0.300
E41/0183 (P2)	10.2	25	1235510	5023479	2.20	10.20	Yes	2.785
E41/0184 (P3)	10.0	25	1235260	5023606	2.00	10.00	Yes	0.10
E41/0185 (P4)	10.0	25	1235380	5023306	2.00	10.00	Yes	2.845

Despite the short duration of groundwater monitoring in Glenorchy, the data clearly indicates several notable issues. Arsenic concentrations in three bores (Figure 25) exceed the DWSNZ MAV of 0.01mg/L, with concentrations ranging between 0.0121mg/L (bore no. E41/0185) and 0.84mg/L (E41/0182), which is the maximum groundwater arsenic concentration in Otago. The arsenic source is likely to be geological, i.e. schist from the surrounding geology. The high arsenic concentrations are likely attributed to the reducing groundwater conditions, caused by the high density of septic tanks, which provide organic matter that lead to reducing geochemical conditions and increase arsenic mobility. However, Glenorchy is on a reticulated water supply, which is monitored by QLDC, hence the public health risk from arsenic consumption is low.

There were also some exceedances of the E. Coli DWSNZ MAV, with a count of 5MPN/100mL in bore E41/0185, situated near a hotel (Figure 26). This bore also had ammonia concentration of 16.9mg/L which substantially exceeds the DWSNZ aesthetic Guideline Value (GV) of 1.5mg/L (

Figure 27). There were no exceedances of the nitrate MAV in any of the bores, with concentrations ranging between 0.0005 and 2.0mg/L (Bore E41/0185, Figure 28).

Due to the shallow depths of the bores in Glenorchy the groundwater quality was also assessed against Schedule 15 of the RPW and NPS-FM. The bores are located in Group 3 of Schedule 15, and are also very close to the northern end of Lake Wakatipu, which is in Group 5. Despite the short data availability, the results show that ammonia and TP concentrations in all bores apart from E41/0183 exceed the Schedule 15 limits. Total Nitrogen in all bores exceed the Group 5 limits. Conversely, the DRP limit for Group 3 (0.005mg/L) is only exceeded in bore E41/0185 (Figure 29). The observed elevated nutrient concentrations are likely due to septic tanks input, particularly near bore E41/0185.

In summary, despite the short availability of data from Glenorchy the data indicates several groundwater quality issues, related to both drinking water and nutrient impact on Lake Wakatipu. The risks to drinking water are diminished as Glenorchy is on a reticulated town supply. However, nutrient input through groundwater discharge to the lake can adversely impact lake water quality. Further risk to recreation water quality is the area near the jetty, where groundwater transits from strongly reducing to oxidised conditions which lead to the deposition of iron (ES3, 2018).

Figure 25: Groundwater dissolved arsenic concentration in the Glenorchy GWMZ

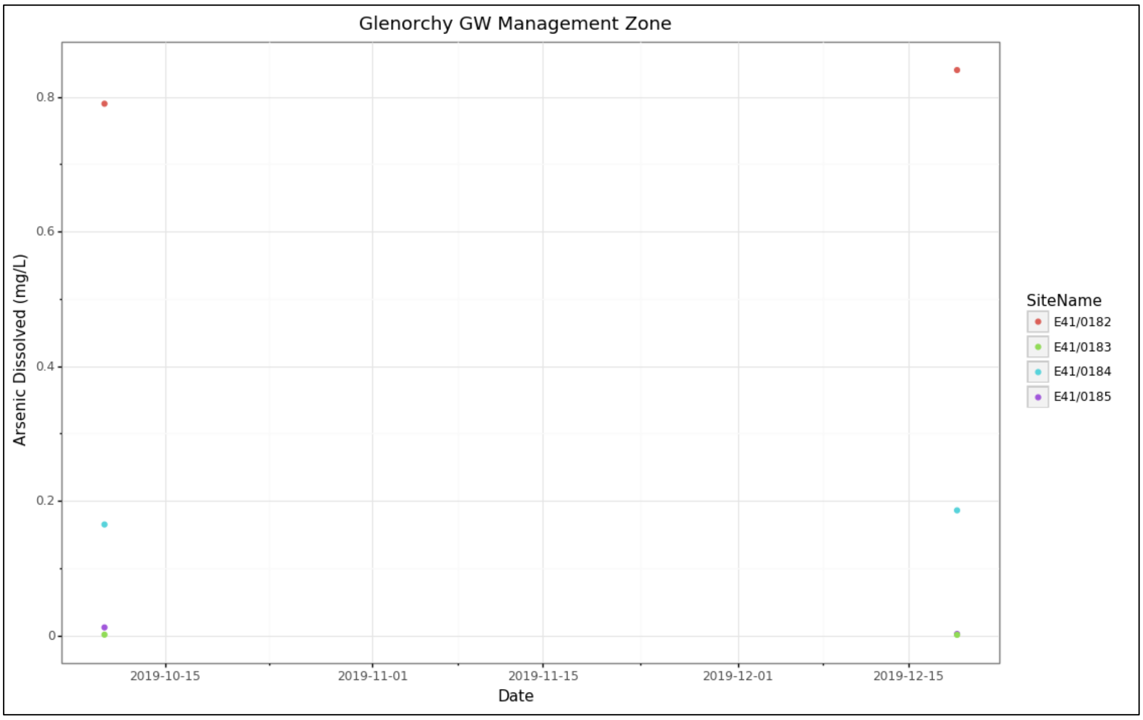


Figure 26: Groundwater E. coli results for the Glenorchy GWMZ

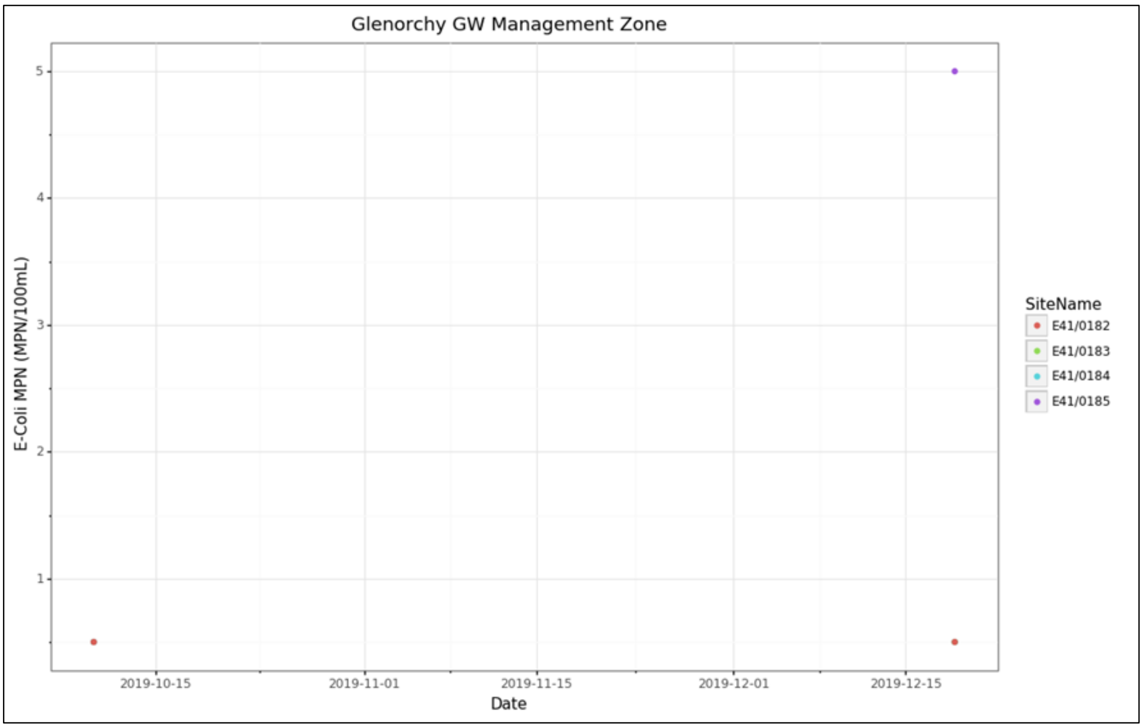


Figure 27: Groundwater ammonia concentration in the Glenorchy GWMZ

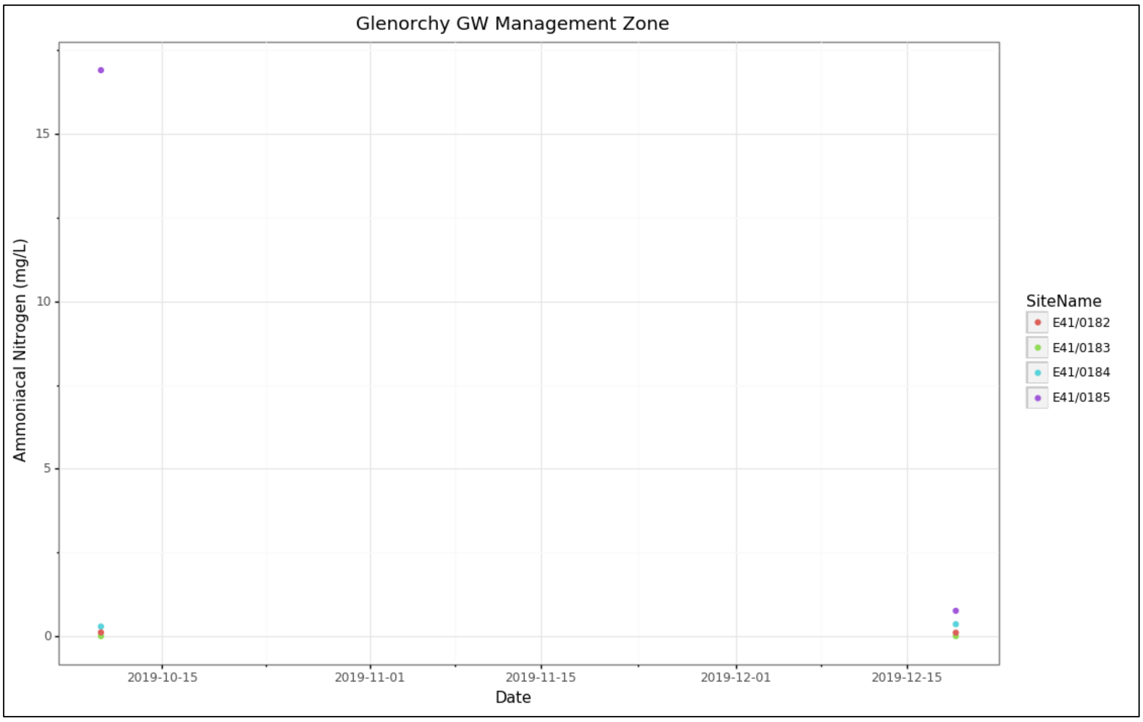


Figure 28: Groundwater nitrate concentration in the Glenorchy GWMZ

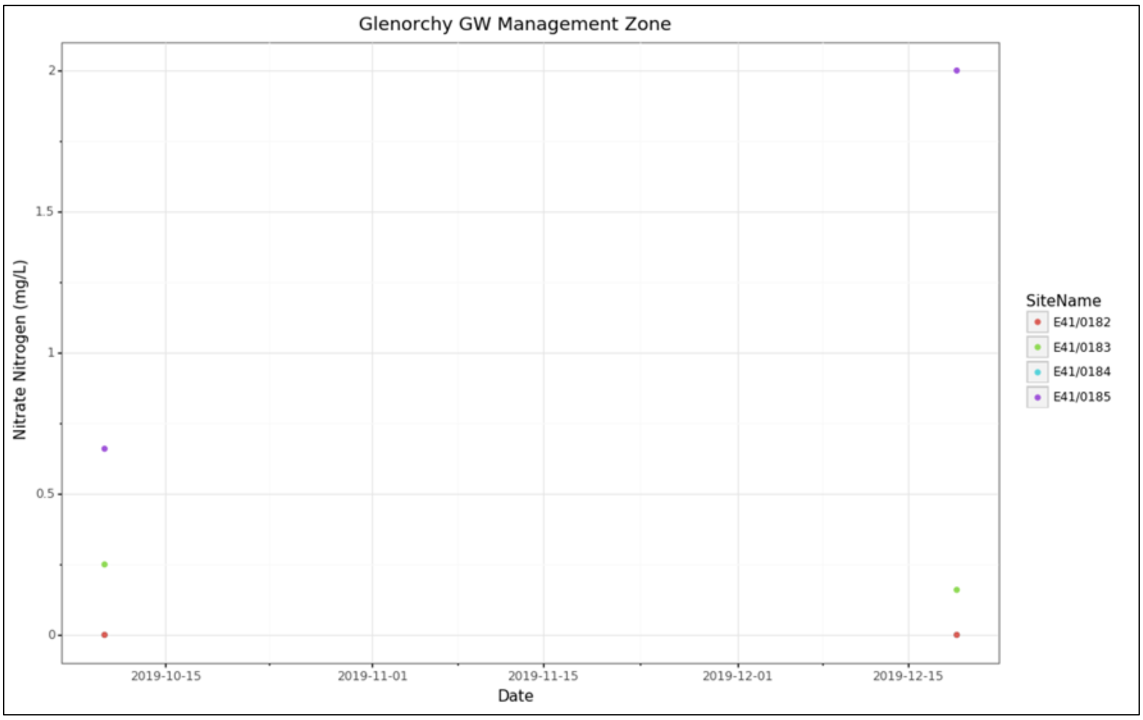
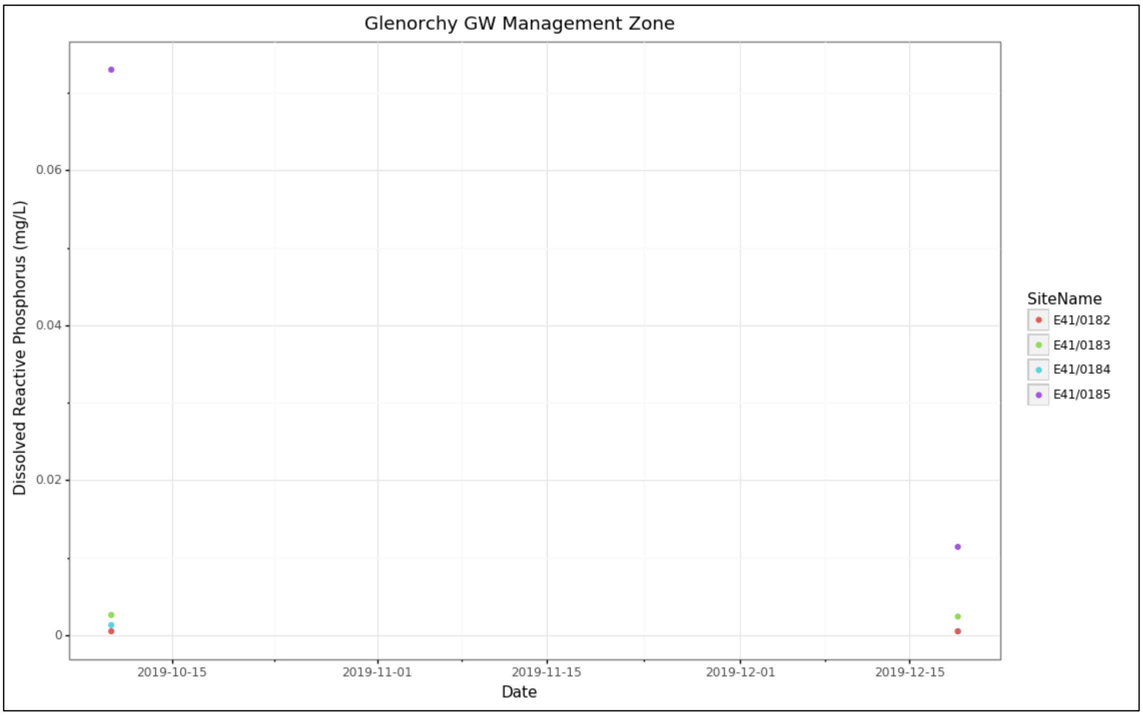


Figure 29: Groundwater DRP concentration in the Glenorchy GWMZ



4.2.4. The Dunstan Rohe

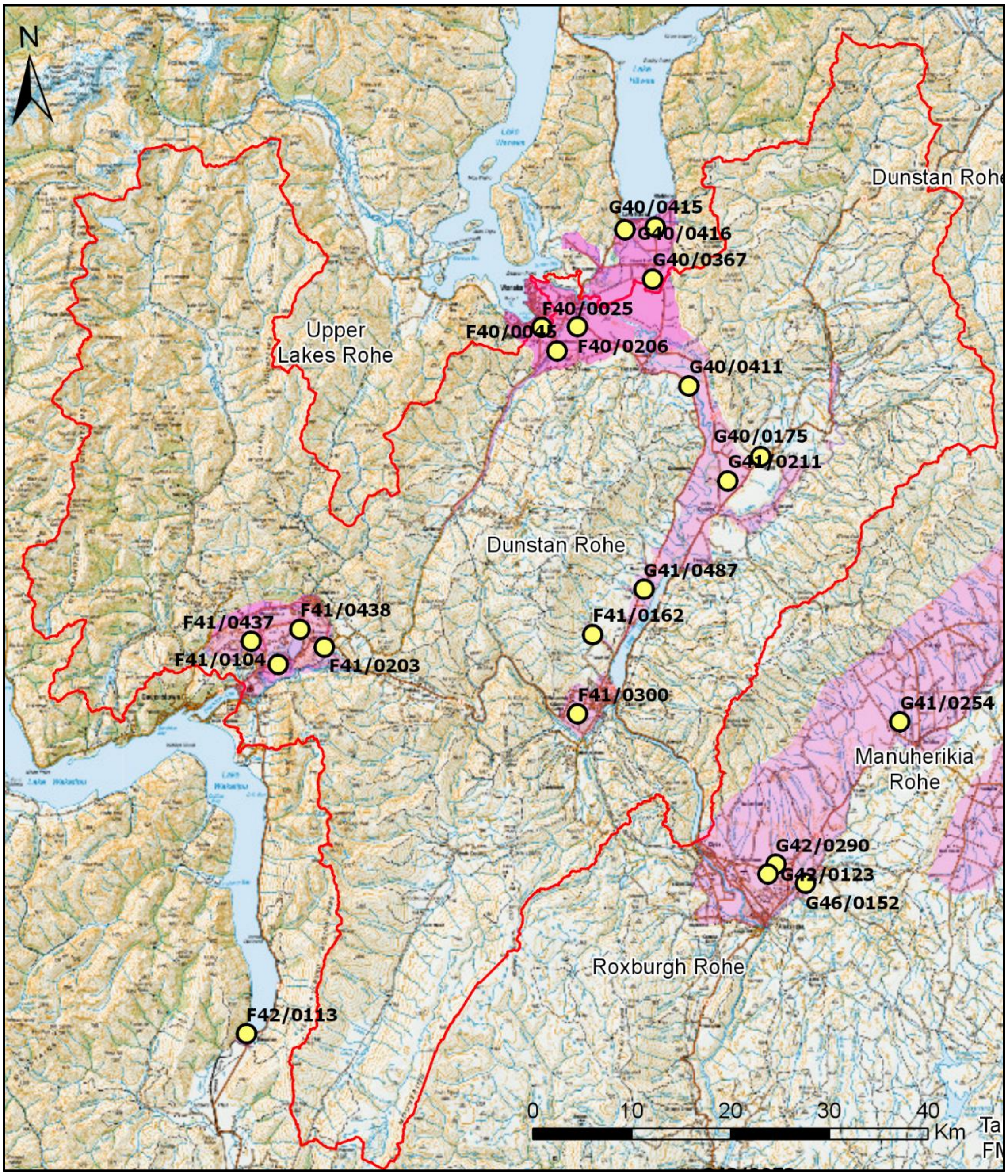
The Dunstan Rohe encompasses the upper catchment of the Clutha River between south of Wanaka and Lake Dunstan alongside the Shotover catchment to the north of Queenstown. It runs from the outlets of lakes Wanaka, Wakatipu and Hawea down to Clyde dam. This rohe includes the Kawarau, Nevis, Shotover, Upper Clutha, Hawea, Cardrona, Arrow, and Lindis Rivers alongside many smaller tributaries of the Clutha such as the Lowburn, Amisfield Burn, Bannock Burn and Luggate Creek. The outflows of Lakes Wanaka and Wakatipu are un-regulated whereas the outflow of Lake Hawea is controlled by the Hawea Dam. This rohe also includes Lake Dunstan, a hydroelectric power lake created by the Clyde Dam,

Figure 30. These catchments contain diverse landforms from the rugged Kawarau gorge, primarily native covered Shotover catchment to extensive agriculture and fruit growing areas around Lake Dunstan.

The bores in this rohe are divided to the following aquifers and GWMZ:

- The Wanaka & Cardrona Basin (Section 4.2.4.1)
- The (former) Wakatipu Basin (Section 4.2.4.2)
- The Cromwell Terrace Aquifer (Section 4.2.4.3)
- Lowburn Alluvial Aquifer (Section 4.2.4.4)
- The West Bank of the Upper Clutha (section 4.2.4.5)
- Lower Tarras (Section 4.2.4.6)

Figure 30: Location of the Dunstan Rohe (red outline), aquifers (green) and SoE monitoring bores (red dots). Aquifer names are shown in Figure 1.



The SoE results suggest that groundwater quality in the monitoring bores in the Dunstan rohe is generally good (particularly in the Cromwell Terrace aquifer and Lowburn Alluvial aquifer monitoring bores), with low E. coli and nitrate concentrations below the DWSNZ MAV in most bores. However, groundwater quality in some bores, particularly in Wanaka, the former Wakatipu basin, and Lower Tarras reflect issues of the rapid development in these areas which can lead to elevated E. coli, nitrate, and DRP concentrations. Although arsenic concentrations in most of the monitoring bores in the rohe are generally below the MAV, due to the prevalence of schist lithology in these areas, it is important that bore owners regularly test their water.

Groundwater quality from most of the shallow monitoring bores suggests potential for adversely impacting surface water quality that interact with groundwater, with nitrate and DRP concentrations in most bores exceeding the Schedule 15 limits. Ammonia concentrations are usually below the limits (Table 3, Table 15). It is likely that some of the elevated nitrate and DRP concentrations are also due to poor borehead protection.

Table 15: Median concentrations for DWSNZ/ecosystem health parameters for the Dunstan rohe

Aquifer	Ammoniacal Nitrogen (mg/L)	Arsenic Dissolved (mg/L)	Dissolved Reactive Phosphorus (mg/L)	E-Coli (MPN/100mL)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)
Cromwell Terrace	0.005	0.001	0.007	0.500	2.350	1.525*
East Wanaka Basin Cardrona Gravel	0.005	0.001	0.005	0.500	1.270	2.050
Lowburn Alluvial Ribbon	0.005	0.001	0.003	0.500	0.330	0.355
Lower Tarras	0.005	0.001	0.004	0.500	1.095	1.160
Luggate GW Management Zone	0.003	0.001	0.023	0.500	7.750	7.700
Mid Mill Creek	0.003	0.001	0.002	0.800	0.113	0.144
Morven	0.005	0.001	0.003	0.500	1.100	0.170
Pisa GW Management Zone	0.003	0.001	0.002	0.500	0.245	0.230
Speargrass-Hawthorn	0.003	0.000	0.004	0.800	2.500	2.500
Unnamed	0.005	0.001	0.014	0.500	0.860	0.940
West Wanaka Basin Cardrona Gravel	0.005	0.001	0.003	0.500	0.390	0.400
Windemeer	0.260	0.014	0.009	0.500	0.028	0.280
Rohe median	**0.005**	**0.001**	**0.004**	**0.500**	**0.978**	**0.670**

***Note that TN has only been monitored since September 2017, which can potentially explain why the TN for the Cromwell Terrace aquifer and the rohe is lower than the median nitrate concentration. Some samples also show higher nitrate than TN, although the result is within the analytical variation for these methods.**

4.2.4.1 The Wanaka and Cardrona Basin

4.2.4.1.1 Aquifer information

The Wanaka Basin and the Cardrona Gravel Aquifer cover a sedimentary basin that consists of gravel-dominated strata downstream of the Cardrona River's Larches flow site. The aquifer is bounded by Lake Wanaka to the northwest and the Clutha River to the north east. The aquifer has complex hydrogeology due to deposition and reworking by glacial and fluvial activity over several phases of glacial advance and retreat. However, it generally behaves as a relatively consistent unit. There are also two outliers of basement strata within the basement.

The main source of recharge in the aquifer is flow losses from the Cardrona River where it enters the basin alongside some land surface recharge. Groundwater generally flows in a northerly direction from the low permeability hills toward the aquifer discharge points, which include the downstream reach of the Cardrona River, the Clutha River and Lake Wanaka. Groundwater depth varies across the aquifer, being around 20-30m deep below ground level where the Cardrona enters the basin, with shallower groundwater levels at the points of discharge near the Clutha River and Lake Wanaka. Bullock Creek, which flows through the township of Wanaka and has high value for the community, is spring-fed, hence, abstractions from the aquifer are likely to impact its flow. Groundwater use in the basin include irrigation and domestic supply (PDP, 2017b).

4.2.4.1.2. Groundwater quality results

Groundwater quality in the Wanaka area is monitored in three bores, details of which are summarised in Table 16. The aquifer is divided to and East and West Wanaka basins. Bore F40/0025 (150mm diameter) is located at Golf Course Road, Wanaka, at NZTM E1294352 N5042604. The bore depth is 40.0m. There is no bore log or screen information for this bore. Bore F40/0045 (100mm diameter) is situated at Faulks Road, approximately 470m east of the Cardrona River, at NZTM E1295870 N5040239. The bore depth is 60m. There is no bore log or screen information for this bore. Bore no. F40/0206 (150mm diameter) is located at Morris Road, at NZTM E1297955 N5042689. The log for this bore describes fine sand to 4.2m underlain by silty fine sands and gravels to 18.6m. There is then sandy gravel to the well bottom at 45.0m. There is no screen information for this bore, but it is likely that it is screened within the lower sandy gravels unit. Both bores F40/0045 and F40/0206 are located in the East Wanaka Basin.

Table 16: A summary of details for monitoring bores in the Wanaka Basin

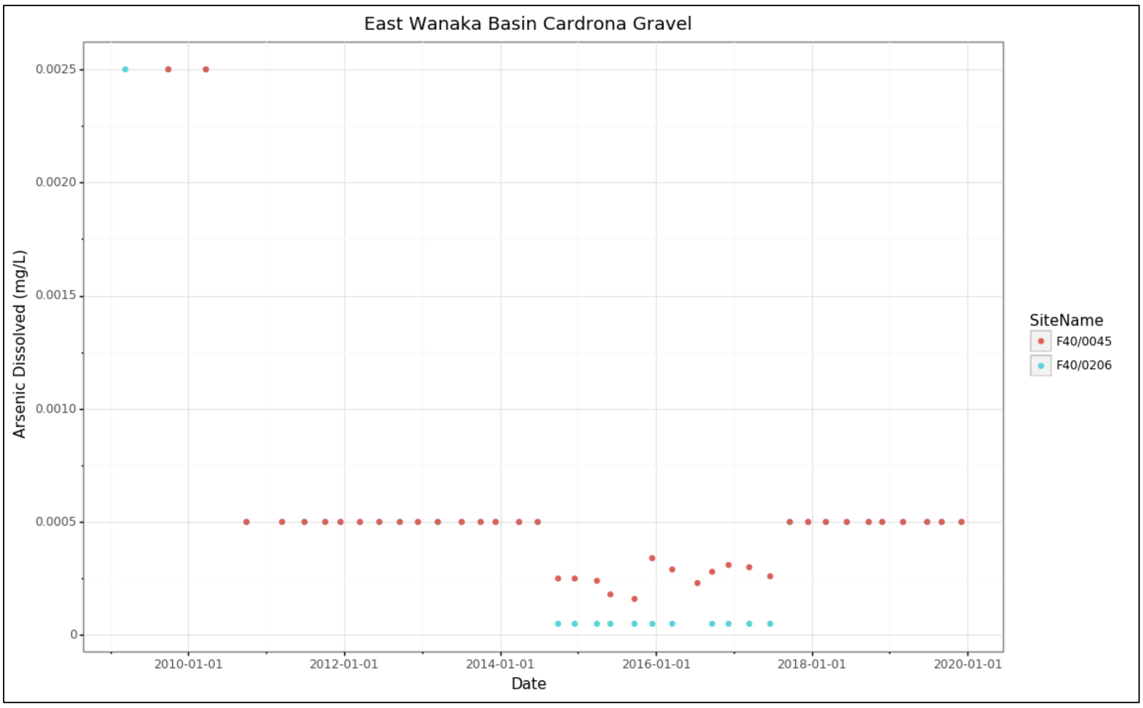
Bore no.	Depth	Diameter (mm)	Easting	Northing	Screen Top (m)	Screen Bottom (m)	Bore log available?
F40/0025	40.0	150	1294352	5042604	N. A.	N. A.	No
F40/0045	60.0	100	1295870	5040239	N. A.	N. A.	No
F40/0206	45.0	150	1297955	5042689	N. A.	N. A.	Yes

The groundwater quality results from the East and West Wanaka Basins were compared against the DWSNZ. The results show no exceedances of the dissolved arsenic MAV (

Figure 31). The
E. Coli results are generally below the MAV, although an exceedance of 4 MPN/100mL was measured in bore F40/0025 in December 2019 (Figure 32). Nitrate concentrations are all below the DWSNZ MAV, ranging between 1.5 and 4.5mg/L. However, one substantially higher sample of 11.2mg/L, which is just below the MAV, was measured in December 2012 (Figure 33). Although these results are below the MAV, some of them exceed the nitrate groundwater concentration for natural/low intensity land use (Daughney and Morgenstern, 2012). Nitrate concentrations in the remaining bores are lower, ranging between 0.61 and 1.13mg/L (F40/0206) and 0.21 to 0.78mg/L (F40/0025).

Due to the depth of all bores exceeding 20m, the results were not assessed against the RPW or NPS-FM standards for surface water quality. However, the DRP and nitrate concentrations in bore F40/0045 would exceed the Schedule 15 limits for Group 3 (Table 2, Figure 34). The ammonia concentrations are below the GV, with a maximum value of 0.06mg/L (bore F40/0025, Figure 35).

Figure 31: Groundwater dissolved arsenic concentrations for the Wanaka Basin



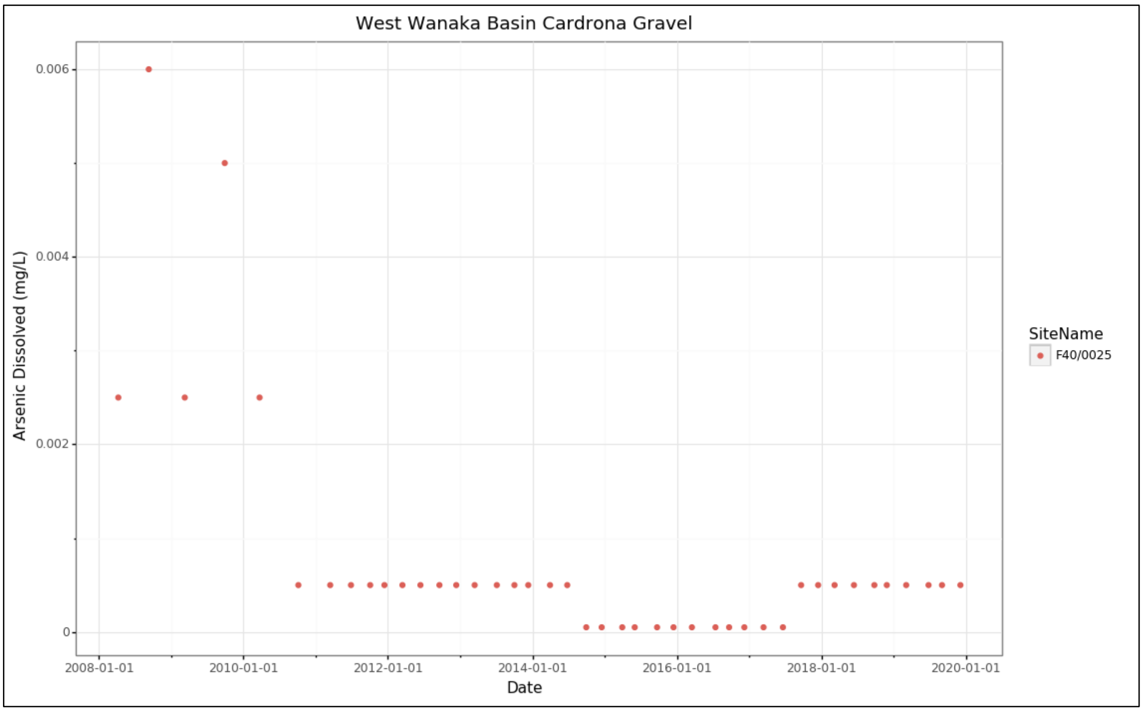
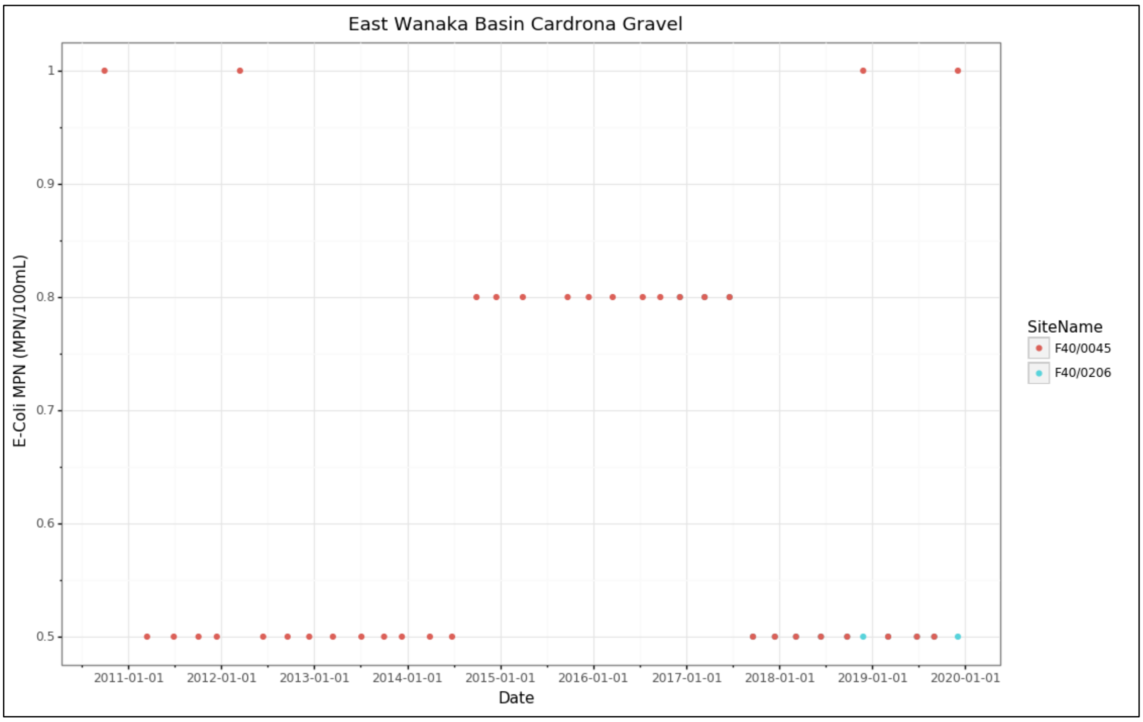


Figure 32: Groundwater E. coli count for the Wanaka Basin



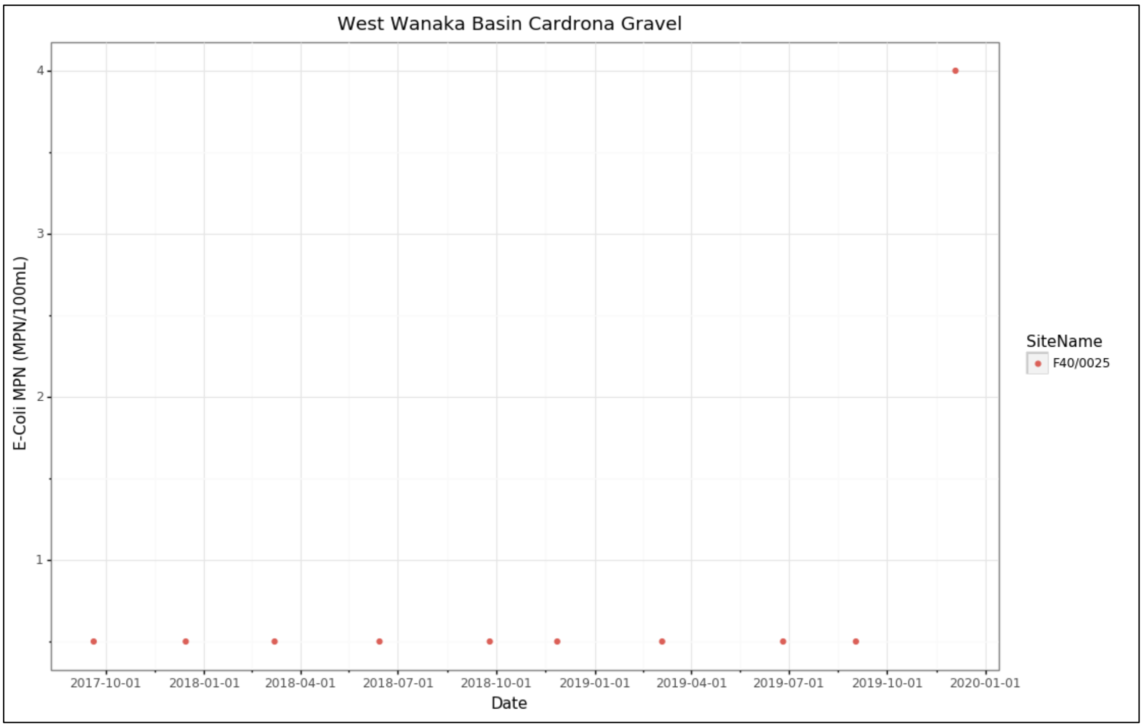
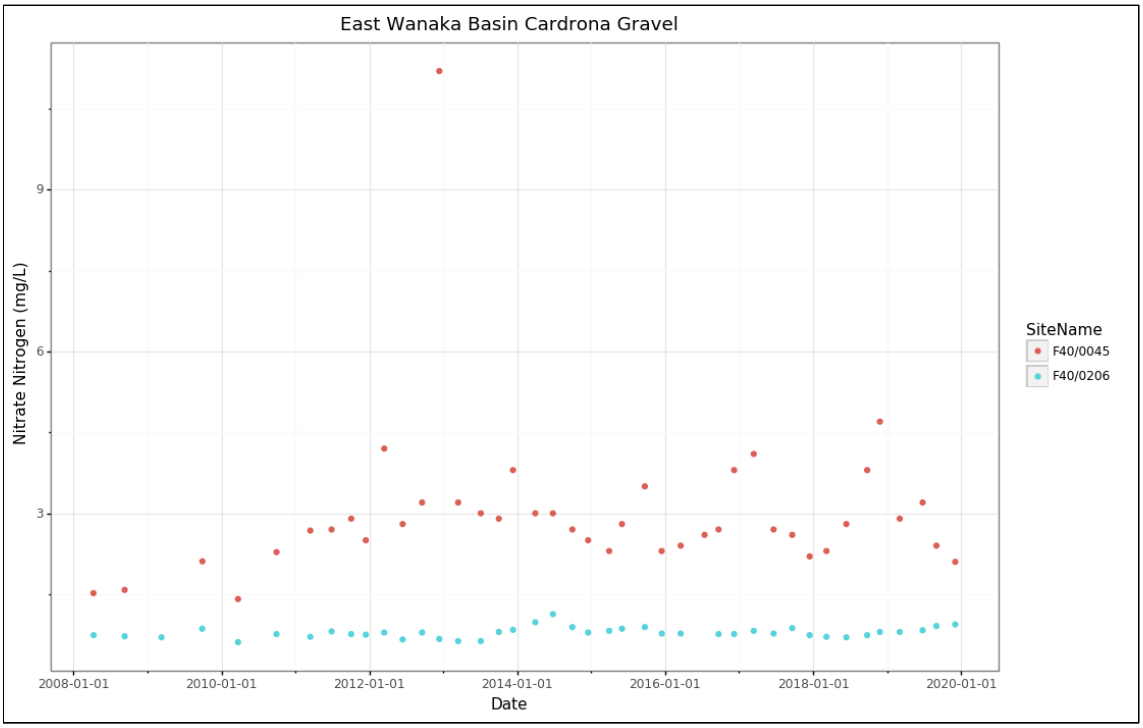


Figure 33: Groundwater nitrate concentrations for the Wanaka Basin



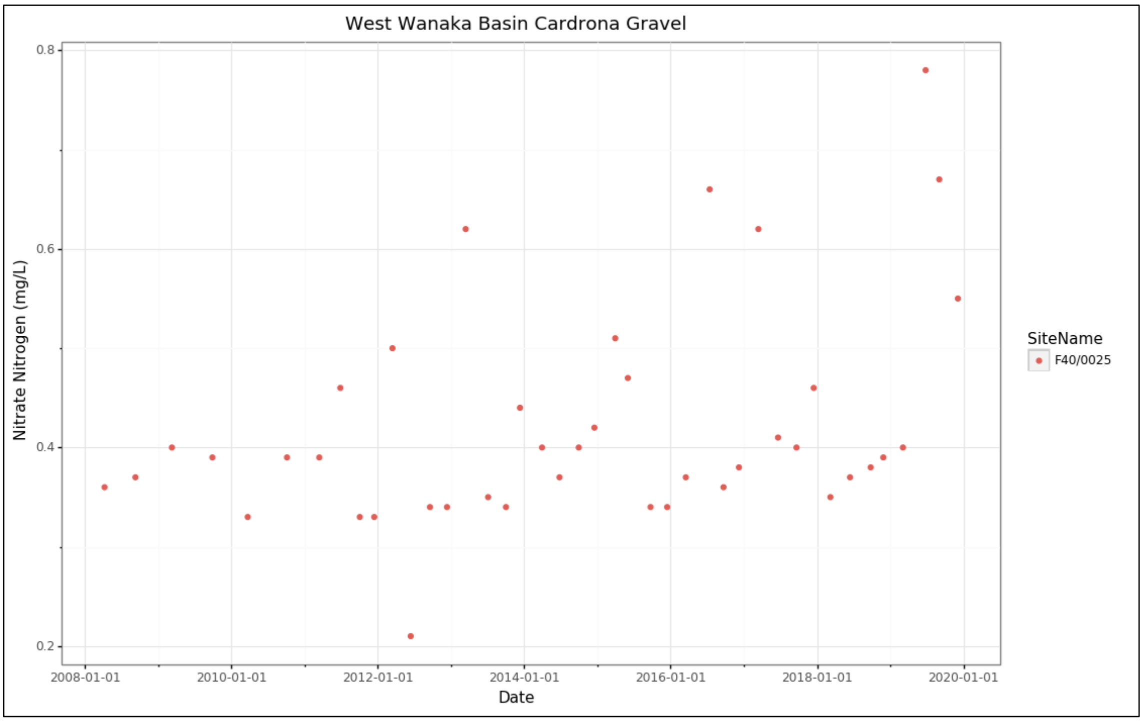
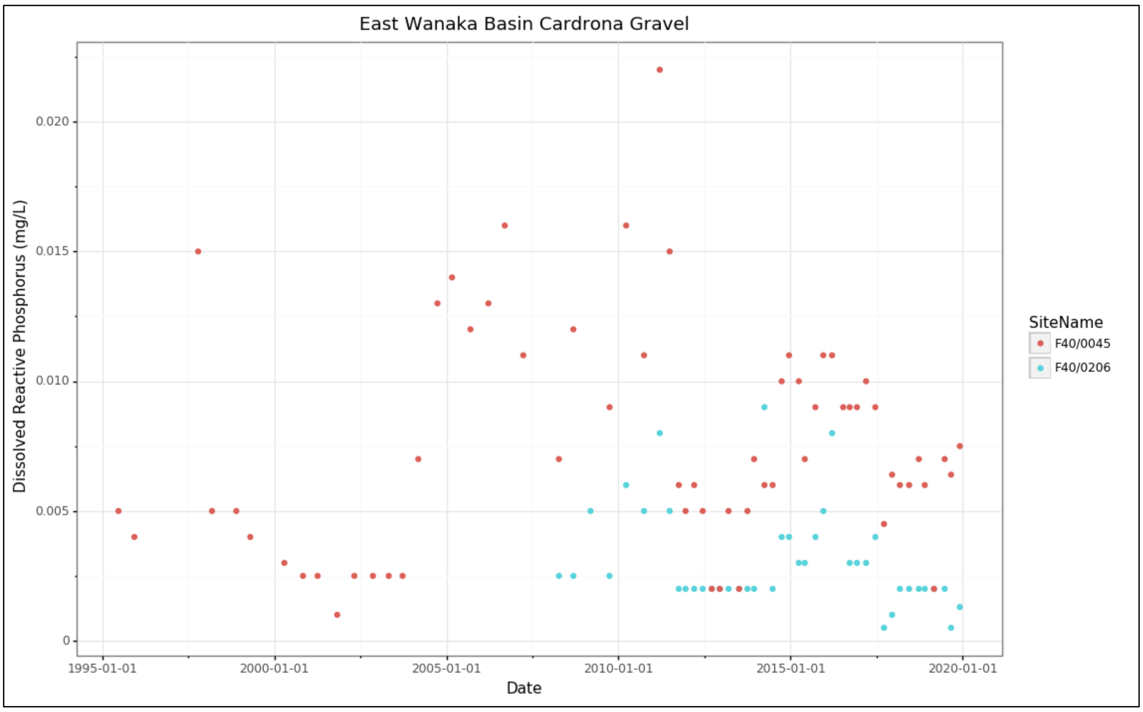


Figure 34: Groundwater Dissolved Reactive Phosphorus for the Wanaka Basin



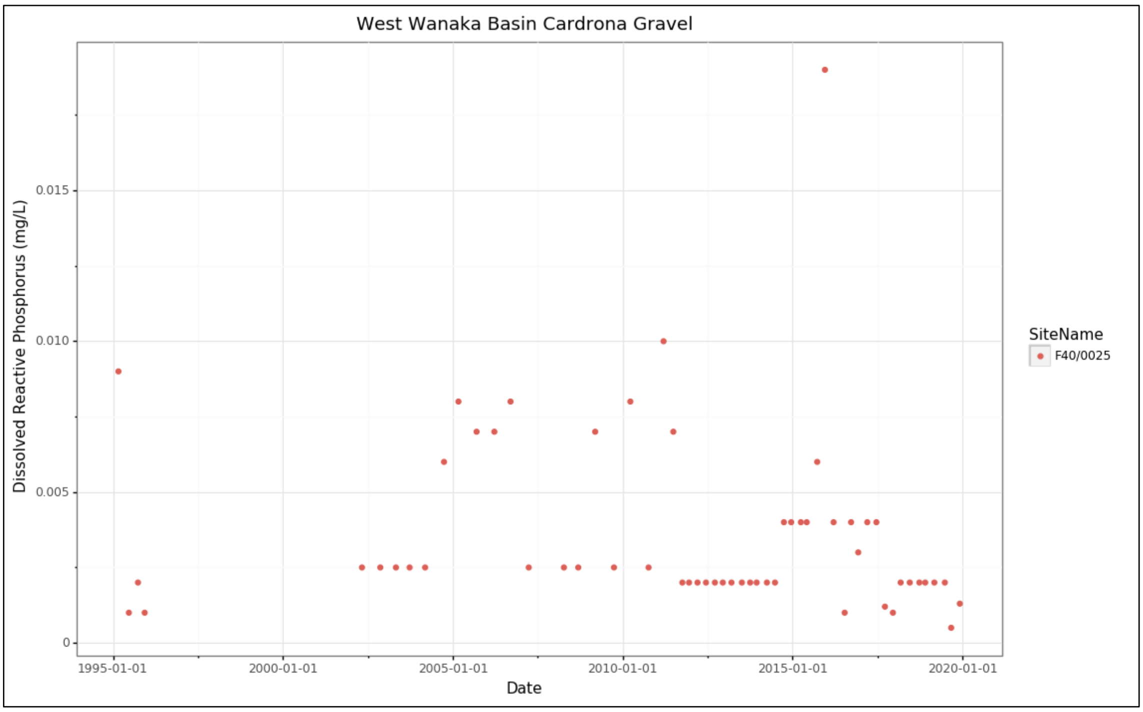
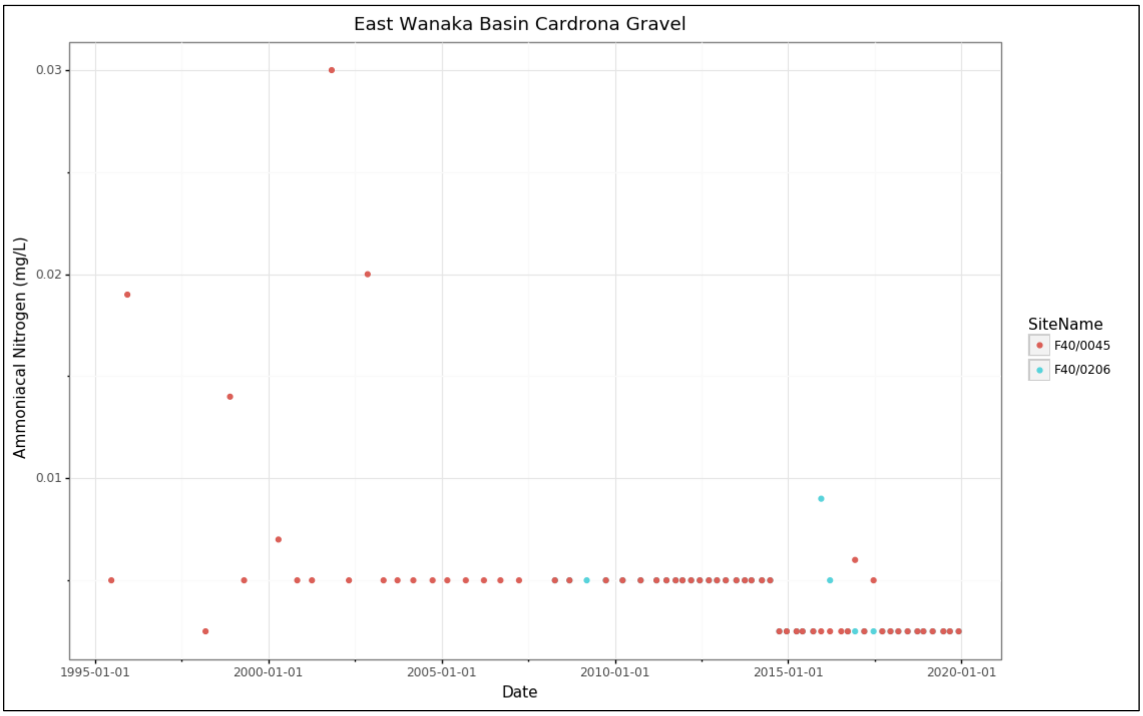
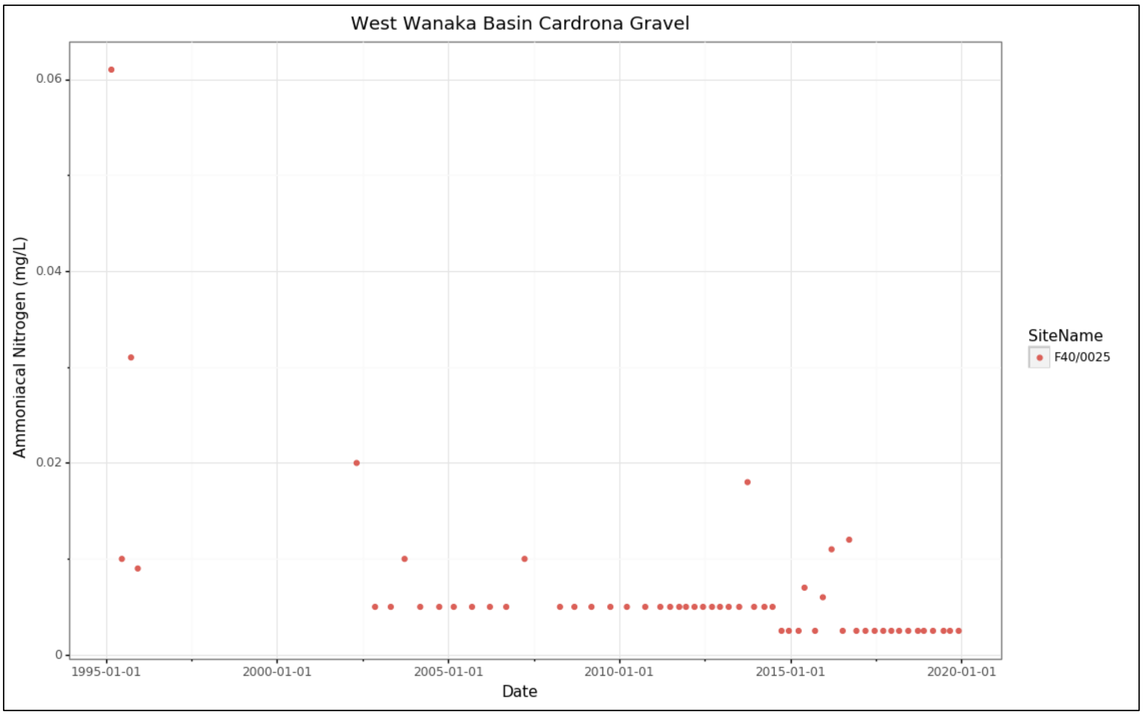


Figure 35: Groundwater ammonia concentrations for the Wanaka Basin





4.2.4.2 The Wakatipu Basin

4.2.4.2.1 Aquifer information

The Wakatipu basin is located near Queenstown and it contains some of the Upper Clutha's main surface water features: Lake Wakatipu and the Kawarau, Arrow, and Shotover Rivers. The basin is composed of metamorphosed schist bedrock overlain by Quaternary sediments from the Pleistocene and Holocene periods. In contrast to other parts of inland Otago, there are almost no Manuherekia Tertiary sediments in the basin. The geomorphology and hydrogeology of the Wakatipu Basin were significantly altered by glacial processes, where the glaciation/inter-glaciation cycles left characteristic deposits (i.e. glacial till, lacustrine deposits, fan, and alluvial sand/gravels, and terrace alluvium) and significantly impacted the levels of Lake Wakatipu (ORC, 2014a).

The Wakatipu Basin was originally considered in the RPW as one basin that contains several aquifers. The conceptual model is of eight small, laterally separated aquifers that are separated by basement ridges, groundwater flow divides, and rivers. The aquifers are thin and laterally distributed, and some were defined as alluvial ribbon aquifers. The individual Mean Annual Recharge (MAR) and allocation limits for each aquifer were based on the rainfall, soil, and aquifer area (ORC, 2014a). However, these were refined when the area, and allocation for some aquifers, was reviewed and adjusted (ORC, 2017b). The recharge and allocation from the revised aquifer areas was recalculated in November 2019 by using current climate data up to that period (ORC, 2019).

The dominant groundwater type in the basin is calcium-carbonate, indicative of fresh, young groundwater. The main groundwater uses in the area are municipal/community water supply and irrigation (ORC, 2014a). Groundwater quality in the aquifer is generally fair, although there are issues regarding the protection of drinking water quality (MoH, 2018). These include some areas with elevated nutrients due to grazing and septic tanks associated with this rapidly developing area. It also includes elevated arsenic concentrations in some aquifers, e.g. Ladies Mile (formerly known as Windemeer), which are attributed to the prevalent schist minerals that form the bedrock of the basin (e.g. Bloomberg, 2018) and potentially anthropogenic activities e.g. historical sheep dips (ORC, 2014a).

4.2.4.2.2 Groundwater quality monitoring

There are currently four SoE groundwater quality monitoring bores in the aquifers of the former Wakatipu Basin, whose details are summarised in Table 17. The bore locations are shown in

Figure 30). Bore no. F41/0104 (100mm diameter) is located at Howards Drive, Queenstown, at NZTM E1267649 N5008496, in the Ladies Mile (former Windemeer) aquifer. The bore depth is 60m. There is no available screen information or lithological log for this bore. The SWL in the bore in November 2019 was 40.70m. The Morven aquifer is monitored through bore F41/0203 (50mm diameter), situated at Morven Ferry Road, NZTM E1272318 N5010248. The bore depth is 4.1m and the log describes gravel fill and sand to 1.2m underlain by gravels and sand to the bore bottom. There is no information regarding the screen depth in the bore. The SWL in the bore in November 2019 was 4.26m below MP. Groundwater quality in the Speargrass Hawthron aquifer is monitored in bore F41/0437, situated at Domain Road, NZTM E1264923 N5010849. The bore log describes 0.5m of top soil/silt underlain by fine to coarse gravel to

20.0m. There is then fine to coarse sand with some fine gravel underlain by fine, sandy silt to the bore bottom at 30m. The bore is screened between 24.35 and 24.85m, within the coarse sand/fine gravel horizon. The SWL in November 2019 was 23.745m below MP. The fourth monitoring bore, F41/0438, is located north of Lake Hayes, NZTM E1269859 N5012093. The bore log describes sandy gravels to the bore bottom at 6.0m. The bore is screened at a depth of 5.5m within this horizon. The SWL in the bore in November 2019 was 0.607m below MP.

Table 17: Summary of monitoring bore details for the Wakatipu Basin

Bore No.	Aquifer	Depth (m)	Diam. (mm)	Eastings	Northings	Screen Top (m)	Screen bottom (m)	Bore Log avail.?
F41/0104	Ladies Mile (Windemeer)	60.00	100	1267649	5008496	N.A.	N.A	No
F41/0203	Morven Ferry	4.10	50	1272318	5010248	N.A.	N.A	Yes
F41/0437	Speargrass-Hawthorn	24.85	N.A	1264923	5010849	24.85	24.35	Yes
F41/0438	Mid-Mill Creek	6.0	N.A	1269859	5012093	6.0	5.5	Yes

In relation to the DWSNZ, the dissolved arsenic concentrations for the Wakatipu Basin are shown in

Figure 36. The results show that arsenic concentrations in the Ladies Mile bore (F41/0104) consistently exceed the DWSNZ MAV of 0.01mg/L, with most of the results range between 0.01 and 0.019mg/L. The concentrations in the other bores are below the MAV, although the Morven Ferry and Mill Creek bores each had one result between 0.0075 and 0.01mg/L in December 2015. The results in the Speargrass-Hawthorn bore were substantially below the MAV. The consistent elevated arsenic concentrations in the Ladies Mile bore are concerning, although elevated arsenic is common within the Wakatipu Basin due to the local schist lithology (e.g. Bloomberg, 2018). None of the bores had ammonia concentrations that exceeded the 1.5mg/L Guideline Value for aesthetic determinants (Figure 37).

Figure 36: Groundwater dissolved arsenic concentrations for the Wakatipu Basin

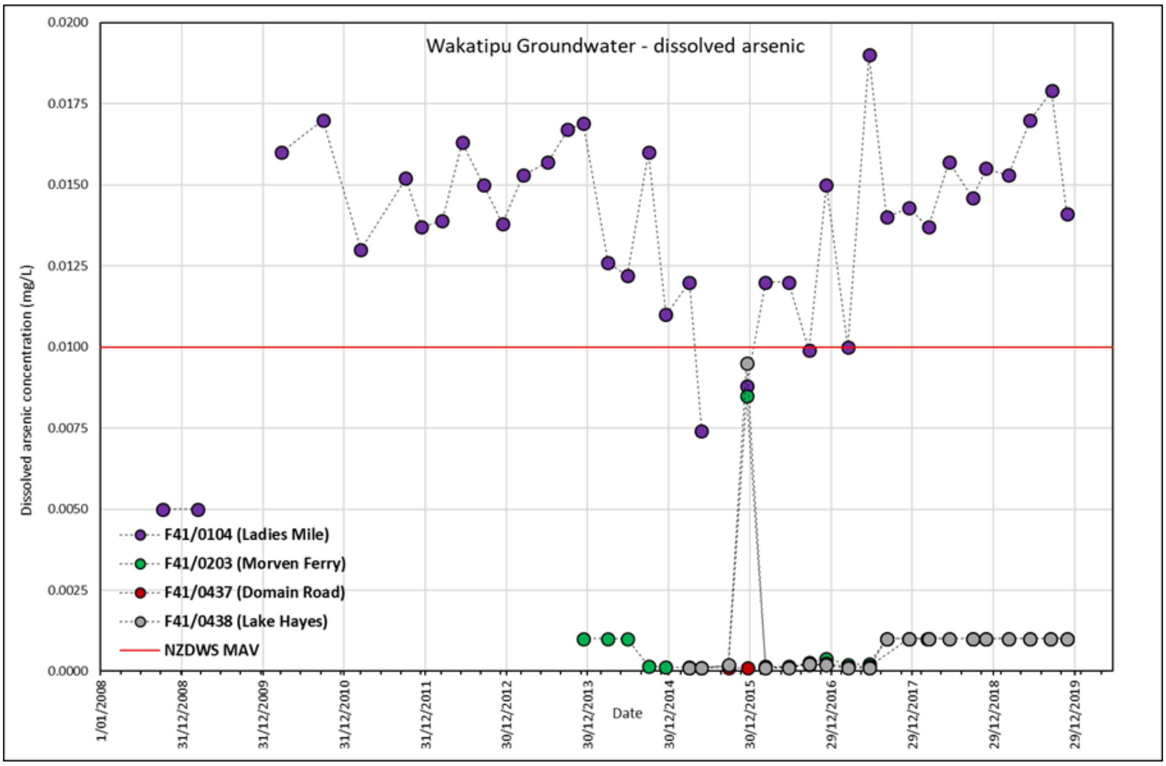
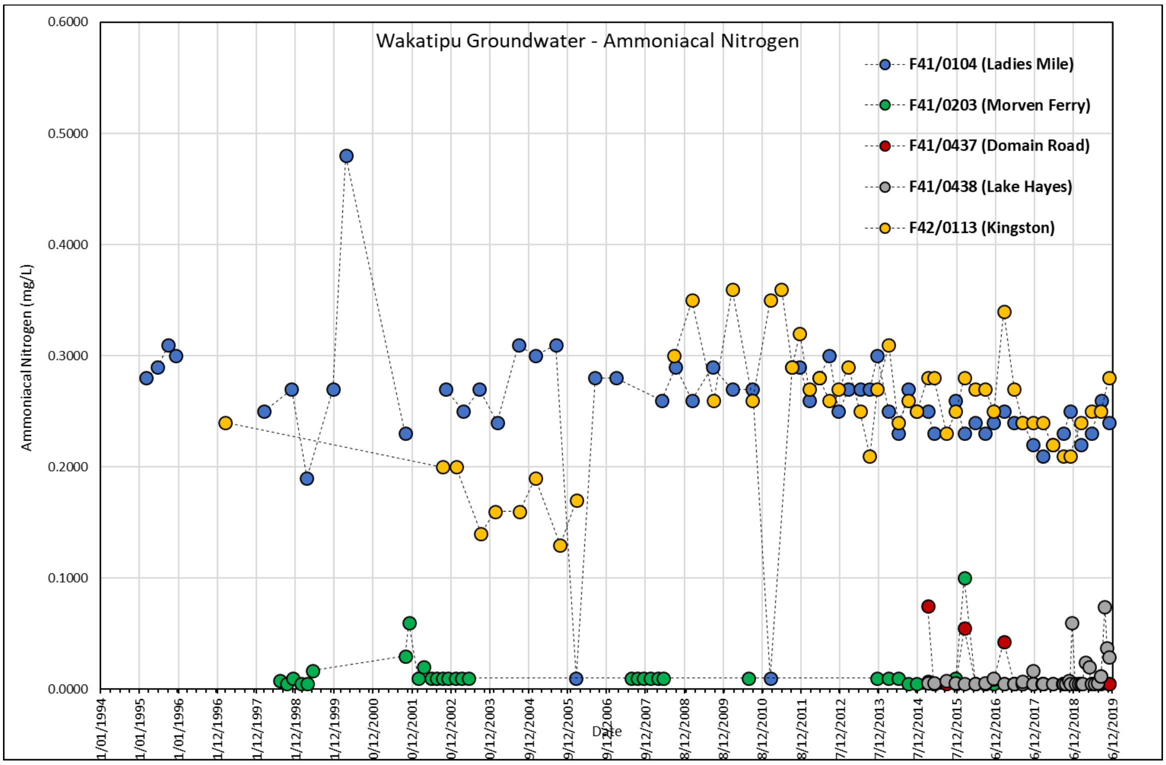
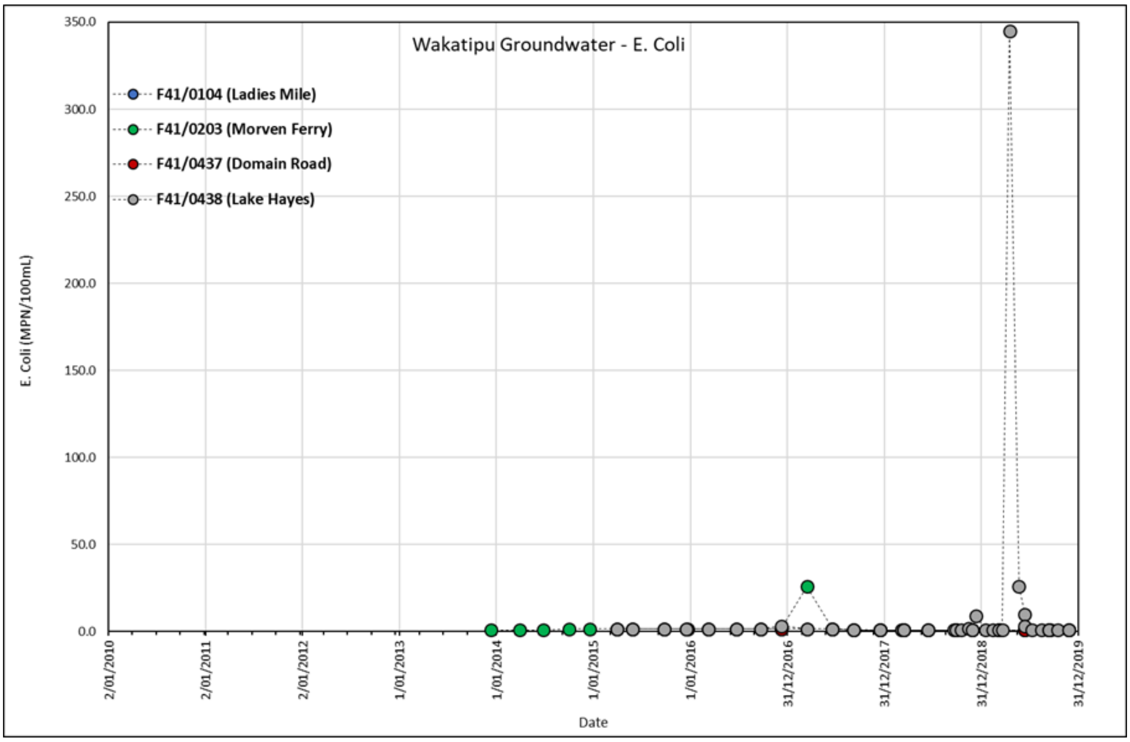


Figure 37: Groundwater ammonia concentrations for the Wakatipu Basin



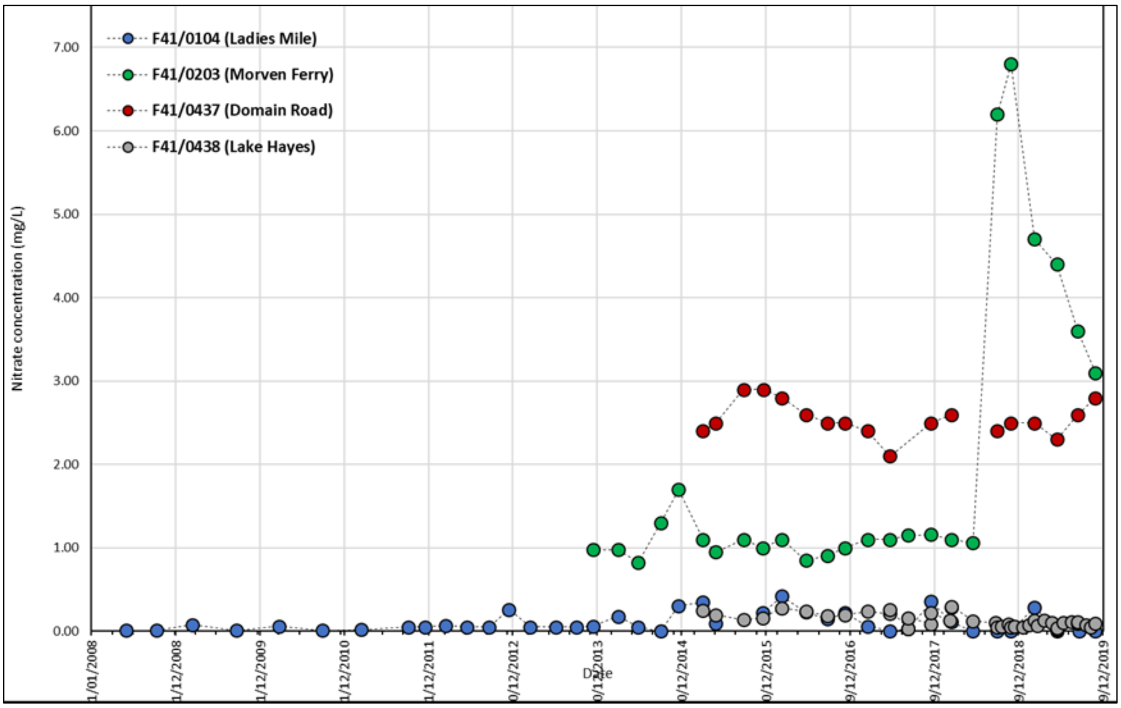
The E. coli data for the Wakatipu basin is shown in Figure 38. Bores F41/0104 and F41/0437 had no E. coli exceedances over the DWSNZ MAV of 1 MPN/100mL. The E. Coli in bore F41/0203 was generally below the DWSNZ MAV, with one exceedance of 26 MPN/100mL in March 2017. In contrast to these, bore no. F41/0438 had several exceedances, notably between April and June 2019, with measurements of 345, 26, and 10MPN/100mL. However, these exceedances are potentially due to poor bore security, as the borehead is located at ground level, in an area known to be occasionally flooded by surface water and is frequented by rabbits/ducks. Nevertheless, faecal contamination is likely to be prevalent in this area due to the rural life style and high density of septic tanks. It is therefore imperative that bore owners maintain bore security and regularly check their water supply to avoid faecal contamination.

Figure 38: Groundwater E. Coli counts for the Wakatipu Basin



Nitrate concentrations in all bores were below the DWSNZ MAV of 11.3mg/L, although some concentrations above ½ of the MAV were measured in the Morven Ferry bore (F41/0203), Figure 39. The concentrations in this bore ranged between approximately 1.0 and 2.0 mg/L between the start of measurements in January 2013 and September 2018, where concentrations substantially increased to 6.2mg/L. Concentrations then steadily declined, falling to 3.1mg/L in November 2019. The causes for this high increase are unclear and can be potentially related to a change in land use. In contrast to these higher concentrations, those in the remaining bores were lower, with the Speargrass-Hawthorn bore ranging between approximately 2.0 and 3.0mg/L and the Ladies Mile (F41/0104) and Mid Mill Creek (F41/0438) below 1.0mg/L.

Figure 39: Groundwater nitrate concentrations for the Wakatipu Basin



Potential impacts on surface water were then assessed from the shallow monitoring bores (<20m) in the Wakatipu Basin, with the results compared against Schedule 15 of the RPW (Table 18) and the NPS-FM NOF (Table 19). This included the bores in the Morven and Mid Mill Creek aquifers. The results show that the 80th percentile nitrate concentrations in both bores exceed the Schedule 15 limits, with the Morven bore concentrations exceeding the limit by 42 times. These exceedances are likely due to the shallow bore depths, surrounding land use, and potential issues with bore security. In contrast to that, the ammonia and DRP concentrations in both bores are below the RPW limits.

Table 18: Wakatipu Basin 80th percentile values for water quality variables & comparison with Schedule 15 limits

Bore number	**Aquifer**	**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)		**0.075**	**0.010**	**0.100**
F41/0203	**Morven**	3.200	0.005	0.010
F41/0438	**Mid Mill Creek**	0.212	0.004	0.012

Compliance with the NPS-FM NOF is shown in Table 19. This again highlights potential issues, particularly for nitrate. The Morven bore nitrate concentration is emplaced in band B for the median concentration and Band C for the 95th percentile. When a site falls in Band C there are "Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects (MfE, 2020)." The Mid Mill Creek bore is in Band A for both the median and 95th percentile nitrate concentration.

The results for ammonia show that the median concentrations in both bores are in Band A, with maximum concentrations in Band B. Band A reflects an environment where there is no observed toxicity effect on tested species, which provides a 99% protection level. Band B reflect a site where ammonia concentrations begin to occasionally impact the 5% of the most sensitive species (MfE, 2020). The DRP concentrations are in Band A for both bores.

The results against the RPW and NOF suggest that interaction of groundwater from these bores with surface water may adversely impact surface water quality, particularly regarding nitrate in the Morven Ferry bore. Although the Mid Mill Creek bore was placed in Band B for ammonia, due to the already existing water quality issues in Lake Hayes (ORC, 2017a) it is not likely that interaction with the groundwater will further degrade it.

Table 19: NPS-FM NOF comparison summary for the Wakatipu Basin

		Nitrate concentration (mg/L)		NOF Band	
Bore no.	**Aquifer**	**Median**	**95th percentile**	**Median**	**95th percentile**
F41/0203	**Morven (Wakatipu)**	1.1	5.9	B	C
F41/0438	**Mid Mill Creek**	0.113	0.2805	A	A
		Ammoniacal nitrogen concertation (mg/L)		**NOF Band**	
Bore number	**Aquifer**	**Median**	**Max.**	**Median**	**Maximum**
F41/0203	**Morven (Wakatipu)**	0.005	0.1	A	B
F41/0438	**Mid Mill Creek**	0.0025	0.074	A	B
		DRP concentration (mg/L)		**NOF Band**	
Bore number	**Aquifer**	**Median**	**95th percentile (mg/L)**	**Median**	**95th percentile**
F41/0203	**Morven (Wakatipu)**	0.0025	0.0066	A	A
F41/0438	**Mid Mill Creek**	0.002	0.005	A	A

4.2.4.3. Cromwell Terrace Aquifer

4.2.4.3.1 Aquifer information

The Cromwell Terrace aquifer is located on an elevated glacial outwash surface that rests on the fork of the Upper Clutha/Kawarau Rivers confluence. Despite its small area of 22km^2, the Cromwell Terrace aquifer is of great significance to the local communities. The aquifer is shallow and unconfined and is closely impacted by landuse and surface water. It was formed by at least three glacial outwash terraces that coalesced in the Cromwell confluence area and include gravel formations from the Upper Clutha and Kawarau catchments. The outwash is generally underlain by relatively impermeable Manuherekia Group mudstone, lignite, and schist. The overlying soils that were formed on the terrace surface are sandy with generally low water retention. The terrace is not crossed by any surface water courses although artificial races and ponds were built across some of its surface. The hydrology of the fringing Kawarau River was substantially altered when Lake Dunstan was filled following completion of the Clyde Dam in 1993. The measured mean rise in water table after this was around 10.5m, hence the aquifer stores a much larger water resource.

Groundwater uses include irrigation, stock and domestic (including town/community) supply. Aquifer pumping tests from completed bores in the Cromwell township area indicate generally high to extremely high Transmissivity. The aquifer is in a dynamic equilibrium with Lake Dunstan, with a modest volume of recharge in the Ripponvale area and discharge of its excess further downstream. Due to the high transmissivity, the aquifer responds very rapidly to groundwater extraction by inducing infiltration from the Lake (ORC, 2014b).

4.2.4.3.2 Groundwater quality monitoring

There is only one groundwater quality SoE monitoring bore in the Cromwell Aquifer Terrace, F41/0300 (150mm diameter). The bore is situated at Sandiflat Road, near the Highlands Motor Sports Park, at NZTM E1297971 N5003508. The bore depth is 48.71m. The bore log describes clay/fine gravels to 1.54m underlain by coarse/fine sandy gravels to 12.64m. There is then boulders to 13.10m underlain by sandy gravels to the well bottom (48.76m) with a horizon of boulders between 30.10 and 30.50m. The bottom sandy gravel horizon, between 30.50 and 48.76m, is described as coarse sandy gravels. The top of the screen leader is located within the coarse sandy gravel horizon, at a depth of 47.61m. The SWL in the bore in December 2019 was 33.3m below MP.

The assessment against the DWSNZ are shown in Figure 40 to

Figure 44. Regarding the DWSNZ, the results indicate good groundwater in the bore. Nitrate concentrations were all below the 11.3mg/L MAV. Nitrate concentrations were between 2.44 and 4.06mg/L during the initial monitoring period (2009 – 2011), with concentrations then continuously falling, reaching around 1.1mg/L in 2019 (Figure 40). Dissolved arsenic concentrations were generally substantially below the DWSNZ MAV of 0.01mg/L, although a sample from March 2009 was close to it at 0.009mg/L (Figure 41). Most of the E. coli results are below the <1 MPN/100mL MAV, although some of the earlier results read <2 and <1.6MPN/100mL, which are potentially related to different analytical Limits of Detection (Figure 42). This suggests that the risk of faecal contamination is low. Ammonia concentrations were below the aesthetic GV value of 1.5mg/L (Figure 43). Due to the bore's depth of 48.71m it was not assessed for ecosystem impacts. However, due to its depth it is not likely to interact with surface water.

Figure 40: Groundwater nitrate concentrations for the Cromwell Terrace Aquifer

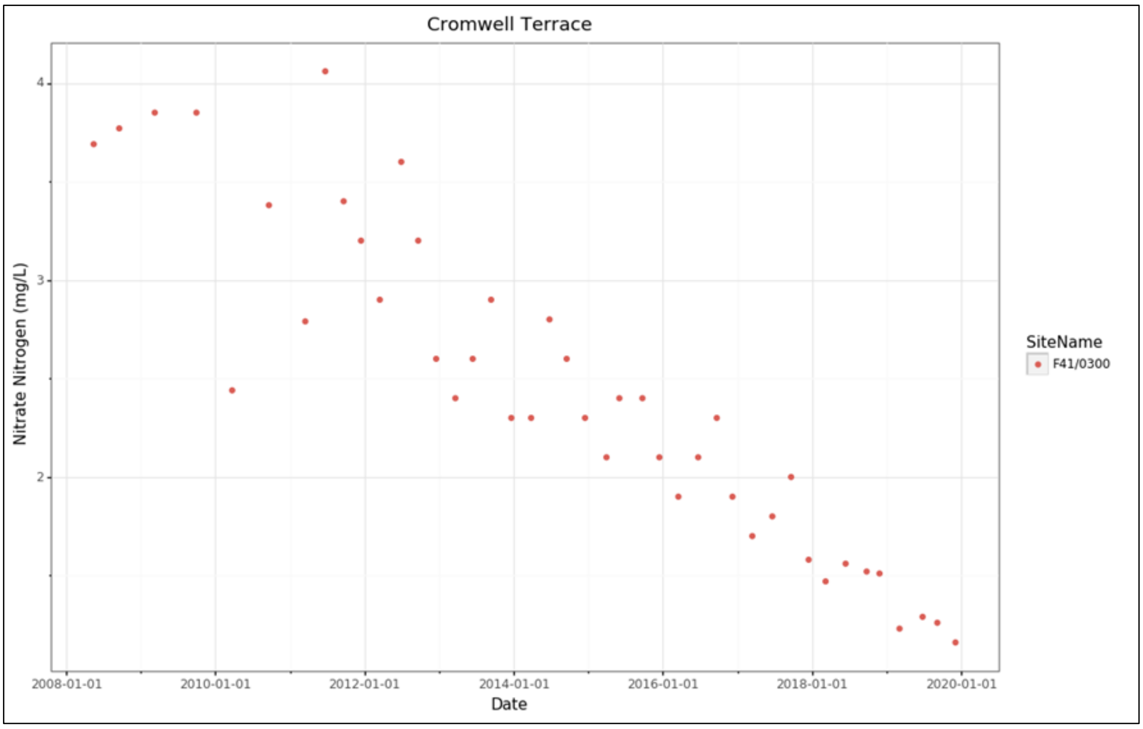


Figure 41: Groundwater dissolved arsenic concentration for the Cromwell Terrace Aquifer

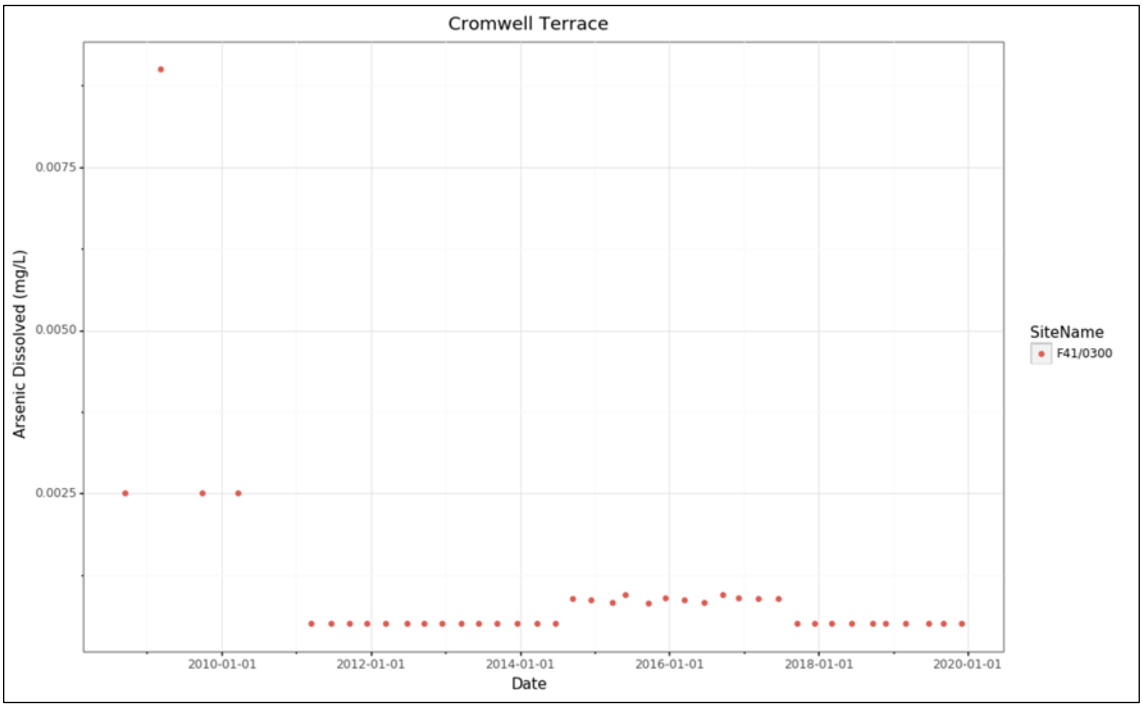

Cromwell Terrace
Arsenic Dissolved (mg/L)
0.0075
0.0050
0.0025
2010-01-01
2012-01-01
2014-01-01
2016-01-01
2018-01-01
2020-01-01
Date
SiteName
F41/0300

Figure 42: Groundwater E. coli count for the Cromwell Terrace Aquifer

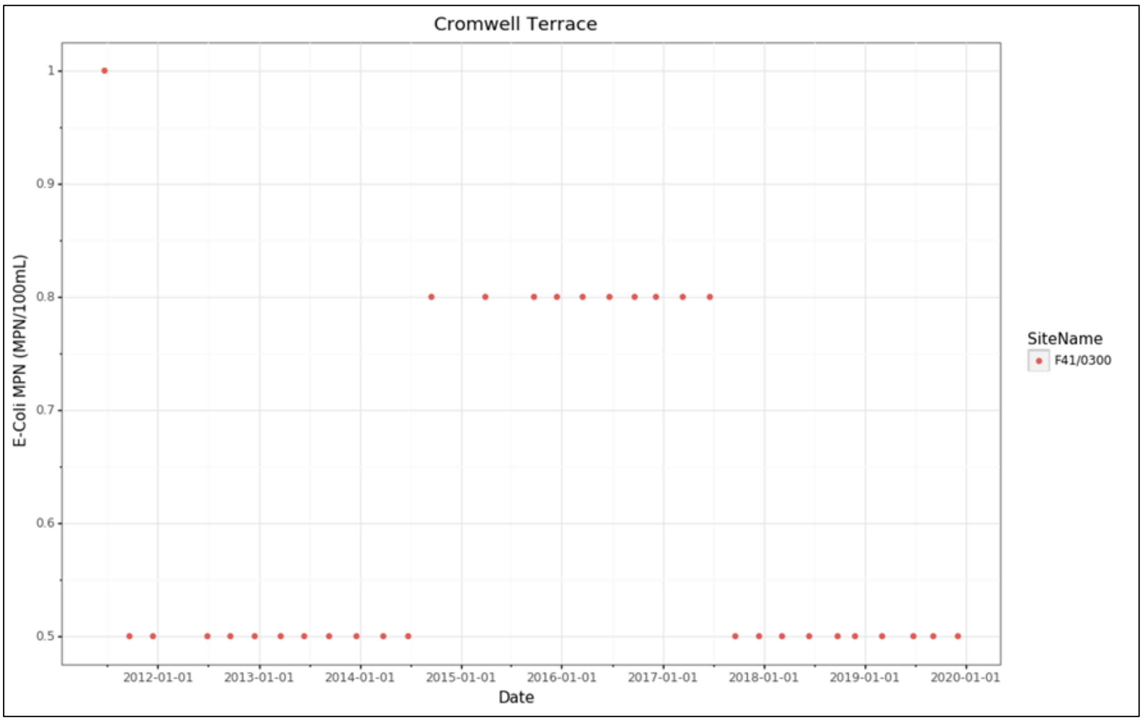


Figure 43: Groundwater ammonia concentration for the Cromwell Terrace Aquifer

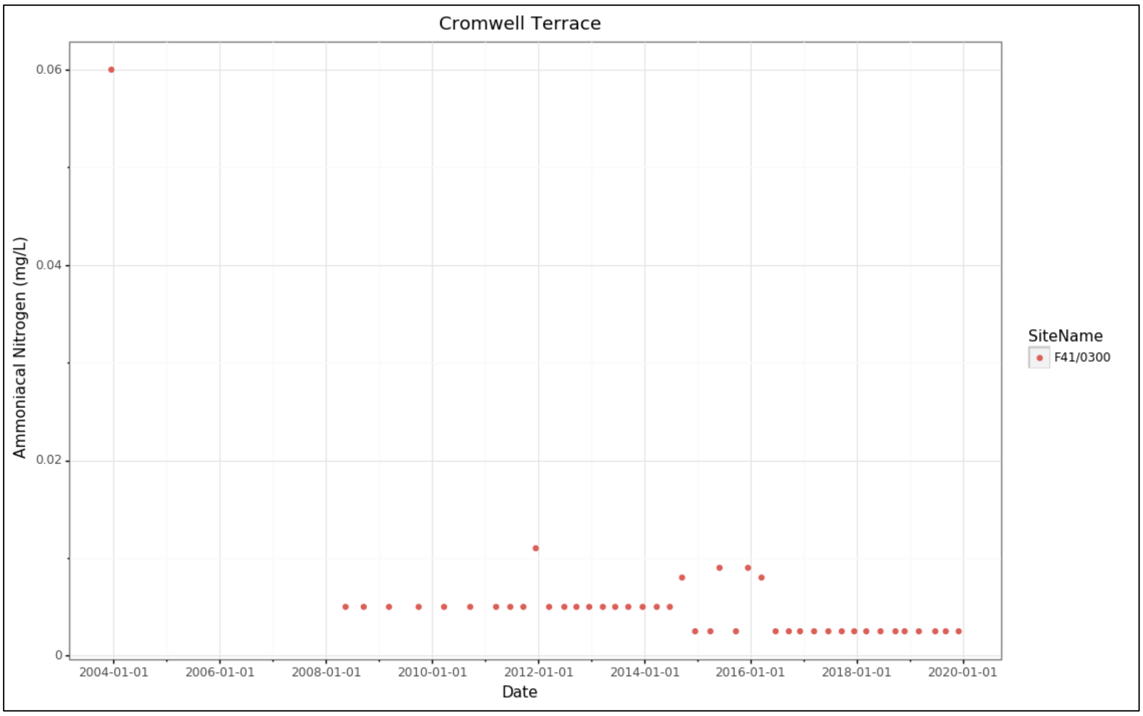
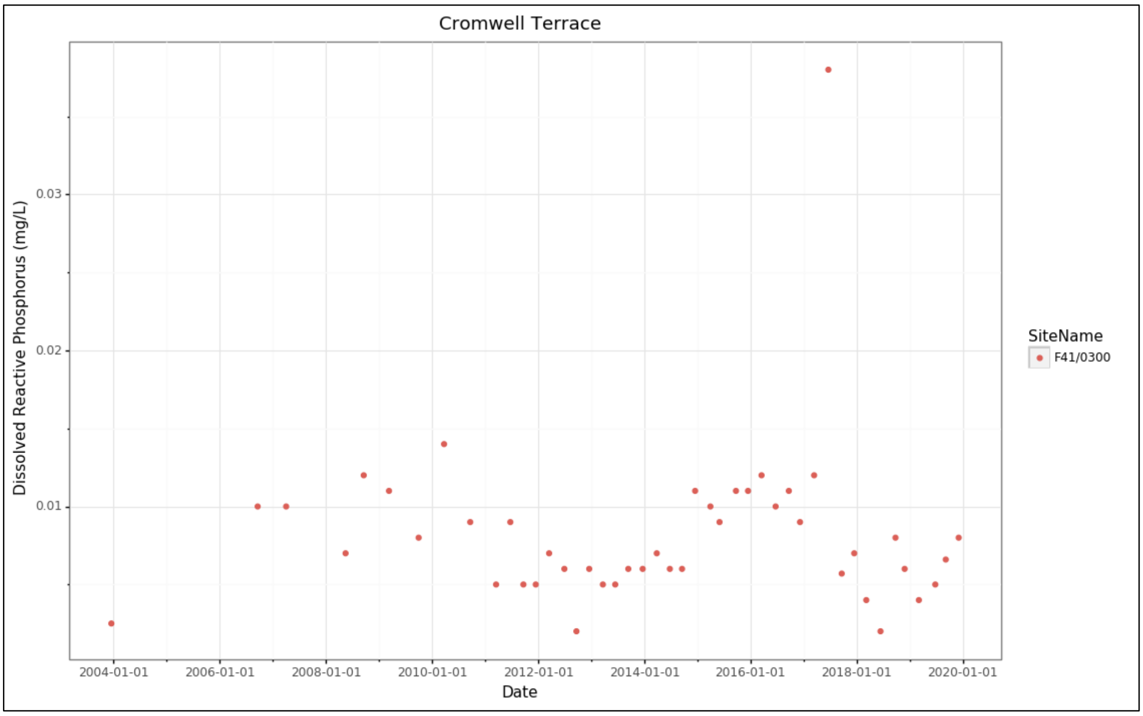


Figure 44: Groundwater Dissolved Reactive Phosphorus concentration for the Cromwell Terrace Aquifer



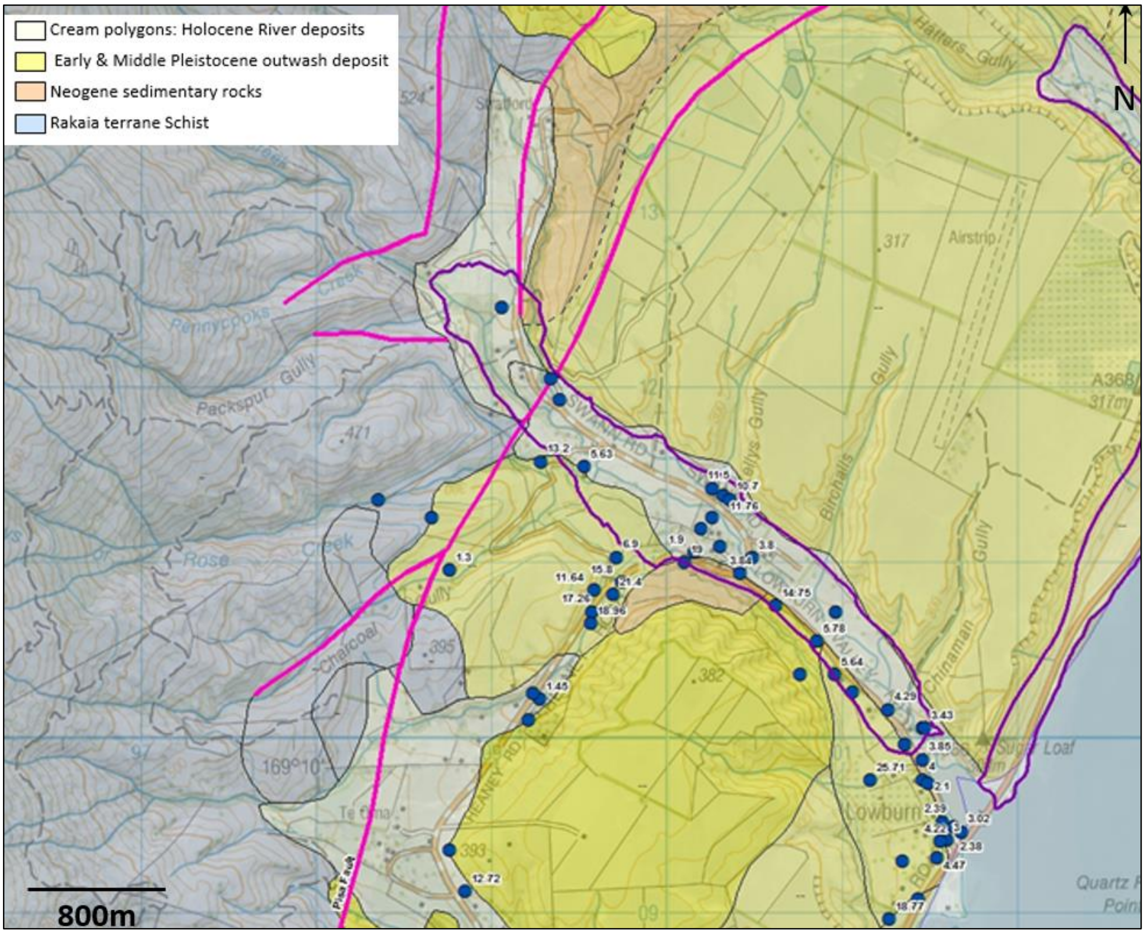
4.2.4.4 Lowburn Alluvial aquifer

4.2.4.4.1 Aquifer information

The Lowburn Alluvial Ribbon aquifer is located north of Cromwell and west of Lake Dunstan. It is bounded to the west by the eastern side of the Pisa Range (Lowburn Face), whose peaks reach elevations of around 1500-1600m. It is bounded to the east by Lake Dunstan. The western boundary of the delineated aquifer zone is located where the Low Burn descends from the Lowburn Face and enters the narrow valley. The aquifer includes the narrow river valley that is approximately 100m lower than the surrounding terraces to the north and south (ORC, 2018a).

The aquifer is located within Holocene river deposits composed of unconsolidated gravel, silt, clay and minor peat of modern-postglacial flood plains. The ranges to the west/southwest of the aquifer are composed of Rakaia Terrane schist whilst the terraces in the north and south are composed of Early/Mid Pleistocene outwash deposits and a small portion of Neogene sedimentary rock near the intersection between Lowburn Valley Road and Heaney Road, Figure 45 (Turnbull, 2000).

Figure 45: Geological setting for the Lowburn Alluvial Ribbon Aquifer (from Turnbull, 2000)



The main groundwater uses in the area are irrigation, stock water, and domestic supply. According to the ORC database there are 16 completed bores in the Lowburn Alluvial Ribbon aquifer, whose depth ranges between 2 and 20m. The depth of two bores are not known. There is information regarding the SWL for 12 bores, and it ranges between 1.90 and 14.75m below Measuring Point. Screen depth information is only available for one bore, F41/0449, which is screened between 15.65 and 16.65m, within a horizon of sandy/silty gravels.

4.2.4.4.2 Groundwater quality monitoring

Groundwater SoE monitoring in the Lowburn Alluvial Aquifer is currently conducted in one bore, F41/0162 (125mm diameter), drilled in June 1995. The bore is located at Swann Road, NZTM E1299519 N5011550 (

Figure 30). The bore is 16.53m deep, hence one of the deeper ones in the area. The bore log describes topsoil to 0.30m underlain by cobbles and sandy gravels to 3.3m. There is then sandy gravels with some cobbles to the bore bottom at 16.53m. The depth to the top of the screen leader is 15.77m, suggesting that the bore abstracts from an unconfined sandy gravel aquifer. The SWL in the bore ranges between 4.65 and 6.83m below MP. The maximum annual fluctuation is around 1.00-1.50m, with the lowest levels generally observed in December or March. The SWL in December 2019 was 5.1m below MP. Groundwater quality from bore F41/0162 was assessed against the DWSNZ, Figure 46, Figure 47, and Figure 48. The results indicate good groundwater quality. Most E. coli results are below the <1 MPN/100mL MAV, although some of the earlier results read <2 and <1.6MPN/100mL. This suggests a low risk of faecal contamination, with the exceedances potentially related to different analytical Limits of Detection. There were no arsenic concentrations that exceeded the 0.01mg/L MAV. The nitrate concentration is also much lower than the DWSNZ MAV, ranging between 0.24 and 0.52mg/L. All ammonia concentrations were below the 1.5mg/L GV.

Figure 46: Groundwater E. Coli count for the Lowburn Alluvial Aquifer

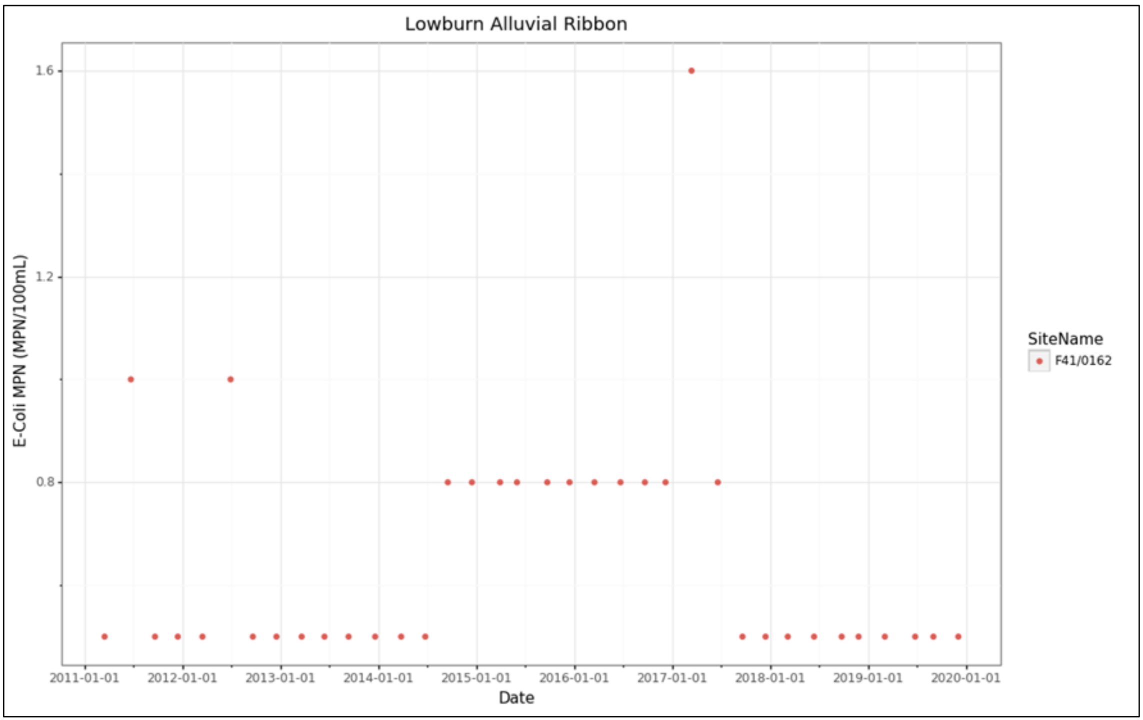


Figure 47: Groundwater dissolved arsenic concentration for the Lowburn Alluvial Aquifer

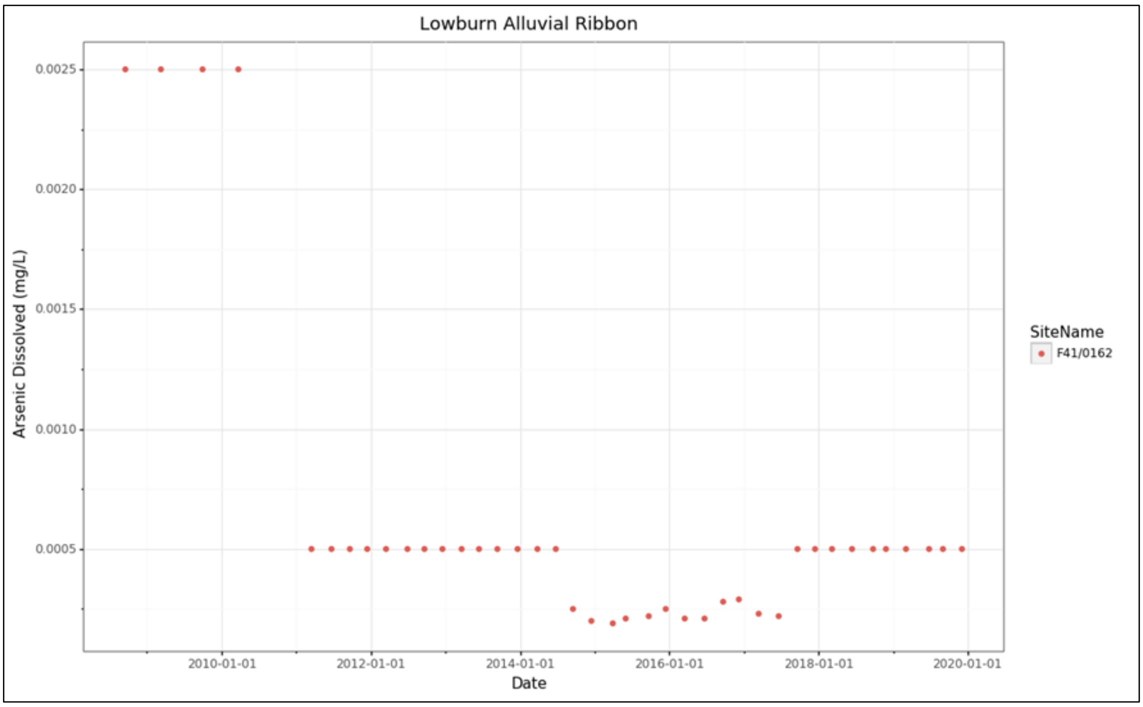


Figure 48: Groundwater nitrate concentration for the Lowburn Alluvial Aquifer

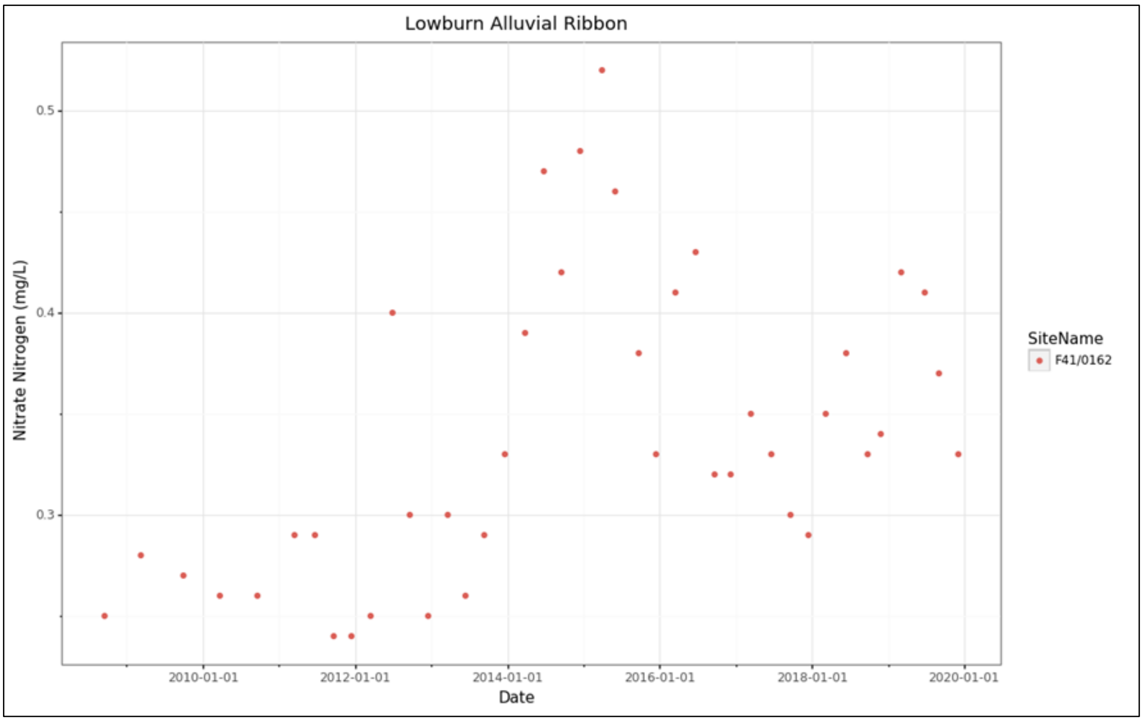
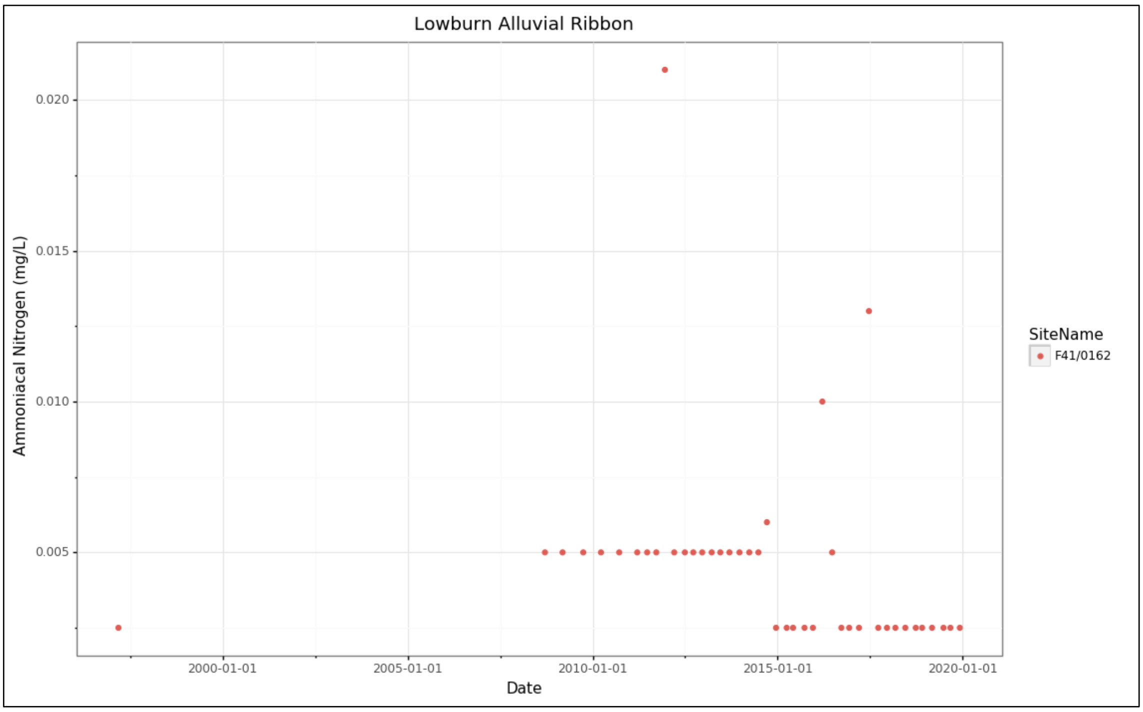


Figure 49: Groundwater ammonia concentration for the Lowburn Alluvial Aquifer



The results were then compared against the RPW Schedule 15 (Table 20) limits and the NPS-FM (

Table 21). The Lowburn Alluvial aquifer is located in Group 2 of Schedule 15. The results show that the site is non-compliant with the nitrate limits, which are around five times higher than the threshold. This suggests that interaction of groundwater with surface water, such as the Low Burn, may increase eutrophication and algal growth potential. The results are compliant with the DRP and ammonia limits. Regarding the NPS-FM NOF, all the results sit within the A Band.

Table 20: Schedule 15 comparison results for the Lowburn Alluvial aquifer for 80th percentile for nitrate, DRP, and ammonia.

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
F41/0162	Clutha	Dunstan	Lowburn	0.410	0.008	0.010

Table 21: NOF comparison for the Lowburn Alluvial aquifer

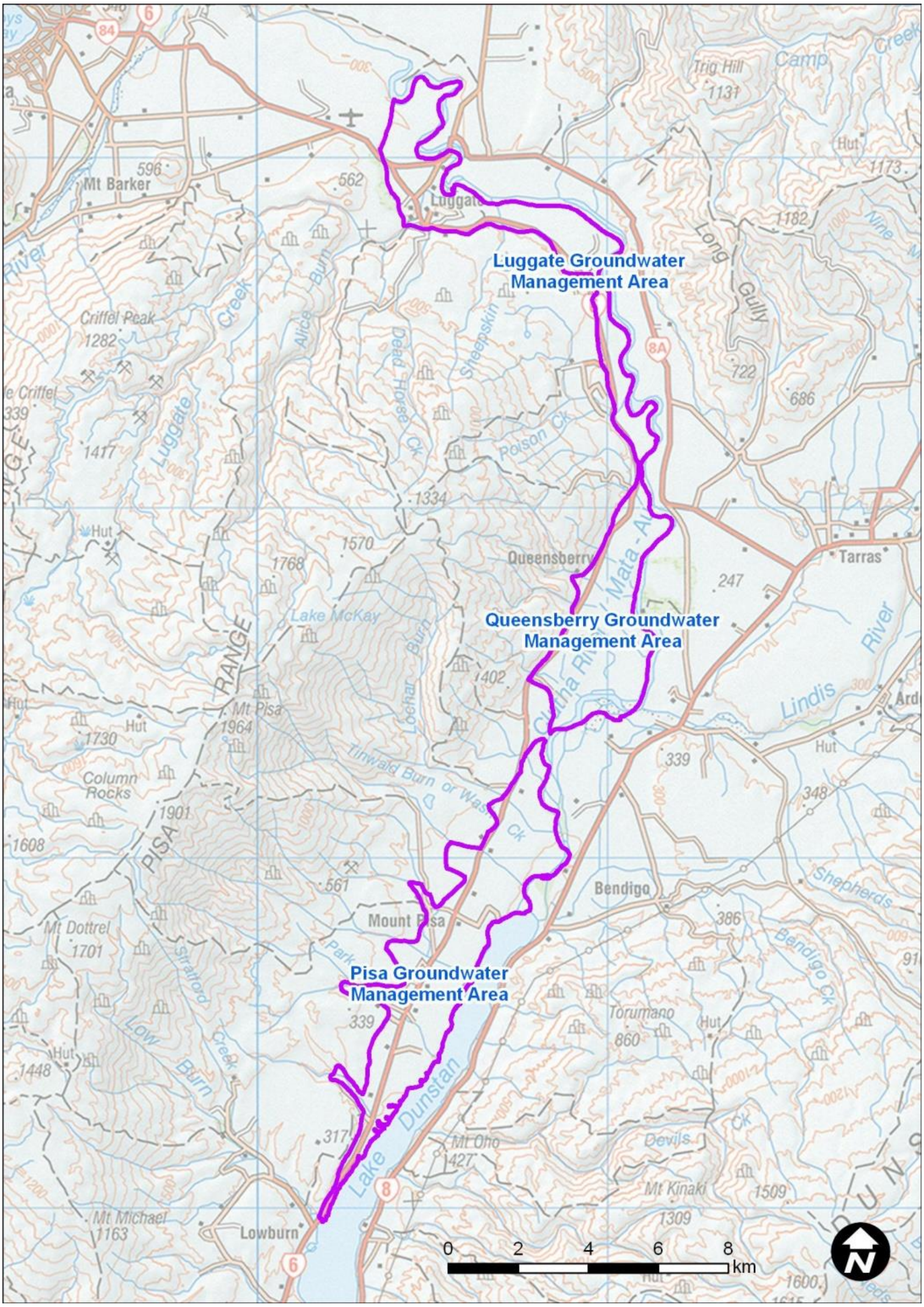
	Nitrate		NOF Band	
Bore no.	**Median (mg/L)**	**95th percentile (mg/L)**	**median**	**95th percentile**
F41/0162	0.33	0.47	A	A
	Ammoniacal nitrogen		**NOF Band**	
Bore number	**median (mg/L)**	**Max (mg/L)**	**Median**	**Maximum**
F41/0162	0.005	0.021	A	A
	DRP		**NOF Band**	
Bore number	**Median (mg/L)**	**95th percentile (mg/L)**	**Median**	**95th percentile**
F41/0162	0.00325	0.01095	A	A

4.2.4.5 West Bank of the Upper Clutha

4.2.4.5.1 Aquifer information

The West Bank of the Upper Clutha, situated between Lowburn and Luggate, includes the Pisa, Luggate, and Queensberry Groundwater Management Zones (GWMZ). These were delineated using a 1:250,000 GNS geological map (QMap) for the West Bank of the Upper Clutha (Turnbull, 2000). The GWMZ were identified based on geological classification of Quaternary sediment Q1-Q4 and some Q6 sediment that are located between the Clutha River on the east and the Pisa Range in the west. This work identified three GWMZ where alluvial sediment "pinch" between schist and/or older sediment and the Clutha River. Areas where the sediment extends west into valleys were excluded (ORC, 2018b). The location of these delineated GWMZs is provided in Figure 50. The Pisa GWMZ is situated between Lowburn to the south, and Kind Creek in the north. The Queensberry GWMZ's northern boundary is around Edward Burn. The Luggate GWMZ is located north of the Burn until the southern boundary of the Wanaka Basin.

Figure 50: Location of GWMZ on the West Bank of the Clutha (from ORC, 2018b)



The database search shows there are 116 bores within the three GWMZ, 113 of which have recorded depths. The bore depths in these GWMZ range between 5.80 and 102m. SWL are recorded in 99 of the bores, with the SWL ranging between 1.25 and 33.4m below MP. Screen depth information is available for 32 bores, with the top of screen depths ranging between 9.67 and 102m, although this lower screen depth is likely to be an error as the maximum recorded bore depth is also 102m. Groundwater uses in the area include irrigation, community, stock, domestic supply and commercial use. This area experiences a rapid expansion of horticulture/viticulture with increasing demand for water applied *via* drip irrigation. This has induced ORC to begin developing a monitoring program, with two bores drilled in the Pisa and Luggate GWMZ in 2017 (ORC, 2018b). There is currently no groundwater monitoring in the Queensberry GWMZ.

4.2.4.5.2 Groundwater quality measurements

There are two SoE bores for monitoring groundwater quality in the West Bank of the Upper Clutha area. Groundwater in the Luggate GWMZ is monitored in bore G40/0411 (150mm diameter), drilled in May 2017. The bore is situated at Pukerangi Drive at NZTM E1309254 N5036692. The bore depth is 17.75m. The log describes silty coarse gravels and cobbles to 2.5m underlain by sandy coarse gravels and cobbles to 5.6m. There is then silty/sandy schist gravel to 9m underlain by schist to 12m. The silt is fractured from 12m to the bottom of the bore at 17.75m. The bore is screened between 12.75 and 17.75m, within the fractured schist. The SWL in November 2019 was 8.112m below MP.

Groundwater in the Pisa GWMZ is monitored in bore G41/0487 (150mm diameter), located at Smiths' Way, NZTM E1304667 N5016105. The bore depth is 28.99m. The bore log describes sandy coarse gravels and some cobbles to 21.4m underlain by sands with finer gravels to 22.5m. There are then silty coarse gravels to 28.8m underlain by brown silts to the bore bottom at 29.4m. The bore is screened at a depth of between 25.99 and 28.99m, within the bottom silty, coarse gravel horizon. The SWL in November 2019 was 20.15m below MP.

Regarding the DWSNZ, groundwater quality in both bores is generally good, with the main issue being elevated nitrate concentrations in bore G40/0411 (Figure 51). Although the concentrations in the bore did not exceed the 11.3mg/L MAV, it ranged between 5.2 and 9.9mg/L, which is close to exceeding the MAV. These high concentrations are potentially due to cultivation of a paddock next to the bore or to septic tanks. The concentrations in bore G41/0487 were substantially lower, ranging between 0.192 and 0.33mg/L. Concentrations in neither bore exceeded the dissolved arsenic MAV of 0.01mg/L (Figure 52). However, due to the prevalence of schist lithology in the area, and the high spatial heterogeneity of dissolved arsenic in groundwater, it is important that bore owners in the area regularly test their bores for arsenic. There was no E. coli detected in neither bore (Figure 53). Ammonia concentrations in neither of the bores exceeded the DWSNZ GV of 1.5mg/L (Figure 54).

Figure 51: Groundwater nitrate concentration for the Luggate/Pisa GWMZ

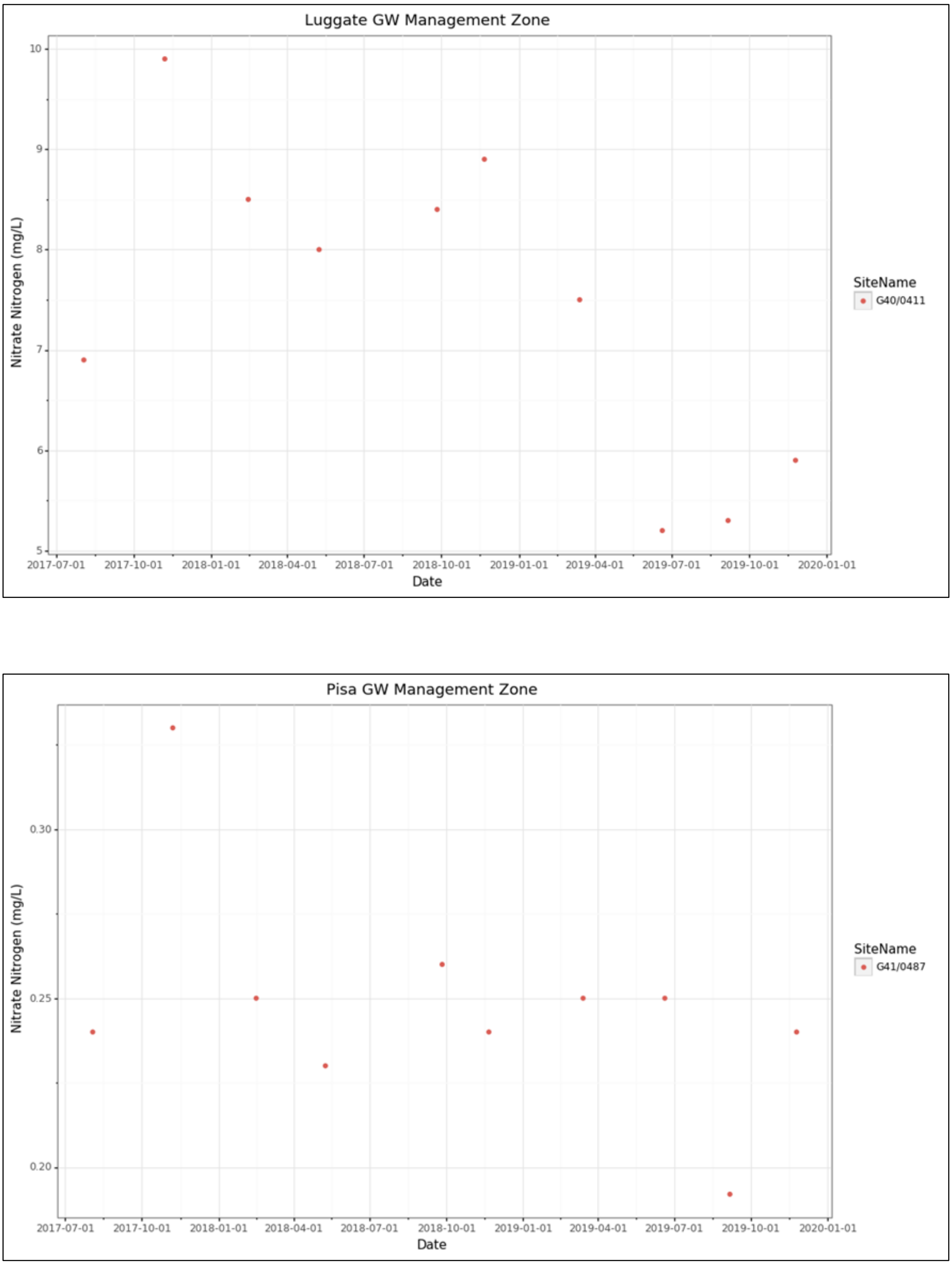
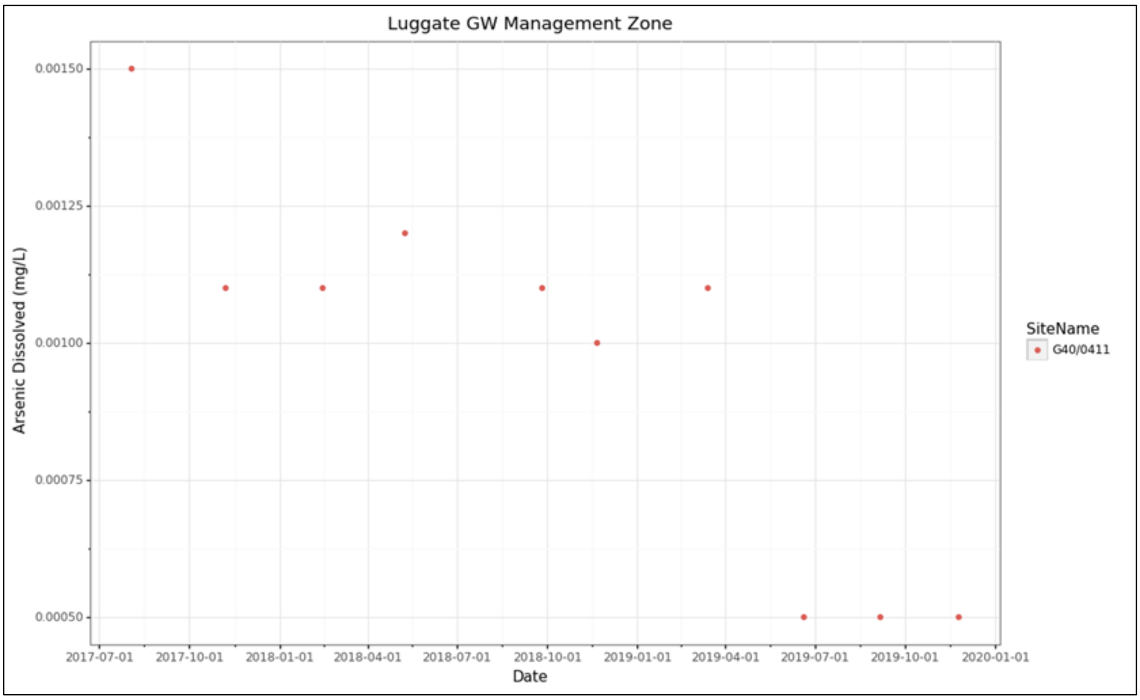


Figure 52: Groundwater dissolved arsenic concentration for the Luggate/Pisa GWMZ



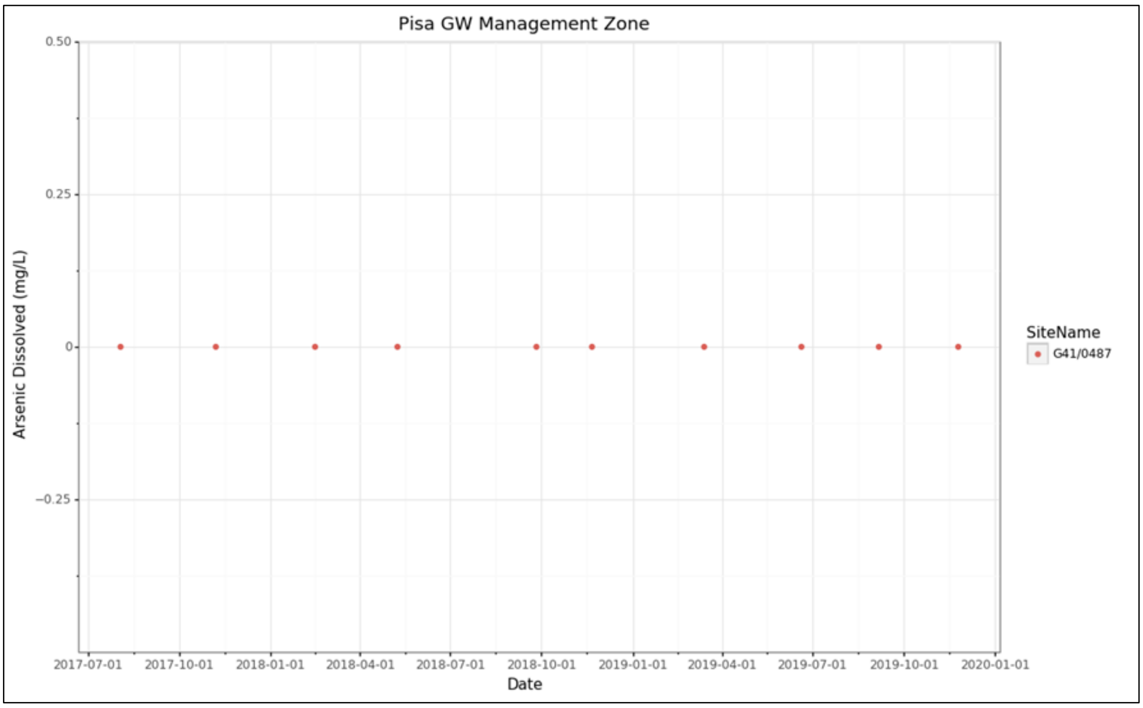
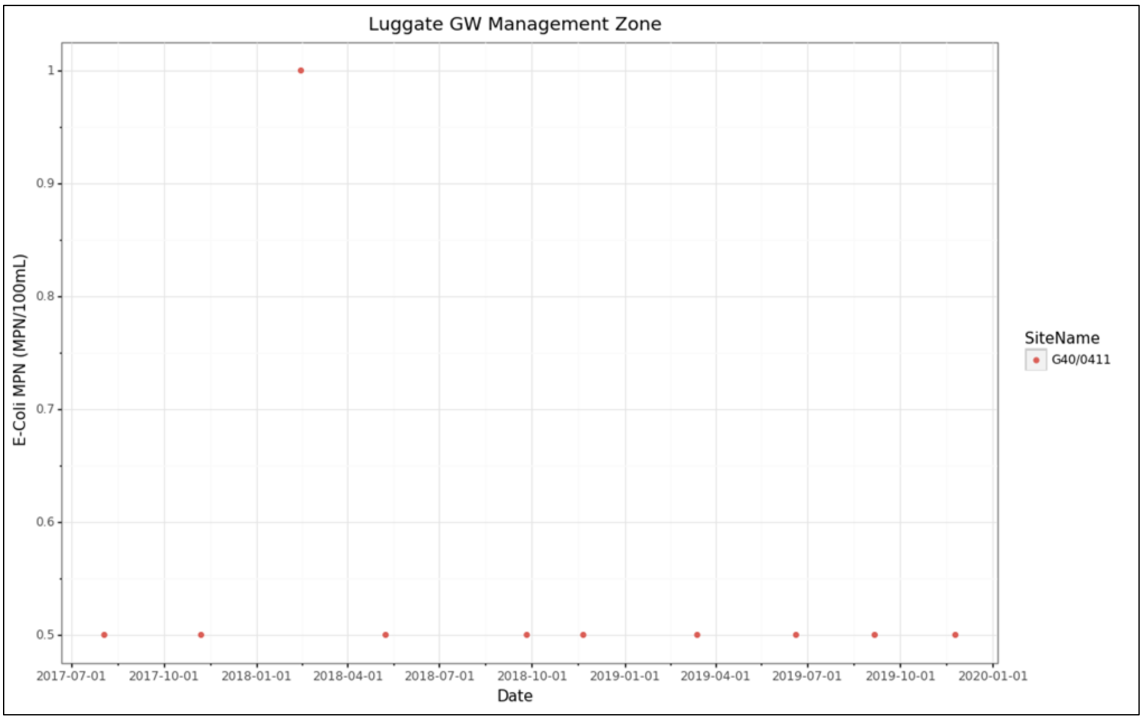


Figure 53: Groundwater E. Coli count for the Luggate/Pisa GWMZ



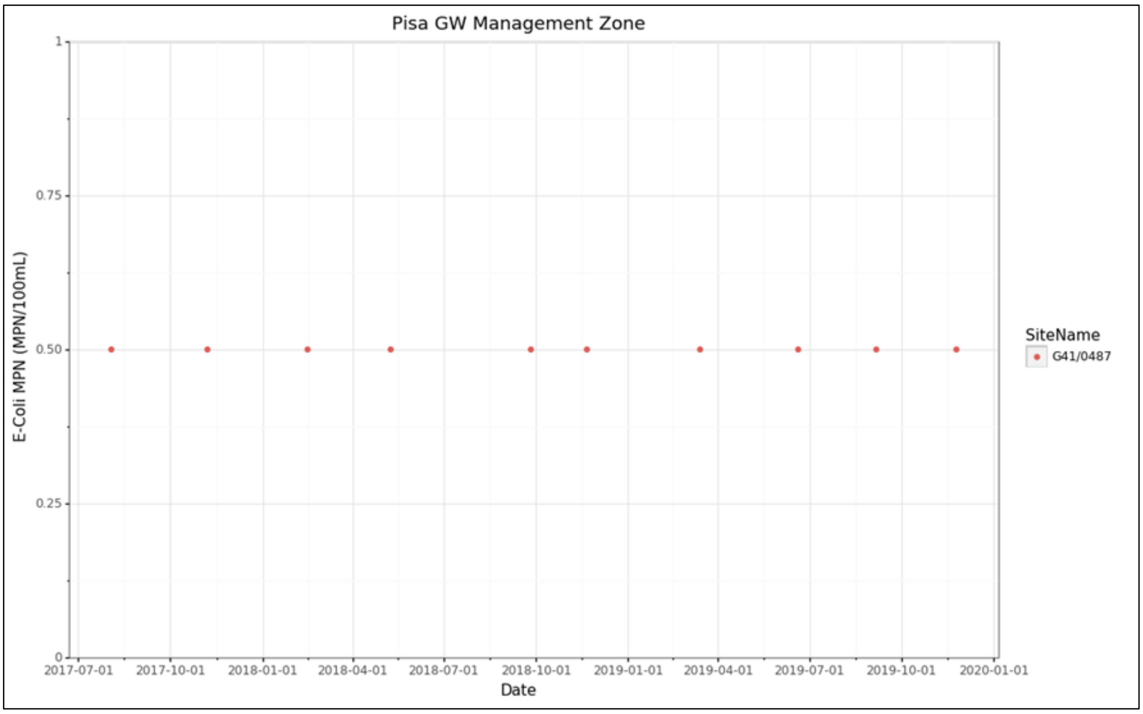
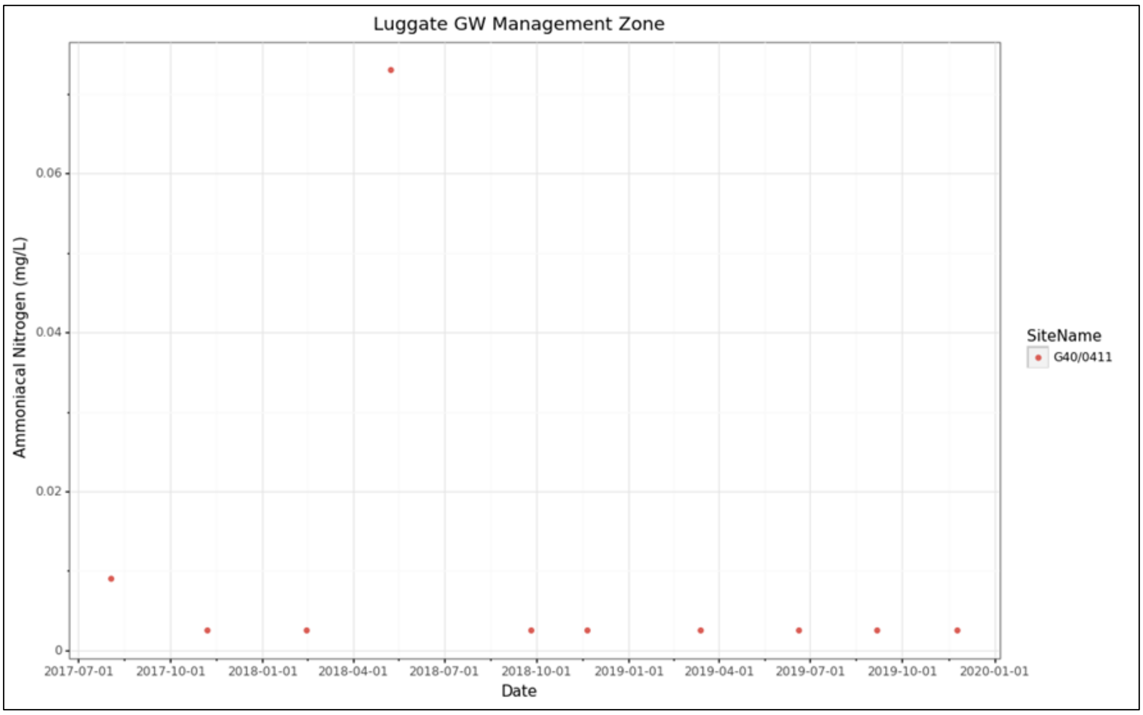


Figure 54: Groundwater ammonia concentration for the Luggate/Pisa GWMZ



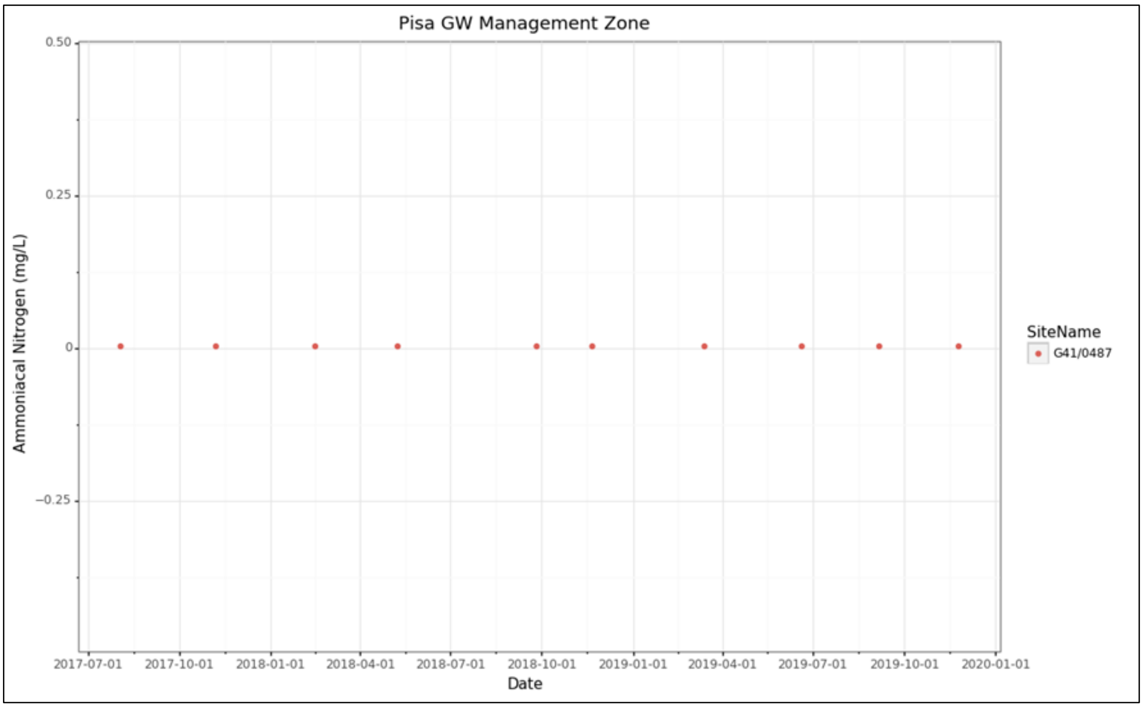
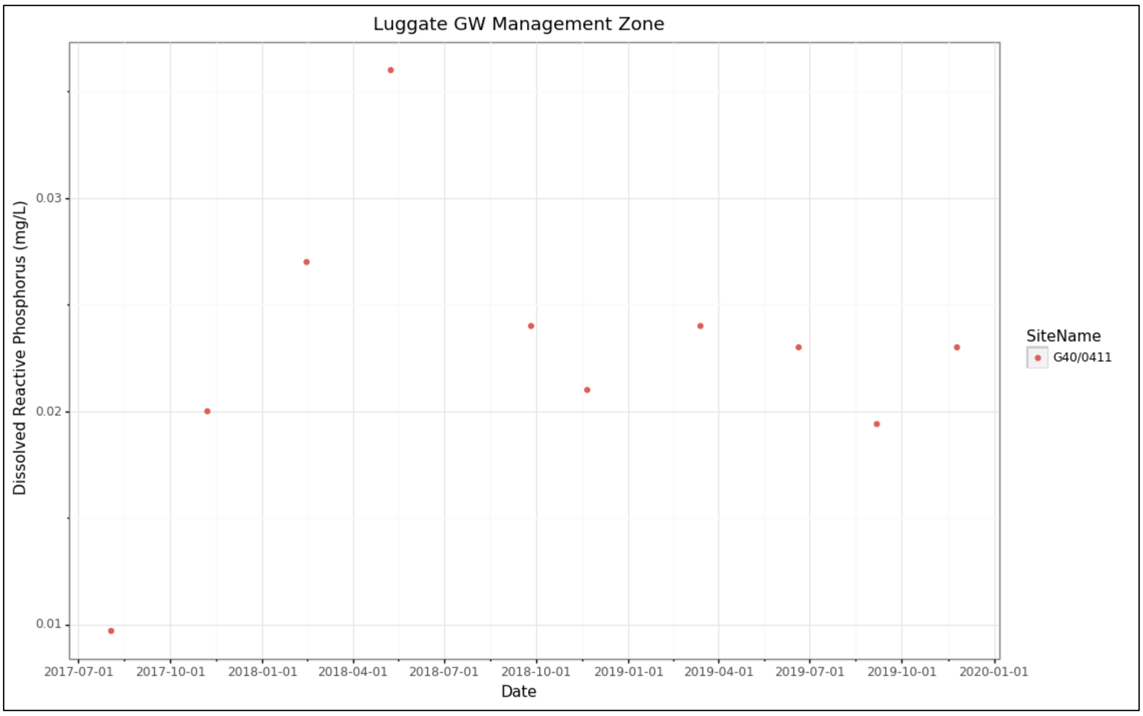
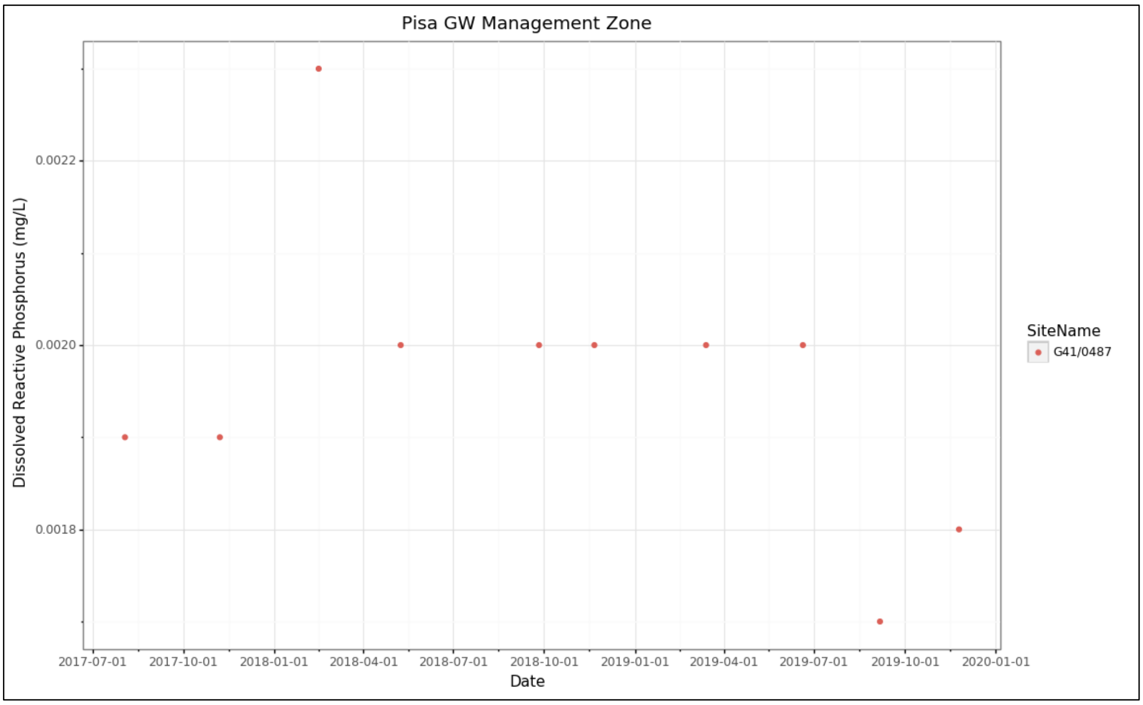


Figure 55: Groundwater Dissolved Reactive Phosphorus concentration for the Luggate/Pisa GWMZ





Comparison of the results against the Schedule 15 limits are provided in Table 22. The results from bore G41/0487 were not analysed as the bore is deeper than 20m. The results for bore G40/0411 (Luggate GWMZ) show non-compliance, as the 80th percentile nitrate and DRP concentrations (Figure 54 and Figure 55) substantially exceed the Schedule 15 limits. These results indicate potential issues with excessive nitrate and DRP concentrations in case of groundwater discharge to springs/streams, particularly for an unnamed stream situated approximately 265m west of the bore. Conversely, the ammonia concentrations are below the threshold.

Table 22: 80th percentile values for water quality variables & comparison with Schedule 15 limits for the West Bank of the U. Clutha

	Group 2 Sched. 15 limit (mg/L)	**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Bore number	**Aquifer**	**0.075**	**0.010**	**0.100**
G40/0411	Luggate GWMZ	8.340	0.0246	0.006

These results are also reflected in the assessment against the NPS-FM NOF, Table 23. The median and 95th percentile nitrate concentration are in Band D and C, respectively, which are below the National Bottom Line. Band C describes an environment with impacts on growth of multiple species where toxicity starts approaching acute impact levels (i.e. death risk) for sensitive species at higher concentrations (>20mg/L). The median and 95th percentile DRP concentrations are also in Bands D and C, respectively. Band D for DRP describes an environment where ecological communities are impacted by concentrations that substantially exceed natural reference conditions. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa that is sensitive to hypoxia are lost. The classification for median and maximum ammonia concentrations are Band A and B, respectively. At Band B, 95% of the species are protected, with an occasional impact on the 5% most sensitive species starting to occur (MfE, 2020).

Table 23: NPS-FM NOF comparison summary for the W. Bank of the Upper Clutha

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G40/0411	7.75	9.45	D	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G40/0411	0.0025	0.073	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G40/0411	0.023	0.032	D	C

4.2.4.6 Lower Tarras Aquifer

4.2.4.6.1 Aquifer information

The Lower Tarras aquifer is located on the eastern side of the Upper Clutha, where it is bounded by the Clutha River to the west, SH8/SH8A to the south, east and north and Grandview ridge to the east. There are currently no monitoring bores in the Bendigo and Lindis alluvial aquifer or the Ardgour Valley areas, although it is planned to add them.

The Bendigo-Tarras area has a dry climate, with a mean annual rainfall of between 400 and 500mm. The main water uses in the area are vineyards/cherries irrigation and large central pivots which are increasingly used for pasture irrigation. Flood irrigation is also used for pasture. Groundwater occurs within different geological units including highly permeable sandy gravel glacial outwash deposits on the lower terraces, which are used for irrigation. There are also low yielding, clay rich deposits around Tarras settlement which only contain a limited groundwater resource, and are used for domestic/stock water supply. Bores in the Ardgour Valley abstract from the Lindis alluvial ribbon aquifer, which is highly connected to the Lindis River, hence, takes in this area can deplete its streamflow. Due to these, most of the irrigation production bores are situated in the southern Bendigo area (ORC, 2010a).

The Clutha and Lindis rivers are both significant for the groundwater in the area as they are highly connected with the groundwater system. However, the two contrast in their size and sensitivity to stream depletion, with the Clutha having a mean flow of around 250m^3/second whereas the low Lindis dries out during most summers. Careful groundwater management, which allows resource development in areas where groundwater is buffered by recharge from the Clutha, is therefore required to lessen the impacts on the lower Lindis.

Groundwater in the Bendigo and Tarras basin is found in Quaternary and Tertiary age sediments that rest in a depression formed in the underlying schist. The basin is underlain by Haast schist of the Rakaia Terrane which acts as basement rock to the basin. The basin’s shape is controlled by faults and folds through the schist. The basement rocks are overlain by non-marine Miocene quartz conglomerate, sandstone, mudstone and lignites of the Manuherekia Group, which is represented in the Tarras Bendigo area by silt deposits and quartz sands. These are overlain by Quaternary deposits of sand, silts and gravel. The silty sandy layer is found at the ground surface just north of Tarras (ORC, 2010a).

Bore logs from the area show well sorted gravels in the Clutha Valley to a depth of approximately 50m and thinly layered silts and clay bound sands in the Tarras area. The depth of the aquifer base was refined using geophysics. The depth to the silty mudstone varied from 20-30m in the Ardgour Valley to >120m deep in the Clutha Valley. The data suggests that the underlying silt deposits of the Bendigo area dip to the NE and rise again at the edge of the terrace. These silt deposits underlie the dry Quaternary terraces and restrict horizontal groundwater movement below them. These silt deposits contain the shallow groundwater within the Lindis alluvial ribbon aquifer in the Ardgour Valley.

Piezometric maps show that groundwater generally flows into the aquifer from the Clutha in the northern area of the Tarras/Bendigo allocation zones and returns to the river in the southern areas. The Lindis strongly impacts groundwater flow as water moves into the deeper gravels after exiting the Ardgour Valley at the Lindis Crossing. Water levels in the Lindis

Crossing bridge are approximately 7m above the level of the Clutha indicating that groundwater levels drop a significant amount between the bridge and the Lindis/Clutha confluence.

There are four available aquifer pumping test reports from the area. The reported permeability in the more recent alluvium sand and gravels is high, with the reported Transmissivity in the lower terraces ranging between 3,000 and 5,000m^2/day (bores G41/0231, G41/0316, and G41/0286). In contrast to that, the Tarras settlement area was not impacted by fluvial reworking of the glacial sediments and it is underlain by low permeability, clay-rich sediments. Hence, bores in this area are more suitable to supply the low requirements of domestic supplies volumes (ORC, 2010a).

4.2.4.6.2 Groundwater quality results

There are two groundwater SoE monitoring bores in the Lower Tarras area. Bore no. G40/0175 (125mm diameter) was drilled in November 2002. The bore is located at Munro Lane, NZTM E 1316489 N5029566. The bore depth is 12.64m. The bore log describes silty sandy gravels to 6.8m underlain by silts to 7.5m. There is then silty/sandy gravels to the bore bottom at 12.8m. The log also describes grey clay at a depth of 12.8m, suggesting that this is the aquifer depth. The top of the screen leader is located at a depth of 11.44m, and the reported screen length is 1.00m, hence the top of the screen is at a depth of 11.640m the bottom silty/sandy gravels. Water levels in bore G40/0175 fluctuate between 2.00 and 3.00m below MP. However, significantly lower levels were measured in March 2017 (5.92m), December 2017 (6.6m) and March 2018 (7.05m). The drops in the summer (December and March) in 2017 and 2018 was significant, at around 3-4m. However, these drops were not observed during other years of measurement. The SWL in the bore in December 2019 was 2.9m below MP.

Bore G41/0211 (125mm diameter) is located at Maori Point Road, NZTM E1313189 N5027098. The bore was drilled in October 1999. The bore depth is 41.51m. The bore log describes coarse gravels to 15.4m underlain by grey sand to 16.2m. There is then sandy gravels to 22.6m, underlain by cobbley gravel to 22.9m and rock to 23.2m. There is then coarse cobbles to 30.9m underlain by sandy gravels to the bore bottom at 40.90m. This log suggests that the bore abstracts from an unconfined sandy gravels aquifer. The top of the screen leader is at a depth of 40.38m, within a sandy gravels horizon described as slightly silty (between 39.2 and 40.90m). The SWL in the bore ranges between 25.5 and 27.28m below MP. The lowest levels are measured in December/March although in some years water levels recover in March. The highest levels are in June. The normal seasonal fluctuations are usually around 1m. However, there was an anomaly in June 2019 where the levels were higher at 25.50m below MP, with an increase of 1.71m from previous measurement. The SWL in the bore in December 2019 was 27.1m below MP.

The assessment against the DWSNZ for E. coli, dissolved arsenic, and ammonia is shown in Figure 56, Figure 57,

Figure 58, and

Figure 59. Bore G41/0211 did not have any E. coli exceedances, although the data between September 2014 and March 2017 shows <1.6MPN/100mL. In contrast to that, several of the results in bore G40/0175 exceeded the MAV, notably with counts of 180 MPN/100mL (December 2013) and 4 MPN/100mL (March 2018). These indicate a contamination risk of the bore, likely due to its shallow depth and potential issues with borehead security (Figure 56). No samples in neither bore exceeded the MAV for arsenic (Figure 57) or the GV for ammonia (

Figure 58). The nitrate concentrations in both bores are much lower than the DWSNZ MAV of 11.3mg/L. The concentrations in bore G40/0175 range between 0.8 and 1.1mg/L. There is no discernible trend in nitrate concentrations, and they are low although there is intensive grazing around the bore. These results are similar to the nitrate concentrations from bore G41/0211, which range between 0.9 and 1.2mg/L. The data from this bore does not show a trend, although there is some increase over recent years (

Figure 59). Very high DRP concentrations, of 2.98mg/L were measured in bore G41/0211 in March 2009. However, this seems to only be a single spike (

Figure 60).

Figure 56: Groundwater E. Coli count for the Lower Tarras aquifer

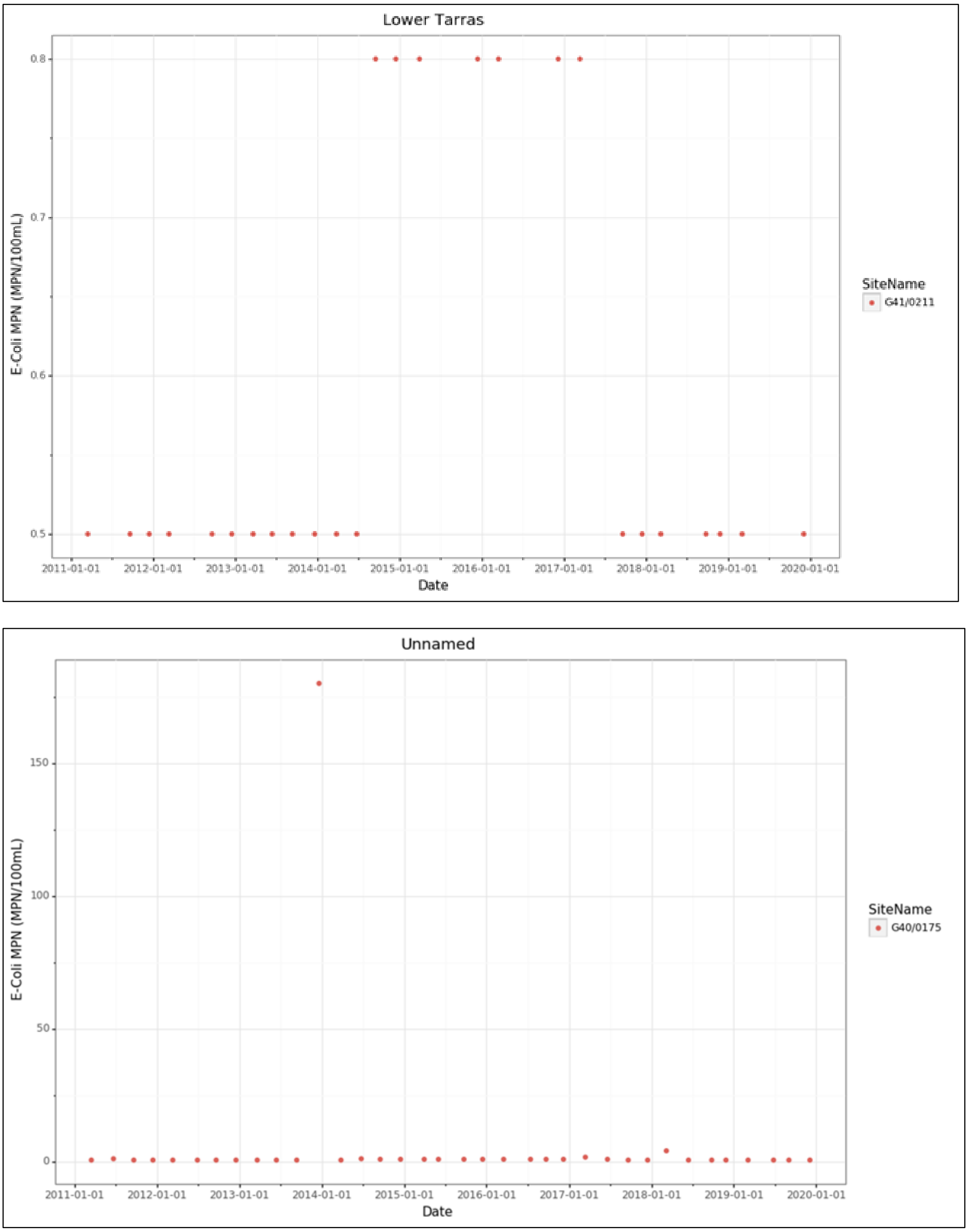
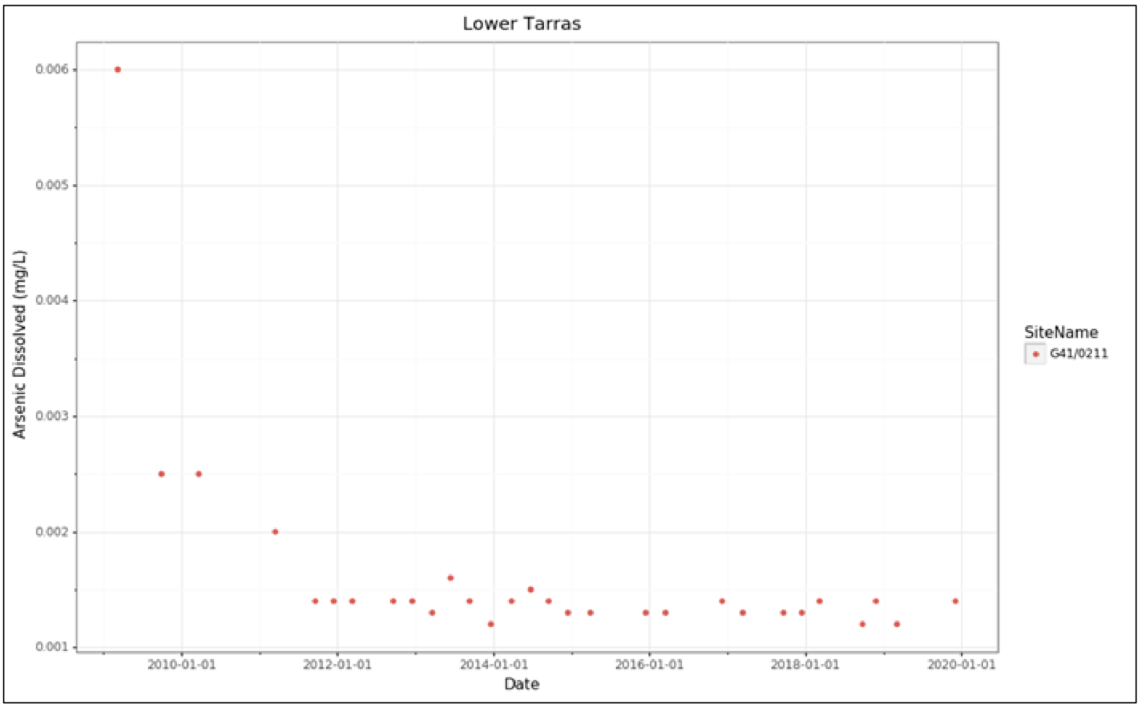


Figure 57: Groundwater dissolved arsenic concentration for the Lower Tarras aquifer


Lower Tarras
Arsenic Dissolved (mg/L)
0.006
0.005
0.004
0.003
0.002
0.001
2010-01-01
2012-01-01
2014-01-01
2016-01-01
2018-01-01
2020-01-01
Date
SiteName
G41/0211

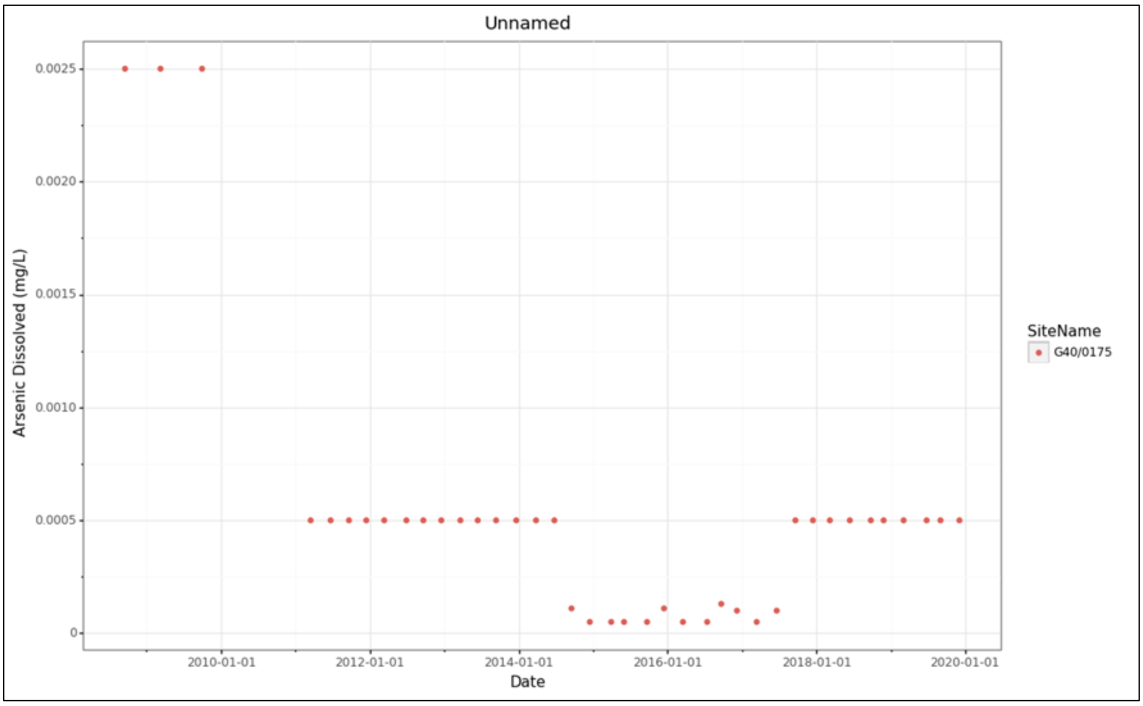
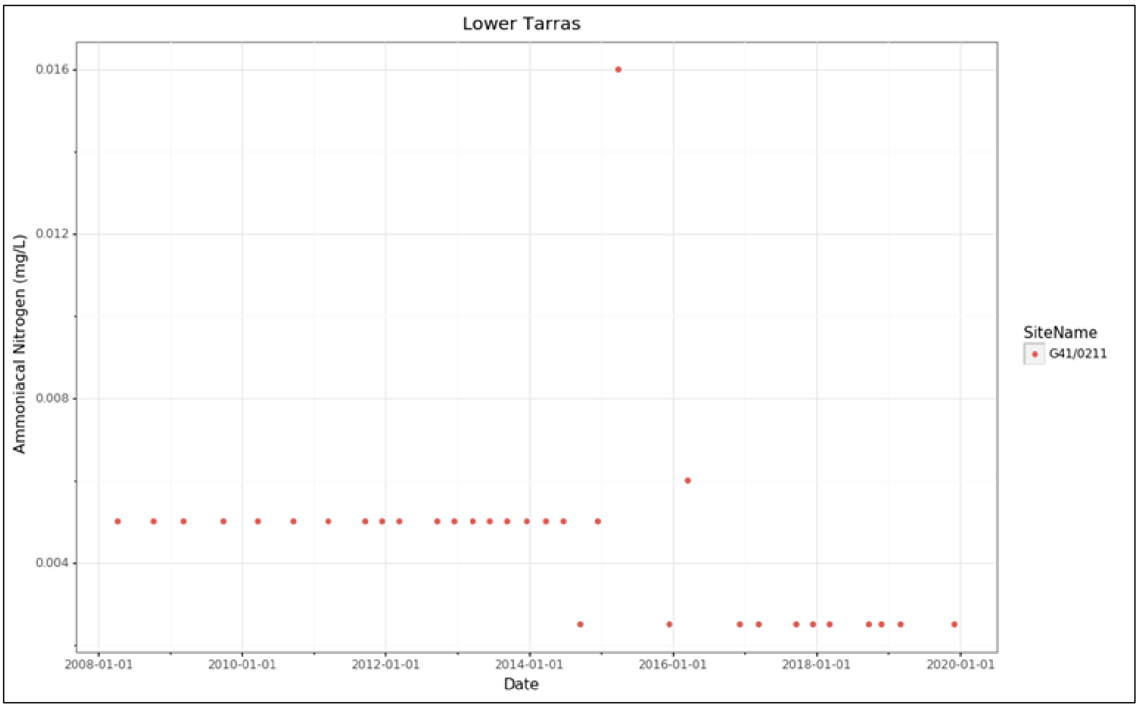

Unnamed
Arsenic Dissolved (mg/L)
0.0025
0.0020
0.0015
0.0010
0.0005
0
2010-01-01
2012-01-01
2014-01-01
2016-01-01
2018-01-01
2020-01-01
Date
SiteName
G40/0175

Figure 58: Groundwater ammonia concentrations for the Lower Tarras aquifer



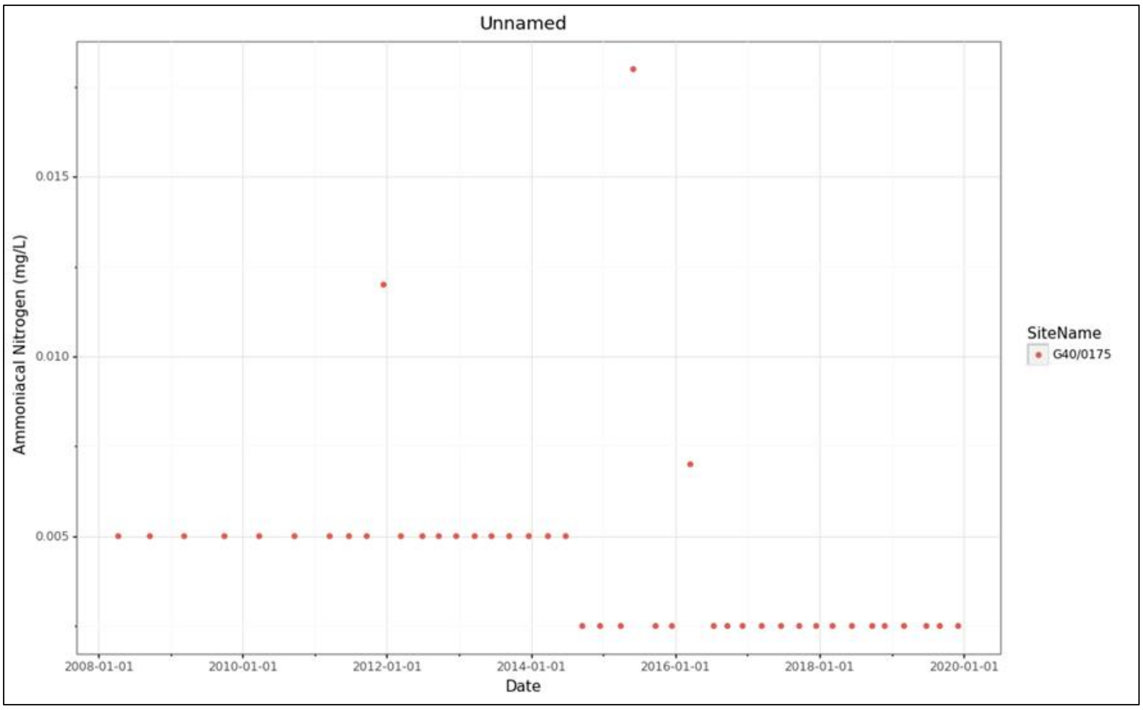
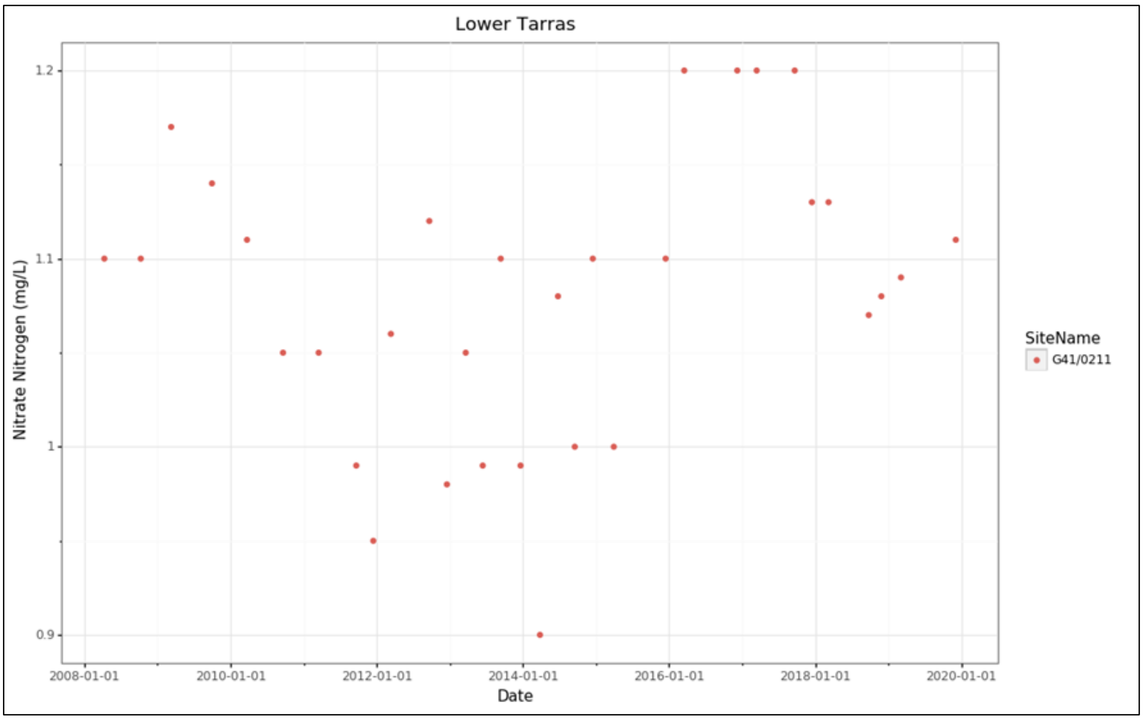


Figure 59: Groundwater nitrate concentration for the Lower Tarras aquifer



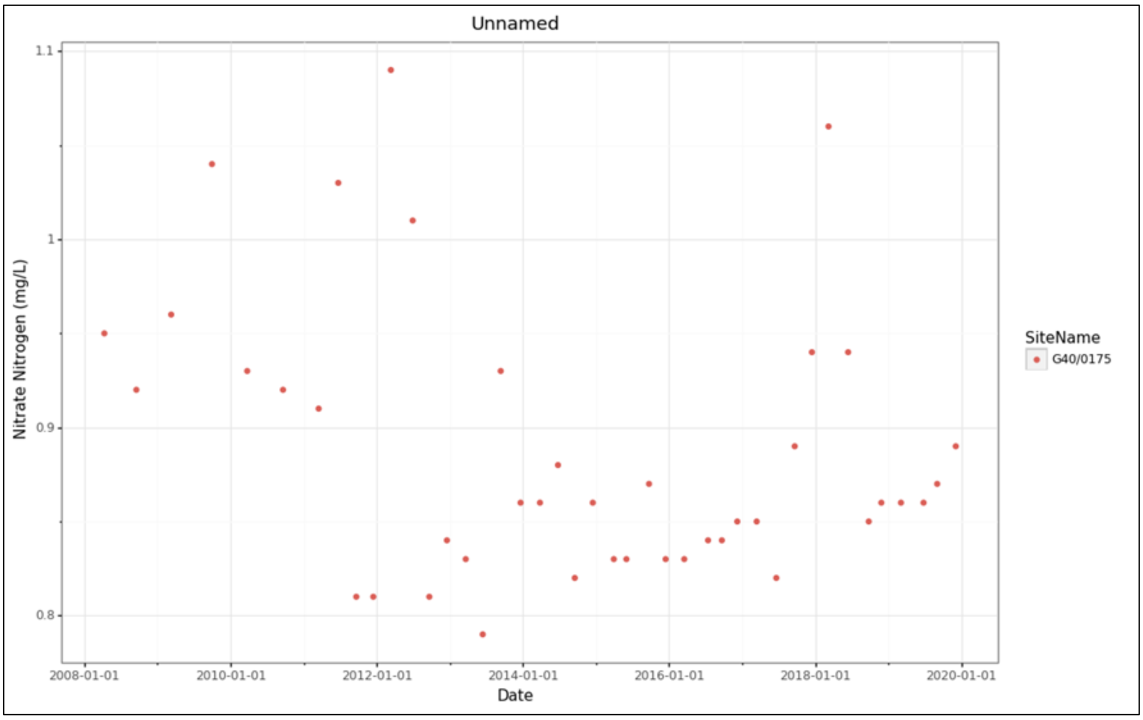
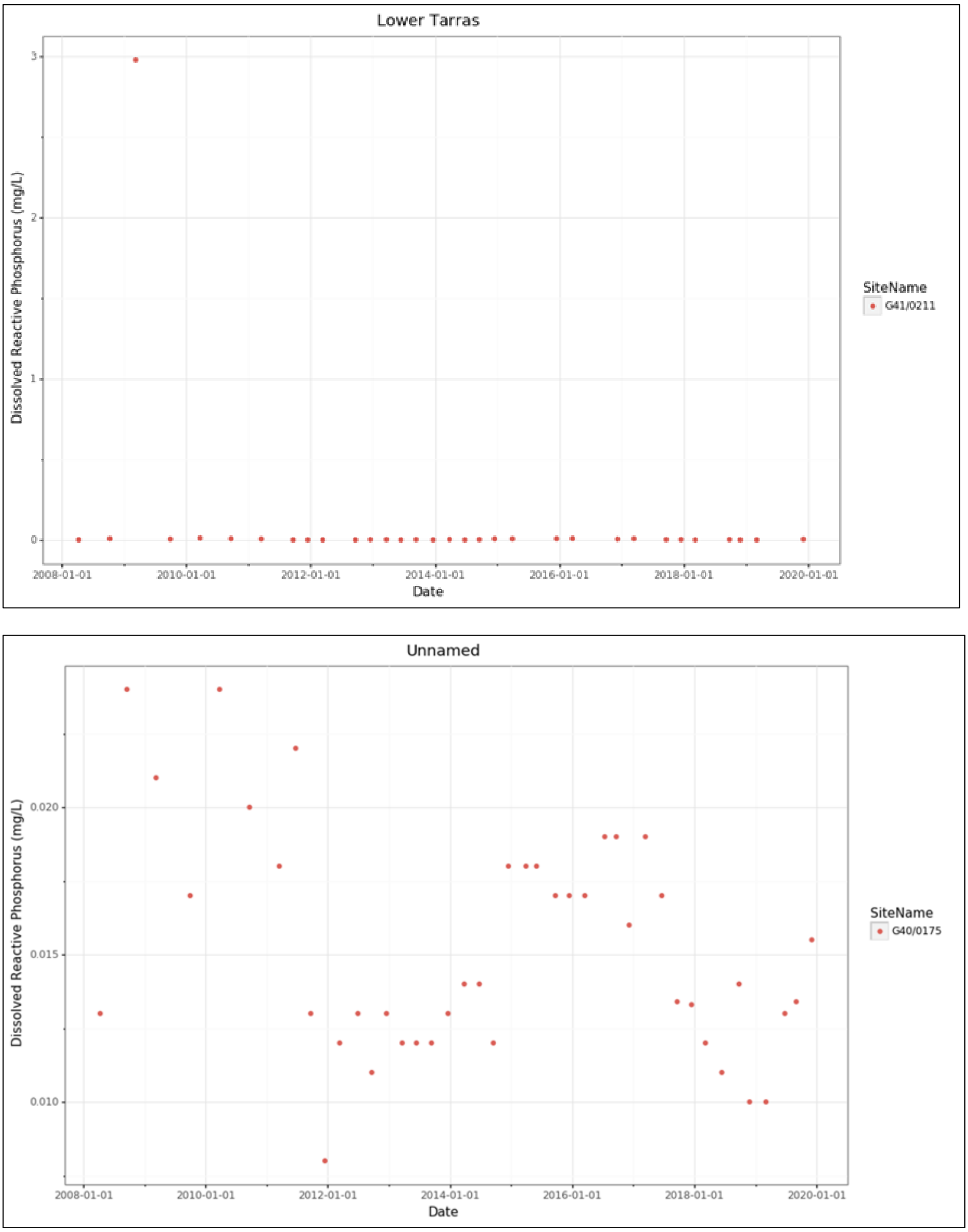


Figure 60: Groundwater Dissolved Reactive Phosphorus concentrations for the Lower Tarras aquifer



Regarding potential impact on surface water ecosystems, nitrate, DRP, and ammonia concentrations for bore G40/0175 were compared against the RPW (Table 24) and NPS-FM thresholds (Table 25). Due to the depth of bore G41/0211, its results were not used for this analysis. Bore G40/0175 is located in Group 2 of Schedule 15. The results show noncompliance for nitrate and DRP, with nitrate concentrations substantially exceeding the Schedule 15 limits. Conversely, ammonia concentrations are below the limits. These non-compliances suggest potential adverse impacts on surface water quality. The analysis with the NPS-FM thresholds shows that the DRP concentrations are in Band C for the median and B for the 95th percentile.

Table 24: Results for comparison with Schedule 15 limits for nitrate, DRP, and ammonia

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G40/0175	Clutha	Dunstan	Tarras	0.938	0.018	0.010

Table 25: NPS-FM NOF comparison summary for the Lower Tarras aquifer

	Nitrate			NOF Band	
Bore no.	median (mg/L)		95th percentile (mg/L)	median	95th percentile
G40/0175	0.86		1.0395	A	A
	Ammoniacal nitrogen		NOF Band		
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum	
G40/0175	0.005	0.018	A	A	
	DRP		NOF Band		
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile	
G40/0175	0.014	0.02195	C	B	

4.2.5 Manuherekia Rohe

The Manuherekia Rohe encompasses the catchment of the Manuherekia River, which flows for approximately 64km and has a catchment area of 3,033km^2. The catchment includes two major depressions, the Ida and Manuherekia Valleys, which are connected by the Pool Burn Gorge through Rough Ridge. The catchment is one of New Zealand's driest, with a strongly semi-arid, continental climate characterised by warm, dry summers and cold winters. Irrigation water is therefore at a high demand. The headwaters of the river are in the Hawkdun and Saint Bathans Ranges and the Dunstan Mountains. The river flows in a southwest direction and empties into the Clutha at the Alexandra township. The rohe contains SoE monitoring bores within three aquifers: the Manuherekia GWMZ (Section 4.2.5.1), Manuherekia Alluvium aquifer (Section 4.2.5.2), and the Manuherekia Claybound aquifer (Section 4.2.5.3). The Manuherekia Claybound and Alluvium are part of the Alexandra Basin alongside the Earnscleugh and Dunstan Flats. There are no monitoring bores in the Earnscleugh or the Ida Valley aquifer and the Dunstan Flats aquifer only has one monitoring bore that is solely monitored for groundwater levels (G42/0695), although the National Groundwater Monitoring Programme (NGMP) sampling has been undertaken for Geological & Nuclear Sciences (GNS) in the Dunstan Flats in the past.

In relation to the DWSNZ, the results from the SoE monitoring bores generally indicate fair/good groundwater quality. E. coli is the main issue, with exceedances measured in most monitoring bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherekia Alluvium Aquifer and Manuherekia Claybound Aquifer monitoring bores generally near the reference conditions for low intensity landuse, i.e. <2.5mg/L (Daughney and Morgenstern, 2012). However, increasing concentrations were observed in the Manuherekia GWMZ monitoring bore, where concentrations exceed ½ of the MAV. No elevated arsenic concentrations were detected in any of the monitoring bores in the rohe.

In relation to potential impacts on ecosystem health, the results from the shallow monitoring bores show elevated nitrate and DRP, with concentrations exceeding the Schedule 15 limits. The DRP concentrations for the Manuherekia Alluvium bore are in Band D, below the National Bottom Line. This suggests that interaction of the aquifers with surface water can adversely impact it. The median concentrations for DWSNZ and ecosystem health parameters are shown in Table 26.

Table 26: Median concentrations for DWSNZ/ecosystem health parameters for the Manuherekia rohe

Aquifer	**Ammoniacal Nitrogen (mg/L)**	**Arsenic Dissolved (mg/L)**	**Dissolved Reactive Phosphorus (mg/L)**	**E-Coli (MPN/100mL)**	**Nitrate (mg/L)**
Manuherekia Alluvium	0.003	0.000	0.024	0.650	1.100
Manuherekia Claybound	0.005	0.001	0.013	0.500	1.345
Manuherekia GWMZ	0.005	0.001	0.014	0.500	1.600

4.2.5.1 The Manuherekia GWMZ

4.2.5.1.1 Information summary

The Manuherekia GWMZ is bounded to the east by the Hawkdun Range, to the north and west by the Dunstan Mountains, to the south by the Raggedy Range and to the south/west by the Manuherekia Alluvium and Claybound aquifers. The geology of the Manuherekia GWMZ is composed of basement schist geology, where the upper few metres were altered to pale-green colour by water-rock interaction. The schist is overlain by Tertiary sediments of the Manuherekia Group, which consist of terrestrial flood plain, lake, and lake delta sediments that is up to 300m thick. These sediments were deposited in a low-energy environment and comprise of sand, silts, and clay sequences. Thin veneers of Holocene river gravels, associated with modern streams or river drainage, overly the Tertiary sediments. The surface hydrology comprises of the Idaburn catchment, which drains the Ida range in the north and the Poolburn catchment, draining the South Ridge. These streams meet at the Poolburn Gorge, where water flows through the gorge into the Manuherekia River. A groundwater survey has not been conducted in the area to date. However, it is assumed that the groundwater flow direction will follow the topography and flow in a similar direction to the surface hydrology, with groundwater contributing baseflow to the tributaries and streams in the Idaburn and Poolburn catchments (ORC 2018b).

There are 20 completed bores within the Manuherekia GWMZ. Bore depths range between 2.7 and 60.37m. There is SWL information for 19 of the bores, indicating shallow SWL that ranges between 0.77 and 7.5m below MP. Screen depth information is available for six of the bores, with the top of screen depth ranging between 2 and 14.02m, highlighting the shallow aquifer depth. The main groundwater uses are irrigation, stockwater, and domestic/community supply. There are no consented groundwater takes within the GWMZ.

4.2.5.1.2 Groundwater quality monitoring results

Groundwater quality and levels in the Manuherekia GWMZ are monitored in bore G41/0254 (125mm diameter). The bore is located at Donnelly Road, west of Omakau, NZTM E1330618 N5002689. The bore is shallow with a total depth of 6.5m. The bore log describes silty sandy clay to 1.8m underlain by sandy gravels to 3.8m. There is then blue mudstone down to the bore bottom at 6.5m. The top of the screen is located at a depth of 1.82m, within a horizon of sandy gravels. It is not possible to measure the SWL in the bore due to a pump running continuously.

The comparison against the DWSNZ indicates some exceedances of the E. coli MAV, notably 11 MPN/100mL (March 2017) and 6 MPN/100mL (March 2018), Figure 61. None of the results exceeded the dissolved arsenic MAV of 0.01mg/L, with a maximum arsenic concentration of 0.006mg/L in February 2009. Concentrations have then been <0.001mg/L since then (Figure 62). Nitrate concentrations were below the DWSNZ MAV of 11.3mg/L. However, the data shows a pronounced increase in nitrate concentrations, which were around 1.0mg/L at the start of monitoring in 2010. Concentrations then fluctuated between 1.0 and 2.0mg/L until 2014. It then increased steadily, reaching a maximum concentration of 5.3mg/L, over ½ of the MAV, in March 2019 (Figure 63). The ammonia concentrations are below the GV of 1.5mg/L (Figure 64).

Figure 61: Groundwater E. Coli count for the Manuherekia GWMZ

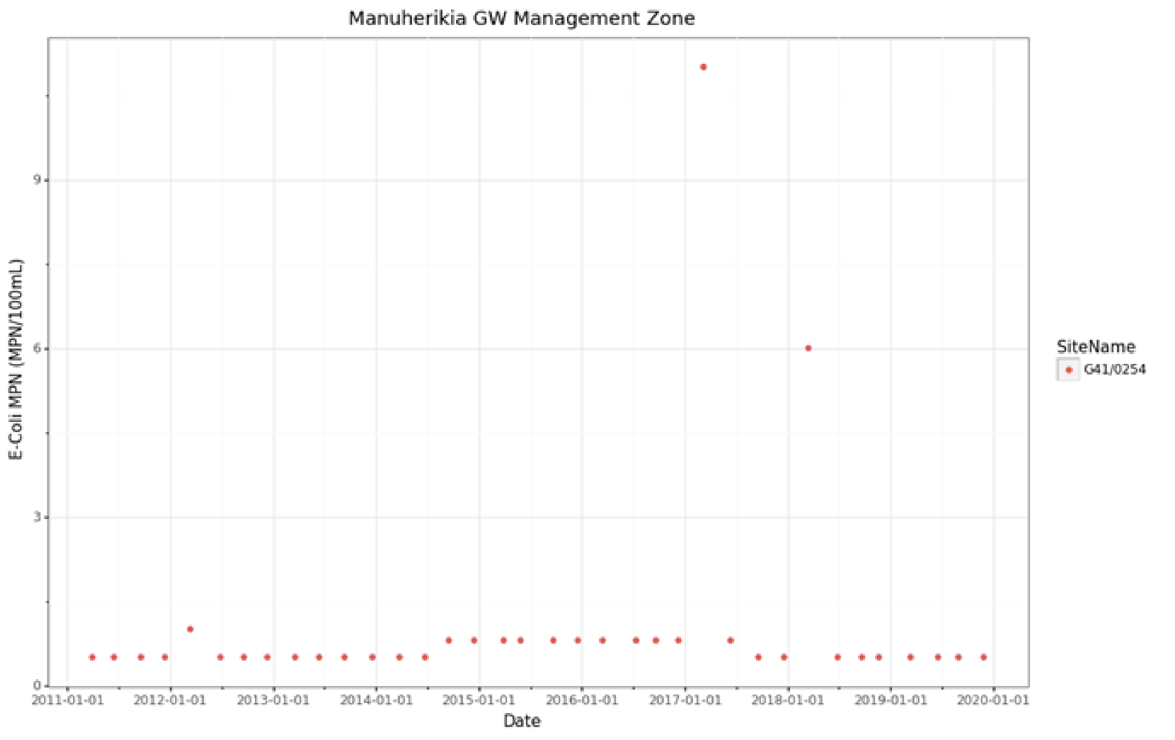


Figure 62: Groundwater dissolved arsenic concentrations for the Manuherekia GWMZ

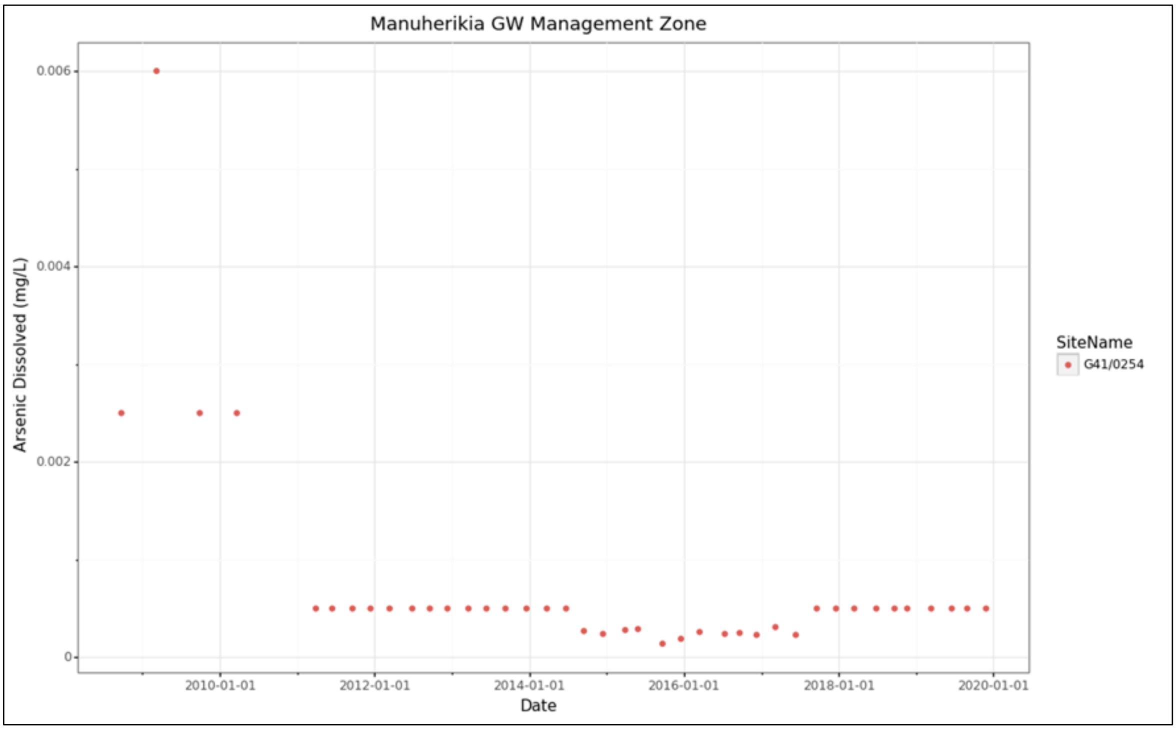


Figure 63: Groundwater nitrate concentrations for the Manuherekia GWMZ

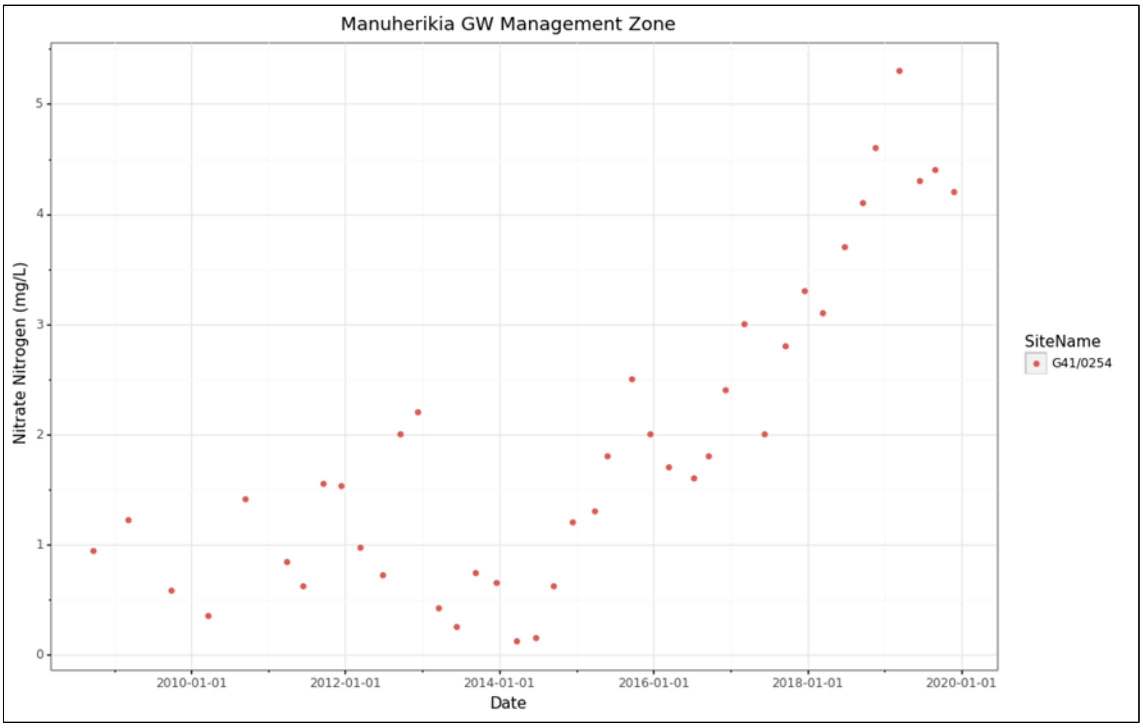


Figure 64: Groundwater ammonia concentrations for the Manuherekia GWMZ

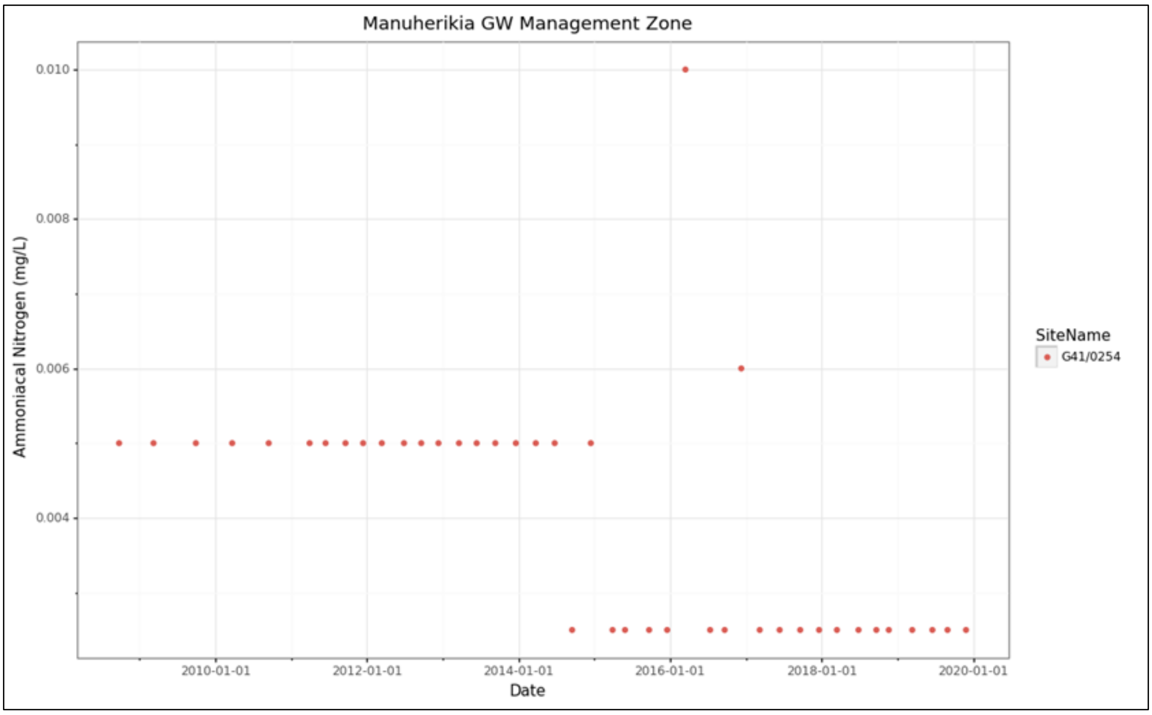
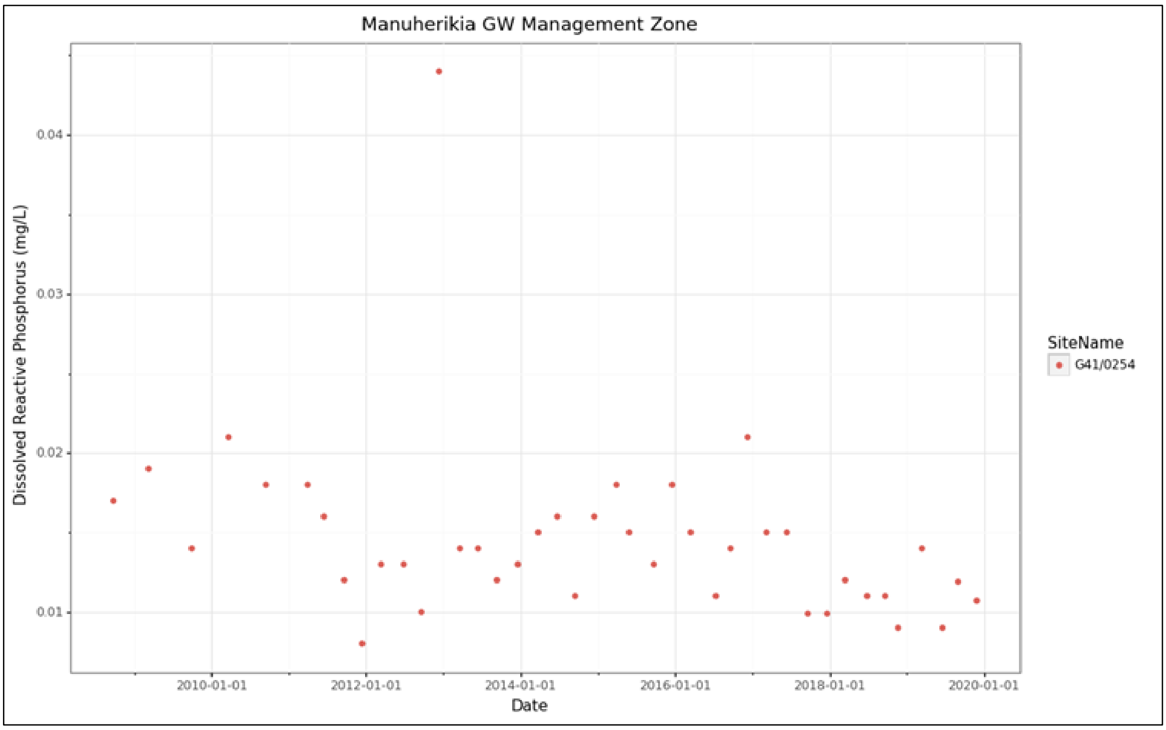


Figure 65: Groundwater Dissolved Reactive Phosphorus concentrations for the Manuherekia GWMZ



Groundwater quality data from bore G41/0254 was then assessed against the RPW (Table 27). The results show potential water quality issues. The 80th percentile nitrate and DRP concentrations exceed the Schedule 15 limits (Figure 65), with nitrate concentration exceeding it by around 40 times. The ammonia concentrations are within the limits.

Compliance with the NPS-FM NOF is shown in Table 28. The median and 95th percentile concentrations for nitrate are in Band B and C, respectively. Nitrate concentrations at Band C will have growth impacts on up to 20% of species, mainly which are sensitive such as fish, although there are no acute effects. The median and 95th percentile concentrations for DRP are in Bands C and B, respectively. DRP concentrations in Band C exceed natural reference conditions and impact ecological communities. If other conditions that favour eutrophication also exist, DRP enrichment can cause increased algal and plant growth, loss of sensitive fish and macroinvertebrate taxa and high respiration and decay rates (MfE, 2020). Both median and maximum ammonia concentrations are in Band A. The elevated nitrate and DRP concentrations can adversely impact surface water quality, particularly a tributary of Thomsons Creek situated approximately 250m away from the bore. The steady increase in groundwater nitrate concentration since 2014 is also concerning.

Table 27: Results for comparison with Schedule 15 limits for nitrate, DRP, and ammonia

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G41/0254	Clutha	Manuherekia	Manuherekia GWMZ	3.100	0.017	0.010

Table 28: NPS-FM NOF comparison summary for the Manuherekia GWMZ

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G41/0254	1.6	4.4	B	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G41/0254	0.005	0.01	A	A
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G41/0254	0.014	0.021	C	B

4.2.5.2 The Manuherekia Alluvium Aquifer

4.2.5.2.1 Aquifer information

The Manuherekia Alluvium aquifer is defined by the flood plain of the Manuherekia River on its true left bank between the exit from the Ophir Gorge and Alexandra. It is a shallow, unconfined aquifer hydraulically connected to the Manuherekia River and is underlain by Manuherekia Formation consolidated sediments. The depth of the alluvium base is approximately 8m. The water table is shallow and is sloping towards the river. There is no available aquifer pumping test information from this area. The inflows/outflows of the Manuherekia alluvium aquifer are closely tied to the Manuherekia River and to low efficiency irrigation. Water for the irrigation schemes is harvested through the upper and lower Manorburn dams, and is used over the aquifer during the irrigation season. Some groundwater discharge occurs as seepage flow on the western (downhill) side of Fisher Lane, which coincides with the transition from the modern floodplain to the Hawea glacial advance terrace surface sediments. Anecdotally, flow from this spring is likely to be higher once irrigation starts in September (ORC 2012c).

According to the database, there are 35 completed bores within the Manuherekia Alluvium Aquifer. The depths of 34 are reported, which range between 3.68 and 13.46m. The SWL is reported in 32 bores, which ranges between 1.15 and 10.46m. Screen depth information is available for 8 of the bores, with the top of screen depth ranging between 8.49 and 12.96m. This illustrates the shallow aquifer and water table depth.

4.2.5.2.2 Groundwater quality monitoring results

Groundwater quality in the Manuherekia Alluvium aquifer is monitored in bore G46/0152 (150mm diameter), drilled in October 2014. The bore is located at Galloway Road, NZTM E1321034 N4986341. The bore log is mainly composed of sandy and silty gravels. It describes 4.4m of coarse sandy gravel underlain by 0.5m of brown sandy silts. There is then silty coarse gravels to 6.9m underlain by sandy coarse gravels and silt to 10.1m. These are underlain by blue clays down to the bore bottom at 10.50m. The bore is screened between 9.50 and 10.00m, within a horizon of sandy coarse gravels and silts. Groundwater levels in the bore range between 2.7 and 5.8m below MP, with a strong seasonal fluctuation of around 2.5m. It is noted that water levels in the bore are highest during the summer irrigation season and lowest during the winter, highlighting the main role of irrigation recharge, which is the dominant source in this area of low rainfall and high evaporation. There is no noticeable trend of lowering groundwater levels. However, altering flood irrigation to more efficient methods may reduce irrigation recharge, and therefore water levels, in the bore, although this may be potentially offset by a reduction in abstraction (ORC, 2012c).

Groundwater quality results from bore G46/0152 were compared with the DWSNZ. The results show several exceedances of the E. coli MAV, although the counts were low, with a maximum of 4.9MPN/100mL in March 2017 (

Figure 66). Nitrate concentrations in the bore are much lower than the DWSNZ MAV of 11.3mg/L, with concentrations ranging between 0.91 and 1.36mg/L (Figure 67). There were no elevated dissolved arsenic concentrations above the MAV

(

Figure 68). All ammonia concentrations are below the GV of 1.5mg/L (Figure 69).

Figure 66: Groundwater E. Coli count for the Manuherekia Alluvium Aquifer

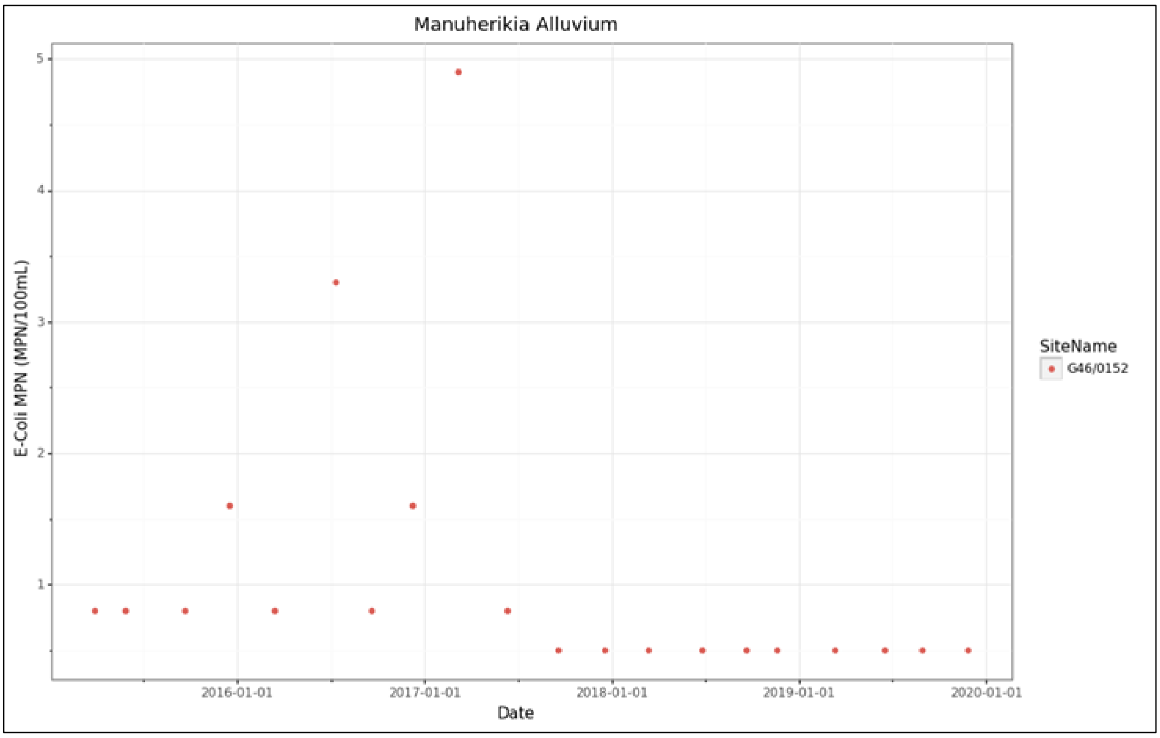


Figure 67: Groundwater nitrate concentrations for the Manuherekia Alluvium Aquifer

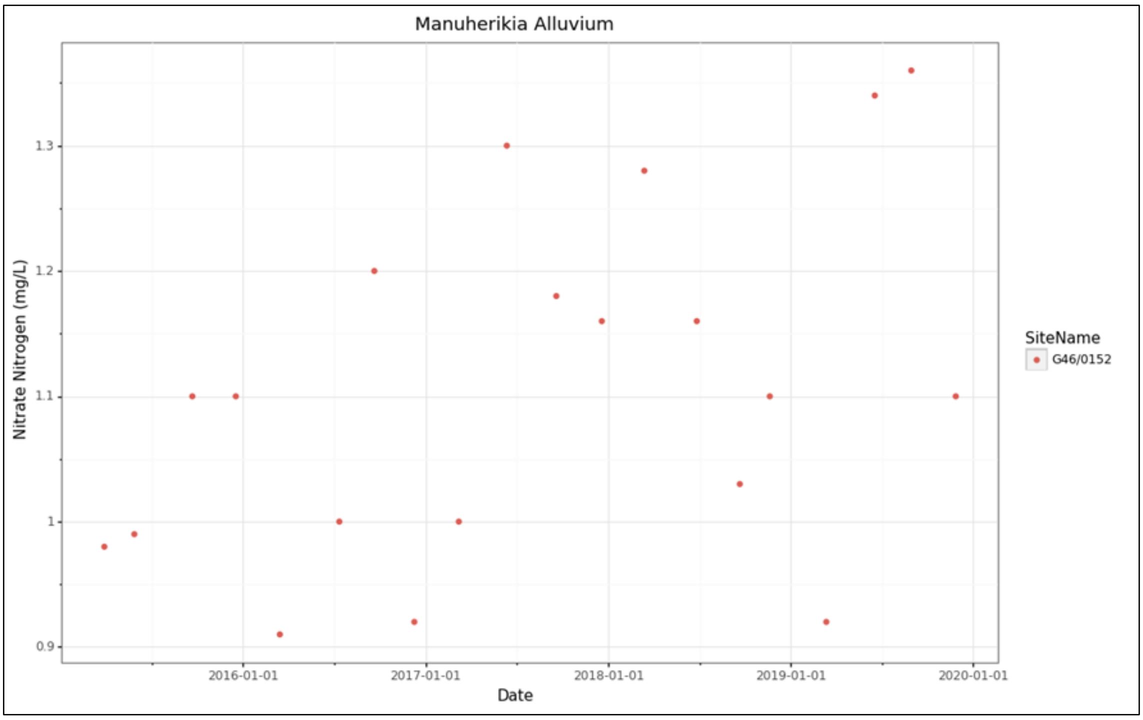


Figure 68: Groundwater dissolved arsenic concentrations for the Manuherekia Alluvium Aquifer

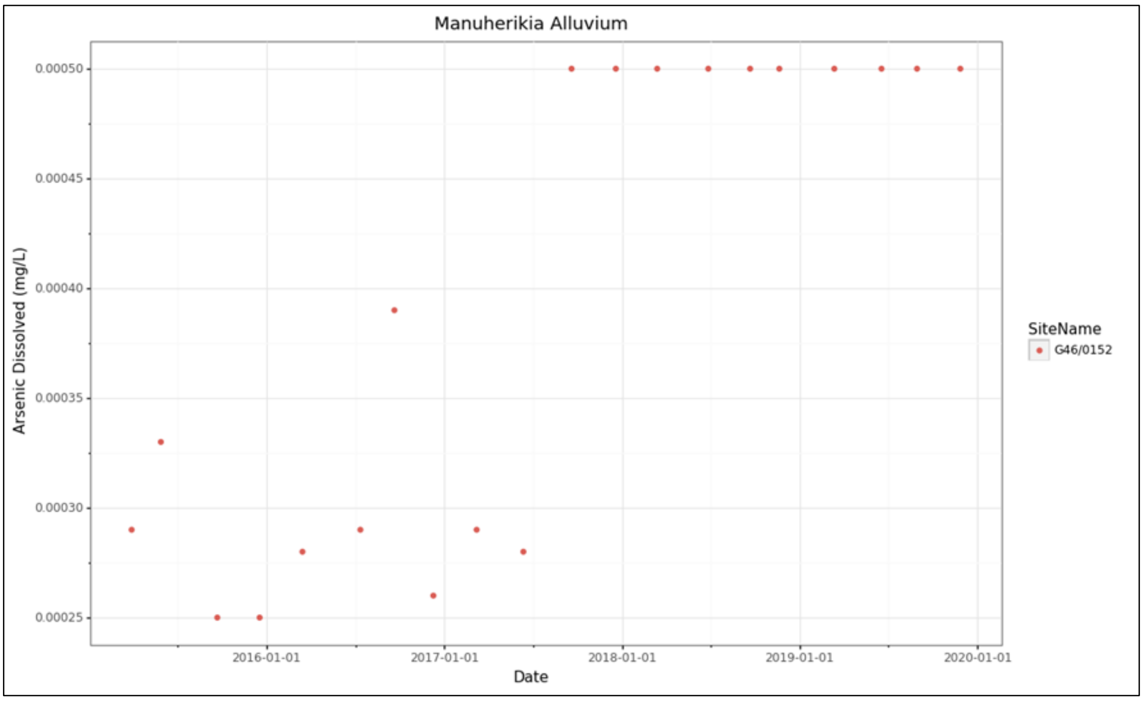


Figure 69: Groundwater ammonia concentrations for the Manuherekia Alluvium Aquifer

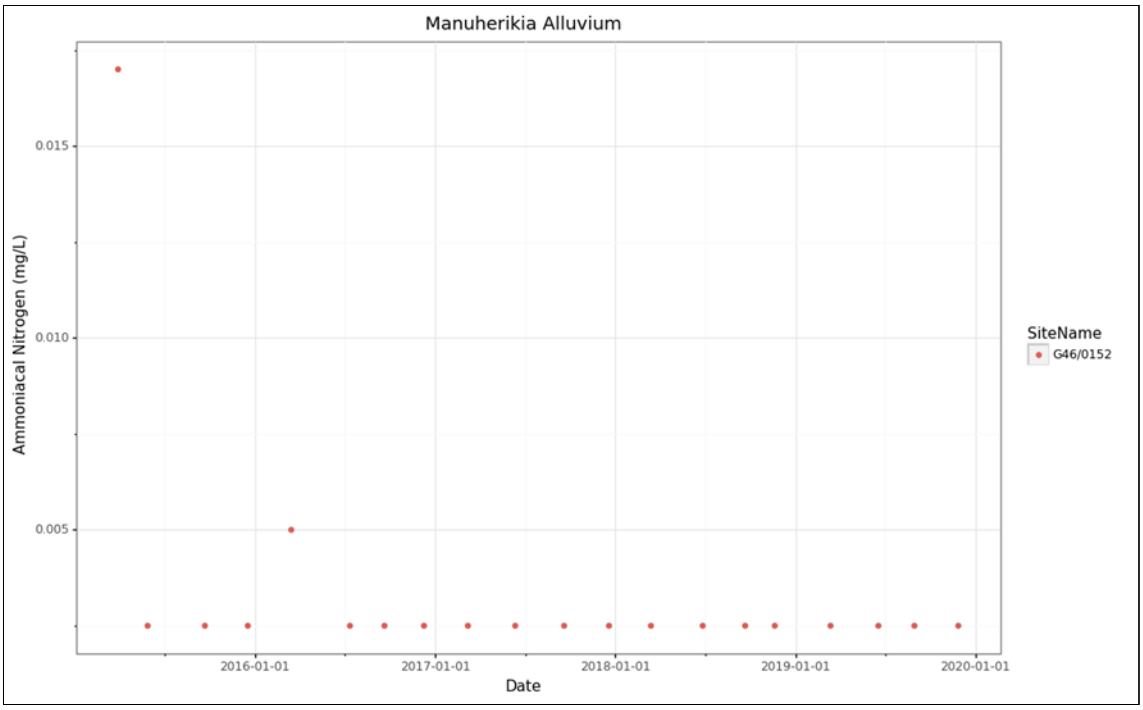
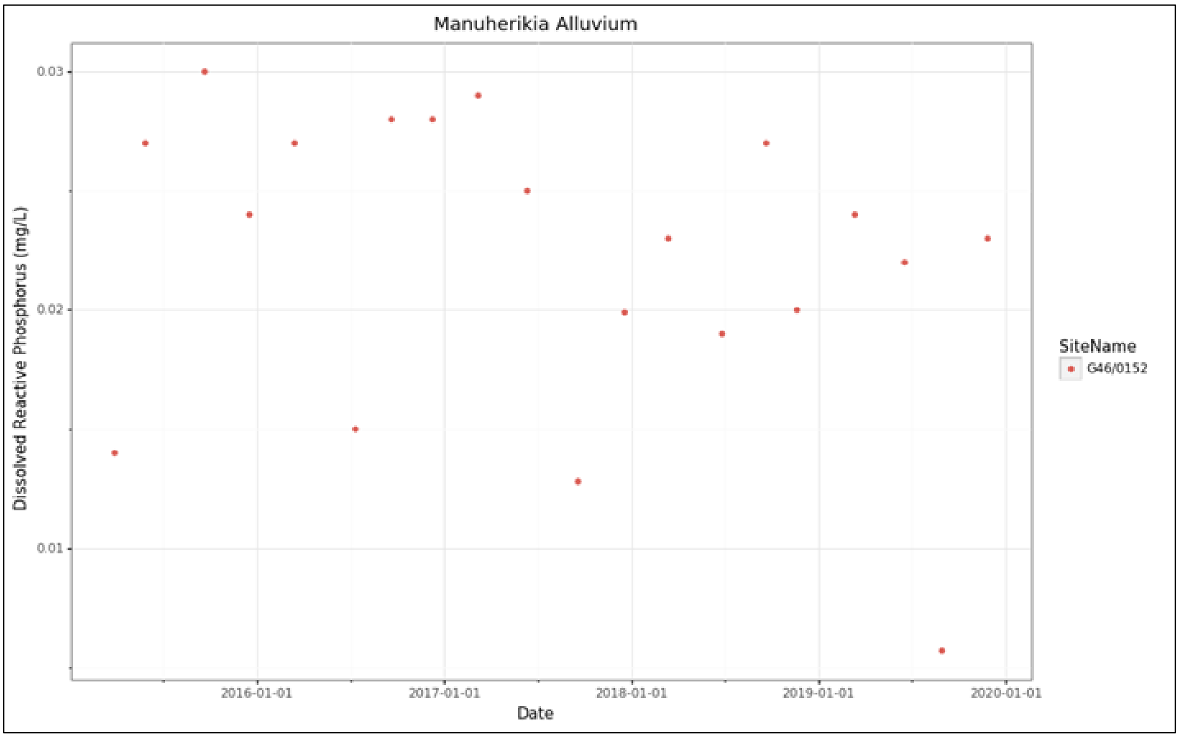


Figure 70: Groundwater Dissolved Reactive Phosphorus concentrations for the Manuherekia Alluvium Aquifer



Bore G46/0152 is located in Group 2 of the RPW's Schedule 15. The 80th percentile concentrations for nitrate, DRP, and ammonia were assessed against Schedule 15 of the RPW, Table 29. The nitrate and DRP concentrations are non-compliant with the Schedule 15 limits, exceeding the threshold by approximately 16 and 2.7 times, respectively (Figure 70). This suggests potential impacts on connected surface water. Conversely, the ammonia concentrations are below the Schedule 15 limits.

Table 29: Results for comparison with Schedule 15 limits for nitrate, DRP, and ammonia

Bore number			**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)			**0.075**	**0.010**	**0.100**
G46/0152	Manuherekia	Manuherekia Alluvium	1.216	0.027	0.005

The comparison against the NPS-FM NOF is shown in Table 30. The DRP and nitrate data shows some potential concerns. The DRP median concentration is in band D, below the National Bottom Line, where ecological communities are impacted by substantial DRP concentrations above natural reference conditions. Combined with other conditions that favour eutrophication, DRP enrichment stimulates excessive primary production and significant changes in fish and macroinvertebrate communities, as taxa that are sensitive to hypoxia are lost (MfE, 2020). The median nitrate concentrations are in Band B, where there are some growth effects on up to 5% of species, although this band still provides for a good level of protection with some minor effect on growth rate of the most sensitive species (Hickey, 2013; ORC, 2017a). In contrast to these, the ammonia median and maximum concentrations are both in Band A, which provides 99% species protection level with no observed effect on any species (MfE, 2020).

Table 30: NPS-FM NOF comparison summary for the Manuherekia Alluvium Aquifer

	Nitrate		NOF Band		
Bore no.	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile	
G46/0152	1.1	1.341	A	B	A
	Ammoniacal nitrogen		NOF Band		
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum	
G46/0152	0.0025	0.017	A	A	
	DRP		NOF Band		
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile	
G46/0152	0.0235	0.02905	D	B	

4.2.5.3 The Manuherekia Claybound aquifer

4.2.5.3.1. Aquifer information

The Manuherekia Claybound Aquifer is located north of the Alexandra township. The aquifer is bound to the east by the Manuherekia River channel, north/west by the Dunstan Mountains/Leaning Rock Range, north by McArthur Gully and Springvale Creek, which drain the Leaning Rock Range. It is bound to the south/south west by the Dunstan Flats Aquifer where the boundary is marked along the stream/race that flows along Dunstan Road. Apart from the Manuherekia River, which forms the aquifer's southeastern boundary, the only natural surface water body that crosses it is the Waikerikeri Creek. Due to the combination of the dry climate, high evaporation, and permeable outwash gravels which prevent surface runoff and flow there are no perennial surface water bodies found in the Airport Terrace or Letts Gully parts of the aquifer.

The aquifer can be roughly divided into a northern and southern parts where Springvale Road serves as a boundary. The northern part of the aquifer, to the north of Springvale Road, is drained by the Waikerikeri Creek which flows south from the Dunstan Mountains and empties into the Clutha south of the SH8/Mutton Town Road confluence. There are generally very few bores in this part, apart from a group of bores near the gorge/terrace of the Waikerikeri Creek south of Glen Atholl. The southern part of the aquifer is drained by the Tumatakuru Creek and McArthur Gully which also drain the Dunstan Mountains during rain storms. These creeks flow to the south, where drainage is divided between these and the Waikerikeri Creek by the ridge north of bore G42/0462. Although many of these are likely to be ephemeral, their flowing direction is to the southeast, towards the Manuherekia River.

The area comprises of two distinct groups of formations: The Lindis outwash formation composes the Airport Terrace and Letts Gully Road area, south of Springvale road. The second formation is composed of less distinct landforms such as the older Waikerikeri fans situated to the north. The aquifer was named in 1998 to distinguish it from the high permeability outwash of the Dunstan Flats and the lower permeability outwash of the Lindis advance sediments. The “Claybound” term potentially originated from bore logs north of Springvale Road, where a wide variability of sediment sizes was “lumped” into a single lithological description (i.e. “claybound”).

Groundwater exploration north of Springvale Rd encountered pervasively silty, significantly thick weathered gravels and moderate depth to the water table. Pumping tests associated with vineyard development indicated hydraulic conductivity of around 1m/d, which is substantially lower than the Dunstan Flats. This can be potentially attributed to geochemical alteration (weathering) of non-quartz components of the outwash which enriches the weathered material with finer silts/clays and reduces its permeability. In contrast to that, bore logs indicate that the Letts Gully Road area, situated near the Dunstan Flat aquifer and the Clutha River has more permeable sediments with less silt and clay within gravel deposits. The water table is relatively deep in the area, ranging between around 40 and 65m below ground level. However, water tables in bores near the Waikerikeri Creek terrace/Glen Athol are shallower, at around 20m below MP (ORC, 2018b).

According the database there are 111 completed bores within the Manuherekia Claybound Aquifer. Total depth information is available for 95 of those, with bore depths ranging from 1.7 to 70.95m. 58 of these bores (i.e. 61%) are deeper than 30m. SWL information is available for 61 bores, with the reported SWL ranges between 1.07 and 63.23m. Screen depth information is available for 26 bores, and is ranging between 5.05 and 68.38m. The main groundwater uses in the aquifer are domestic, stockwater, community supply and irrigation. Two bores hold a groundwater take consent.

4.2.5.3.2 Groundwater quality monitoring results

Groundwater quality in the Manuherekia Claybound Aquifer is monitored in two SoE bores. Bore no. G42/0123 (100mm diameter) is located at Letts Gully Road, NZTM E1317225 N4987272. The bore depth is 32.40m. There is no lithological log or screen information available for the bore. The data for bore G42/0123 shows that groundwater levels in the bore range between 25.92 and 27.84m below MP with a seasonal fluctuation of between 1.0 and 1.5m. The lowest groundwater levels are generally measured in September and/or December, with a recovery in March, indicating that groundwater levels are strongly impacted by irrigation recharge. The data suggests that the groundwater levels in the bore are falling, with lower recovery in levels than was measured during the start of monitoring. However, this can be due to increased irrigation efficiency, which reduces recharge (ORC, 2012c).

Bore G42/0290 (100mm diameter) is located at Springvale Road, at NZTM E1318011 N4988269. The total bore depth is 16.1m. There is no lithological log or screen information available for this bore. Groundwater levels were quarterly monitored in the bore since March 2015. Groundwater levels in bore G42/0290 range between 15.51 and 16.57m below MP, with a seasonal fluctuation of around 1m. Similar to bore G42/0123 and the data from the Manuherekia Alluvium Aquifer, the lowest levels are also in September with a recovery during December/March, suggesting substantial irrigation recharge. Similar to the data from bore G42/0123, water levels and recovery in this bore also seem to be falling, potentially attributed to more efficient irrigation (ORC, 2012c). It is worthy to note that the Manuherekia Irrigation Scheme water races, which have a known history of leakage, run in proximity to bores G42/0123 and G42/0290.

The comparison of groundwater quality results against the DWSNZ shows that none of the samples in either bore exceeded the dissolved arsenic MAV of 0.01mg/L (Figure 71). There were also no E. coli results which exceeded the MAV (

Figure 72). Nitrate concentrations in both bores are substantially below the 11.3mg/L MAV. The concentrations in bore G42/0290 range between 1.5 and 2.7mg/L. The concentrations in bore G42/0123 range between 0.0 and 1.180mg/L (Figure 73). These concentrations only slightly exceed the value for natural groundwater in New Zealand (Daughney and Morgenstern, 2012). The ammonia concentrations are below the GV of 1.5mg/L (

Figure 74). These results suggest that there are no potential risks to drinking groundwater quality from these bores.

Figure 71: Groundwater dissolved arsenic concentrations for the Manuherekia Claybound Aquifer

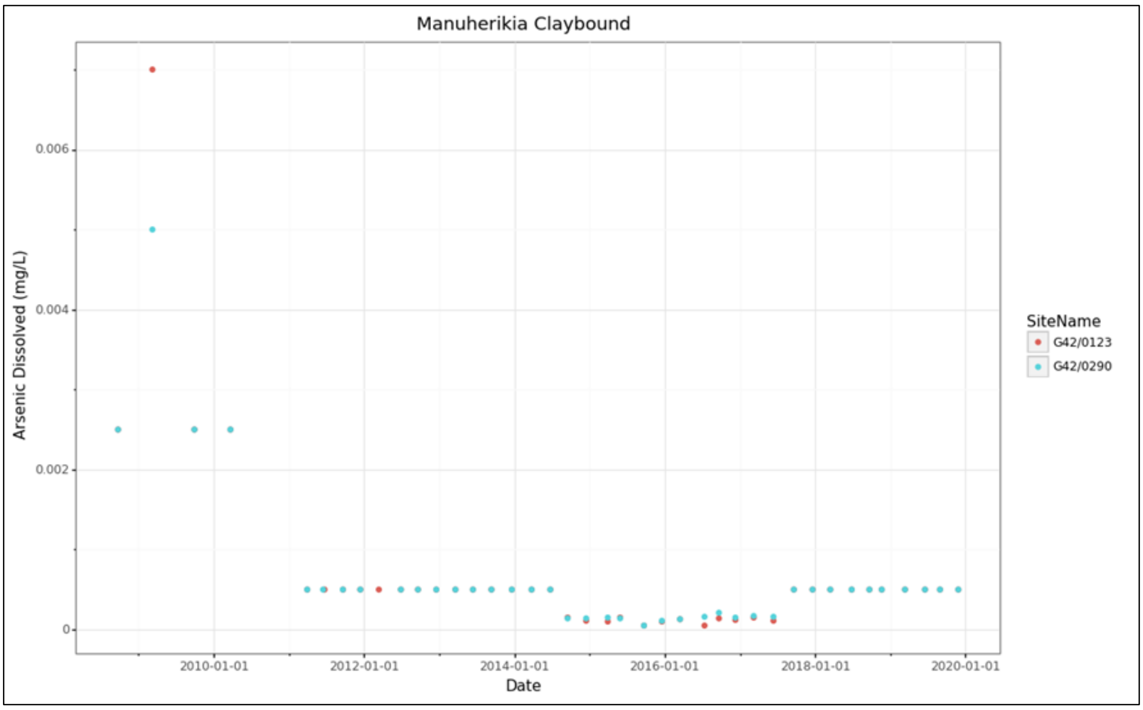


Figure 72: Groundwater E. Coli count for the Manuherekia Claybound Aquifer

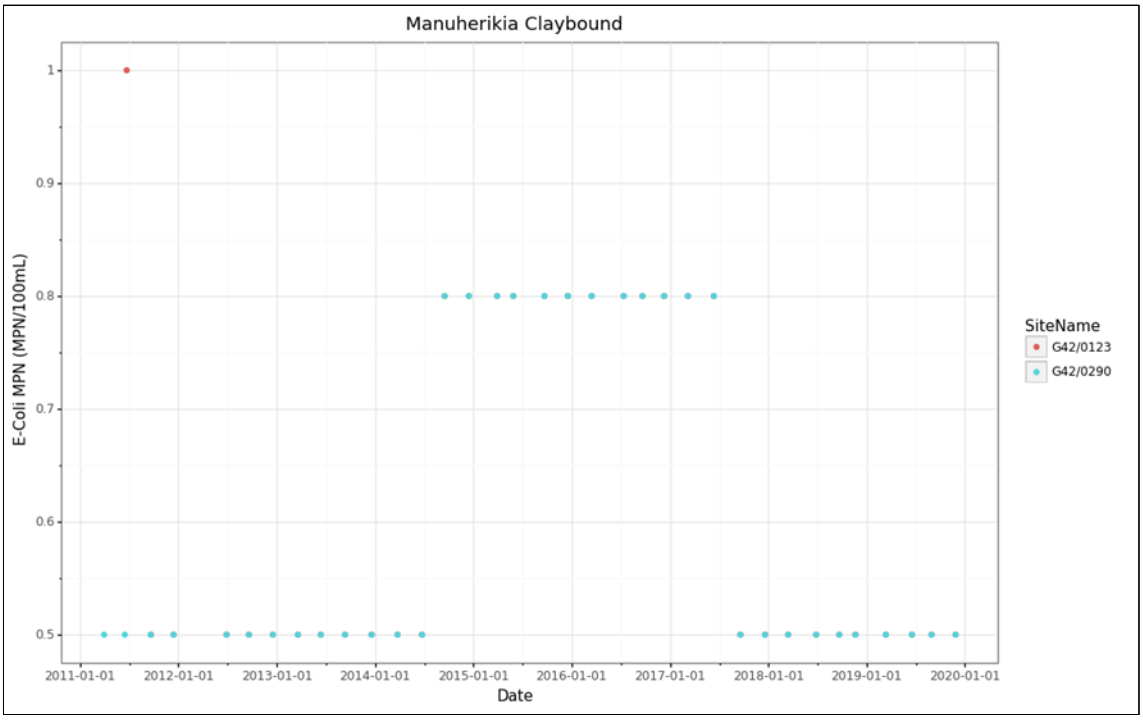


Figure 73: Groundwater nitrate concentrations for the Manuherekia Claybound Aquifer

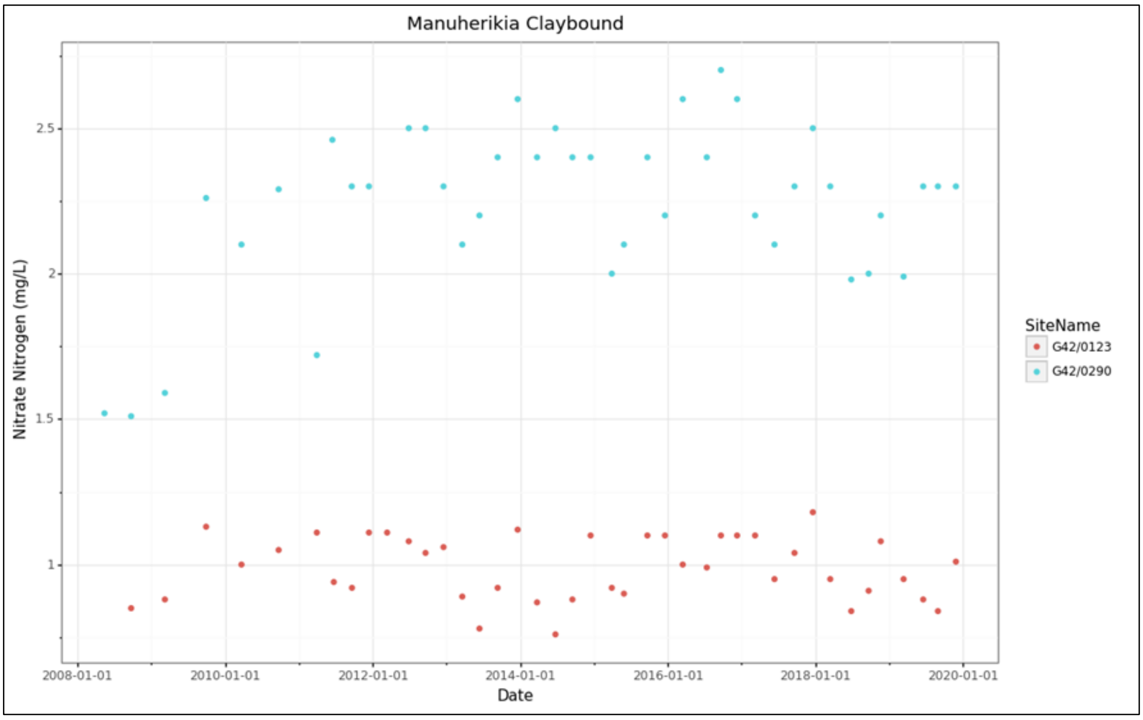


Figure 74:Groundwater ammonia concentrations for the Manuherekia Claybound Aquifer

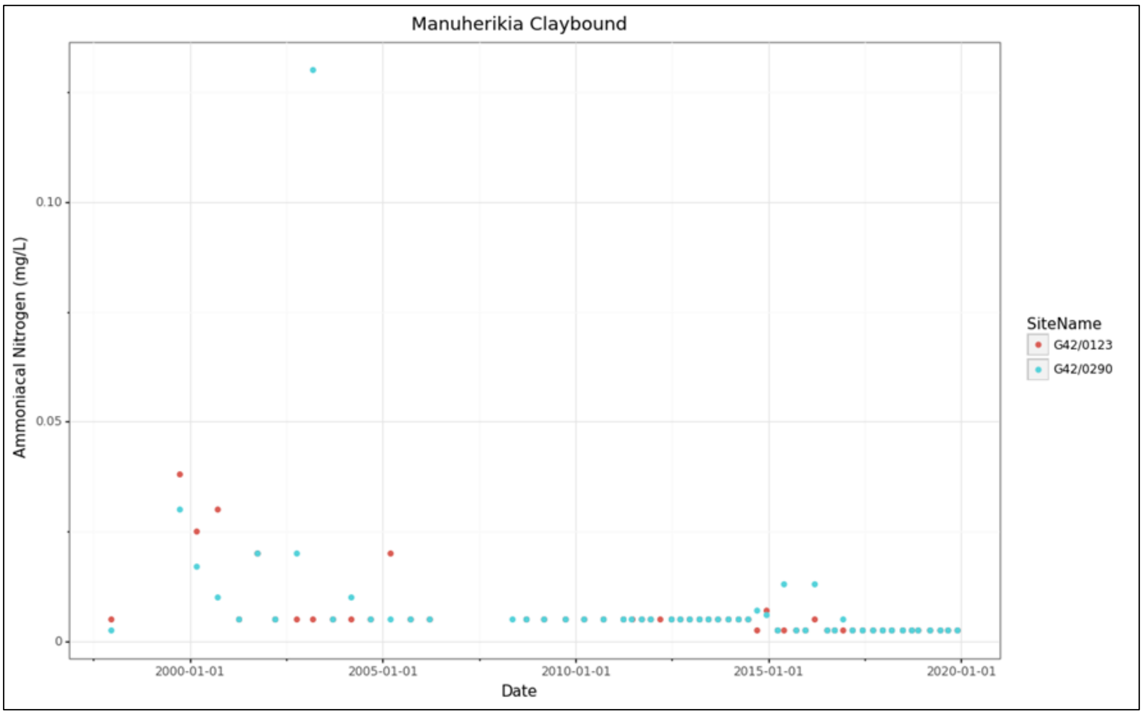
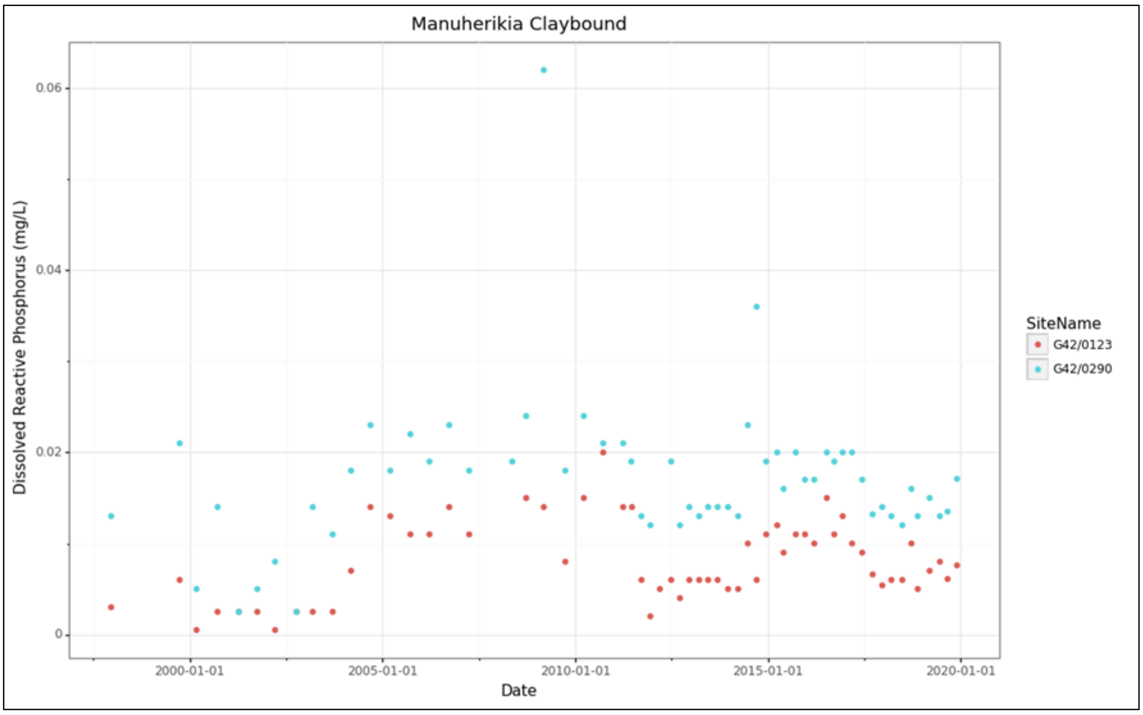


Figure 75: Groundwater Dissolved Reactive Phosphorus concentrations for the Manuherekia Claybound Aquifer



The results were then assessed against the RPW and NPS-FM to determine any potential impacts on surface water quality. Bore G42/0123 was excluded due to its depth. Bore G42/0290 is located in Group 2 of Schedule 15. The results show noncompliance with the limits, with 80th percentile nitrate and DRP concentrations at 32 and twice the limits, Table 31. There were also high DRP results of 0.038 and 0.065mg/L, with most results ranging between 0.01 and 0.0125mg/L (Figure 75). The nitrate and DRP results show an increase between approximately 2000 and 2005, followed by stable concentrations until 2015, where they slightly fell. The 80th percentile ammonia concentrations are within the Schedule 15 limits. The nitrate and DRP concentrations from the bore suggest potential impacts on surface water quality. The bore is located near a surface water feature that flows to the southeast, towards the Manuherekia River.

Table 31: 80th percentile values for water quality variables identified in Schedule 15.

Bore number		**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)		**0.075**	**0.010**	**0.100**
G42/0290	Manuherekia Claybound	2.460	0.020	0.010

Groundwater quality results were also analysed against the NPS-FM NOF attributes,

Table 32. The median and 95th percentile nitrate concentrations are both in Band B, where some growth effects are expected on 5% of the species. The median and 95th percentile DRP concentrations are in Bands C and B, respectively. Band C indicates an impact on ecological communities by DRP concentrations that moderately exceed natural reference conditions. If combined with other factors that increase eutrophication, DRP enrichment can cause increased algal/plant growth, loss of sensitive macro-invertebrates and fish taxa, alongside high respiration and decay rates. The median and maximum ammonia concentrations are in Band A and B, respectively. Band B provides 95% species protection level for toxicity, where impacts on the most sensitive 5% occur occasionally (MfE, 2020).

Table 32: Manuherekia Claybound Aquifer NOF comparison for nitrate, ammonia, and DRP

	Nitrate		NOF Band	
Bore no.	median (mg/L)	95th percentile (mg/L)	median	95th percentile
G42/0290	2.3	2.6	B	B
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
G42/0290	0.005	0.13	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G42/0290	0.017	0.024	C	B

4.2.6 The Lower Clutha Rohe

The Lower Clutha rohe runs from the Roxburgh Dam to the Clutha River mouth south of Balclutha. The region includes the catchments of the Pomahaka (2,060km^2), Waitahuna (406km^2), Waipahi (339km^2), Tuapeka (249km^2), and Waiwera (208km^2) rivers. In contrast to the Upper and Mid Clutha regions, the lower Clutha is dominated by alluvial plains, rolling hill country and lowlands. The Roxburgh and Ettrick rohe are located in Central Otago. The South Otago basin includes four aquifers: the Pomahaka, Clydevale, Wairuna, and Kuriwao, of which the first two contain current SoE monitoring bores (ORC, 2014d). However, aquifers in this area have been reviewed several times and some of these are not found in the RPW. The rohe also includes the Inch Clutha gravel aquifer, located near the Clutha mouth.

Groundwater quality results from the Lower Clutha rohe indicate some significant water quality issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. Among the identified factors in degraded water quality in southwest Otago are the wide-spread use of artificial paddock drainage and shallow water tables. One of the bores in the Inch Clutha gravel aquifer has elevated arsenic concentrations above the MAV and high DRP concentrations. The results also show issues with elevated nitrates and DRP (Table 33 and Table 34), with concentrations in most shallow bores exceeding the Schedule 15 limits and NOF bands. Some of these issues are due to shallow monitoring bores that are not properly secured. These results also support surface water quality results from this area, which are generally poor (ORC, 2017a). The median results for the DWSNZ and ecosystem health parameters are shown in

Table 35.

Table 33: 80th percentile values for Schedule 15water quality variables for the Lower Clutha rohe

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Clutha	Lower Clutha	Inch Clutha	0.282	0.270	0.013
G44/0127	Clutha	Lower Clutha	Pomahaka Alluvial	5.020	0.015	0.010
G44/0136	Clutha	Lower Clutha	Pomahaka	0.050	0.099	0.016
G43/0224b	Clutha	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G43/0009	Clutha	Lower Clutha	Ettrick	4.960	0.013	0.010
G43/0072	Clutha	Lower Clutha	Roxburgh	5.320	0.010	0.011

Table 34: Lower Clutha rohe NOF comparison for nitrate, ammonia, and DRP

	Nitrate concentration (mg/L)		NOF Band	
Bore no.	median (mg/L)	95th percentile (mg/L)	median	95th percentile
G44/0127	4.1	5.9455	C	C
G44/0136	0.005	0.05	A	A
G43/0009	4.6	5.52	C	C
G43/0224b	7.9	8.66	D	C
G43/0072	5	5.5	C	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G44/0127	0.005	0.056	A	B
G44/0136	0.012	0.023	A	A

G43/0009	0.005	0.38	A	B
G43/0224b	0.0025	0.062	A	B
G43/0072	0.0025	0.113	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile (mg/L)
G44/0127	0.011	0.0325	C	C
G44/0136	0.019	0.1146	D	D
G43/0009	0.009	0.0198	B	A
G43/0224b	0.002	0.03195	A	C
G43/0072	0.006	0.012	B	A

Table 35: Median concentrations for DWSNZ/ecosystem health parameters for the Lower Clutha rohe

Aquifer	Ammonia (mg/L)	Dissolved Arsenic (mg/L)	DRP (mg/L)	E-Coli (MPN/100mL)	Nitrate (mg/L)
Clydevale	0.0200	0.0005	0.0110	0.5000	0.0050
Ettrick	0.0025	0.0005	0.0074	0.5000	4.9000
Inch Clutha	0.0185	0.0025	0.2100	0.5000	0.1000
Pomahaka	0.0120	0.0011	0.0190	0.5000	0.0050
Pomahaka Alluvial Ribbon	0.0050	0.0005	0.0110	0.5000	4.1000
Roxburgh	0.0060	0.0005	0.5000	4.4000	5.0000

4.2.6.1 The Roxburgh basin

4.2.6.1.1 Aquifer information

The Roxburgh basin is located in Central Otago and is defined by an alluvial terrace situated between the Roxburgh township to the south and the Roxburgh dam to the north. The terrace is almost entirely bound by the schist which makes up the Knobbly Range in the east and the Old Man Range in the west. The basin is underlain by fairly impermeable Haast schist and its shape was formed by a series of major north-south trending faults and folds located throughout the basin. Across Central Otago, the basement rocks are, in places where faulting or folding has protected them from erosion, overlain by non marine Miocene quartz conglomerate, sandstone, mudstone, and lignites of the Manuherekia group. Within the Roxburgh area, this group is represented by lignite and fine-grained muddy sediments. These are relatively impermeable and effectively form the base of the water bearing zones in the overlying Quaternary gravels. The aquifer consists of Quaternary glacial outwash, alluvial fans and tailings containing sand, silt, and gravel. These sediments were deposited by the Clutha River following a series of glacial periods and they form the terraces seen today. Adjacent to the foothills are alluvial fan deposits consisting of gravel intercalated with boulder clay. There are also man made tailing (sluicing) deposits of well sorted sands and gravels that make up the terraces' southwestern boundary (ORC, 2014c).

The Clutha River dissects the basin and separates it into two aquifers: Roxburgh East and West, with areas of 13.6km^2 (east) and 0.4km^2 (west), respectively. The shallow geology of the Roxburgh East area is comprised of unconsolidated Pleistocene outwash gravels, moraine, and glacial till. The aquifer boundaries were defined based on topography, and is assumed to be limited to sediments that were accumulated between the Clutha in the west and the mountain ranges to the east. The aquifer sediments are overlain by patches of thin, recent auriferous stream alluvium along the Clutha bank. There are reports of coal seams within the Roxburgh East outwash gravels, although these are more likely to be found in the underlying basement rocks. The aquifer area is surrounded by outcropping schist basement. Two subparallel north-south striking faults were mapped within the schist terrain adjacent to the Roxburgh Dam north of the aquifer area. These faults were not mapped as extending into the aquifer area itself although this possibility cannot be ruled out as the surface expression of these structures may be masked by the unconsolidated Pleistocene deposits (ORC, 2014c).

The Roxburgh West area is located at the western edge of the tectonically formed Roxburgh basin, in a narrow zone between the Clutha and the steep, east-facing slopes of the Old Man Range. The Roxburgh West aquifer consists of Quaternary river alluvium gravels locally intercalated with boulder gravels of alluvial fan origin that overlie schist basement rock. The maximum thickness of the gravel aquifer is around 25-30m. The configuration of the basement rock schist ‘bench’ is not known, but is assumed to generally slope gently eastward toward the Clutha. The aquifer thins out towards the west, with only a thin veneer of gravels potentially overlying schist close to the western margin of the aquifer. The Quaternary gravels contain an unconfined aquifer, representing a single hydrologic unit, although there are probably preferential flow paths, e.g. through alluvial fan deposits. The eastern aquifer margin is exposed on the banks of the Clutha (Irricon, 1997). Bore logs from the area indicate that it is dominated by silty/sandy gravels, with some gravel layers reported as containing boulder. There are also minor interlayers of clay and sandy clay. The depth of the unconsolidated deposits, which are likely to represent glacial outwash, exceeds 19.8m in three of the bores. The log for the southernmost bore (G43/0111), located on the Clutha bank, reports shallow schist basement rock at 1.1m. The depth to bedrock increases to the north, reaching 20.3m in bore G43/0126 (ORC, 1999a). Information based on mineral investigations from the early 2000s and more recent 2018 – 2020 exploration by Central Otago District Council points to a central, north-south trending paleo-channel being the primary zone of active groundwater flow in the Roxburgh West aquifer. The deepened outwash sandy gravel within the paleo-channel tends to have elevated hydraulic conductivity and saturated thickness, and hence channelises local groundwater flow.

According to the database there are 29 bores in the Roxburgh aquifer area, although the completion status for most is marked as blank. Depth information is available for 23 bores, with depths ranging between 1.2 and 35m. There is reported SWL for 10 bores, which ranges between 4.75 and 18m. Screen information is only available for one bore, G43/0222, which is screened between 13.24 and 16.14m. The main uses include domestic, irrigation, and industrial.

4.2.6.2 Groundwater quality monitoring

There is currently one groundwater quality SoE bore monitored in the Roxburgh Basin, G43/0072 (150mm diameter). The bore is situated in a paddock 150m west of SH8 at NZTM E1310456 N4954944, approximately 5km north of the Roxburgh township. The total bore depth is 16.8m and there is no bore log or screen information available.

The comparisons of groundwater quality results against the DWSNZ shows that there were no exceedances of the E. coli (Figure 76) or dissolved arsenic (Figure 77) MAVs. Groundwater nitrate concentrations range between 3.4 and 5.5mg/L (Figure 78). These concentrations are lower than the DWSNZ MAV of 11.3mg/L, although the higher concentrations are approximately at ½ of it. There were also no ammonia concentrations that exceeded the GV of 1.5mg/L (Figure 79). The results suggest that, in relation to the drinking quality standard, there are no groundwater quality issues in the bore although it is prudent to watch the nitrate concentrations.

Figure 76: Groundwater E. Coli count for the Roxburgh Basin

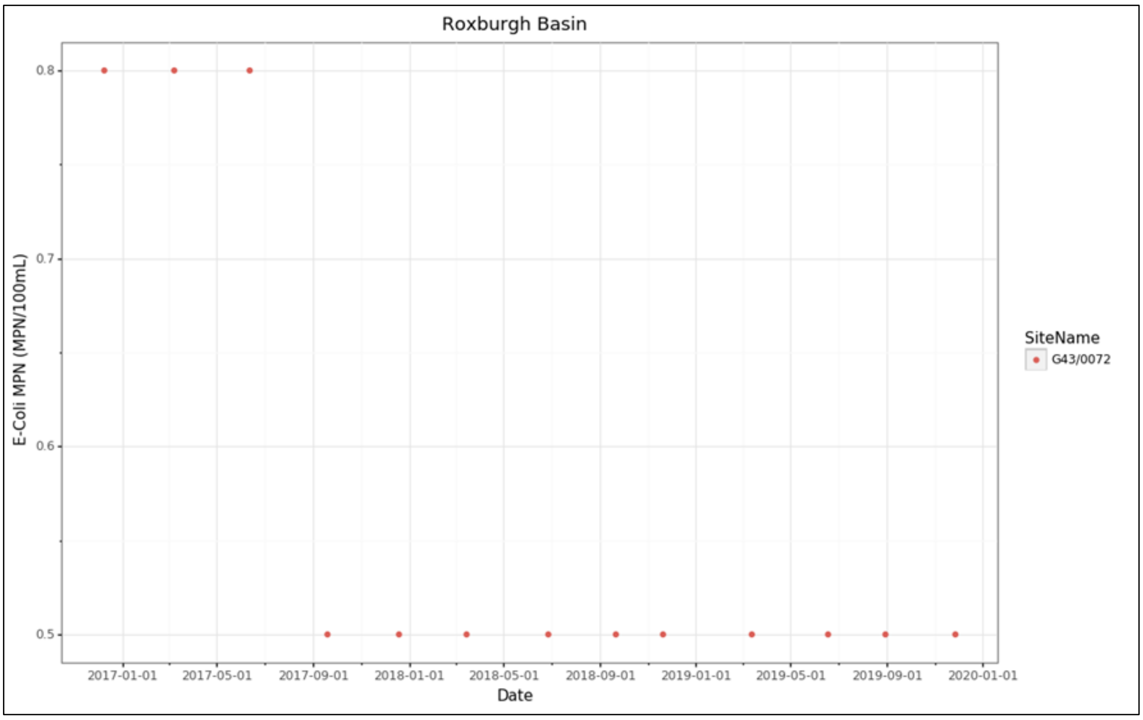


Figure 77: Groundwater dissolved arsenic concentrations for the Roxburgh Basin

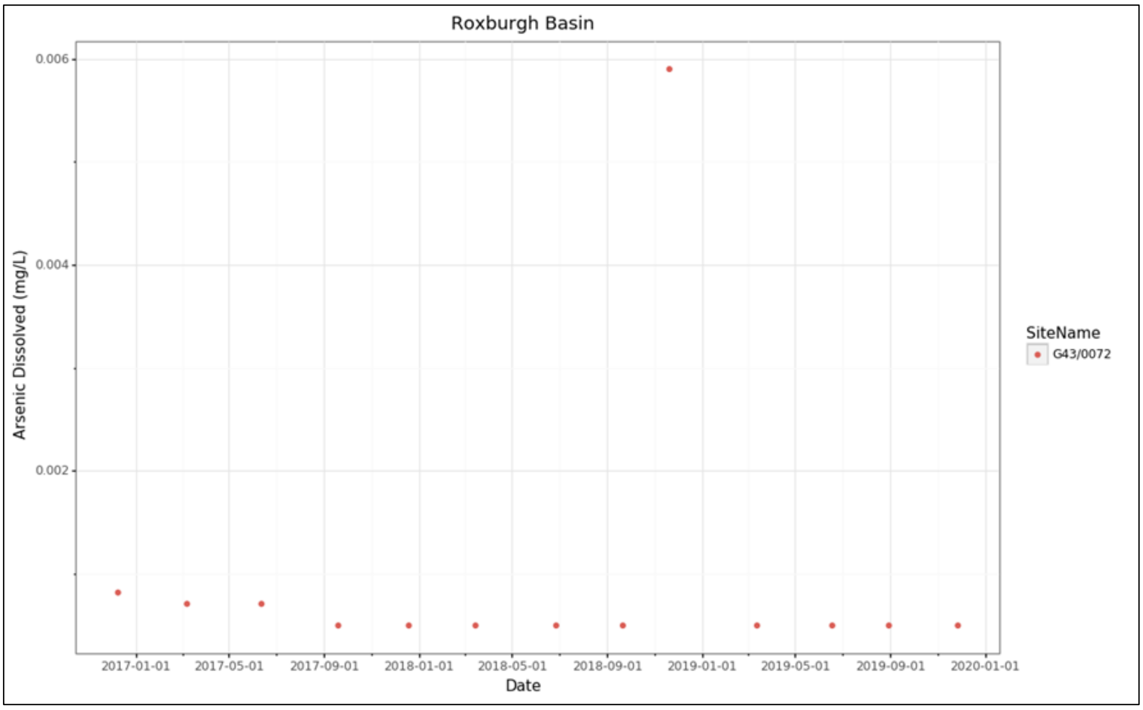


Figure 78: Groundwater nitrate concentrations for the Roxburgh Basin

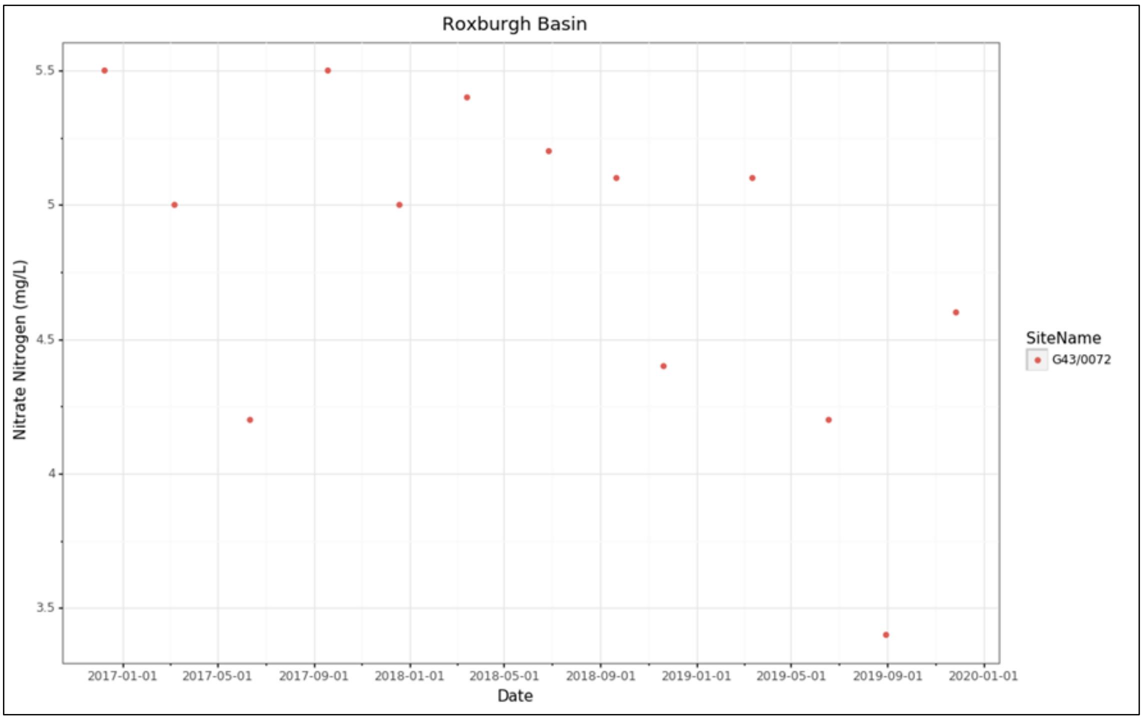


Figure 79: Groundwater ammonia concentrations for the Roxburgh Basin

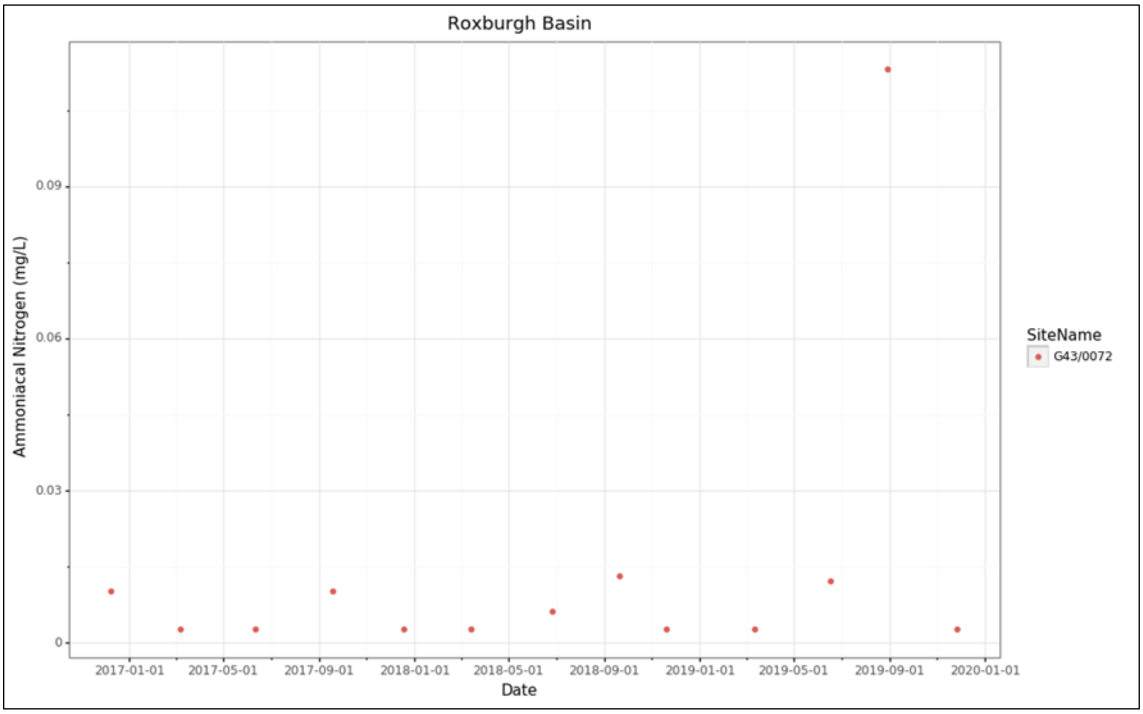
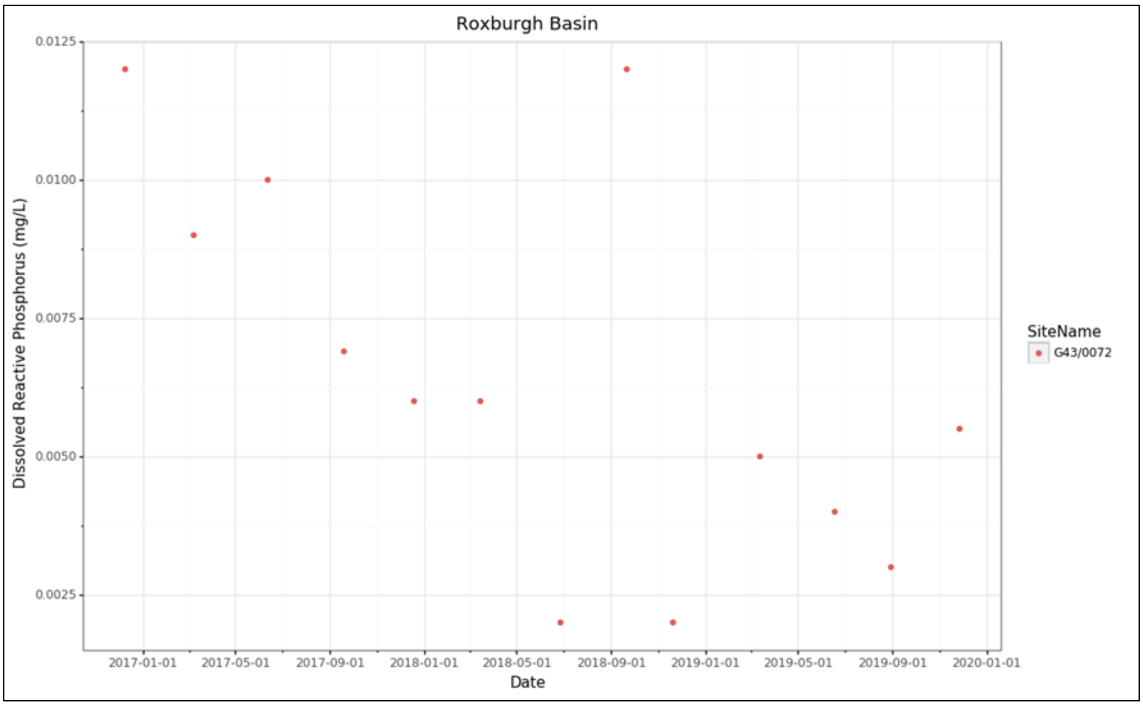


Figure 80: Groundwater Dissolved Reactive Phosphorus concentrations for the Roxburgh Basin



The groundwater quality results were also compared against the RPW (Table 36) and the NPS-FM NOF (Table 37). The Roxburgh monitoring bore, G43/0072, is located in Group 2 of Schedule 15. The results show that the 80th percentile nitrate concentrations are approximately 70 times the Schedule 15 limits. The DRP 80th percentile concentrations is at the Schedule 15 limit (Figure 80). Conversely, ammonia concentrations are below the limit.

Table 36: 80th percentile values for water quality variables identified in Schedule 15.

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G43/0072	Clutha	Lower Clutha	Roxburgh	5.320	0.010	0.011

The results were then assessed against the NPS-FM NOF, Table 37. Both the median and 95th percentile for nitrate are in Band C, with growth effects on up to 20% of species (mainly sensitive ones such as fish), with no acute effects (MfE, 2020). The median and maximum ammonia concentrations are A and B, respectively, with Band B providing 95% species protection level, with an occasional initial impact on the 5% most sensitive species (MfE, 2020). The median and 95th percentile for DRP are in Bands B and A, respectively. Ecological communities are slightly impacted by minor DRP elevation above natural reference conditions in Band B. If there are additional conditions that favour eutrophication sensitive ecosystems may experience additional plant/algal growth, loss of sensitive macroinvertebrate taxa and higher decay and respiration rates (MfE, 2020). These results indicate potential issues with surface water quality, particularly regarding nitrates and DRP.

Table 37: NOF comparison for nitrate, ammonia, and DRP for the Roxburgh basin

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G43/0072	5	5.5	C	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
G43/0072	0.0025	0.113	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G43/0072	0.006	0.012	B	A

4.2.6.3 The Ettrick Basin

4.2.6.3.1 Aquifer information

The Ettrick basin is a sedimentary basin beneath the Ettrick Flats on both sides of the Clutha, which includes the lower reaches of the Benger Burn and Ettrick township. The basin area is 14.3km^{2}and is comprised of an unconfined Quaternary alluvium aquifer underlain by a thick mudstone sequence of the Tertiary Manuherekia Group coal measures which lies on the impermeable basement schist rock. The schist bounds the western and southern boundaries (ORC, 1995).

The basin is a sediment-filled topographic depression formed as a result of movement on a normal fault at its western boundary (a “half-graben”). In the case of the Ettrick Basin, the schist hills in the west moved upward while the schist basement rocks below the basin moved down. This early Pleistocene displacement allowed the preservation of the Miocene coal measures. Subsequent Pleistocene glacial outwash sedimentation over time created the Ettrick outwash terraces encountered today.

Bore log data indicate that the unconfined aquifer is between 4 and 30m thick and is comprised of boulders, cobbles, sandy gravels, silty gravels and clay bound gravels, which are interfingered with silt and clay lenses. The aquifer is around 30m thick along the western boundary (adjacent to the schist outcrop) and thins to around 4m in the east as it approaches the Clutha. However, the saturated aquifer thickness is only between 4 and 11m. The aquifer water balance is dominated by the Clutha and Benger Burn. The Clutha is the main discharge zone for the aquifer (i.e. groundwater flows from west to east towards the Clutha). The Clutha probably does not play a major role in groundwater recharge, apart from episodic flood events. However, these are not sufficiently predictable nor regular to be included in the aquifer water balance (ORC, 2014c).

The Benger Burn is another main source of recharge for the aquifer. The Burn is located in the rain shadow of the Umbrella Mountains and the upper Pomahaka, and is generally drier than the catchments to the south and west. However, its annual rainfall of 650-750mm in the hills and 600-650mm on the flats still exceeds the median rainfall of other catchments further north in Central Otago. Due to aspect and higher altitude the upper reaches of the North branch of the Burn receive higher annual rainfall than the South branch. The Burn loses a significant amount of water to the Ettrick Basin aquifer where it first meets the alluvial gravels on the flats. In order to gain a better understanding of natural gains and losses in the lower reaches, two flow stations were installed in the Benger Burn in December 2011: Benger Burn Booths is located us stream within the schist foothills west of the basin. The other station, Benger Burn @ SH8 is positioned downstream, near the Burn/Clutha confluence (ORC, 2014c).

The data shows that, despite a baseflow of 60L/s at the (upper) Booths flow site, there was no surface flow at SH8 during the latter part of the irrigation season. However, although irrigation takes account for some of this loss, it is difficult to determine their impact due to issues with water metering. Furthermore, flow losses of >100L/s were observed during April/May 2013. These are not likely due to irrigation, which usually does not occur during these months. The data also shows gain in flow during winter and spring, likely due to increased flow from the southern branch of the Burn, which enters the main stem between the two gauging stations. Due to a combination of low rainfall and losses to groundwater in its lower reaches, the South Branch does not significantly contribute to surface flows in the Benger Burn during the irrigation season. The difference in the flow between the two sites does not only show changes in flow between the two sites, but also provides insight into the Burn’s contribution to the groundwater system. Some of the losses to the aquifer are probably associated with the lower reaches of the South Branch of the Burn, although there is no gauging data to support it. Most of the observed flow losses are probably recharging the aquifer, making the Burn a main source of the Ettrick basin. It is also likely that groundwater takes will further induce the loss of surface water from the Burn during the irrigation season (i.e. aquifer levels will fall and steepen the hydraulic gradient and induce further losses from the stream) [ORC, 2014c].

4.2.6.3.2 Groundwater quality monitoring

Groundwater quality in the Ettrick basin is monitored in two SoE bores. Bore G43/0009 (100mm diameter) is located southeast of the SH8-Clutha Road intersection, at NZTM E1317341 N4939478. The bore depth is 15.2m. There is no available bore log or screen depth information for this bore.

Bore G43/0224b (50mm diameter) is located at Marsh Road, approximately 1.13km west of the Clutha River, at NZTM E1316403 N4941145. The bore was drilled in 2017 as part of ORC’s Ettrick Basin investigation. The bore log describes sand to 1.0m underlain by fine to coarse sand and gravels with a trace of silt to 5m. There is then gravels which coarsen with depth to 21.9m. The gravels are then underlain by mudstone to 22.17m. The bore contains two piezometers, both of which are screened in the gravel horizon. The shallower piezometer, G43/0224a, is screened between 9.73m and 12.73m and the deeper, G43/0224b, is screened between 17.33 and 20.33m. This bore was drilled for an ORC groundwater investigation project, during which it was sampled monthly between February 2017 and June 2018, after which the sampling became quarterly.

Groundwater quality results from the SoE bores were compared against the DWSNZ. The results show several E. coli exceedances in both bores, with a maximum of 18 MPN/100mL

(May 2017 and March 2019), Figure 81. Groundwater nitrate concentrations in both bores are below the DWSNZ MAV of 11.3mg/L. However, the concentrations in bore G43/0224b are high, ranging between approximately 6.9 and 9.1mg/L, where the upper end is near the MAV. The concentrations in bore G43/0009 are above the concentrations for natural groundwater (<2.5mg/L, Daughney and Morgenstern, 2012), ranging between 3.62 and 6.5mg/L, which exceed ½ of the MAV of 11.3mg/L (

Figure 82). There were no exceedances of the dissolved arsenic MAV in neither bore (Figure 83). There are no ammonia concentrations that exceed the GV of 1.5mg/L (

Figure 84).

Figure 81: Groundwater E. Coli count for the Ettrick Basin

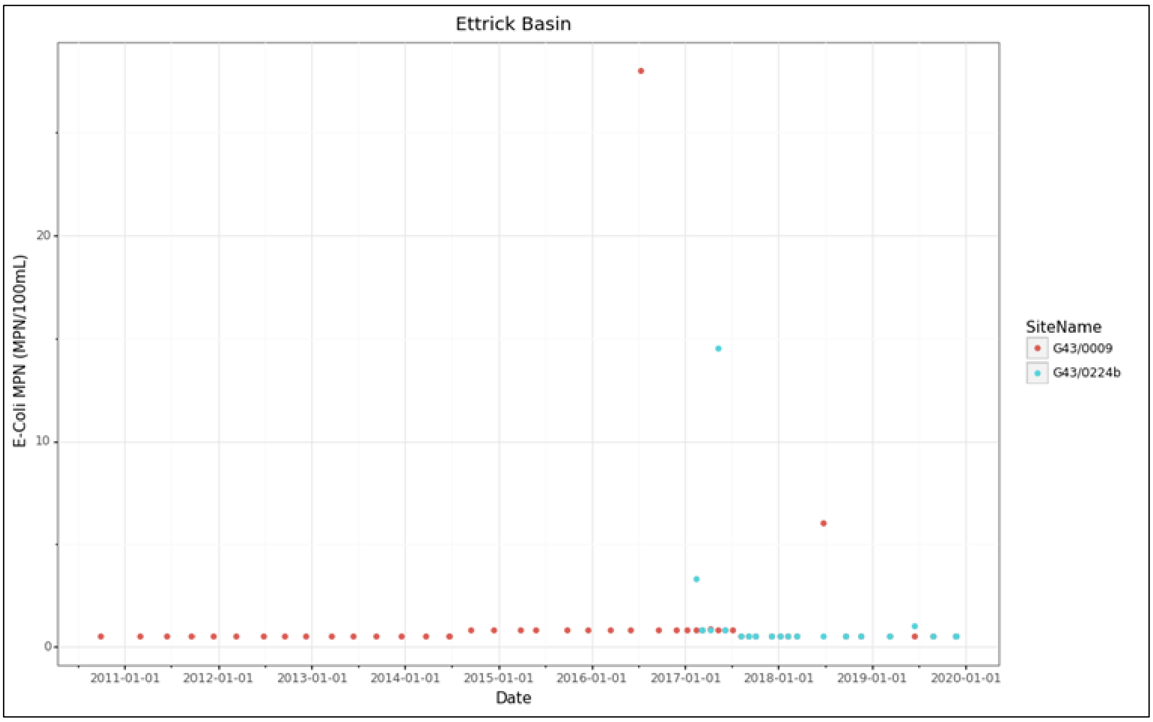


Figure 82: Groundwater nitrate concentrations for the Ettrick Basin

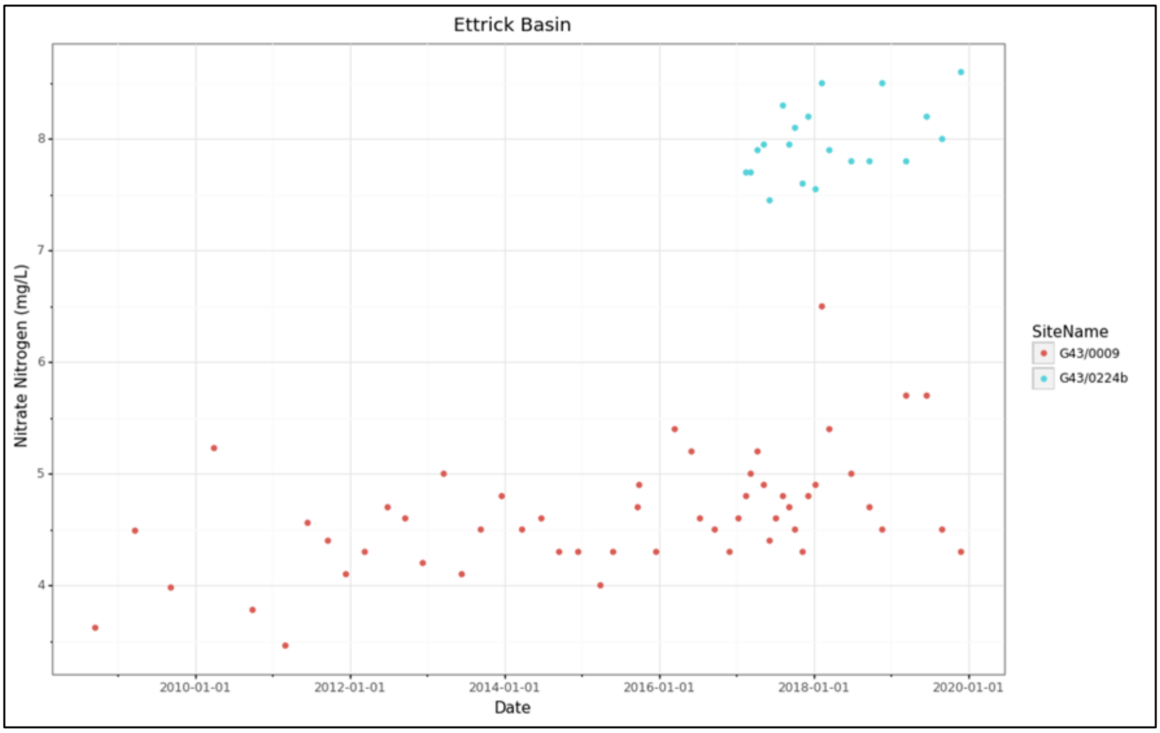


Figure 83: Groundwater dissolved arsenic concentrations for the Ettrick Basin

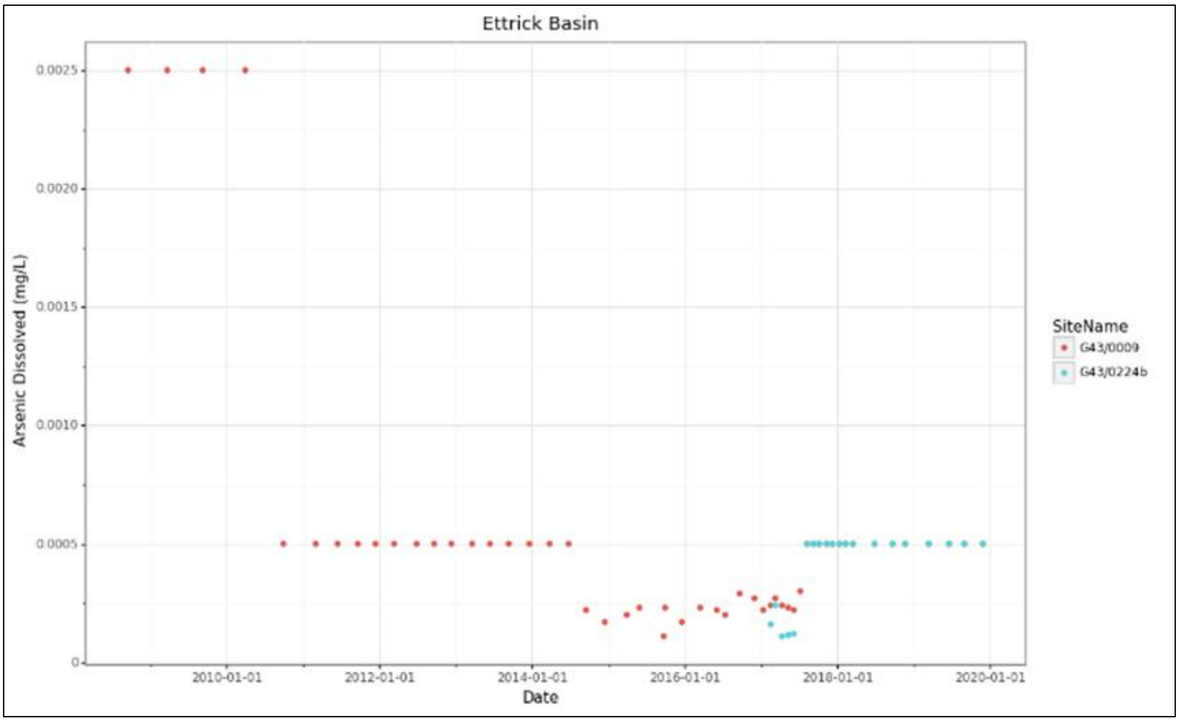


Figure 84: Groundwater ammonia concentrations for the Ettrick Basin

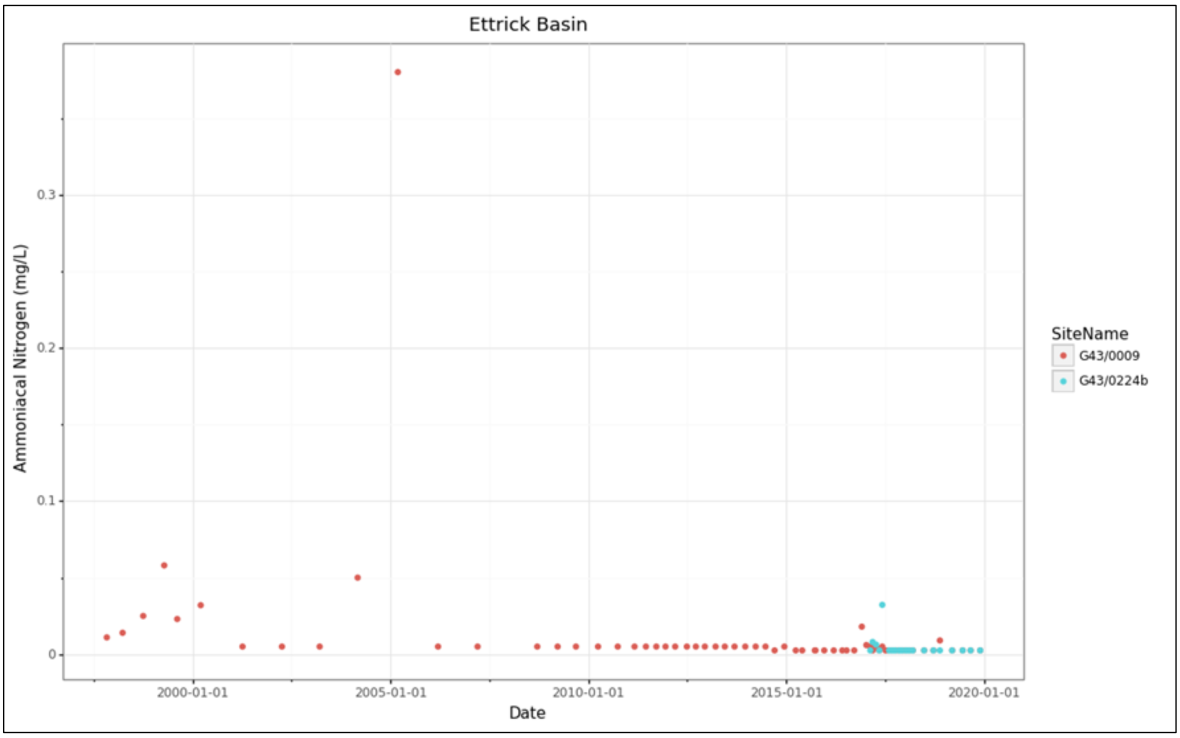
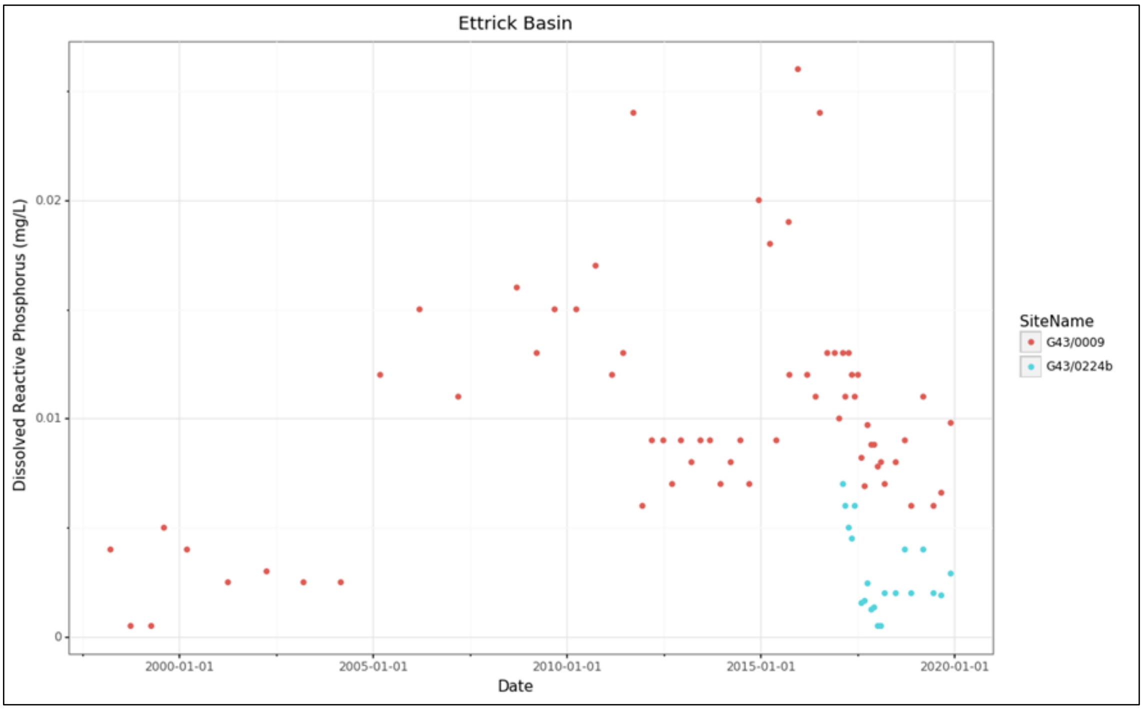


Figure 85: Groundwater Dissolved Reactive Phosphorus concentrations for the Ettrick Basin



The potential impact of groundwater quality in the bores on surface water was analysed against the RPW (Table 38) and (

Table 39). Bore G43/0224 is located in Group 1 of Schedule 15 whilst bore G43/0009 is in Group 2. The results show a high degree of non-compliance with the limits for nitrate, with both bores exceeding the respective limits by around 19 times. Bore G43/0009 also exceeds the 80th percentile concentration for DRP (Figure 85). Conversely, ammonia concentrations in neither bore exceed the limit (Table 38). This indicates potential impact on surface water quality, particularly in relation to eutrophication from nitrate and DRP.

Table 38: 80th percentile values for Schedule 15 water quality variables for the Ettrick Basin

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
G43/0224b	Clutha	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G43/0009	Clutha	Lower Clutha	Ettrick	4.960	0.013	0.010

Potential impacts of nitrate are also highlighted in the assessment against the NPS-FM NOF (

Table 39). This shows that the median concentrations in both bores are in Bands C (G43/0009) and D (G43/0224). Band D is below the National Bottom Line. It will impact growth of multiple species and starts approaching acute impact level (i.e. risk of death) for sensitive species. The 95th percentile for both bores is in Band C, where growth effects on up to 20% of the species is expected, though no acute effects (MfE, 2020). Median ammonia concentrations for both bores are in Band A, and both maximum concentrations are in Band B. This band provides 95% species protection level, with initial impact on the 5% most sensitive species occasionally. DRP concentrations in the bores are mixed, with median concentrations in bore G43/0009 in the B Band and in the A band for bore G43/0224. The 95th percentile for bore G43/0009 is in Band A whilst that of bore G43/0224 is in Band C, where ecological communities are impacted by moderate DRP elevated above natural reference condition. If other conditions that favour eutrophication occur DRP enrichment can increase algal/plant growth, loss of sensitive fish & macroinvertebrate taxa, and high respiration/decay rates (MfE, 2020).

Table 39: NOF comparison for nitrate, ammonia, and DRP for the Ettrick basin

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G43/0009	4.6	5.52	C	C
G43/0224b	7.9	8.66	D	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G43/0009	0.005	0.38	A	B
G43/0224b	0.0025	0.062	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G43/0009	0.009	0.0198	B	A
G43/0224b	0.002	0.03195	A	C

4.2.6.4 The Pomahaka Basin

4.2.6.4.1. Aquifer information

The South Otago basins consist of the Pomahaka, Clydevale, Wairuna and Kuriwao basins. Of these, only the Pomahaka and Clydevale have SoE monitoring bores. The Southern Otago basins are composed of the Cretaceous to Cenozoic sediments deposited upon the Waipounamu Erosion Surface, of a complex fluvio-marine origin. The Hillfoot and Livingstone faults, along with a series of SE trending fault lines, traverse the Clydevale/Wairuna/Kuriwao basins. The basement rock north of the Livingston fault is comprised of fine to medium grained grey sandstone and mudstone whilst the basement south of the fault consists of coarse-grained volcaniclastic sandstone and mudstone. This layer is overlain by carbonaceous clay and deeply weathered clasts of quartz, greywacke, argillite, semischist and schist, which outcrop in the southwest area of the mapped Pomahaka Basin. There are also thin veneers of Quaternary gravel, moraines, and glacial till along the surface water bodies (ORC, 2014d).

The Pomahaka is the largest of the Lower Clutha catchments, with an area of 3,600km^2. The upper reaches are steep and dominated by tussock while the lower reaches mainly flow through pastoral rolling hill country. The headwaters of the river originate in the Umbrella Range and flow in a south west direction to the confluence with the Clutha near Clydevale.

The catchment climate is considered mild, with consistent rainfall throughout the year. The annual rainfall varies from around 700mm in the low latitude parts of the catchment to 1,400mm in the Blue and Umbrella Mountains. The rainfall contributes to higher river flow in the Pomahaka, with the recorded flow at Glenken (the Upper catchment) ranging between 0.8 and 480m^3/second. This includes natural flushing flows, which are important for removing algae and the flushing of nutrients and sediment. Conversely, streams with a low frequency of flushing flows are susceptible to algal proliferations, particularly if they contain high concentrations of nutrients. The Pomahaka experiences around 8 flushing events per year, with this frequency generally exceeding that of streams in North/Central Otago. Soil profiles in the Pomahaka catchment vary with topography and elevation, with the rolling hill country of the lower catchment dominated by insoluble organic, pallic and grey soils. The more mountainous areas of the catchment have primarily semi-arid soils. The Pomahaka River also supports a regionally significant brown trout fishery (ORC, 2017a).

The predominant land cover in the Pomahaka catchment is high producing grassland followed by plantation forestry and native cover. Most of the intensive agriculture within the catchment takes place in relatively flat, rolling country through the middle and lower catchment and the river terraces that border the Clutha River. Land uses in the catchment have significantly changed over recent decades, with the number of dairy farms increasing from 38 to 105 between 1999 and 2008. These conversions typically occur in the middle and lower parts of the catchment, particularly around Tapanui, Heriot and Clydevale. Most farms are located in relatively low-lying areas with poor draining soils, which rely on artificial drainage such as tile drains. However, if not managed properly, tile drains can transmit a significant flow of nitrogen, phosphorus, and bacteria from grazed pastures to waterways. The tile drains also allow riparian zones to be bypassed (ORC, 2017a).

The Pomahaka and Kuriwao basins are referred to as unconfined gravel aquifers. The basins are largely comprised of hard rock and low yielding claybound gravel aquifers. Gravel with properties of an unconfined gravel aquifer exists along surface water bodies that traverse the basins. The unconfined gravel aquifers are more likely to be thin veneers of gravel, i.e. alluvial ribbons, located along the flood plains of the meandering rivers. Although the western side of the mapped Pomahaka Basin comprises of late Quaternary gravels, logs suggest that the gravels are claybound and flow test data suggest that the gravels are low yielding. Some bore logs indicate that a semi-confined gravel lens is also present although this lens may not be continuous. Most bores in this area are located close to streams/creeks. However, due to the low yielding properties of the aquifer, the likelihood of increased groundwater use is low, hence, designating an aquifer zone around the claybound gravels was deemed unnecessary at the time (ORC, 2014d).

The piezometric surface was analysed for both the whole South Otago area and for each individual basin, with water level measurements obtained from bores screened in both alluvium and rock. The regional groundwater flow direction follows the contours of the land, with flow influenced by the Pomahaka and Clutha rivers. The local groundwater flow follows the contours of the land and flows towards discharging rivers and streams. (ORC, 2014d).

The Pomahaka Alluvial Ribbon aquifer is an unconfined aquifer located in South Otago and underlies the townships of Tapanui, Kelso, and Heriot. The aquifer area is around 250km^2 within the Pomahaka River basin with most of the aquifer lying between the river and the Blue Mountains, which form its eastern boundary.

Geologically, the aquifer is hosted in glacial deposits with overlying alluvial sediments and a thin strip of alluvial gravels along the river banks. The boundaries were identified based on topography, with the aquifer extent assumed to be limited to the sediments deposited in the river basin between the surrounding hills and mountain range. The geology of the Pomahaka Basin is dominated by surficial Pleistocene outwash gravels, moraines, and glacial till underlain by weathered and faulted gravels of the Wanganui series. There is also a thin ribbon of recent alluvium deposits along the Pomahaka River. These unconsolidated deposits are underlain by Eocene quartz sands, quartzite, clays, and lignite seams and beds of mudstone, sandstone and conglomerate, which also outcrop southwest of the aquifer area. The regional basement comprises of metamorphic rocks of Permian-Carboniferous age that outcrop north of the Pomahaka area and in the Blue Mountains to the east. It is inferred that the alluvial deposits are in hydraulic connection with the associated water courses whereas the elevated Early Quaternary Gravels are assumed to be in less hydraulic connection. Groundwater outflows from the Quaternary Gravels are likely to initially enter modern river terraces (ORC, 1999b).

Geological maps show the aquifer is divided into two principal basins of 82km^2 and 124km^2, with a combined area of 206km^2. These are referred to as the Kelso and Tapanui basins, for the towns that are located within each of them. The sides and floor of the sedimentary basins are couched in Permian – Mesozoic hard rock. Within the basins, the deepest sediments are mainly fine-grained sandstone, siltstone, claystone and lignite seams of Miocene age. Quaternary sands and gravels cover the basin floor with a thin veneer over the low permeability rocks and sediments of the basement and fine-grained sediments. The reported depth of the Quaternary deposits at the Kelso basin is between 7m and 47m (although these greater depth are rare). Conversely, this information is poorly known for the Tapanui basin. The basement rock divide between the Kelso and Tapanui basins also defines the groundwater yield, with low/insufficient yield from the thin, clay-rich Quaternary gravel deposits, which require deeper drilling into the fractured rock aquifer dominates the Tapanui Basin. Conversely, the Kelso basin tends to have deeper, more permeable gravel and clay-bound gravel deposits hence there is less usage of bores that abstract from fractures. The water table depth tends to be shallowest on younger terrace surfaces close to the main surface water features such as the Pomahaka River and is deepest underneath the Early Quaternary Terrace Gravels towards the margins (ORC, 1999b).

Mapping and bore log information shows that bores located in the northern part of the aquifer were drilled through relatively thin sediments and are penetrating the underlying basement rock, with most bores screened in the rock rather than the shallow sediments. The sediment then becomes thicker to the south, with a maximum thickness of >47m (bore G45/0116, situated west of Kelso).

Aquifer pumping test results indicate a relatively low yield in the area, with Transmissivity (T) values that are more consistent with fine-medium sand than with gravels. This is likely to be explained by the frequent observations of clay and claybound gravels in many bore logs, which may infill pore space within gravel and effectively reduce aquifer hydraulic conductivity and Transmissivity. Mapping of the estimated aquifer Transmissivity suggest that the lowest values are found in the northern edge of the aquifer, where the gravel thickness is likely to be the narrowest. Conversely, higher Transmissivity values, of around 50m^2/day, are found in the central part of the aquifer, near Kelso, where sediment thickness is greater and probably includes alluvial gravels. There is no information regarding the Transmissivity of bores located in the large area south of Tapanui. There is no information regarding the Storativity and the aquifer Specific Yield. Based on the low Transmissivity of the aquifer, it is likely that the specific yield will be relatively low, at around 0.1. However, it is required to conduct constant discharge pump tests in order to confirm that (ORC, 1999b).

According to the database there are 31 bores within the Pomahaka basin. The bores show a wide range in depth, between 4.4 and 78.5m. There is reported SWL for 26 of the bores, which ranges between 1 and 14.8m. Screen depth is reported for 12 bores, with depths ranging between 2.5 and 77m. Most screens lengths range between 1-3m. The main reported water uses include dairy shed, domestic, stockwater and irrigation (ORC, 1999b).

4.2.6.4.2 Groundwater quality monitoring

There are two groundwater quality monitoring bores in the Pomahaka basin. Bore G44/0127 (100mm diameter) is located approximately 880m northwest of the Paradise Flat/Ardmore Road intersection, at NZTM E1306679 N4910886. The bore depth is 5.2m. The bore log describes clay/topsoil to 1.0m underlain by blue/brown gravels to 4m. There is no information regarding the screen depth, however it is likely to be within the bottom gravel horizon.

Bore G44/0136 (50mm diameter) is situated in Glencoe, at NZTM E1310773 N4912370. The bore is situated approximately 5.5km west of the foothills of the Blue Mountains, near one of the tributaries of the Pomahaka. The tributary flows in a westerly direction to the south of Pebble Ridge and then flows toward the southwest, entering the Pomahaka south of Kelso. The bore depth is 5.5m. There is no bore log or screen depth information available for it.

The assessment of groundwater quality results against the DWSNZ showed some issues. E. coli in both bores were generally below the MAV, although some exceedances were observed, with a maximum count of 5 MPN/100mL (Figure 86). The last exceedances were measured in April 2018. The results went back down following the exceedance, suggesting it was a single event rather than an occurring trend. This suggests that there is some risk, albeit fairly low, of faecal contamination from the bores. However, the bores are very shallow, with poor borehead protection. Nitrate concentrations in both bores are below the DWSNZ MAV of

11.3mg/L. However, nitrate concentrations in bore G44/0127 range between 2.9 and 6.86mg/L, with the higher end of the results exceeding ½ of the MAV (

Figure 87). No dissolved arsenic concentrations exceeded the 0.01mg/L MAV (

Figure 88). There are no ammonia concentrations that exceed the GV of 1.5mg/L (

Figure 89). The results are generally good in relation to the DWSNZ, although there is a degree of risk of faecal contamination and nitrates.

Figure 86: Groundwater E. Coli for the Pomahaka Basin

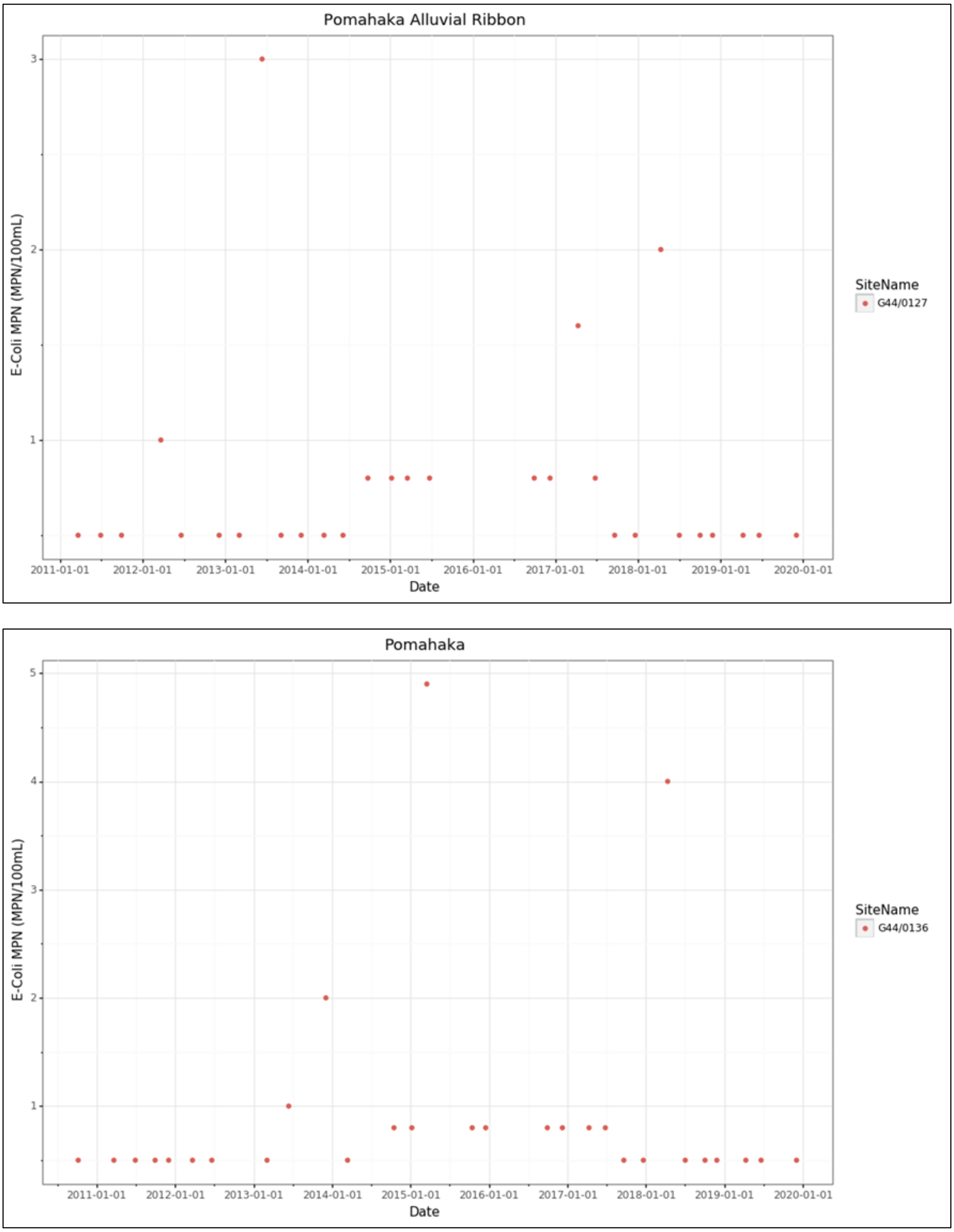
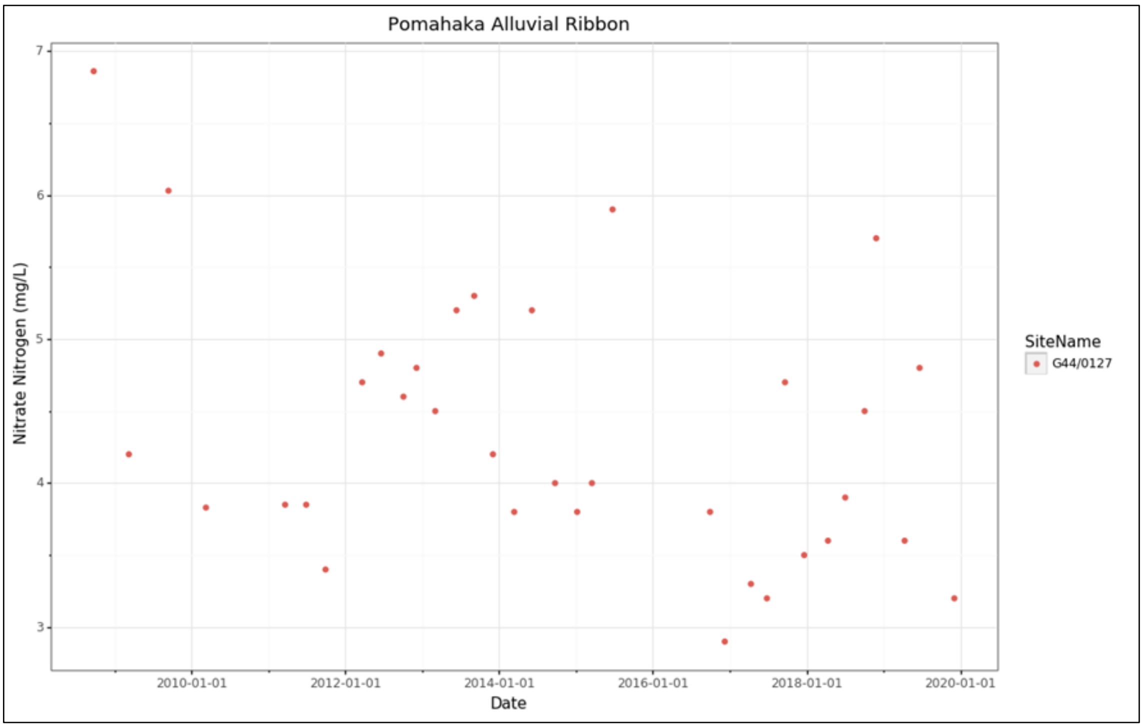


Figure 87: Groundwater nitrate concentrations for the Pomahaka Basin



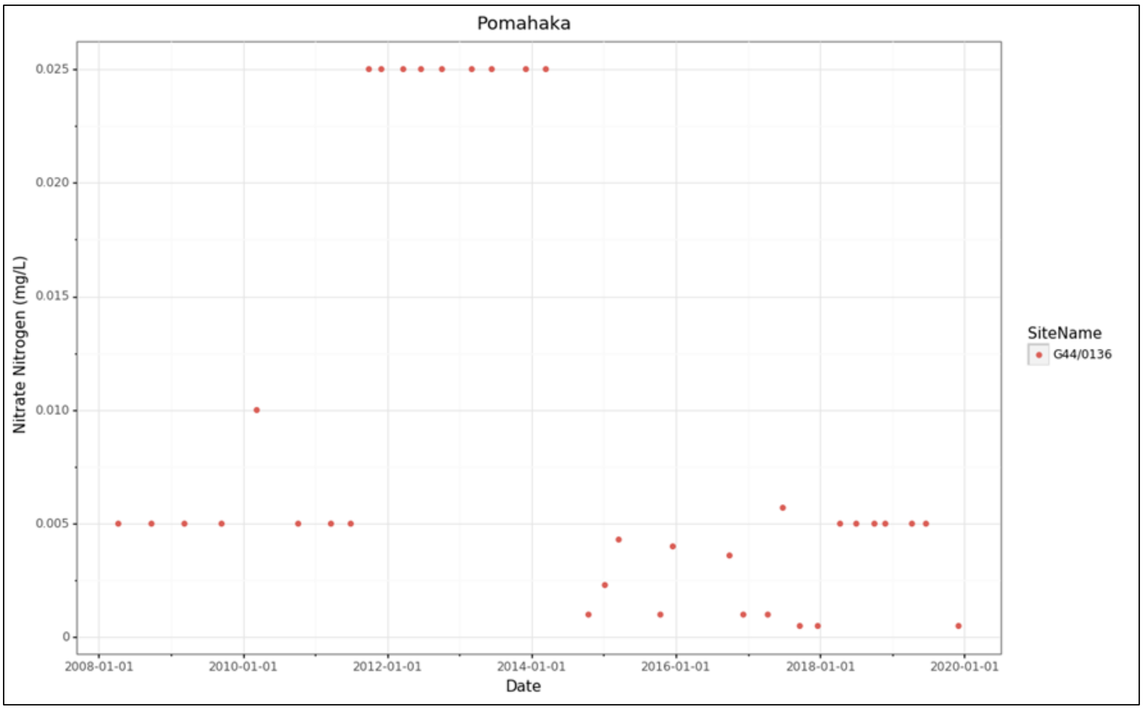
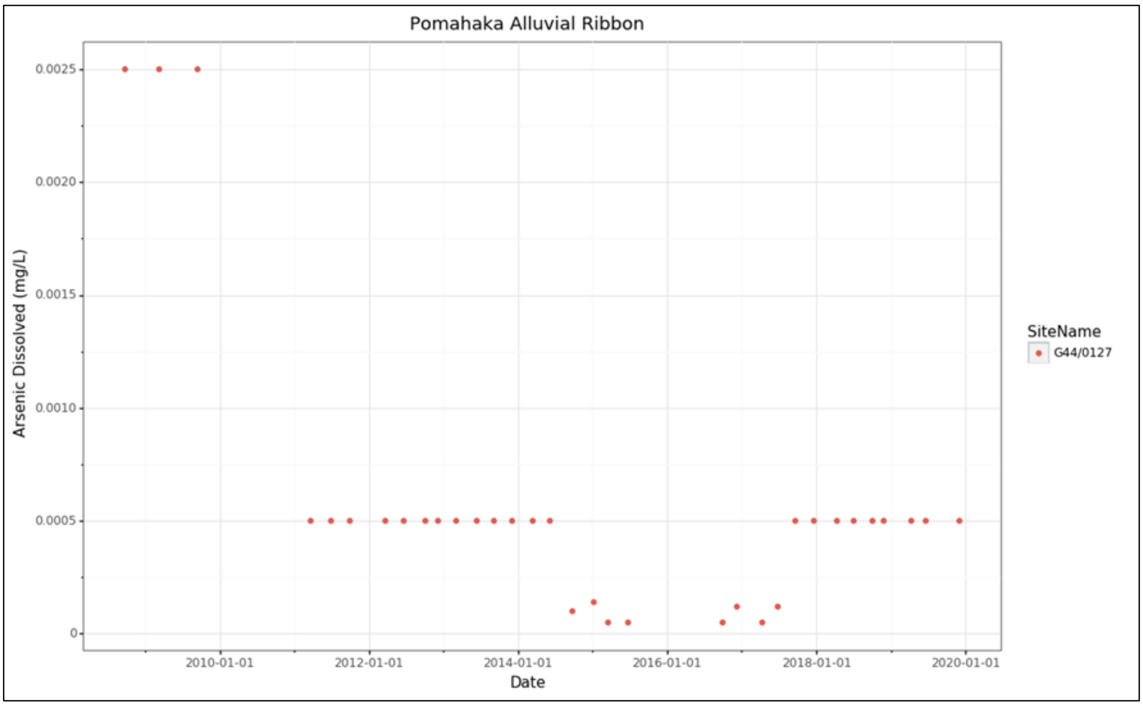


Figure 88: Groundwater dissolved arsenic concentrations for the Pomahaka Basin



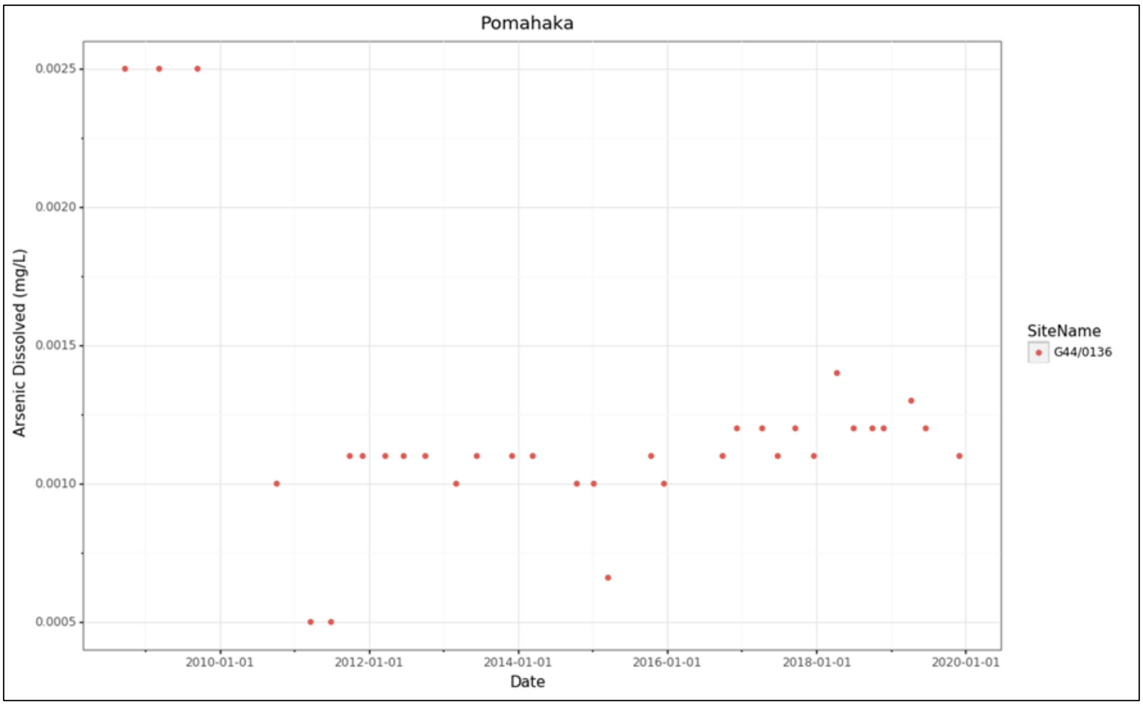
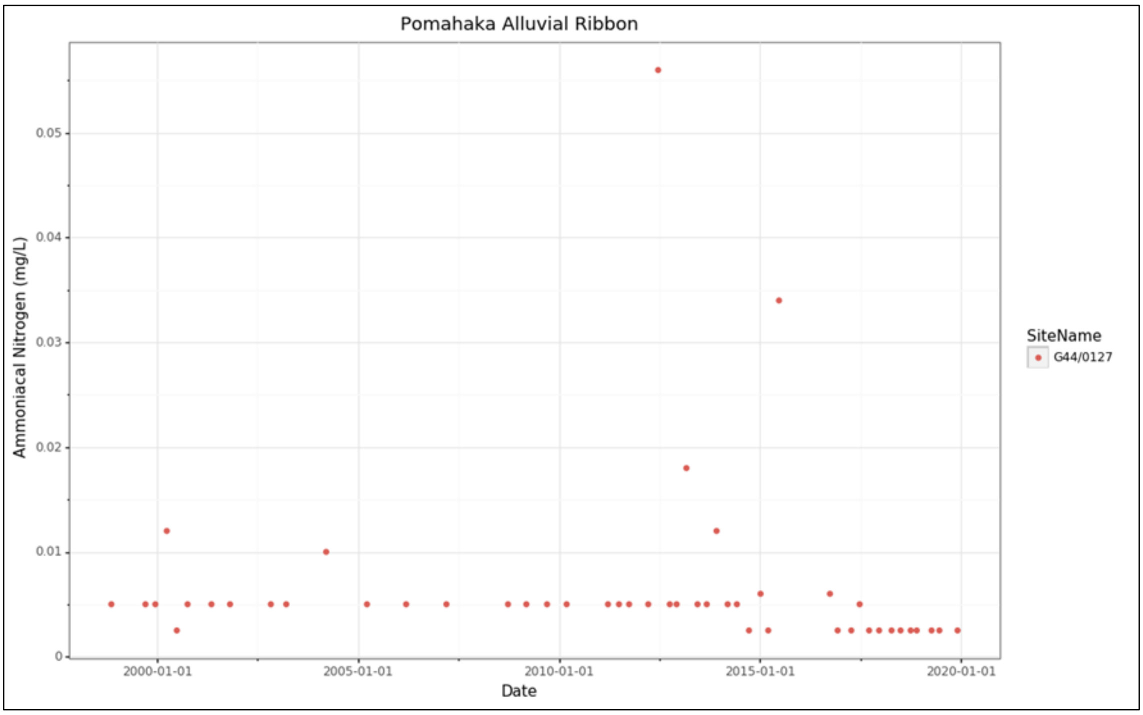


Figure 89: Groundwater ammonia concentrations for the Pomahaka Basin



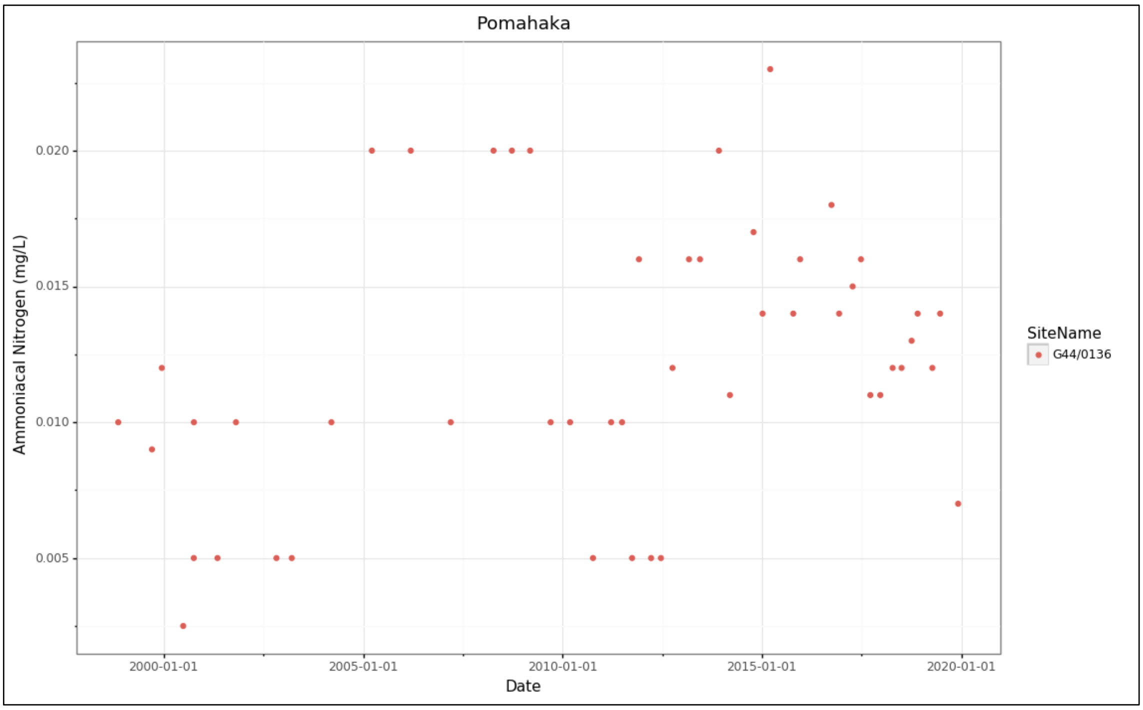
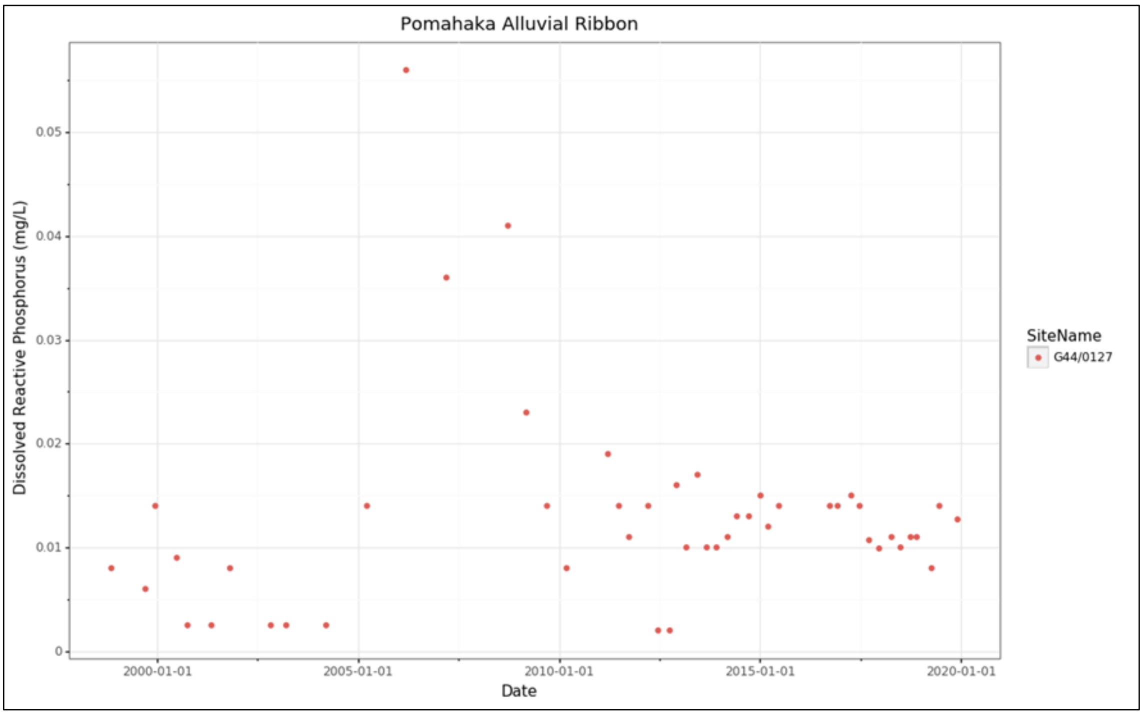
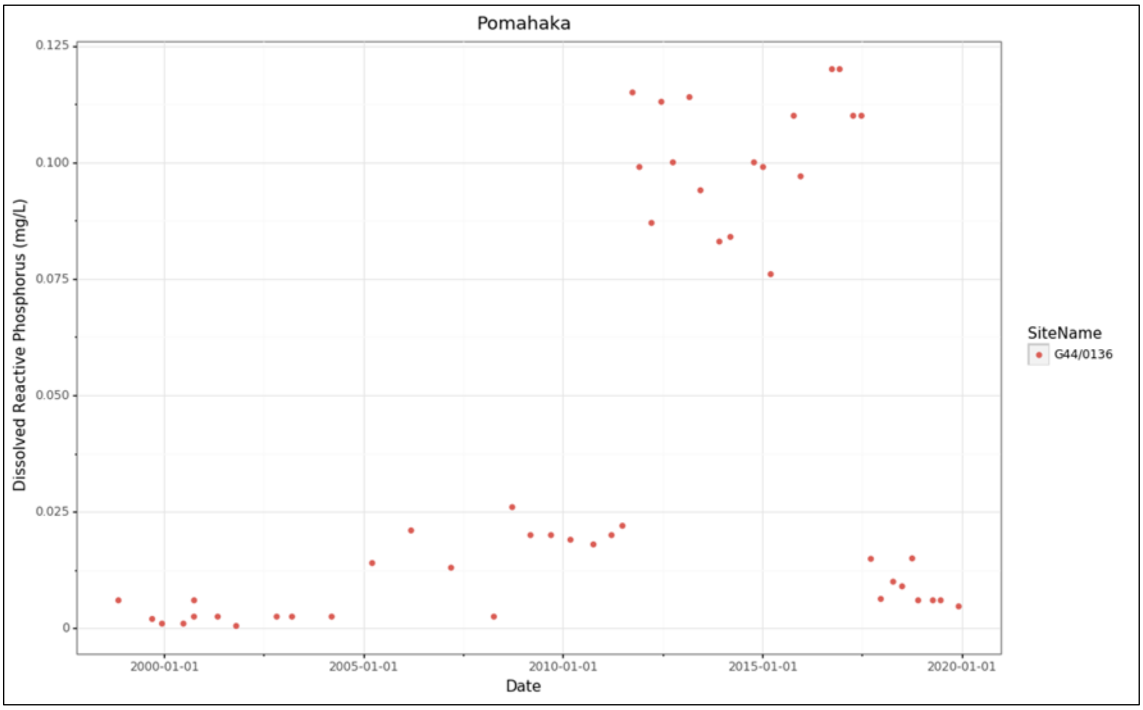


Figure 90: Groundwater Dissolved Reactive Phosphorus concentrations for the Pomahaka Basin





The results were then assessed against the RPW (Table 40) and NPS-FM (Table 41). Bores G44/0127 and G44/0136 are located in Group 1 of Schedule 15. The results show that bore G44/0127 is non-compliant with Schedule 15, with concentrations exceeding the limits by approximately 11 times. The DRP and ammonia are within the limits. The situation is opposite in Bore G44/0136, where DRP concentrations exceed the limits by approximately 4 times, with high increases in concentrations, ranging between 0.075 and 0.125mg/L, between October 2011 and June 2017 (

Figure 90). Nitrate and ammonia concentrations are compliant with the Schedule 15 limits.

Table 40: 80th percentile values for Schedule 15 water quality variables for the Pomahaka Basin

Bore number	Nitrate (NO_3-N) [mg/L]	Dissolved Reactive Phosphorus (DRP) [mg/L]	Ammoniacal nitrogen (NH_4-N) [mg/L]
Group 1 Sched. 15 limit (mg/L)	**0.444**	**0.026**	**0.10**
G44/0127	5.020	0.015	0.010
G44/0136	0.050	0.099	0.016

The assessment of groundwater quality against the NOF is shown in Table 41. This shows that bore G44/0136 is in Band A for both nitrate and ammonia. The median and 95th nitrate concentrations for G44/0127 are in Band C, where growth effects on up to 20% of species, mainly sensitive ones such as fish, are expected, although no acute effects. Both median and maximum ammonia concentrations are in Band A for bore G44/0136. The maximum ammonia concentrations for bore G44/0127 are in Band B, which provides 95% species protection level, with a start of occasional impact on the 5% most sensitive species. The results for DRP are poor for both bores, with the median and 95th percentile concentrations for G44/0127 in Band C and those of G44/0136 in Band D. Band C for DRP has moderate DRP concentrations above natural reference conditions that impact ecological communities. Band D is below the National Bottom Line for DRP, where ecological communities are impacted by substantial DRP concentrations above natural reference conditions. For both bands, if combined with other factors that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as sensitive taxa to hypoxia are lost. These results show potential serious problems regarding the groundwater quality results from the Pomahaka bores, particularly regarding DRP and nitrates, with these potential impacts elevated due to the bores' shallow depths (circa 5m).

Table 41: NOF comparison for nitrate, ammonia, and DRP for the Pomahaka basin

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G44/0127	4.1	5.9455	C	C
G44/0136	0.005	0.05	A	A
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G44/0127	0.005	0.056	A	B
G44/0136	0.012	0.023	A	A
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G44/0127	0.011	0.0325	C	C
G44/0136	0.019	0.1146	D	D

4.2.6.5 The Clydevale aquifer

4.2.6.5.1 Aquifer information

The Clydevale & Wairuna basins are located in the Clutha District. The basins are bounded by the Clutha and Pomahaka Rivers to the east, the Blue Mountains to the west and the catchment boundaries of the Wairuna and Waiwera Streams. The water table is generally shallow and groundwater movement usually follows topography. Rainfall infiltration is the main source of recharge for both basins, with around 2.5-3.5% of rainfall recharging the aquifer, hence most precipitation runs off as surface water. The main groundwater uses in the basins are dairy shed, stock water, and domestic supply (ORC, 2004).

The geology of the basins consists of the following features: massive occurrences of sandstone, mudstone and siltstone are found in the south whilst greywacke and argillite were observed from Clifton and to the north. Haast schist is found north of the area opposite the Tuapeka Mouth. There are also thin veneers of quartzose clay or silt bound gravels that occur opposite of Clydevale and extend towards the Pomahaka/Clutha confluence. There are also some alluvial outwash gravels adjacent to major rivers and in some low lying tributary stream areas. Bore logs confirm the prevalence of low permeability rock, which is different to the heterogenous glacial/post glacial deposits common in Central Otago.

Despite the geological heterogeneity in the basin, the yield from these formations is very low. The hydraulic parameters and bore success rates (i.e. bores that yield satisfactory volumes/rates for either domestic, stockwater, or dairy shed supply) in both aquifers are very low, with the latter generally ranging between 40 – 87%. Due to the low Transmissivity and high drawdown in the aquifers, the radial separation between bores should be >350m, with this distance based on the nominal yield for both basins (0.5L/s). Due to the low permeability of the strata in the area, most bores are deeper than 100m in order to intersect sufficient fracture flow that will permit groundwater abstraction and provide sufficient working drawdown (ORC, 2004).

4.2.6.5.2 Groundwater quality monitoring

There is one monitoring bore within the Clydevale basin area, No. G45/0225 (200mm diameter). The bore is located north of Wairuna Settlement Road near a tributary of the Pomahaka River that flows from Anise Hill towards the northeast at NZTM E1307731 N4897236. The bore log describes yellow clay and sandy silt to 0.7m underlain by brown gravels to 3.8m. There is then grey/blue mudstone to the bore bottom at 5.2m. The bore is screened between 3.2 and 5.2m, within brown gravels. Groundwater quality results from the bore were compared against the DWSNZ. The data indicates several issues, particularly related to elevated E. coli and nitrates. There were several exceedances of the E. coli MAV, with the highest count of 161 MPN/100mL, measured in November 2018. The other exceedances ranged between 3 and 9.8 MPN/100mL (Figure 91). Nitrate concentrations range widely, varying between 1.63 and 12.0mg/L, which exceeds the 11.3 mg/L MAV (June 2019),

Figure 92. The results indicate no samples above the MAV for arsenic (Figure 93). There are no ammonia concentrations that exceed the GV of 1.5mg/L (

Figure 94).

Figure 91: Groundwater E. Coli count for the Clydevale aquifer

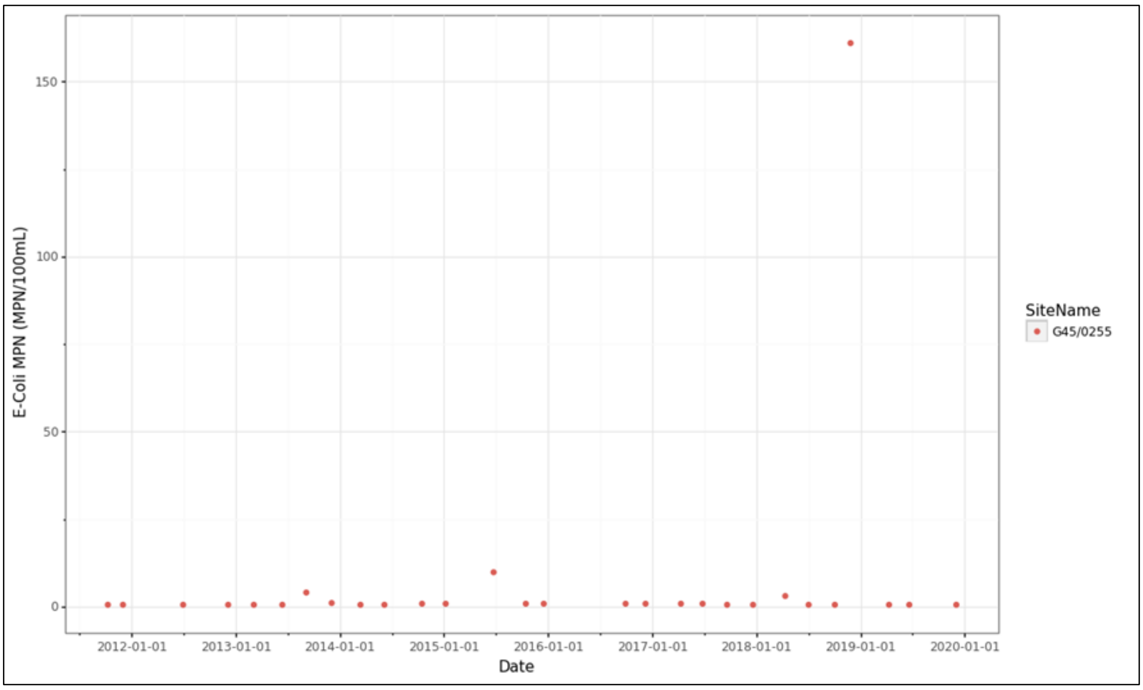


Figure 92: Groundwater nitrate concentrations for the Clydevale aquifer

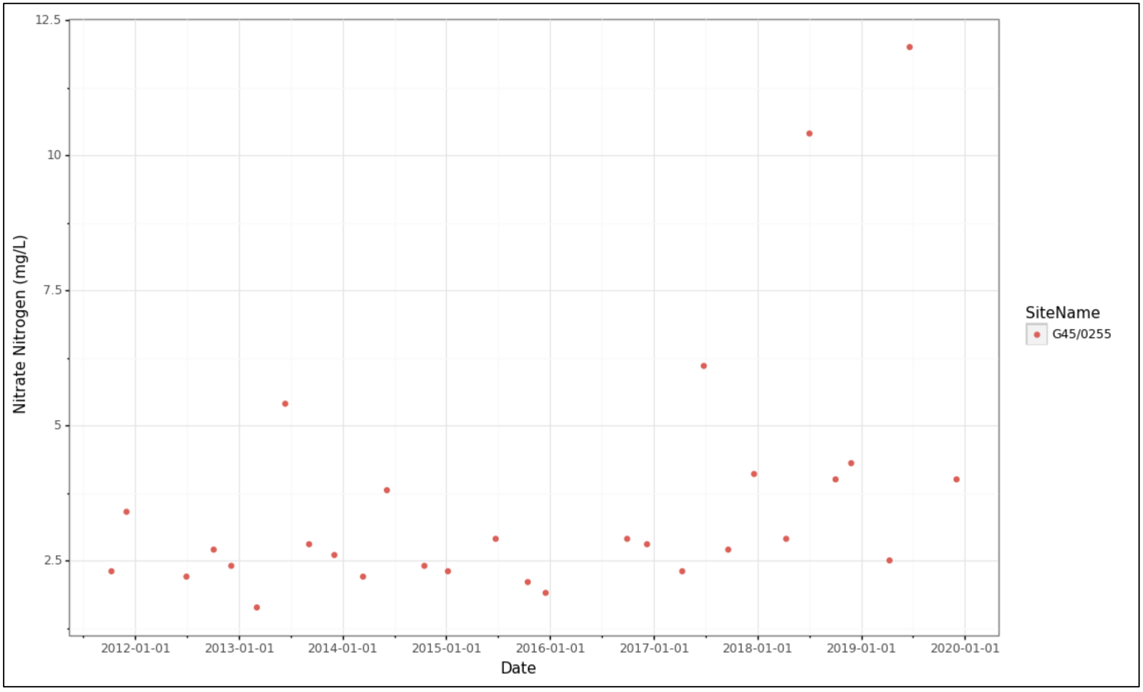


Figure 93: Groundwater dissolved arsenic concentrations for the Clydevale aquifer

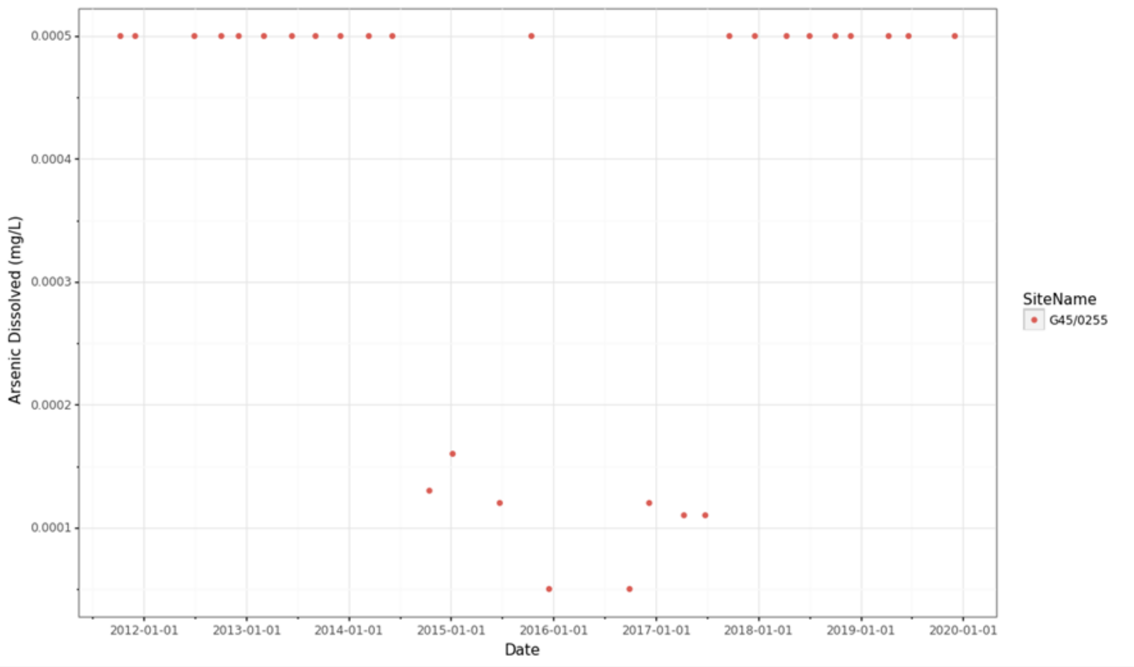


Figure 94: Groundwater ammonia concentrations for the Clydevale aquifer

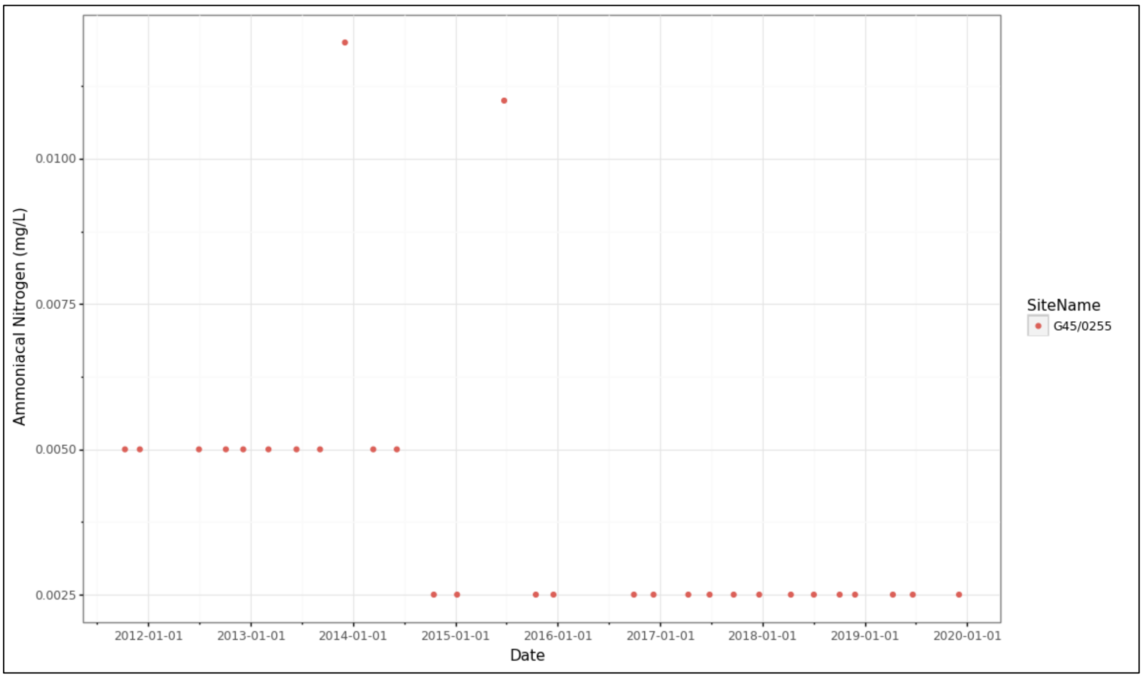
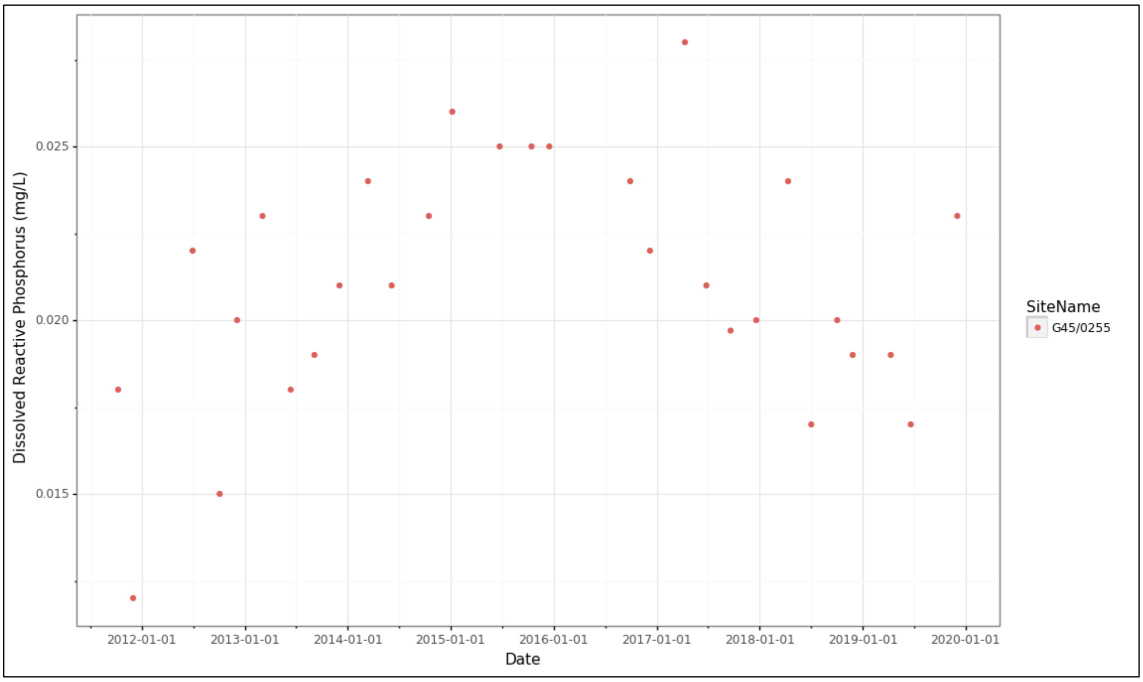


Figure 95: Groundwater Dissolved Reactive Phosphorus concentrations for the Clydevale aquifer



The assessment against the RPW shows that groundwater concentrations in bore G45/0225 comply with the Schedule 15 limits for ammonia and DRP (Table 42). However, the nitrate concentrations substantially exceed the limits. Although compliant with the RPW limits, DRP concentrations are relatively high and are increasing, reaching 0.026mg/L in January 2015. It then flattened at 0.025mg/L until March 2016 where they generally dropped, reaching as low as 0.018mg/L. Despite the lower concentrations, there were also several increases between 2017 and 2019. These increases were close to the maximum concentrations measured prior to

2015 (i.e. around 0.023-0.025mg/L), Figure 95. These fluctuations and increases are a potential cause for concern. The assessment against the NPS-FM NOF also shows concern regarding DRP, where the median concentration is in Band D. Both median and 95th percentile nitrate concentrations are in Band C. Conversely, both ammonia concentrations are in Band A (Table 43).

Table 42: 80th percentile values for Schedule 15 water quality variables for the Clydevale aquifer

Bore number	**Nitrate (NO$_3$-N) [mg/L]**	**Dissolved Reactive Phosphorus (DRP) [mg/L]**	**Ammoniacal nitrogen (NH$_4$-N) [mg/L]**
Group 1 Sched. 15 limit (mg/L)	**0.444**	**0.026**	**0.10**
G45/0225	4.04	0.024	0.0118

Table 43: NOF comparison for nitrate, ammonia, and DRP for the Clydevale Aquifer

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G45/0225	2.8	8.68	C	C
	Ammoniacal nitrogen			
Bore number	median (mg/L)	Max (mg/L)		
G45/0225	0.0115	0.012	A	A
	DRP			
Bore number	Median (mg/L)	95th percentile (mg/L)		
G45/0225	0.021	0.0256	D	B

4.2.6.6 Inch Clutha Gravel Aquifer

4.2.6.6.1 Aquifer information

The Inch Clutha Gravel Aquifer is situated in the Lower Clutha Plain, southeast of the Balclutha township. It is located on an alluvial floodplain bounded by gently rolling hills of between 60-100m. The plain is approximately 8km wide and 12km long, with an area of around 90km^2. The gradient across the plain is generally uniform, at <10m above Sea Level. The Clutha River divides into two branches downstream of Balclutha, the Matau and the Koau, which split the area to three blocks: Kaitangata, Inch Clutha and Paretai (although the Paretai block is located in the Catlins FMU). The water table is shallow and requires careful management.

The Lower Clutha Plain (delta) is impacted by tectonic activity with evidence for movement during Quaternary times. Late Cretaceous to early Cenozoic erosion surface is inferred to a depth of around 200m below sea level underneath the delta. However, the extent and thickness of Tertiary sediments within the valley that are concealed beneath the Quaternary sediments is largely unknown. The Quaternary geology of the delta is of an alluvium filled valley formed by the inundation of the meandering Clutha River following changes in sea level. The main controls on the delta's landscape evolution were the position of sea level, and sediment transport by the river and at the coast, which combined to form river terraces of various ages and elevations. Throughout the Quaternary period, climatic fluctuations and the resultant glaciation advance/retreat sequences impacted the Clutha's sediment load flow and gradient. All Quaternary deposits consist of unconsolidated angular to well-rounded gravel and subordinate sand and mud. Post glacial (Holocene) floodplain deposits on the Lower Clutha Plain are fine-grained, well sorted and dominated by fine sand and silt and reworked beach sand mixed with peat near the coast. Near Paretai, there are remnants of older terrace gravels preserved up to 40m above sea level and overlain by around 5m of loess. Alluvial terrace deposits are sourced from locally derived sandstone clasts and are relatively clay rich, hence likely to have reduced permeability. The thickness of the Quaternary strata is unknown, however, it is likely to exceed 25m at the coastal zone. As deltas generally form when sediment-laden fluvial systems deposit bedload when entering an open water body, which leads to up-gradient coarsening where coarser, usually less well sorted, bedload is preferentially deposited (i.e. near the river-sea interface). Due to that, there is potentially a mid zone of permeability in the delta. The depth to the water table is generally shallow and under topographical control, between 0-6m below ground level. Shallower water table sites were measured on the plain itself while wells that are located on terraces have a slightly deeper water table. The aquifer is likely to be composed of sand, gravels, mud and peat. It is likely to form a hydraulically interconnected unit although it is also likely to be heterogenous, with variability in permeability and connectedness to surface water. However, the magnitude of aquifer-river interactions is unknown and there is very little information regarding aquifer properties in the area (ORC, 1998a).

The ORC database shows 9 bores in the Inch Clutha Gravel Aquifer. Total depth information is available for eight of these, ranging between 9 and 155m. Despite this large range the variability in SWL is much narrower, ranging between 1.2 and 13.3m, indicating the shallow water table in the area. Screen depth information is available for 4 bores, which depths ranging between 8 and 18.5m. The screen lengths are approximately 1-2m. Groundwater use in the area is volumetrically low, with the main uses include domestic, stockwater, dairy shed wash and commercial. There are two consented groundwater abstractions in the area.

4.2.6.6.2 Groundwater quality monitoring

Groundwater quality monitoring in the Inch Clutha Gravel Aquifer is monitored in two SoE bores. Bore H46/0118 (1,400mm diameter) is located north of Kaka Point Road, near the Otanomomo settlement, at NZTM E1349089 N4868050. The bore is situated approximately 2.1km west of the Koau Branch of the Clutha River. The bore is actually located in the Catlins FMU and is the only SoE monitoring bore in this FMU. However, as it abstracts from the Inch Clutha Gravel Aquifer, the results were included in this section. The bore depth is 12m. There is no screen depth or log information available for this bore. Bore H46/0144 (100mm diameter) is located east of Kaitangata Highway, at NZTM E1354935 N4870284. The bore depth is 38m. The log describes gravels and clay to 4.5m underlain by grey clay to 20m. There is then 0.50m of fine white quartz underlain by grey clay to the well bottom at 37.8m. There is no screen depth information for this bore. However, the original bore log also states that the grey clays are underlain by gravels and sand at 37.8m to an unknown depth. Based on the provided bore depth of 38m, it is reasonable to assume that the depth of gravels is at least 0.20m. The original log also states that the screen length is 1.5m, although the depth of the screen top is not provided. It is assumed that the uppermost screen depth is around 36.5m, although it may be deeper, which indicates that the total bore depth is greater than 38m. Nevertheless, this information suggests that the bore abstracts from the lower gravel/sands horizon and is confined by >20m of overlying clay layers. SWL data is available in Hilltop between December 2011 and June 2013. However, it is currently not possible to physically measure SWL in the bore. The reported SWL was usually around 1.10m below MP, with one exception of 6.91m in October 2012.

The groundwater quality results from the bores were analysed against the DWSNZ. Bore H46/0144 has issues with elevated dissolved arsenic, with most concentrations after 2010 exceeding the 0.01mg/L MAV, ranging between 0.014 and 0.020mg/L,

Figure 96. However, the bore owner confirmed that it is not used for drinking. All E. coli results from both bores were below the MAV (

Figure 97). Nitrate concentrations in both bores are much lower than the DWSNZ of 11.3mg/L MAV. Concentrations in bore H46/0118 generally range between 0 – 0.5mg/L, although higher concentrations of between 1.40 and 1.75mg/L were measured between June 2014 and June 2018. The concentrations in bore H46/0144 are lower, ranging between 0 and 0.25mg/L, Figure 98. Ammonia concentrations in bore H46/0144 range between 1.65 and 2.29mg/L (

Figure 99), which exceed the DWSNZ GV of 1.5mg/L. The results indicate groundwater quality issues regarding elevated arsenic and ammonia concentrations, although the latter can be possibly due to the bore location near a dairy shed.

Figure 96: Groundwater dissolved arsenic concentrations for the Inch Clutha Gravel aquifer

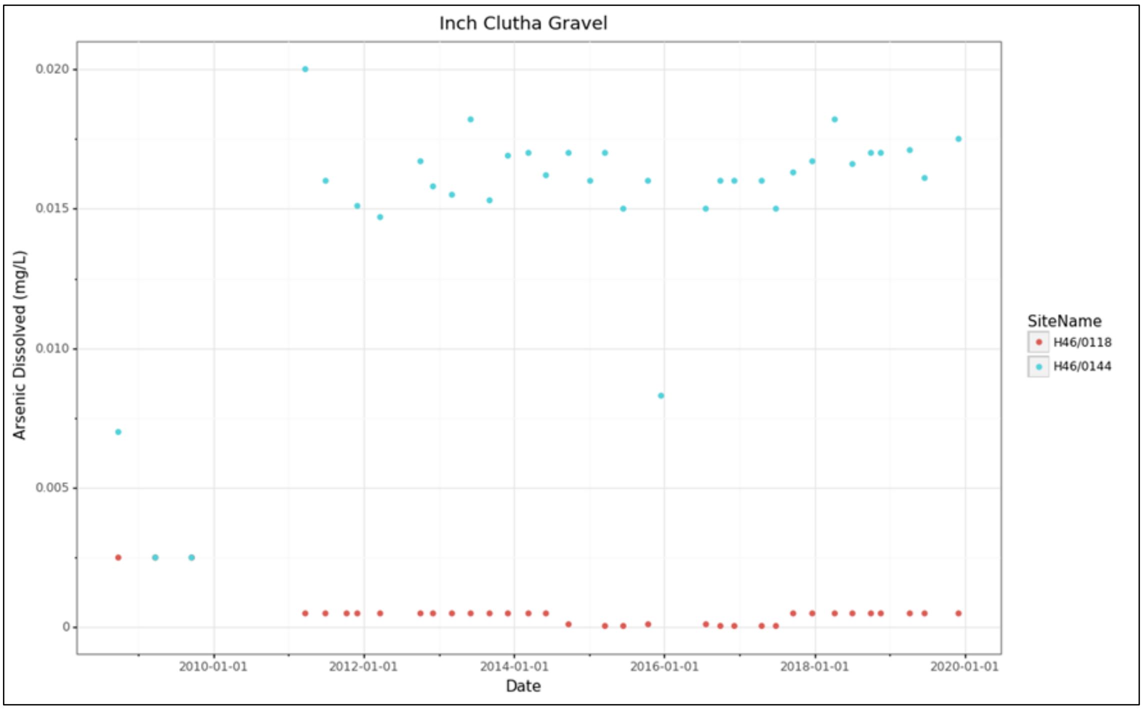


Figure 97: Groundwater E. Coli for the Inch Clutha Gravel aquifer

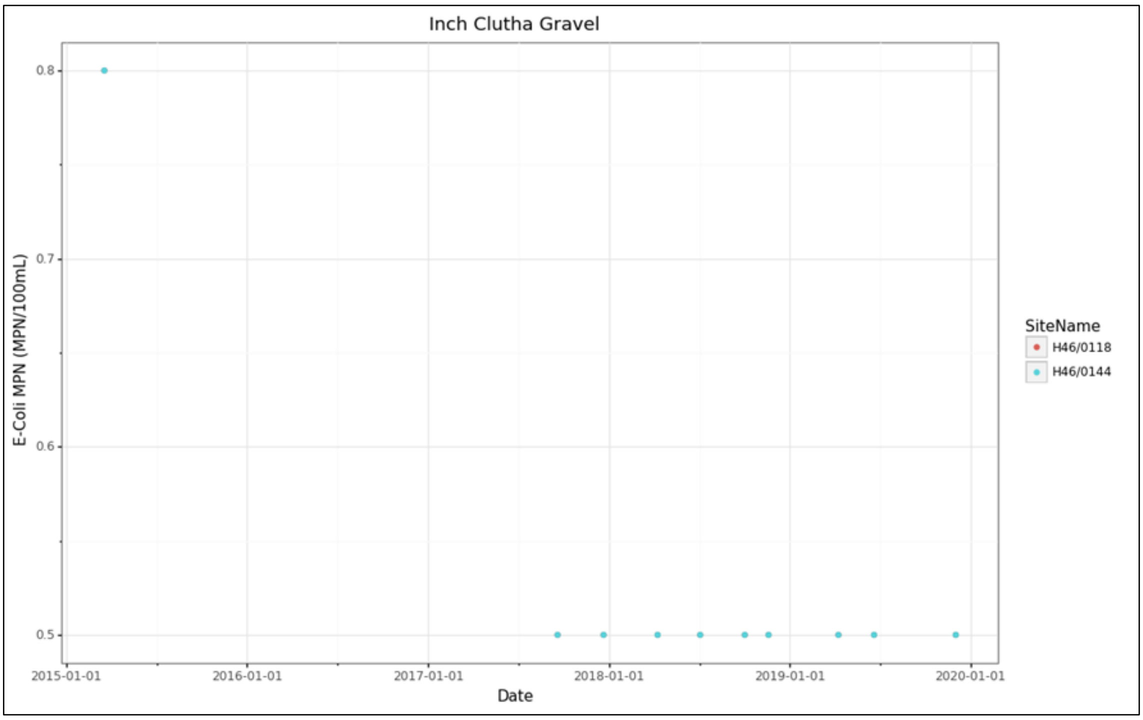


Figure 98: Groundwater nitrate concentrations for the Inch Clutha Gravel aquifer

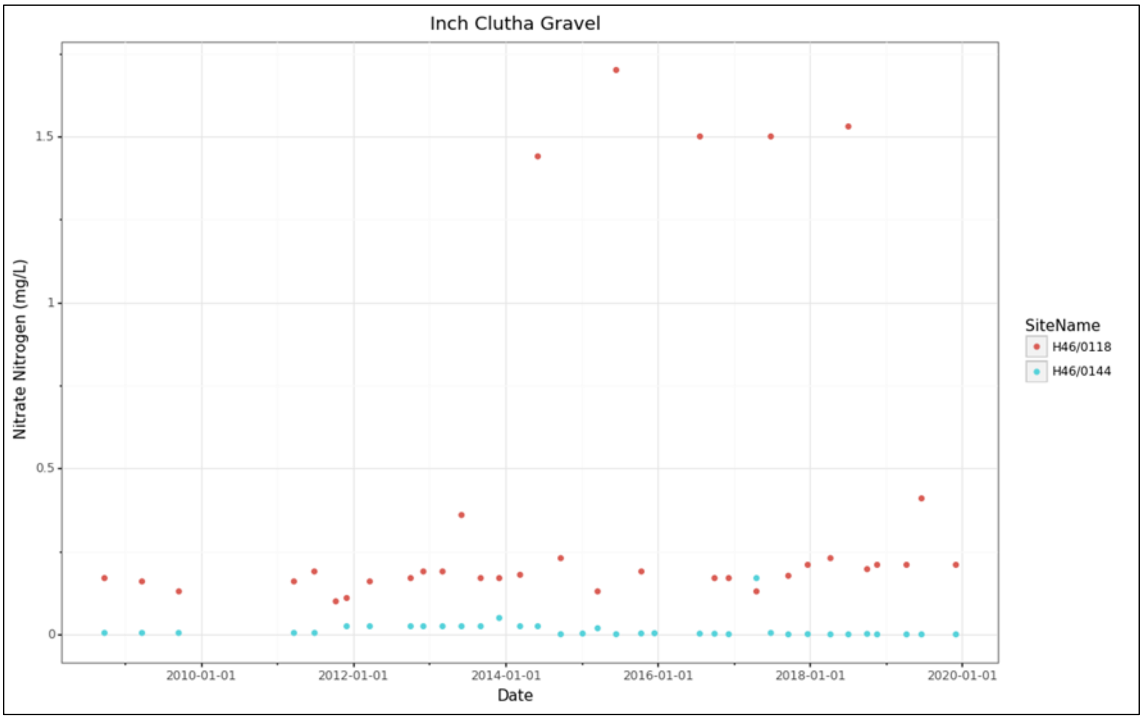


Figure 99: Groundwater ammonia concentrations for the Inch Clutha Gravel aquifer

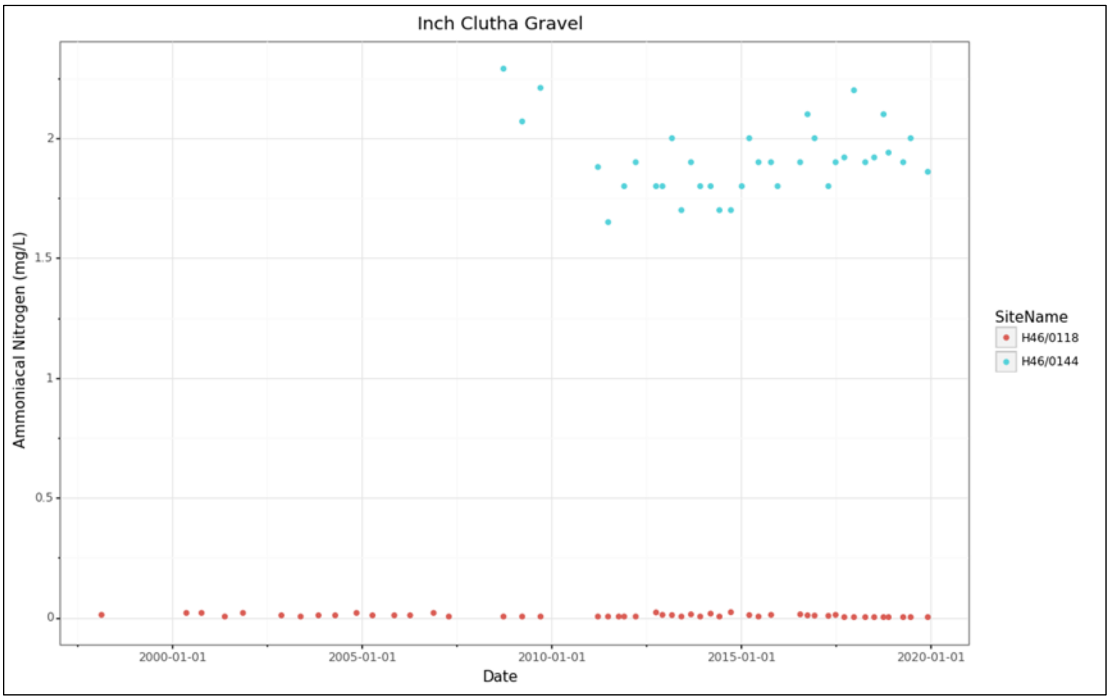
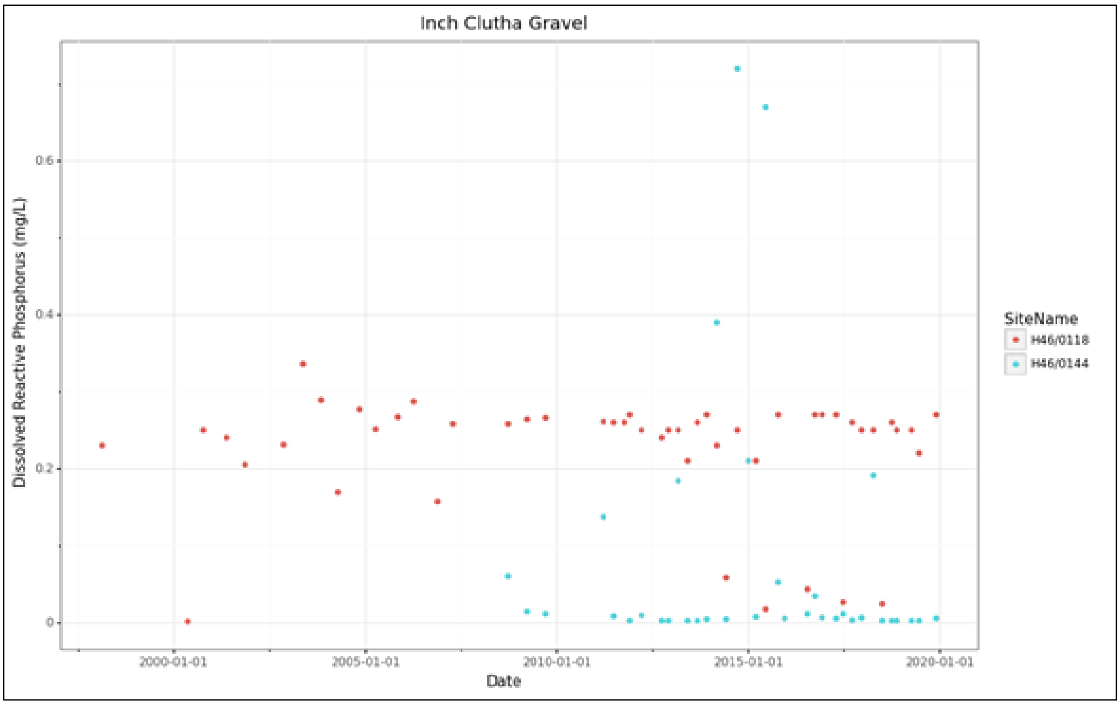


Figure 100: Groundwater Dissolved Reactive Phosphorus concentrations for the Inch Clutha Gravel aquifer



Groundwater quality results from bore H46/0118 were also assessed against the RPW (Table 44) and the NPS-FM NOF (Table 45). The results from bore H46/0144 were not assessed due to the bore depth. Bore H46/0118 is located in Group 1 of the Schedule 15 receiving water groups. The results show noncompliance with the DRP threshold, with the 80th percentile concentration exceeding the limit by over 10 times (Figure 100). The nitrate and ammonia concentrations are below the limits.

Table 44: 80th percentile values for Schedule 15 water quality variables for the Inch Clutha Gravel Aquifer

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Clutha	Lower Clutha	Inch Clutha	0.282	0.270	0.013

The results were then assessed against the NPS-FM NOF, Table 45. The results indicate a similar pattern to the Schedule 15 assessment, with both the median and 95th percentile DRP concentrations in Band D, which is below the National Bottom Line. DRP concentrations at this band are substantially elevated above natural reference conditions and are impacting ecological communities. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and hypoxia losses of sensitive taxa, causing significant changes in fish and macroinvertebrates communities. The 95th percentile nitrate concentration is in Band B, where some growth on up to 5% of species occurs (MfE, 2020). The median and maximum ammonia concentrations are both in Band A.

Table 45: NOF comparison for nitrate, ammonia, and DRP for the Inch Clutha Gravel

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
H46/0118	0.19	1.5105	A	B
	Ammoniacal nitrogen			
Bore number	median (mg/L)	Max (mg/L)		
H46/0118	0.008	0.023	A	A
	DRP			
Bore number	Median (mg/L)	95th percentile (mg/L)		
H46/0118	0.25	0.283	D	D

4.3 Dunedin & Coast FMU

4.3.1 FMU background information

The Dunedin & Coast FMU contains one groundwater quality monitoring bore, H45/0314, located in the Tokomairiro Plain GWMZ. The median results for DWSNZ and ecosystem health parameters from the FMU are shown in Table 46.

Table 46: Median concentrations for DWSNZ/ecosystem health parameters for Dunedin & Coast FMU

	Arsenic Dissolved (mg/L)	E-Coli (MPN/100mL)	Nitrate Nitrogen (mg/L)	Ammoniacal Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)
Tokomairiro Plain GWMZ	0.002	0.650	0.001	0.064	0.014

4.3.2 Tokomairiro Plain GWMZ

The Tokomairiro plain is an alluvial basin located approximately 60km southwest of Dunedin on SH1. The plain is approximately 4km wide and 14km long with an area of around 65km^2. It is bounded in the east and west by hills rising to around 350m. The climate is similar to Dunedin and the Taieri Plain with warm summers, cool winters, and a relatively even rainfall distribution of around 650-750mm/year. The prevailing wind direction is from the southwest.

The elevation of the plain is between 35-40m above sea level at Milburn (north) and Moneymore (south), with drainage from these points towards the centrally located Milton (via the east/west branches of the Tokomairiro River) and then southeast to the coast via the Tokomairiro River valley. There are also numerous tributaries that traverse the plain, with the area between Clarksville and Milton being prone to flooding and requires drainage management.

The main impediment to agricultural development has previously been the poorly drained yellow grey soils. Tile drainage has been an important aspect of development, which still continues as new drains and maintenance of the existing drain network. Landuse has been intensive sheep farming with some cropping. Some farms then converted to dairy in the 1990s, which accounted for around 25% of the plain's area (ORC, 1998b). Milton town is on reticulated water supply, sourced from the East branch of the Tokomairiro River, which replaced groundwater. However, residents remarked regarding the taste which may indicate high iron/manganese concentrations in the former groundwater source. Rural properties across the plains are supplied via the North Bruce scheme, apart from those who opted out, who generally still use groundwater and some rainwater collection. The scheme supply is deemed sufficient for sheep farming. However, it is not for dairying, which needed to be supplemented, usually using private, individual private bores (ORC, 1998b).

The Tokomairiro Basin is located within the easternmost fault angle depression or graben of the Otago basin and has a complex structural history, being dissected by several faults. The basement rock throughout the Tokomairiro Basin is composed of Otago Schist (part of the Haast Schist) overlain by Tertiary sediments where they have resisted erosion. Although the Tertiary deposits elsewhere can potentially include aquifers, they are unlikely to form variable aquifers in the Tokomairiro Basin. The Tertiary sediments are overlain by Quaternary sediments, which appear to be continuous, with most of the wells in the area abstract from the shallower Quaternary sediments.

Three Quaternary sediments were mapped at Milburn. These include fan gravel, well-bedded pebbly gravels with grey reddish silts that dip up to 20° to the northwest. Alluvial deposits form the low terrace of the surface of the Tokomairiro catchment are differentiated from the more recent alluvium occurring in the incised valleys and streams. The older deposits, which are exposed on the banks of the Tokomairiro River, consist of slightly weathered, unconsolidated sand, silt and gravel. Much of the area is blanketed by 3-4m of loess, principally composed of silt sized quartz grains, which was deposited very recently during the last Glacial Advance (<30,000 years).

There are generally no springs or artesian flowing wells on the plain. That, and the generally consistent depth of the water table suggest an unconfined aquifer. However, there are several bores that exhibit a degree (although for some it may just be seasonally) of artesian flow, indicating that stratified, semi confined or perhaps confined conditions may occur in some parts of the plain and at greater depths. This is similar to the pattern observed in the Lower Taieri plain which has a similar geological history. Groundwater flow is determined by the surface drainage patterns and generally follows the surface topography. Groundwater from Milburn-Back Road area flows west to the North Branch of the Tokomairiro whilst groundwater in the Moneymore area flows north to the west branch of the Tokomairiro near the Clarksville-Milton reach. Groundwater will therefore naturally seep into the Tokomairiro throughout most of its length across the plain. There is no aquifer pump test information available from the area (ORC, 1998b).

According to the database there are 169 bores in the Tokomairiro Plain basin. There is total depth information for 103 bores, with depths ranging between 1.9 and 70m. The SWL information is for 22 bores, and ranges between 0.1 and 16.14m, which is similar to the information provided in ORC (1998b). Screen depth information is available for 5 bores and it ranges ranging between 0.8 and 44.11m. Screen lengths are usually around 1m. Bore logs are available for 15 bores. The main groundwater uses include stock water, domestic, irrigation, commercial and investigation.

4.3.2.1 Groundwater quality monitoring

Groundwater quality in the Tokomairiro Plain GWMZ is monitored at bore H45/0314 (125mm diameter). The bore is located west of the intersection between Limeworks Road and SH1 near Milburn, at NZTM E 1368244 N4892910. The bore depth is 11.28m. The bore log describes 2.1m of clay underlain by claybound gravels to 18.7m underlain by mudstone to 19.7m. However, the recorded bore depth is 11.28m. There is no screen depth information for this bore but it is likely to be screened within the clay bound gravel horizon, at a likely depth of around 9-10m.

Groundwater quality results from bore no. H45/0314 were compared against the DWSNZ. None of the results exceeded the E. Coli (

Figure 101) or dissolved arsenic (

Figure 102) MAVs. Nitrate concentrations are low, with a maximum of 0.0065mg/L, which is substantially lower than the 11.3mg/L MAV,

Figure 103. The ammonia concentrations are also below the GV,

Figure 104. These results do not suggest that there are any groundwater quality issues in this bore.

Figure 101: Groundwater E. Coli count for the Tokomairiro GWMZ

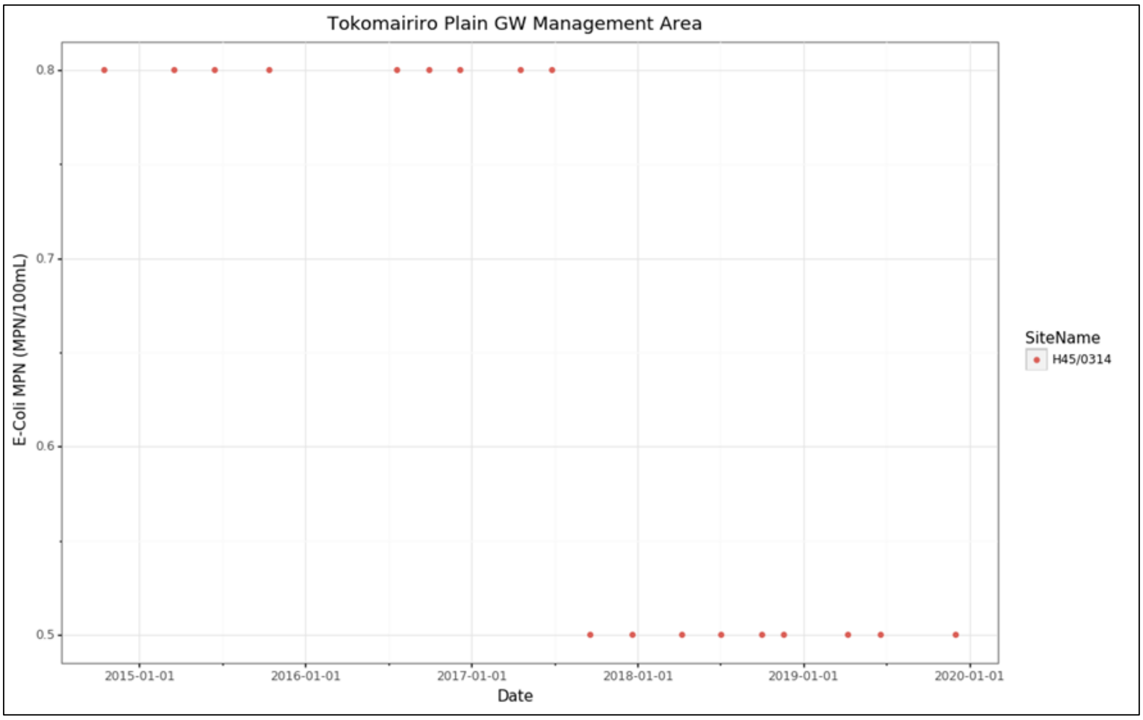


Figure 102: Groundwater dissolved arsenic concentrations for the Tokomairiro GWMZ

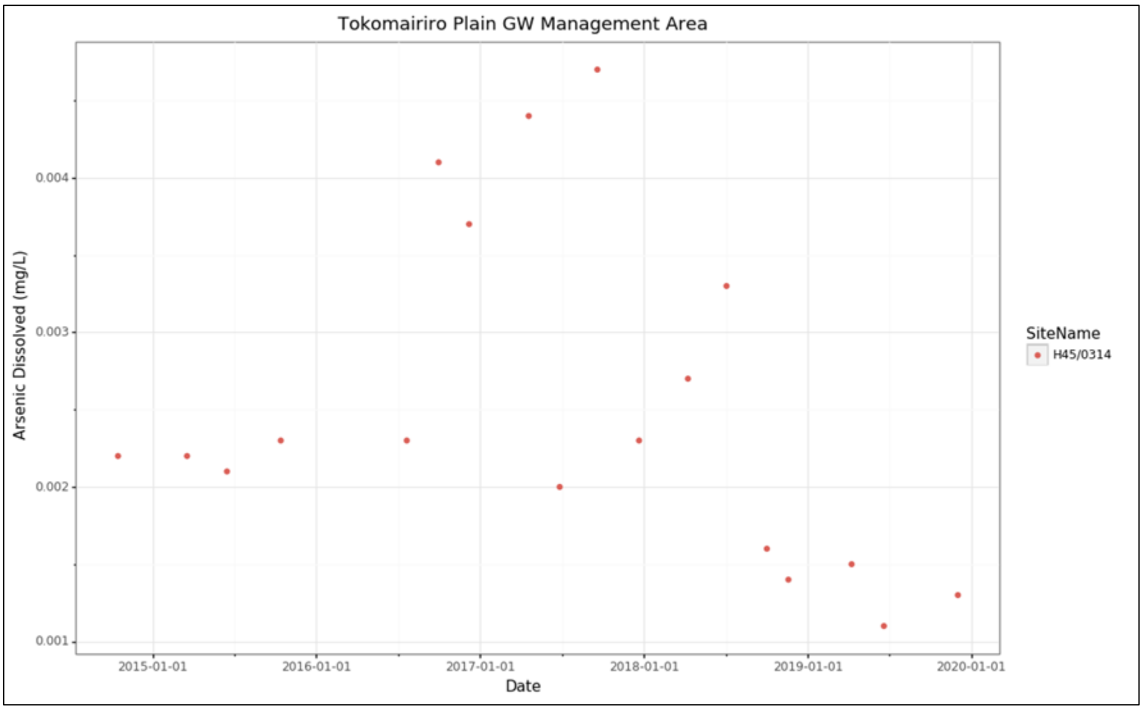


Figure 103: Groundwater nitrate concentrations for the Tokomairiro GWMZ

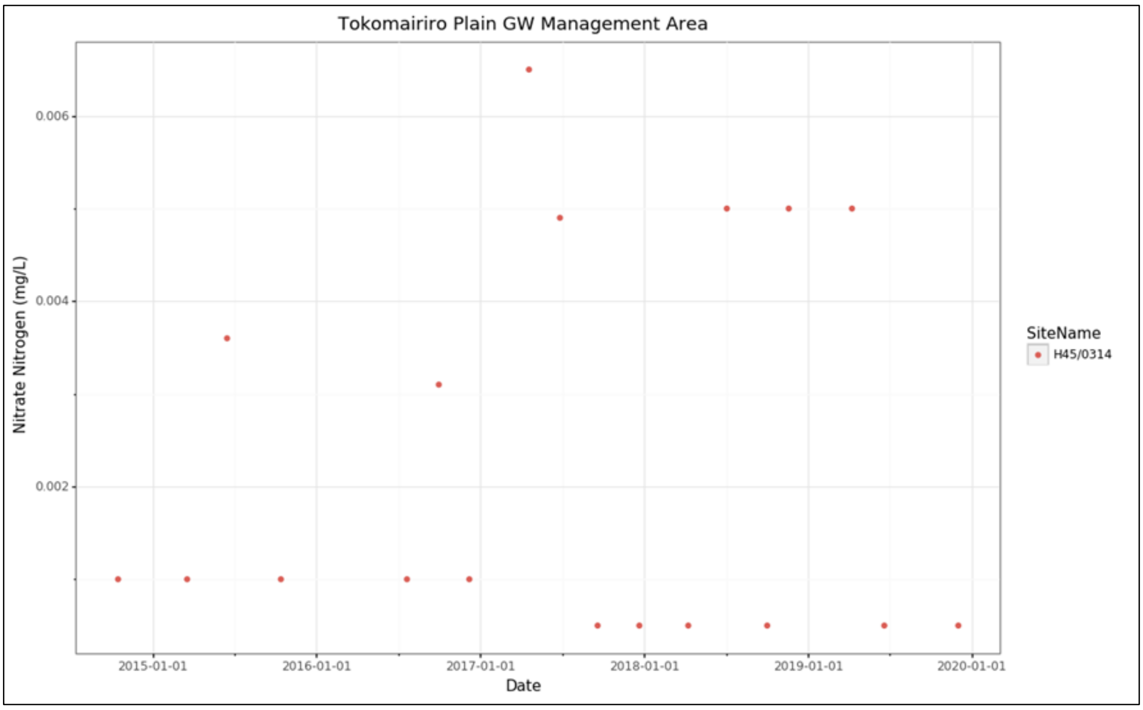


Figure 104: Groundwater ammonia concentrations for the Tokomairiro GWMZ

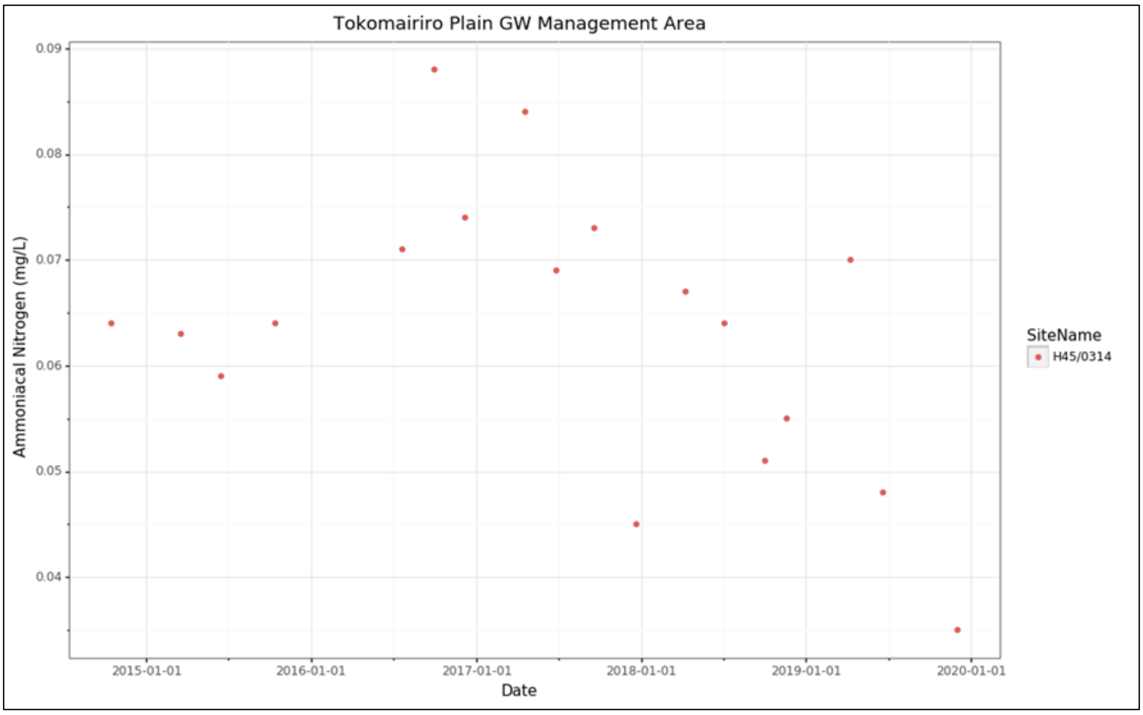
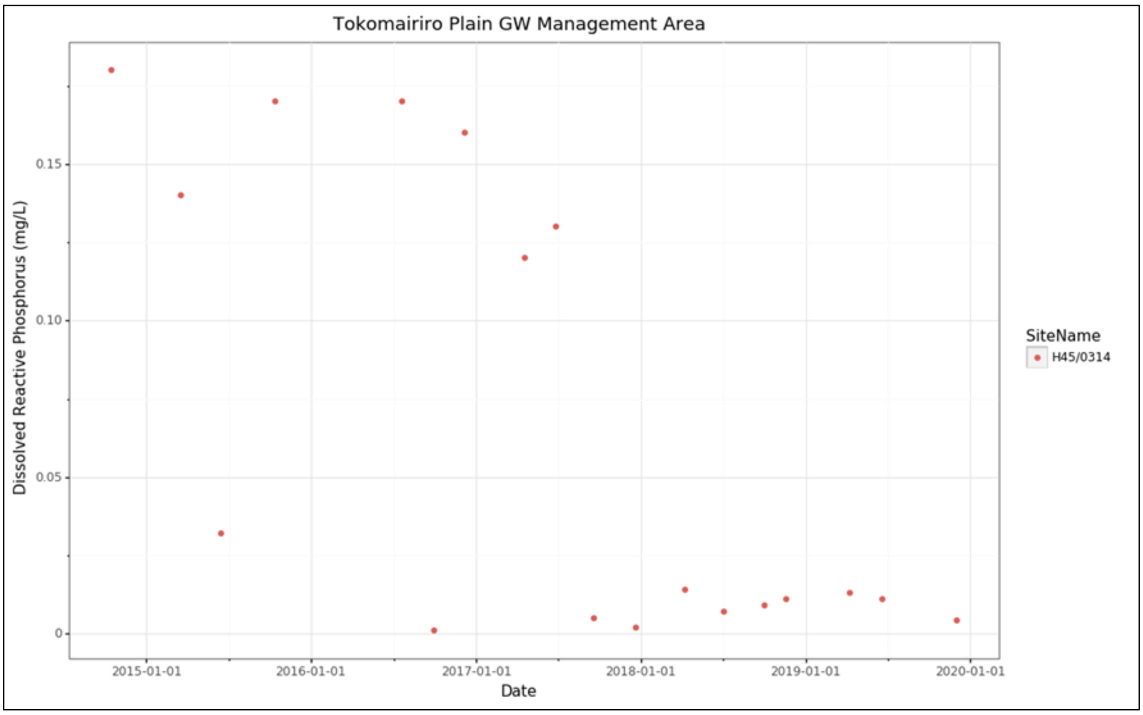


Figure 105: Groundwater Dissolved Reactive Phosphorus concentrations for the Tokomairiro GWMZ



The results were then assessed against the Schedule 15 limits (Table 47) and the NPS-FM NOF (Table 48). Bore H45/0314 is located in Group 1 of the Schedule 15 receiving water group. The results indicate potential issues with DRP, with the 80th percentile concentrations exceeding the limit by over five times. The DRP results were high, ranging between 0.0175 and 0.125mg/L between 2014 and 2017. Concentrations than fell after June 2017, ranging between 0.001 and 0.014mg/L,

Figure 105. This decline is potentially associated with a change in land use. The nitrate and ammonia concentrations are below the Schedule 15 thresholds.

Table 47: 80th percentile values for Schedule 15 water quality variables for the Tokomairiro GWMZ

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H45/0314	Dunedin & Coast		Tokomairiro	0.006	0.152	0.072

The results were then compared against the NPS-FM NOF, Table 48. The median and 95th percentile DRP concentrations are in Band C and D, respectively. DRP concentrations at Band D are substantially elevated above natural reference conditions and are impacting ecological communities. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and hypoxia losses of sensitive taxa, causing significant changes in fish and macroinvertebrates communities. The median and maximum ammonia concentrations are both in Band B, where an adverse toxicity impact on the 5% most sensitive species begins to take place. This band provides a 95% species protection level (MfE, 2020). The median and 95th percentile nitrate concentrations are in both in Band A. These results indicate potential issues, particularly regarding DRP although concentrations appear to fall from the 2017 peak. Elevated ammonia concentrations seem to also present an issue, although to a lesser degree. It is therefore important to maintain a watch on groundwater quality at this site.

Table 48: NOF comparison for nitrate, ammonia, and DRP for the Tokomairiro GWMZ

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
H45/0314	0.001	0.01	A	A
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
H45/0314	0.064	0.088	B	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
H45/0314	0.0135	0.1715	C	D

4.4. The Taieri FMU

4.4.1 Background information

The Taieri FMU contains the catchment of the Taieri River, with an area of 5,650km^2. This FMU includes the Maniototo Tertiary Aquifer, Strath Taieri Basin, and the Lower Taieri Basin (Figure 106). Background information on the FMU is provided in Section 4.4.1. Groundwater quality results for the FMU is provided in Section 4.4.2. Descriptions of the different aquifers and their groundwater quality results are provided for the Maniototo Tertiary Aquifer (Section 4.4.3), Strath Taieri aquifer (Section 4.4.4), and the Lower Taieri aquifer (Section 4.4.5).

The Taieri River is Otago's second largest, with a total length of 318km, the 4th longest in New Zealand. The Taieri originates in the Lammerlaw, Lammermoor and the Rock and Pillar Ranges in Central Otago. It then meanders in a north easterly direction across the Upper Taieri River Scroll Plain, a large natural wetland located in the centre of the Maniototo and Styx basins. This unique area contains nationally and regionally significant landscape and biodiversity values.

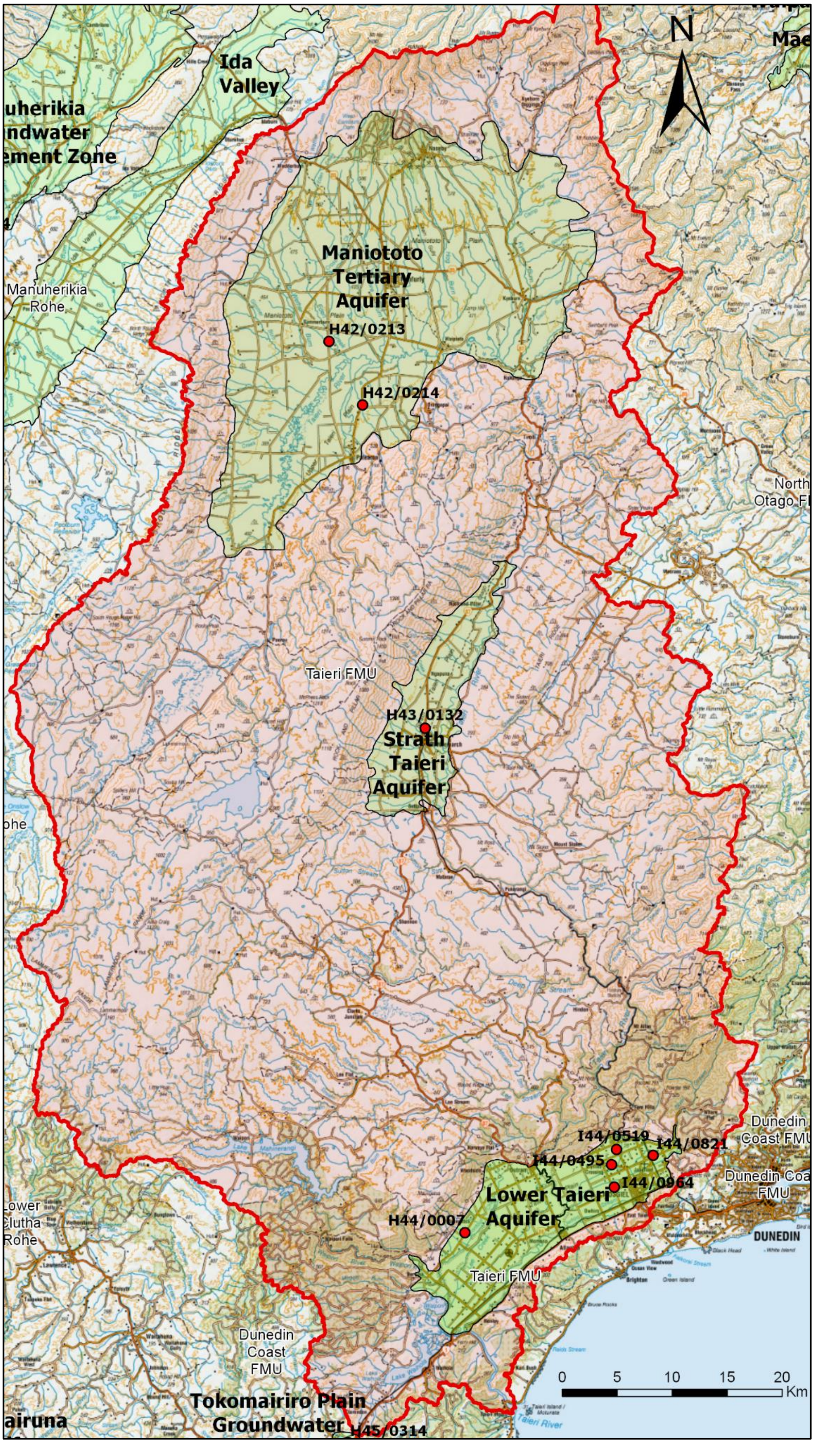
The Upper Taieri has two major catchments whose sizes exceed 1,000km^2: the Logan Burn and the Kye Burn. The Logan Burn originates in the Rock and Pillar and Lammermoor Ranges. The Rock and Pillar Range is located to the east. It is about 20km in width and it extends north east from the Lammermoor range for around 45km. The highest peak on the Rock and Pillar, Summit Rock, is 1,450m above sea level (asl). This prominent feature divides the Upper and Strath Taieri, where the Taieri River collects tributaries from the ridge's western, northern, and eastern slopes. The Kye Burn originates in the Ida Range and Kakanui Mountains. These ranges contain the highest elevations in the catchment (Mount Ida, 1691masl and Mt. Pisgah, 1,643masl, respectively) and are snow capped for several months of the year.

Many of the tributaries from the surrounding ranges flow into the Taieri River through gorges and down alluvial fans located on the Maniototo Plain. The tributaries from Rough Ridge in the west include the Linn Burn and Totara Creek. Tributaries from the Rock and Pillar Range in the south include the Logan Burn, Sow Burn, and Pig Burn. Tributaries from the Ida Range in the north include the Kye Burn, Wether Burn, and the Hog Burn. The tributaries from the Kakanui Mountains in the northeast include the Swin Burn. From the Maniototo, the Taieri flows through an incised gorge and crosses the Taieri Plain, where it joins the catchments of Lakes Waipori and Waihola, becoming tidal before flowing through another gorge and into the sea at Taieri Mouth, approximately 30km south of Dunedin (ORC, 2017a).

Rainfall throughout the Taieri catchment is highly variable and is especially low in Central Otago due to the Alps' rain shadow effect. The predominantly dry climate, combined with significant areas of low relief typical of the Upper Taieri, Maniototo, and the Strath Taieri Plains increases the need for irrigation. This intensifies landuse (e.g. arable cropping) and raises the pressure on water resources and quality. Rivers located in dry areas have low water yields, which reduces their dilution and flushing capacity. Land use intensification in these catchments can therefore increase their susceptibility to elevated nutrients and water quality degradation (ORC, 2017a). The Upper Taieri is one of the driest, coldest, and hottest areas in New Zealand, with a high temperature range of between 30 and -15°C in the summer and winter, respectively, recorded near Naseby and in the north of the Taieri catchment. The mean annual rainfall is highly variable, with a minimum of 396mm (Patearoa) and a maximum of 758mm (Dansey's Pass). The lowest rainfall is usually during winter and early spring, and the highest rainfall in December.

The region is dominated by catchments that receive very low mean annual rainfall (<500mm), with REC of predominantly cool/dry low elevation rivers and cool/dry hill rivers. The predominant land cover through the region is high producing grassland. The upper reaches of the Logan Burn and Kye Burn are steep and have moderate to severe physical limitations for arable cropping. These areas are dominated by low producing grassland and native cover. The ranges in the Upper Taieri catchment are also dominated by native cover. Land use intensity on low producing grassland have low nutrient leaching levels, which provide for good water quality.

Figure 106: Location of the Taieri FMU (red), aquifers (green) and SoE monitoring bores (red dots)



4.4.2 Summary of groundwater quality results

The median groundwater quality results for the DWSNZ and ecosystem health parameters for the FMU are shown in Table 49. The results indicate potential risk for faecal contamination, with bores in all three of the FMU's aquifers exceeding the E. coli MAV. There are also elevated nitrates in some bores, which exceed ½ of the MAV. Conversely, nitrate concentrations in other bores were within natural reference conditions. Elevated arsenic was measured in one sample in the Strath Taieri in 2009. However, it is likely that this was a single incident, potentially due to sampling or analytical error, and does not indicate continuous risk. The assessment against surface water quality limits is summarised in Table 50 and Table 51. This indicates potential issues, with exceedances of the Schedule 15 limits for nitrates in all aquifers, nitrates and DRP in two aquifers and ammonia in one. . It is likely that some of these elevated results are due to monitoring bores being shallow, insecure, and located near high risk land uses (e.g. dairy farms or septic tanks). The potential impact on surface water quality is enhanced due to bores' shallow depth and proximity to surface water bodies.

Table 49: Median concentrations for DWSNZ/ecosystem health parameters for the Taieri FMU

Aquifer	**Ammonia (mg/L)**	**Dissolved Arsenic (mg/L)**	**DRP (mg/L)**	**E-Coli (MPN/100mL)**	**Nitrate Nitrogen (mg/L)**
Lower Taieri	0.009	0.001	0.015	0.500	1.530
Maniototo Tertiary	0.050	0.001	0.049	0.800	1.715
Strath Taieri	0.005	0.001	0.039	0.500	1.460

Table 50: NOF comparison for nitrate, ammonia, and DRP for the Taieri FMU

	Nitrate Nitrogen (mg/L)		NOF Band	
Bore no.	50% (mg/L)		95%ile	Band
H43/0132	1.46	B	1.7	B
I44/0519	2.4	C	3.3	B
H42/0213	0.0495	A	0.2215	A
H42/0214	4	C	5.865	C
	Ammoniacal Nitrogen (mg/L)		NOF Band	
Bore no.	50%	max	Median	95th percentile
H43/0132	0.005	0.049	A	A
I44/0519	0.019	5.43	A	D
H42/0213	0.235	0.55	B	C
H42/0214	0.0025	0.25	A	B
	Dissolved Reactive Phosphorus (mg/L)		NOF Band	

Bore no.	Median	95th percentile	Median	95th percentile
H43/0132	0.039	0.054	D	C
I44/0519	0.0025	0.0111	A	A
H42/0213	0.1125	0.1984	D	D
H42/0214	0.0425	0.04915	D	C

Table 51: Schedule 15 comparison results for the Taieri FMU

Bore number			**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
I44/0519	Taieri	Lower Taieri	2.900	0.006	0.102
H42/0213	Taieri	Maniototo Tertiary	0.109	0.143	0.386
H42/0214	Taieri	Maniototo Tertiary	4.320	0.047	0.007
H43/0132	Taieri	Strath Taieri	1.600	0.048	0.010

4.4.3. The Maniototo Tertiary aquifer

4.4.3.1 Aquifer information

The Maniototo is a low-lying basin in Central Otago. It is surrounded by the Kakanui and Ida ranges to the north and east, the Rock and Pillar range to the south and the Rough Ridge range to the west. The elevation of the basin ranges between 300 and 600m above sea level and the surrounding ranges rising over 1000m. The defined aquifer area is 785km^2, making it the largest in Otago.

The Maniototo is drained by the Taieri River, which flows through the southern part of the basin and captures all surface drainage from the surrounding ranges. The river emerges from a rock gorge into the basin south of Patearoa. It then exits the basin south of Kokonga where it enters another rocky gorge. The topography between these two points is flat and the river is meandering, forming many oxbow lakes and marshes. Much of this land is included within the Upper Taieri Wetlands Complex, listed in the RPW as a regionally significant wetland.

The rainfall in the northern part of the basin, along the Ida Range and Kakanui Mountains, receives higher rainfall than the southern part. The surrounding ranges receive significantly higher rainfall than the basin, with a total of >2,000mm/year. Rainfall is concentrated in the summer months and some precipitation falls as snow during the winter. However, the annual Potential Evapotranspiration (PET) exceeds rainfall, often by >400-600mm. PET has a strong seasonal trend which reflects the hot summers and cool winters. The main land use in the basin is sheep and beef grazing. Due to the dry climate, irrigation is used to support pasture growth for stock grazing. However, dairy farming has increased in recent years, particularly in the southern part of the basin. There is also forestry in the northern part, west of Naseby (ORC, 2014e).

The Upper Taieri/Maniototo area contains several important wetlands. The Upper Taieri Wetlands Complex includes three sub areas located on the Taieri River floodplain: the Styx (Paerau) basin Wetlands, the Maniototo Basin Wetlands, and Taieri Lake Wetlands. The Styx Basin wetland consist of a scroll plain landform of meanders, oxbows, old braids backwater and cut offs that stretch from near Paerau to Canadian Hut. It includes the 136ha Serpentine Wildlife Management Reserve. The Maniototo Basin Wetlands, downstream of the Styx Wetlands, are of similar landform and includes the 37.5ha Eden Creek Wildlife Management Reserve and the 44ha Halls Road Wildlife Management Reserve. The Taieri Lake Wetlands lie adjacent to the Taieri River, downstream of the Maniototo Wetlands. They encompass part of the 187ha Taieri Lake Recreation Reserve. The Belmont Inland Saline Management Area is a 20.4ha salt pan south of the Puketoi Road/ Puketoi Runs Road intersection.

The Maniototo Basin is underlain by greywacke of the Rakaia Terrane, typically composed of quartzofeldspatic sandstone and mudstone. The basin's shape was formed by a series of northeast trending folds and faults, some of which are still currently active. The basin geology consists of sedimentary rock of Miocene and Pliocene age (the Manuherekia and Hawkdun groups) overlain by Quaternary sediments. The Manuherekia group sediments were deposited in deltaic, fluvial and lake margin setting (i.e. low energy environment) and comprise of quartz, conglomerate and sandstone with minor sandstone and lignite seams. The Hawkdun Group overlies the Manuherekia group and hosts the well indurated Maniototo Conglomerate that covers most of the area northeast of Ranfurly. The Quaternary sediments were deposited by fan or alluvial processes. The older Pleistocene materials that make up the terraces are composed of weathered gravel and sand with some loess cover. The more recent Holocene alluvium were deposited along river and stream valleys and are comprised of unconsolidated sands and gravels. The sediment thickness in the Maniototo basin was not determined in detail but data suggests that the depth to the (greywacke) basement ranges between 88 and >250m. Most of the sediments described in the logs are composed of mudstone or siltstone with thinner units of sandstone, conglomerate, and some lignite measures (ORC, 2014e).

The aquifer systems in the Maniototo are complex and can be divided to two main categories: shallow unconfined aquifer in the Quaternary sediments (Pleistocene and Holocene) and a deeper confined aquifer in the Cenozoic sediments (Neogene and Paleogene). The Pleistocene sediments are older and form the basin terraces whilst the younger Holocene alluvium deposits are located in flat valley bottoms adjacent to surface water bodies. Both are comprised of unconsolidated sands and gravels although they are also likely to contain lenses of finer material. These sediments form a permeable, unconfined aquifer that can be high yielding and normally consist of a shallow water table.

The deep confined aquifers of the Cenozoic sediments have a deep water table and are at times artesian. These sediments are comprised of siltstone/mudstone with minor sandy layers. Most of the artesian bores are found in the southern part of the basin, near the entrance of the Taieri River to the basin, in the central part, near the Eden Creek/Taieri confluence, and east of that area, near the crossing of the Taieri and Ranfurly Patearoa Road (near the Ewe Burn). There is also one artesian bore in the Kye Burn area (ORC, 2014e).

Groundwater flow direction is generally to the southeast, broadly following surface topography, and discharging into the Taieri River as baseflow. Previous studies on some of the streams that flow into the Taieri showed that some tributaries like the Kye Burn and Sow Burn lose groundwater for a reach as the streams come out of the hillside and flow over the alluvial gravels. Flow is then re-established before the streams discharge into the Taieri River. This illustrates the importance of groundwater to the basin's hydrology, particularly during low flows (ORC, 2014e).

The catchment is considered fully allocated for surface water, although some storage potential may be available. Irrigation in the basin has grown significantly and the currently maximum take from the basin is around 1.41 million m^3/year. Some of the bores are screened in the shallow Pleistocene/Holocene sediments whilst others are from deeper confined Paleogene or Neogene sediments. Irrigation takes from the deeper confined aquifer were only developed since 2003. The confined aquifers are likely to abstract from discontinuous lenses of sand and gravel. The discontinuous nature of these lenses makes it difficult to determine whether groundwater users are abstracting from the same aquifer, which makes aquifer management difficult. Additionally, there is also the risk of abstracting from a perched/very limited aquifer which can be overused and depleted. Although the unconfined aquifers are separated from the confined ones by low permeability aquitard materials, abstraction from the lower, confined aquifer may still impact the unconfined aquifer and surface water by inducing leakage (i.e. from the overlying aquifer, surface water, or at the margins of water bearing layers where the aquitard may thin out) [ORC, 2014e].

Available aquifer and hydrogeological properties information for the Maniototo is limited. The ORC database holds pumping test information for two bores: H42/0190 (86m deep, abstracting from the confined aquifer) and bore H42/0203 (5.5m deep, unconfined). The estimated Transmissivity ranges between 400-500m^2/d. There are also specific capacity tests from 10 drilling logs, with inferred Transmissivity ranging between 4 and 618m^2/day for the confined aquifer and between 3 and 465m^2/day for the unconfined aquifer (ORC, 2014e). However, although these can provide an estimate of the aquifer permeability, they also strongly depend on bore construction, pumping duration and flow rate. The lack of such data highlights the need to obtain this information during consent application process.

Groundwater samples indicate similar composition to that of the Kye Burn, suggesting that groundwater are derived from the same source as the Kye Burn and that groundwater contributes to the Burn's baseflow. However, the data suggests potential for cation exchange processes, which, coupled with the mixing of shallow and deeper groundwater, will continue to provide additional variation of these parameters. Water mixing can be due to bore construction across different strata, upwelling of deeper groundwater from the hills as it discharges to the Kye Burn (and the Taieri) and the proximity of bores to geological faults. Some bores that abstract from the Tertiary sediments, which are usually deeper than 30m, may also represent older groundwater with longer residence time (ORC, 2014e).

The main sources of groundwater recharge in the basin are rainfall, irrigation excess and surface water recharge. Rainfall recharge was assessed by ORC (2011). The mean annual recharge for the 38 year model period is 40.6mm, or 31.6million m^3/year. The data shows strong variability with variation of between 2 and 160mm recharge/year, which reflects variation in the timing and depth of annual rainfall. The rainfall recharge is around 6% of the annual rainfall and the highest recharge is on average during the winter months. Irrigation returns were not included in the model (ORC, 2011).

The Maniototo Basin is fully drained by the Taieri. The total volume of groundwater abstractions minus any losses to groundwater through evapotranspiration is likely to result in net flow loss for the Taieri after a sufficiently long duration for a steady state condition to occur. Hence, any groundwater takes in the basin can potentially decrease baseflow to the

Taieri. After pumping starts, the stream depletion rate can slowly increase. The duration of reaching maximum depletion rate can range between hours and decades and it depends on the aquifer properties and the distance of the bore from the stream. This is the time lag or lag effect. In some circumstances, stream depletion can continue to increase even after pumping stops (ORC, 2014e).

For the shallow Quaternary unconfined aquifers in the Maniototo, stream depletion is a function of the distance from the stream and the hydraulic conductivity of the aquifer and stream bed. For the Neogene/Palaeogene confined aquifers, the limited hydraulic connection with the surface water due to the aquitard between the aquifer and stream bed may further increase the lag effect. Hence, takes from the confined aquifer, even close to the stream may have a significant time lag. Therefore, despite any provisions designed to consider surface water depletion by groundwater takes in the RPW, these will not be effective in addressing the potential for long term baseflow depletion for the Taieri, which is significantly over-allocated. Any further groundwater abstraction from the Maniototo Basin is therefore likely to contribute to further worsen the situation

According to the database there are 201 bores in the Maniototo basin. Total depth information is available for 143 of these, with recorded depths ranging between 0.25 and 205m. The SWL information is available for 64 of the bores, with the reported SWL ranging between 0.04 and 34.6m. There is screen information for nine of the bores, with the reported top of screen depth ranging between 2.6 and 41.41m. Bore logs are available for 34 of the bores. The main groundwater uses include domestic, irrigation, stock water, exploration and monitoring.

4.4.3.2 Groundwater quality measurements

Groundwater quality in the Maniototo is monitored in two bores, both of which were drilled in October 2014. Bore H42/0213 (150mm diameter) is located south of the Maniototo Road-Gimmerburn-Waipiata Road intersection, at NZTM E1366536 N4993063. The bore depth is 5.6m. The bore log describes coarse brown gravels to 3.8m underlain by blue clay and silts to the bore bottom at 5.6m. The bore is screened between 2.6 and 5.6m, within the gravels and clay/silts horizon. The bore is located very close to Eden Creek. The SWL in this bore ranges between 0.6 and 1.38m below MP, with an annual fluctuation of around 0.35m. The lowest levels are usually measured in late summer (March) and the highest in spring or early summer. There does not appear to be a continuous decline in water levels.

Bore H42/0214 (150mm diameter) is located east of the Sow Burn at the Patearoa-Ranfurly/Greer Road intersection, NZTM E1369602 N4987279. The bore depth is 9m. The bore log describes top soil to 0.4m underlain by alternating horizons of gravels and sand to 5m, whose depths range between 0.5 and 2.0m. There is then silt/silty clay to 7m. These are underlain by silty clay with minor angular quartz gravel underlain by silty fine sand with some clay and gravels down to the well bottom at 9m. The bore is screened at a depth of between 6.0 and 9.0m, within silty clay, where the bottom 1.5m also have some gravel and sands. The overlying silt/clay layer is likely to provide some degree of confinement. Groundwater levels in the bore range between 1.20 and 2.19m below MP. The annual range in water levels in the bore is usually between 0.70 and 0.80m although the range in 2018 was lower at around 0.20m. The lowest water levels are usually in late summer and the highest during spring/early summer. Due to their shallow depths, levels in the bores are likely to be strongly responsive to rainfall.

Groundwater quality results from the bores were assessed against the DWSNZ. The results indicate a high potential for faecal contamination and elevated nitrates. The exceedance of the E. Coli MAV in bore H42/0213 included high counts of 450 (March 2016) and 1,300 (December 2018) MPN/100mL. The results from bore H42/0214 also show some E. Coli exceedances, albeit at a lower count, with a maximum of 79MPN/100mL (December 2018), Figure 107. Nitrate concentrations in both bores are lower than the MAV of 11.3mg/L. However, concentrations in bore H42/0214 range between 3.6 and 6.8mg/L, with the upper ends of this range exceeding ½ of the MAV. The concentrations in bore H42/0213 are much lower, ranging between 0.002 and 0.230mg/L, Figure 108. Dissolved arsenic concentrations in neither of the bores exceeded the MAV of 0.01mg/L, Figure 109. Ammonia concentrations in both bores are lower than the GV of 1.5mg/L, Figure 110.

Figure 107: Groundwater E. Coli count for the Maniototo Tertiary Aquifer

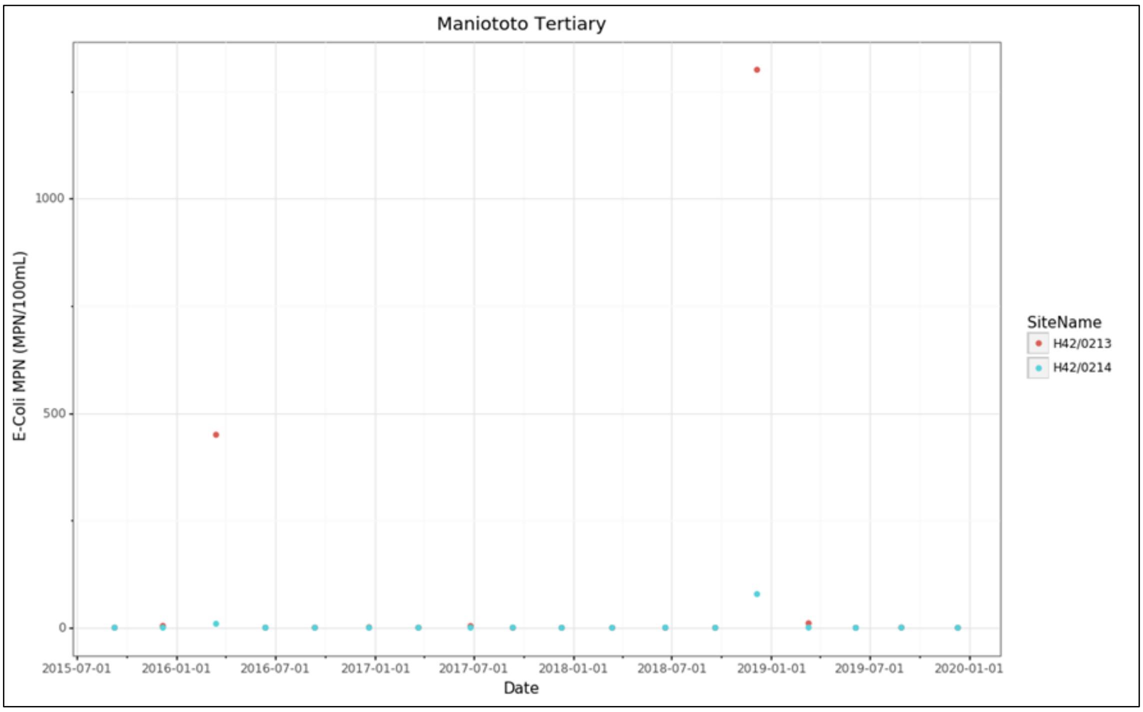


Figure 108: Groundwater nitrate concentrations for the Maniototo Tertiary Aquifer

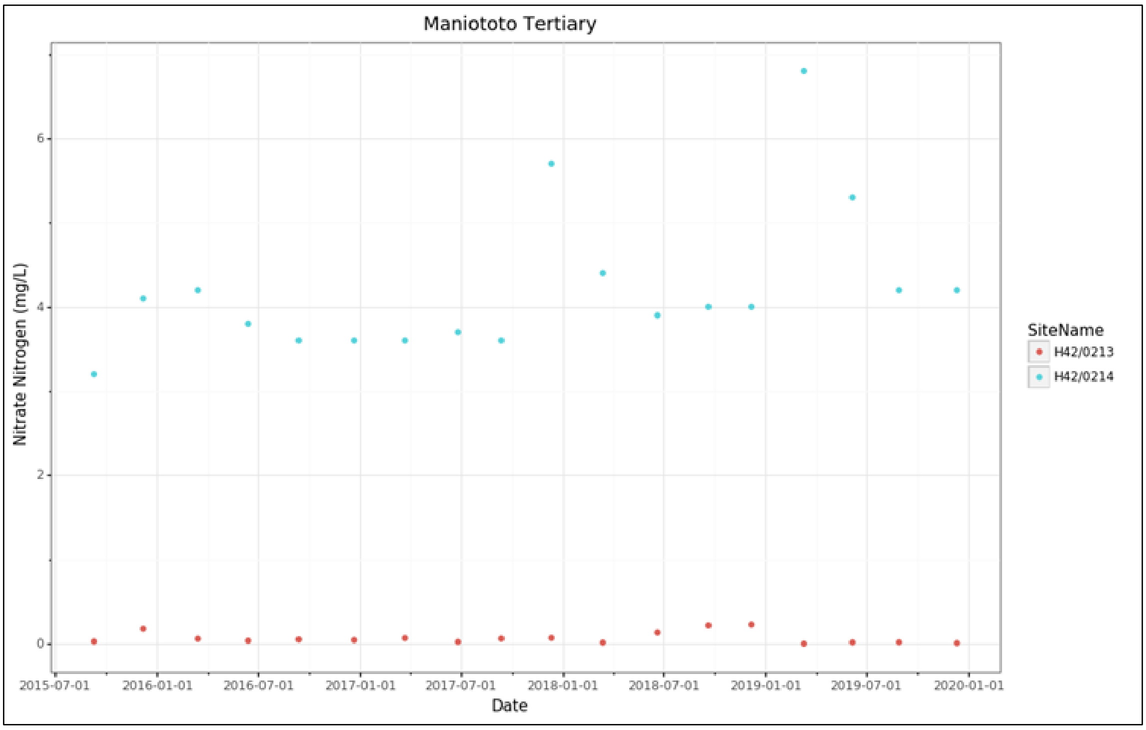


Figure 109: Groundwater dissolved arsenic concentrations for the Maniototo Tertiary Aquifer

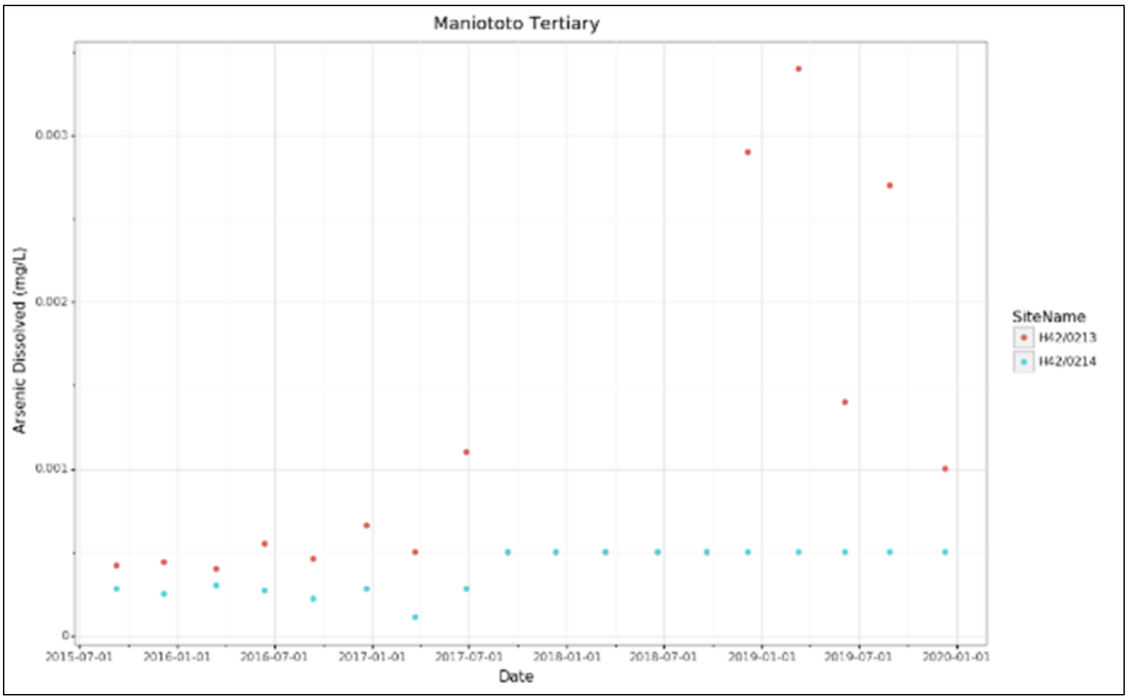


Figure 110: Groundwater ammonia concentrations for the Maniototo Tertiary Aquifer

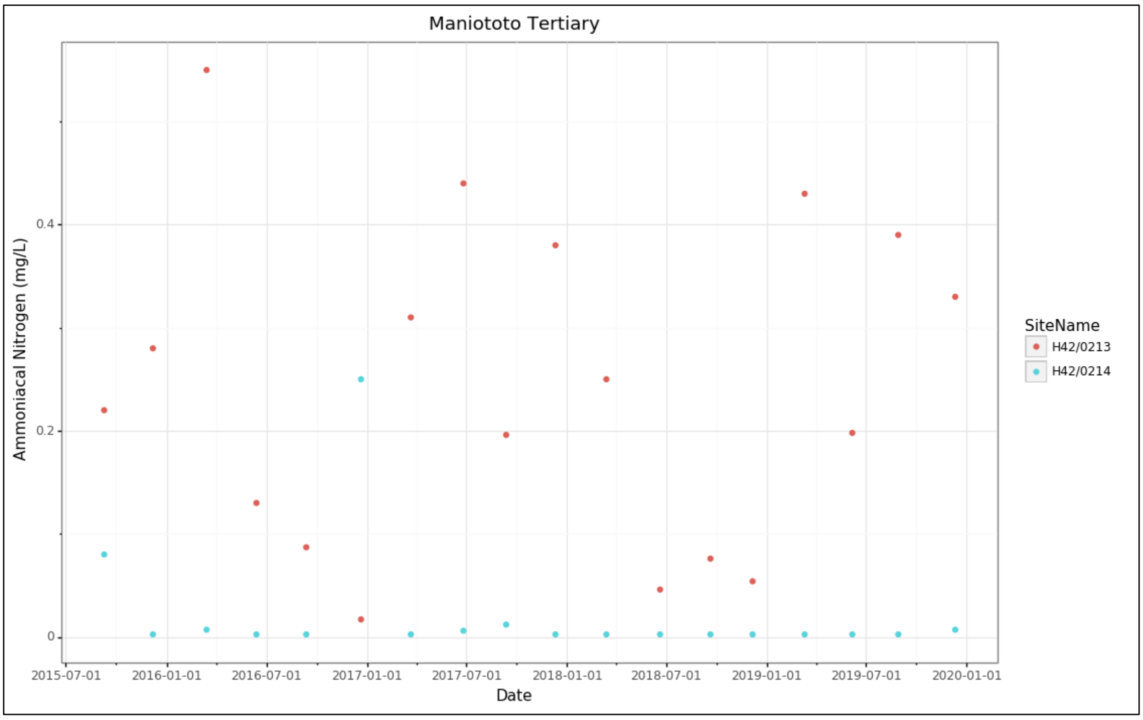
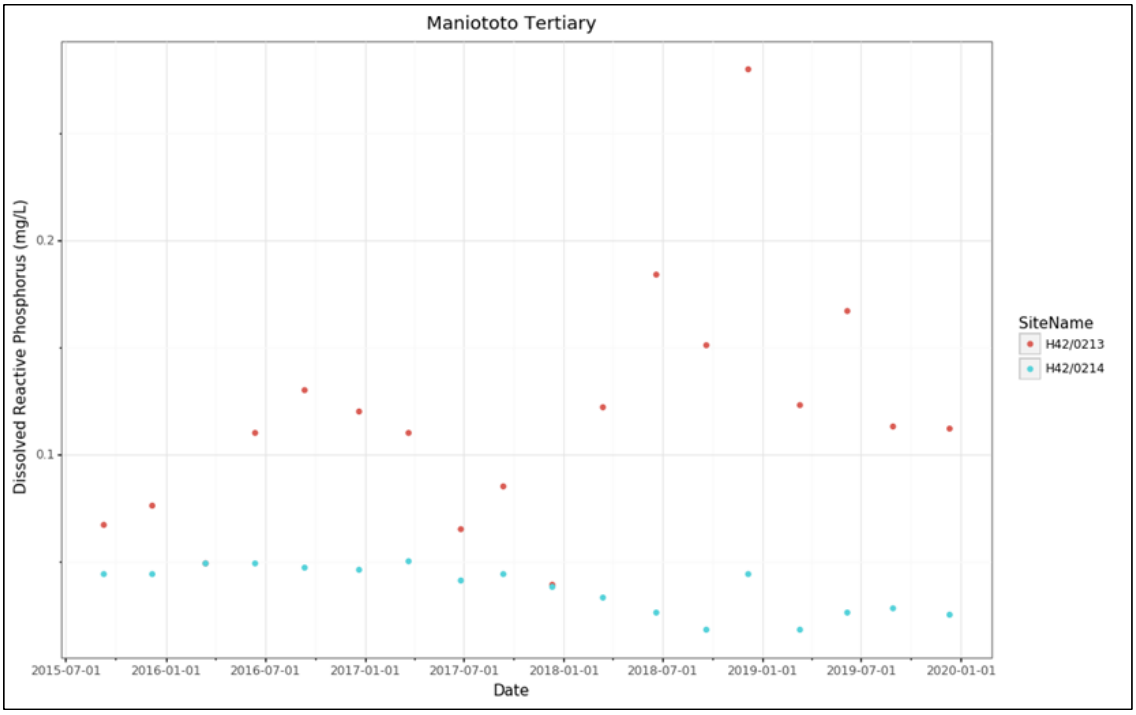


Figure 111: Groundwater Dissolved Reactive Phosphorus concentrations for the Maniototo Tertiary Aquifer



The results were then assessed against the Schedule 15 limits (Table 52) and the NPS-FM NOF (Table 53). Both bores are located in Group 2 and are shallow, hence, interaction with surface water can adversely impact surface water quality. The results indicate potential water quality issues, with the 80th percentile nitrate and DRP concentrations in both bores exceeding the Schedule 15 limits. The nitrate concentrations in bore H42/0214 exceed the limit by around 57 times and by around two times in bore H42/0213. The DRP concentrations in bore H42/0213 and H42/0213 exceed the limit by approximately 14 and 4 times, respectively, Figure 111. Ammonia concentrations in bore H42/0213 exceed the limit by 3.86 times. The concentrations in bore H42/0214 are below the threshold.

Table 52: 80th percentile values for Schedule 15 water quality variables for the Maniototo Tertiary Aquifer

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.075**	**0.010**	**0.100**
H42/0213	Taieri		Maniototo Tertiary	0.109	0.143	0.386
H42/0214	Taieri		Maniototo Tertiary	4.320	0.047	0.007

The results were also compared against the NPS-FM NOF, Table 53. The assessment shows poor results, particularly for DRP, with the median concentration for both bores in Band D and the 95th percentile concentration in Band D for bore H42/0213 and Band C for bore H42/0214. DRP concentrations at Band D are substantially elevated above natural reference conditions and are impacting ecological communities. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and hypoxia losses of sensitive taxa, causing significant changes in fish and macroinvertebrates communities. The median and 95th percentile nitrate concentrations for bore H42/0214 are in Band C, with growth effects on up to 20% of (mainly sensitive) species but no acute effects. The concentrations for bore H42/0213 are both in Band A. The median and maximum ammonia concentrations for bore H42/0213 are in Bands B and C, respectively. Ammonia concentrations in Band C provide 80% species protection level, with a start of regular impact (reduced survival rate) of the 20% most sensitive species. The maximum concentration for bore H42/0214 was in Band B which provides 95% species protection level and a start of impact on the 5% most sensitive species.

Table 53: NOF comparison for nitrate, ammonia, and DRP for the Maniototo Tertiary Aquifer

	Nitrate Nitrogen (mg/L)		NOF Band	
Bore no.	Median (mg/L)	95th percentile	95%ile	Band
H42/0213	0.0495	0.2215	A	A
H42/0214	4	5.865	C	C
	Ammoniacal Nitrogen (mg/L)		NOF Band	
Bore no.	Median (mg/L)	Max.	Median	max
H42/0213	0.235	0.55	B	C
H42/0214	0.0025	0.25	A	B
	DRP (mg/L)		NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
H42/0213	0.1125	0.1984	D	D
H42/0214	0.0425	0.04915	D	C

4.4.4 The Strath Taieri basin

4.4.4.1 Aquifer information

The Strath Taieri basin is located between the Rock and Pillar Range to the west and the Taieri Range to the east. The basin length is approximately 20km and it is around 10km wide, with an area of approximately 200km^2. The basin floor elevation ranges between 200-300masl with the Rock and Pillar rising to a maximum elevation of 1,450m at Summit Rock, around 5km west of the basin. The hills to the east are lower and gentler, with the Taieri Ridge, located along the north eastern side of the basin, reaching 708m and the hills to the southeast/South range between 300-500m.

Surface water drainage consists of the Taieri River, which flows through the basin, and numerous tributaries that drain the adjacent hills. The Taieri enters the basin from a rocky valley to the north and, after meandering along the east side of the basin, turns to the southeast and flows into the Taieri Gorge. The dominant tributary drainage is from west to east with several streams coming off the Rock and Pillar and flowing across the basin into the Taieri. Some of these disappear into alluvial soils before emptying into the Taieri. However, the larger streams are perennial.

The Strath Taieri is characterised by warm summers and cold winters. The mean annual rainfall on the valley floor is around 600-700mm. However, evaporation is also high, at around 500mm/year, which makes the valley prone to drought during dry years. Conversely, the Rock and Pillar range has much higher annual rainfall, at around 1800mm, with evaporation of around 400mm. Hence, even though the valley floor may be dry, flow will remain in many streams that drain the Rock and Pillar range.

The Strath Taieri is a tectonic basin that was formed by the faulting/folding of the Otago Schist basement rocks. The schist age is late Palaeozoic to Mesozoic. During the late Mesozoic-early Cenozoic it was eroded to a relatively flat surface, or a peneplain. This surface was formed in Central Otago during the late Cenozoic either by faulting, folding or both forming a series of northeast trending ridges and valleys that include the Rock and Pillar Range, the Taieri Ridge and the Strath Taieri basin (ORC, 1997c).

The Central Otago ridges, which include the Rock & Pillar and the Taieri Ridge, are asymmetric, with shallower slopes on the west side and steeper slopes in the east. The valleys, including the Strath Taieri basin, are asymmetric in the opposite sense, hence the basement is likely to be deepest along the west side of the valley (i.e. near the steep ridge). The basin was filled with sediment that eroded off the surrounding ridges, mainly the Rock and Pillar. The sediments are predominantly sand and gravels, which become coarser toward the western side of the basin, near the steep slope of the Rock and Pillar. Another source of sediment was deposition from the Taieri River. These fluvial sediments are finer, i.e. fine sands and silts, which were deposited in the slow moving meanders of the river. The resulting soil profile is likely to be a complex system of interlayered lenses of gravel, sand, silty sand and silt (ORC, 1997c).

The areal extent of the sediment is generally between Sutton in the south and approximately 4km north of the Old Rock and Pillar railway station. It is bounded from the east and west by the Taieri River and the Rock and Pillar range, respectively. The sedimentary cover outside of this area is very thin or absent and schist tors are common. To the east, alluvial fans along the base of the Rock and Pillar rise to around 300-400m above sea level, while in the north of the basin sediments do not extend far beyond the old Rock and Pillar station.

The soil throughout the basin area is generally silty sand and gravel, where lenses of finer material are interlayered with coarser material. When holes are dug below the water table the water seems to enter the hole from preferential flow paths as opposed to flow uniformly around the hole. There are also numerous iron pans and minor perched water table observed in an exploration trench west of Middlemarch. Silty soil dominates some areas, where it is difficult to obtain water, at least in shallow wells. Anecdotal information suggests that it is difficult to obtain water on the east side of the railway tracks in Middlemarch township. This area appears to be formerly boggy, with heavy, low yielding soils. These areas can be the remnants of former oxbow lakes or meanders formed during previous flow of the Taieri and deposited finer sediment (ORC, 1997c).

It appears that the Strath Taieri basin contains a single unconfined aquifer that consists primarily of silty gravel. It also contains iron pans and silt lenses that form perched water tables, locally confined aquifer conditions, and channels of preferential groundwater flow. This suggests a fairly heterogenous aquifer with potential for depletion of perched wells. The water table is shallow across much of the valley, at <5m below ground level, but is deeper to the west and locally deeper beneath localised pockets of silt.

The groundwater system in the Strath Taieri is similar to those in the Maniototo, with an unconfined sedimentary aquifer receiving direct rainfall recharge that is augmented by leakage from streams around the basin's edges. Groundwater in the basin generally flows to the east/southeast, parallel to the direction of surface water, before discharging into the Taieri. The horizontal hydraulic gradient, i.e. the slope of the water table, ranges from 0.006 (0.6%) in the southern part to around 0.016 (1.6%) in the northern part of the basin. The hydraulic gradient is around half the gradient of the land surface, hence the water table is deeper in the western part of the valley (i.e. near the steeper side of the Rock and Pillar). Similar to the Maniototo, allocation issues arise due to the close groundwater-surface water interaction, with surface water being fully allocated in the area (ORC, 2006).

According to the ORC database there are 101 bores (completed/blanks status) in the Strath Taieri basin. There is depth information available for 63 of these, with the recorded depths ranging between 2.3 and 103.70m. There is reported SWL data for 20 bores, with the SWL ranging between 0.8 and 35.35m. Screen depth information is available for three of the bores, with recorded top of screen depth ranging between 4.39 and 21.7m. The main groundwater uses in include domestic, stockwater, irrigation and commercial supply. Bore logs are available for 14 bores in the basin. Four of the bores have abstraction consents.

4.4.4.2 groundwater quality monitoring

Groundwater quality monitoring in the Strath Taieri basin is monitored in one bore, H43/0132 (155mm diameter). The bore is located at Swansea Street, Middlemarch, at NZTM E1375278 N4957866. The bore depth is 9.10m. There is no lithological log or screen information available for this bore.

Groundwater quality results from the bore were analysed against the DWSNZ. The results show several exceedances of the E. coli MAV, notably with readings of 80 MPN/100mL (December 2011), 30 MPN/100mL (September 2016), and 9 MPN/100mL (December 2013), Figure 112. This indicates some contamination issues with the bore, although the exceedances are also likely to be due to poor bore security. The dissolved arsenic results show one exceedance, with a concentration of 0.03mg/L (March 2009), which is three times higher than the MAV, Figure 113. However, all the other arsenic results are substantially lower than the MAV, suggesting that the exceedance was an isolated event, potentially due to analytical error. Nevertheless, it is important to keep monitoring arsenic concentrations in this bore. All nitrate concentrations are below the MAV of 11.3mg/L, with most samples ranging between approximately 1.0 and 1.7mg/L. The maximum concentration was 4.7mg/L (December 2012), which is slightly below ½ of the MAV,

Figure 114. Ammonia concentrations were below the aesthetic GV of 1.5mg/L, Figure 115. These results indicate some issues with faecal contamination and potential issues with elevated arsenic. However, the latter is likely to have been a single incident.

Figure 112: Groundwater E. Coli count for the Strath Taieri basin

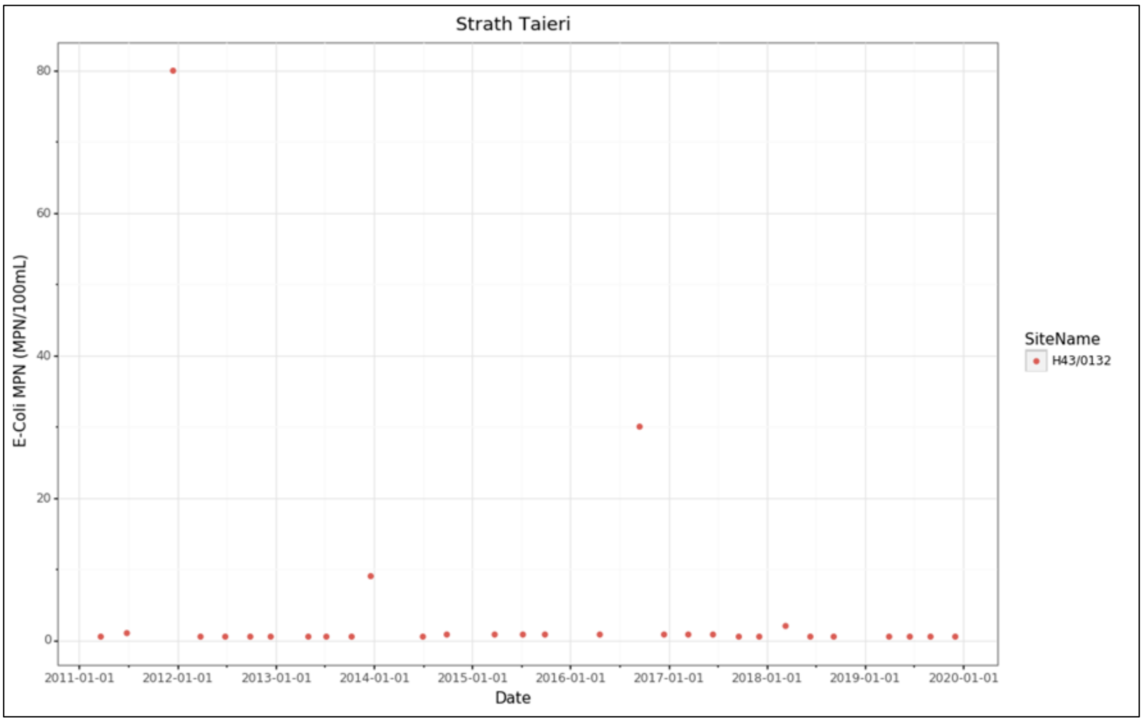


Figure 113: Groundwater dissolved arsenic concentrations for the Strath Taieri basin

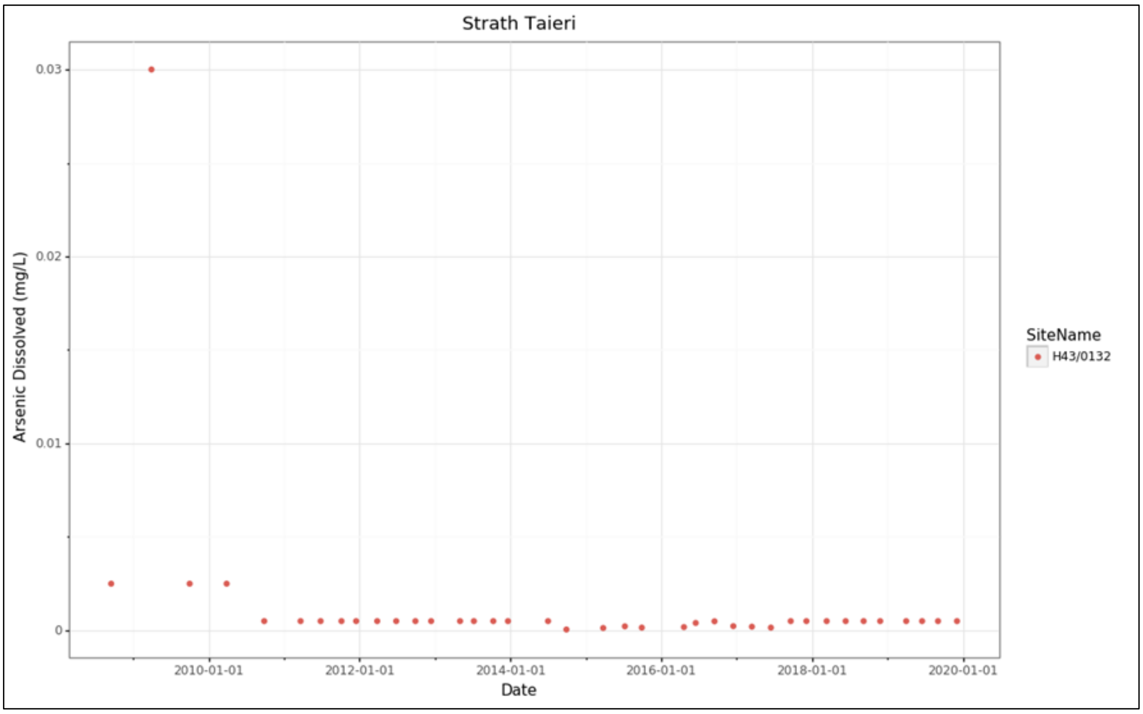


Figure 114: Groundwater nitrate concentrations for the Strath Taieri basin

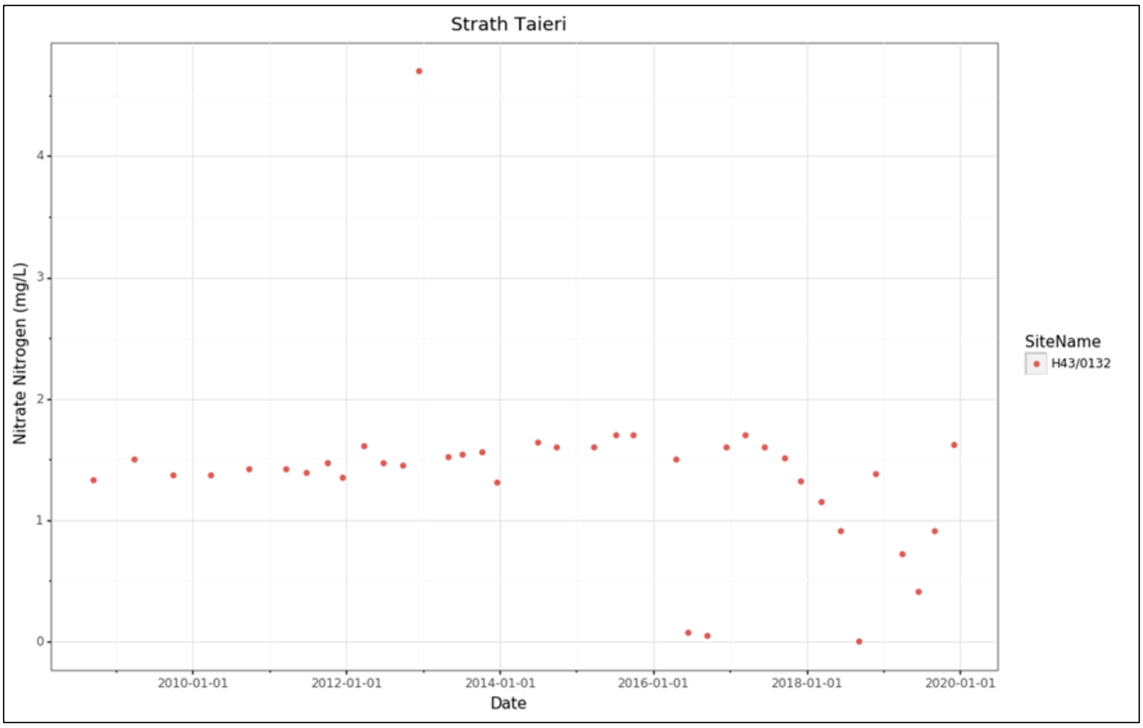


Figure 115: Groundwater ammonia concentrations for the Strath Taieri basin

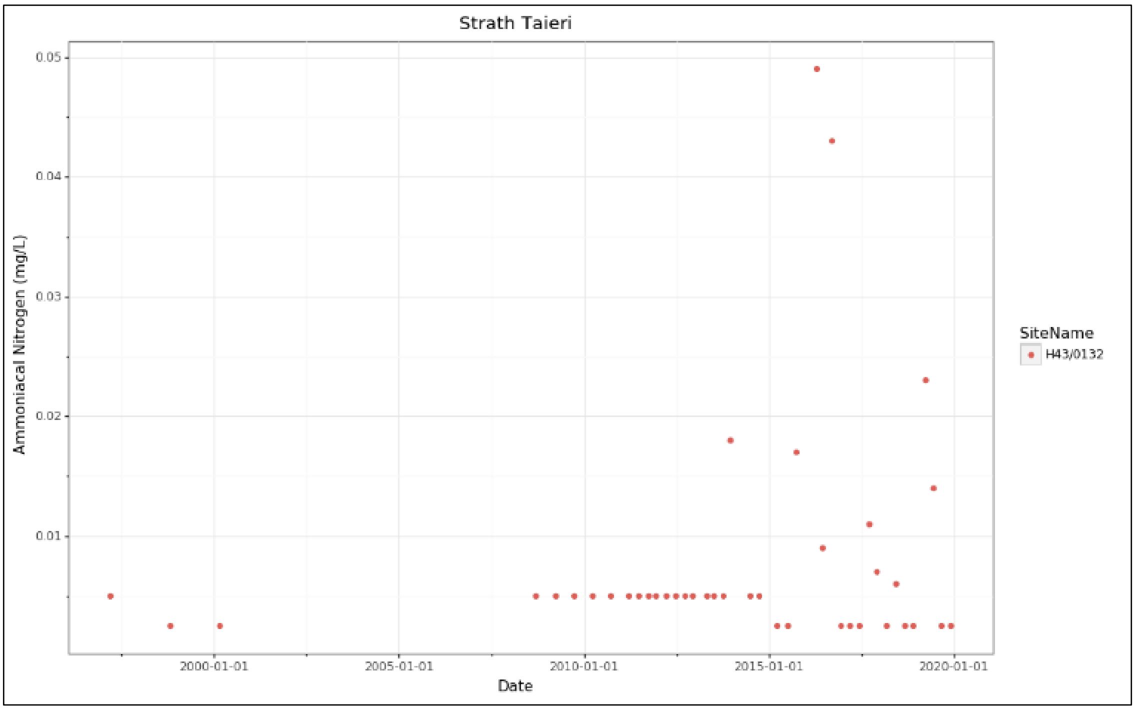
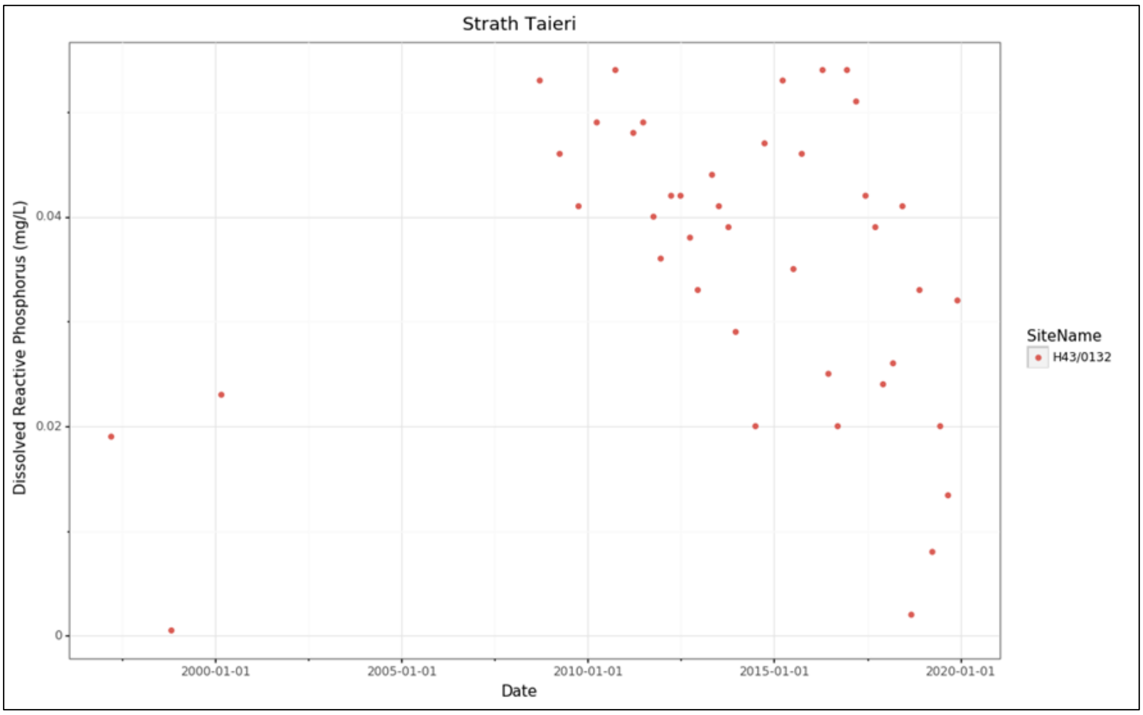


Figure 116: Groundwater DRP concentrations for the Strath Taieri basin



The results were then analysed against Schedule 15 of the RPW (Table 54) and the NPS-FM NOF (Table 55). The results show that the 80th percentile DRP concentrations exceed the limits by around four time. Groundwater DRP concentrations fluctuated over the monitoring period, falling from around 0.058mg/L in 2008 to around 0.02 in July 2014. It then rose again, reaching 0.054mg/L in April 2016. It then fell to around 0.02mg/L in September 2016 followed by an increase to 0.051mg/L in March 2017. It then continued fluctuating between approximately 0.04 and 0.01mg/L (

Figure 116). Nitrate concentrations are over twice the Schedule 15 limit. The ammonia concentrations are below the limit. These results indicate potential water quality issues through the elevated nitrate and DRP concentrations. This risk is further exacerbated due to the bore's shallow depth and proximity to Dewer Stream.

Table 54: 80th percentile values for Schedule 15 water quality variables for the Strath Taieri Aquifer

Bore number			**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
H43/0132	Taieri	Strath Taieri	1.600	0.048	0.010

The assessment against the NPS-FM shows similar results, with the median and 95th percentile DRP concentration in Bands D and C, respectively. This indicates that DRP concentrations are substantially elevated above natural reference conditions. Combined with additional factors that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in fish and macroinvertebrate communities as taxa that are sensitive to hypoxia are lost. The median and 95th percentile nitrate concentrations are in Band B, where some growth effect on up to 50% of species is occurring (MfE, 2020).

Table 55: NOF comparison for nitrate, ammonia, and DRP for the Strath Taieri Aquifer

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
H43/0132	1.46	1.7	B	B
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
H43/0132	0.005	0.049	A	A
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
H43/0132	0.039	0.054	D	C

4.4.5 The Lower Taieri basin

4.4.5.1 Aquifer information

The Lower Taieri groundwater Basin forms a distinct hydrological unit, surrounded on all sides by low permeability rock. Its only connections to the wider Taieri catchment are the Taieri River, Silver Stream, Waipori River and the Henley Gorge section of the Taieri River. The area has been extensively drained since European settlement in the mid 1800s, transforming its former predominant marsh/wetland character to grazed pasture. These changes have substantially altered the Lower Taieri's hydrology, including an increase in the demand for using groundwater to supplement the existing surface water resources. The understanding and usage of groundwater in the basin has increased over recent years. For instance, the town supply for Mosgiel, alongside many rural dwellings, are sourced from groundwater. Groundwater also significantly impacts the local ecology of the modified Lower Taieri by supporting seepage to drains, lakes and wetlands (ORC, 2010c)

The Lower Taieri plain lies in a north east trending tectonic depression that is around 40km long and 5-10km wide. It extends from Abott's Hill in the northeast for around 30km to lakes Waipori and Waihola in the southwest with a total area of around 210km^2. The plain ranges in elevation from 40m ASL at the northern end to around sea level at Waipori and Waihola lakes in the southern end. The southern end of the basin is separated from the Tokomairiro Basin by a low bedrock divide near Milburn.

The Quaternary geology of the Lower Taieri reflects the depositional and tectonic influences of the last 2 million years. The basin's origin is tectonic, since the western and eastern basement blocks become up-thrust relative to the basin floor through the tectonic action of faults at the margins. The basin floor has also subsided and the outlet to the sea was only kept open through the down cutting processes of the Taieri River as the seaward hills were upfaulted. The basin floor is currently inferred to be around 300m below sea level and the basin was consequently filled with Tertiary and Quaternary sediments since the reactivation of the eastern bounding Titri Faulting.

The resulting basin is filled with sediment from both the Quaternary and older Tertiary periods (65 – 2 million years BP). Following the post glacial sea level rise between 4000-8000 years BP, the basin was rapidly inundated by the sea and estuary water. All the West and much of East Taieri became a coastal embayment or estuary as far up the basin as the Mosgiel outskirts. This newly embayment/estuary was filled with silty sediments, which resulted in the deposition of a consistently silty/clayey sand lower permeability layer in the shallow basin sediments, commonly termed the "Waihola Silt-Sand". This horizon thickens up to 25m in the southwest towards the basin exit. Groundwater in the gravels underneath this Waihola Silt-Sand is semi-confined. Hence, this Waihola Silt-Sand deposit is significant in dividing the groundwater system into vertically segregated compartments. These are underlain by gravel-dominated Quaternary sediments, identified based on available bore logs that tap the top of the semi-confined aquifer alongside deeper bores. Information suggests that there are two aquifers beneath the Waihola Silt-Sand: the "confined Mosgiel-Momona aquifer" and the "Henley Deep aquifer". The base of the Henley Deep aquifer is deeper than 154.3m BGL (the bottom of the Waipori 99-1 bore). The confined Mosgiel-Momona Aquifer was also encountered in an investigation bore at the airport (I44/0921). Although the drilling stopped at the top of the Henley Deep Aquifer, a marker horizon of the Waipori (lignite) aquitard common to the Henley and the Mosgiel-Momona aquifers was logged at the same stratigraphic level as in bore Waipori 99-1. The lignite divided the confined Mosgiel-Momona and the Henley Deep aquifers.

The Quaternary sediments in the Mosgiel area are more variable than those in the West Taieri area. The Waihola Silt-Sand extends into the East Taieri, perhaps as far as Riccarton Road, though not as far as Mosgiel. Logs from the Mosgiel-Wingatui areas show rapid transitions from one lithology to the next and generally poorer sorting, with logs with indefinite descriptions (e.g. silty sandy clay-bound gravel) more common in the Mosgiel District. These poor sorting and high sediment variability is inferred to be due to the proximity of mixed sediment sources, e.g. the Silver, Mill and Owhiro Streams, hill slope outwash channels, and flood flows.

The main surface water bodies of the Lower Taieri plain are the Taieri River, Silver Stream and the Waipori River, which enter the plains from schist rock gorges. Other prevailing hydrological features are Lakes Waipori and Waihola, the intervening wetland complex and drainage creeks and channels.

The climate of the Taieri Plain is sub humid, with precipitation of around 700-800mm on the plain and up to 1200 in the Maungatua Range. Precipitation distribution is relatively even with winter being the driest. Potential evapotranspiration at the airport was around 780mm/year.

The Lower Taieri plains are mainly covered with grass paddocks, except for the two small wetlands in East Taieri and the Waipori-Waihola Wetland complex. Most of the area outside the wetlands (i.e. under artificial drainage) is used for cattle grazing with some market garden and berry cropping around Outram. Farming ranges from large commercial dairies to small life style blocks. There are also some processing, manufacturing and service industries on the plains alongside urban/semi urban areas in Mosgiel, Kinmont, East Taieri, Allanton and Outram.

The main groundwater uses are domestic, stock, dairy shed and irrigation supplies. Irrigation is relatively low and most abstraction takes are for insurance against dry years. The highest takes by volume are for the Mosgiel town supply followed by abstraction and re-injection of groundwater used in ‘ground source’ heat exchanges at Dunedin Airport.

Groundwater is found throughout the Quaternary sequences, however, higher volumes and yields tend to be correlated with coarser deposits (sands, sandy gravel and coarse gravels). The Lower Taieri basin is characterised by larger sediment grain size segregation (i.e. better sorting) in West Taieri and higher variability and poorer sorting in East Taieri.

The Mosgiel and North Taieri areas are underlain by an unconfine aquifer, in contrast to the semi-confined conditions found further down gradient on the plains. This is supported by the following observations: High – moderate nitrate concentrations at depth, indicating the infiltration of soil drainage, a consistently downward vertical groundwater pressure gradient, and an absence of laterally continuous and recognisable confining layer. The water bearing layers in East Taieri tend to be more highly stratified with short pumping tests suggesting a degree of semi confined conditions. However, regarding longer term behaviour, the groundwater response is closer to a stratified, unconfined aquifer. There are several areas with flowing artesian conditions at the East Taieri and the lower West Taieri Drainage area. A reduction in flowing artesian conditions may be the impact of land drainage, causing long term drawdown. The mapping of bore depths suggests that most bores are <40m deep, but there are also deeper ones. The greatest depths to groundwater are found in deeper bores in North Taieri and the shallowest depth to water is beneath lower lying, drained areas (ORC, 2010c).

Water level surveys indicate elevated groundwater heads in the North Taieri area, north of Mosgiel, which decline with distance to the southwest. This is similar to the surface topography of the Taieri plains, with ground level of around 30m amsl north of Mosgiel which grades down to a couple of metres of sea level in the southwest (Henley). Several distinct transitions were noted within this pattern (ORC, 2010c):

- the abstraction from the Mosgiel bores over many decades seems to have induced the formation of a hollow in the groundwater surface, where groundwater converges from upgradient recharge areas.

- School Swamp at East Taieri functions as a discharge zone for this part of the groundwater system and a similar convergence of local groundwater level contours.
- The Taieri River appears to control the shape of the groundwater level surface
- The West Taieri Drainage scheme produces a large scale deflection of the groundwater level surface.
- The Lake Waipori/Waihola Wetlands Complex is a strong local control on adjacent groundwater levels.

There are several aquifer tests available from the Lower Taieri basin. The first is a 72 hours test for the Wingatui bore (I44/0089) when it was pumped at 26L/s in July 1947. The test data was re-analysed recently by ORC using steady drawdown-distance data and the Transmissivity was calculated for the screened water bearing layers (18-53m depth). The derived Transmissivity was around 380-400m^2/day.

The Outram bridge well field unconfined aquifer has very high Transmissivity, ranging between approximately 14,500 and 17,000m^2/day. However, these parameters solely relate to the DCC Outram well field, which is believed to be a restricted zone of higher permeability. Exploratory drilling and geophysics indicated that the higher permeability conditions declined rapidly approximately 200-300m downstream of the Outram Bridge. The transmissivity of water supply bores in Mosgiel, derived from pumping tests conducted between 1970 and 1990, ranges between 80 and 1,250m^2/day. This indicates a high range in transmissivity values. However, there is a bias in the results, as only the most efficient/high yielding bores were tested, hence this range over represents higher permeability zones of the groundwater system. The tests estimated a Storativity of around 1x10^{-4}m and estimated leakage of around 2x10^{-4}/day, indicating semi-confined conditions. Estimated aquifer parameters are also available for the West Taieri area, where bores seem to penetrate through the Waihola Silt-Sand aquitard and into the top of the Mosgiel-Momona Confined Aquifer. The transmissivity ranges between 740 to 1,530m^2/day and the Storativity is around 1.2x10^{-4} to 3x10^{-4}. The Mosgiel-Momona confined aquifer, where bores are around 30m deep, had Transmissivity ranges between 1200 and 1,600m^2/day. However, more closely supervised tests on fully penetrating bores derived T range between 650 to 850m^2/day and a Storativity range of 9x10^{-3} to 7x10^{-4}. It is inferred that the lower and narrower range in aquifer Transmissivity results for the deeper bores is a partial consequence of the newer test bores being fully penetrating. Furthermore, these latter tests also indicate a much lower variability in hydraulic properties in the West Taieri aquifer area than in the Mosgiel area, which is consistent with observations of the sedimentary geology (ORC, 2010c).

The main sources of groundwater recharge are rainfall and recharge from surface water (The Taieri River, Silver Stream, Waipori River. An investigation of groundwater-surface interaction between Silver Stream and the aquifer indicated that water from the Silver Stream recharges the shallow groundwater between Puddle Alley and Wingatui at around 30L/s during low flows. Due to the downward hydraulic gradient shallow groundwater slowly flows downward to lower water bearing units in the groundwater system. The Silver Stream therefore provides a partial recharge source to the deeper water supply aquifer, albeit mixing with water of other origin that have taken much longer time (e.g. years) to reach that greater depth. The direction and magnitude of groundwater recharge to the aquifer may change due to changes in the flow rate/stage height of the Silver Stream (including freshes and floods that produce bank storage) and the shallow groundwater level in the water bearing layer in closest contact with the stream. This indicates that the Silver Stream is in dynamic equilibrium with the adjoining groundwater, which is occasionally perturbed by low and high flow events. The outputs of groundwater from the basin include discharge into wetlands like the School Swamp and Lake Waipori Wetlands Complex, drains, or groundwater abstraction from bores (ORC, 2010c).

The Lower Taieri basin has several anthropogenic groundwater quality issues. The main one is elevated nitrate concentrations, which are restricted to the stratified unconfined water bearing layers in the north of the basin near Mosgiel and North Taieri where there are oxidised geochemical conditions. Elevated iron and manganese concentrations are another main limitation for groundwater quality in the Lower Taieri. Salinity is an issue in a small area of the West Taieri, particularly within the West Taieri Drainage Scheme perimeter. The Lower Taieri River at Henley Ferry and distributary branches of lakes Waihola and Waipori are tidal, where surface water saline intrusion penetrates these water bodies for up to 15km upstream from the Taieri mouth. Groundwater salinity is also impacted by the Holocene marine and estuarine sediments of the Waihola Silt-Sand formation, which were deposited under saline/brackish conditions (ORC, 2010c).

4.4.5.2 Groundwater quality monitoring

Groundwater quality in the Lower Taieri basin is currently monitored in five bores, whose depths range between 17.50 and 40.50m. The bore details are summarised in Table 56. Four of the bores are located within approximately 3.5km north and west of Mosgiel. The remaining bore is located at Maungatua Road, on the northwestern part of the plain. Screen depth information is not available for any of the bores. Bore logs are available for two bores, I44/0821 and I44/0964. The bore log for I44/0821 (27.38m depth) is mainly composed of clay truncated by thin layers of gravels. The log describes clay and thin gravel layers to 21.7m underlain by gravels to 22.9m. There is then clay to the bottom of the bore at 53.1m with thin layers of gravel, all <1.2m thick, at 42.0, 48.0m and 51.9m. There is no screen information available for this bore. However, considering the recorded total bore depth of 27.38m, it is likely screened within the gravels/heavy clay bound gravels at a depth of approximately 22m. This lithology, particularly the substantial upper clay layer, suggests that the bore abstracts from a confined/semi confined aquifer. Groundwater levels in bore I44/0821 were monitored manually since January 2017. Water level in the bore ranges between 9.286 and 10.665m below MP with an annual range of between 0.301 and 1.379m. The highest water levels are in winter/early spring. There does not appear to be a declining trend in water levels in this bore.

The bore log for bore no. I44/0964 (40.5m deep) is composed of alternating horizons of gravels and clay. The log describes 0.4m of top soil underlain by brown gravels to 3.80m. There is then alternating horizons of clay and gravel to 6.4m, mainly underlain by clay with some gravel layers <1.2m thick, to 24.8m. The lithology then changes below this depth and becomes more gravel-dominated, with brown sandy gravels down to 33.3m underlain by clay to 34.9m. There is then alternating horizons of gravels and clay, approximately 2m thick, down to the bore bottom at 40.60m. The recorded bore depth is 40.50m. The original bore log indicates that the top of the screen leader is 1.80m long and that the screen length is 1.500m. Based on a total bore depth of 40.50m, the top of the screen is at a depth of 39.00m, within a horizon of clay, although this might be an error in the bore log. This information suggests that the bore abstracts from a semi confined/unconfined aquifer overlain by a shallow unconfined aquifer.

Table 56: Summary of groundwater quality monitoring bores details for the Lower Taieri

Bore no.	Depth (m)	Diam. (mm)	Eastings	Northings	Screen top (m)	Screen Bottom (m)	Log avail.
H44/0007	24.4	100	1378924	4912001	n.a.	n.a.	No
I44/0495	22.9		1392261	4918203	n.a.	n.a.	No
I44/0519	17.5		1392705	4919569	n.a.	n.a.	No
I44/0821	27.38	100	1396046	4919018	n.a.	n.a.	Yes
I44/0964	40.5	100	1392510	4916131	n.a.	n.a.	Yes

The assessment of groundwater quality results against the DWSNZ indicate a high risk of faecal contamination, with E. coli exceedances in three of the monitoring bores. The highest ones were in bore H44/0007, ranging between 8 and 340MPN/100mL. The exceedances in bore I44/0519 ranged between 2 and 280 MPN/100mL and those in bore I44/0495 ranged between 1.6 and 22 MPN/100mL (Figure 117). These indicate a high risk of faecal contamination, which is not surprising considering the bores are located near risky land uses (i.e. dairy sheds, septic tanks) and many suffer from poor borehead protection. Groundwater nitrate concentrations in all five bores are below the DWSNZ MAV of 11.3mg/L (

Figure 118). However, concentrations over ½ the MAV (i.e. over 5.5mg/L) were measured in bores no. I44/0821 and I44/0964, although the high concentrations in the latter bore are likely due to a single event. The concentrations in bore I44/0821 range between approximately 5.10 and 6.92mg/L and those in in bore I44/0964 generally range between approximately 1.2 and 1.6mg/L. However, a much higher concentration of 6.00mg/L was measured in October 2011, although this is likely to have been due to a single event, as concentrations in the following sample were much lower. Some of the concentrations in bore I44/0519 are above the 2.5mg/L nitrate threshold for low intensity land use (Daughney & Morgenstern, 2012), with this level exceeded in most samples after 2017. The maximum concentration was 3.70mg/L, measured in November 2018. Although these are still substantially lower than the MAV, the data suggests an increase in nitrate concentrators, with these observations further corroborated by the risky land uses in the area. Conversely, nitrate concentrations in the other bores (H44/0007, I44/0495) are below 1.0mg/L. Dissolved arsenic concentrations in all bores ranged between 0.0001 and 0.005mg/L, which are below the DWSNZ MAV of 0.01mg/L (Figure 119). Ammonia concentrations in bore I44/0519 range between 0.005 and 5.43mg/L, which substantially exceed the aesthetic GV of 1.5mg/L. The data shows two exceedances of the GV, with measurements of 2.16mg/L (October 2004) and 5.43mg/L (July 2005),

Figure 120. These exceedances are likely due to poor bore security and/or contamination from a nearby septic tank. Apart from these, concentrations were below 0.65mg/L. As the bore is situated approximately 400m west of Mill Stream, this may potentially hamper surface water quality.

Figure 117: Groundwater E. Coli count for the Lower Taieri Aquifer

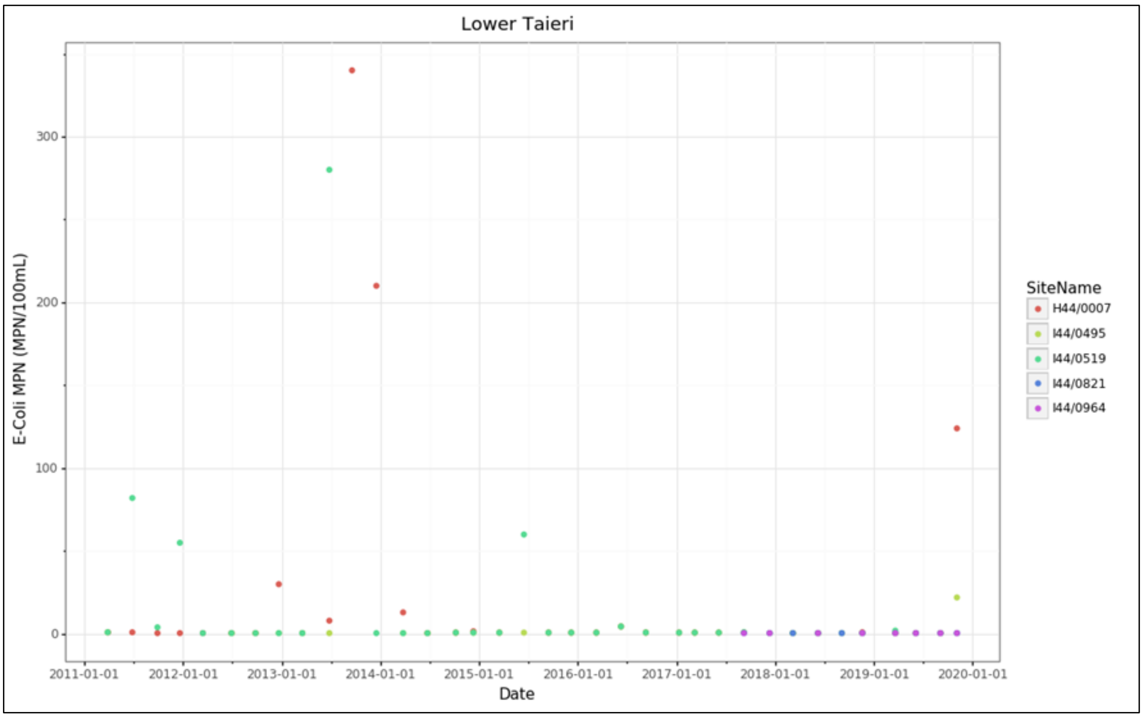


Figure 118: Groundwater nitrate concentrations for the Lower Taieri Aquifer

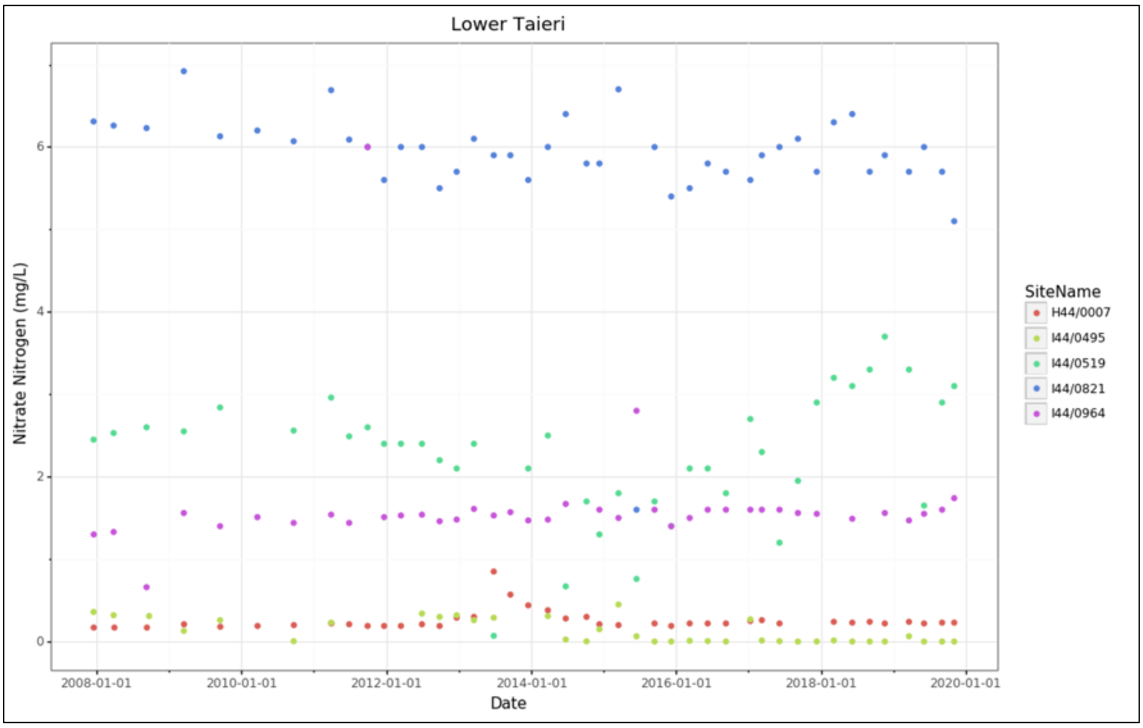


Figure 119: Groundwater dissolved arsenic concentrations for the Lower Taieri Aquifer

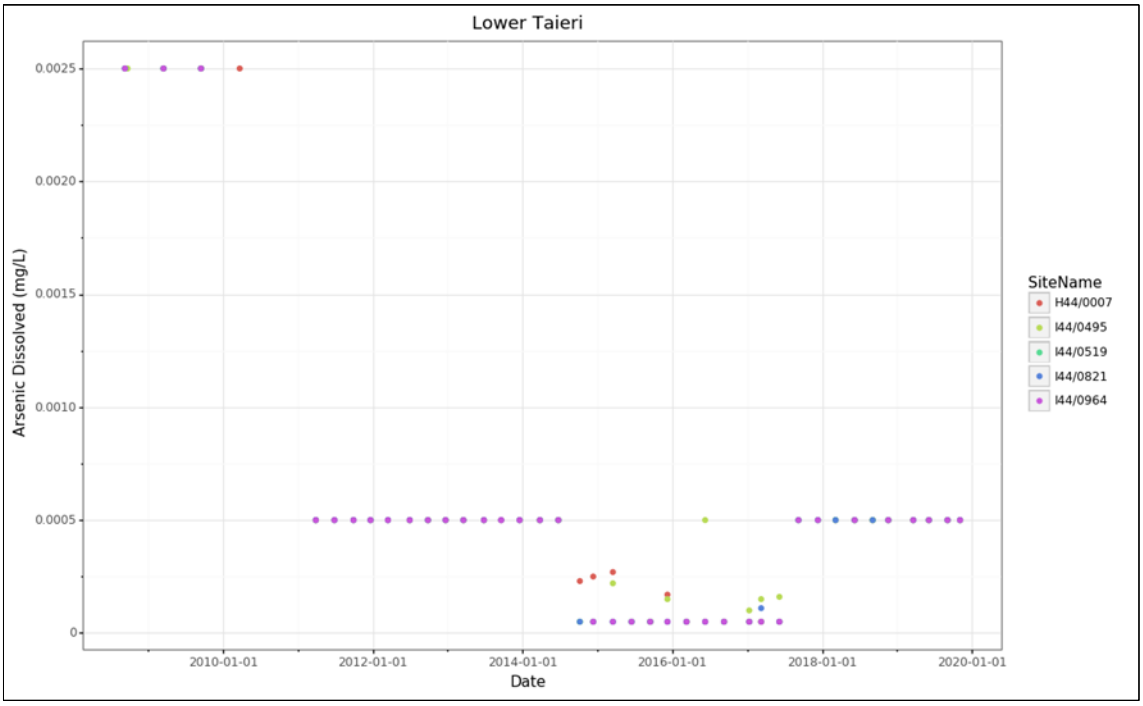
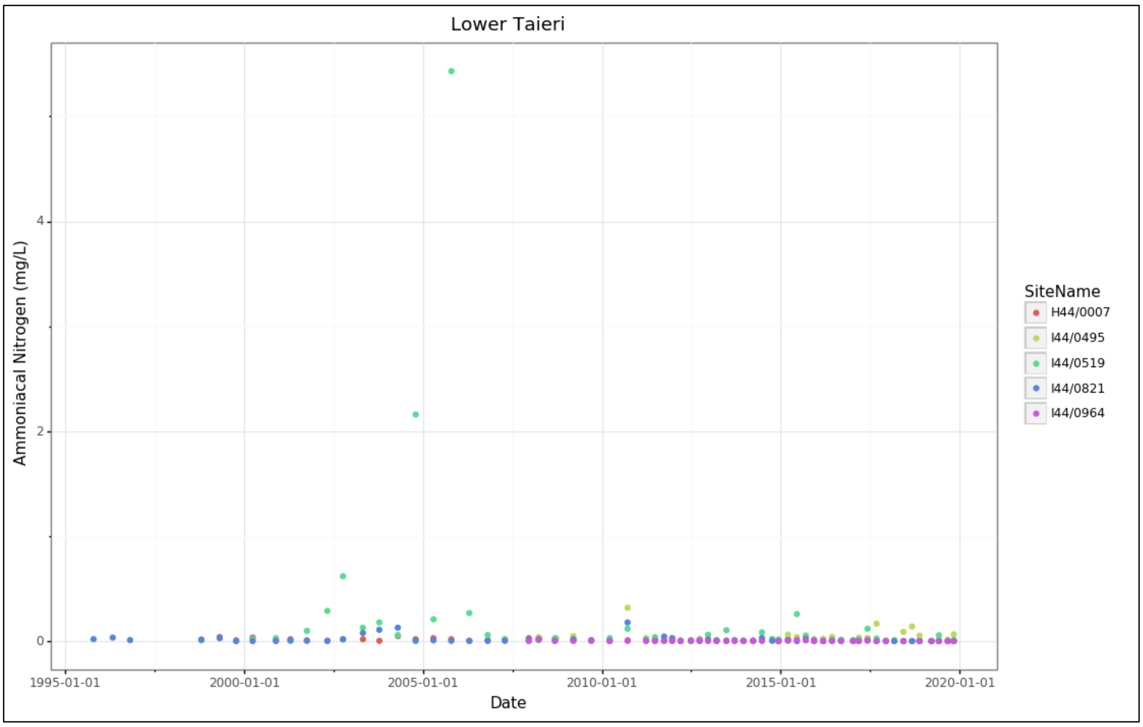


Figure 120: Groundwater ammonia concentrations for the Lower Taieri Aquifer



The results were then assessed against the RPW (Table 57) and NPS-FM NOF (Table 58). Bore I44/0519 is the only bore shallower than 20m. The results indicate potential water quality issues, with both the 80th percentile nitrate and ammonia concentrations exceeding the Schedule 15 limits. The nitrate 80th percentile concentrations exceed the threshold by 39 times. The ammonia concentrations only slightly exceeded the limits. The DRP concentrations were below the threshold.

Table 57: 80th percentile values for Schedule 15 water quality variables for the Lower Taieri Aquifer

Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
I44/0519	Taieri	Lower Taieri	2.900	0.006	0.102

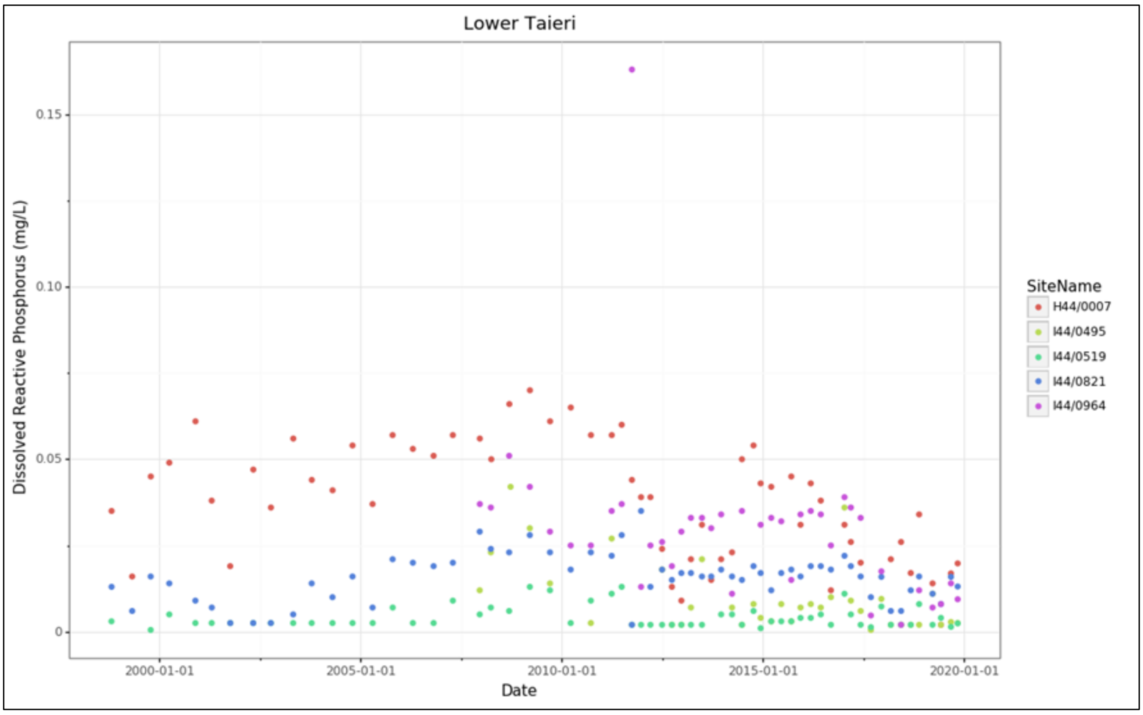
The assessment against the NPS-FM shows that the median and 95th percentile nitrate concentration are in band C and B, respectively (Table 58). At Band C growth effects on up to 20% of species (mainly sensitive species, such as fish) is expected but no acute effects. The ammonia maximum concentration in Band D, where ammonia toxicity starts to approach acute impact level (i.e. risk of death) for sensitive species (MfE, 2020). However, the median ammonia concentration is in Band A, suggesting the issues are related to single incidents rather than a persisting issue.

Table 58: NOF comparison for nitrate, ammonia, and DRP for the Lower Taieri Aquifer

	Nitrate Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**median**	**95th percentile**
I44/0519	2.4	3.3	C	B
	Ammoniacal Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	max	**Median**	**95th percentile**
I44/0519	0.019	5.43	A	D
	Dissolved Reactive Phosphorus (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**Median**	**95th percentile**
I44/0519	0.0025	0.0111	A	A

Although groundwater quality from most of the Lower Taieri SoE bores was not assessed against the RPW and NPS-FM, the DRP results from some bores shows some potential issues. The median DRP concentrations in bores H44/0007 (0.039mg/L), I44/0964 (0.031mg/L) and I44/0821 (0.016mg/L) are high. Concentrations also show fluctuations over time, potentially due to changes in land use and/or septic tank density and efficiency (Figure 121).

Figure 121: Groundwater Dissolved Reactive Phosphorus concentrations for the Lower Taieri Aquifer



4.5 The North Otago FMU

The North Otago region covers an area of around 2,202 km^2 (220,208Ha) from around Waikouaiti in the south to the Waitaki River in the north. The location of the FMU is shown in Figure 122. It encompasses parts of the lower Waitaki Plains, Kakanui, Waianakarua, and Shag catchments. The FMU also contains several aquifers: the North Otago Volcanic Aquifer (NOVA), Lower Waitaki Plains aquifer, Kakanui-Kauru Alluvium aquifer, and the Shag Alluvium aquifer (. It also includes the Papakaio aquifer, which is currently not been monitored, although it is planned to monitor it in the future.

The North Otago region is dominated by catchments that receive very low rainfall (<500mm/year) and are predominantly cool/dry low elevation rivers and cool/dry hill rivers. The predominantly dry climate and extensive areas of low relief topography of the lower river catchments is extensively used for cropping and irrigation. These activities increase the pressure on groundwater and surface water resources. The main land cover throughout North Otago is high producing grassland, which reflect areas actively managed and grazed for dairy, beef, lamb, wool, and deer farming. This land cover dominates the Shag and Kakanui catchments. Conversely, the Upper catchments of the Kakanui, Shag, and Waianakarua are mountainous and less suitable for intensive grazing. These areas are dominated by low producing grassland, forestry and native cover. Those low intensity land uses typically leach low nutrient levels and generally provide good water quality. Low yielding rivers (located on dry areas) have reduced dilution and flushing capacity, which tend to be more susceptible to elevated nutrients should land use in these upper catchments intensify (ORC, 2017a).

Figure 122: Location of the North Otago FMU (red), aquifers (green) and SoE monitoring bores (red dots)

Groundwater quality results from the different aquifers in the North Otago FMU were assessed against the DWSNZ surface water quality standards (i.e. the RPW and NPS-FM), with the latter being critical due to the strong groundwater-surface water interaction in many North Otago catchments. The results indicate significant groundwater quality issues, especially the elevated nitrate concentrations, which are the highest in Otago, and E. coli exceedances. Nitrate concentrations in monitoring bores in the NOVA and Kakanui-Kauru aquifers substantially exceed the 11.3mg/L MAV, with concentrations in some bores exceeding 32.2mg/L. Additionally, nitrate concentrations in some bores in the Lower Waitaki aquifer are over ½ of the DWSNZ MAV. Potential faecal contamination is also a concern, with elevated E. coli measured in some bores in each of the FMU's aquifers, with a maximum count 6,200 MPN/100mL (bore J43/0006). In contrast to these issues, there were no elevated dissolved arsenic concentrations in any of the bores.

Table 59: Median concentrations for DWSNZ/ecosystem health parameters for the N. Otago FMU

Aquifer	Ammonia (mg/L)	Arsenic Dissolved (mg/L)	Dissolved Reactive Phosphorus (mg/L)	E-Coli (MPN/100mL)	Nitrate Nitrogen (mg/L)
Kakanui-Kauru Alluvium	0.0025	0.0005	0.01	0.5	2.95
Lower Waitaki Plains	0.026	0.00011	0.0065	0.8	4.735
NOVA	0.005	0.0005	0.017	0.5	10
Shag Alluvium	0.005	0.0005	0.0085	0.65	0.75

The potential impact on surface water quality was assessed by comparing nutrient concentrations in shallow bores to the RPW (Table 60) and NPS-FM NOF limits (Table 61). The results indicate potential adverse impacts on surface water quality, particularly due to the strong groundwater-surface water interaction in the FMU. The results show elevated nitrate and DRP, with concentrations in all bores substantially exceeding the Schedule 15 limits. The assessment against the NPS-FM also illustrates these issues, with most concentrations in the C and D bands. All of these indicate significant groundwater quality issues in this FMU, which has the most degraded groundwater quality in the region.

Table 60: Schedule 15 comparison for the North Otago FMU

Bore number		Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**Aquifer**	**0.075**	**0.010**	**0.100**
J41/0008	NOVA	27.660	0.057	0.010
J41/0762	Kakanui	4.940	0.011	0.016
J41/0764	Kakanui	3.400	0.011	0.006
J41/0771	Kakanui	11.000	0.010	0.012
J42/0126	Kakanui (township)	21.600	0.026	0.010

J43/0006	Shag	1.116	0.011	0.010
J41/0317	Lower Waitaki	5.800	0.032	0.010
J41/0442	Lower Waitaki	1.072	0.005	0.005
J41/0586	Lower Waitaki	7.280	0.009	0.005

Table 61: NOF comparison for nitrate, ammonia, and DRP for the North Otago FMU

	Nitrate		NOF Band	
Bore number	Median (mg/L)	95th percentile	Median	95th percentile
J41/0008	26	28.2	D	D
J41/0317	4.735	6.66	C	C
J43/0006	0.75	1.604	A	B
J42/0126	20	22	D	D
J41/0762	4.3	5.88	C	C
J41/0764	2.1	3.9	B	C
J41/0771	7.2	12	D	D
J41/0442	0.82	1.385	A	A
J41/0586	6.3	7.495	C	C
	Ammonia		NOF Band	
Bore number	Median (mg/L)	Max. (mg/L)	Median (mg/L)	Max. (mg/L)
J41/0008	0.005	0.065	A	B
J41/0317	0.005	0.034	A	A
J43/0006	0.005	0.025	A	A
J42/0126	0.005	0.01	A	A
J41/0762	0.007	0.043	A	A
J41/0764	0.0025	0.026	A	A
J41/0771	0.0025	0.034	A	A
J41/0442	0.0025	0.0086	A	A
J41/0586	0.0025	0.013	A	A
	Dissolved Reactive Phosphorus (mg/L)		NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
J41/0008	0.048	0.062	D	D
J41/0317	0.026	0.039	C	D
J43/0006	0.0085	0.01375	A	B
J42/0126	0.0184	0.029	B	D
J41/0762	0.009	0.012	A	B

J41/0764	0.01	0.012	A	C
J41/0771	0.009	0.011	A	B
J41/0442	0.005	0.006	A	A
J41/0586	0.0065	0.01	A	B

4.5.1 The North Otago Volcanic Aquifer

4.5.1.1 Aquifer information

The North Otago Volcanic Aquifer (NOVA) serves as an important water source for parts of the Waitaki District that are underlain by the volcanic sediments. The main groundwater uses include domestic, stock take, and irrigation, which mainly rely on the shallow volcanic sediments. Groundwater also provides important baseflow which sustains some creeks during dry weather. The aquifer mapped zone extends over much of the land that is underlain by volcanic sediments.

The aquifer is located beneath downlands and tablelands west/south of Oamaru. The main surface water drainage overlying the aquifer include Waiareka Creek (in the Kakanui catchment), Awamoa Creek and Oamaru Creek (which drain individually to the coast). Landon Creek is located in the far north of the area but is mainly ephemeral.

Broadly, the sediments that make up the NOVA comprise the following strata and geological materials:

- Waiareka Tuffs: marine tuff beds, columnar jointed basalt intrusions, pillow lavas siltstone with volcanic ash inclusions and occasionally diatomite.
- Totara & McDonald limestone: marine carbonate sediments including massive fine-grained limestone and calcareous siltstone often with significant volcanic association.
- Deborah volcanics – marine tuffs, pillow lava, columnar jointed basalt, crystal breccia, ash bed and siltstone with significant volcanic influences.

It is important to recognise that the boundaries between these strata are seldom precise and that they were all deposited in a setting of varying sea floor depths close to a subsurface volcanic eruption that ultimately extended above sea level for a brief period. Under the base of the volcanic sequences there are marine sediments without volcanic influences which are deposited in deep water. These sediments are fine-grained, very silty and have low permeability. The volcanic sequences are overlain by deeper water fine marine sediments (the Gee Greensand and the Rifle Butts formation) that also have low permeability. The sedimentary thickness of the volcanic sequences exceeds 500m in places (e.g. beneath the northern part of Oamaru, which include 245m of Deborah Volcanics, 30m of limestone and 235m of Waiareka Volcanics). To the west of the Waiareka Creek catchment, the volcanic sequence is due to sedimentary and erosion processes. There are also several recognised fault/fold structures that deform the volcanic aquifers (ORC, 2008).

The North Otago climate is temperate and is impacted by strong oceanic influences of air streams from the Pacific, the southwest and the northwest, which are tempered by passing over elevated parts of the South Island interior. This variability in air stream direction strongly impacts temperature, evaporation and rainfall patterns. It is also impacted by non seasonal factors such as El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation which can change air streams' balance, climate, and hydrology. The mean annual rainfall near the centre of the aquifer is around 580mm and is lower, around 450mm/year in the east end of the aquifer (Grandview). The PET usually exceeds rainfall, which induces significant soil moisture deficits in late spring, summer and most of autumn in most years. Due to that, soil moisture surplus and aquifer recharge occurs tends to be confined to the winter and early spring, which leaves relatively low potential for aquifer recharge.

The main land use in the area is pastoral and arable farming. There is also market gardening concentrated in the east of the area, within an approximate triangle located between Alma, Oamaru and Kakanui townships. The Waiareka Valley has undergone a significant transformation in 2007 through the large Downlands Irrigation Scheme which uses surface water from the Waitaki River. This has helped to overcome the area's soil moisture deficits which allowed the intensification and expansion of irrigated pasture (mainly dairying, which has replaced sheep) and arable cropping (ORC, 2008).

The groundwater flow pattern within the NOVA is fairly simple. The highest water table is under the higher tablelands within the NOVA whilst the lowest levels were found along the axis of the Waiareka Valley and the Kakanui Estuary. Groundwater flow patterns broadly follow surface topography, flowing from higher elevation ridges and tablelands toward the ocean and surface water (i.e. the Waiareka Creek, Oamaru Creek, or the Kakanui Estuary). On the north side of the Kakanui Estuary, the Waiareka Aquifer appears to recharge in the rolling land along the aquifer's western boundary and flow east into the Waiareka Creek, a significant receptor for groundwater within the Waiareka Aquifer. This is balanced by southwestern flow into the east bank of the Waiareka Creek. Groundwater flow divides between the Waiareka Creek and the Ocean along a line situated approximated near Weston and Kakanui.

The piezometric map shows steep gradients in areas of low recharge, which can infer a low to moderate hydraulic conductivity. Reported Transmissivity from several aquifer pumping tests is low, ranging between 5.4 and 80m^2/day. The drawdowns in the volcanic aquifer bores are relatively high, indicated by the reported low Transmissivity and the low specific capacity of around 0.5 to 1.5L/s/m of drawdown. This low permeability indicates that groundwater was only used due to the lack of any other feasible supply option.

In general, most of the information on the landward portions of the NOVA suggests that it behaves as an unconfined aquifer with artefacts of fracture/fissure flow evident in pumping test analysis. The aquifer displays unconfined recharge and flow towards the nearest down gradient perennial water body. However, there are a few exceptions such as areas where the aquifer is overlain by the fine marine sediments of the Gee Greensand and Rifle Butts Formation which seem to form a semi-confining layer atop the volcanic aquifer. These two formations are overlying the Deborah Volcanics for much of the coastal zone and presumably thicken out to sea, hence, for much of its potential contact with the ocean the NOVA is largely semi confined or confined.

Due to the fracture/fissure occurrence of groundwater in the volcanic aquifer the drawdown response in pumping tests shows a dual confined/unconfined signature, hence the initial drawdown curve is consistent with that of a confined aquifer. However, subsequently, the drawdown rate is more consistent with that of an unconfined aquifer. Storativity was only obtained from one test where an observation bore was used (J41/0714). The initial Storativity (S) coefficient was $4x10^{-4}$, which is analogous to the S coefficient for a confined aquifer. However, this was not sustained for more than a few hours and an analysis of long term drawdown data from the bore showed a shift to a storage coefficient of $1x10^{-2}$ (1%) although the inconsistency of aquifer tests to provide accurate storage data is known. Independent comparison of recharge-inducing rainfall events and water table rise in the Webster well (J41/0178) suggested an average unconfined storage of 0.10, or 10%, which is consistent with more recent Specific Yield (Sy) estimation of 0.09 or 9% (ORC, 2008).

The only reliable indication of significant interaction of the NOVA with adjoining aquifers is between the NOVA and the Kakanui Alluvial Aquifer, in the area between Gemmells Crossing and the Kakanui Estuary. In contrast, groundwater levels in the Waiareka Aquifer are significantly higher than the adjoining and overlying alluvial aquifer, with the flow gradient dominated by upward flow from the NOVA into the base of the Alluvium. Based on that, it is expected that the volcanics contribute groundwater to the alluvium aquifer. This was supported by elevated Electrical Conductivity and sodium concentrations in the alluvium (ORC, 2008).

4.5.1.2 Groundwater quality measurements

Groundwater quality in the NOVA is monitored in three bores, whose details are summarised in

Table 62. Most of the monitoring bores are located in areas of cropping, which increases the potential for elevated nutrient concentrations. Bore no. J41/0008 (1000mm diameter) is situated at Fortification Road, Whitecraig, NZTM E1434870 N5000331. The bore's depth is 20m. There is no bore log or screen information for the bore. Although this bore has been monitored since January 1986, the bore head security is very poor and has a high contamination potential. The SWL in the bore was monitored since July 2015. Water levels range between 5.025m and 7.98m below MP. The seasonal variation in water levels is between approximately 1.3 and 2.0m.

Bore J41/0249 (250mm diameter) is located north of Woolshed Road at NZTM N1430982 N5000848. The bore depth is 90m. The bore log describes topsoil and clay to 2.6m underlain by brown, fractured rock to 24.2m. There is then fractured blue rock to 90.0m, underlain by Waiareka Volcancics rock to 91.0m. Both fractured rock units are described as water bearing. The log states that the casing depth is 5.5m. Based on that, it is assumed that the remainder of the bore is open hole and that it abstracts from the fractured rock units. The SWL in the bore was monitored since April 2016, although there is a gap in monitoring between March 2017 and April 2019. The highest water level in the bore, 1.993m below MP, was measured in November 2019 and the lowest, 5.266m below MP, was measured in April 2019. The data suggests that the highest water levels are in winter/early spring and the lowest during summer. However, it also includes a high variability, of around 3.273m, in groundwater levels during 2019, which can potentially be attributed to pumping from the bore or measurement error. Due to that, and to the short availability of data (considering the gap between 2017 and 2019), it is difficult to assess whether the water levels in the bore follow a trend.

Bore J42/0126 (250mm diameter) is located at Fenwick Street, Kakanui township, NZTM E1434931 N4994910, approximately 1km north of the Kakanui River mouth. The bore depth is 10.9m. The bore log describes topsoil and yellow clay to 4.2m underlain by sand and gravels to 7m. There is then 1m of rock followed by sand, silts and weathered rock fractures to 18m underlain by broken rock to the bottom of the bore at 18.8m. The bottom of the bore, at a depth of 10.9m, is located within a horizon of sandy silts and weathered rock. There is no information regarding the screen depth, however, it is likely to be screened in the bottom sandy silts/weathered rock layer, at an approximate depth of around 8.0m. This suggests that the aquifer is relatively shallow, with a basement depth of around 18m. Groundwater levels were monitored in this bore since July 2015. The highest water level, 2.285m, was measured in April 2016 and the lowest, 14.12m, measured in July 2015. Water levels in the bore generally range between approximately 2.285 and 4.45m below MP, with two measurements of substantially lower levels of 14.12m (April 2016) and 9.362m (December 2017) below MP. The reasons for the lower readings are unclear, but it can be due to the bore pumping or measurement error. Interestingly, lower SWL at the same time were also measured in bore J41/0008, which increases the likelihood of it being related to dry conditions and associated higher pumping from the bore.

Groundwater levels in the NOVA is monitored for the Deborah (Webster bore, J41/0178, since August 1986) and the Waiareka (Isbister bore, J41/0198, since December 1997) bores. The Waiareka bore has shown a steady decline since around September 2002, falling from an elevation of approximately 123.2m to 121.45 in mid 2008. This level restricts takes by 50%. The Deborah bore has declined from a max. of around 130.8m in August 2000 to around 128.15m in June 2006, which is within a 50% restriction zone. However, the water levels in the bores have recovered and have been above the restriction level since mid 2007 although it appears that they were dipping back into it in mid 2008 (ORC, 2008).

Table 62: Summary of monitoring bore details for the NOVA

Well Number	Depth (m)	Diam. (mm)	Drill Date	Eastings	Northings	use	Bore Log?
J41/0008	20	1000	1/01/1972	1434870	5000331	Irrigation	No
J41/0249	90	250	1/01/1985	1430982	5000848	Irrigation	Yes
J42/0126	10.9	250	1/04/1995	1434931	4994910	Irrigation	Yes

Groundwater quality results from the NOVA SoE monitoring bores were compared against the DWSNZ. The results indicate significant issues with elevated nitrate concentrations, which are the highest in Otago. Nitrate concentrations in bores J41/0008 and J42/0126 substantially exceed the 11.3mg/L MAV, with concentrations in bore J42/0126 ranging between 17.0 and 22.0mg/L and those in bore J41/0008 ranging between 9.0 and 32.2mg/L. The concentrations in bore J41/0249 range between 3.29 and 6.20mg/L, with the upper end of these exceeds ½ of the MAV,

Figure 123. Monitoring of E. Coli in the NOVA only started in 2017. This has indicated some issues in bore J41/0008, with two exceedances of 27MPN/100mL (June 2018) and 4 MPN/100mL (September 2019). There were no exceedances in bores J41/0249 and J42/0126, Figure 124.

Arsenic concentrations in all bores were below the MAV of 0.01mg/L,

Figure 125. Ammonia concentrations in all monitoring bores were below the GV of 1.5mg/L, Figure 126.

Bore J41/0008 is also sampled as part of the Institute for Environmental Research (ESR)'s National Pesticides in Groundwater Survey, which is conducted every four years. Glyphosate was measured in the bore during the 2018 survey, with this bore being the only one in New Zealand where glyphosate was detected. Furthermore, DDT was also detected in the bore, which indicated that the contamination source was from the surface and close to the borehead (ESR, 2019). Considering the very poor borehead security, these results are unsurprising.

Figure 123: Groundwater nitrate concentrations for the NOVA

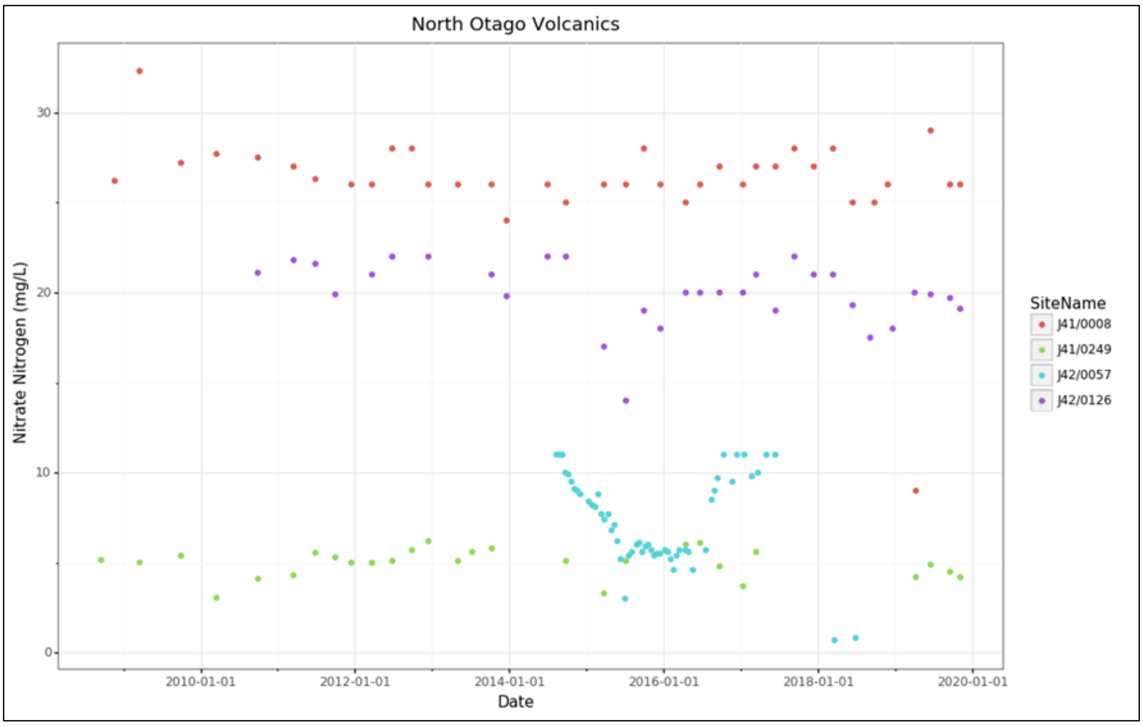


Figure 124: Groundwater E. Coli count for the NOVA

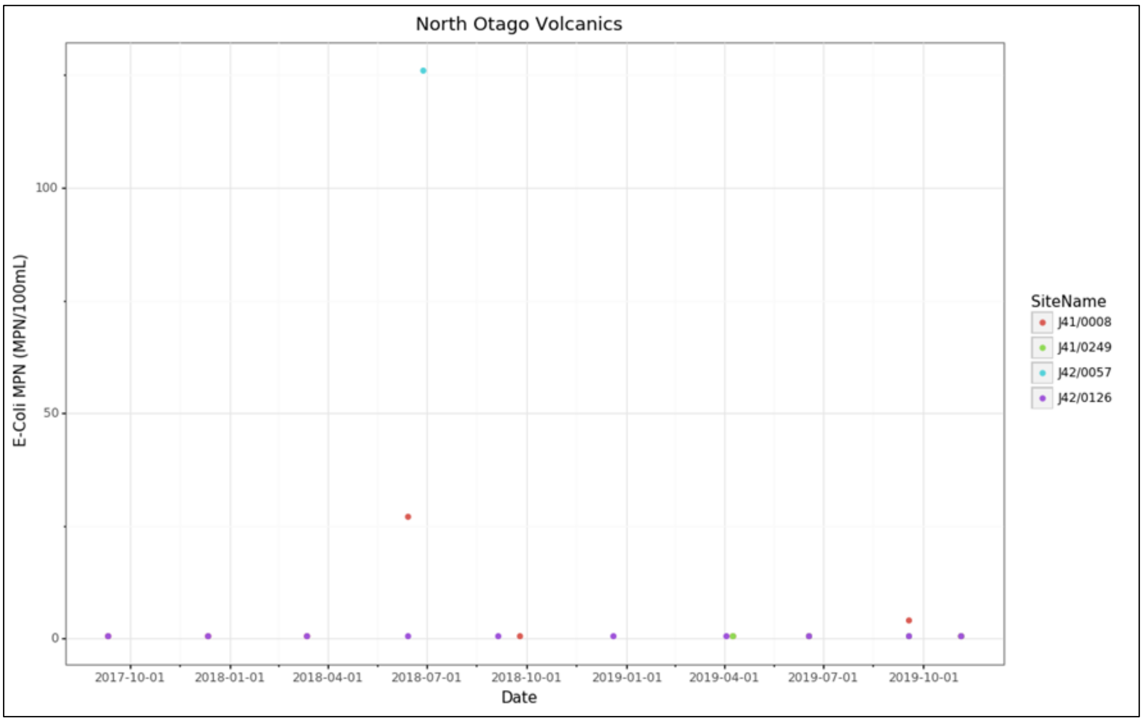

North Otago Volcanics
E-Coli MPN (MPN/100mL)
100
50
0
2017-10-01
2018-01-01
2018-04-01
2018-07-01
2018-10-01
2019-01-01
2019-04-01
2019-07-01
2019-10-01
Date
SiteName
J41/0008
J41/0249
J42/0057
J42/0126

Figure 125: Groundwater dissolved arsenic concentrations for the NOVA

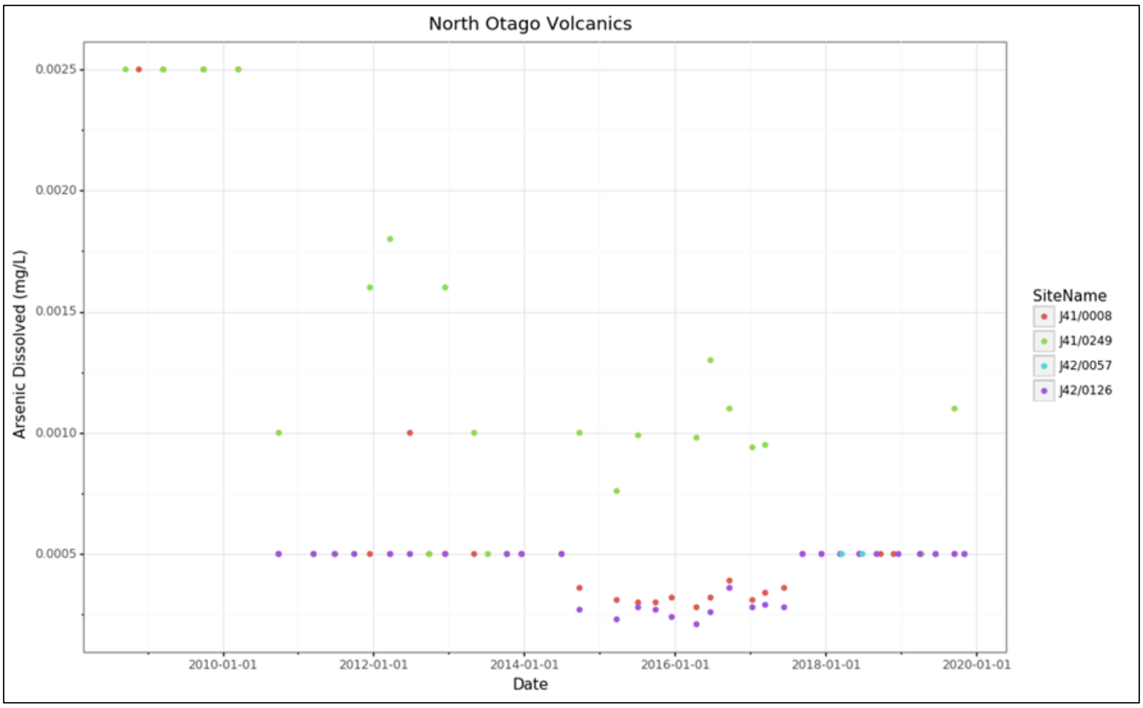


Figure 126: Groundwater ammonia concentrations for the NOVA

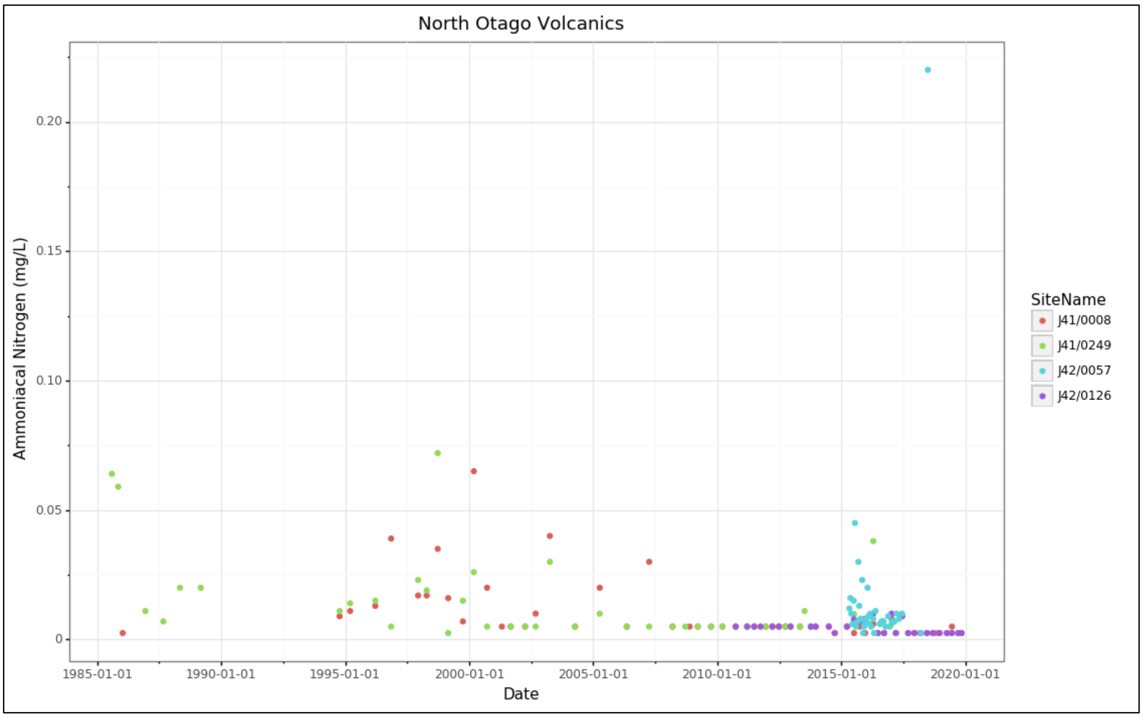


Table 63: 80th percentile values for Schedule 15 water quality variables for the NOVA

Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
J41/0008	N. Otago	NOVA	27.660	0.057	0.010
J42/0126	N. Otago	NOVA	21.600	0.026	0.010

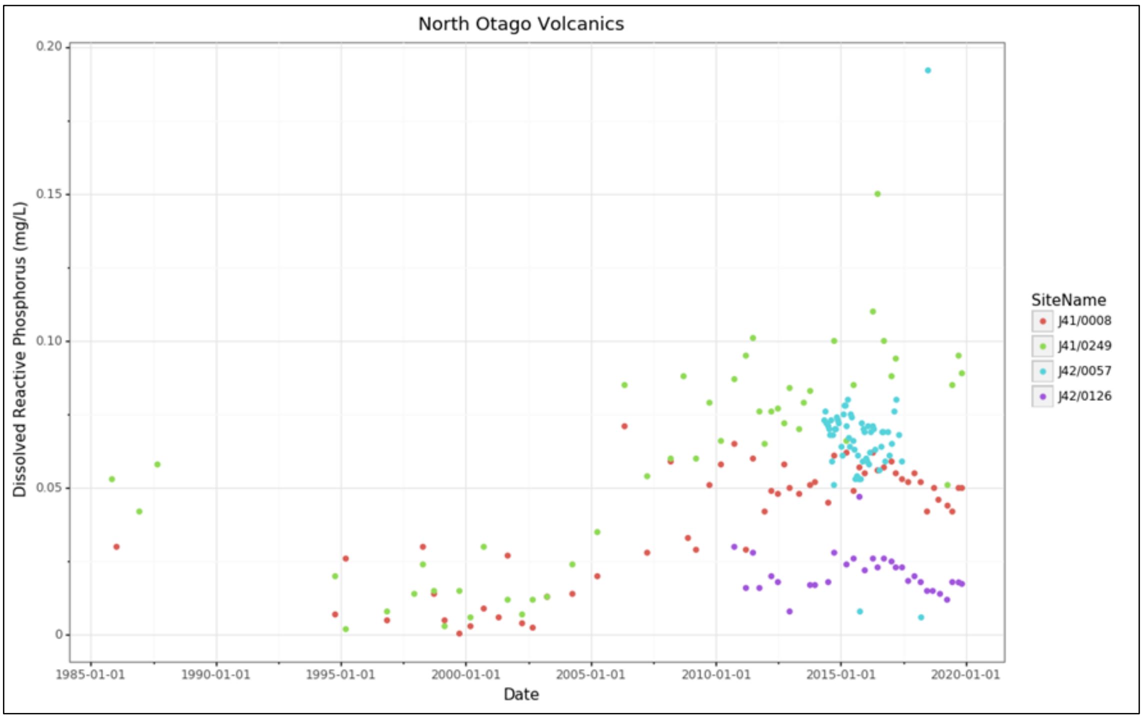
Groundwater quality results were then analysed against the RPW (

Table 63) NPS-FM NOF (Table 64). Due to their shallow depths, only bores J41/0008 and J42/0126 were included in this assessment. Both bores are located in Group 2 of Schedule 15 of the RPW. The results further indicate severely elevated nitrate concentrations, with the 80th percentile concentrations in bore J41/0008 and J42/0126 exceed the threshold by 369 and 288 times, respectively. The DRP concentrations also exceed the limits by around 6 (J41/0008) and 3 (J42/0126) times. The ammonia concentrations are below the limit.

These results are also mirrored in the assessment against the NPS-FM, with the median and 95th percentile nitrate concentrations from both bores in Band D, substantially elevated above the median (6.9mg/L) and 95th percentile (9.8mg/L) National Bottom Lines for nitrate. These highly elevated nitrate concentrations impact on the growth of multiple species and exceed the concentration for acute impact level (i.e. risk of death) for sensitive species of 20mg/L (MfE, 2020). Therefore, interaction of these bores with surface water can severely hamper surface water quality.

Alongside nitrates, DRP concentrations in bore J41/0008 are also high (Figure 127), with both the median and 95th percentile concentrations placed in Band D, exceeding the median (0.018mg/L) and 95th percentile (0.054mg/L), below the National Bottom Lines. These concentrations are substantially elevated above natural reference conditions. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrates and fish communities as taxa that is sensitive to hypoxia are lost. The DRP 95th percentile and median DRP concentrations are in Bands C and B, respectively. DRP concentrations in Band C are moderately elevated above natural reference conditions. If other conditions that favour eutrophication exist, DRP enrichment can cause increased algal and plant growth, loss of sensitive macroinvertebrate & fish taxa and high rates of decay and respiration (MfE, 2020).

Figure 127: Groundwater Dissolved Reactive Phosphorus concentrations for the NOVA



The median and maximum ammonia concentrations in bore J41/0008 are in Bands A and B, respectively. Ammonia concentrations in Band B provide 95% species protection level, with concentrations starting to impact occasionally on the 5% most sensitive species (MfE, 2020). Both median and maximum concentrations in bore J42/0126 are in Band A.

Table 64: NOF comparison for nitrate, ammonia, and DRP for the North Otago Volcanic Aquifer

	Nitrate		NOF Band	
Bore number	Median (mg/L)	95th percentile	Median	95th percentile
J41/0008	26	28.2	D	D
J42/0126	20	22	D	D
	Ammonia		NOF Band	
Bore number	Median (mg/L)	Max. (mg/L)	Median (mg/L)	Max. (mg/L)
J41/0008	0.005	0.065	A	B
J42/0126	0.005	0.01	A	A
	Dissolved Reactive Phosphorus (mg/L)		NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
J41/0008	0.048	0.062	D	D
J42/0126	0.0184	0.029	B	C

4.5.2 Kakanui-Kauru Alluvial Aquifer & Shag alluvial aquifers

4.5.2.1 Aquifer information

The Kakanui River catchment area is 894km^2. The catchment is bordered by Pisgah Spur and the Kakanui Mountains to the south and west and is separated from the Waitaki catchment, situated to the north, by rolling hill country. The main tributaries of the Kakanui are the Kauru River (catchment area of 143km^2), Island Stream (122km^2) and the Waiareka Creek (213km^2) (Ozanne and Wilson, 2013).

From its source in the Kakanui Mountains, the Kakanui River flows in a northeast direction through gorges incised in downlands or rolling country for around 40km before emerging onto plains at Clifton. It then flows to the southeast at a gentler gradient through highly developed pastures, where it merges with the broad, gravel-bedded Kauru River. The Kakanui water is heavily used for irrigation. Land use has intensified in the Kakanui catchment over the past 20 years, with increasing concerns regarding the intensification and subsequent water quality degradation. The lower Kakanui and Waiareka Creek are dominated by mixed sheep/beef/dairy/cropping and, recently dairy farming, increased by the introduction of the North Otago Irrigation Company (NOIC) water to the Waiareka Creek catchment. In contrast to that, the landuse in the upper Kauru and upper Kakanui is lower intensity sheep/beef farming and native vegetation. There is strong groundwater-surface water interaction in the alluvial gravels of the Kauru and the main stem of the Kakanui, particularly upstream of Gemmels

Crossing, which strongly affects water quality. Conversely, groundwater-surface water interaction in Waiareka Creek is low.

The Shag is a medium sized river with a catchment size of around 550km^2. The headwaters of the Shag are located on the south western slopes of Kakanui Peak in the Kakanui Mountains. From there, the Shag flows in a southeasterly direction for 90km past the township of Palmerston, before entering the Pacific Ocean south of Shag Point. The river supports high ecological values including high diversity of native fish, waterfowl, and regionally significant fisheries. The catchment is dominated by extensive agriculture and forestry with some short rotation cropping in the lower catchment. Parts of the catchment are utilised for the Oceana Gold hard rock goldmine at Macraes Flat, which includes open pit and underground mines. The existing mine operation discharges water and associated contaminants to the Deepdell Creek catchment. These operations are covered by numerous resource consents that include extensive monitoring and reporting. These are available through Oceana Gold (ORC, 2017a).

4.5.2.2 Groundwater quality measurements

There are three SoE monitoring bores in the Kakanui-Kauru Alluvium aquifer. The bores were installed in January 2014, as part of the Kakanui monitoring programme, three of which were left as SoE monitoring bores after the sampling for the programme has ended. Bore J41/0762 (Kakanui bore 3, 100mm diameter) is located at NZTM E1425455 N5007458. The bore depth is 3.3m. The log is composed of sandy gravel and minor silt. Bore J41/0764 (Kakanui bore 5, 100mm diameter) is situated at NZTM E1425354 N5004854. The total bore depth is 9.6m. The log describes coarse gravel to 9.6m underlain by sandy clay to 9.8m. Bore J41/0771 (Kakanui bore 10, 100mm diameter) is situated at NZTM E1429017 N5001748. The total bore depth is 4.1m. The log describes silty sand to 0.4m underlain by sandy gravel and cobbles to 3.3m. There is then 0.2m of clay/sand underlain by stiff clay to the bore bottom at 4.1m. This information indicates that the bores abstract from a shallow unconfined aquifer. It also indicates that the aquifer is very shallow, with basement depth of less than 10m.

Water level measurements in J41/0764 began in May 2015, with water levels ranging between 4.368 and 5.985m. The annual variability in water levels ranges between approximately 0.40 and 1.70m. Static Water Level measurements in bore J41/0762 began in May 2015, with levels ranging between 1.096 and 2.79m below MP. The seasonal variation in groundwater ranges between approximately 0.30 and 1.20m.

Groundwater in the Shag Alluvium Aquifer is monitored in bore J43/0006 (300mm diameter). The bore is situated at Mill Road, Palmerston NZTM E1421870 N4962122. The bore is 9.1m deep. The log describes topsoil and clay to 0.61m underlain by claybound gravel to 1.22m. There is than gravel to 9.14m, with the layer between 1.22 and 3.05 containing traces of clay and the layer between 3.05 and 9.14 described as gravel and sand. There is then sandstone to 10.14m. Screen information is not available for the bore, although it is likely to be screened within the bottom gravel/sand layer. Water levels are not monitored in bore J43/0006, potentially due to continuous pumping.

The comparison of groundwater quality against the DWSNZ indicate issues with elevated E. coli and nitrates. High E. coli exceedances were measured in the bores, which included the highest count in Otago (6,200MPN/100mL) in bore J43/0006 (September 2010) and a count of 291MPN/100mL (December 2018) in bore J41/0762, Figure 128. Some of the Kakanui bores also have substantial issues with elevated nitrate, with maximum concentrations in bores J41/0762 and J41/0771 exceeding the DWSNZ MAV of 11.3mg/L, Figure 129. Nitrate concentrations in the bores also show strong fluctuations, potentially related to changes in land use. The maximum concentrations in J41/0764 are 4.50mg/L which exceed the reference for groundwater under low intensity landuse (Daughney and Morgenstern, 2012). The concentrations in bore J43/0006 are lower, with a maximum of 2.64mg/L, which slightly exceeds the low landuse reference conditions. There are no exceedances of the arsenic MAV in the bores (Figure 130). Ammonia concentrations in the bores do not exceed the GV of 1.5mg/L (Figure 131).

Figure 128: Groundwater E. Coli count for the Kakanui/Shag Alluvium Aquifers

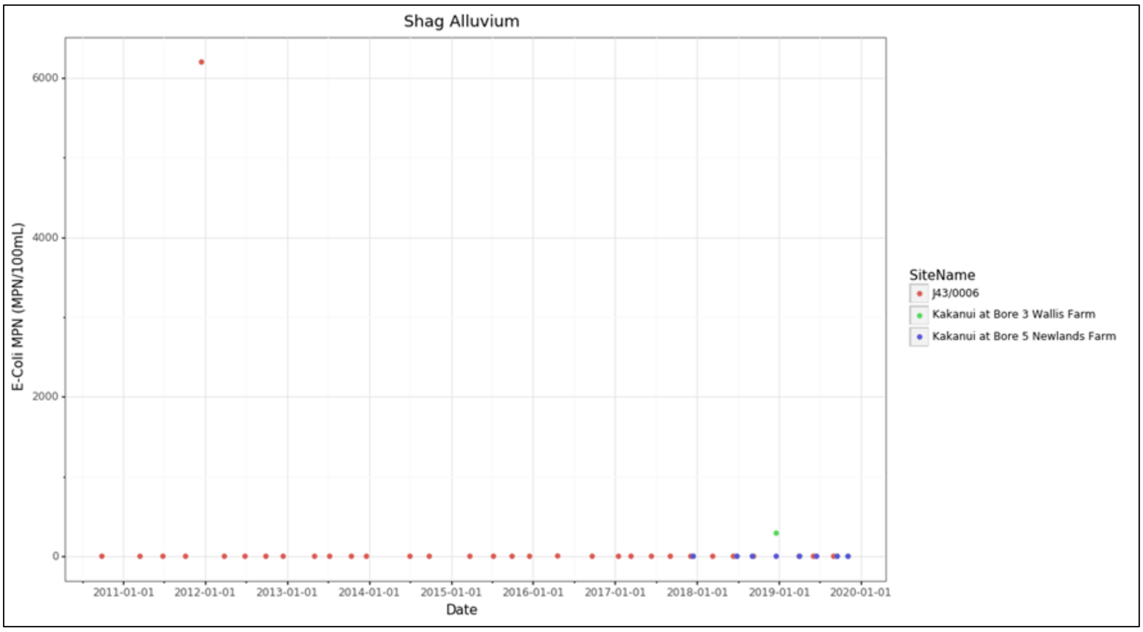


Figure 129: Groundwater nitrate concentrations for the Kakanui/Shag Alluvium Aquifers

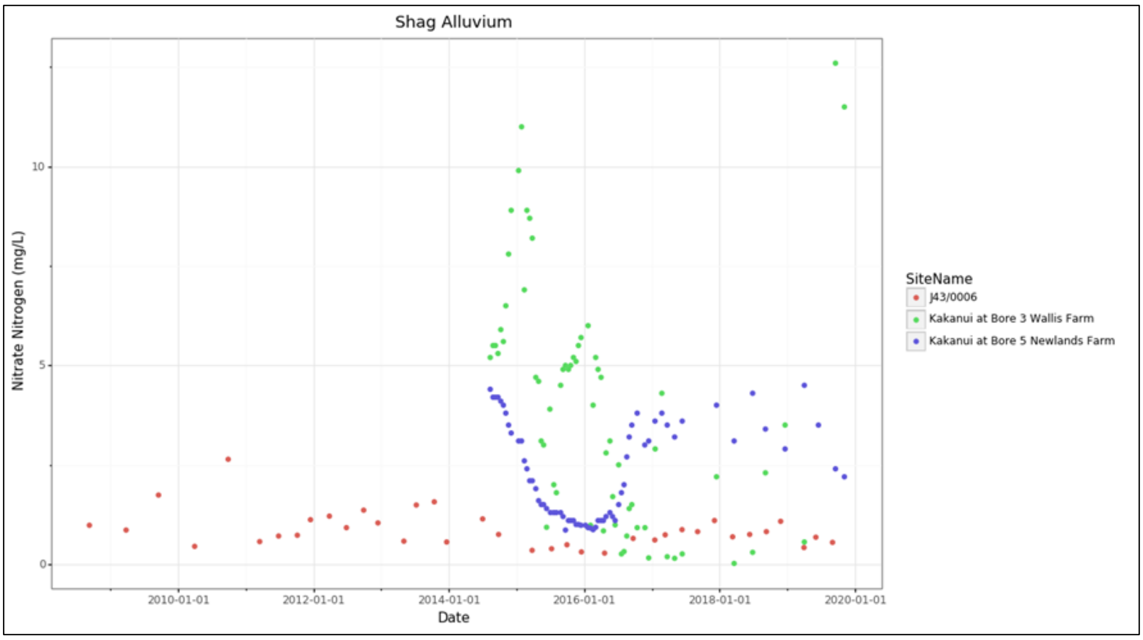


Figure 130: Groundwater dissolved arsenic concentrations for the Kakanui/Shag Alluvium Aquifers

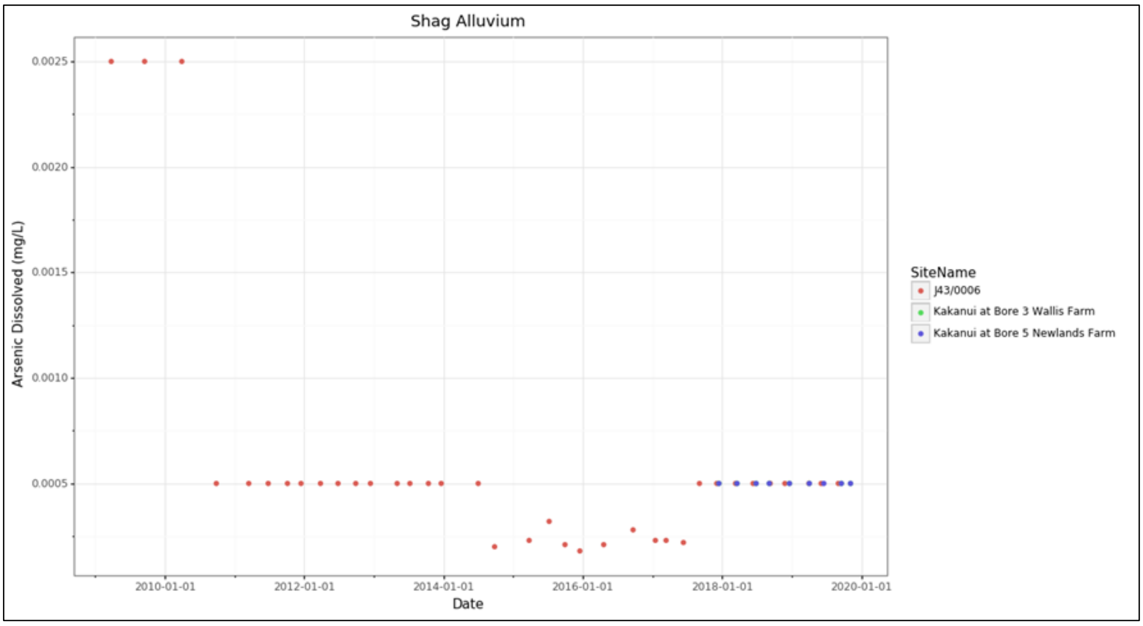
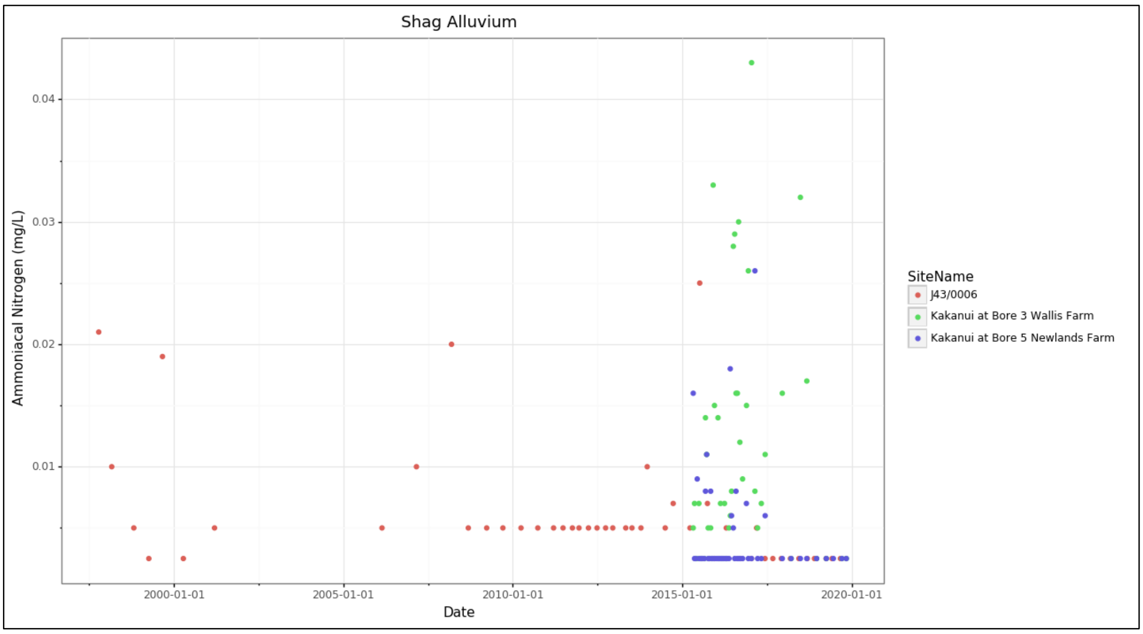


Figure 131: Groundwater ammonia concentrations for the Kakanui/Shag Alluvium Aquifers



Nutrient concentrations from the bores were then assessed against the RPW and NPS-FM NOF. The bores are located in Group 2 of Schedule 15 of the RPW. The results indicate substantial potential water quality issues, with the 80th percentile nitrate concentrations exceeding the Schedule 15 limits by between approximately 147 (J41/0771) and 15 (J43/0006) times, Table 65. DRP concentrations in all bores also exceed the threshold, although the concentrations are closer to the limits (Figure 132). The ammonia concentrations are below the limits.

Table 65: 80th percentile values for Schedule 15 water quality variables for the Kakanui-Kauru Alluvial Aquifer

Bore number	Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**0.075**	**0.010**	**0.100**
J41/0762 Kakanui bore 3	4.940	0.011	0.016
J41/0764 Kakanui bore 5	3.400	0.011	0.006
J41/0771 Kakanui bore 10	11.000	0.010	0.012
J43/0006	1.116	0.011	0.010

The comparison of nitrate concentrations from the bores against the NPS-FM NOF also indicates some issues, particularly for the Kakanui bores, with median and 95th percentile concentrations for bore 10 in Bands D and those for bore 3 in Band C. Nitrate concentration in Band D is below the National Bottom Line, indicating impacts on growth of multiple species which begins to approach acute impact level (i.e. death risk) for sensitive species at concentrations that exceed 20mg/L. The concentrations for bore J43/0006 are lower, with the median and 95th percentile in bands A and B, respectively.

The DRP concentrations are dominated by spiking concentrations, with the 95th concentrations in bands C and B. Ecological communities where DRP concentrations are in band C are impacted by moderately elevated above natural reference conditions. If other conditions that favour eutrophication also exist, DRP enrichment can increase algal and plant growth, loss of sensitive macroinvertebrate and fish taxa and high decay and respiration rates.

Figure 132: Groundwater Dissolved Reactive Phosphorus concentrations for the Kakanui/Shag Alluvium Aquifers

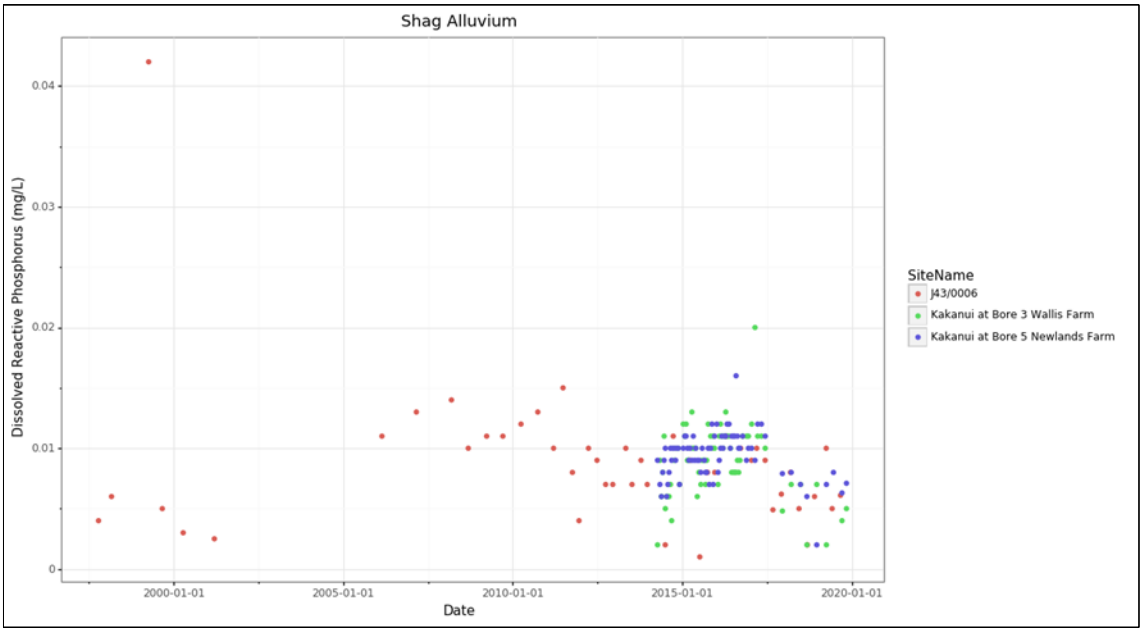


Table 66: NOF comparison for nitrate, ammonia, and DRP for the Kakanui-Kauru Alluvial Aquifer

Nitrate			NOF Band	
Bore number	Median (mg/L)	95th percentile	Median	95th percentile
J43/0006	0.75	1.604	A	B
J41/0762	4.3	5.88	C	C
J41/0764	2.1	3.9	B	C
J41/0771	7.2	12	D	D
Ammonia			NOF Band	
Bore number	Median (mg/L)	Max. (mg/L)	Median (mg/L)	Max. (mg/L)
J43/0006	0.005	0.025	A	A
J41/0762	0.007	0.043	A	A
J41/0764	0.0025	0.026	A	A
J41/0771	0.0025	0.034	A	A
Dissolved Reactive Phosphorus (mg/L)			NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
J43/0006	0.0085	0.01375	A	B
J41/0762	0.009	0.012	A	B
J41/0764	0.01	0.012	A	C
J41/0771	0.009	0.011	A	B

4.5.3 The Lower Waitaki Aquifer

4.5.3.1 Aquifer information

The Lower Waitaki Plains aquifer is located approximately 20km north of Oamaru. The aquifer area is around 19,793ha and it has a triangle shape, stretching from a narrow point at Black Point in the west to its widest margin along the North Otago coast (Figure 122). The Plains' alluvial sand and gravel formation hosts an unconfined aquifer, with potentially local semi confined conditions associated with silt and clay lenses. Three main soil types were identified for the area:

- Well drained soils mainly composed of sandy loams (potentially gravelly and stony), covering approximately half of the plains in the north along the Waitaki River margin (e.g. Rangitata sandy loam on the lower terraces near the river, and Stewart silty loam on the higher terraces);
- Moderately well drained soils mainly composed of silty loams (intermediate soils such as Ngapara and Darnley silty loams) covering the southern half part of the Plains;
- Imperfectly drained soils mainly made of silty loams (heavier soils such as Pukeuri silty loam), encountered in a limited number of locations across the Plains (e.g. Hilderthrope and Pukeuri).

Soil maps indicate that most of the soils along the river terraces and in the northern half of the Plains are free-draining, suggesting that these are suitable for intensive pastoral farming and less suitable for cropping/horticulture. Based on that, the upper part of the Plains are mainly used for dairying whilst cropping is practiced on the heavier soils in the southern part of the valley.

Dairy farming composes the main land use on the Plains, with its expansion linked to the Lower Waitaki Irrigation Scheme. The scheme abstracts water from the Waitaki River, on the upper edge of the Waitaki Plain, where a managed race delivers water through the lower Plains and down to Oamaru. The water uses include agricultural, commercial, and domestic uses. The scheme's peak daily distribution volume is around 1.2million m^3, of which approximately 1.123 million m^3 is used for irrigation (ORC, 2016c).

The geology of the Lower Waitaki Plains is mainly composed of Holocene and late Pleistocene unconsolidated gravels and sands, which were deposited during successive phases of glacial advance/retreat. The more recent sediments were deposited adjacent to the Waitaki River and the coastline. The Plains' alluvium overlies consolidated Tertiary sedimentary rocks (i.e. the Rifle Butts Formation) which consist of various conglomerates, sandstones, siltstone and mudstone. Available bore logs indicate that the depth to the Tertiary sediment basement ranges between 13 and 45.80m, with the aquifer deepening towards the west. The basement sediments comprise of sandstone, siltstone, and mudstone. The morphology of the Plains is impacted by the local fault system.

Groundwater levels have been monitored in the Dennisons bore J41/0377 since March 1997. The seasonal fluctuation in water levels is around 1.5m, although a range of 2.0m was also observed in some years (e.g. 2011). The highest water levels occur in March/April, following recharge from irrigation during the summer, although some episodic high levels were occasionally measured during winters (e.g. July 2013, 2017). These are likely connected to high flow from the Waitaki River or hillside catchments. Water levels then recede during the winter months, with the lowest levels usually observed in September and October. An upward trend was observed between 1997 and 2002, following the aquifer's equilibration to the new recharge dynamics posed by the irrigation scheme. There is currently no stage monitoring on the lower Waitaki River, and the nearest groundwater level monitoring bore is around 9km away from the river, hence, groundwater-river interaction is not directly investigated (ORC, 2016c).

Piezometric maps suggest that groundwater flow direction generally follows topography, with the highest hydraulic heads near Black Point and the lowest at the coast. The flow direction in the upper part of the aquifer is from the southwest towards the northeast/Waitaki River. Groundwater in the lower part flows from the west towards the east/southeast and the ocean. The hydraulic gradient is shallower along the western parts of the foot hills (aquifer recharge area) and steeper in the southeast near the coast (discharge area). The mean gradient is around 1:270m, similar to the land surface gradient. The data also indicated that the depth to groundwater ranges between approximately 1 and 15m below ground level, with the shallowest water tables measured near the Waitaki River and the deepest near the coast and away from the river (i.e. to the east and south). The measurements also indicated the expansion of the shallow water table towards the central part of the plains during the summer, following recharge by irrigation returns. A large part of the Lower Waitaki Plain is listed as a Groundwater Protection Zone in the RPW. This is likely due to the high permeability of the soil in the area (ORC, 2016c).

4.5.3.2 Groundwater quality monitoring

Groundwater quality in the Lower Waitaki Plains aquifer is monitored in five bores, the details of which are summarised in Table 67. Bore J41/0317 (150mm diameter) has been monitored since June 1993 whilst the other four bores were added following an ORC investigation of the area in 2016.

Bore J41/0317 (150mm diameter) was drilled in June 1983. The bore is located at Steward Road approximately 1km west of SH1, NZTM E1448327 N5020845. The total bore depth is 16.5m. There is no bore log or screen information for this bore.

Bore J41/0442 (150mm diameter) was drilled in June 1997. The bore is located at Jardine Road, Oamaru, NZTM E1435789 N5022981. The total bore depth is 11.4m. The bore log describes tight silty gravel/pebbles to 3.9m underlain by tight sandy gravels/pebbles/cobbles to 7.3m. There is then silty gravel/pebbles to 10.4m underlain by silty clay to the bore bottom at 11.4m. The bore is screened at a depth of between 8.4 and 10.4m, within a horizon of silty gravel/pebbles. The SWL in the bore in November 2019 was 4.07m below MP.

Bore J41/0586 (125mm diameter) was drilled in July 2003. The bore is located at Ferry Road, Oamaru, NZTM E1444388 N5022051. The total bore depth is 10.9m. The bore log describes coarse, cobbley gravels to 11.6m underlain by clay to the bore bottom at 12.7m. The bore is screened between 10.30 and 10.90m, within a layer of cobbley gravels. The SWL in December 2019 was 3.190m below MP.

Bore J41/0576 (200mm diameter) was drilled in December 2003. The bore is located at MacDonalds Road, Oamaru (Hilderthorpe) at NZTM E1447793 N5017591. The total bore depth is 23.0m. The bore log describes 1.0m of topsoil underlain by grey gravels to the bore depth at 23.0m. The bore is screened in the gravels, at a depth of between 21.0 and 23.0m. There is no SWL information for the bore (likely due to the inability to measure it through the borehead setup). The SWL at the time of drilling was 7.4m below MP. The bore log indicates that it abstracts from an unconfined gravel aquifer at least 23m deep.

Bore J41/0571 (150mm diameter) was drilled in August 2002. The bore is located at Hilderthorpe-Pukeuri Road, Oamaru, NZTM E1446095 N5014890. The total bore depth is 23.5m. The bore log describes top soil and clay to 1.3m underlain by small sandy gravels to 11.1m. There is then weathered gravels to the bore bottom at 23.5m. The length of the leader and screen are 2.040m, with a leader length of 0.700m, indicating that the bore is screened at a depth of 22.16m, within the weathered gravels horizon. This indicates that the bore abstracts from an unconfined gravel aquifer. The SWL in December 2019 was 7.18m below MP.

This information indicates that the bores abstract from an unconfined gravel aquifer. The aquifer and SWL are deeper in bores J41/0571 and J41/0576, situated in the eastern, lower part of the plains, than in the other SoE monitoring bores which are situated in the upper part of the Plains. This is consistent with previous findings (ORC, 2016c).

Table 67: Summary of groundwater quality SoE bore details for the Lower Waitaki Plains Aquifer

Well Number	Depth (m)	Diam. (mm)	Drill Date	Easting NZTM	Northing NZTM	Screen Top (m)	Screen Bottom (m)	Bore Log?
J41/0317	16.5	150	1/01/1983	1448327	5020845	N.A.	N.A.	No
J41/0442	11.4	150	3/06/1997	1435789	5022981	8.4	10.4	Yes
J41/0586	10.9	125	25/07/2003	1444388	5022051	10.3	10.9	Yes
J41/0576	23	200	5/12/2003	1447793	5017591	N.A.	N.A.	Yes
J41/0571	23.5	150	12/08/2002	1446095	5014890	N.A.	N.A.	Yes

Groundwater quality results from the Lower Waitaki SoE bores was assessed against the DWSNZ. The results indicate some groundwater quality issues. Exceedances of the E. coli MAV were measured in all bores, with the most exceedances observed in the long term monitoring bore, J41/0317 (Figure 133). E. coli has been monitored in this bore since September 2012. The highest exceedance was 150MPN/100mL (September 2016). Most of the exceedances were measured during spring/summer, likely associated with the higher water table during these seasons due to irrigation recharge (ORC, 2016c). The monitoring of E. coli in the other bores began in March 2017. Exceedances of the MAV were noted in all four bores, with E. coli counts ranging between 1.6 and 9 MPN/100mL (Figure 133). This indicates high potential risk for faecal contamination in the Lower Waitaki aquifer.

Groundwater nitrate concentrations in the Lower Waitaki bores suggest potential issues, with most bores having relatively high concentrations (Figure 134). Nitrate concentrations in bore J41/0317 were monitored since November 2008. Concentrations range between 2.8 and 8.6mg/L, which exceeds ½ of the DWSNZ MAV of 11.3mg/L. The data also shows high fluctuations and increasing concentrations, particularly since March 2015. The concentrations in bores J41/0576 and J41/0586 range between approximately 5.3 and 7.9mg/L, which also exceeds ½ of the MAV. Concentrations in these bores, and in bore J41/0571, have also generally increased since the start of monitoring in June 2016. Although groundwater nitrate concentrations were below the MAV, their increase still indicate issues with potential nitrate contamination. Dissolved arsenic concentrations in all bores were below the 0.01mg/L MAV (

Figure 135). All ammonia concentrations were below the aesthetic GV of 1.5mg/L (Figure 136).

Figure 133: Groundwater E. coli count for the Lower Waitaki Aquifer

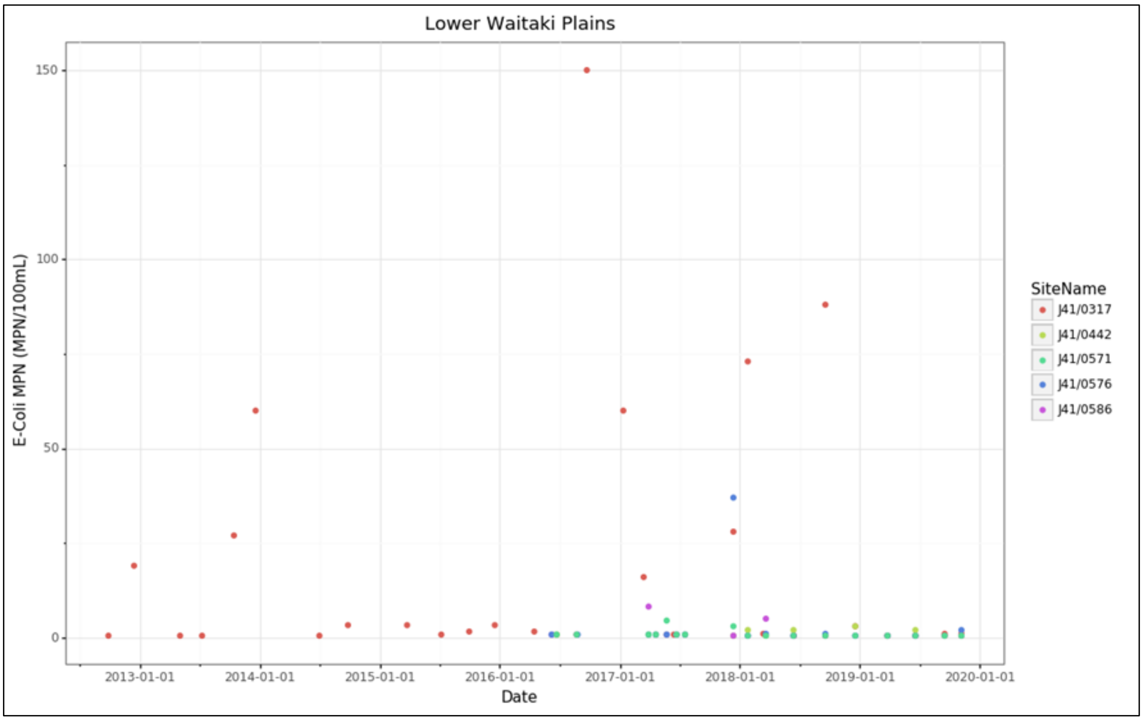


Figure 134: Groundwater nitrate concentrations for the Lower Waitaki Aquifer

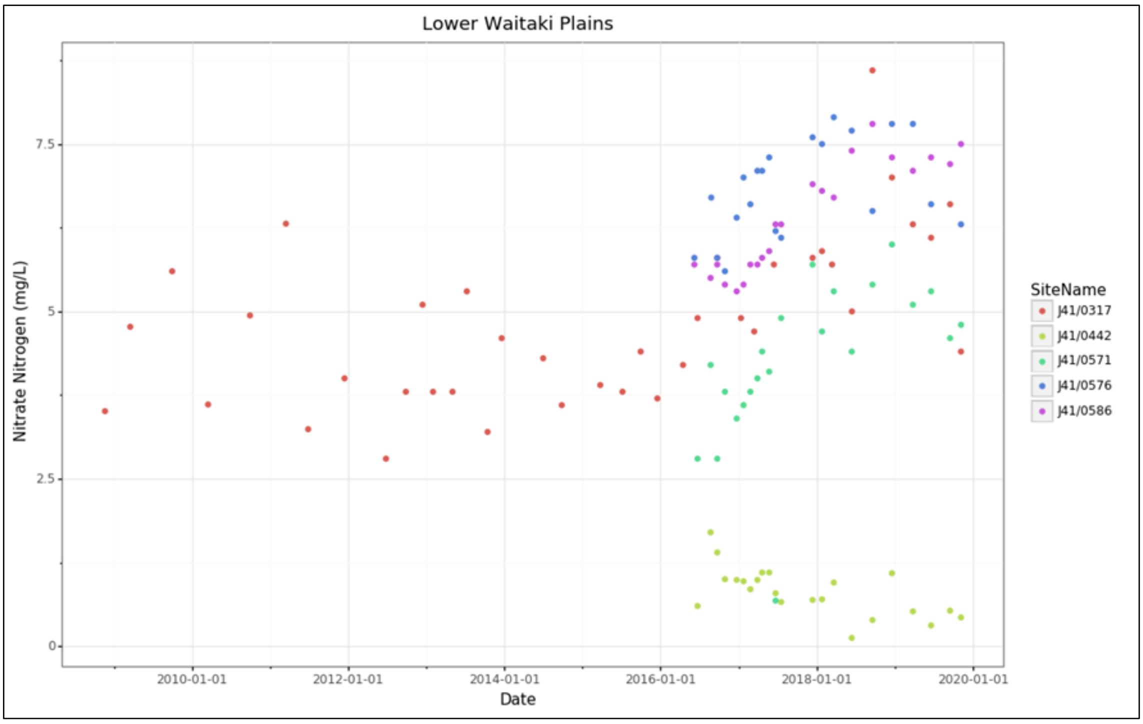


Figure 135: Groundwater dissolved arsenic concentrations for the Lower Waitaki Aquifer

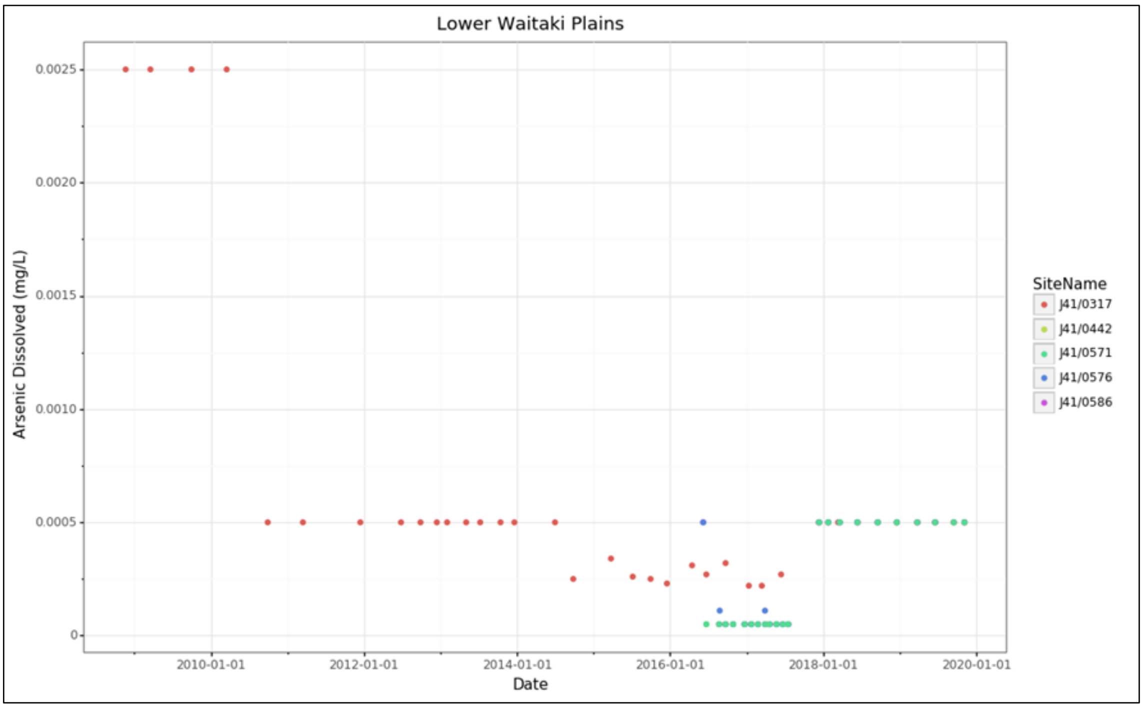
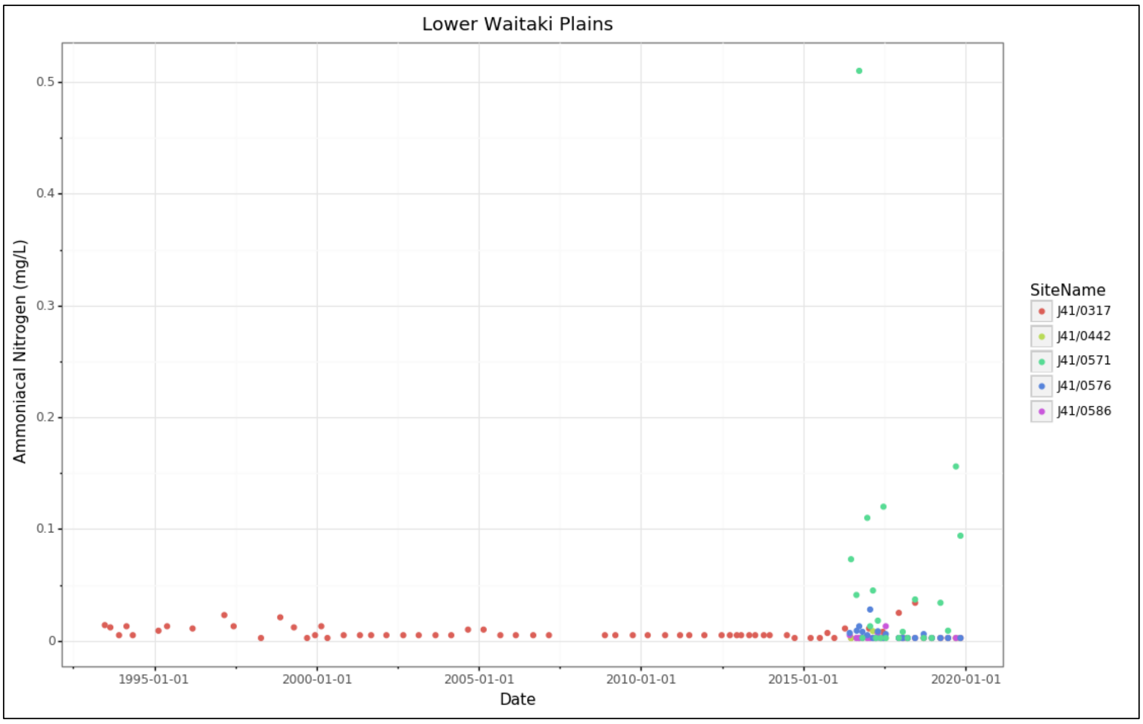


Figure 136: Groundwater ammonia concentrations for the Lower Waitaki Aquifer



Potential impacts of groundwater quality on surface water systems was assessed by comparing nutrient concentrations from shallow bores (<20m) against the RPW and the NPS-FM NOF. Bores shallower than 20m in the Lower Waitaki aquifer include J41/0317, J41/0442, and J41/0586, all of which are located in Group 2 of Schedule 15. The 80th percentile nitrate concentrations in all bores exceed the Schedule 15 limit of 0.075mg/L, with concentrations in the bore exceeding the limit by between 14 (J41/0442) and 97 times (J41/0586). DRP concentrations in bore J41/0317 exceed the limit by more than three times, with maximum concentrations of 0.144mg/L (

Figure 137). Conversely, DRP concentrations in the other bores are below the limit. Ammonia concentrations in all three bores are also below the Schedule 15 limit (Table 68).

Figure 137: Groundwater Dissolved Reactive Phosphorus concentrations for the Lower Waitaki aquifer

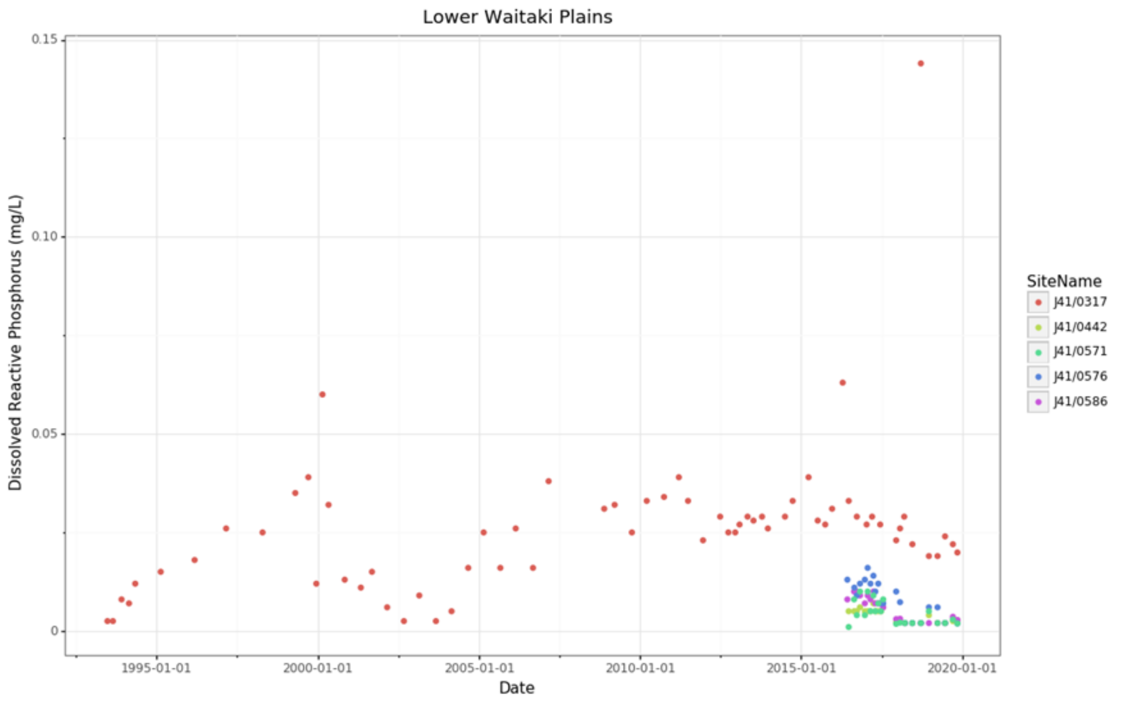


Table 68: 80th percentile values for Schedule 15 water quality variables for the Lower Waitaki Aquifer

Group 2 Sched. 15 limit (mg/L)	Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Bore number	**0.075**	**0.010**	**0.100**
J41/0317	5.800	0.032	0.010
J41/0442	1.072	0.005	0.005
J41/0586	7.280	0.009	0.005

The assessment against the NPS-FM NOF further highlights the elevated nitrates in the Lower Waitaki groundwater, with the median and 95th percentile concentrations in bores J41/0317 and J41/0586 in Band C, where there are growth effects on up to 20% of species, mainly of which are sensitive such as fish, though no acute effects are expected. The median and 95th percentile nitrate concentrations for boreJ41/0442 are in Band A (Table 69).

The DRP assessment for bore J41/0317 also shows potential issues, with the median and 95th percentile DRP concentrations in Bands C and D, respectively. Band D is below the National Bottom Line, where ecological communities are impacted by DRP concentrations that substantially exceed natural reference conditions. If combined with other conditions that favour eutrophication, DRP enrichment can drive excessive primary production and significant changes to macroinvertebrate and fish communities, as species that are sensitive to hypoxia are lost. The 95th percentile DRP concentration for bore J41/0586 is in Band B, where ecological communities are slightly impacted by minor DRP exceedance of natural reference conditions. If other conditions that favour eutrophication occur, sensitive ecosystem may experience additional algal and plant growth, loss of sensitive macroinvertebrate taxa and higher rates of respiration and decay (MfE, 2020). Ammonia concentrations for all bores are in Band A.

Table 69: NPS-FM NOF comparison for nitrate, ammonia, and DRP for the Lower Waitaki Aquifer

	Nitrate Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**median**	**95th percentile**
J41/0317	4.735	6.66	C	C
J41/0442	0.82	1.385	A	A
J41/0586	6.3	7.495	C	C
	Ammoniacal Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	max	**Median**	**95th percentile**
J41/0317	0.005	0.034	A	A
J41/0442	0.0025	0.0086	A	A
J41/0586	0.0025	0.013	A	A
	Dissolved Reactive Phosphorus (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**Median**	**95th percentile**
J41/0317	0.026	0.039	C	D
J41/0442	0.005	0.006	A	A
J41/0586	0.0065	0.01	A	B

5. Discussion & Recommendations

This report highlights a wide variability in groundwater quality across Otago, with some areas having substantial issues (e.g. North Otago, Lower Clutha) whilst others generally have good groundwater quality (e.g. the Upper Lakes). The report also highlights other issues regarding the condition and suitability of the monitoring network. In order to help improve groundwater quality in Otago, the following recommendations are based on this report:

- Ensure groundwater users maintain good borehead security to prevent contaminant migration into bores. It is also recommended to tighten the rules regarding bore security in the Regional Plan/consent conditions.
- Publish the groundwater quality monitoring results on the ORC website with suitable symbology that clearly indicates when parameters exceed the DWSNZ MAVs.
- Encourage bore owners to regularly test their bore water, especially in areas of high risk (i.e. Central Otago/Upper Lakes for arsenic and areas of intensive farming/On Site Waste Management Systems for E. coli and nutrients).
- Many of the areas where the SoE data shows degraded groundwater quality (e.g. North Otago, Lower Clutha) are used for intensive farming. Some of these are situated on permeable substrate (e.g. the Lower Waitaki and Kakanui-Kauru). It is recommended to review the regulatory/planning regimes around high risk land uses (e.g. intensive farming, On Site Waste Management Systems), particularly in vulnerable catchments.
- Many SoE bores are situated on private land and require maintenance and better head protection. Furthermore, many of the bores’ locations are based on previous availability rather than their representation of aquifers. Due to these issues, it is recommended to implement a dedicated programme to replace unsuitable bores with new, dedicated ones. The new bores will ideally be emplaced on TLA reserve land in order to ensure long term access. When suitable existing bores are identified on private land, it is recommended that access for monitoring is ensured by signing a formal agreement with the land owners. It is also recommended to have an ongoing maintenance programme for the bores, where they are pumped, surveyed, and the head security is confirmed on a regular basis.

6. Conclusions

This report summarises the results from ORC's groundwater quality SoE monitoring programme. The groundwater SoE quality network currently consists of 54 monitoring bores, situated on both public and private land with varying degree of borehead security. Although bores are located in each FMU, their distribution is not even, with the Catlins and Dunedin & Coast FMUs having only one monitoring bore each. Furthermore, some of the aquifers in the region are currently not monitored. This report assesses groundwater quality results from the start of monitoring in each currently active SoE bore until the end of 2019. Groundwater quality in the SoE bores is monitored quarterly for microbiological parameters, major ion geochemistry, and metal concentrations. The sampling follows the National Environmental Monitoring Standards [NEMS] (2019) and the samples are analysed in an accredited laboratory.

This report summarises the state of groundwater quality in Otago in relation to drinking water quality. This is assessed by comparing groundwater E. coli, dissolved arsenic, and nitrate concentrations against the DWSNZ thresholds. The report also assesses the impact on surface water quality by comparing groundwater nutrient concentrations in shallow bores against the RPW and NPS-FM NOF. However, as these standards do not currently include limits for nutrients in groundwater, this approach only provides an overview, rather than a direct analysis.

The E. coli assessment was based on the percentage of samples in each SoE bore that exceeded the DWSNZ MAV. The data shows that E. coli was detected in 75% of the bores in the region at a point during the monitoring period and that exceedances were detected in each of Otago's FMU/rohes. This indicates that potential faecal contamination is a significant water quality issue across Otago. The proportion of E. coli exceedance across Otago (75%) is similar to that of the Clutha, North Otago and Taieri FMUs. However, a wider variability was observed within the different rohes of the Clutha FMU, with higher proportions in the Manuherekia and Lower Clutha rohes, indicating a higher contamination risk in these rohes. Conversely, the proportion of exceedance in the Upper Lakes rohe was lower than the regional, whilst that of the Dunstan rohe was similar to it. The data from the Catlins and Dunedin & Coast FMU is highly skewed due to each FMU having only one monitoring bore. An assessment of E. coli exceedance and bore depth shows that the highest proportion of E. coli exceedance was in bores shallower than 10m (92%) and the lowest (40%) in bores deeper than 60m. This data indicates that groundwater and bores in Otago are vulnerable to faecal contamination. Elevated E. Coli can also be a local issue and is strongly dependent on bore security, hence, the SoE data does not present a complete mapping of this risk. Nevertheless, it is strongly recommended that bore owners ensure adequate borehead security and regularly test their groundwater.

Arsenic in groundwater can originate from anthropogenic (e.g. sheep dips, treated timber posts) and geological sources such as schist lithology, reduced peat deposits, and volcanic rocks. Exposure to elevated arsenic can lead to a range of cancers. The spatial distribution of maximum arsenic concentrations in Otago groundwater shows that concentrations exceeded the MAV in only seven SoE monitoring bores, five of which are located in the Upper Clutha/Wakatipu Basin area, which are underlain by schist lithology known to contain arsenic. No arsenic concentrations above the MAV were detected in any bores in the North Otago, Dunedin & Coast, or Catlins FMUs. Nevertheless, due to the abundance of arsenic-containing schist lithology, particularly in the Upper Clutha area, and the high spatial variability of arsenic in groundwater, it is strongly recommended that bore owners regularly test their water.

Nitrate (NO_3-N) is a key nutrient required for the growth of plants and algae. However, excess nitrate can adversely impact water quality (e.g. eutrophication) and also cause health concerns. Groundwater nitrate concentration data shows that none of the aquifers in Otago has a median nitrate concentration above the DWSNZ MAV of 11.3mg/L. However, it did highlight a variable degree of nitrate contamination in relation to the MAV, with the median concentration in some aquifers, particularly in North Otago and the Lower Clutha, closer to the MAV. Conversely, the median nitrate concentrations in many aquifers are low, suggesting either low impact from landuse (i.e. concentrations below <2.5mg/L, [Daughney and Morgenstern, 2012]) or denitrification. However, the potential for denitrification was not addressed in this report.

The potential impacts of groundwater quality in Otago on ecosystems was investigated by assessing groundwater nutrient concentrations (nitrate, DRP, and ammonia) in bores shallower than 20m against the RPW Schedule 15 limits and the NPS-FM NOF. The results show that groundwater concentrations of nitrate and DRP usually exceed the surface water limits. Conversely, most ammonia concentrations were below the limit. However, it is important to note that, due to the absence of standards for groundwater nutrient limits, this assessment is only an overview.

The groundwater quality assessment for each FMU/aquifer shows that, similar to surface water, groundwater quality across the region is also highly variable. The results from the Clutha FMU show high variability, with good groundwater quality in some rohe (i.e. the Upper Lakes, Dunstan) and degraded quality in others, particularly the Lower Clutha. The main issues are elevated E. coli and dissolved arsenic concentrations in some bores, with elevated nutrient concentrations also common. The results from the Upper Lakes and Dunstan rohes generally show compliance with the DWSNZ, although elevated E. coli counts were measured in some bores. Elevated dissolved arsenic concentrations were also measured in some bores, although their source is likely to be the prevalent schist lithology. Nitrate concentrations are generally below the DWSNZ for nitrates. However, nutrient concentrations usually exceed the RPW and NPS-FM surface water limits, with particularly high DRP and nitrate concentrations in Kingston and Glenorchy. These are likely due to high septic tanks density and to shallow, poorly-secured boreheads. These nutrients can potentially adversely impact water quality in Lake Wakatipu, although groundwater (and nutrient) fluxes into the Lake are likely to be substantially lower than the surface water inflows. Groundwater quality in the Manuherekia rohe is generally fair although E. coli exceedances were measured in most bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherekia Alluvium Aquifer and Manuherekia Claybound Aquifer monitoring bores generally near the low intensity landuse reference value. However, increasing nitrate concentrations were observed in the Manuherekia GWMZ monitoring bore, where concentrations exceed ½ of the MAV. No elevated arsenic concentrations were measured in any of the monitoring bores in the rohe. The results from the shallow monitoring bores show that nitrate and DRP concentrations exceed the surface water limits. Groundwater quality results from the Lower Clutha rohe indicate significant water quality issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. The results also show elevated nutrient concentrations, with some of these issues due to shallow monitoring bores and poor bore security. These results also support the reported poor surface water quality results from this area (ORC, 2017a).

Groundwater results from the Taieri FMU indicate potential risk of faecal contamination, with E. coli exceedance measured in all the FMU's aquifers. The pattern of nitrate concentrations is mixed, with elevated concentrations over ½ of the MAV in some bores and concentrations around the low intensity landuse value in others. The assessment against surface water quality standards indicates potential issues, with exceedances of the nutrient limits in most aquifers. It is likely that some of these elevated results are due to monitoring bores being shallow, insecure, and located near risky land uses (e.g. dairy farms and/or septic tanks). Nevertheless, these can potentially adversely impact surface water quality and ecosystem health.

The results indicate that the North Otago FMU has the most degraded groundwater quality in Otago, with high E. coli exceedances and elevated nitrate concentrations, particularly in the NOVA. Potential faecal contamination is also a concern, with elevated E. coli measured in some SoE bores in each of the FMU's aquifers. Conversely, there were no elevated dissolved arsenic concentrations in any of the bores. The results also indicated high nitrate and DRP concentrations which substantially exceed the surface water limits. Understanding the potential impact on surface water quality is imperative due to the prevalence of groundwater-surface water interaction in this FMU.

Based on this report, the following actions are recommended:

- Ensure bore owners practice good bore security to prevent contaminant migration to bores and encourage frequent groundwater testing. This includes improving ORC's regulatory and education regimes.
- Publishing the SoE groundwater quality monitoring results on the ORC website with suitable symbology to clearly indicate when parameters exceed the DWSNZ MAVs.
- Review the legislation and management of known high risk activities to water quality in areas of poor groundwater quality.
- Embark on a programme to replace unsuitable SoE bores with new dedicated ones. It is also recommended to have an ongoing maintenance programme for the bores.

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Appendix 1: List of monitoring bores for the SoE network

Bore number	Depth (m)	Diameter (mm)	Eastings (NZTM)	Northings (NZTM)	FMU	Rohe
F40/0025	40	150	1294352	5042604	Clutha / Mata-Au	Dunstan Rohe
F40/0045	60	100	1295870	5040239	Clutha / Mata-Au	Dunstan Rohe
F40/0206	45	150	1297955	5042689	Clutha / Mata-Au	Dunstan Rohe
F41/0104	60	100	1267649	5008496	Clutha / Mata-Au	Dunstan Rohe
F41/0162	16.53	125	1299519	5011550	Clutha / Mata-Au	Dunstan Rohe
F41/0203	4.1	50	1272318	5010248	Clutha / Mata-Au	Dunstan Rohe
F41/0300	48.71	125	1297971	5003508	Clutha / Mata-Au	Dunstan Rohe
F41/0437	24.85	0	1264923	5010849	Clutha / Mata-Au	Dunstan Rohe
F41/0438	6	0	1269859	5012093	Clutha / Mata-Au	Dunstan Rohe
G40/0175	12.64	125	1316489	5029566	Clutha / Mata-Au	Dunstan Rohe
G40/0411	17.75	150	1309254	5036692	Clutha / Mata-Au	Dunstan Rohe
G41/0211	41.51	125	1313189	5027098	Clutha / Mata-Au	Dunstan Rohe
G41/0487	28.99	150	1304667	5016105	Clutha / Mata-Au	Dunstan Rohe
G43/0009	15.2	100	1317341	4939478	Clutha / Mata-Au	Lower Clutha
G43/0072	16.8	150	1310456	4954944	Clutha / Mata-Au	Lower Clutha
G43/0224b	12.73	50	1316402	4941149	Clutha / Mata-Au	Lower Clutha
G44/0127	5.2	100	1306679	4910886	Clutha / Mata-Au	Lower Clutha
G44/0136	5.5	50	1310773	4912370	Clutha / Mata-Au	Lower Clutha
G45/0225	128	200	1307731	4897236	Clutha / Mata-Au	Lower Clutha
H46/0144	38	100	1354935	4870284	Clutha / Mata-Au	Lower Clutha
G41/0254	6.5	125	1330618	5002689	Clutha / Mata-Au	Manuherekia
G42/0123	32.4	100	1317225	4987272	Clutha / Mata-Au	Manuherekia
G42/0290	16.1	100	1318011	4988269	Clutha / Mata-Au	Manuherekia
G46/0152	10	150	1321034	4986341	Clutha / Mata-Au	Manuherekia
E41/0182	10.1	25000	1235134	5023214	Clutha / Mata-Au	Upper Lakes
E41/0183	10.2	25000	1235510	5023479	Clutha / Mata-Au	Upper Lakes
E41/0184	10	25000	1235260	5023606	Clutha / Mata-Au	Upper Lakes
E41/0185	10	25000	1235380	5023306	Clutha / Mata-Au	Upper Lakes
F42/0113	4.4	75	1264431	4971121	Clutha / Mata-Au	Upper Lakes
G40/0367	17.1	150	1305561	5047533	Clutha / Mata-Au	Upper Lakes

G40/0415	30.07	250	1305860	5052754	Clutha / Mata-Au	Upper Lakes
G40/0416	30.5	200	1302748	5052499	Clutha / Mata-Au	Upper Lakes
H45/0314	11.28	125	1368244	4892910	Dunedin Coast	
J41/0008	20	1000	1434870	5000331	North Otago	
J41/0249	90	250	1430982	5000848	North Otago	
J41/0317	16.5	150	1448327	5020845	North Otago	
J41/0442	11.4	150	1435789	5022981	North Otago	
J41/0571	23.5	150	1446095	5014890	North Otago	
J41/0576	23	200	1447793	5017591	North Otago	
J41/0586	10.9	125	1444388	5022051	North Otago	
J41/0762	3.3	0	1425455	5007458	North Otago	
J41/0764	9.6	0	1425354	5004854	North Otago	
J41/0771	4.1	0	1429017	5001748	North Otago	
J42/0126	10.9	250	1434931	4994910	North Otago	
J43/0006	9.1	300	1421870	4962122	North Otago	
H42/0213	5.6	150	1366536	4993063	Taieri	
H42/0214	9	150	1369609	4987274	Taieri	
H43/0132	9.1	155	1375279	4957869	Taieri	
H44/0007	24.4	100	1378924	4912001	Taieri	
I44/0495	22.9	0	1392261	4918203	Taieri	
I44/0519	17.5	0	1392705	4919569	Taieri	
I44/0821	27.375	100	1396046	4919018	Taieri	
I44/0964	40.5	100	1392510	4916131	Taieri	
H46/0118	12	1400	1349089	4868050	The Catlins	

Appendix 2: SoE groundwater quality monitoring parameters and analytical methods

Parameter	Method	Limit of Detection
Total anions & cations for anion/cation balance	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH	0.07meq/L (anions) 0.05meq/L (cations)
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c	0.1 pH units
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (modified for Alkalinity <20) 23rd ed. 2017.	1.0g/m^3 as CaCO3
Carbonate Alkalinity	Calculation: from alkalinity and pH, valid where TDS is not >500 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.	1.0g/m^3 as CaCO3
Bicarbonate Alkalinity	Calculation: from alkalinity and pH, valid where TDS is not >500 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.	1.0g/m^3 as CaCO3
Hydroxide Alkalinity	Calculation: from alkalinity and pH, valid where TDS is not >500 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.	1.0g/m^3 as CaCO3
Free Carbon Dioxide Calculation	Calculation: from alkalinity and pH, valid where TDS is not >500 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.	1.0g/m^3 at 25 °C
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B 23rd 1-6	1.0g/m^3 as CaCO3

Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B	0.1mS/m
Approx. Total Dissolved Salts	Calculation: from Electrical Conductivity.	2g/m^3
Dissolved Arsenic	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed.	0.0010g/m^3
Dissolved Cadmium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.00005g/m^3
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.05g/m^3
Dissolved Chromium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.0005g/m^3
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.02g/m^3
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.02g/m^3
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.0005g/m^3
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.05g/m^3
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.02g/m^3
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified)	0.5g/m^3
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F- C	0.05g/m^3
Total Nitrogen*	Alkaline persulphate digestion, automated Cd reduction/sulphanilamide colorimetry. APHA 4500-N C & 4500-NO3- I (modified) 23rd ed. 2017.	0.010g/m^3
Total Ammoniacal-N	Phenol/hypochlorite colorimetry. Flow injection analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH3 H 23rd ed. 2017.	0.005g/m^3
Nitrite-N Trace	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I (modified) 23rd ed. 2017.	0.0010g/m^3
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House. 0.0010 g/m3	0.0010g/m^3

Nitrate-N + Nitrite-N Trace	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO3- I (modified) 23rd ed. 2017.	0.0010g/m^3
Total Organic Nitrogen (TON), trace level	Calculation: TN - (NH4N + NO3N + NO2N)	0.012g/m^3
Dissolved Reactive Phosphorus (trace)	Filtered sample. Molybdenum blue colorimetry. Flow injection analyser. APHA 4500-P G 23rd ed. 2017.	0.0010g/m^3
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis and also modified to include a reductant to reduce interference from any arsenic present in the sample) 23rd ed. 2017. NWASCO, Water & soil Miscellaneous Publication No. 38, 1982	0.004g/m^3
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5g/m^3
Escherichia coli	MPN count using Colilert (Incubated at 35°C for 24 hours), Colilert 18 (Incubated at 35°C for 18 hours), APHA 9223 B 23rd ed. 2017.	1 MPN/100mL