Groundwater Quality State and Trends in Tāmaki Makaurau / Auckland 2017-2024

State of the Environment Reporting

Dr Laura Buckthought

August 2025

Technical Report 2025/21

aucklandcouncil.govt.nz

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ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-991377-81-4 (PDF)

The Peer Review Panel reviewed this report

Review completed on 6 August 2025

Reviewed by two reviewers

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Date: 6 August 2025

Recommended citation
Buckthought, L. (2025). Groundwater quality state and trends in Tāmaki Makaurau / Auckland 2017-2024. State of the environment reporting. Auckland Council technical report, TR2025/21

Cover image Fielding Road Volcanic Bore. Taken by Gina Gascoigne, Environmental Specialist, Auckland Council

Executive summary

Auckland Council undertakes long-term monitoring of groundwater quality as part of its State of the Environment reporting. The monitoring is used to assess state and detect trends in physical, chemical and microbiological properties of groundwater in some of the region's aquifers. The results enable council to track changes in groundwater over time. They can be used to identify potential contamination and risk, and evaluate the effectiveness of council initiatives, policies and groundwater management strategies.

Several pressures affect groundwater quality in the Auckland region including agricultural and horticultural production, urban stormwater discharge and water abstraction for drinking and irrigation purposes.

The groundwater quality programme started in 1998 with the purpose of monitoring aquifers in specific parts of the Auckland region where groundwater use is very important, or where quality is considered at risk (now or in the future). Site locations and monitoring frequency have changed over time, but since 2014, quarterly sampling at 18 sites has occurred, with three sites added since 2020.

This report provides an overview of the state and identifies trends in groundwater quality at these sites over the most recent seven-year period (2017-2024). This short trend period begins after a change in laboratory, which was associated with step-changes in the results for some parameters.

High nitrate concentrations in the shallow basalt aquifers and springs of the Pukekohe area remain a key concern. Median nitrate-N concentrations at some sites exceed the drinking water Maximum Acceptable Value (MAV). These levels reflect long-term impacts from intensive horticultural activity and are unlikely to decline quickly due to long groundwater residence times (18-36 years). These aquifers also contribute nitrate-laden baseflow to local streams, some of which exceed national toxicity thresholds. While nitrate levels appear stable, no improving trends have been observed.

Urban groundwater in Auckland's isthmus shows signs of contamination from stormwater infiltration via soak pits. *E. coli* and nitrate levels are consistently elevated, as is lead at one site, likely from urban sources.

In areas underlain by sedimentary geology, elevated soluble iron concentrations were common, with increasing trends at several sites, potentially linked to declining dissolved oxygen levels. Overall, the influence of underlying geology and redox conditions have been suggested as influencing variability in metal and ion concentrations, but this remains speculative in the absence of site-specific geological investigations.

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1 Introduction

Groundwater is water that has accumulated over time underground and is stored in the cracks and tiny spaces between soil, sand and rocks. It forms when water (e.g. rainfall) seeps into the ground and percolates downward through the soil. Eventually it reaches layers of rock or subsoil that holds water well. This water-saturated layer is called an aquifer. Groundwater moves through aquifers under the force of gravity, following the natural slope of the land and underground geology. The speed of movement depends on the geology, moving faster through materials like sand and gravel, and slower through dense materials like clay and solid rock which are less permeable. The upper surface of an aquifer, where the ground is saturated with water, is called the water table. The water table rises and falls with rainfall recharge, water usage and natural drainage.

Aquifers can be likened to underground reservoirs and are tapped into by drilling wells and pumping water to the surface for drinking supply, irrigation, industrial and other uses (Figure 1). Natural processes are generally slow in groundwater (Moreau et al., 2025) and while being underground somewhat protects groundwater, there is still a risk of pollution. Chemicals and nutrients from agricultural and industrial activities can seep into the ground and contaminate aquifers. Overuse (when water is pumped out at a rate faster than it can be replenished) can lower the water table and affect natural water flow to rivers and lakes.

The recharge area (where water infiltrates the ground to replenish aquifers), aquifer transmissivity (how easily water flows through the aquifer), storativity (how well aquifers release water when their water level changes) and the degree of aquifer confinement from the overlying geology are important factors controlling the effects of land use activities on groundwater quality. Any activity that results in the discharge of contaminants to ground can have a significant impact on groundwater quality.

In urban areas, such activities include those associated with ports, airports, railways, roads, services (particularly wastewater networks and pipelines), urban stormwater runoff, construction excavations and even airborne pollutants from industrial air discharges and vehicle emissions. In rural areas, activities that pose a risk to groundwater include farming (farm dumps, pesticide and fertiliser application and irrigation, farm animal wastes, sheep dips), horticultural activities, septic tanks and cesspit discharges (Fetter, 1992). Landfills, storage/treatment/burial pits or ponds, material stockpiles, graveyards, above ground and underground storage tanks and quarrying can also be associated with groundwater contamination in both urban and rural areas (Fetter, 1992; Kermode, 1992). Protecting groundwater from overuse and pollution sources is essential to prevent contamination and ensure sustainable water supplies and healthy ecosystems into the future.

The Auckland Council Environmental Evaluation and Monitoring Unit (EEMU) monitors the state of the environment from the mountains to the sea. This includes groundwater monitoring and is necessary so we can understand and assess the life supporting capacity of ecosystems, detect trends in water quality, and to evaluate the efficiency of council initiatives, policies and management strategies.

We operate a long-term groundwater quality monitoring programme in specific parts of the Auckland region where groundwater use is very important, or where groundwater quality is considered at risk (now or in the future). Groundwater in Auckland is a vital resource for drinking water (humans and animals) and agriculture. It helps to maintain flow in many rivers and lakes, supporting natural ecosystems. Human activities and land use change can affect the quality of Auckland's groundwater. Effects of historic land use activities can still be observed today in aquifers containing old groundwater (often deep and confined aquifers that contain water that infiltrated a long time ago) (Rosen and White, 2001). This means regular monitoring is needed to identify contaminants or issues that could affect how it is used in the future.

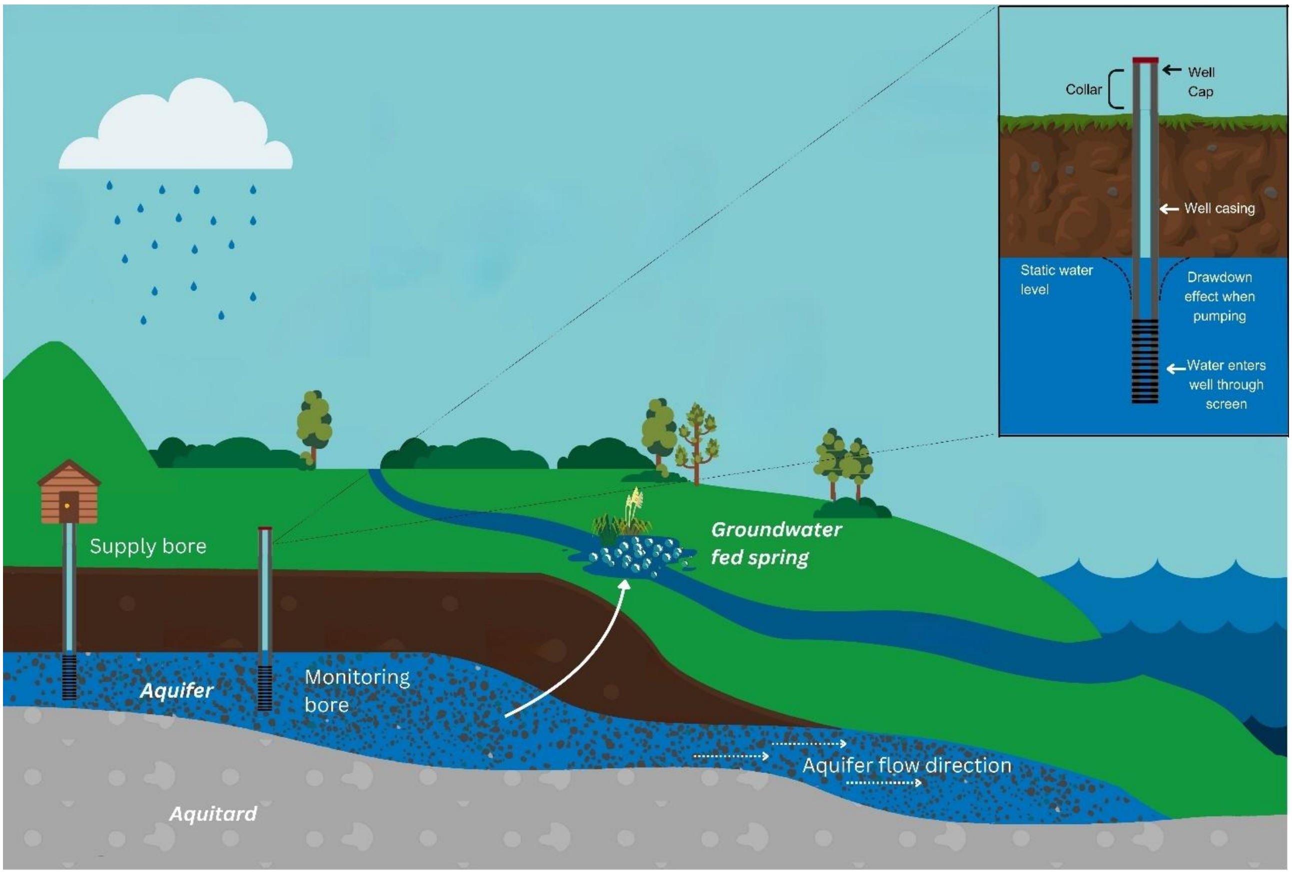

Figure 1: Schematic of a simplified groundwater system showing how monitoring bores penetrate through overlying layers into the aquifer. Inset shows the main components of a monitoring bore.

1.1 Geology of the Auckland region

The Auckland region is geologically diverse, shaped over 250 million years by tectonic activity, volcanism, and marine sedimentation. This has resulted in a complex mix of basement greywacke, Miocene volcanic and sedimentary rocks, and more recent Quaternary volcanic features that define the modern urban landscape.

Auckland is underlain by basement rocks of the Waipapa and Murihoku Groups, dating from the late Paleozoic to Mesozoic periods (Morgenstern et al., 2023). These rocks consist primarily of greywacke and argillite, which are exposed in the Hunua and Waitākere Ranges due to tectonic faulting and uplift.

The Waitākere volcanics in the western region consist of andesitic to basaltic lava flows from the Miocene epoch, forming an eroded volcanic arc associated with tectonic subduction-related activity. These rocks create the rugged topography of the Waitākere Ranges, characterised by steep outcrops and waterfalls (Hayward, 2006).

The Waitematā Group is comprised of marine sedimentation including interbedded sandstone, siltstone, and mudstone, deposited in a submarine fan environment. These rocks are prominently exposed in the East Coast Bays Formation on coastal cliffs along Auckland's North Shore (Ballance, 2011).

The Auckland and South Auckland Volcanic Fields represent the youngest geological features in the region (Morgenstern et al., 2023). These consist of basaltic lava flows and tephra erupted during the Pleistocene and Holocene epochs (Briggs et al., 1994; Edbrooke, 2001). The Auckland Volcanic Field, currently dormant, includes over 50 volcanic cones (e.g., Maungawhau / Mt Eden), craters (e.g., Lake Pupuke), tuff rings (e.g., Ōrākei Basin), and lava fields (e.g., Maungakiekie / One Tree Hill, Rangitoto Island) (Hayward, 2019). The South Auckland Volcanic Field is older and considered extinct, with around 80 volcanic centres, including scoria cones, tuff rings, and lava flows. Many of these features are now eroded or buried, though Pukekohe Hill (a lava dome) remains prominent (Németh et al., 2012).

1.2 Purpose and objectives

The purpose of this report is to assess the state of groundwater quality from key aquifers monitored across the Auckland region and to identify temporal trends in groundwater quality over time using long-term data sets. State summary statistics were assessed for 21 monitored groundwater sites for the five-year period ending June 2024 and temporal trends were assessed in the 18 sites with sufficient data for the most recent seven-year period (2017-2024).

Auckland Council's groundwater quality monitoring programme also supports the following objectives:

- Fulfil Auckland Council's responsibilities under section 35 of the Resource Management Act (RMA) 1991 to monitor and report on state and trends of groundwater in the Auckland region.
- Inform the efficacy and efficiency of council policy initiatives and strategies.

- Provide information to Māori that supports them in their role as kaitiaki to protect and enhance te mauri o te wai (the life supporting capacity of water).
- Assist in identifying impacts of land use activities and on groundwater quality.
- Provide baseline data to support resource consent processes and related compliance monitoring for groundwater.
- Enhance public understanding among Aucklanders of groundwater quality issues in the region and promote awareness of effective management strategies.
- Contribute groundwater quality data to support national environmental reporting initiatives.

1.3 Supporting documents

This report is one of a series of technical publications prepared in support of *Te oranga o te taiao o Tāmaki Makaurau – The health of Tāmaki Makaurau Auckland's Natural Environment in 2025: a synthesis of Auckland Council State of the Environment reporting*.

All related reports (past and present) are published on the Knowledge Auckland website.

All data supporting this report can be requested through our Environment Auckland Data Portal. Here you can also view live rainfall, river flow and air quality data and use several data explorer tools.

The Water Quality and River Ecology Data Explorer provides summary statistics and interactive graphics for water quality and freshwater ecology data across multiple domains, including groundwater.

Previous reports on the state and trends of groundwater quality in Auckland were published in:

- 2017, covering the period 1998-2013 (Kalbus et al., 2017)
- 2021, covering the period 2010-2019 (Foster and Johnson, 2021)
- 2007, covering the period 1998-2005 (Auckland Regional Council, 2007)

2 Programme overview

2.1 Current network

Auckland Council's groundwater quality monitoring programme was primarily designed for detecting long-term changes in water quality across the region, focussing on aquifers where the use or demand for water was high and/or where aquifers were vulnerable to contamination (Crowcroft and Scoble, 1997). This included pressures from land use—such as agriculture, horticulture, urban stormwater, and industrial activities. Changes in land use can also increase demand for water abstraction, affecting groundwater quantity and quality.

Auckland Council currently monitors groundwater quality in eight aquifers, which are represented by 21 monitoring sites, three of which are surface springs (Figure 2). The network also incorporates sites for the National Groundwater Monitoring Programme (NGMP) where field data and water samples are collected by Auckland Council, but sample analysis is managed by Geological and Nuclear Science (GNS). Six of these sites are part of the NGMP programme.

In this report, aquifers monitored under the groundwater quality programme are grouped into four key geographical areas: Pukekohe, Urban (central isthmus), Kumeū, and Ōmaha. Their geology and rationale for inclusion in the monitoring programme are summarised in Table 2-1 and Sections 2.2.1 to 2.2.4 below.

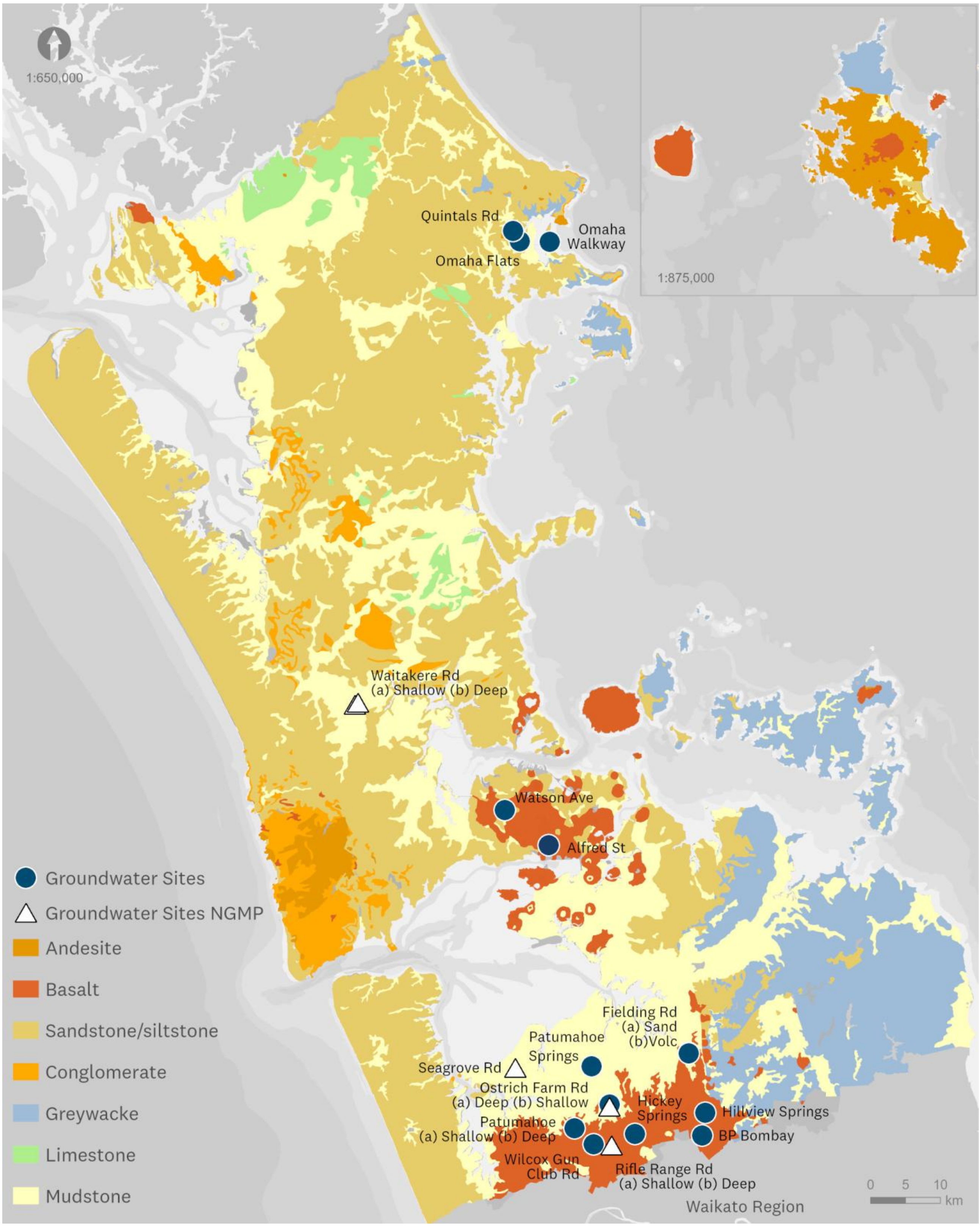

Figure 2: Groundwater quality monitoring site locations in the Auckland region shown with mapped surface geology

2.2 Aquifers

2.2.1 Pukekohe area

Volcanic aquifers

The Franklin volcanic aquifers comprise three main eruptive centres: Bombay, Pukekohe, and Glenbrook. Two distinct periods of volcanic activity are represented—older Bombay basalts and younger Pukekohe basalts—separated by intervening silts and clays (Auckland Regional Water Board & Waikato Valley Authority, 1977). These volcanic deposits form prominent landforms in the region, notably Pukekohe Hill and the Bombay Hills (White et al., 2019). The aquifer materials include basalt lava flows, scoria cones, and tuff rings composed of exploded bedrock, tephra, and ash. The cumulative thickness of the aquifer reaches up to 200 metres (Morgenstern et al., 2023; Viljevac, 2002).

The basalts are heterogeneous but generally exhibit high transmissivity and significant groundwater throughflow (ARC, 1996; Viljevac, 2002). Geological modelling has been used to visualise the main volcanic aquifer structures in the area (Figure 3, White et al., 2019).

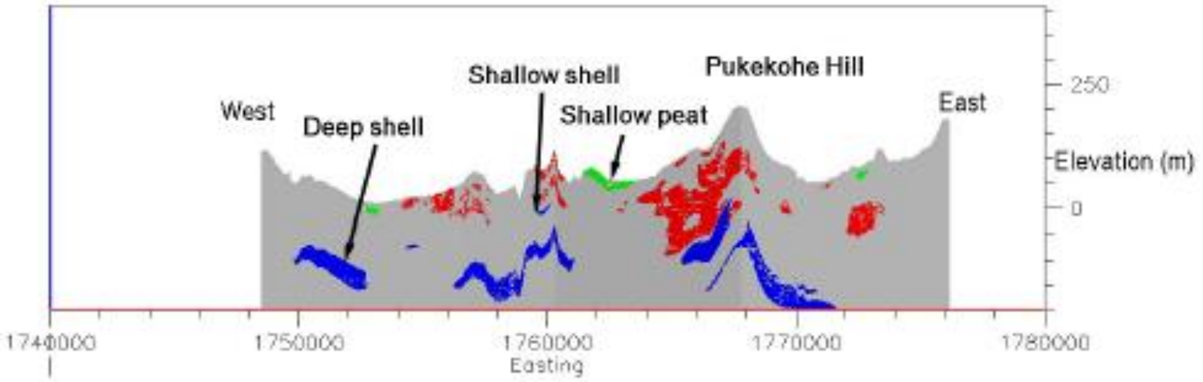

Figure 3: Cross section west to east: volcanic aquifers (red), peat (green), and shell aquifers (blue), through the area where the monitored Franklin volcanic aquifer sites are positioned (adapted from White et al., 2019).

Recharge to the shallow basalt aquifers occurs primarily via rainfall infiltration in unconfined zones, and through vertical leakage and lateral throughflow to deeper, confined aquifers (ARC, 1996; White et al., 2019). The estimated recharge rate to the Pukekohe basalt aquifer is approximately 680 mm/year (Viljevac et al., 2002). Groundwater residence times range from 6-40 years in the shallow Pukekohe basalts and 30-67 years in the Bombay basalts (Morgenstern et al., 2023). Residence times are much longer in the deeper basalts, estimated at ~350 years (Rifle Range Deep) (Morgenstern et al., 2023).

The Pukekohe basalt aquifer systems are distinguishable by their water chemistry, particularly nitrate-N, dissolved oxygen, and iron concentrations (White et al., 2019):

- Shallow, oxygenated groundwater with elevated nitrate-N concentrations, often discharging to springs. There are seven sites in this group (including three springs), classified as "unconfined" or "spring" in Table 2-5
- Deeper, low oxygen (anoxic) groundwater that flows into the underlying Kaawa Formation. Two sites are in this group, identified as "confined" aquifers in Table 2-5.

Kaawa Formation aquifer

The Kaawa Formation, of Pliocene age, consists of weakly cemented and marine sands with shell horizons. The Kaawa shell horizons form important aquifers in the Franklin area (Viljevac et al., 2002). The Kaawa Formation underlies the Franklin volcanic basalts and is recharged mainly by vertical leakage from these basalts, and secondarily from overlying sedimentary units in areas where basalt is absent (Figure 4).

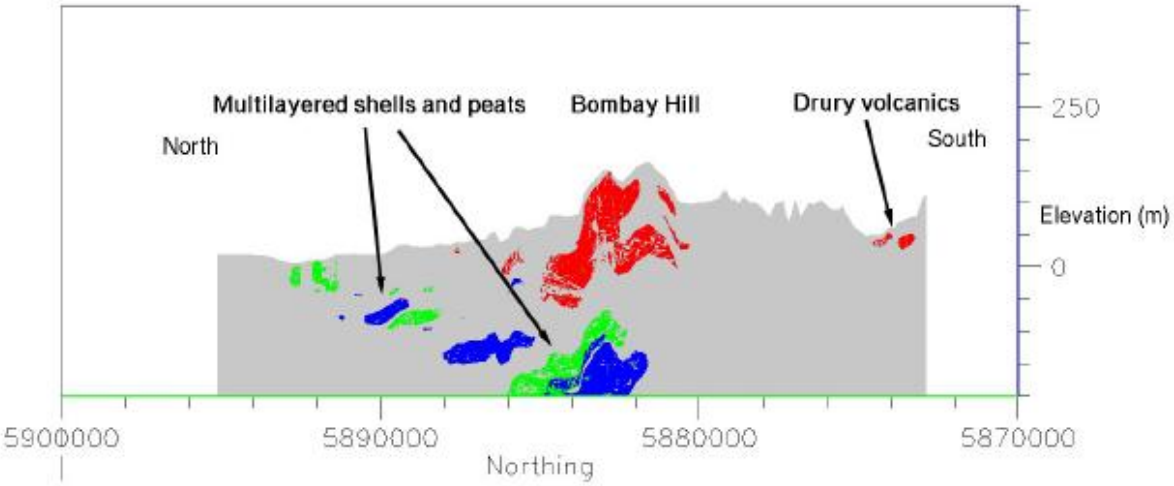

Figure 4: Cross section north to south: volcanic aquifers (red), peat (green) and shell aquifers (blue) (adopted from White et al., 2019).

Recharge rates to the Kaawa aquifer are much lower than the basalt aquifers, estimated at between 176 (Viljevac et al., 2002) and 273 ± 108 mm/year (White et al., 2019). Hydraulic properties vary significantly, with transmissivity ranging from 13 to 500 m^2/day and storativity between 10^{-2} and 10^{-5} (Auckland Regional Water Board, 1989; Viljevac et al., 2002). Transmissivity is highest near Pukekohe and decreases northwards toward the edges of the shell deposits (Viljevac et al., 2002). Groundwater residence times in the Kaawa aquifer are vastly older than the basalts, ranging from ~3,500 years near Bombay Hill, increasing with distance from recharge zones to 9,100, 15,000, and up to 28,000 years (Morgenstern et al., 2023).

There are three monitoring sites in the Kaawa aquifer, listed in Table 2-5.

Drury-Bombay sand aquifer

The Drury-Bombay sand aquifer comprises semi-confined sands of the Pleistocene-aged Tauranga Group, including Puketoka Formation alluvium (Murphy, 1991; Edbrooke, 2001). Recharge to the Puketoka sands is estimated at roughly 10% of annual rainfall in water resource assessments supporting consent applications. Groundwater residence time in this aquifer is estimated at ~200 years, based on data from the Fielding Rd Sand bore (Morgenstern et al., 2023).

There is one monitoring site in this aquifer (Fielding Rd Sand), listed in Table 2-5.

2.2.2 Urban area

In the urban area, monitoring focuses on the Three Kings and Onehunga volcanic aquifers located on the central Auckland isthmus (Table 2-1). These aquifers were formed from multiple eruption phases and consist of fractured basalt lava, scoria, and poorly bedded tuffs with embedded volcanic bombs (Searle, 1962; PDP, 2017). They overlie the erosional surface of the Waitematā and Tauranga Group sedimentary rocks.

Hydrological characteristics are comparable to other basalt aquifers, such as those in Pukekohe, with high infiltration rates and transmissivity values due to fracturing and secondary porosity. Recharge occurs via rainfall infiltration through soil, and stormwater disposal soak holes (Namjou et al., 2006).

These aquifers are critical for stormwater management, as their high permeability allows for rapid infiltration. However, the lack of overlying sedimentary or clay layers results in low natural filtering capacity, increasing vulnerability to contamination. The urban and industrial land uses above the aquifers could potentially heighten the risk of water quality degradation.

The Three Kings and Onehunga volcanic aquifers each have one monitoring site (Table 2-5).

2.2.3 Kumeū area

In the Kumeū area, monitoring focusses on the Kumeū West Waitematā aquifer. This aquifer is part of the Waitematā Group sedimentary rocks, composed of alternating layers of sandstone and mudstone, with occasional sand, silt, shells, and minor clay or gravel (Ballance, 1976; White et al., 2020). The sandstone bed thickness varies across the region, ranging from a few metres to over 1,000 metres (Crowcroft & Smaill, 2001). These sedimentary rocks form much of the region's basement geology, except in areas such as the Hunua Ranges, northern zones with Onerahi rocks, and some offshore islands (Ballance, 1976).

Although the Waitematā Group generally exhibits low permeability due to its fine-grained matrix, permeability can be locally enhanced by fracturing, jointing, and faulting. Typical transmissivity values range from 5 to 120 m^2/day, with recharge rates between 4 and 76 mm/year (Earthtech, 2018). Horizontal permeability is significantly greater than vertical permeability due to pronounced bedding and vertical restriction by mudstone layers (White et al., 2020).

There are two sites in the Kumeū West Waitematā aquifer (Table 2-5). They represent the shallow and deep zones of the aquifer, respectively. While no formal separation exists between shallow and deep zones, differences in hydraulic behaviour and water chemistry justifies monitoring both.

2.2.4 Ōmaha area

There are three sites in the Ōmaha area (Table 2-5): two are within the Waitematā Group, discussed above. The other is in the Ōmaha Sand aquifer (Table 2-5).

The Ōmaha Sand aquifer is a small but important coastal aquifer located between the Whangateau Harbour and the Matakana River beneath the Ōmaha Flats. It consists of Quaternary-age sand deposits overlying less permeable clays and older sedimentary formations, allowing for unimpeded water movement.

Recharge to the aquifer occurs via rainfall infiltration through sandy soils (ARC, 1992). The aquifer supports rural and horticultural water supply, domestic use, and sustains wetland systems and baseflows to nearby rivers and estuaries.

Due to its shallow and unconfined nature, the Ōmaha Sand aquifer is vulnerable to:

- Weather events – High rainfall can overwhelm natural drainage, causing elevated groundwater levels and flooding.
- Saltwater intrusion – Its coastal position makes it susceptible to saline intrusion under conditions of drought or over extraction
- Contamination – the permeable nature of the soil allows for rapid infiltration, making it vulnerable to contaminants from activities such as horticulture, agriculture, and stormwater runoff.

Table 2-1: Summary of the geology of the aquifers monitored in the groundwater quality monitoring programme, and the rationale for their inclusion in the monitoring network.

Area	Aquifer	Geology type	Rationale for inclusion
Pukekohe	Franklin Sand (Drury/Bombay)	Semi-confined sands of the Pleistocene age Tauranga Group, which includes Puketoka Formation alluvium.	Similar land use as the Franklin volcanic aquifers. One of two sites at this location (shallower) providing opportunity to track water chemistry along the vertical recharge path.
	Franklin Volcanic	Basalts from lava flows in three main eruptive centres near Bombay, Pukekohe, and Glenbrook. Shallow, largely unconfined aquifers with some deeper basalts. Groundwater age: 6-67 years.	Important area for horticultural vegetable production; nitrate contamination observed in the shallow aquifers. Aquifers provide baseflow to surface streams resulting in failures of National Policy Statement for Freshwater Management, National Bottom Lines for nitrate toxicity.
	Franklin Kaawa	Sedimentary material underlying the basalts of the Franklin Volcanic Field. Groundwater age: 3500-28000 years.	Relied upon as a water source for municipal supply and irrigation. Potentially vulnerable to nitrate contamination via recharge from the contaminated shallow aquifers above.
	Waiau Pā Waitematā	Early Miocene aged basement rocks for the area. Consolidated sequence of marine interbedded mudstones and graded sandstones.	NGMP site and one of the few basement rock monitoring sites in the region.
Urban	Three Kings Basalt	Basalts from several eruption phases overlying the erosional surface of the Waitematā and Tauranga Group sedimentary rocks.	Vulnerability of the aquifer to urban sources of contamination due to connectedness to the surface, and its use for stormwater disposal.
	Onehunga Volcanic	Basalts from several eruption phases overlying the erosional surface of the Waitematā and Tauranga Group sedimentary rocks.	Vulnerability of the aquifer to urban sources of contamination due to connectedness to the surface, and its use for stormwater disposal.
Kumeū	Kumeū Waitematā	A sub-group of the Waitematā aquifers situated within the Waitematā Group sedimentary rocks. Comprised of alternating sandstones and mudstones, with some sand, silt, shells and minor clay and gravels.	Two NGMP sites. Shallow and deep extents monitored to enable understanding of changes in water chemistry with depth.
Ōmaha	Ōmaha Sand	Unconsolidated dune and alluvial sands overlying the Waitematā Group over most of the Ōmaha Flats and Ōmaha Spit.	Highly vulnerable to weather extremes, saltwater intrusion and contamination.
	Ōmaha Waitematā	Interbedded sandstones and mudstones of the Waitematā Group overlying the basement Greywacke rock.	Significantly increased abstraction in recent years with observed impacts on summer water levels.

2.3 Programme history

Auckland Council's groundwater quality monitoring programme was established in 1998. It was based on the premise of regular and long-term collection of water quality data across the primary aquifer types in the Auckland region, with a focus on the most heavily used aquifers. The programme originally comprised 24 sites (including NGMP sites). Site selection was based on aquifer representativeness, geographic spread, varied land use and long-term site accessibility (Crowcroft and Scoble, 1997). The principal objectives of the programme were to

- Determine temporal and spatial variability of selected water quality parameters at sites with different overlying land use influences.
- Establish a baseline of groundwater quality information from which trends (direction and magnitude) can be determined.
- Assessment of the effectiveness of land use planning policies intended to protect groundwater quality and ensure existing environmental controls are adequate to avoid unacceptable adverse effects.

The sampling frequency of the initial groundwater monitoring programme varied for different sites. The optimum frequency was identified as being quarterly. However, annual and bi-annual frequencies were assigned to sites in slow moving aquifers and monitoring frequencies also differed year to year (Table 2-2). Over time, this has resulted in different data records for different sites.

Table 2-2: Initial five-year sampling frequency schedule for sites in the Groundwater Quality Monitoring Programme (Crowcroft & Scoble, 1997).

Aquifer	Year 1 (1998)				Year 2 (1999)				Year 3 (2000)				Year 4 (2001)				Year 5 (2002)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Ōmaha Sandstone	■	■	■	■	■				■				■				■			
Waiwera Geothermal	■	■	■	■	■				■				■				■			
Parakai Geothermal	■	■	■	■		■				■				■				■		
Kaipara Sands	■	■	■	■		■				■				■				■		
Sandstone Orewa	■	■	■	■		■				■				■				■		
Sandstone Kumeū	■	■	■	■			■				■				■				■	
Kaawa Shell	■			■			■				■				■				■	
Kaawa Sand	■			■				■				■				■	■	■	■	■
Mt Wellington Volcanic	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Three Kings Volcanic	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Mt Richmond Volcanic	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Drury Sands	■				■	■	■	■	■				■				■			
Drury Volcanics	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Bombay Volcanics	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Puke Upper Basalt	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Sandstone Clevedon	■		■				■				■		■	■	■	■			■	
Mangere Sands	■			■				■				■				■				■
Sandstone Wiri	■			■				■				■				■				■
Sandstone Karaka	■			■				■				■				■				■

2013 suspension and network reduction

The Groundwater Quality Monitoring Programme was temporarily suspended in June 2013 due to budget and resourcing constraints. It recommenced in June 2014 with a reduced number of sites. The new network aimed to:

- Prioritise monitoring in aquifers where change in groundwater quality was suspected (e.g., unconfined or semi-confined shallow aquifers).
- Standardise the water quality parameter test profile across all sites.
- Standardise frequency of sampling and monitor all sites on a quarterly basis, which aligned with the frequency of sample collection for the NGMP sites.

Site selection for the reduced network at that time was based on:

- Continued monitoring of NGMP sites required by GNS.
- Aquifers exhibiting change or considered to be under pressure, either through overlying land use activities or abstraction pressure. This was based on knowledge of land use activities at the time: namely horticultural activities in the Pukekohe area (as summarised in Meijer et al., 2016); and urban sites susceptible to stormwater/wastewater infiltration with potentially high metal and microbial concentrations (Lewis et al., 2015).

2017 laboratory change

In 2017, the laboratory provider for sample analysis of all EEMU environmental monitoring programmes was changed from Watercare Services to Hills Laboratories. There were differences in methods and detection limits for some variables between the two laboratories that resulted in notable step changes in the data. At the time of the change in laboratory provider, limited paired sampling and analysis was undertaken. There was insufficient information available to calculate adjustment factors to align old and new methods. These step changes create a risk in trend analysis where the identification of trends are artefacts of the laboratory change and not real environmental change. As such, data with known step changes was excluded from trend analysis.

It was discovered in 2020 that soluble manganese had been mistakenly excluded from the analyte list when the laboratory change occurred. This was added back on from the October 2020 sampling.

2020 analyte review

A review of the groundwater quality programme laboratory test list was carried out in 2020. This review recommended several analytes be removed. It was based on assessment of results from the data record, comparisons with other regional council analyte lists, consultation with NZ Groundwater Forum members, and the National Environmental Monitoring Standards (NEMS) for groundwater quality. These removals came into effect in July 2020 and are summarised below.

Table 2-3: Analytes removed from groundwater quality programme in 2020 and associated rationale

Analyte	Rationale
Hydroxide alkalinity	Total alkalinity is considered sufficient; results were consistently below levels of detection.
Calcium hardness and Magnesium hardness	Total hardness is considered sufficient, with no requirements to speciate. If speciation is required, it can be back calculated from dissolved calcium and magnesium.
Total metals	Removed for budgeting purposes. Both total and soluble forms would be considered gold standard, but most other regional councils measure only soluble forms, also to manage budgets.
Total suspended solids	No other regional councils measure this. It is difficult to interpret and differentiate between sediment naturally migrating through aquifers or introduced at the well itself.
Hexavalent chromium	Consistently below detection levels at all sites. Its severe health impacts are noted and suggested to monitor periodically to ensure there is no contamination.
Total arsenic	Consistently below detection at all sites and not in NEMS.

2020 site review

A review of sites was also conducted in 2020. Four new monitoring sites at existing bores were added to the groundwater programme. In 2022, two new bores were also drilled in Patumāhoe . These new sites are described below:

Table 2-4: Sites added to groundwater quality programme from 2020 and associated rationale

Site	Start	Aquifer	Rationale
Alfred St	Jan 2020	Onehunga Volcanic	Influence of urban land use and ideal site to track change from the Onehunga urban water supply and stormwater soakage.
Quintals Rd	Jan 2021	Ōmaha Waitematā	Significantly increased abstraction in recent years impacting summer water levels. Ōmaha Flats is located near the area of highest water use and irrigation activity. Historic data at Quintals Road bore will allow comparison of water chemistry over time.
Ōmaha Flats	Apr 2021	Ōmaha Waitematā	
Ōmaha Walkway	Apr 2021	Ōmaha Sand	Shallow unconfined sand aquifer, susceptible to contamination.
Patumāhoe Shallow	Nov 2022	Franklin Volcanic	New bore drilled in 2022 to increase understanding of water quality in shallow basalts further north (towards the Manukau Harbour).
Patumāhoe Deep	Nov 2022	Franklin Kaawa	New bore drilled in 2022 to increase data and understanding of water quality in the Kaawa aquifer.

Alfred St, Quintals Rd, Ōmaha Flats and Ōmaha Walkway are all included in this report for state analysis, but they haven't been monitored long enough to include in a robust trend analysis. In the case of Patumāhoe Shallow and Deep, there was not yet enough data to report on trends at these sites. This data will be reported in next State and Trend report and can be viewed on the Water Quality and River Ecology Data Explorer.

2.4 Monitoring sites

Groundwater quality monitoring programme site information is summarised in Table 2-5 below. Those sites characterised as “SOE” (State of Environment) are part of Auckland Council’s network and those as “National Groundwater Monitoring Programme” (NGMP) are part of the GNS Science national network. However, however both are reported here. Further details such as GPS coordinates and site identification numbers can be found in Appendix 1.

Table 2-5: Summary site details for the groundwater quality monitoring programme

Area	Aquifer	Site Name	Aquifer type	Approx depth (m)	Casing depth (m)	Start of record	Sample collection method	Purge method	LTB/ NGMP
Pukekohe	Franklin Volcanic Deep (Drury/Bombay)	Fielding Road Volcanic	Confined	47	16	1999	Portable pump	3 x Volume	SOE
	Franklin Sand (Drury/Bombay)	Fielding Road Sand	Semi-confined	64	57	1998	Portable pump	3 x Volume	SOE
	Franklin Volcanic Shallow	Wilcox Gun Club Rd	Unconfined	27	27	2006	Insitu pump/tap	Low flow	SOE
		Patumāhoe Shallow	Unconfined	32	23	2022	Portable pump	3 x Volume	SOE
		Rifle Range Rd Shallow	Unconfined	42	30	1998	Portable pump	3 x Volume	NGMP
		BP Bombay	Unconfined	80	62	1998	Insitu pump/tap	Low flow	SOE
		Hickey Springs	Spring	Spring		1998	Surface sample	NA (surface)	SOE
		Hillview Springs	Spring	Spring		2010	Insitu pump/tap	Low flow	SOE
		Patumāhoe Springs	Spring	Spring		1998	Surface sample	NA (surface)	SOE
	Franklin Volcanic Deep	Rifle Range Rd Deep	Confined	90	78	1998	Portable pump	3 x Volume	NGMP
	Franklin Kaawa	Ostrich Farm Rd 2 Shallow	Confined	48	46	1998	Portable pump	3 x Volume	SOE
		Ostrich Farm Rd 1 Deep	Confined	84	68	1998	Portable pump	3 x Volume	NGMP
		Patumāhoe Deep	Confined	120	113	2022	Portable pump	3 x Volume	SOE
	Waiau Pā Waitematā	Seagrove Rd	Confined	201	98	1998	Portable pump	Low flow	NGMP
Urban	Three Kings Volcanic	Watson Ave	Unconfined	39	32	1998	Portable pump	3 x Volume	SOE
	Onehunga Volcanic	Alfred St	Unconfined	40	24	2020	Portable pump	3 x Volume	SOE
Kumeū	Kumeū West Waitematā	Waitākere Rd 1 Shallow	Semi-confined	15	10	1998	Portable pump	3 x Volume	NGMP
		Waitākere Rd 2 Deep	Confined	150	78	1998	Portable pump	3 x Volume	NGMP
Ōmaha	Ōmaha Sand	Ōmaha Walkway	Unconfined	7	7	2021	Portable pump	Low flow	SOE
	Ōmaha Waitematā	Quintals Rd	Confined	130	94	1998	Portable pump	Low flow	SOE
		Ōmaha Flats	Confined	90	34	2021	Portable pump	Low flow	SOE

3 Methods

3.1 Data collection

Each site was sampled quarterly using guidance from the National Environmental Monitoring Standards (NEMS) for groundwater quality (NEMS, 2019). For parameters measured in the field, all sensors were calibrated/validated in accordance with NEMS, and certain stabilisation criteria (Table 3-1) were met before water samples are collected.

Table 3-1: Parameters collected in the field and stabilisation criteria for sample collection

Field parameter	Unit	Stabilisation criteria (NEMS, 2019)
Dissolved oxygen (DO)	mg/L	± 0.3
pH	pH	± 0.1
Temperature	^{o}C	± 0.2
Oxygen reducing potential (ORP)	mV	NA
Turbidity	FNU	± 10%
Electrical conductivity (EC)	mS/cm	± 3%

3.1.1 Bore sampling

An electric portable pump (Grundfos MP1) and controller connected to a long hose was used to pump groundwater from bores. A flow cell was attached to the hose and the Exosonde field sensor inserted, ensuring the sensor readings and water samples were collected from groundwater that had not been exposed to air.

Groundwater from bores must be purged prior to sample collection to ensure the water is from the surrounding aquifer itself and not water that has been sitting in the well casing. There are two methods used each with specific NEMS requirements:

1. **Three times purge method:** this involves purging at least three times the calculated volume of the well. Field parameters must be monitored at least four times during the purge, with the last two meeting the stabilisation criteria (Table 3-1).
2. **Low flow purge method:** this involves pumping groundwater at low rates comparable to ambient groundwater flow, minimising drawdown and the mixing of stagnant water with newly drawn aquifer water. It requires purging the calculated total volume in the pump and tubing plus the volume of the drawdown in the well. To ensure adequate purging, three times the volume of the hose (81 L) is purged. The low flow sampling method is preferred as it is more time efficient and less disruptive of the groundwater system.

There are three sites with in-situ pumps and taps (BP Bombay, Wilcox Gun Club Rd and Hillview Springs). The NEMS criteria for the low flow method are only able to be met at three sites: Seagrove

Rd, Quintals Rd, Ōmaha Flats and Ōmaha Walkway. The low flow method is used to purge these bores before sample collection. At all other sites, the three times purge method is used. Once purging is complete, and the stabilisation criteria (Table 3-1) are met, field parameters can be logged and water samples can be collected.

Water samples collected in bottles are immediately placed on ice in a chilly bin for transport to the laboratory.

3.1.2 Spring sampling

Springs were sampled with slightly different methods to the groundwater bores due to their nature. The surface springs samples were collected as follows:

- Patumāhoe Springs: grab samples are collected from a pond formed by the spring, close to a known groundwater discharge location (observed bubbles).
- Hickey Spring: collection is from a covered artesian well at the Watercare Services treatment facility in Pukekohe.
- Hillview Spring: even though samples are collected via an in-situ pump and tap, this site is still considered a spring.

At the Patumāhoe and Hickey springs, the Exosonde sensors are placed in the water and left to stabilise before field parameters are logged. Samples are collected approximately 0.3m below the water surface and placed on ice in a chilly bin.

3.1.3 Laboratory analysis

All NGMP site water samples are promptly sent to the GNS Wairakei Laboratory for analysis. All other samples are sent to Hills Laboratory in Hamilton. Samples are analysed for a range of physical variables, nutrient species, metals, and faecal indicator bacteria (*E. coli*) and meet all NEMS minimum time periods for analysis.

The analytes included in this report are from the current analyte test list only. These analytes and their associated descriptions are shown in Table 3-2 below and their methods are shown in Appendix 2.

The full suite of groundwater analytes is not included in this report for a range of reasons, which differ by analyte. These reasons include: patchy datasets where analyses have stopped and restarted through time; inconsistencies with measured units; results consistently below detection results; and laboratory instrument and analysis method changes. Many of these changes have not been well documented, particularly before the Auckland Council amalgamation as a Unitary Authority in 2010.

Table 3-2: Summary of parameters measured in the Groundwater Quality Programme and reported here

	Analyte	Description
Physical Parameters	Salinity (ppt)	Salinity is the concentration of dissolved salts in water. Salinity levels affect the toxicity of some contaminants. Estuarine waters range from 0.5 to 30 ppt and coastal or oceanic waters are usually 35 ppt.
	Conductivity	Electrical conductivity reflects the total ionic content of the water, which is affected by the presence of dissolved salts such as chloride, nitrate, nitrite, phosphate, sodium, magnesium, calcium etc. In freshwaters, conductivity is a crude indicator of how much matter is in the water while in saline waters, conductivity is primarily related to salinity. Deionised (nearly pure) water has a conductivity of approximately 0.05 mS/cm, while seawater is approximately 50 mS/cm.
	Temperature	Temperature affects biological processes and moderates the toxicity of contaminants. Groundwater temperature is relatively consistent as it is not subject to diurnal fluctuations.
	pH	pH is a measure of the concentration of hydrogen ions in water. Low pH (<7) indicates that the water is more acidic, while high pH (>7) indicates it is more alkaline. Freshwaters are typically between pH 6.5 to 8.0. pH affects biological processes and toxicity of some contaminants such as metals.
	Total alkalinity	Total alkalinity refers to the water's ability to resist changes in pH. Alkaline compounds such as bicarbonates, carbonates, and hydroxides act as a buffer, helping to stabilise pH levels. The alkalinity of groundwater is influenced by rocks and soils, salts, and pollutants and discharges.
	Dissolved Oxygen (DO) mg/L Dissolved Oxygen % Saturation	Dissolved Oxygen (mg/L) is the concentration of dissolved oxygen present in the water, while DO (% saturation) expresses the amount of oxygen as a percentage of the maximum capacity of oxygen the water can hold depending on the temperature, atmospheric pressure and salinity conditions at the time. Cold water can hold more DO so the same concentration (mg/L) will have a lower saturation in cold water compared to warm water.
Nutrients	Nitrogen Species Ammoniacal Nitrogen (NH_3, NH_4^+-N) Nitrite-Nitrogen Nitrate-Nitrogen Total Oxidised Nitrogen (TOxN, NO_2-N, NO_3-N) Dissolved inorganic nitrogen (DIN) Total Nitrogen (TN)	Nitrogen (N) in the environment can be grouped into two main forms: organic nitrogen and inorganic nitrogen. Inorganic forms are bioavailable and can be taken up by plants. Organic N is not bioavailable and can only be converted to inorganic N via microbial processes (or production of inorganic fertilisers). High concentrations of bioavailable N can cause algal blooms, nuisance plant growth and eutrophication, and some forms can be toxic to aquatic organisms. See Figure 5 below for an illustration of the different nitrogen species measured and reported on. Inorganic (bioavailable) forms of N Ammoniacal Nitrogen is a combination of un-ionised ammonia (NH3) and the ammonium ion (NH4$^+$). Un-ionised ammonia is the more toxic form to aquatic life and is highly dependent on water temperature, salinity and pH. Nitrite-Nitrogen (NO_2-N) is an intermediary product formed during the oxidation of ammonium via a microbial process called nitrification. The nitrification process rapidly converts nitrite to nitrate, so it is short lived in the environment. The presence of nitrite typically indicates an active discharge of inorganic (ammonium-containing) N in the immediate vicinity of the sampling site. Nitrate-Nitrogen (NO_3-N) is the end product of the nitrification process. Nitrate is very stable and highly water soluble. It can be toxic to aquatic life in high concentrations. Calculated descriptions of N Total Oxidised N (TON) is the sum of nitrite and nitrate. Dissolved inorganic nitrogen is the total inorganic N fraction and is the sum of ammoniacal nitrogen, nitrite and nitrate nitrogen. Total Nitrogen Total Nitrogen includes all forms of organic, inorganic, dissolved and particulate nitrogen.

	Analyte	Description
	Dissolved Reactive Phosphorus (DRP) Total Phosphorus (TP)	Phosphorus is found in water as dissolved and particulate forms. Dissolved Reactive Phosphorus is immediately bioavailable and can be taken up by plants, adding to nuisance plant growth, eutrophication and algal blooms. Particulate phosphorus consists of organic material, as well as phosphorus in minerals and adsorbed onto mineral surfaces. Total Phosphorus is a measure of both dissolved and particulate forms in a water sample. The adsorption and desorption of phosphate from mineral surfaces creates a buffer that regulates dissolved phosphate concentrations in water.
Bacteria	*E. coli*	*Escherichia coli* bacteria are found in the gut of warm-blooded animals (including humans, cows, ducks etc.). *E. coli* indicate possible faecal pollution. While most *E. coli* themselves are harmless they serve as an easily detectable indicator for other harmful bacteria, protozoa or viruses that may also be in the water, causing increased risk to human health.
Metals and Ions	Soluble copper Total copper	Soluble copper is the fraction of copper dissolved in the water, while total copper includes all forms of dissolved and particulate copper. Copper can be toxic to aquatic fauna in high concentrations. The dissolved fraction more closely represents the bioavailable portion in rivers, but several other water chemistry factors can influence this.
	Soluble zinc Total zinc	Soluble zinc is the fraction of zinc dissolved in the water, while total zinc includes all forms of dissolved and particulate zinc. Zinc can be toxic to aquatic fauna in high concentrations. The dissolved fraction more closely represents the bioavailable portion in rivers, but several other water chemistry factors can influence this.
	Total hardness	Total water hardness is the sum of calcium and magnesium concentrations as calcium carbonate in the water. These compounds generally originate from the weathering of rocks and soil. Water containing calcium carbonate at less than 60 mg/L is generally considered ‘soft’, 60-120 mg/L ‘moderately hard’, and 120-180 mg/L ‘hard’ (WHO, 2011). Most New Zealand waters are considered to be soft (MoH, 2018).
	Soluble iron Soluble manganese	Soluble iron and manganese are dissolved fractions of these two metals, usually occurring naturally where groundwater comes into contact with the soils, rocks and minerals containing solid iron and manganese. The solubility of iron and manganese is affected by the oxygen content of the water (dissolves more readily in deoxygenated conditions) and pH (dissolves more readily in acidic conditions). Changes in these compounds can indicate changes or contamination in the wider environment and they are important for taste and aesthetics.
	Soluble potassium Soluble sodium	Soluble sodium and potassium are salts dissolved in groundwater, occurring where groundwater passes through soils, rocks and minerals. Sodium and potassium are abundant in soils and rocks and highly soluble. Changes in these compounds can indicate changes or contamination in the wider environment.
	Sulphate	Sulphate is a stable form of sulphur and its presence in groundwater can come from mineral dissolution from the surrounding soil, rocks and minerals, but also atmospheric deposition of marine aerosols. Changes in sulphate can indicate changes or contamination in the wider environment and is important from a human health perspective.
	Chloride	Chloride is a naturally occurring ion most commonly derived from dissolved salts such as sodium chloride and magnesium chloride as groundwater passes through soils, rocks and minerals. Chloride concentrations are very high in seawater, so it can also be used to indicate seawater intrusion to aquifers.
	Total dissolved solids	Total dissolved solids are a measure of the dissolved combined content of inorganic and organic substances present in water. In groundwater, total dissolved solids are a product of the aquifer media the water passes through before it enters a well.

To help further explain the different nitrogen species, see (Figure 5) below. Ammoniacal-N, nitrite-N, nitrate-N and total nitrogen (total N) are forms of nitrogen directly measured in the laboratory. Total oxidised nitrogen is a calculation (nitrite-N + nitrate-N), as is dissolved inorganic nitrogen (ammoniacal-N + nitrite-N + nitrate-N). Total N also incorporates organic nitrogen, which is not analysed separately.

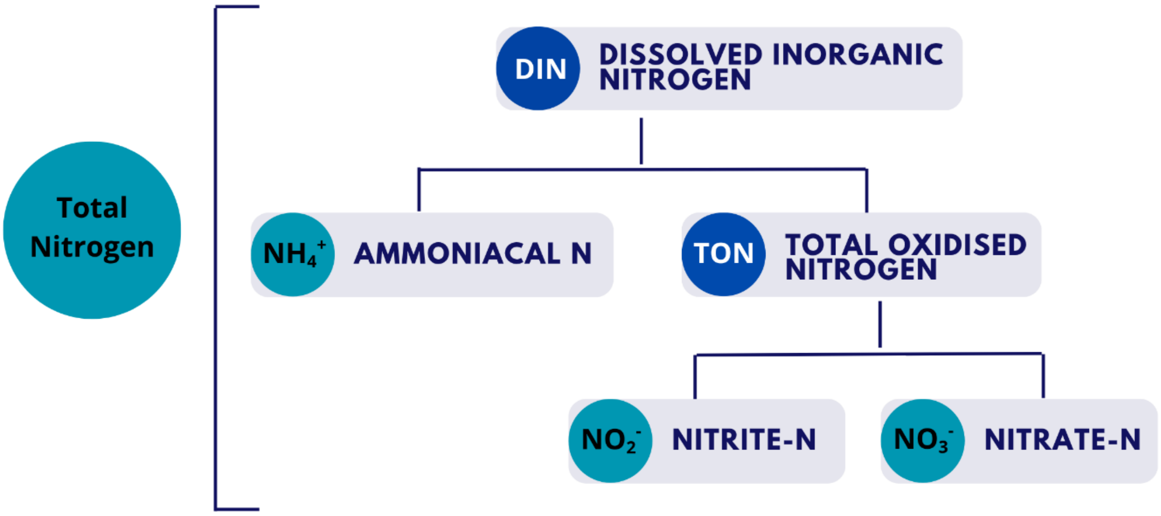

Figure 5: Different forms of nitrogen analysed (shown in teal boxes) with calculated forms of nitrogen (shown in blue boxes) presented in these results. Note that total N also includes organic forms of nitrogen which is not shown in this figure and not analysed separately in groundwater.

3.1.4 Relevant guidelines

The relevant guideline for groundwater quality is the *Drinking Water Standards for New Zealand* Maximum Acceptable Values (MAVs). An MAV represents the maximum concentration of a parameter that, based on current knowledge, is not expected to pose a significant risk to human health over a lifetime of consuming 2 L of water per day for 70 years (MoH, 2019).

The MAV is set differently for nitrate, nitrite, and *Escherichia coli* (*E. coli*). For nitrate and nitrite, the MAV reflects a short-term exposure limit intended to protect bottle-fed infants from methemoglobinemia (blue baby syndrome). Public health guidance recommends applying this limit to bottle-fed infants under six months of age and to pregnant women. *E. coli* concentrations above the MAV indicate a significant risk of waterborne disease.

In this context, MAVs are used as a screening tool to assess groundwater suitability for drinking water supply. They do not represent a regulatory compliance assessment.

3.2 Data processing and quality assurance

All data underwent quality assurance to ensure consistency before analysis. Auckland Council adopted the NEMS quality coding (QC) framework in January 2020 (NEMS, 2020). Data collected prior to this used the IANZ-certified Auckland Council Hydrological 10-151 QC system. Earlier data met best practice standards of their respective periods. Data identified as poor quality, due to non-compliance with NEMS standards, equipment malfunctions, or erroneous values, were excluded from all analyses.

All water quality data are stored in Auckland Council’s water quality archiving database (KiWQM). Data from the NGMP sites (analysed by GNS Wairakei Laboratory) are stored by GNS and provided to us for inclusion into this database.

3.2.1 Limitations

The changes to sampling frequency, the sites and analytes measured and shifts in laboratory service providers described in Section 2.3 all create limitations to data continuity for the groundwater quality programme.

There have also been numerous events that have impacted water quality monitoring operations during the period covered by this report. This includes suspension of monitoring under Covid-19 lockdown conditions during 2020-2021, issues with delivery of samples for laboratory analysis associated with Covid-19 lockdowns and missed samples during and in the aftermath of the Auckland Anniversary flood (January 2023) and Cyclone Gabrielle (February 2023).

Missed sampling events are accounted for in relation to minimum data requirements. This is acknowledged as a limitation for any further interpretation of results where the impacts of these events on water quality may be of interest.

3.3 State analysis

The state analysis calculates a range of statistics for each site/parameter combination (minimum, maximum, median, 25th 75th percentiles, or quartiles) and these are presented as boxplots in the results sections (Section 4).

3.3.1 Time periods and data filtering

The time period, acceptable proportion of gaps and representation of sample intervals by observations within the time period are commonly referred to as site inclusion or filtering rules (e.g. Larned et al., 2018).

The current state assessments were made for the five-year time period to end of June 2024.

Rolling state assessments were also performed for five-year period windows between July and June over the full length of the records. This involved starting the first five-year window (to the end of June 2024), then shifting the five-year window back incrementally by one-year and re-evaluating, until the end of the record.

Because of natural seasonal fluctuations, it is important that each season is well-represented over the period of record. In the case of the groundwater quality programme, which collects quarterly data, this is important given the maximum number of observations over a five-year period is only 20. We therefore applied a rule that restricted site x variable combinations in the state analysis to those with measurements for at least 80% of the sampling intervals in that period (16 out of 20 quarters). This is consistent with national SOE reporting (Whitehead et al., 2021). Site/parameter combinations that do not meet the above criteria are not presented in this report.

3.3.2 Handling censored values

Values below the detection limit for any water quality parameter are considered ‘left censored’ values. To calculate state statistics, these values were replaced with imputed values generated using ROS (Regression on Order Statistics; Helsel 2012), following the procedure described in Larned et al. (2018). The ROS procedure estimates values for the censored data based on the distribution of uncensored values and can accommodate multiple detection limits. In instances where there are insufficient non-censored data to evaluate a distribution for estimated values for censored results, censored values are replaced with half of their reported value.

3.4 Trend analysis

3.4.1 Time periods

The purpose of trend assessment is to evaluate the direction and rate of change in the central tendency of water quality values over time. For a regional study aiming to compare trends between sites and provide a synoptic assessment across the region, it is essential that the trends evaluated at each site have comparable statistical power and adequately represent the time-period. To achieve this, it is standard practice to define consistent time periods (i.e., trend duration and start date) so that all sites are assessed under similar conditions. Trend analysis was undertaken over a defined time period of 7 years to end of June 2024 for all site and parameter combinations.

While a minimum 10-year period is preferred for trend analysis, there are known step changes in the data due to the transition of laboratory services from Watercare Services to Hill Laboratories in 2017. Identifying these changes in the groundwater data is difficult due to the quarterly sampling frequency. However, the step changes are particularly evident in time series data from other programmes with monthly sampling (e.g. the river and coastal water quality programmes). Therefore, similar issues are expected in the groundwater dataset.

To avoid erroneous trend results for periods that span this change it was considered more appropriate to analyse state and trends before and/or after the methodology change (Wood, 2024). We therefore present trends only for data collected after the laboratory change (July 2017 to June 2024).

We recommend caution when interpreting trends over short periods such as this. Although groundwater is somewhat insulated from short term climatic variability, shorter trend assessment periods are more vulnerable to the influence of climatic variability (Snelder et al., 2021), particularly with unusually dry and wet years of 2020, and 2023, respectively. In some instances, such as for parameters measured in the field, 15-year trend periods were assessed (July 2009-June 2024).

3.4.2 Sampling frequency

The groundwater quality programme is designed to sample at a set quarterly frequency (one sample in each season of the year). There are some deviations from this in the data set, namely:

(1) The collection of more than one observation in an interval (i.e. two observations in one quarter). To address this, the sample closest to the middle of the time increment was used.

(2) A change in sampling interval within the trend analysis period (i.e. a shift from annual to quarterly sample collection). This was addressed by coarsening the sampling interval to define the trend time increment for the part of the record with higher sampling frequency. This was achieved by taking the observation in the higher frequency part of the record that was closest to the midpoint of the time increments defined by the coarser part of the record. The reason for not using the median value in

this case is that it will induce a trend in variance, which will invalidate the distributional assumptions of the Mann Kendall S test statistic (Helsel et al., 2020).

3.4.3 Data filtering

In this assessment we used data filtering rules applied by Larned et al., (2018) to set limits on the proportion and distribution of missing data across sample intervals to ensure trends are based on comparable datasets:

1. Retain site/parameter combinations where data are available for at least 80% of the years in the time period;
2. Retain site/parameter combinations where data are available for at least 80% of the sample intervals.

To maximise site inclusion, the definition of time increments was kept flexible. If a site failed to meet filter rule (2) using quarterly data, the data were progressively aggregated to biannual or annual intervals, and the rule was reassessed for that interval. Trends were evaluated using the shortest time increment that satisfied filter rule (2). It is noted that applying these filtering rules results in varying levels of statistical power and temporal representativeness across included sites.

3.4.4 Handling censored values

In the trend direction assessment (see Section 3.4.6.1), censored values were treated according to Helsel (2005, 2012, in Fraser & Snelder, 2025), using methods that are robust to changes in detection limits over time. When assessing trend direction, increases or decreases in a water quality variable were identified wherever possible. A change from a censored value of <1 to a measured value of 10 was considered an increase. A change from a censored value of <1 to a measured value 0.5 was considered a tie, as is a change from <1 to a <5, because neither can definitively be called an increase or decrease (Fraser & Snelder, 2025). When assessing trend magnitude using Sen slopes, (see Section 3.4.6.2) left censored values were substituted with their raw values (i.e., the numeric component of the detection limit) multiplied by 0.5. This step ensured that any values measured exactly at a detection limit were treated as being larger than values less than the detection limit (Fraser & Snelder, 2025).

A new approach was applied to handle changes in detection limits over time on the Sen slope. Inter-observation slopes were considered to be ties and set to zero, regardless of their values, when: (1) both observations were either left or right censored, (2) when one observation was left censored and larger than the other non-censored observation; (3) when one observation was right censored and smaller than the other non-censored observation.

3.4.5 Seasonality assessment

Many water quality parameters show seasonal patterns and accounting for this variability should improve the statistical power of trend assessments. To evaluate this, the data were first tested for seasonal effects using the Kruskal-Wallis test. This is a non-parametric ANOVA that determines the extent to which season explains variation in the water quality observations. Following Hirsch et al. (1982), season/site/variable combinations were identified as being seasonal based on the p-value (p

<0.05) with seasons defined as monthly, bimonthly, or quarterly, depending on the best statistical fit (determined automatically).

3.4.6 Trend assessment

The trend assessment evaluated both the direction (i.e., increasing or decreasing) and rate of change in the central tendency of observed water quality values over a specified period. All state and trend analyses were undertaken by Land and Water People (LWP) and outputs including graphics were provided to Auckland Council. We evaluated trends using the LWP Trends functions (Fraser and Snelder 2025 – LWPTrends_v2502.r) that are implemented in the R statistical computing software (R Core Team, 2023). Trend assessment methods were described by Fraser (2025) following Fraser and Snelder (2025) and are briefly summarised here.

3.4.6.1 Trend direction

Trend direction and its confidence were evaluated using the non-parametric Mann-Kendall or Seasonal Kendall test. While Sen’s slope regression also indicates direction, the Mann-Kendall test was preferred because it more robustly handles censored data. Sen’s slope was the recommended approach for estimating trend magnitude (see next subsection).

The Kendall S statistic was computed by comparing all pairs of observations: positive (concordant) pairs indicate increases over time, negative (discordant) pairs indicate decreases, and tied pairs (same value or time) are counted as zero (Gilbert, 1987). The Kendall S statistic is the number of concordant pairs minus the number of discordant pairs, with the sign of S indicating trend direction.

For the seasonal version, S was calculated within each season (e.g., Quarter 1 across years), and then summed across seasons. Variance was calculated similarly, and confidence was determined using the posterior probability distribution of S, approximated as a normal distribution with mean S and variance var(S) (Snelder et al., 2022).

Confidence (C) was calculated as the proportion of the posterior distribution with the same sign as S, ranging from 0.5 (no confidence) to 1 (complete confidence). Importantly, C reflects confidence in direction, not the magnitude or importance of the trend. As sample size increases, confidence typically increases—even if the trend rate is small.

3.4.6.2 Trend magnitude

Trend magnitude was assessed using Sen’s slope estimator (SSE), the median of all pairwise slopes (i.e., change in value divided by time between samples) (Hirsch et al., 1982).

When seasonal effects are significant ($p \leq 0.05$, Kruskal-Wallis test), the Seasonal Sen Slope Estimator (SSSE) is applied. SSSE was calculated by first estimating the median slope within each season and then taking the median across seasons. For datasets with more than one observation per season-year, only inter-year comparisons within each season were used (Gilbert, 1987).

Uncertainty in trend rate was assessed following Helsel and Hirsch (2002), using ranked slopes to define symmetric two-sided confidence intervals at a 90% confidence level.

Although a trend may be classified as ‘very likely’ increasing or decreasing, a small Sen slope indicates that change will be slow to appear in current state assessments, assuming a linear rate of change. The confidence in the direction indicated by the Sen Slope and estimation of the magnitude of the trend decreases in reliability as the proportion of censored values increases. The Sen slope may be zero where there is a high proportion of censored data in the dataset or tied non-censored values.

3.4.6.3 Trend interpretation

The trend assessment used in this study provided a more nuanced interpretation than a simple yes/no result based on an acceptable error rate. Specifically, the confidence in direction (C) was transformed into a continuous measure of confidence in a decreasing trend (Cd). For negative trends ($S < 0$), Cd = C; for positive trends ($S > 0$), Cd = 1 – C. Cd ranged from 0 to 1, where low values indicated a decreasing trend was highly unlikely—equivalent to high confidence in an increasing trend. Each site/parameter combination was then assigned a confidence in trend direction category according to its evaluated confidence in the trend decreasing shown in Table 3-3. The categorisation follows that used by LAWA (Snelder & Fraser, 2018).

Table 3-3: Confidence categories for decreasing/increasing trend (Cd)

Trend categories	Cd (%)
Very likely decreasing	90-100
Likely decreasing	67-90
Low Confidence	33-67
Likely increasing	10-33
Very likely increasing	0-10

Trends are presented in this report in two ways:

- State vs. trend plots – For each parameter, sites are displayed on a scatter plot with the median concentration on the x-axis and the annual Sen slope (% change per year) on the y-axis. Points are coloured based on the assigned trend categories (Cd) (Table 3-3). Note that only site/parameter combinations with noteworthy results are presented and discussed in these plots. This typically includes trends with high statistical confidence (in either direction) and a substantial magnitude of change (e.g. greater than 1% annual Sen Slope). The complete set of trend results is provided as a supplementary file, available in Appendix 4.
- Aggregate bar charts – The proportion of sites in each trend category is shown by parameter, using color-coded bar charts to visually summarise the balance of increasing and decreasing trends across confidence levels indicated by the categories in Table 3-3.

4 State

4.1 Regional overview

This section presents summary statistics showing the state of groundwater quality for all 21 sites in the Auckland region from 2020-2024. These include two sites in the Kumeū area, three sites in the Ōmaha area, 14 sites in the Pukekohe area and 2 sites in the urban area (see Table 2-5 for site details). The purpose of these charts is to enable comparison of water quality results across all sites in the region after which, Sections 4.2, 4.3, 4.4 and 4.5 provide further details for each specific area. The results are grouped by water quality parameters of similar characteristics and presented in box plots.

There are two distinct groups of dissolved oxygen results: low concentrations and percent saturations representing anoxic conditions including aquifers that are confined and within deeper sedimentary (and some deep basalt) geology; and high concentrations and percent saturations representing shallow oxygenated aquifers with greater connection to the atmosphere (Figure 6).

Median conductivity ranged from 0.2-0.8 mS/cm and TDS from 121-325 mg/L; median pH ranged from 6.5-8.5; median temperature ranged from 14.6 to 19.2 °C and median total hardness ranged from 46 to 178. There were no clear patterns based on location except that conductivity, TDS and hardness tended to be lower at the urban sites and higher at the Ōmaha sites. In general, there was little variation in the results within sites, which is expected due to the limited exposure groundwater has to the atmosphere and climatic variation. Exceptions to this were dissolved oxygen concentrations at shallow oxygenated sites, and almost all physical parameters except pH at the Ōmaha Walkway site (Figure 6).

Median concentrations of ammoniacal-N ranged from 0.001 mg/L at Alfred St (an urban site) to 0.7 mg/L at Fielding Rd Volcanic (a Drury/Bombay site). Nitrite was below levels of detection in most instances at most sites. Median concentrations of nitrate ranged from 0.0003 to 25 mg/L. This large variation is due to nitrate contamination in the shallow basalt aquifers of the Pukekohe area and is discussed in Section 4.2.2. Total oxidised nitrogen and total inorganic nitrogen ranged from 0.0005 to 25 mg/L and 0.03 to 24 mg/L, respectively and were found to be largely aligned to the nitrate concentrations at most sites. Total nitrogen ranged from 0.04 to 25 mg/L (Figure 7), also largely a reflection of the nitrate-N fraction, particularly at the sites with high concentrations.

Median concentrations of dissolved reactive phosphorus ranged from 0.005 to 0.17 mg/L and total phosphorus ranged from 0.02 to 0.2 mg/L. The Kumeū sites tended to be at the low end of these concentrations and both fractions of phosphorus tended to be higher at the urban sites, Fielding Rd Sand (Pukekohe area) and Quintals Rd (Ōmaha area) (Figure 7).

Median soluble copper concentrations ranged from less than detection (0.0005 mg/L) to 0.001 mg/L. All sites were consistently below levels of detection except for Ōmaha Walkway and the two urban sites. Soluble lead concentrations were below levels of detection at all sites except for Wilcox Gun Club Rd (Pukekohe area) with a median concentration of 0.00013 mg/L and Alfred St with a median of 0.00064 mg/L. Soluble zinc concentrations ranged from a median of 0.0005 to 0.18 mg/L and the highest concentrations were observed at the newest sites: Patumāhoe Shallow and Deep. Soluble cadmium concentrations were below detection in all instances at all sites (Figure 8).

Soluble iron ranged from the detection limit of 0.005 to 6.25 mg/L. Relatively high concentrations were observed at anoxic sites located in sedimentary geology and confined deep basalt geology. Similarly, soluble manganese also tended to be higher at sites located in sedimentary geology with anoxic conditions and relatively low at shallow basalt sites and springs. Median concentrations of soluble manganese ranged from 0.0005 to 0.23 mg/L (Figure 8). In low oxygen conditions, iron and manganese dissolve more readily, particularly in the pH is also low (acidic) (OHA, 2023). Without oxygen, iron occurs in its reduced form (Fe_2^+) which is highly soluble. In the presence of oxygen, it occurs as Fe_3^+ which does not dissolve easily.

Soluble potassium ranged from a median of 0.47 to 6.2 mg/L and there was very little variation within sites. The Pukekohe and urban sites tended to have the highest concentrations. Soluble sodium ranged from a median of 16 to 42 mg/L across all sites except Seagrove Rd, where the median was higher at 94 mg/L. This still represents freshwater conditions (not saline), but is likely from the surrounding marine sedimentary geology at this site and its close proximity to the coast. Chloride was also relatively higher (median of 35 mg/L) at this site. Median concentrations of chloride across all sites ranged from 16 to 69 mg/L. The highest was observed at the deep Kumeū site (Waitākere Rd Deep). Median sulphate concentrations ranged from 0.01 to 13.5 mg/L with the lowest concentrations observed at the Kumeū sites and highest at the urban sites (Figure 8).

E. coli concentrations were consistently below detection at most sites (Figure 9). Exceptions were the two urban sites, which had median concentrations of 19 CFU/100mL (Alfred St) and 105 CFU/100mL (Watson Ave). These sites have a greater connection to the surface through cracks and fissures in the rock and receive stormwater discharge after rainfall events. There also may be leaks from underground sewer pipes via cracks and illegal cross-connections. Other sites with occasional detections of *E. coli* were Patumāhoe Springs, a surface pond where faecal contamination can easily enter, and to a lesser extent, Hickey Spring where faecal contamination is possible, but rare. Median concentrations at both these spring sites were still less than 1 CFU/100mL (Figure 9).

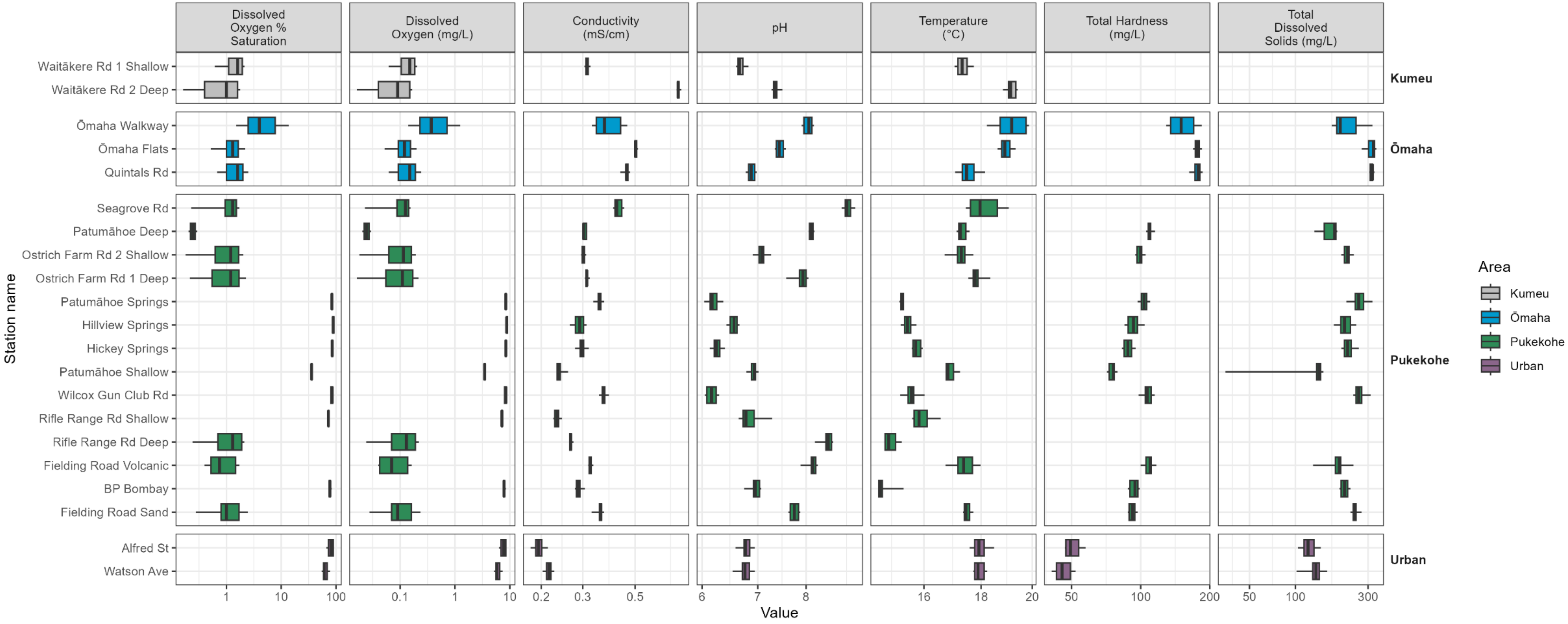

Figure 6: Summary statistics of quarterly results for physical parameters at all groundwater monitoring sites in the Auckland region from 2020-2024. Note all parameters are presented on a log scale.

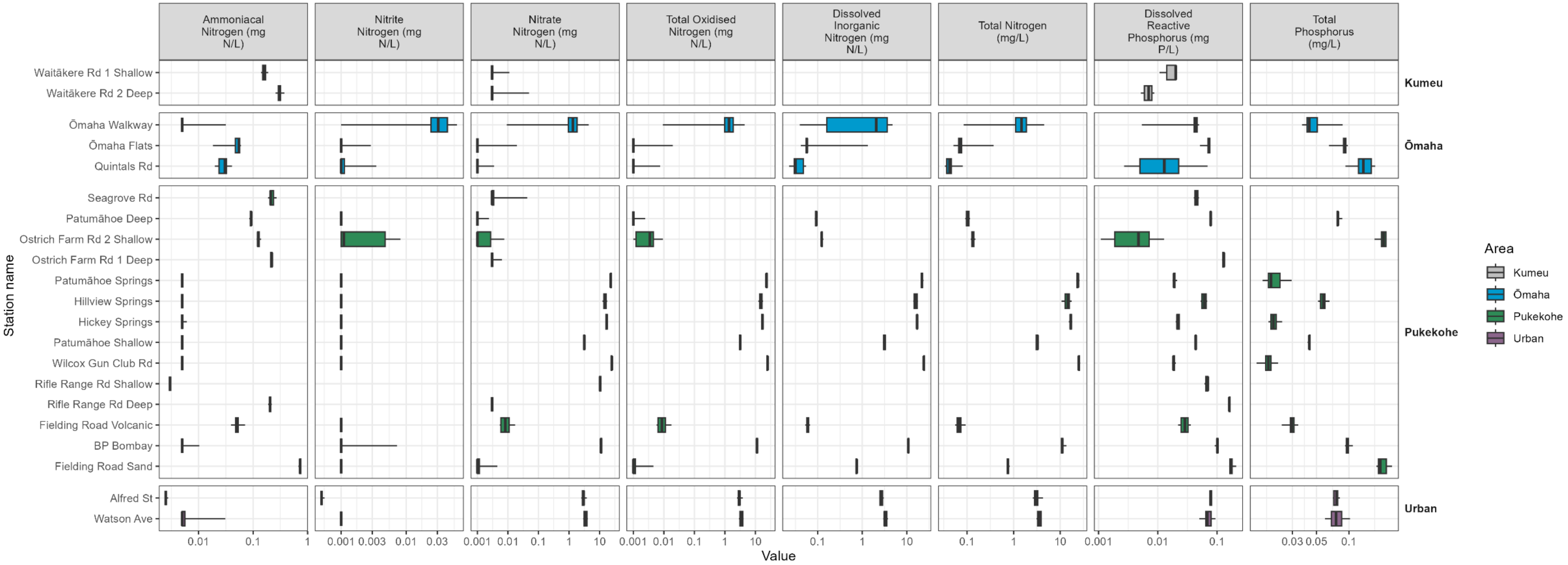

Figure 7: Summary statistics of quarterly results for nutrient (nitrogen and phosphorus) parameters at all groundwater monitoring sites in the Auckland region from 2020-2024. Note all parameters are presented on a log scale.

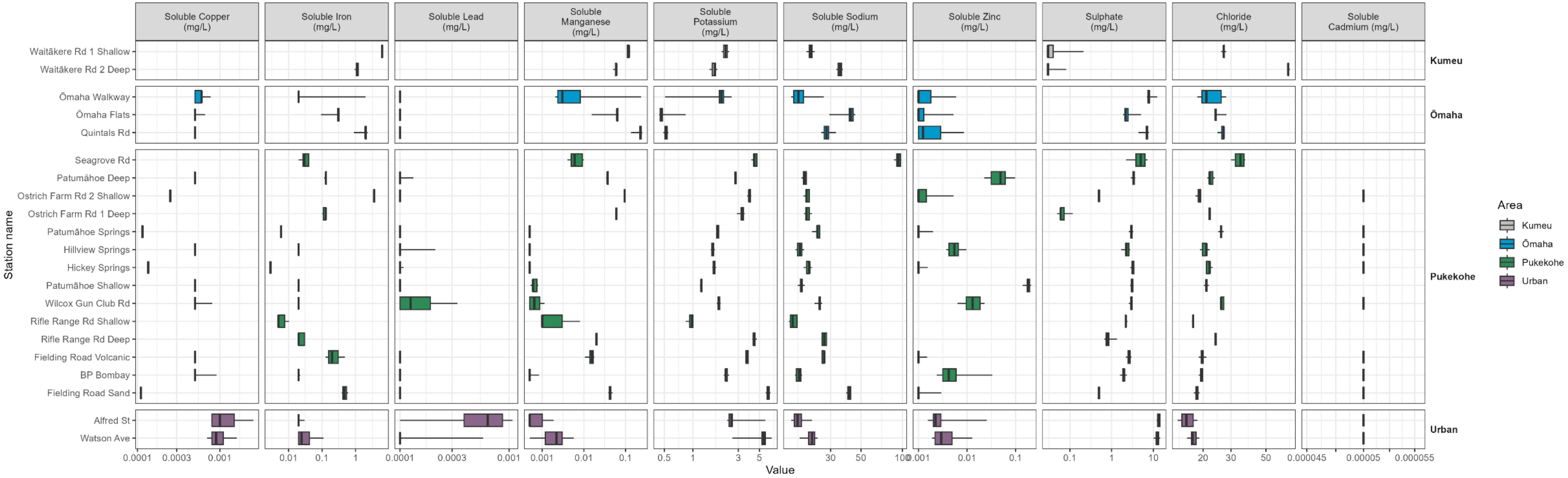

Figure 8: Summary statistics of quarterly results for soluble metal and ion parameters at all groundwater monitoring sites in the Auckland region from 2020-2024. Note all parameters are presented on a log scale.

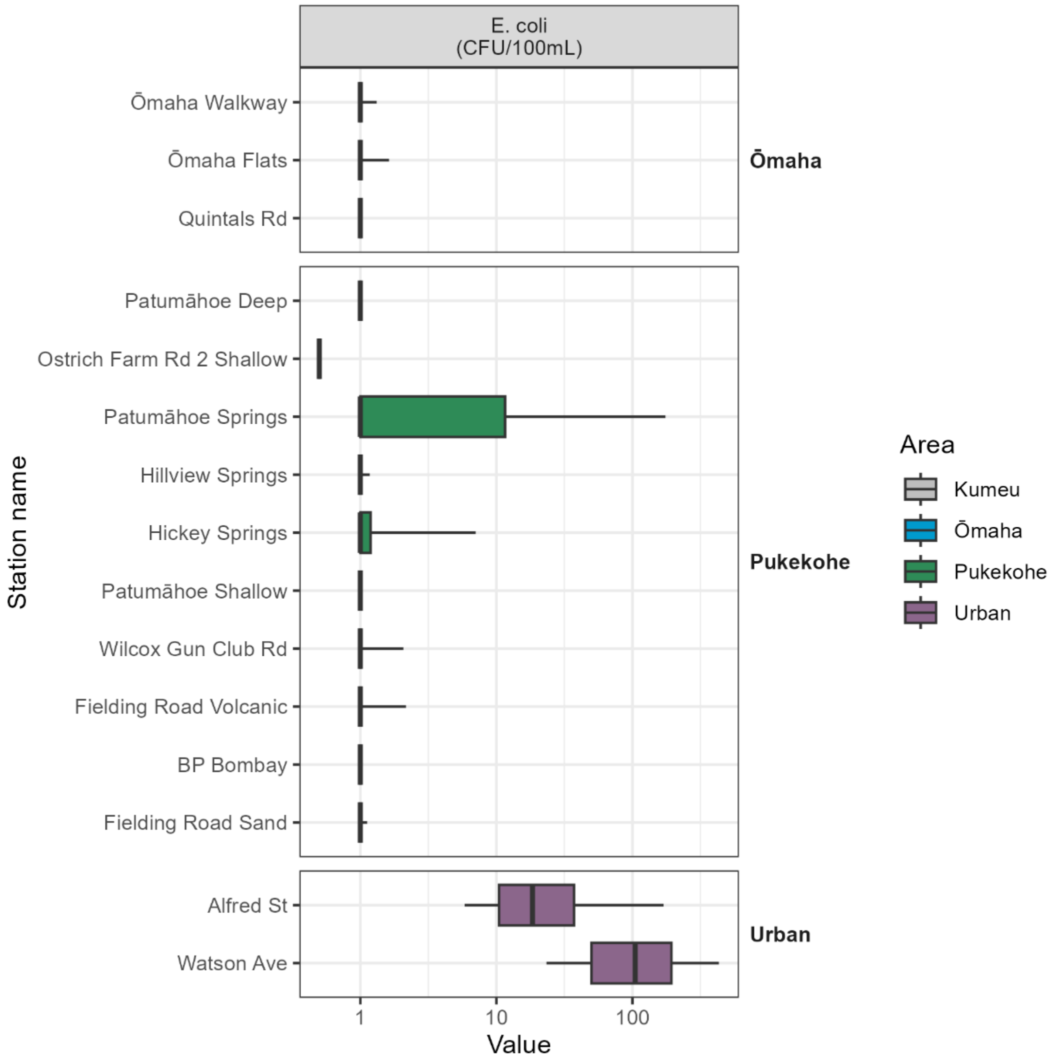

Figure 9: Summary statistics of quarterly results for *E. coli* at all groundwater monitoring sites in the Auckland region from 2020-2024. Note data are presented on a log scale.

4.2 Pukekohe area

This section presents summary statistics showing the state of groundwater quality for 14 sites in the Pukekohe area (Figure 10). These include seven sites in the shallow basalt aquifers (including the three spring sites), two sites in the deep basalts, three sites in the Kaawa aquifer and one in the Waitematā aquifer (see Table 2-5 for site details). Water quality parameters are grouped by similar characteristics and presented in box plots.

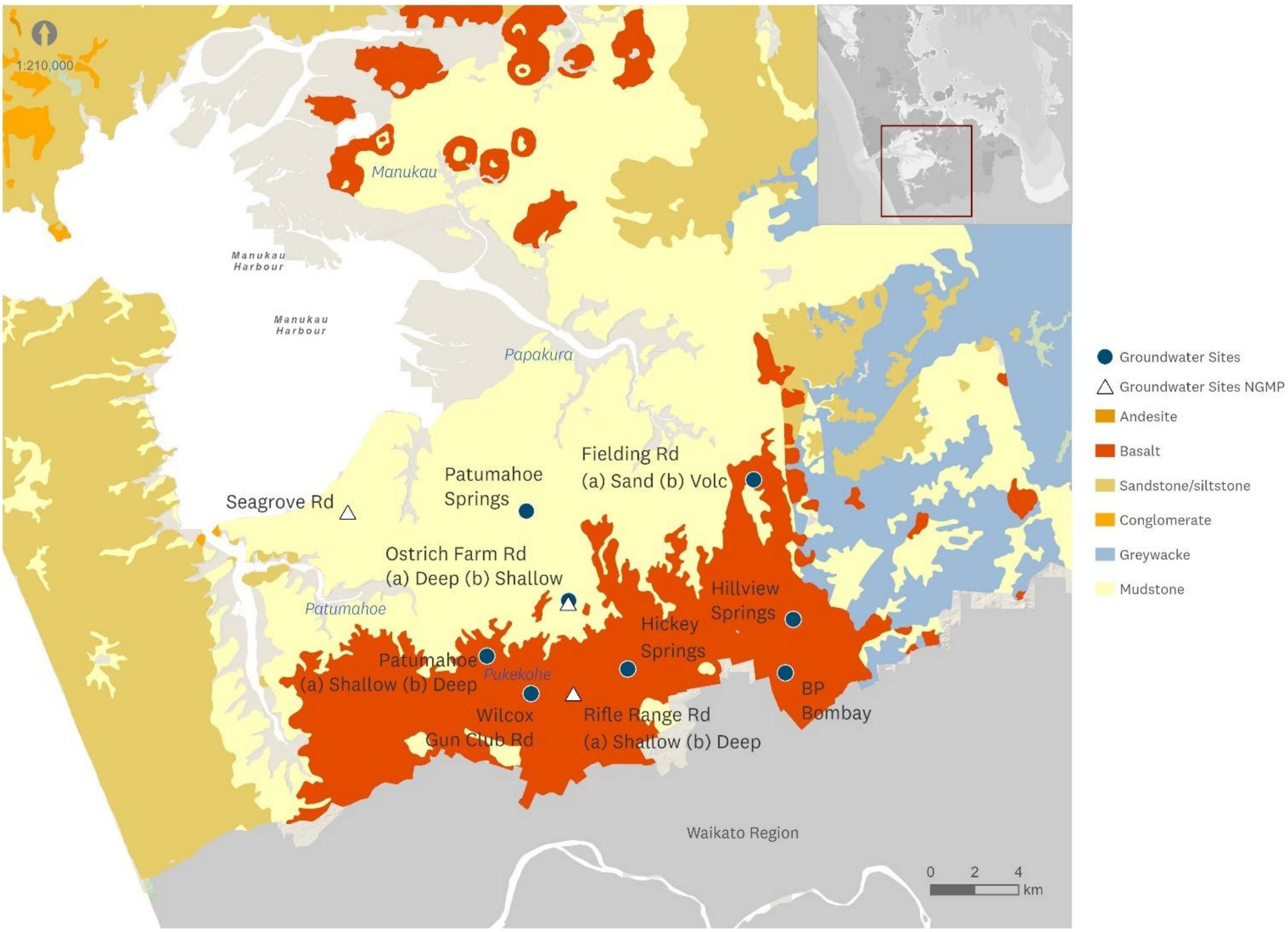

Figure 10: Groundwater quality monitoring sites in the Pukekohe area shown with mapped surface geology. Location in the context of the Auckland region shown as an inset.

4.2.1 Physical parameters

Measuring physical parameters such as dissolved oxygen, conductivity, pH, temperature, hardness and total dissolved solids (TDS) provides a useful snapshot of groundwater conditions and helps identify changes or variability at a site over time. These results are important because they can indicate shifts in water quality, potential contamination or other changes that might affect the health or usability of the groundwater.

Dissolved oxygen concentrations in the Pukekohe area fell into two distinct groups as described in Section 4.1 above:

(1) Very low (close to zero) concentrations and percent saturations, representing confined anoxic environments. These include sites in the sand (Drury/Bombay), sedimentary (Kaawa sand and shell), Waitematā and deep basalt formations.
(2) High concentrations and percent saturations consistent with unconfined, oxygenated environments. These include all the shallow basalt and spring sites.

Most sites fell within a narrow electrical conductivity range of 0.25-0.4 mS/cm. Seagrove Rd shows higher conductivity than other sites, likely due to the older, more confined water having prolonged contact with aquifer minerals and lack of dilution (Moreau et al., 2025) and/or its proximity to the coast.

pH levels at most sites fall within a neutral to slightly alkaline range (6.5-8.5), with low within-site variability indicating high stability. There is a general tendency for lower pH at sites with higher DO, and vice versa. Temperature also shows low variability within sites, with median values ranging from 14.5°C (BP Bombay) to 18°C (Seagrove Rd). The higher temperatures and variability at Seagrove Rd, while within normal range of temperature for groundwater, were unexpected, considering its depth (201 m), and therefore limited influence from surface climatic fluctuations. In contrast, the three spring sites (Patumāhoe, Hillview and Hickey) exhibited some of the lowest temperatures and variability, despite their direct exposure to surface and diurnal temperature changes.

Water hardness generally ranged between 77-120 mg/L, and total dissolved solids ranged between 200-300 mg/L. There were some low values measured for TDS at Patumāhoe Springs. However, these were treated as outliers since median wasn’t considerably lower than other sites and variability was low.

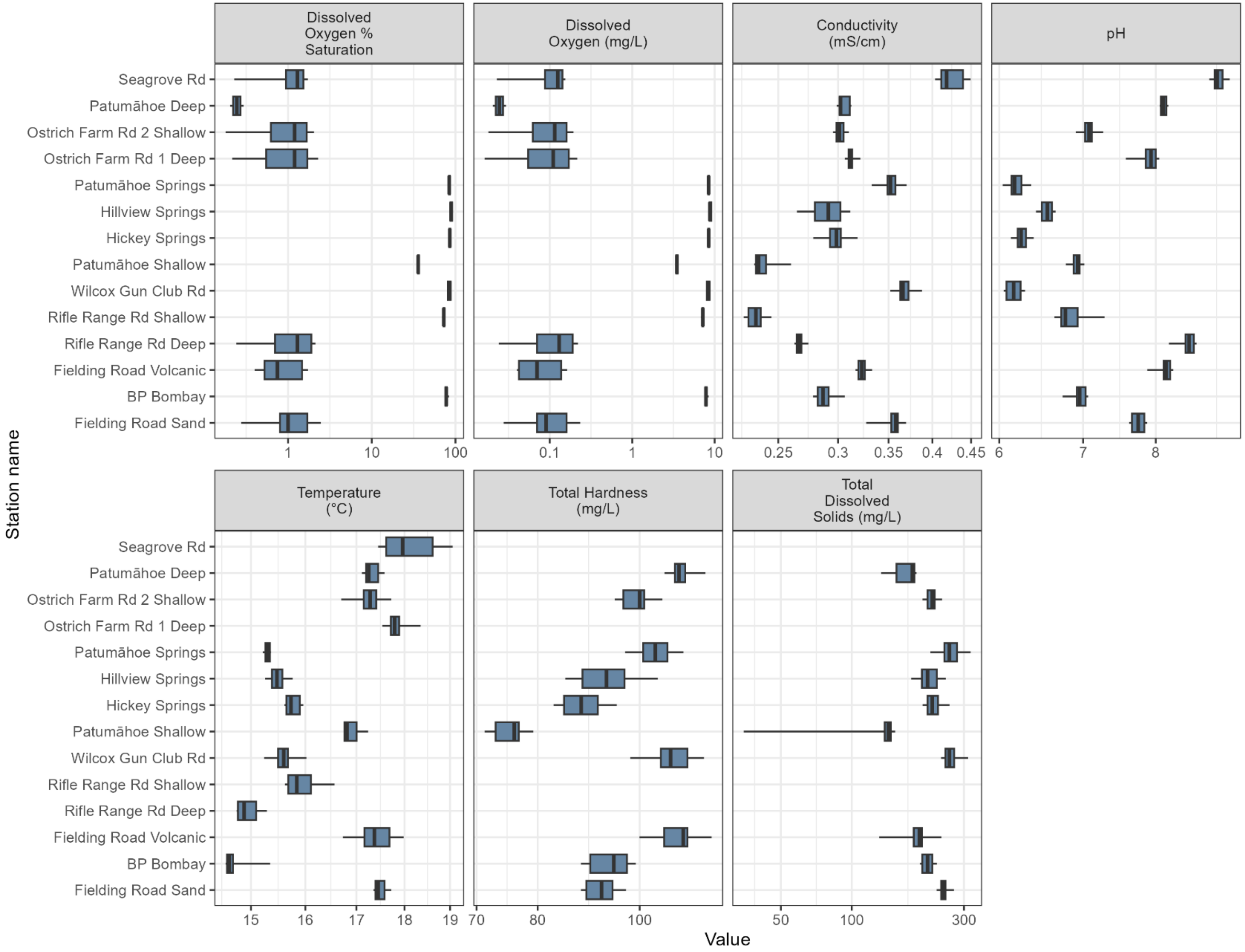

Figure 11: Summary statistics of quarterly results for physical parameters at groundwater monitoring sites in the Pukekohe area from 2020-2024. Note all parameters are presented on a log scale.

4.2.2 Nutrients

Ammoniacal-N was low, with median concentrations of less than 0.3 mg/L at all sites, except Fielding Rd, which had a much higher median of 0.73 mg/L. Rolling five-year medians over time (Appendix 3) show that ammoniacal-N concentrations have consistently been elevated at this site, ranging from 0.54-0.73 mg/L. This suggests the concentrations are a natural occurrence, possibly resulting from anaerobic breakdown of organic materials in the surrounding geology.

Nitrite-N concentrations were largely below levels of detection as expected. This is because nitrite in the environment is rapidly oxidised via nitrification, to nitrate. The upper quartile concentration at Ostrich Farm Rd Shallow is still very low and not of concern.

Nitrate concentrations at sites associated with shallow basalt geology in the Pukekohe area exhibited consistently high nitrate-N concentrations, with medians ranging from 3.2 to 25 mg/L. At six sites, BP Bombay, Hickey Springs, Hillview Springs, Patumāhoe Springs, Rifle Range Rd Shallow, and Wilcox Gun Club Rd, median nitrate-N levels exceeded the New Zealand Drinking Water Standard of 11.3 mg/L (Ministry of Health, 2019). At Patumāhoe Springs (23 mg/L) and Wilcox Gun Club Rd (25 mg/L), concentrations were more than twice this limit. In contrast, nitrate-N concentrations were very low (less than 0.01 mg/L) at all sites not associated with shallow basalt geology, including those located in deeper basalt formations. These sites also had very low oxygen conditions. The reasons for this may include confining or low permeability layers physically preventing nitrate rich water percolation, and/or the reducing conditions (low oxygen content) supporting removal of nitrate via denitrification.

Nitrate contamination in groundwaters in the Pukekohe area is a long-standing issue, resulting from decades of intensive horticultural activity (Meijer et al., 2016). The region’s rich volcanic soils and frost-free climate make it one of New Zealand’s most productive growing areas. Since the 1950s, it has supported intensive vegetable production, supplying up to one-third of the country’s fresh vegetables (Lowe et al., 2010). The high fertiliser inputs required to sustain this productivity have led to significant nitrate leaching through the permeable volcanic soils, where nitrate has accumulated in the underlying shallow basalt aquifers to the levels observed today.

The shallow basalt aquifers s discharge to surface water bodies providing significant baseflow to local streams. The Whangamaire Stream (via Patumāhoe Springs), Whangapouri Creek (via Hickey Springs) and Hingaia Stream (via Hillview Springs) primarily drain the basalt formations of the Pukekohe and Bombay volcanic centres. The upper reaches of the Ngakoroa Stream and Mauku Streams also discharge from the south-western flanks of these volcanic centres (Morgenstern et al., 2023). Consequently, high nitrate-N concentrations are also observed in these surface waters, all of which drain into the Manukau Harbour. Auckland Council's River Water Quality Monitoring Programme reports elevated median nitrate-N concentrations in the Pukekohe area, including 13.1 mg/L in Whangamaire Stream, 3.1 mg/L in Ngakoroa Stream, and 2.2 mg/L in Waitangi Stream (Ingley & Dikareva, 2025).

Some of these river concentrations exceed the National Bottom Line for nitrate toxicity (2.4 mg/L), specified in the National Policy Statement for Freshwater Management, (Ministry for the Environment, 2020). Auckland Council is required to set targets and timelines to reduce nitrate levels below this threshold. Recent estimates of residence time by Morgenstern et al., (2023), described in Section 2.2.1, indicate that it takes on average 18 years for nitrate to travel through the Pukekohe basalt aquifer, and 36 years to travel through the Bombay basalt aquifer. Such long lag times suggest any reductions in nitrate leaching through improvements in land-use practices will take decades to manifest in the spring discharges from the basalts.

Total oxidised nitrogen (TON), dissolved inorganic N (DIN), and total N are heavily influenced by the nitrate-N component. Consequently, elevated concentrations of these parameters are also observed at the same sites that exhibit high nitrate-N concentrations. While Total N may include small contributions from organic nitrogen sources, the close similarity between median DIN and total N concentrations indicates that the vast majority of nitrogen is derived from nitrate-N (and in some cases ammoniacal-N).

Dissolved reactive phosphorus (DRP) concentrations generally ranged between 0.01 and 0.1 mg/L across most sites. Slightly higher concentrations were observed at Fielding Rd Sand, Rifle Range Rd Deep, and Ostrich Farm Rd Deep compared to other sites. Water in contact with volcanic rock is known to naturally exhibit higher DRP levels (Rissmann et al., 2023). That may explain the elevated concentrations at the latter two sites. Additionally, higher phosphorus levels in the sands at the Fielding Rd Sand site could account for the increased DRP observed there, as well as the elevated total phosphorus (TP) concentration at the same site. DRP concentrations were markedly lower and more variable at Ostrich Farm Rd Shallow (Figure 12). In contrast, total P was notably high at this site (Figure 12). This suggests geological and physical conditions in the aquifer support the presence of dissolved phosphorus in the organic form (non-bioavailable), or the adsorption of DRP particulate matter.

Other total phosphorus concentrations were low overall, remaining below 0.1 mg/L at most sites. Fielding Rd Sand recorded a slightly higher median concentration, at 0.2 mg/L. The observed differences are likely due to variations in the local geology, as there are no other distinctive physical site characteristics that would increase phosphorus solubility at this location.

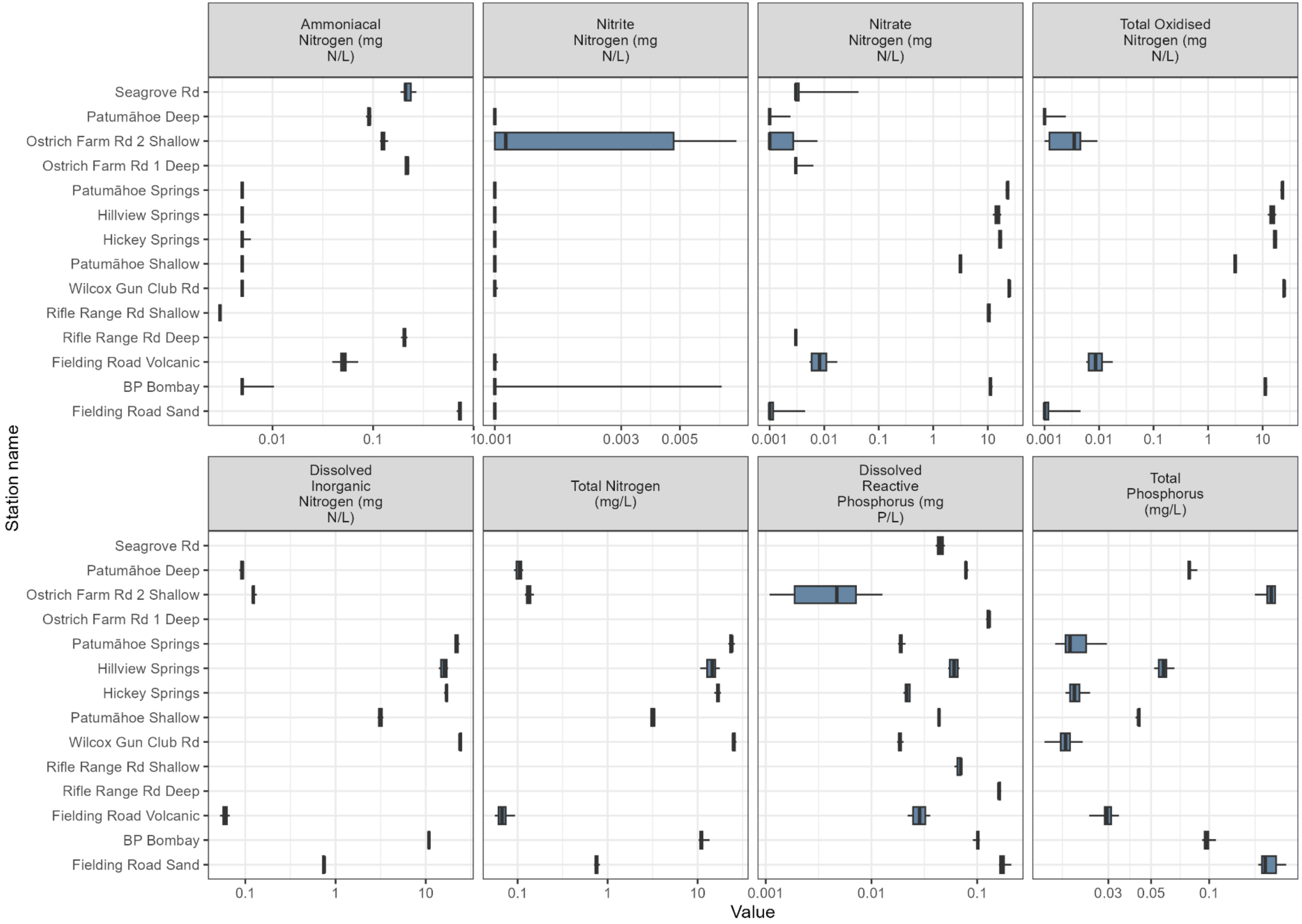

Figure 12: Summary statistics of quarterly results for nutrients (nitrogen and phosphorus) at groundwater monitoring sites in the Pukekohe area from 2020-2024. Note all parameters are presented on a log scale.

4.2.3 Metals and ions

Soluble copper, soluble lead and soluble cadmium concentrations were below detection in most cases, with very low within-site variability. The exception was a notably higher median – and greater variability – observed in soluble lead at the Wilcox Gun Club Rd site. Rolling medians over time (Appendix 3) showed below-detection concentrations from 2017-2021, after which they rose to levels similar to those reported here from 2022 onwards (~0.0001 mg/L). Prior to 2017 (2013-2016), median lead concentrations were similar to those reported for 2022 onwards. However, the low/disjointed sampling frequency over this time meant minimum data requirements were not met. Note these concentrations are still considered low, at roughly two orders of magnitude below the Maximum Acceptable Value for lead in drinking water of 0.01 mg/L (further noting that this refers to total lead and our results are soluble lead).

The Wilcox Gun Club Rd site is located on private land and has an in-situ pump, from which the landowner kindly grants us permission to sample for this programme. The shift in median lead concentrations since 2022 may be due to changes in pump or bore infrastructure. This is unlikely since any upgraded infrastructure is not expected to contain lead (whereas older infrastructure may contain lead).

The nearby clay target shooting club located at 37 Gun Club Road could be a potential source of the higher lead concentrations. The facility is currently known as the Auckland Metropolitan Clay Target Club. It was formerly known as the Pukekohe Road and Gun Club (1910-1921) and later as the Pukekohe Gun Club (1921-1966). The present site was established in 1966 following the amalgamation of the Pukekohe Gun Club and the Auckland Metropolitan Club. It is situated directly opposite the grounds used by these clubs prior to 1966 (Auckland Metropolitan Clay Target Club, 2025). The current facility is located approximately 3 km east of the Wilcox Gun Club Road groundwater monitoring site, with both locations lying within the recharge zone of the Pukekohe Basalt Aquifer (Figure 13).

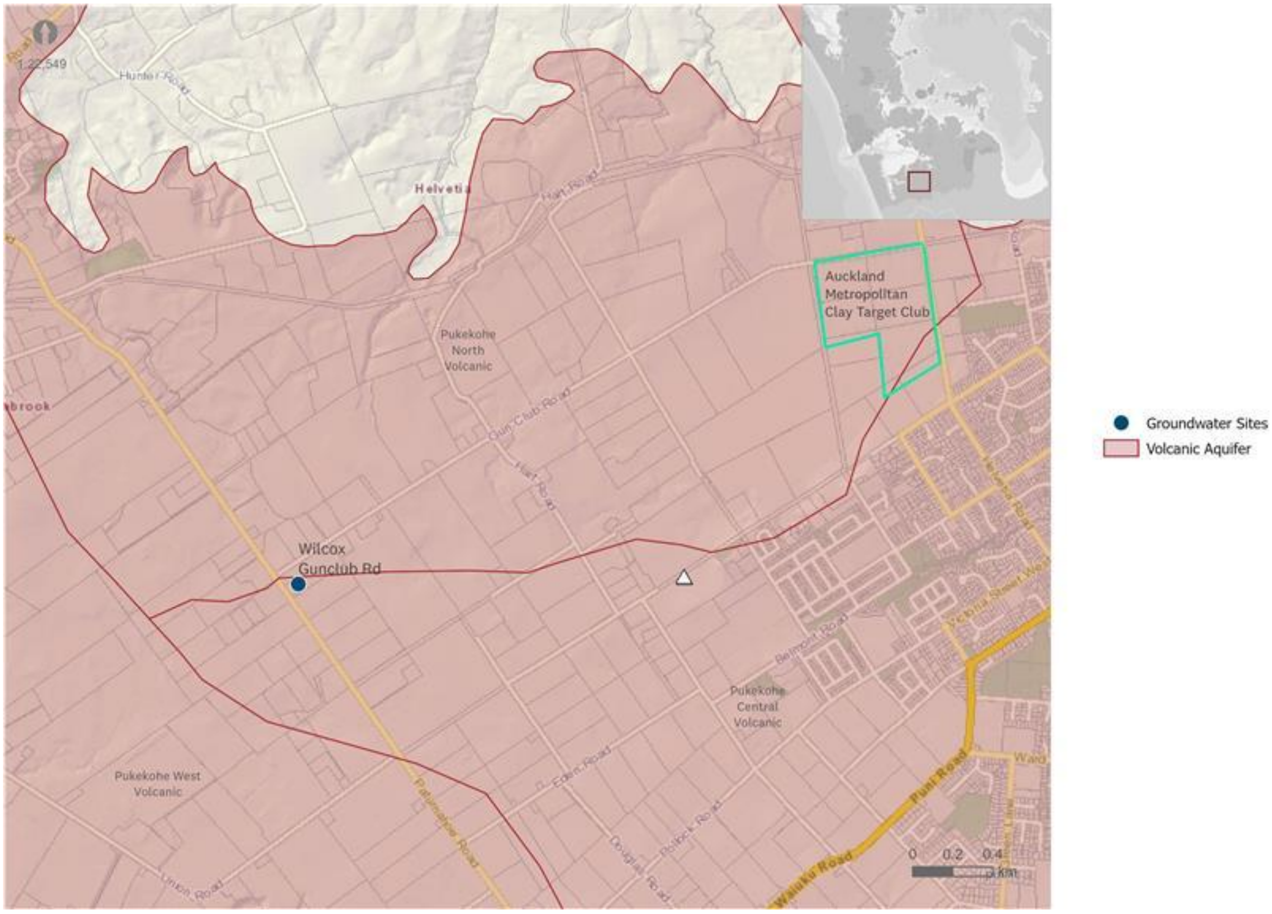

Figure 13: Location of Wilcox Gun Club Rd bore (blue dot) in relation to location of the Auckland Metropolitan Clay Target Club (property extent outlined in cyan). Mapped extent of Pukekohe basalt (volcanic) aquifers is overlain in red striping.

Studies have shown that soil within the shot fall zone of clay target shooting ranges can become heavily contaminated with lead. At a Canterbury facility, Rooney et al. (1999) reported that over 30% of soil samples collected from within the shot fall area exceeded the Australian and New Zealand guideline limit of 300 mg/kg of soil, with some concentrations ranging from 4,000 to 8,300 mg/kg. Other studies have identified elevated lead levels in shallow groundwater beneath shooting ranges, where acidic conditions and unconfined aquifers can facilitate the mobility of lead in solution (Soeder and Miller, 2003).

Soluble iron concentrations at all sites in the Pukekohe area were generally below 0.1 mg/L, with very low within-site variability. However, a notably higher concentration was observed at Ostrich Farm Rd Shallow (3.6 mg/L), and elevated levels were also recorded at Fielding Rd Sand (0.47 mg/L) and Fielding Rd Volcanic (0.2 mg/L). These higher concentrations may reflect the influence of local geology—deep basalts at Ostrich Farm Rd Shallow and Fielding Rd Volcanic, and sedimentary material at Fielding Rd Sand—all of which may contain iron-bearing minerals (Gill, 2010; Blatt et al., 1980). In addition, deoxygenated conditions at all three sites likely contribute to the increased solubility of iron (Hem, 1985). The lower (more acidic) pH at Ostrich Farm Rd Shallow may further enhance iron solubility at this location.

Soluble manganese concentrations were notably higher at sites not underlain by shallow basalt geology, including Seagrove Rd, Patumāhoe Deep, Ostrich Farm Rd Deep and Shallow, Rifle Range Rd Deep, and Fielding Rd Volcanic and Sand. These sedimentary and deep volcanic aquifers may naturally contain higher levels of manganese-bearing minerals (Tucker, 2001). Low oxygen levels, which create reducing conditions, can increase metal solubility, which in combination with the minerals could result in the higher concentrations observed in the groundwater.

Soluble zinc concentrations were highest at Patumāhoe Shallow (median 0.18 mg/L), nearly an order of magnitude greater than the next highest site, Patumāhoe Deep (Kaawa), which were also relatively high (median 0.03 mg/L). While zinc can originate from zinc-rich parent geology—similar to iron and manganese—this seems unlikely here, as other sites in Pukekohe basalt do not show elevated zinc levels. Moreover, Patumāhoe Shallow is a well-oxygenated site, so reducing conditions are not a likely factor.

Anthropogenic influences such as local fertiliser use, inputs from nearby urban activity in Patumāhoe township or industrial activity in neighbouring areas could be investigated as potential sources for this zinc. For example, the Glenbrook Steel Mill (including a galvanising plant), New Zealand's largest single site industrial development, is located 8.5 km to the west of the site. It is possible the elevated zinc concentrations observed at Patumāhoe Deep (Kaawa) results from vertical flow from the overlying Pukekohe shallow aquifer

Sodium and chloride concentrations were notably higher at the Seagrove Rd site than all other sites. This has been observed in previous state and trend reports also (Kalbus et al., 2017; Foster & Johnson, 2021). This site is located in the Waiau Pa Waitematā aquifer, where the geology is comprised of ocean derived sedimentary rocks that have naturally higher sodium and chloride concentrations (Mullaney et al., 2009). An Auckland Regional Council report (ARC, 1993) also noted groundwater located in the deep Waitematā Group (including Seagrove Rd) is naturally elevated in sodium (and boron) and that seawater intrusion was not identified at the time. These elevated concentrations have also been known to cause toxicity problems for sensitive indoor crops where water from this aquifer has been used (ARC, 1993).

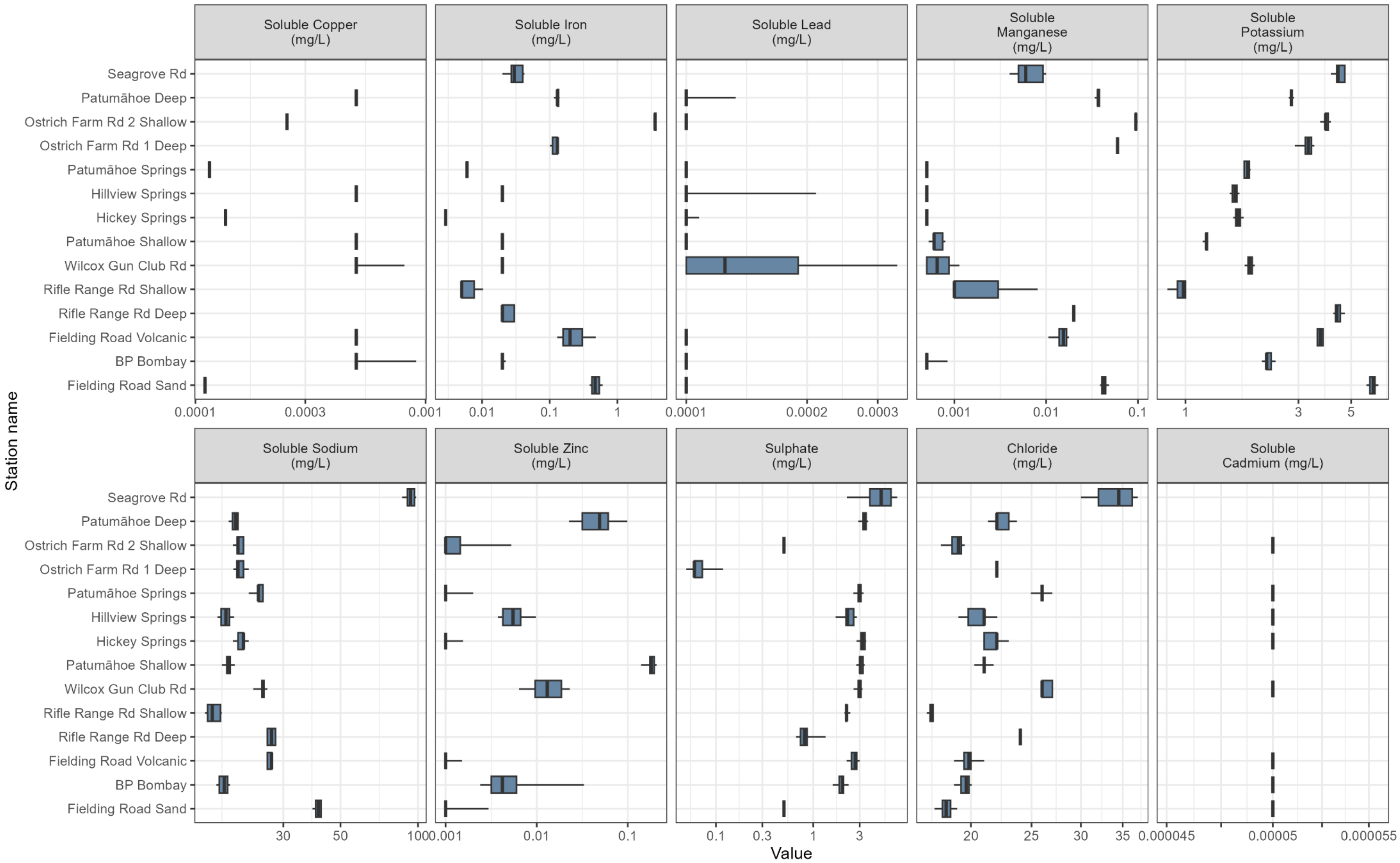

Figure 14: Summary statistics of quarterly results for soluble metal and ion parameters at groundwater monitoring sites in the Pukekohe area from 2020-2024. Note all parameters are presented on a log scale.

4.2.4 *E. coli*

E. coli indicates faecal contamination from warm-blooded animals, and as such, we do not expect to observe it in purged groundwater samples. *E. coli* concentrations were consistently at or below the level of detection at all bore sites, and at Hillview Springs (where samples were collected via an in-situ pump). Its absence served as a good indication that the groundwater was “well filtered” and had slowly percolated through the ground, rather than entered the system rapidly via fractures, bypass flow, or contamination entering the bore from the surface.

Exceptions to this pattern were observed at Patumāhoe and Hickey Springs, which showed greater variability – although their median *E. coli* concentrations remained at or below the detection limit. Patumāhoe Springs, being an open pond located next to a road, was likely influenced by occasional contamination from bird droppings or overland flow, explaining the increased variability in the data. Hickey Springs is also a surface site, but the sampling location has a cover on it. The slightly higher variability at this site may be explained by contamination either directly or washed in from the edges while the lid is open or from small animals entering under the lid.

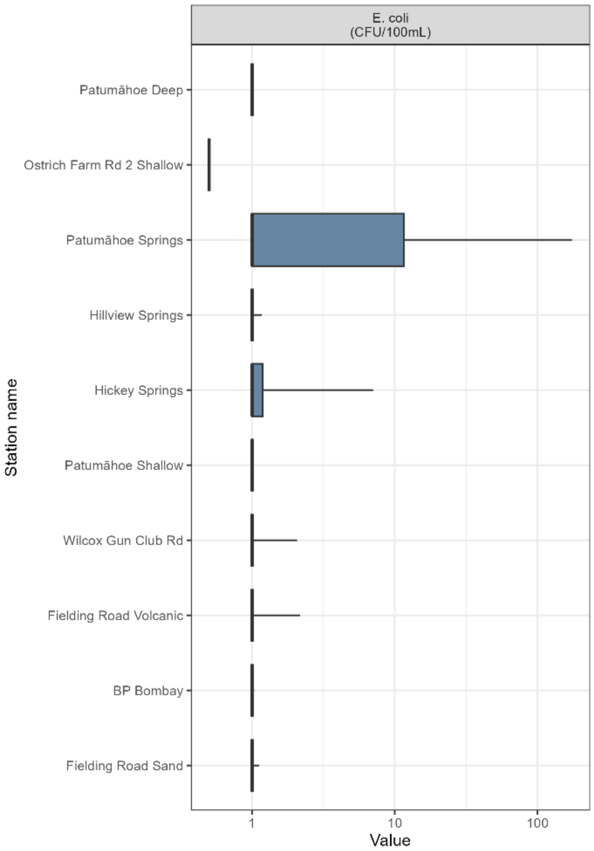

Figure 15: Summary statistics of quarterly results for *E. coli* at groundwater monitoring sites in the Pukekohe area from 2020-2024. Note data are presented on a log scale.

4.3 Urban area

This section presents summary statistics showing the state of groundwater quality parameters for the two urban isthmus sites: Watson Ave, located in the Three Kings Volcanic aquifer; and Alfred Street, located in the Onehunga aquifer. Both these aquifers have similar basalt geology (Section 2.2.2). As for the previous section, the parameters are grouped by similar characteristics and presented in box plots.

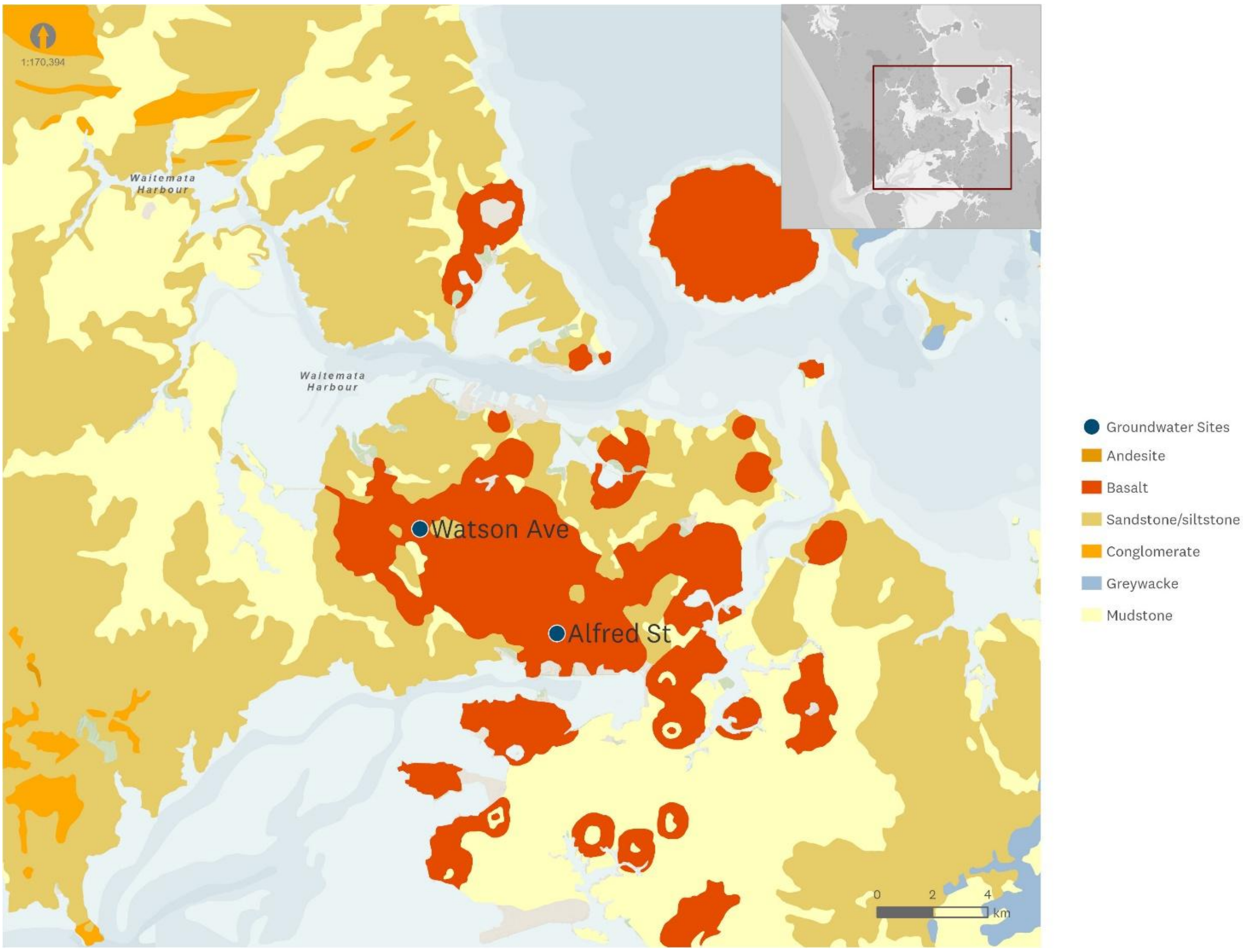

Figure 16: Groundwater quality monitoring sites in the Urban area shown with mapped geology. Location in the context of the Auckland region shown as an inset.

4.3.1 Physical parameters

Both urban sites were well oxygenated, with Alfred St showing higher oxygen concentration and percent saturation than Watson Ave. This was likely due to greater connectivity to the surface via cracks and fractures. Temperature was very similar at both sites and showed low variability, ranging from 17.8 to 18.2 °C. pH was also stable and comparable between the two sites.

Total hardness was low at both sites compared to others in the region (Figure 6). Basalt rocks typically contain low levels of calcium and magnesium, so groundwater in these geological settings tends to have lower hardness (Hem, 1985). Additionally, the shallow, unconfined nature of the aquifers and the regular input of rainwater via stormwater soakpits (Strayton and Lillis, 2013) could effectively dilute calcium and magnesium concentrations.

Conductivity and total dissolved solids (TDS) were also the lowest at these urban sites compared to all other monitored sites (Figure 6), despite the influence of stormwater discharge. This is likely related to the low concentrations of calcium and magnesium ions (reflected by the low hardness), and also lower levels of sodium and chloride (see Figure 8), which contribute significantly to conductivity and TDS in fresh waters.

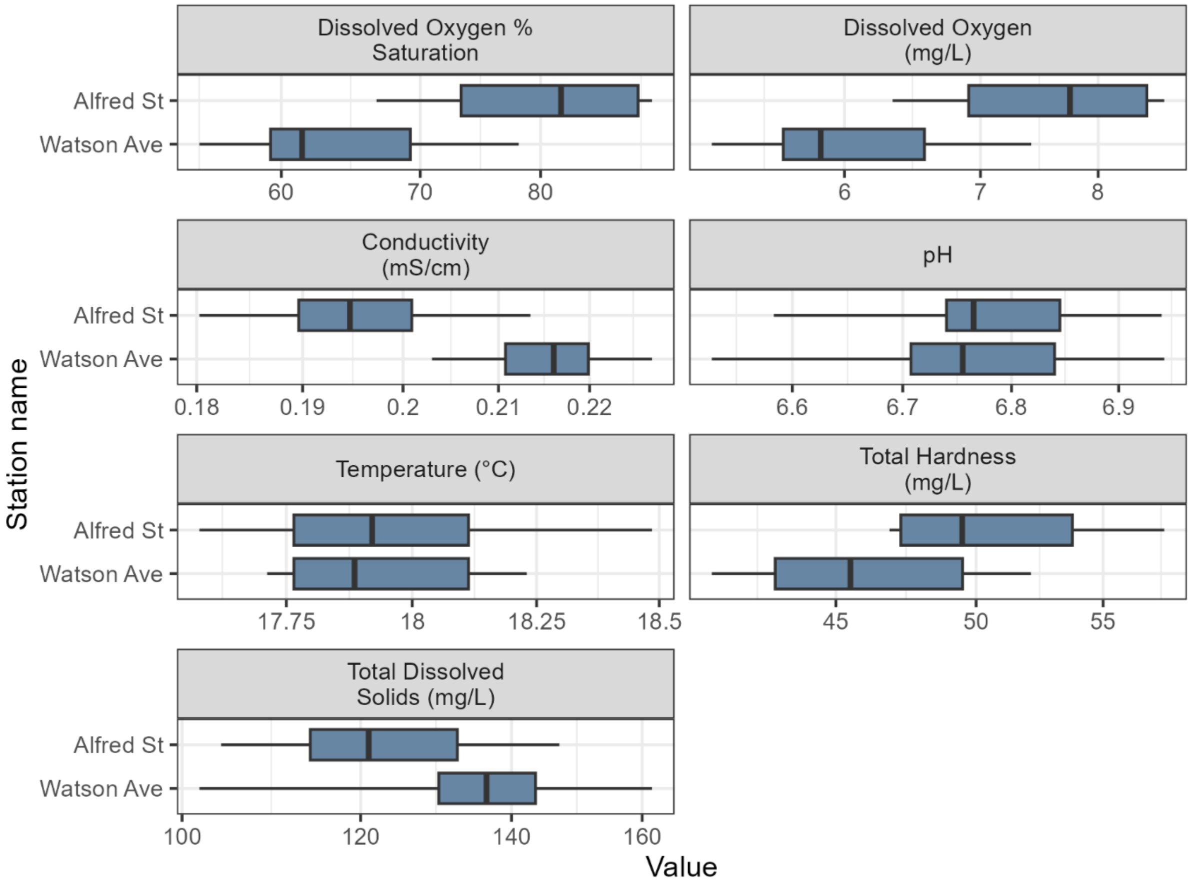

Figure 17: Summary statistics of quarterly results for physical parameters at groundwater monitoring sites in the Urban Area from 2020-2024.

4.3.2 Nutrients

Ammoniacal nitrogen concentrations at these two sites were among the lowest recorded across all sites (see section 4.1) suggesting very little ammonical-N sources enter the aquifers via stormwater soak pits. Given the high levels of oxygen in these aquifers (Figure 17), it is possible for nitrification of ammoniacal N to occur, converting ammoniacal-N to nitrate (also explaining the non-detection of nitrite). However, if appreciable amounts of ammonical-N were being nitrified, much greater variability would be observed in the data due to spikes occurring during and after rainfall events.

Nitrate concentrations were similarly high at both sites (though not as high as those observed in the shallow basalt aquifers in the Pukekohe area), with median concentrations ranging from 3.0 to 3.4 mg nitrate-N/L. Some of this nitrate may have entered the aquifer directly during rainfall events via stormwater discharge. Additionally, there could be a source of organic nitrogen (via stormwater discharge) in the aquifer which is consistently mineralised and oxidised to the more stable nitrate form. As observed in the shallow basalt aquifers of the Pukekohe area, nitrate was the dominant contributor to DIN, TON, and total N concentrations.

Median DRP concentrations were slightly higher at Alfred St (0.08 mg/L) than at Watson Ave (0.068 mg/L). Total phosphorus (TP) concentrations were the same as DRP at Alfred St (0.08 mg/L) and slightly higher at Watson Ave (0.076 mg/L). These concentrations were lower than expected, given the presence of stormwater discharge, and may reflect the use of stormwater management methods that allow settling before infiltration into the aquifer (Strayton and Lillis, 2013). This enables sediment and particulate-bound phosphorus to settle out of suspension, reducing phosphorus inputs to the aquifer.

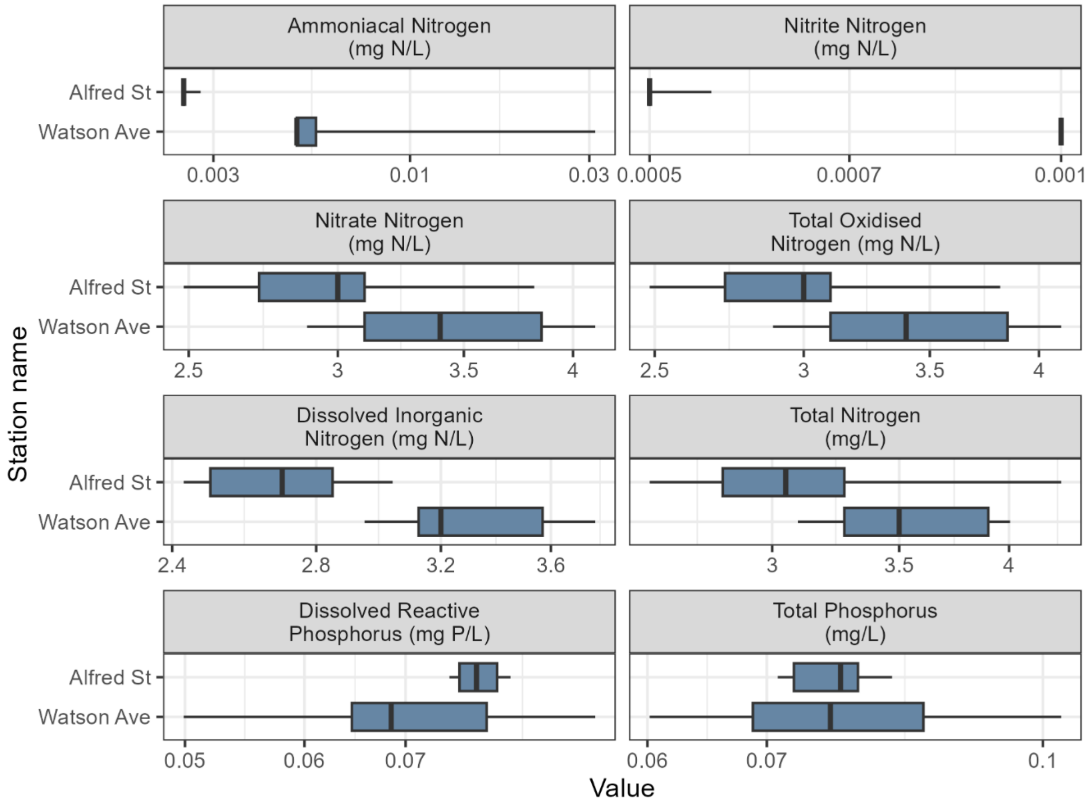

Figure 18: Summary statistics of quarterly results for nutrient (nitrogen and phosphorus) parameters at groundwater monitoring sites in the Urban Area from 2020-2024.

4.3.3 Metals and ions

Soluble copper concentrations were slightly elevated compared to all other non-urban sites (Figure 8) but remained several orders of magnitude below the Maximum Acceptable Value (MAV) (Ministry of Health, 2019). Zinc concentrations were also slightly elevated compared to most non-urban sites (except some sites in the Pukekohe area). These elevated results were expected in an industrialised urban environment receiving stormwater discharge and were consistent with concentrations observed in Auckland’s river systems draining urban catchments (Ingley et al., 2025).

Concentrations of manganese, cadmium, and iron were low and well below MAVs, where applicable. Lead concentrations at Watson Ave were mostly below detection limits. However, they were notably higher at Alfred St, with a median concentration of 0.00064 mg/L, the highest lead concentrations recorded at any site (Figure 8). The source of this lead is unknown and requires further investigation. Historical incidents of lead contamination, namely the nearby Green Stream groundwater plume (Kirk, 2010) identified elevated lead concentrations in the vicinity of the site. This plume was attributed to contamination from a fertiliser company that operated from 1910-1984. There are also multiple E-Waste and battery recycling businesses in the local area, but further investigation is required to determine if these activities have any impact on groundwater.

Chloride and sodium concentrations were low compared to all other sites, though both ions were slightly higher at Watson Ave than at Alfred St. Sulphate concentrations were the highest of all sites at Alfred St and Watson Ave, likely due to urban inputs combined with enhanced mineral weathering driven by increased infiltration and recharge from stormwater disposal (Appelo & Postma, 2005).

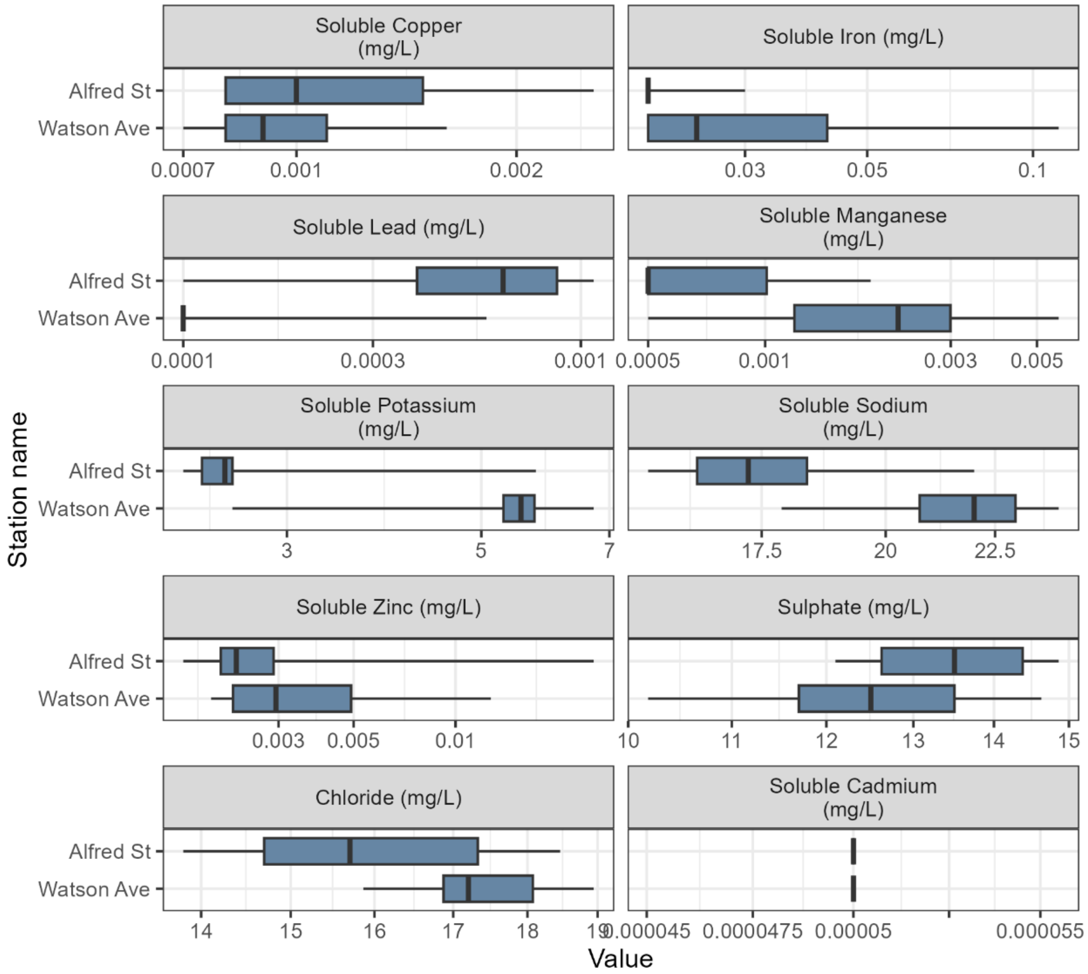

Figure 19: Summary statistics of quarterly results for metal and ion parameters at groundwater monitoring sites in the Urban Area from 2020-2024.

4.3.4 *E. coli*

The urban sites were the only sites (with the exception of Patumāhoe Springs) where *E. coli* concentrations were detected. This was expected and likely to be a combination of exfiltration from leaks from sewerage pipes (in dry weather) and infiltration from contaminated stormwater (in wet weather). Concentrations were consistently higher at Watson Ave than Alfred St.

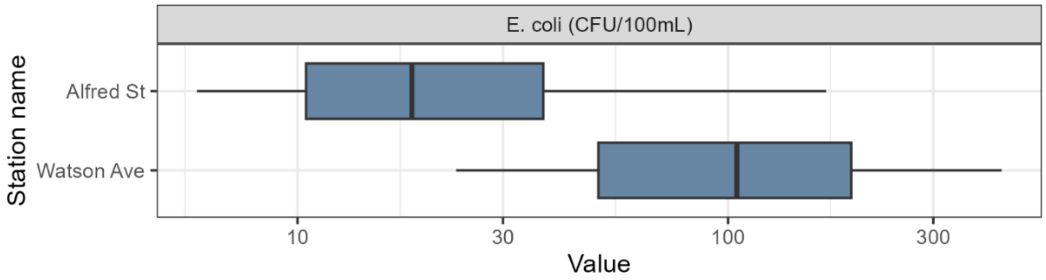

Figure 20: Summary statistics of quarterly results for *E. coli* at groundwater monitoring sites in the Urban Area from 2020-2024.

4.4 Kumeū area

This section presents summary statistics showing the state of groundwater quality parameters for the two Kumeū sites (Figure 21). Both sites are located in the Kumeū West Waitematā aquifer, part of the Waitematā Group sedimentary rocks (Section 2.2.3). Parameters are grouped by similar characteristics and presented in box plots.

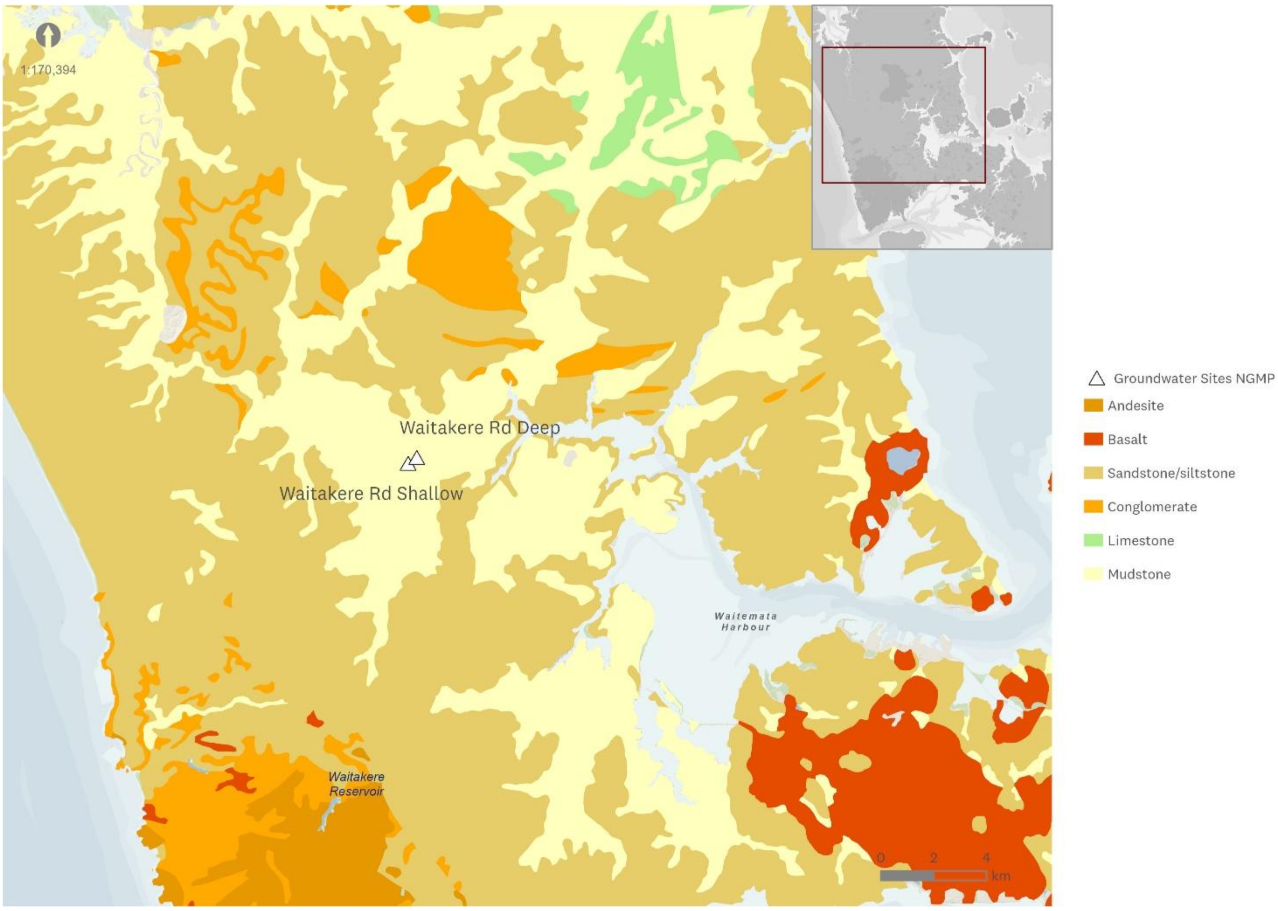

Figure 21: Groundwater quality monitoring sites in the Kumeū area shown with mapped geology. Location in the context of the Auckland region shown as an inset.

4.4.1 Physical parameters

Dissolved oxygen (concentration and percent saturation) is very low (anoxic) at both Kumeū sites. All other physical parameters are consistently different from each other at the two sites: temperature is almost 2°C cooler at the shallow site (median 17.3°C) than the deep (median 19.1°C); pH is lower (more acidic) at the shallow site (6.7) than the deep (7.4) and conductivity is lower at the shallow site (0.31 mS/cm) than the deep (0.76 mS/cm).

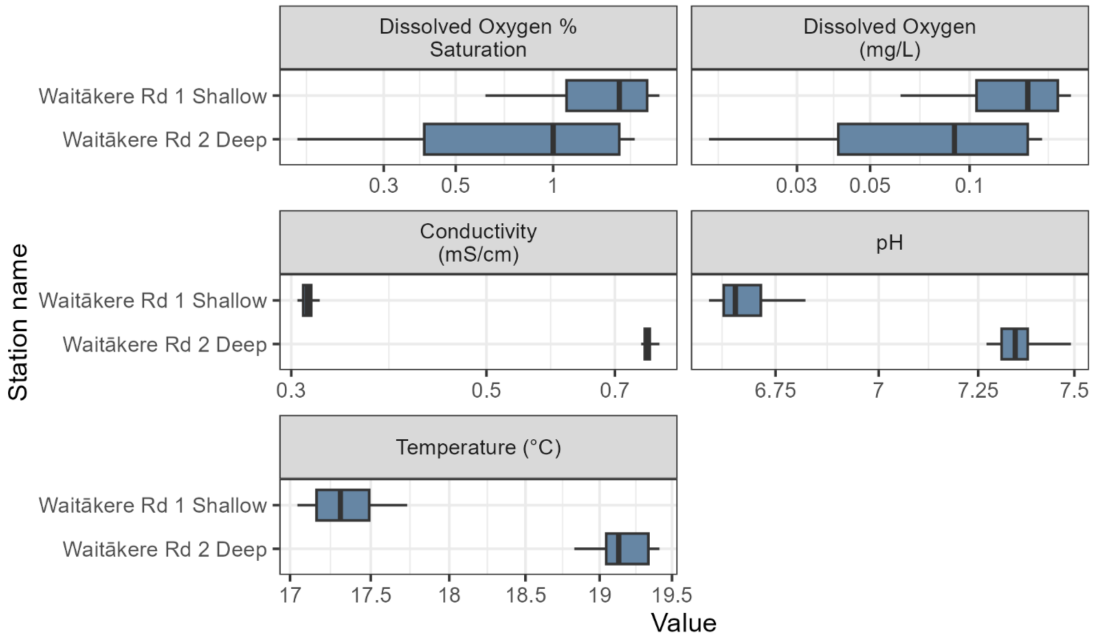

Figure 22: Summary statistics of quarterly results for physical parameters groundwater monitoring sites in the Kumeū Area from 2020-2024.

4.4.2 Nutrients

Ammoniacal nitrogen concentrations were among the highest recorded in the region (refer to regional summary), with values of 0.16 mg/L at the shallow site and 0.3 mg/L at the deep site. This could arise from ammonification – the breakdown of small pockets of organic matter under anoxic conditions, releasing ammoniacal N (Johnson et al., 2022). The reduction of nitrate to ammoniacal-N is another pathway that may contribute to these higher concentrations. Furthermore, the absence of oxygen inhibits nitrification, thereby ensuring this N remains as ammoniacal-N.

Dissolved reactive phosphorus concentrations were some of the lowest of all sites in the region (Figure 7) but concentrations in the shallow site were more than double (0.02 mg/L) those at the deep site (0.0075 mg/L). For reference, the national median DRP concentration (2019-2014) was 0.012 mg/L (Moreau et al., 2025) so these concentrations are not considered low in the national context. pH can affect solubility of phosphorus, with both high and low pH favouring the formation of insoluble calcium phosphate compounds and iron or aluminium phosphates, respectively (McLaren & Cameron, 1996). The lower pH, coupled with higher temperature at Waitākere Rd Deep may be responsible for locking up phosphorus and thereby the lower concentration of DRP at this site.

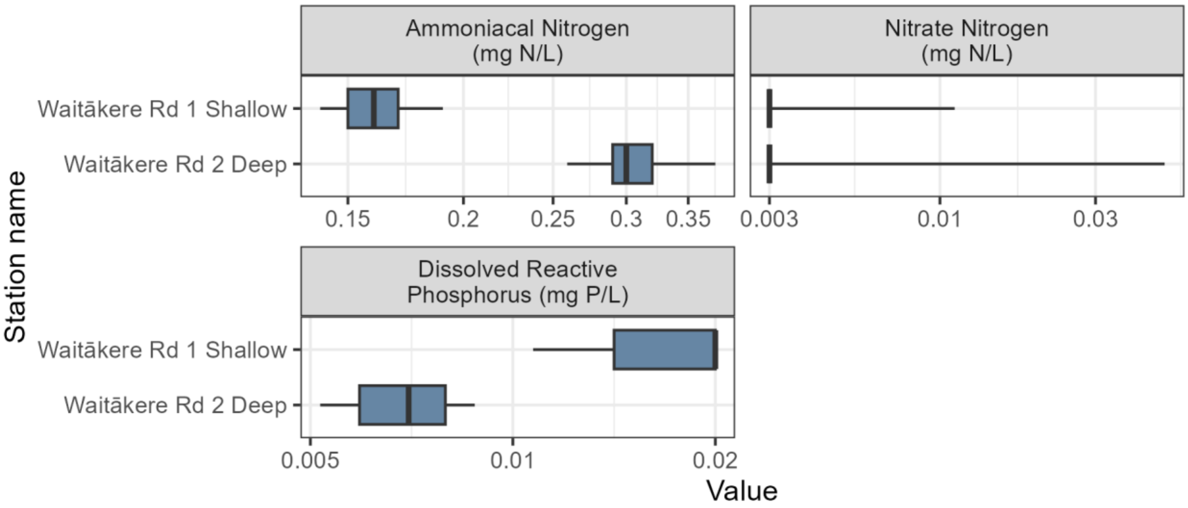

Figure 23: Summary statistics of quarterly results State of nutrient (nitrogen and phosphorus) parameters for groundwater monitoring sites in the Kumeū Area

4.4.3 Metals and ions

Soluble iron and manganese concentrations at the Waitākere Rd Shallow and Deep sites are some of the highest reported in Auckland. At the deep site, soluble iron had a median concentration of 1.15 mg/L, which was high relative to most other sites in the region. Concentrations were five times higher at the shallow site, with a median of 6.3 mg/L. Similar concentrations were reported at these sites by Kalbus et al. (2017) and Foster and Johnson (2021), where they were attributed to reducing conditions in the natural surrounding geology. While there are no Maximum Acceptable Values (MAVs) for iron, these concentrations exceed the aesthetic guideline value of 0.2 mg/L. This guideline value is based on taste and potential discolouration of water, the latter of which is observed at both sites.

Sodium and chloride concentrations were much higher at the Waitākere Rd Deep site than at the shallow site. A possible explanation is a greater marine influence on the deeper sedimentary geology, similar to what has been observed at the Seagrove Rd site in the Waiau Pa Waitematā aquifer.

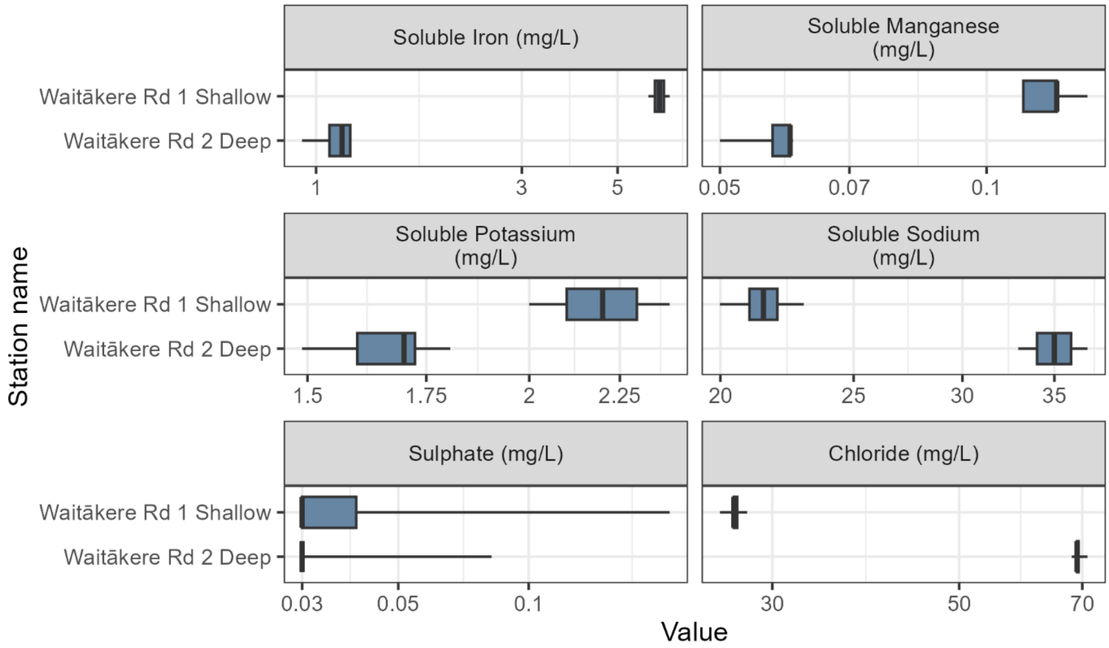

Figure 24: Summary statistics of quarterly results for metal and ion parameters at groundwater monitoring sites in the Kumeū Area from 2020-2024.

There is no summary *E. coli* data available for the two Waitākere Rd sites as they are NGMP sites and GNS do not analyse water samples for *E. coli*.

4.5 Ōmaha area

This section presents summary statistics showing the state of groundwater quality parameters for the three Ōmaha Area sites (Figure 25). Two of these are located within the Waitematā Group Sedimentary rocks, and the other is in the Ōmaha Sand aquifer (see Section 2.2.4). Parameters are grouped by similar characteristics and presented in box plots.

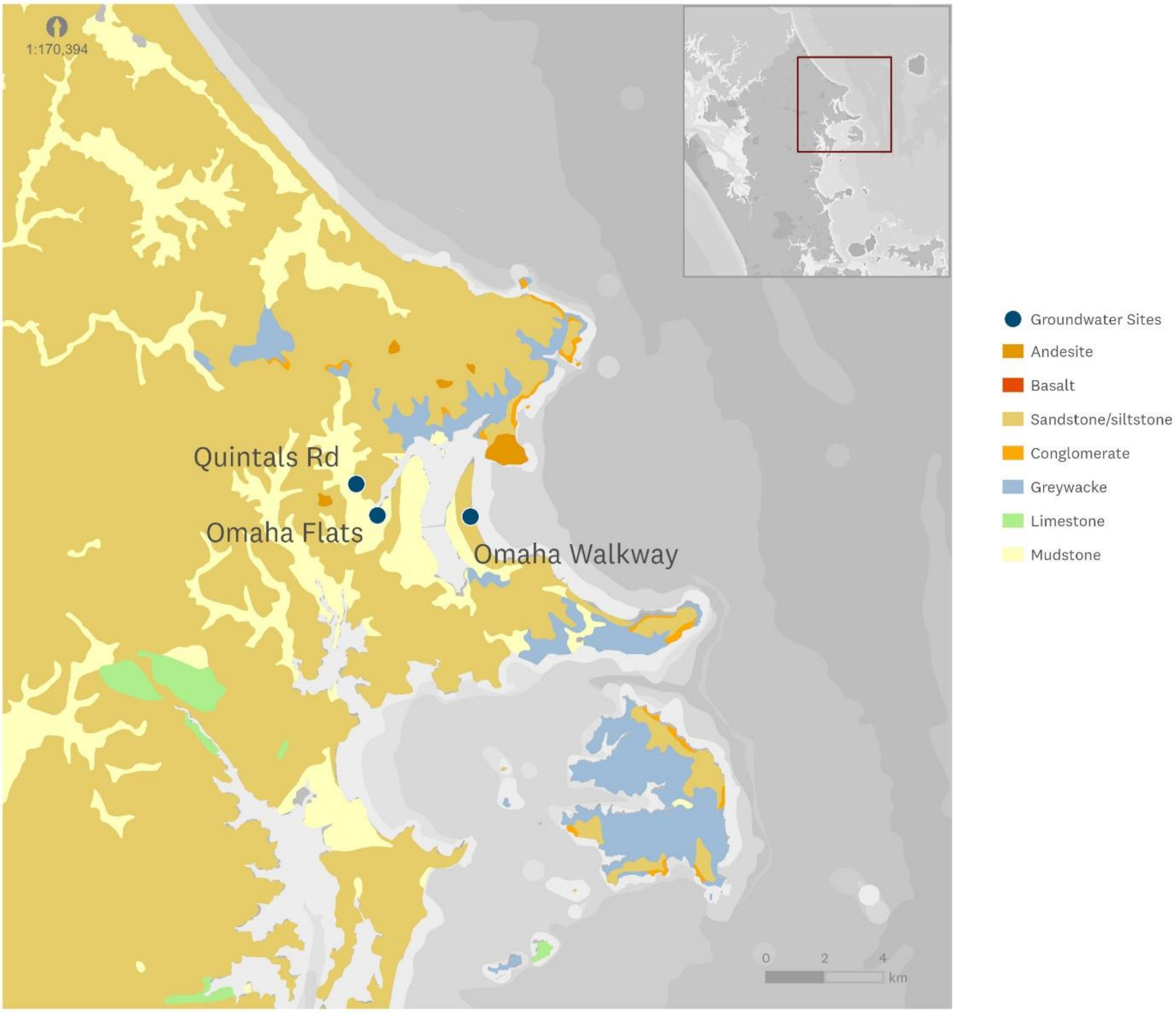

Figure 25: Groundwater quality monitoring sites in the Ōmaha area shown with mapped geology. Location in the context of the Auckland region shown as an inset.

4.5.1 Physical parameters

Dissolved oxygen concentrations and percent saturation were very low (anoxic) at all three sites in the Ōmaha area. Ōmaha Walkway had slightly higher oxygen concentrations and is in the sand aquifer whereas the other two sites are in the Waitematā Group rock aquifer.

pH varied across the three sites, with median values of 6.9 at Quintals Rd, 7.4 at Ōmaha Flats, and 8.1 at Ōmaha Walkway. Temperature was lower at Quintals Rd (median of 17.5 °C) and higher at Ōmaha Flats (18.9 °C) and Ōmaha Walkway (19.2 °C).

Conductivity, total dissolved solids (TDS), and hardness were lower and more variable at Ōmaha Walkway compared to the other two sites. This was likely due to the aquifer's greater connectedness to the surface and its shallow depth (7 m), making these parameters more sensitive to inputs from rainfall recharge—including dilution from 'softer' rainwater in the case of hardness. At the other two sites, which are located in the deeper Waitematā Group rock aquifer, conductivity, TDS, and hardness were more likely influenced by the dissolution of minerals in the surrounding geology.

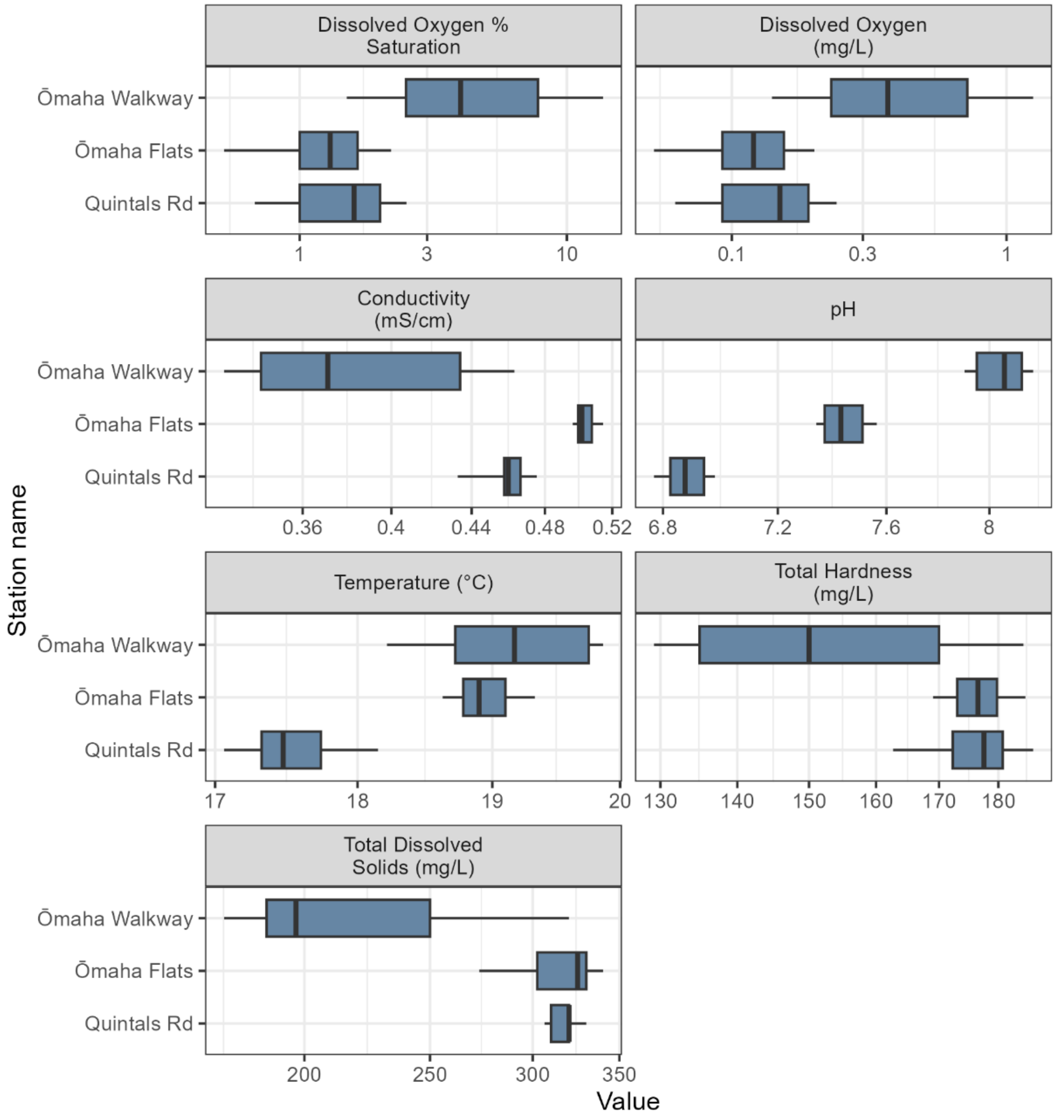

Figure 26: Summary statistics of quarterly results for physical parameters groundwater monitoring sites in the Ōmaha Area from 2020-2014.

4.5.2 Nutrients

At Ōmaha Walkway, ammoniacal nitrogen (NH_4^+) concentrations were below detection limits, while nitrite-N was frequently detected and nitrate-N had a median concentration of 1.3 mg/L. Since ammoniacal-N is the precursor to nitrite-N in the nitrification pathway, it is unusual to observe nitrite-N in the absence of ammoniacal-N in oxygenated conditions. There are possible explanations such as instant nitrification of ammoniacal-N or reduction of nitrate-N to nitrate by certain bacteria in anoxic hotspots, but the complexity of nitrogen cycling dynamics means that a detailed site-specific investigation would be required for clarify the processes occurring here. As observed at other sites across the region, total oxidised nitrogen (TON), dissolved inorganic nitrogen (DIN), and total nitrogen (TN) were largely composed of nitrate-N.

Dissolved reactive phosphorus (DRP) concentrations were within the mid-range of those observed across the region (Figure 27 and Figure 7). Variability was low at Ōmaha Walkway and Ōmaha Flats, but greater at Quintals Rd. It is known that water abstraction from these aquifers has increased significantly in recent years, which may have affected DRP concentrations.

Total phosphorus (TP) concentrations ranged from 0.043 mg/L at Ōmaha Walkway, to 0.092 mg/L at Ōmaha Flats, and 0.14 mg/L at Quintals Rd. The low TP at the Ōmaha Walkway sand aquifer was likely due to lower phosphorus content in the sandstone. In contrast, TP concentrations increased with depth in the Waitematā Group rock aquifers.

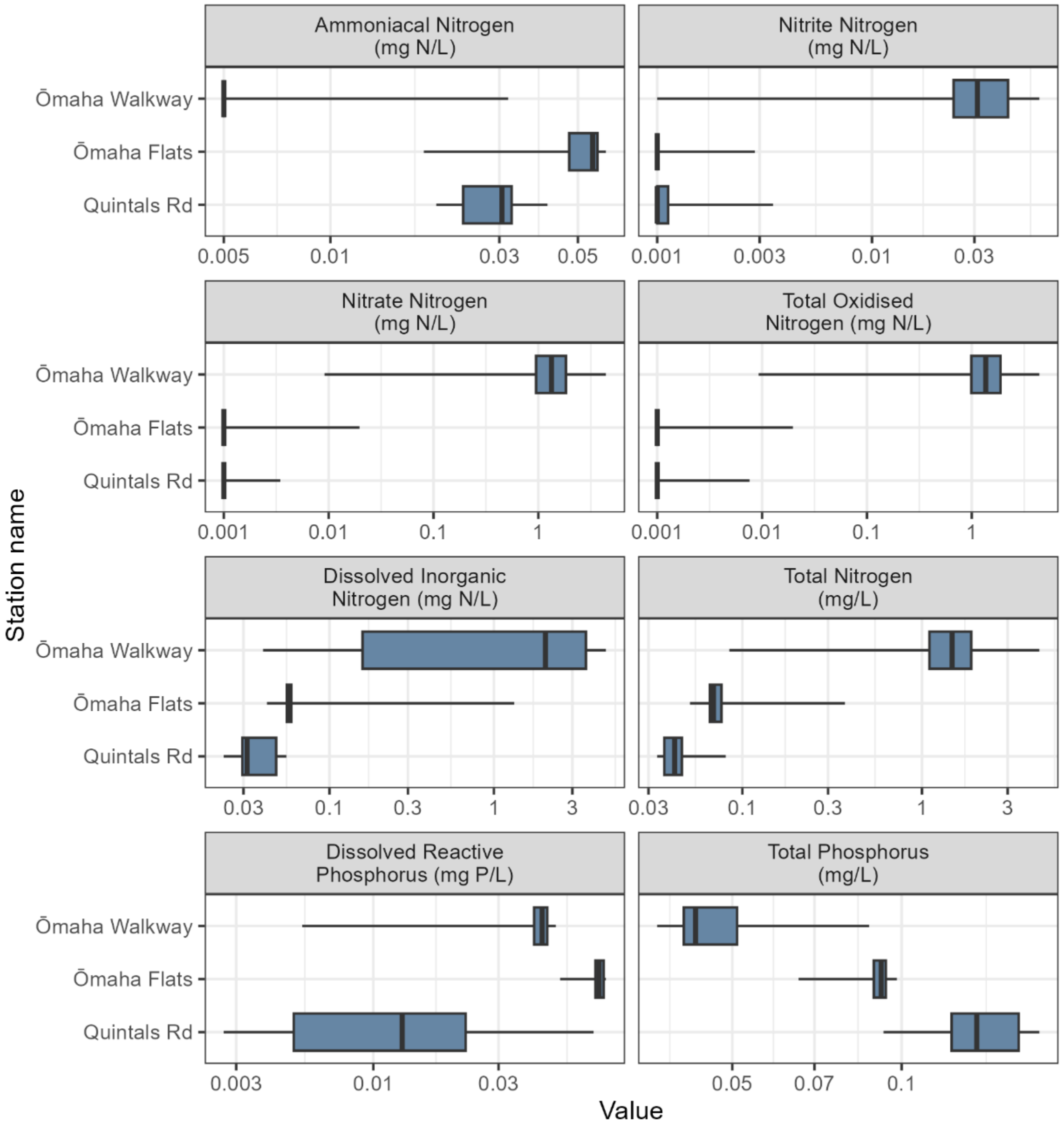

Figure 27: Summary statistics of quarterly results for nutrient (nitrogen and phosphorus) parameters at groundwater monitoring sites in the Ōmaha Area from 2020-2024.

4.5.3 Metals and Ions

Soluble iron was high compared to other sites in the region at Quintals Rd (2 mg/L) and Ōmaha Flats (0.31 mg/L) (both deeper Waitematā Group rock sites). These concentrations were of a similar magnitude to those observed in other sites with Waitematā Group rocks (Table 2-5, Figure 8). A similar pattern was also observed with soluble manganese.

Soluble potassium was higher at Ōmaha Walkway (median of 1.99 mg/L) than at the other two Ōmaha sites (0.47 and 0.53 for Ōmaha Flats and Quintals Rd, respectively), but comparable to concentrations observed at most other unconfined shallow sites in the region (Figure 8).

Sodium was higher at Ōmaha Flats and Quintals Rd than most other sites within Waitematā geology in the region (Figure 8) with little variation. This is likely a reflection of the sedimentary geology. Sodium and chloride are more variable in Ōmaha Walkway due to the relatively quick impacts of rainfall and recharge on the aquifer.

Sulphate is relatively high at all three Ōmaha sites, particularly Ōmaha Walkway and Quintals Rd. This could be due to the mineralogy in the surrounding Waitematā Group rocks, for example gypsum, which has been observed in the Waitematā Group rocks (Martin, 2001) typically contains high levels of soluble sulphate (Hem, 1985)

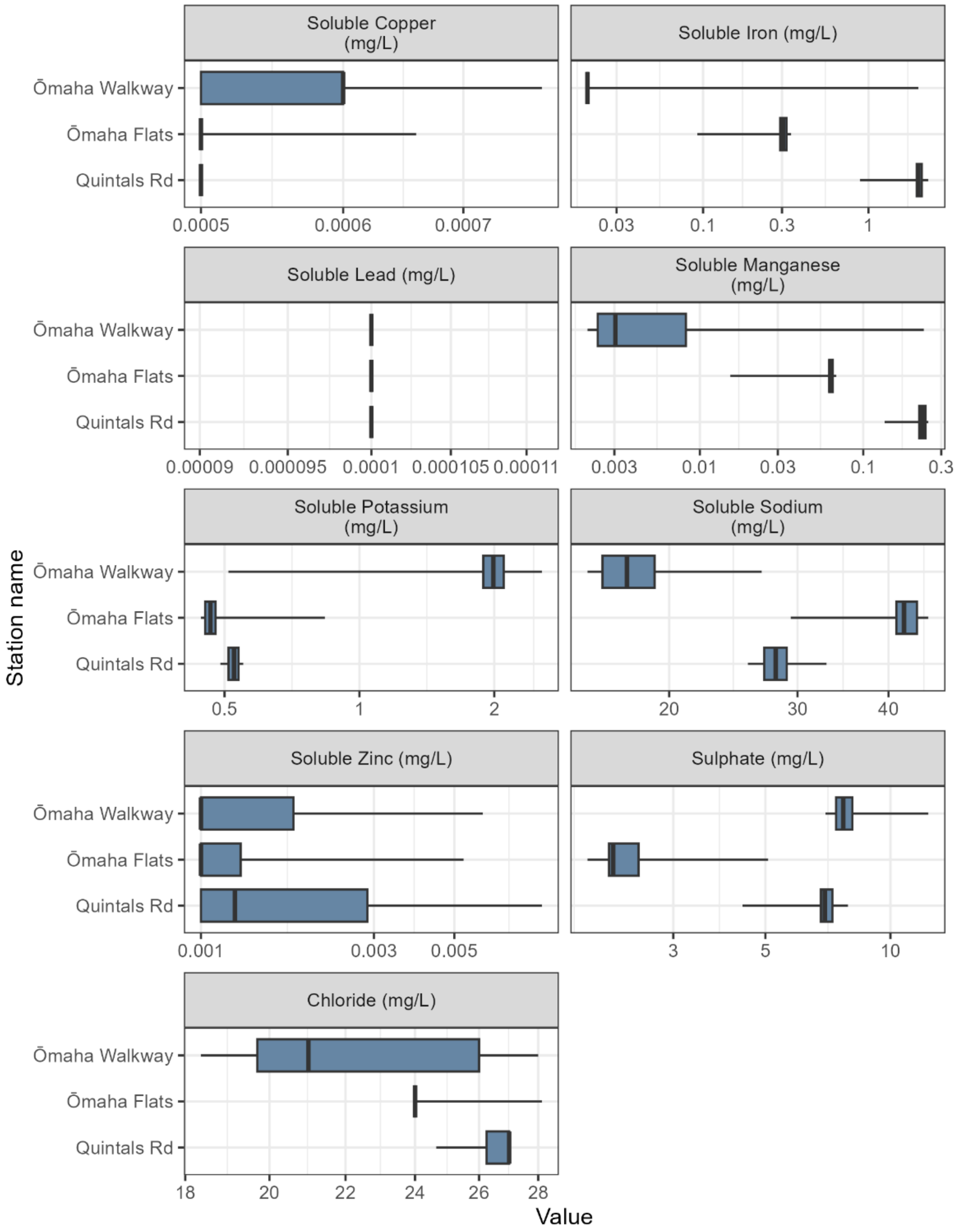

Figure 28: Summary statistics of quarterly results for metal and ion parameters at groundwater monitoring sites in the Ōmaha Area from 2020-2024.

4.5.4 *E.coli*

E. coli concentrations at all three Ōmaha sites were consistently below detection

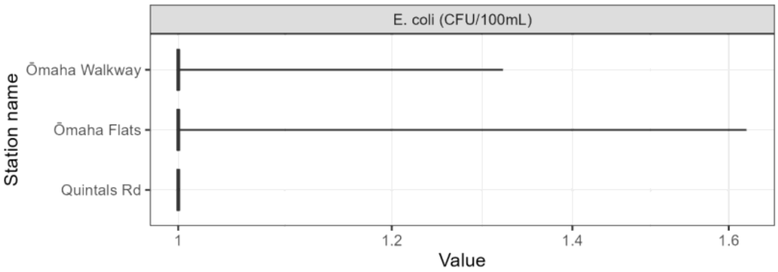

Figure 29: Summary statistics of quarterly results for *E. coli* at groundwater monitoring sites in the Ōmaha Area from 2020-2024.

5 Trends

This section presents trend results for all sites in all areas and is organised by parameter type. Trends are discussed in this report if they have a confidence category of *very likely* or *likely* and the trend magnitude exceeds 1% per year (classed as a meaningful trend). This threshold is an arbitrary one but is chosen because it signals where environmental change may be observed soonest and has been applied in other groundwater quality state and trends assessments (Ministry for the Environment, 2007, Scarsbrook, 2006). All trends of all magnitudes are also presented as a supplementary file available in Appendix 4.

5.1 Regional overview

From a regional perspective, there were slightly more parameters with decreasing trends than increasing trends (Figure 30). While for many parameters this generally indicates a positive environmental shift, many of these trends are of very low magnitude or have a Sen slope of zero (Figure 30).

The physical parameters predominantly show decreasing trends, which reflects an improvement in environmental conditions for most parameters. However, dissolved oxygen (DO) is decreasing at several sites. While declining DO is not inherently a sign of deteriorating water quality—particularly in naturally low-oxygen or anoxic aquifers—it can affect redox conditions, altering the solubility and mobility of other parameters. These physical trends may also indicate changes in hydrology, such as altered flow or recharge patterns and/or be influenced by severe weather events such as the 2020 drought followed by floods in 2023.

Increasing ammoniacal-N concentrations were observed at several deep sites in sedimentary geology. In contrast, there are decreasing nitrate-N trends at a few sites, including four in the shallow basalt aquifers of the Pukekohe area. While this may suggest a positive environmental change, three of these four sites have Sen slopes of zero, indicating that the magnitude of improvement is minimal (Figure 31). Trends in DRP and total phosphorus are mixed across the region, with roughly equal numbers of increasing and decreasing trends. No clear patterns emerge based on geological setting or surrounding land use.

For most metals and ions, trend magnitudes are low, with the majority having a Sen slope of zero due to many data points being below the detection limit (Figure 31). Notable exceptions include increasing soluble iron at three sites in the Pukekohe area, declining soluble zinc, and increasing sodium and sulphate at some Pukekohe and urban sites, including Watson Ave.

It is important to note that Figure 30 and Figure 31 present a summary of all site-parameter trend combinations, including low-magnitude trends that did not meet the threshold for the detailed discussion that follows in Sections 5.2-5.4.

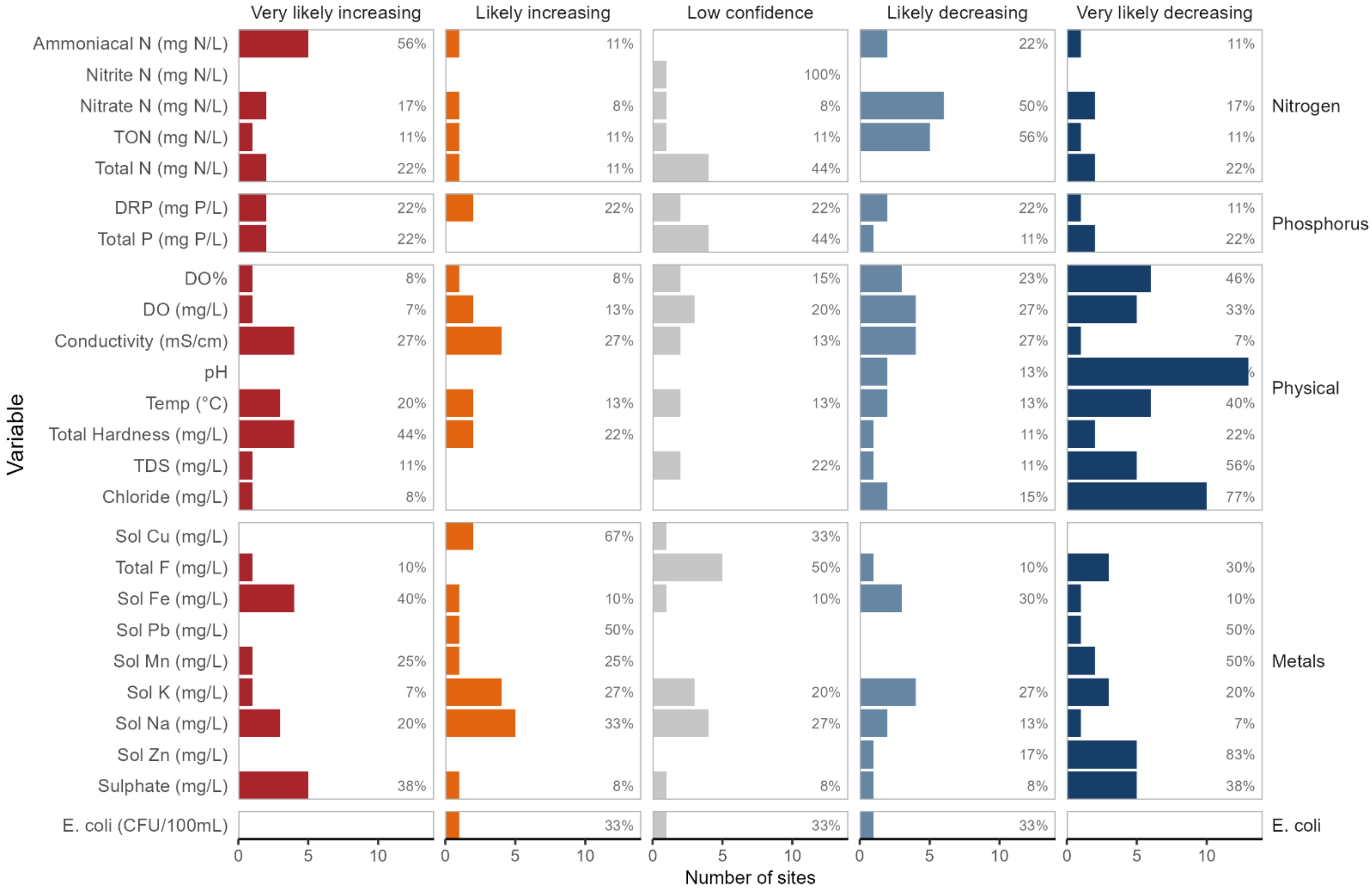

Figure 30: Number of groundwater sites in each trend confidence category for the period 1 July 2017-30 June 2024. The percentage of total (n) sites represented by each bar is shown beside it.

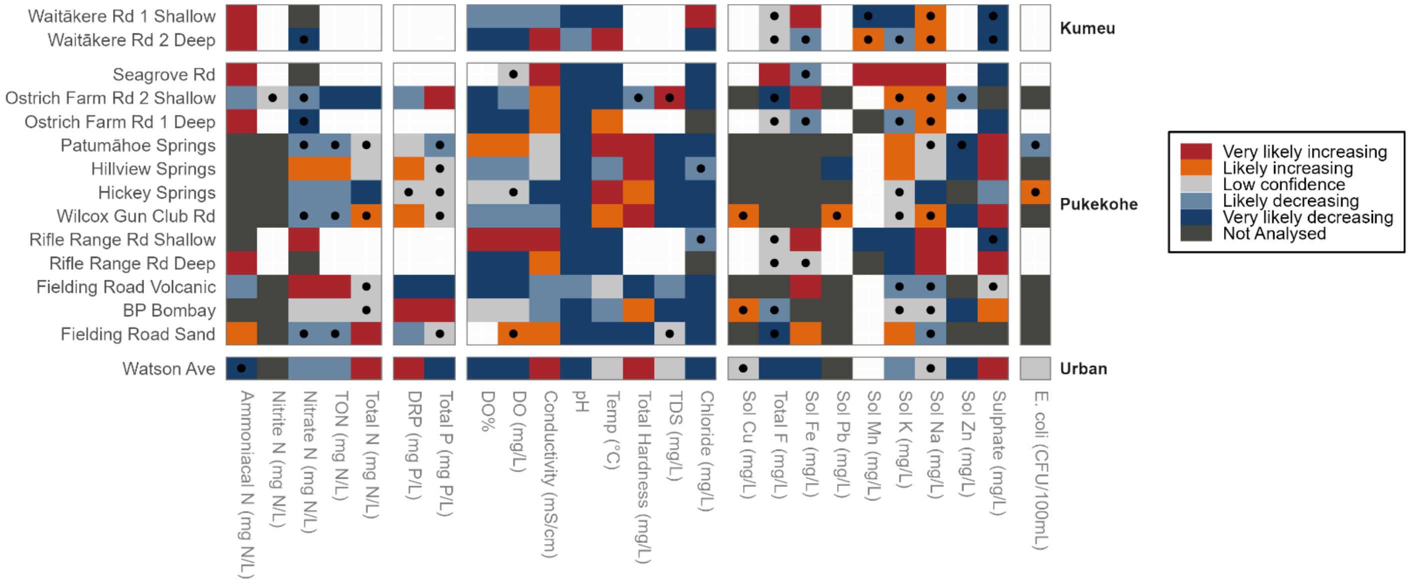

Figure 31: Summary of trend confidence for each site parameter combination. Colours indicate trend confidence. Black dots represent a zero Sen slope.

5.2 Physical parameters

Decreasing trends in dissolved oxygen (both mg/L and percent saturation) were observed at four Pukekohe sites: Ostrich Farm Rd Shallow and Deep, Rifle Range Rd Deep and Fielding Rd Volcanic; and the two Kumeū sites: Waitākere Rd Deep and Shallow. While these trends appeared significant in terms of annual percentage change – up to 50% (Figure 32c,d) the absolute changes were very small, at less than 0.05 mg/L (Appendix 4, supplementary file). Furthermore, all these sites are located in confined and semi-confined aquifers with naturally low oxygen conditions, so the observed decreases of this magnitude do not raise environmental concern. There was also a small (-2.6%/year) decreasing trend in DO at Watson Ave (Urban). This is an oxygenated site that receives stormwater discharge and may represent a decline in water quality, particularly since oxygen is used for many microbial processes that break down contaminants. This trend will continue to be monitored and may require further investigation. There was also an increasing trend in total hardness at this site (2.4%/year) (Figure 32g). While total hardness is low at this site compared to all other sites in the region (Figure 6), this may require investigation of whether stormwater discharges are affecting this trend.

An increasing trend in dissolved oxygen was observed at Rifle Range Rd Shallow (Figure 32c,d). In this case, the opposite pattern was observed where the annual percent change was small, but the absolute change was more notable at 0.15 mg/L or 1.5% saturation (Appendix 4, supplementary file). Rifle Range Rd Shallow is an oxygenated site (median concentration 7.1 mg/L, 72% saturation) so this increasing trend may indicate greater connectedness with the atmosphere. The increasing trend in groundwater level reported at this site for the latest (2010-2019) time period (Johnson, 2021) suggests the increasing DO is more likely to be a function of increased recharge rather than abstraction changing water levels and exposing previously submerged areas to oxygen. In the absence of a more recent trend analysis at this site, the unconfined nature of this aquifer supports the idea that recent high rainfall (2022/2023) may have increased recharge. The increasing DO may indicate a general improvement in water quality, through support for a broader range of aquatic life (e.g. stygofauna) as it provides the oxygen necessary for respiration and other biological processes (Weaver et al., 2024).

Increasing trends in conductivity were observed at Rifle Range Rd Shallow and Seagrove Rd sites. These increases were small, at just over 1% per year (Figure 32e). Conductivity reflects the concentration of dissolved ions in water and can be used as a proxy measure for total dissolved solids (TDS) (Hem, J., 1985). This increase in conductivity was not accompanied by an increasing trend for TDS; instead, four sites – Hillview Springs, Hickey Springs, Patumāhoe Springs and Wilcox Gun Club Rd – showed decreasing trends (Figure 32f). A review of Sen Slope results for longer-term trends (10 and 15-year periods – not presented here as described in Section 3.4.1) for both parameters was undertaken to compare with the seven-year results. These longer-term results showed no meaningful increasing or decreasing trends in conductivity for either period. In contrast, the TDS data showed meaningful decreasing trends at Hillview Spring and Wilcox Gun Club Rd over both 10- and 15-year periods, and at Patumāhoe and Hickey Springs over the 15-year period only. These findings are consistent with the trends shown in Figure 32f. For this reason, we consider the

TDS results to be a more reliable indication of dissolved ion concentrations in groundwater. We suggest that the increasing conductivity trends observed over the seven-year period may be anomalous and should be revisited in future analyses, particularly as longer time series become available.

One meaningful decreasing trend in temperature was observed at the Seagrove Rd site (Figure 32a). This site exhibited the greatest variation in temperature, as discussed in Section 4.2.1. Given its depth (Table 2-5) and physical separation from climatic and weather influences, we would have expected it to show the least variation. Although this trend does not, on its own, indicate either an improvement or degradation in water quality, temperature can influence other parameters, including redox and microbial processes. These, in turn, can affect chemical reaction rates and the solubility of metals, minerals, and gases. For this reason, it will be closely monitored in future trend analyses as longer time series become available.

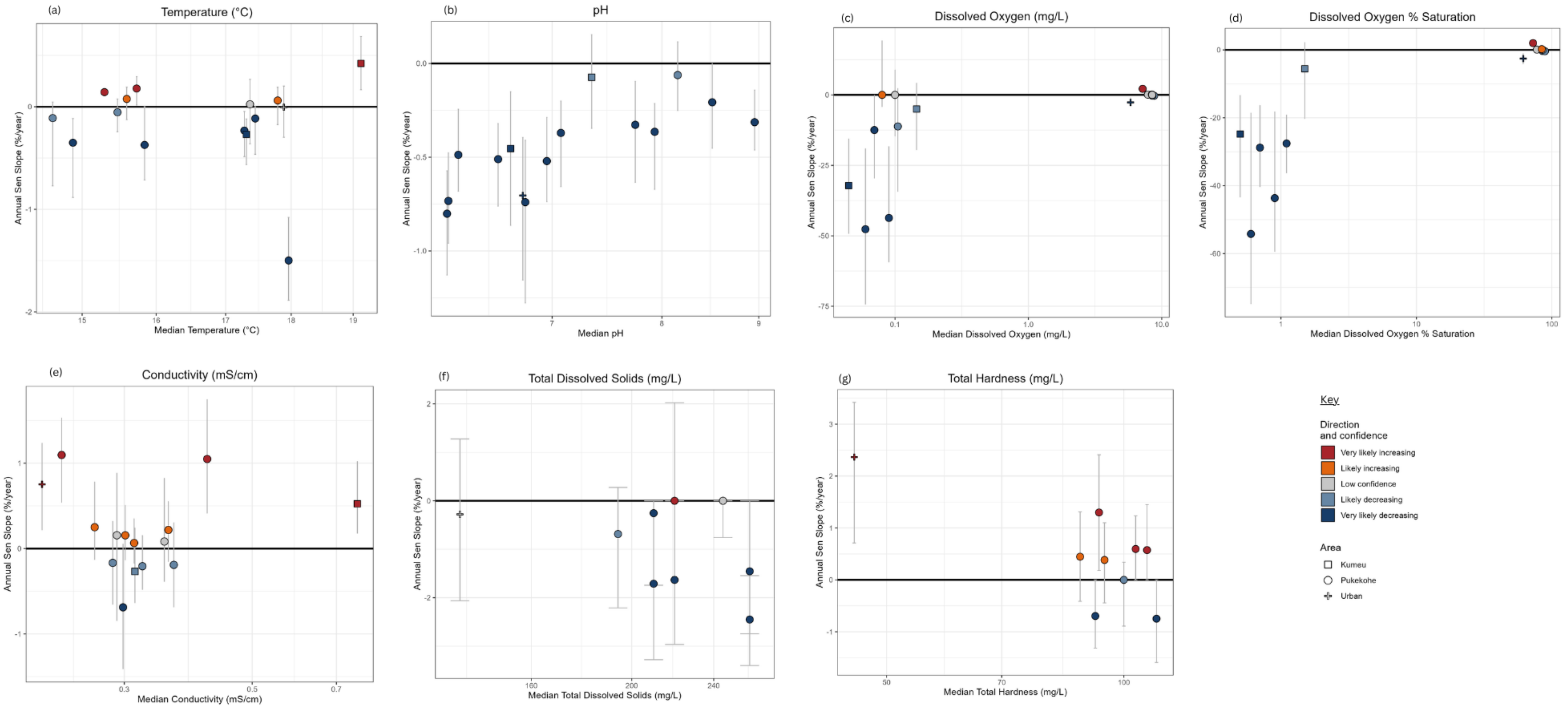

Figure 32: Trend magnitude expressed as annual Sen slope in % change/year (y-axis) vs. median state (x-axis) for: (a) Temperature; (b) pH; (c) Dissolved oxygen concentration (mg/L); (d) Dissolved Oxygen % saturation; (e) Conductivity; (f) Total dissolved solids and (g) Total hardness. Symbols above the zero line indicate increasing trends; those below indicate decreasing trends. Symbols represent individual sites with shapes indicating site location area and colour indicating trend confidence.

5.3 Nutrients

Decreasing trends in ammoniacal-N concentrations were observed at two sites: Ostrich Farm Rd Deep (1.6%/year) and Seagrove Rd (2.0%/year) (Figure 33a). Both sites are located in deep aquifers under deoxygenated (anoxic) conditions. Given there is no other indications of anthropogenic activity affecting these sites, it is likely this trend is due to changes in geological conditions/processes. In any case, the decreasing trend in ammoniacal-N represents an improvement in water quality conditions.

In contrast, increasing trends in ammoniacal-N of a similar magnitude were observed at two Pukekohe sites: Fielding Rd Volcanic (1.2% per year) and Ostrich Farm Rd Shallow (2.2% per year); and the two Kumeū sites, Waitākere Rd Shallow (3.0 % per year) and Waitākere Rd Deep (4.1% per year) (Figure 33a). These sites are all located in anoxic aquifers. These trends are unlikely to result from localised contamination, which would typically cause greater variability in ammoniacal-N concentrations over time (Figure 12). Ammoniacal-N does not leach easily through soil because positively charged ammonium ions bind to negatively charged soil particles (Cameron et al., 2013). Although it can bypass this barrier via preferential flow through macropores, cracks, or fractures, such a process would likely produce sporadic spikes and inconsistent data patterns—again, not observed at these sites (Figure 10).

Although basalt generally contains lower nitrogen content than sedimentary rock (Johnson et al., 2022), the nitrogen it does contain is often present as ammonium ions incorporated within the mineral structure, rather than as organic nitrogen, as the case in sedimentary geology (Stevenson, 1962). Under anoxic conditions, where nitrification is inhibited and adsorption capacity is limited (due to the lower clay content of basalt), ammonium may be released from the rock into groundwater (Johnson et al., 2022). The declining trend in DO also observed at all four of these sites (Figure 32c,d) could explain the increasing ammoniacal-N trends.

At all sites where trends in ammoniacal-N were observed (increasing and decreasing), the background concentrations were low. The declining trends do not necessarily indicate a meaningful improvement in water quality, but nor do the increasing trends raise environmental concern. However, continued increases over time could pose a future environmental risk, so this should continue to be monitored.

An increasing trend in nitrate-N was observed at the Fielding Rd Volcanic site (11.4% per year, equivalent to 0.0008 mg/L per year) (Figure 33b). This bore was located in the deeper basalts, which are characterised by anoxic conditions and currently low nitrate concentrations (2020-2024 median: 0.007 mg/L) (Figure 10, Figure 12). The increasing trend was most likely due to vertical leakage of comparatively nitrate-rich water from the overlying aquifers (White et al., 2019; Morgenstern et al., 2023). Despite the low background concentration and small absolute increase, the high percentage change signals a concerning level of environmental degradation. The previous Groundwater State and Trend analysis (Foster and Johnson, 2021) reported a decreasing trend (“improving”) in nitrate-N at this site, but it later clarified the trend magnitude didn’t meet the “limit of precision threshold”

(>0.001 mg/L/yr). That trend would not have been identified as meaningful in this report. There was no trend in nitrate observed at this site in Kalbus (2016).

Another increasing trend in nitrate-N (3.2% per year, equivalent to 0.3 mg/L per year) was observed at Rifle Range Rd Shallow. This site is located in the shallow basalts, where nitrate concentrations are already high (median: 10.5 mg/L) (Figure 7, Figure 12). Although Rifle Range Rd Shallow lies near the Pukekohe basalt aquifer, the groundwater is older (c. 40 years), about twice the age of groundwater from nearby sites such as Wilcox Gun Club Rd (c. 19 years) and Patumāhoe Springs (c. 17 years), both known to discharge from the shallow Pukekohe basalt lava (Morgenstern et al., 2023). Nitrate concentrations at Rifle Range Rd Shallow were also lower than at Wilcox Gun Club Rd (25 mg/L) and Patumāhoe Springs (23 mg/L). These differences suggest that groundwater at Rifle Range Rd Shallow may receive recharge from a different source than the nearby sites and/or possibly receives vertical leakage of nitrate-rich water from the Pukekohe basalt itself. Since this aquifer is more confined, it takes longer for enough nitrate-rich water to increase concentrations, hence the lower concentrations compared to the unconfined aquifers around it. This may also explain the increasing nitrate concentrations at this site, while no similar trend was observed at the other Pukekohe basalt locations (Figure 33b).

As discussed in Section 4.2.2, TON (a calculation of nitrate-N + nitrite-N) is heavily influenced by the nitrate-N component, as nitrite-N is negligible in almost all cases. Therefore, the trends observed for TON reflect nitrate and have been discussed above. One exception is a decreasing trend in TON at Ostrich Farm Rd Shallow (-7% per year) (Figure 33c). This represented a very small concentration change (0.0002 mg/L per year) and is a result of a few detections of nitrite at this site near the start of the trend period (see Figure 12 in Section 4.2.2).

An increasing trend in total N was observed at Watson Ave (urban). There were no similar trends in the inorganic forms of N at this site (ammoniacal-N, nitrite-N or nitrate-N). Therefore, this is most likely due an increase in the amount of organic N from increased organic matter entering the aquifer via stormwater discharge.

At Ostrich Farm Rd Shallow, there was a decreasing trend in DRP (-7% per year) (Figure 33e) and an increasing trend in total P (2.6 % per year) (Figure 33f). This suggests a shift from dissolved forms of phosphorus to bound or precipitated forms. The increasing trend in soluble iron (Figure 34a) and decreasing trend in DO (Figure 32c, d) at this site may play a role here. Lower DO supports the reduction of ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), which can then react with phosphorus to form insoluble iron-phosphate minerals (McLaren & Cameron, 1996), thus reducing the dissolved fraction of phosphorus and increasing the solid fraction. This explanation is supported by increasing trends in soluble iron concentrations (Figure 34a) and decreasing trends in DO (Figure 32c, d) also observed at this site.

At Fielding Rd Volcanic (also in the Pukekohe area) there was a decreasing trend in DRP (-3.9% per year) (Figure 33e) and a decreasing trend in total P (-5.2 % per year) (Figure 33f). This signals a decline in the total amount of phosphorus in the aquifer. These trends were also observed in the last two state and trend analyses (Foster and Johnson, 2021; Kalbus et al., 2016). It may be a result of changes to land use and management over time in this area. It is generally uncommon for DRP to leach through the soil profile, as it tends to bind to soil particles before it can percolate into the groundwater system. However, soils in these vegetable production areas have elevated Olsen P (a measure of plant available P) levels (Guinto et al., 2025). When soils become effectively saturated with phosphorus, the potential for leaching increases (McLaren & Cameron, 1996), which may have occurred in the past. It is possible that improvements to fertiliser management in this area in recent decades could have halted or slowed this process, and resulted in the decreasing DRP and total P concentrations.

An increasing trend in DRP was observed at Watson Ave (5.6% per year) (Figure 33e). This could be due to an increase in the levels of P in stormwater over time, which is discharged into the aquifer. There could also be a shift in the form of phosphorus present in the groundwater from insoluble forms towards more soluble (and bioavailable) DRP. This is supported by the decreasing trend in Total P at this site (Figure 33f). There are many potential sources of phosphorus in urban areas such as this, including industrial discharges, road dust (tyre wear and exhaust), runoff from construction sites, litter, animal waste, and car and house wash run off (Yang & Lusk, 2018). While changes in recent land use, such as new industrial activity, increased construction activity and increased traffic volume may explain some of the increasing DRP trend, the decreasing total P trend can only be explained by a reduction in particulate-associated phosphorus entering the aquifer, or an increase in the rate or amount of adsorption within the aquifer.

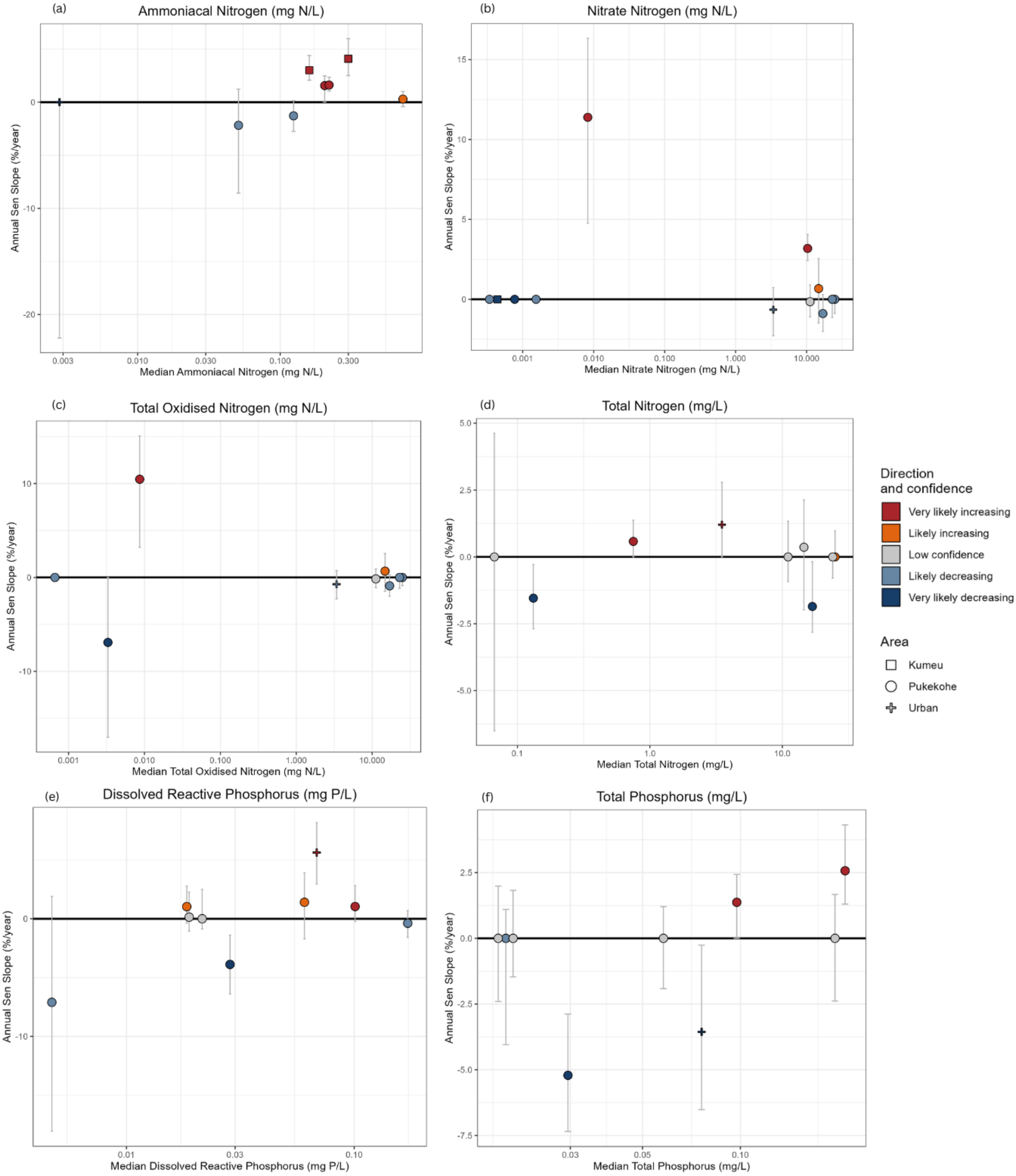

Figure 33: Trend magnitude expressed as annual Sen slope in % change/year (y-axis) vs. median state (x-axis) for: (a) Ammoniacal N; (b) Nitrate N; (c) Total oxidised N; (d) Total N; (e) Dissolved reactive P and (f) Total P. Symbols above the zero line indicate increasing trends; those below indicate decreasing trends. Symbols represent individual sites with shapes indicating site location area and colour indicating trend confidence.

5.4 Metals and Ions

Despite the higher lead concentrations observed at the Wilcox Gun Club Rd site compared to other sites, the likely increasing trend detected at this site had a sen slope of zero. In the previous two Auckland Groundwater State and Trends reports (Foster and Johnson, 2021; Kalbus et al., 2017), soluble lead was not analysed.

Increasing trends in soluble iron were observed at three Pukekohe sites: Rifle Range Rd Shallow (11% per year), Fielding Rd Volcanic (11.5% per year), and Ostrich Farm Rd Shallow (1.3% per year) (Figure 19a). Although the annual percentage increase at Ostrich Farm Rd Shallow was the smallest, the concentration increased by 0.045 mg/L per year—an order of magnitude higher than the other sites in absolute terms (Appendix 4, supplementary file). These three sites are located in different aquifers with varying geological compositions: shallow basalt, deep basalt, and sedimentary, respectively. The same trend was observed at Fielding Rd Volcanic by Foster and Johnson (2021) and Kalbus et al. (2016); and at Ostrich Farm Rd Shallow by Foster and Johnson (2021) only (noting the laboratory change may have affected trend results in that study).

The bore caps and collars at all three sites are in a corroded state and general poor condition. While it is possible corrosion may have entered the well casing during sampling, this should have been removed with the purging process, so is unlikely to be the cause for these trends. These well caps and collars are scheduled for replacement in 2025. The cap at Rifle Range Rd Shallow is in better condition, although corrosion remains a possibility here.

The low oxygen conditions at Fielding Rd Volcanic and Ostrich Farm Rd Shallow supports the presence of iron in its reduced and dissolved form (Fe^{2+}) and the decreasing trend in DO at these sites (Figure 32c) may also support the increasing trend. The same is not true for Rifle Range Rd Shallow, which has high oxygen levels and an increasing trend in DO (Figure 32c).

Decreasing trends in soluble iron and soluble zinc were observed at Watson Ave (Figure 34a,c). The site is well oxygenated, which supports the presence of iron in the non-soluble oxidised form (Fe(III)) and the adsorption of zinc onto iron surfaces (Dzomback and Morel, 1990) but does not explain the trends. The most likely reason for these trends is either: (1) a reduction of contamination of iron and zinc in the surrounding environment and therefore a reduction in the amount entering the groundwater via stormwater discharge; or (2) dilution of these contaminants by higher levels of recharge due to the higher than usual rainfall that occurred in Auckland during the 2022/2023 period (Auckland Council, 2025).

There were declining trends in soluble zinc at BP Bombay (-14.4% per year), Hillview Springs (-8.4 per year) and Wilcox Gun Club Rd (-11.7% per year). With zinc concentrations being at a low baseline, these changes were small (0.002-0.0005 mg/L per year) (Appendix 4, supplementary file). These sites are all located in shallow basalt aquifers (BP Bombay and Hillview Springs in the Bombay basalt and Wilcox Gun Club Rd in the Pukekohe basalt) and are oxygenated.

There was a decreasing trend in soluble manganese observed at Rifle Range Shallow (Figure 34b). However, this site has some of the lowest concentrations for this parameter. The trend analysis was influenced by left-censored values, which increases the uncertainty in the trend magnitude.

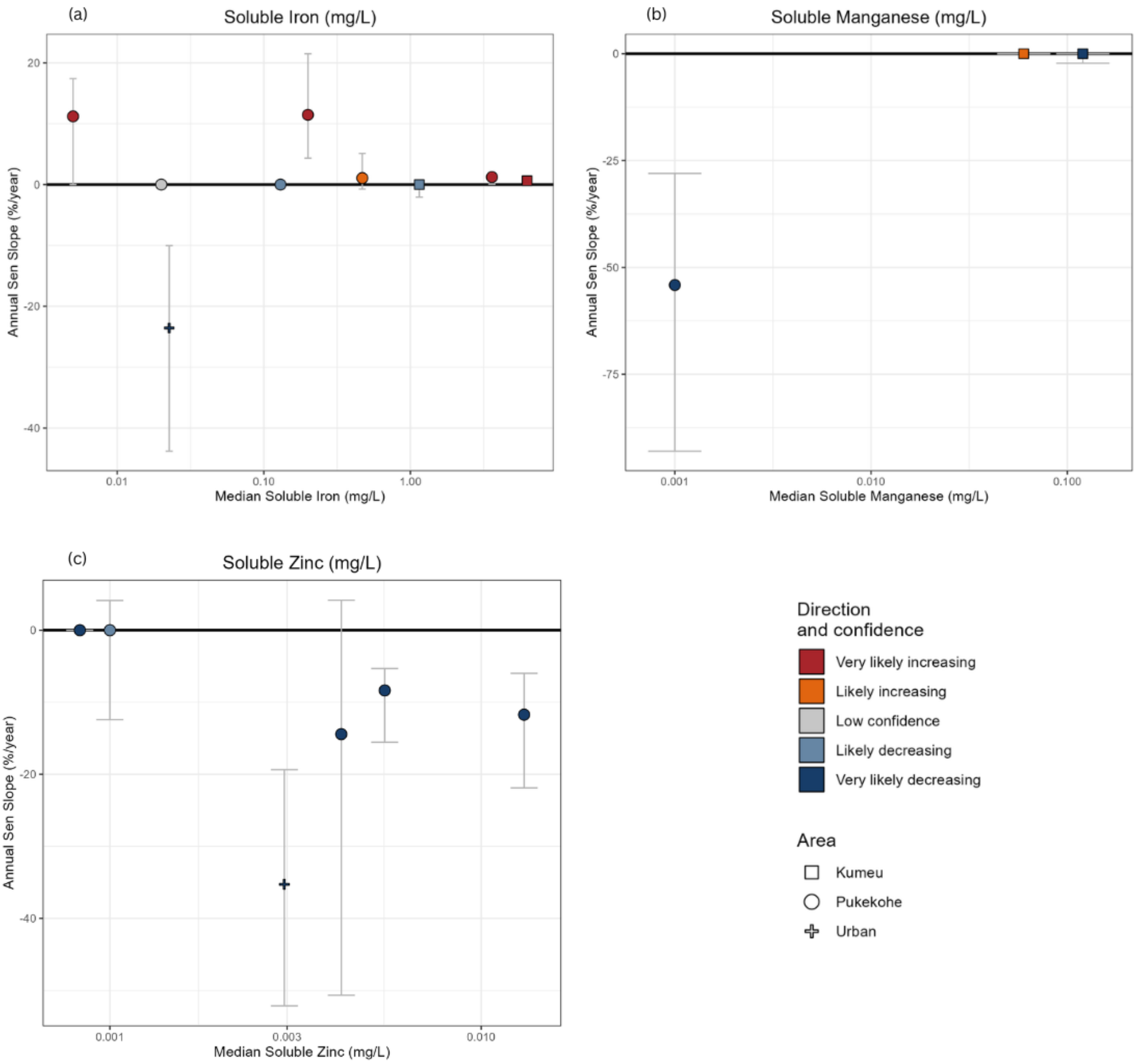

Figure 34: Trend magnitude expressed as annual Sen slope in % change/year (y-axis) vs. median state (x-axis) for: (a) Soluble iron; (b) Soluble manganese and (c) soluble zinc. Symbols above the zero line indicate increasing trends; those below indicate decreasing trends. Symbols represent individual sites with shapes indicating site location area and colour indicating trend confidence.

Increasing trends in sulphate were observed at BP Bombay, Hillview Springs, Patumāhoe Springs, Rifle Range Deep, and Wilcox Gun Club Rd (Figure 35b). All of these sites are located in shallow basalt aquifers, except for Rifle Range Deep, which is situated in the deep basalts. It is unlikely this is due to anthropogenic land use such as fertiliser application because if this were the case, similar trends would be expected at the other shallow basalt sites. Another possible explanation is sulphate release from basalt weathering processes (Appelo & Postma, 2005).

At Seagrove Rd, a decreasing trend in chloride (-2.9% per year), an increasing trend in sodium (1% per year), and an increasing trend in soluble potassium (1.73% per year) were observed (Figure 35a,c,d). Given this site's proximity to the Manukau Harbour, the rise in sodium might suggest saltwater intrusion, but the decreasing trend in chloride doesn't support this (Figure 35d). The increasing potassium concentration is unlikely to be a result of fertiliser application, as this would typically coincide with elevated nitrate levels due to leaching, which is not observed, leaving these trends unexplained.

There was a small decreasing trend in chloride at Watson Ave. Since chloride does not readily react or degrade in groundwater (a conservative tracer) (Hem, 1985), this trend could be a reflection of altered recharge/dilution patterns due to the higher than usual rainfall over the 2022/2023 period (Auckland Council, 2025), as with the declining trends in iron and zinc described above.

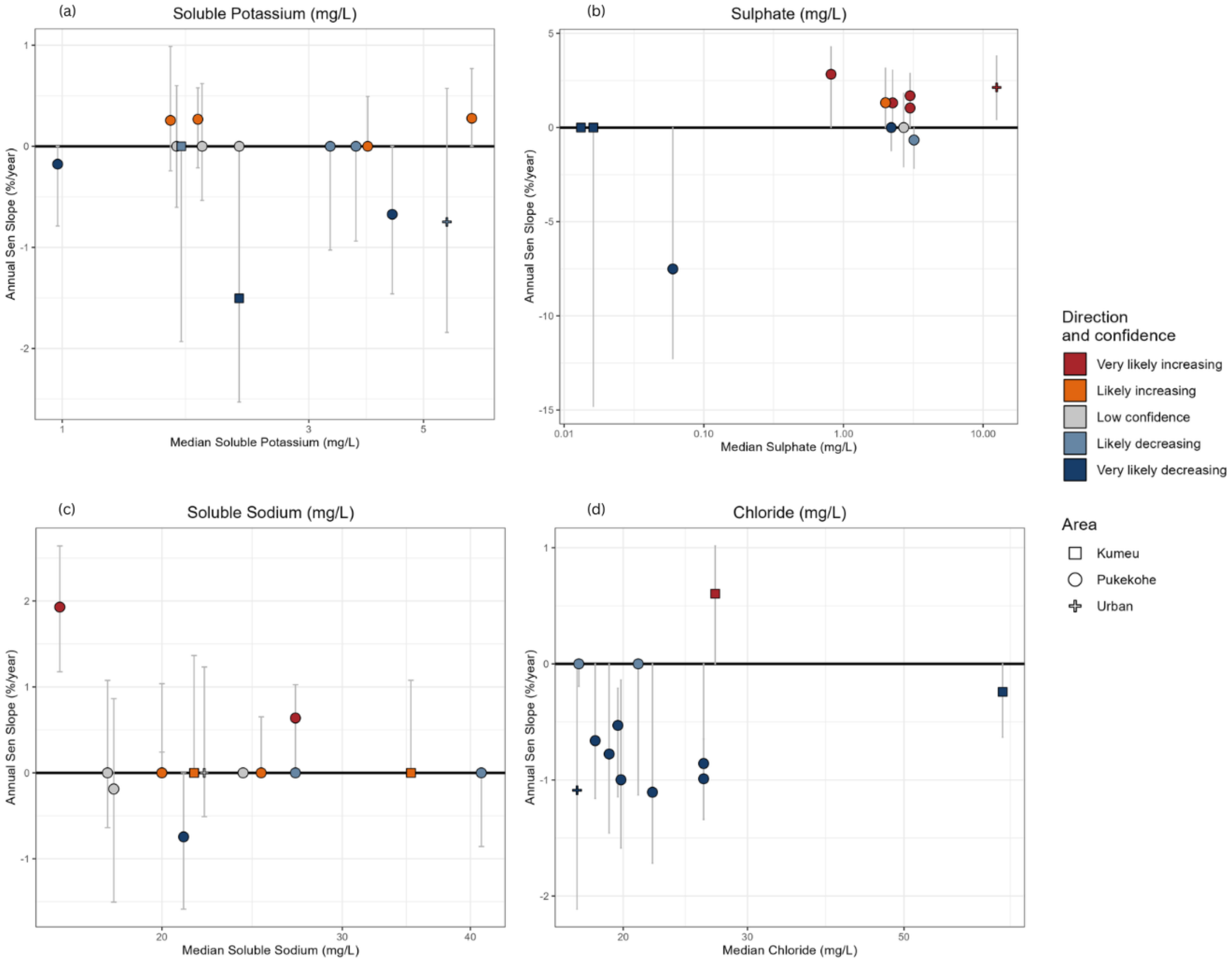

Figure 35: Trend magnitude expressed as annual Sen slope in % change/year (y-axis) vs. median state (x-axis) for: (a) Soluble potassium; (b) Sulphate; (c) Soluble sodium and (d) Chloride. Symbols above the zero line indicate increasing trends; those below indicate decreasing trends. Symbols represent individual sites with shapes indicating site location area and colour indicating trend confidence.

6 Summary

This report has provided an overview of the current state of groundwater quality and assessed trends over the most recent seven-year period (2017-2024). Groundwater quality was generally good across the region, however there were some key localised pressures and issues:

Nitrate contamination in Pukekohe Area

High nitrate concentrations in the shallow basalt aquifers and springs of the Pukekohe area remain a significant environmental concern. Median nitrate-N levels reach up to 25 mg/L, exceeding the drinking water Maximum Acceptable Value (MAV) of 11.3 mg/L, and reflect long-term impacts of intensive horticultural land use. These aquifers also contribute baseflow to local streams, some of which exceed national toxicity thresholds for ecosystem health. No trends were observed at high-nitrate sites, suggesting levels are stable but not improving. Due to long mean residence times in these aquifers (18-36 years), any improvements in nitrate levels that do occur in the future will take decades to become evident.

Potential lead source in Pukekohe Area

Elevated soluble lead concentrations at the Wilcox Gun Club Rd site may be linked to historical and ongoing target shooting activities. The Auckland Metropolitan Clay Target Club, located within the aquifer's recharge zone and 3 km from the monitoring site, is a possible source. Lead contamination from spent ammunition is well documented at shooting ranges, where lead particles accumulate in soil and can, over time, leach into shallow groundwater. While concentrations remain below drinking water standards, there was a likely increasing trend (albeit with a sen slope of zero). This may indicate a potential legacy contamination issue and warrants further investigation.

Contamination pathways in urban aquifers

In the urban isthmus aquifers, stormwater discharge via soak pits creates a direct connection between surface and groundwater. This is reflected in elevated *E. coli* concentrations, particularly at Watson Ave, suggesting a consistent contamination source. Alfred St also shows elevated lead levels, though insufficient data prevents trend analysis. Elevated nitrate levels—though lower than in Pukekohe—are likely introduced via regular stormwater discharge events to the aquifers. Low total hardness, chloride, conductivity, and TDS values are common in basalt geology, but are also likely to be influenced by dilution from frequent rainfall and stormwater inputs.

Elevated and increasing soluble iron concentrations

Higher soluble iron (and manganese) levels were found at almost all sites underlain by sedimentary geology with anoxic conditions. Dissolved oxygen (DO) levels influence iron and manganese solubility, explaining these observations. Increasing trends were observed at three sites (all in the Pukekohe area). In some cases, declining DO trends supported the observed trends, but this is not consistent across all sites, suggesting additional or alternative contributing factors.

Influence of background geology

The local geology (and oxygen levels) are likely to be influencing the variability in soluble metals and ion concentrations (e.g., iron, manganese, zinc, lead, potassium). However, without site-specific geological investigations—currently outside the scope of the monitoring programme—these interpretations remain speculative. Supplementary analysis of total concentrations for selected parameters could provide additional context and support more detailed evaluations of future results.

7 Acknowledgements

Auckland Council's groundwater quality monitoring programme has benefited from the efforts of numerous people since its inception. We acknowledge the efforts from members of the environmental teams within Auckland Council for their help with undertaking the sampling, with special thanks to Julia O'Grady and Gina Gascoigne.

Thanks to Kylie Robertson and Jade McMurtry for data management and quality assurance processes.

Thanks to both RJ Hill Laboratories and Watercare Services Ltd for their services in laboratory analysis of these samples.

Thanks to Caroline Fraser of LWP Ltd for undertaking the State and Trend analysis and production of graphics.

Thank you to Jenni Gadd, Sietse Bouma and Andrew Millar, Nicki Wilson and Caroline Fraser for providing review, comments and suggestions that improved this report.

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Appendix 1: Site information

Table A1- 1: Site I.D and location information for current sites in the Groundwater Quality Programme

Site Name	Station number	Latitude	Longitude	X	Y	SOE/ NGMP	Aquifer
Fielding Road Volcanic	7419009	-37.114	174.963	1774447	5890664	SOE	Franklin Volcanic Deep (Drury/Bombay)
Fielding Road Sand	7419007	-37.114	174.963	1774443	5890653	SOE	Franklin Sand (Drury/Bombay)
Wilcox Gun Club Rd	7428031	-37.204	174.852	1764324	5880929	SOE	Franklin Volcanic Shallow
Patumāhoe Shallow	7432003	-37.189	174.829	1762311	5882633	SOE	Franklin Volcanic Shallow
Rifle Range Rd Shallow	7428110	-37.203	174.873	1766250	5880967	NGMP	Franklin Volcanic Shallow
BP Bombay	7419121	-37.193	174.982	1775891	5881877	SOE	Franklin Volcanic Shallow
Hickey Springs	7419127	-37.193	174.901	1768720	5882057	SOE	Franklin Volcanic Shallow
Hillview Springs	7419126	-37.171	174.985	1776245	5884311	SOE	Franklin Volcanic Shallow
Patumāhoe Springs	43915	-37.129	174.848	1764114	5889239	SOE	Franklin Volcanic Shallow
Rifle Range Rd Deep	7428103	-37.203	174.873	1766258	5880972	NGMP	Franklin Volcanic Deep
Ostrich Farm Rd 2 Shallow	7418023	-37.165	174.870	1766027	5885160	SOE	Franklin Kaawa
Ostrich Farm Rd 1 Deep	7418027	-37.166	174.870	1766016	5885089	NGMP	Franklin Kaawa
Patumāhoe Deep	7432001	-37.189	174.829	1762310	5882631	SOE	Franklin Kaawa
Seagrove Rd	7417021	-37.131	174.756	1756024	5889134	NGMP	Waiau Pā Waitematā
Watson Ave	6487015	-36.884	174.738	1754847	5916559	SOE	Three Kings Volcanic
Alfred St	6497007	-36.917	174.794	1759789	5912783	SOE	Onehunga Volcanic
Waitākere Rd 1 Shallow	6475015	-36.782	174.560	1739213	5928139	NGMP	Kumeū West Waitematā
Waitākere Rd 2 Deep	6474003	-36.784	174.559	1739082	5927989	NGMP	Kumeū West Waitematā
Ōmaha Walkway	6437130	-36.338	174.779	1759657	5977107	SOE	Ōmaha Sand
Quintals Rd	6437005	-36.328	174.735	1755760	5978227	SOE	Ōmaha Waitematā
Ōmaha Flats	6437021	-36.338	174.744	1756485	5977154	SOE	Ōmaha Waitematā

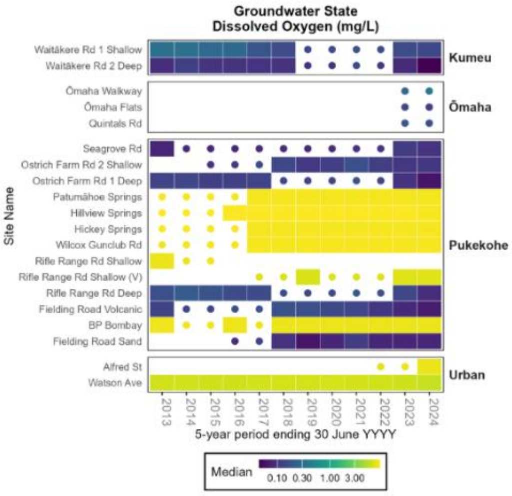
Appendix 2: Laboratory analytical methods for water quality parameters

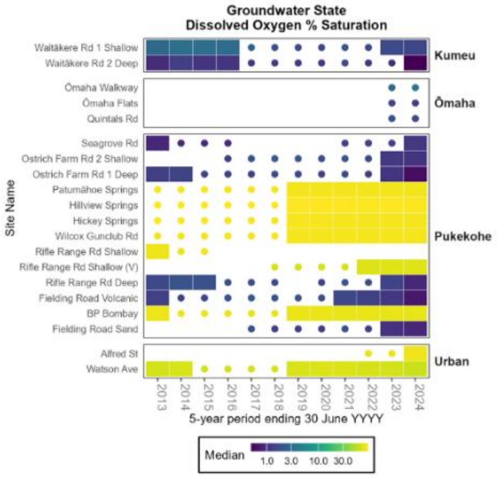
Table A2- 1: Water Quality parameters and analytical methods for the Groundwater Quality Programme

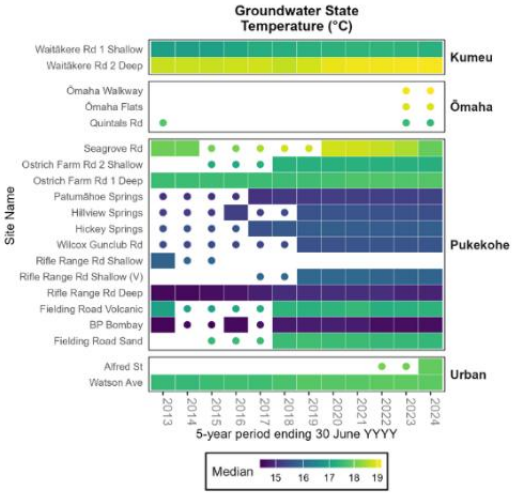
Test	Method description	Default detection limit
Meq/L Difference in Ion Balance	Calculation from Sum of Anions and Cations. Please note: The result reported for the 'Meq/L Difference in Ion Balance' is an absolute difference between the 'Sum of Anions' and 'Sum of Cations' based on the formula taken from APHA. This does not indicate whether the 'Sum of Anions' or the 'Sum of Cations' produced a higher value. APHA 1030-E 23rd ed 2017.	0.10 meq/L
Total anions for anion/cation balance check	Calculation: sum of anions as mEquiv/L calculated from Alkalinity (bicarbonate), Chloride and Sulphate. Nitrate-N, Nitrite-N. Fluoride, Dissolved Reactive Phosphorus and Cyanide also included in calculation if available. APHA 1030 E Online edition.	0.07 meq/L
Total cations for anion/cation balance check	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH (H+) also included in calculation if available. APHA 1030 E Online edition.	0.05 meq/L
% Difference in Ion Balance	Calculation from Sum of Anions and Cations. Please note: The result reported for the '% Difference in Ion Balance' is an absolute difference between the 'Sum of Anions' and 'Sum of Cations' based on the formula taken from APHA. This does not indicate whether the 'Sum of Anions' or the 'Sum of Cations' produced a higher value. APHA 1030 E Online edition.	0.10%
Turbidity	Analysis by Turbidity meter. APHA 2130 B Online edition (modified).	0.05 NTU
pH	pH meter. APHA 4500-H+ B Online edition. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (modified for Alkalinity <20) Online edition.	1.0 g/m3 as CaCO3
Carbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D Online edition.	1.0 g/m3 at 25°C
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D Online edition.	1.0 g/m3 at 25°C
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B Online edition.	1.0 g/m3 as CaCO3
Total Dissolved Solids (TDS)	Filtration through GF/C (1.2 µm), gravimetric. APHA 2540 C (modified; drying temperature of 103 - 105°C used rather than 180 ± 2°C) Online edition.	10 g/m3
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.05 g/m3
Dissolved Copper	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.0005 g/m3
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.02 g/m3
Dissolved Lead	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.00010 g/m3

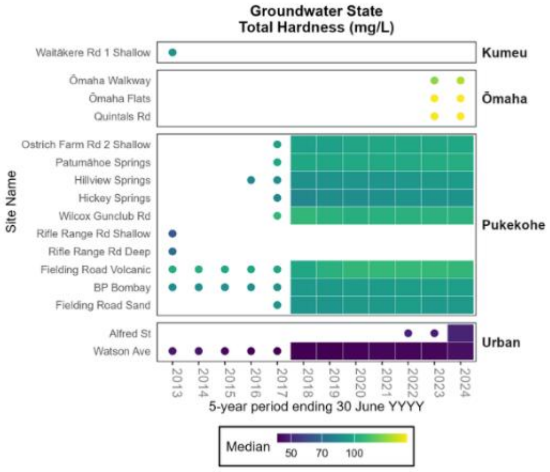
Test	Method description	Default detection limit
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.02 g/m3
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.0005 g/m3
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.05 g/m3
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.02 g/m3
Dissolved Zinc	Filtered sample, ICP-MS, trace level. APHA 3125 B Online edition.	0.0010 g/m3
Bromide	Filtered sample. Ion Chromatography. APHA 4110 B (modified) Online edition.	0.05 g/m3
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified) Online edition.	0.5 g/m3
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F- C Online edition.	0.05 g/m3
Dissolved Inorganic Nitrogen*	Calculation: NH4-N + NO3-N + NO2-N. In-house calculation.	0.005 g/m3
Total Nitrogen	Alkaline persulphate digestion, automated Cd reduction/sulphanilamide colorimetry. APHA 4500-N C & 4500-NO3- I (modified) Online edition.	0.010 g/m3
Total Ammoniacal-N Trace	Phenol/hypochlorite colorimetry. Flow injection analyser. (NH4-N = NH4+- N + NH3-N). APHA 4500-NH3 H Online edition.	0.005 g/m3
Nitrite-N Trace	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3 - I (modified) Online edition.	0.0010 g/m3
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House	0.0010 g/m3
Nitrate-N + Nitrite-N Trace	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO3 - I (modified) Online edition.	0.0010 g/m3
Dissolved Reactive Phosphorus (trace)	Filtered sample. Molybdenum blue colorimetry. Flow injection analyser. APHA 4500-P G Online edition.	0.0010 g/m3
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H (modified) Online edition.	0.002 g/m3
Reactive Silica	Filtered sample. Heteropoly blue colorimetry. Flow Injection Analyser. APHA 4500-SiO2 F (modified) Online edition.	0.10 g/m3 as SiO2
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) Online edition.	0.5 g/m3

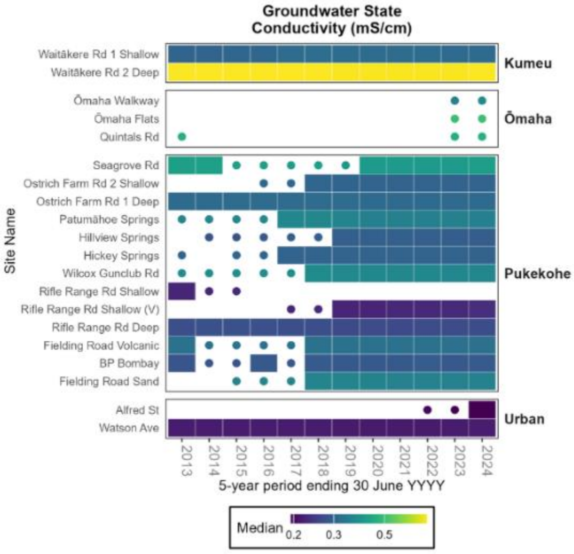
Appendix 3: Rolling state results

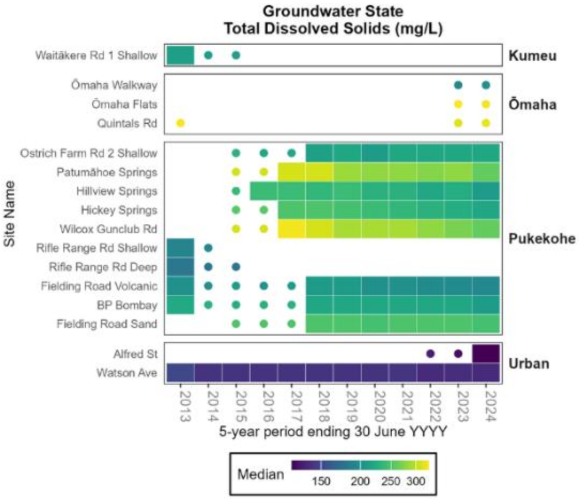

Groundwater State
Dissolved Oxygen (mg/L)
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.10 0.30 1.00 3.00


Groundwater State
Dissolved Oxygen % Saturation
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
1.0 3.0 10.0 30.0

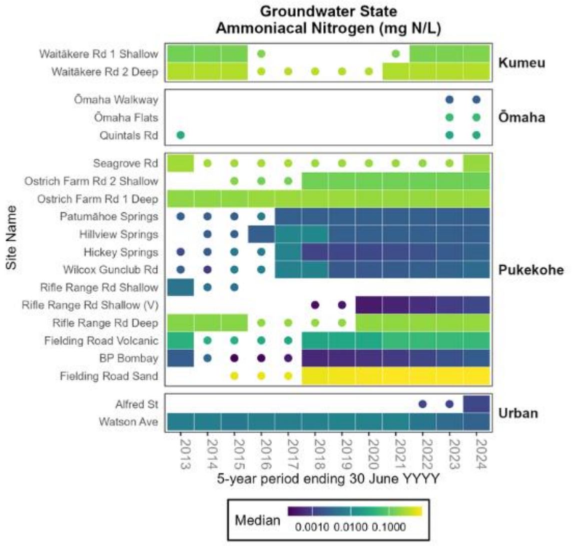

Groundwater State
Temperature (°C)
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
15 16 17 18 19

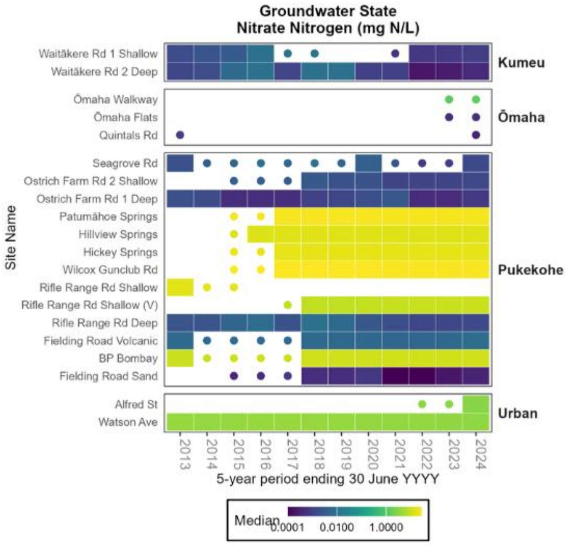

Groundwater State
Total Hardness (mg/L)
Waitākere Rd 1 Shallow
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
50 70 100

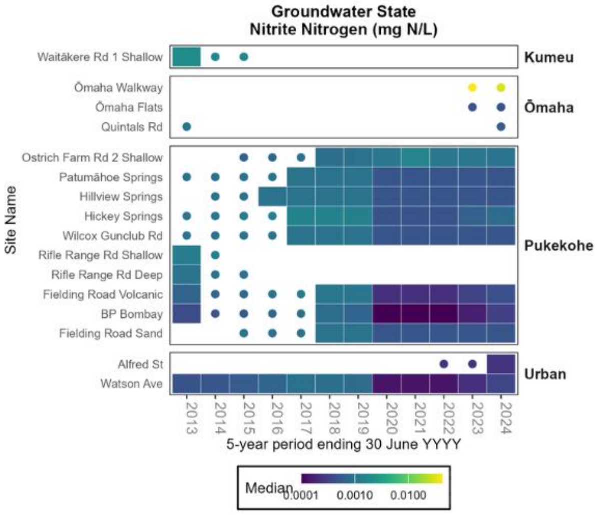

Groundwater State
Conductivity (mS/cm)
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.2 0.3 0.5

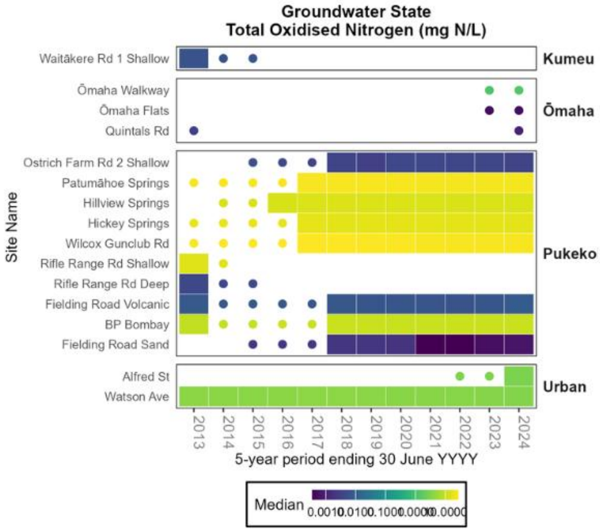

Groundwater State
Total Dissolved Solids (mg/L)
Waitākere Rd 1 Shallow
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
150 200 250 300

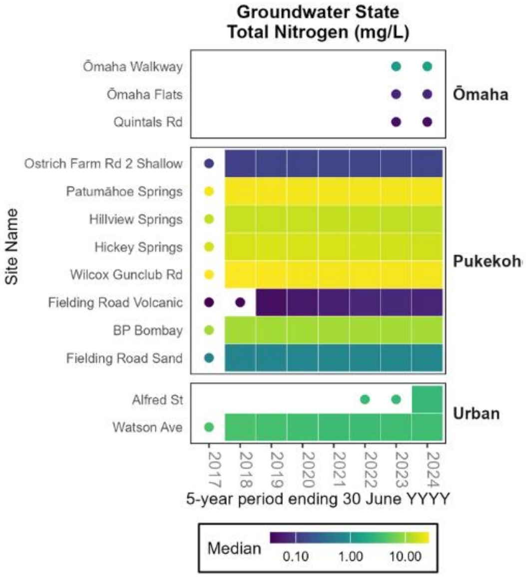

Groundwater State
pH
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024
5-year period ending 30 June YYYY
Median 6 7 8

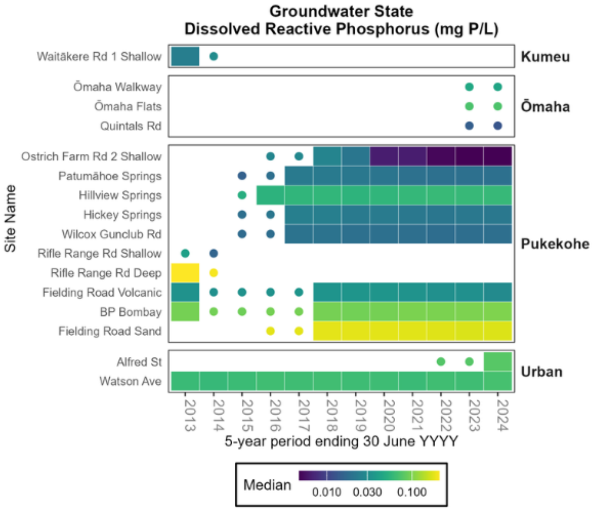

Groundwater State
Ammoniacal Nitrogen (mg N/L)
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024
5-year period ending 30 June YYYY
Median 0.0010 0.0100 0.1000

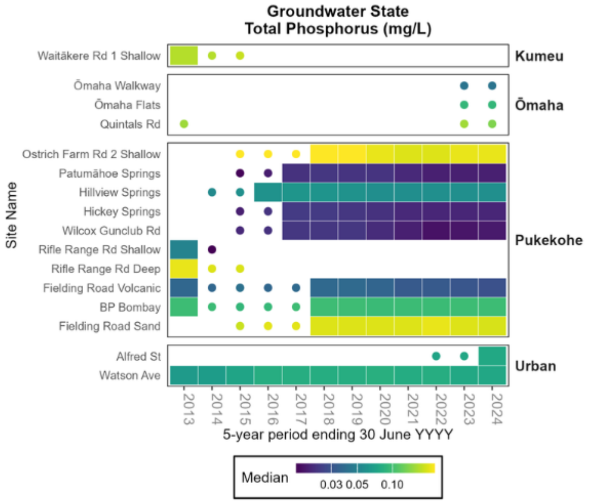

Groundwater State
Nitrate Nitrogen (mg N/L)
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024
5-year period ending 30 June YYYY
Median 0.0001 0.0100 1.0000

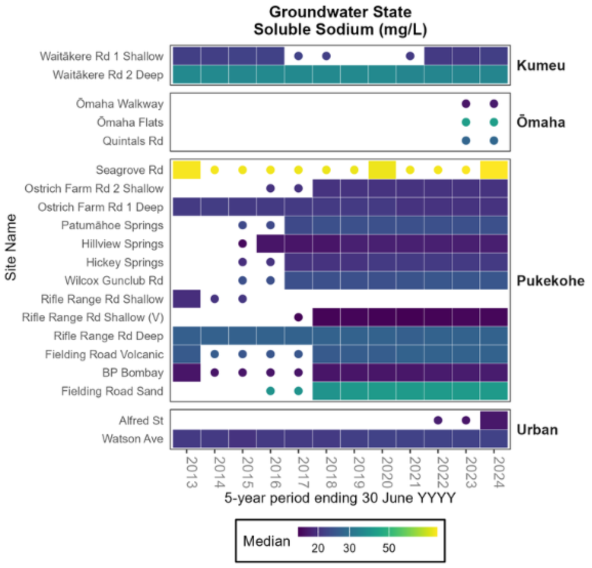

Groundwater State
Nitrite Nitrogen (mg N/L)
Waitākere Rd 1 Shallow
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
Site Name
2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024
5-year period ending 30 June YYYY
Median 0.0001 0.0010 0.0100

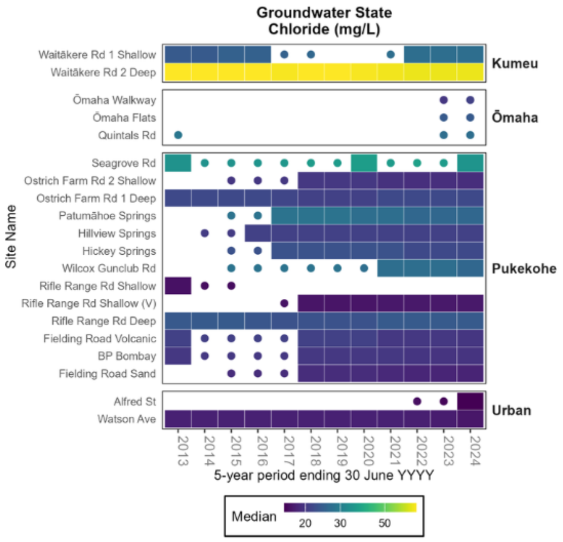

Groundwater State
Total Oxidised Nitrogen (mg N/L)
Waitākere Rd 1 Shallow
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukeko
Alfred St
Watson Ave
Urban
Site Name
2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024
5-year period ending 30 June YYYY
Median 0.0010 0.0100 0.1000 1.0000 10.0000

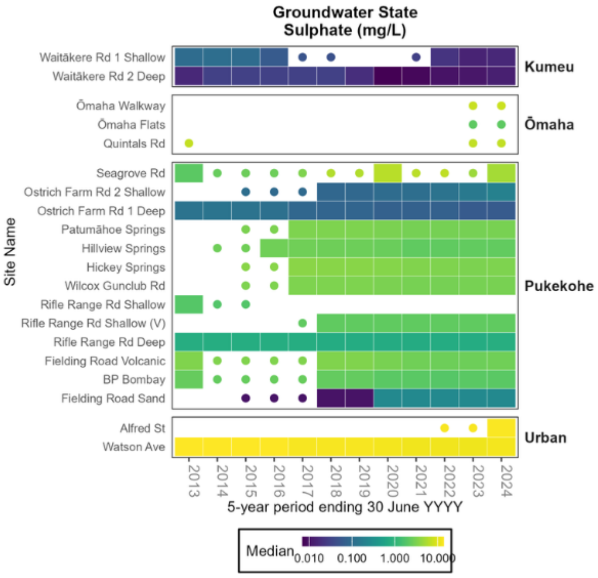

Groundwater State
Total Nitrogen (mg/L)
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekoh
Alfred St
Watson Ave
Urban
Site Name
2017 2018 2019 2020 2021 2022 2023 2024
5-year period ending 30 June YYYY
Median 0.10 1.00 10.00

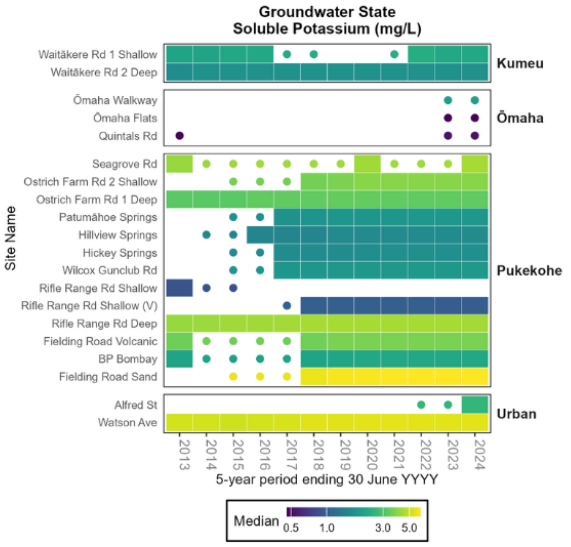

Groundwater State
Dissolved Reactive Phosphorus (mg P/L)
Site Name
Waitākere Rd 1 Shallow
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.010
0.030
0.100

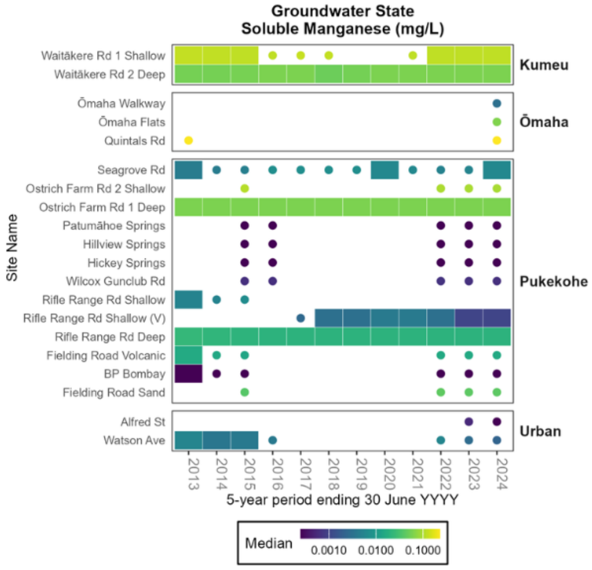

Groundwater State
Total Phosphorus (mg/L)
Site Name
Waitākere Rd 1 Shallow
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.03
0.05
0.10

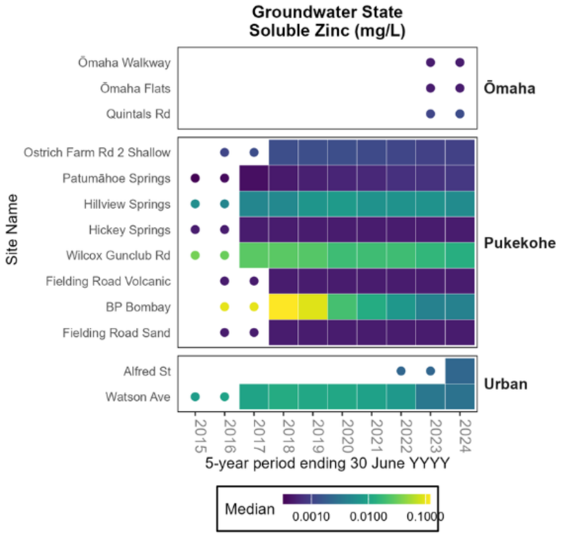

Groundwater State
Soluble Sodium (mg/L)
Site Name
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
20
30
50

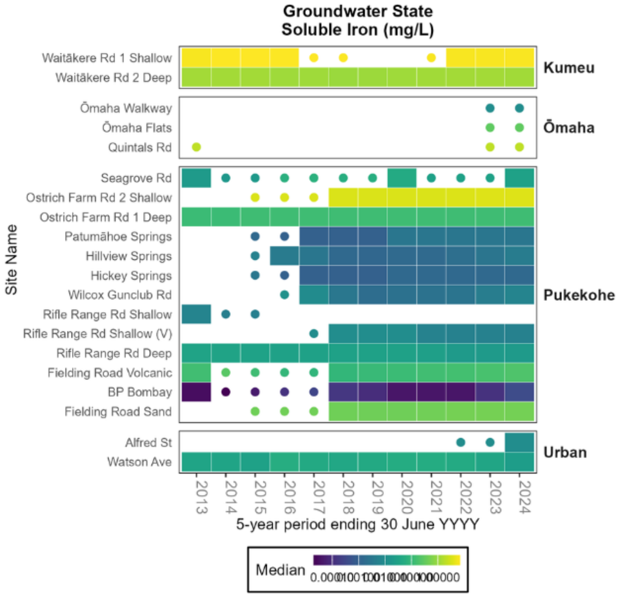

Groundwater State
Chloride (mg/L)
Site Name
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
20
30
50

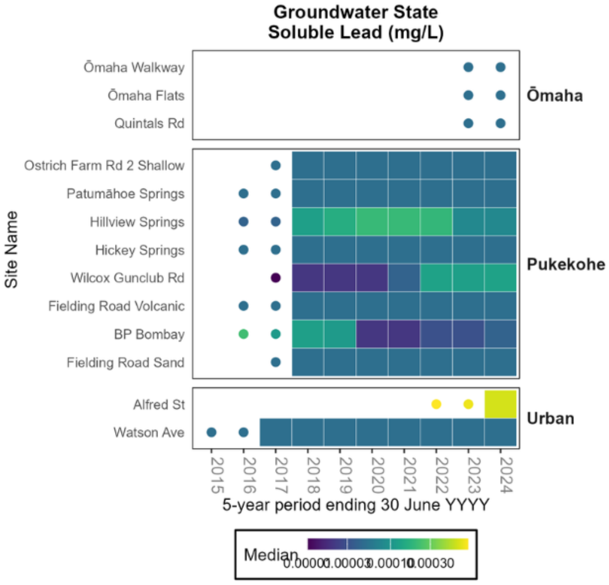

Groundwater State
Sulphate (mg/L)
Site Name
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.010
0.100
1.000
10.000

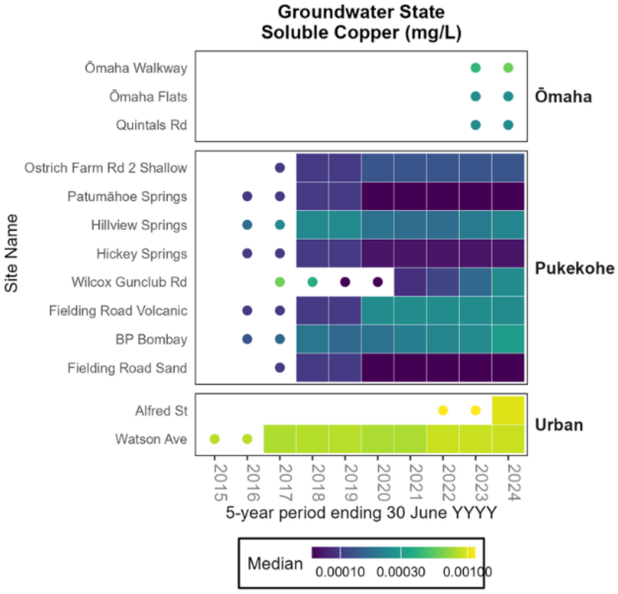

Groundwater State
Soluble Potassium (mg/L)
Site Name
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.5
1.0
3.0
5.0

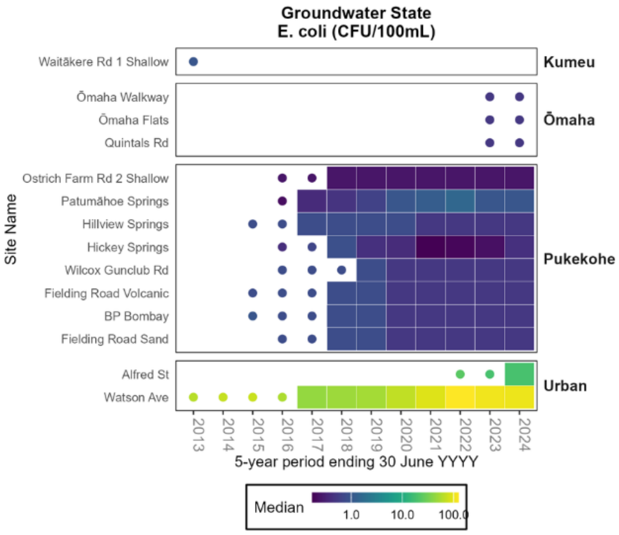

Groundwater State
Soluble Manganese (mg/L)
Site Name
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.0010
0.0100
0.1000


Groundwater State
Soluble Zinc (mg/L)
Site Name
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.0010
0.0100
0.1000


Groundwater State
Soluble Iron (mg/L)
Site Name
Waitākere Rd 1 Shallow
Waitākere Rd 2 Deep
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Seagrove Rd
Ostrich Farm Rd 2 Shallow
Ostrich Farm Rd 1 Deep
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Rifle Range Rd Shallow
Rifle Range Rd Shallow (V)
Rifle Range Rd Deep
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median


Groundwater State
Soluble Lead (mg/L)
Site Name
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.00001
0.00003
0.00010
0.00030


Groundwater State
Soluble Copper (mg/L)
Site Name
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
0.00010
0.00030
0.00100


Groundwater State
E. coli (CFU/100mL)
Site Name
Waitākere Rd 1 Shallow
Kumeu
Ōmaha Walkway
Ōmaha Flats
Quintals Rd
Ōmaha
Ostrich Farm Rd 2 Shallow
Patumāhoe Springs
Hillview Springs
Hickey Springs
Wilcox Gunclub Rd
Fielding Road Volcanic
BP Bombay
Fielding Road Sand
Pukekohe
Alfred St
Watson Ave
Urban
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
5-year period ending 30 June YYYY
Median
1.0
10.0
100.0

Appendix 4: State and trend results

The full suite of state and trends results is provided as a supplementary data file published on Knowledge Auckland.

Find out more:
environmentaldata@aucklandcouncil.govt.nz
or visit knowledgeauckland.org.nz and
aucklandcouncil.govt.nz