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Waikato groundwater quality monitoring optimisation.

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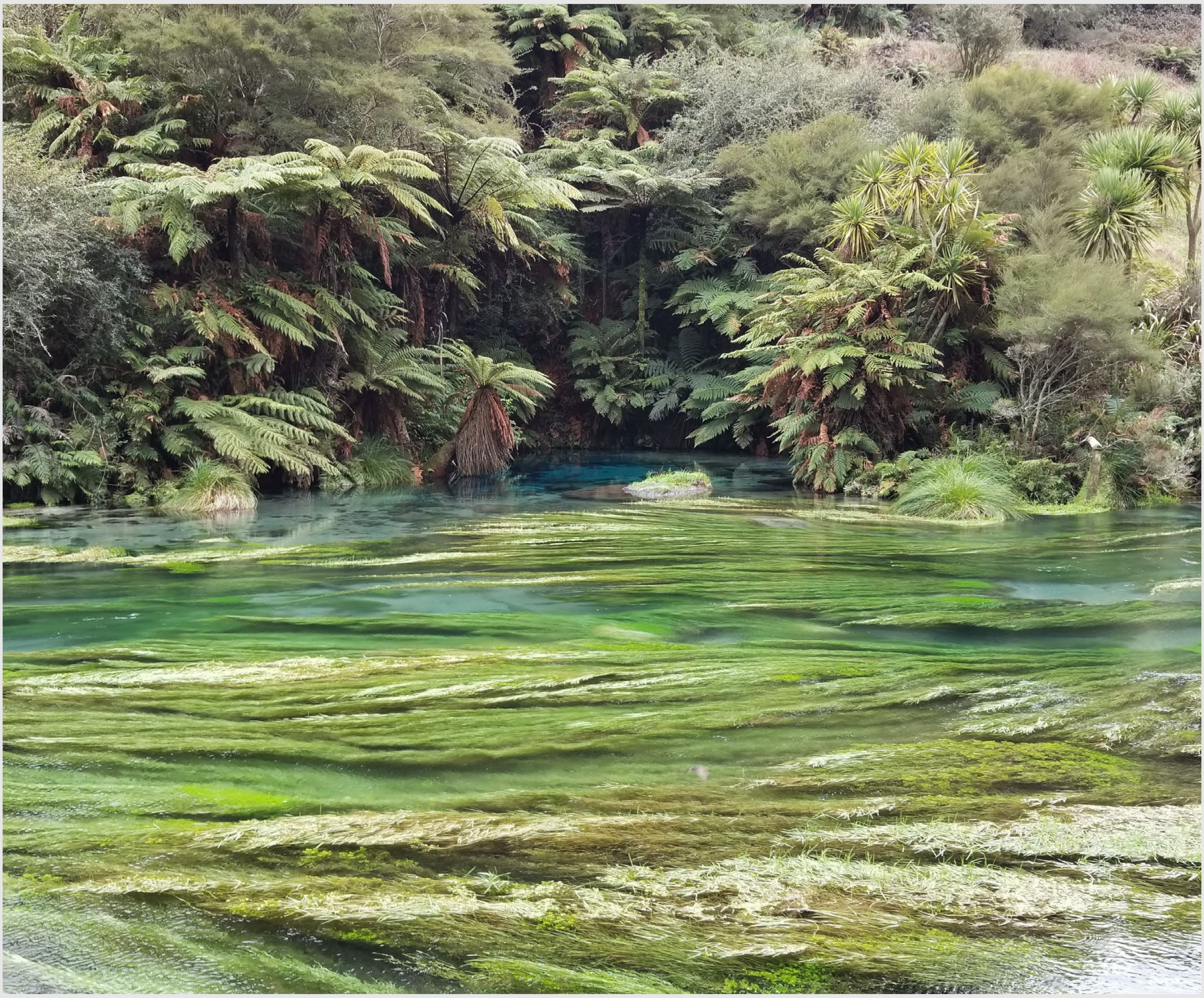
National Groundwater Quality Monitoring Framework



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NGQM Framework Report 2026/01

GNS Science Consultancy Report 2025/108

July 2026

Waikato Regional Council
Te Kaunihera ā Rohe o Waikato

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PURPOSE

This report summarises the joint review of Waikato's groundwater quality monitoring network between Waikato Regional Council and Earth Sciences New Zealand.

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EXECUTIVE SUMMARY

Groundwater quality monitoring in the Waikato region has been revised to ensure it achieves objectives and addresses critique in respect to national consistency and transparency. Regional State of the Environment (SoE) monitoring undertaken since the 1990s has evolved in an ad hoc fashion, although it has provided very useful information to inform management of the resource to date. In contrast, national SoE monitoring, also initiated in 1990, has largely remained static. This collaborative review has involved wide consultation, with the proposed approach supported by regional councils, relevant Crown Research Institutes (CRIs) and government departments.

An initial literature review resulted in proposed differentiation of Surveillance and Evaluative monitoring. The former involves more passive characterisation of groundwater quality state and trends. The latter is a more targeted approach, notably to assess the efficacy of policies and management initiatives.

The existing monitoring programme comprises an SoE network (110 wells, 10 of which are shared with the National Groundwater Monitoring Programme [NGMP] network) and a ‘Schools (Community)’ network of rural schools (~80 wells). Surveillance monitoring is a combination of the existing SoE and Schools (Community) monitoring. In the Waikato, Evaluative monitoring includes initiatives for the protection of water quality in the Lake Taupō catchment and others, which includes existing SoE sites. Also, evaluation of management to protect aquifers in the Coromandel from seawater intrusion. This report proposes to replace the current SoE monitoring programme so that there is both a Surveillance network and an Evaluative network.

The SoE network was reviewed in respect to spatial location, hydrogeological characteristics, availability of information, site access, sampling logistics and, notably, the power of site data to detect change. The Schools (Community) network was considered during the review of the SoE network, however, it is proposed to review this network separately at a later stage.

To assess priority areas for both Surveillance and Evaluative monitoring, a geospatial index-overlay method was used. Spatial units for this method consisted of a 10 km x 10 km grid overlaid by hydrogeologically defined polygons. The combination of weights and ratings to mappable units provided the basis for informed decisions on the design of the Surveillance regional monitoring network. This uses a consistent monitoring site density approach, whereby higher priority areas were assigned greater densities. The design of the Evaluative network was informed by a similar approach, but in targeted areas, and with a specific objective in mind. The index factor weightings were varied for Surveillance and Evaluative purposes, and may be changed in a transparent fashion.

The review of Surveillance monitoring involved comparison of the existing monitoring well distribution and characteristics with the index-mapped priority areas. Various adjustments were required involving rationalising some existing sites, while also adding some new monitoring wells. The latter involved some field confirmation of suitability. Some of the additional sites involve collaboration with a third party, typically with district councils monitoring drinking water supplies.

A standardised base suite of chemical parameters was agreed by regional councils for national consistency through the Groundwater Special Interest Group (2024). This base suite includes major ions for groundwater characterisation, some nutrients (e.g. nitrate), various calculated parameters (e.g. hardness) and field parameters (e.g. temperature). It sets out the minimum expectations for Surveillance/SoE monitoring of groundwater quality, but many councils choose to monitor additional parameters (e.g. arsenic) for a variety of reasons.

Site distribution in the region for the NGMP was also reviewed, using the same index-overlay method, this time against the Ministry for the Environment and StatsNZ reporting topics under the Environmental Reporting Act (2015). The proposed network consists of 17 existing or planned regional monitoring sites representing all identified primary monitoring aquifers and a selection of secondary monitoring

aquifers. Coordinating sampling between regional and national programmes allows for simultaneous data collection, reducing both time and cost, while enhancing data coverage and maintaining sampling frequency. The proposed changes include data compilation to support freshwater national reporting to address data gaps.

At the regional scale, the optimised Surveillance network proposes to add 31 sites and to drop 23 sites. Revision of sampling frequency at some sites are also proposed within the current quarterly, annual and biennial frequency framework. Changes to the Schools (Community) network were also proposed, although further review is planned. At the national scale, the optimised Surveillance network proposes to grow the network from 10 to 17 sites shared with the regional network. Additional sites were identified in the Upper Waikato, Hamilton Basin and the Western areas. No changes are proposed to the analytical suite and sampling frequency for regular operations. Evaluative monitoring was differentiated to assess the efficacy of policy and management initiatives in the Lakes Taupō and Rotopiko catchments and also Coromandel coastal aquifers.

Extensive stakeholder engagement was undertaken throughout this process, with the aim of developing an approach that could be applied to similar initiatives in the future. A key outcome of the consultation was the recognition that transparency is critical, particularly given the influence of subjective design choices on the final monitoring programme. The process also demonstrated that meaningful improvements require iterative refinements, to balance strategic objectives with practical implementation considerations.

Recommendations provided in this report aim to: implement the proposed changes within the Waikato region, undertake similar reviews in other regions, streamline data management, ensure long-term connections between data collection and national reporting, and review national monitoring needs.

GLOSSARY

Adaptive management monitoring: targeted monitoring aimed at understanding how the environment responds to changes in human pressures and stressors.

Compliance monitoring: monitoring activities documenting whether consent holders are complying with conditions of consents (e.g. water quality trigger values exceeded).

Evaluative monitoring: in the context of groundwater quality, monitoring activities aiming to: (1) understand, forecast and assess the implications of management choices; (2) assess whether outcomes (set in public or policy processes) are being achieved; (3) inform model simulation and reduce uncertainty, and (4) give a national overview to reporting at the national scale as required. These aims were defined collaboratively between central government, regional authorities and Crown Research Institutes (CRIs) with a view to replace current State of the Environment (SoE) monitoring (Moreau 2024).

Groundwater Reliance (GR) Index: an index developed to provide national consistency and communicate the relative significance of groundwater use in an area, and thus help determine the appropriate level of monitoring effort. The GR Index is used to categorise areas with consideration for human-driven and environment groundwater needs. In this report, the GR Index is defined as a combination of well density and groundwater abstraction volume, but in future should incorporate receiving environment metrics.

Groundwater class: a designation of an area/aquifer to the classes of Primary, Secondary (A, B or Undifferentiated) or Tertiary, based on the importance of the groundwater resources to humans and the environment.

Primary class: aquifers with high intergranular and/or fracture permeability that may support water supply and/or river base flow, or significant water bodies.

Secondary class: rock and soil layers with a wide range of water permeability and storage. This class can be further divided into (A) capable of supporting water supplies at a local rather than regional scale, and may form an important source of base flow to rivers, and (B) may store and yield limited amounts of groundwater due to localised features, such as fissures, thin permeable horizons and weathering.

Surveillance monitoring: in the context of groundwater quality, monitoring activities aiming to: (1) assess state and trends in groundwater quality, and describe spatial and temporal patterns; (2) associate any trends with causes at a broad scale, such as land use, point-source pollution or natural; (3) derive reference state and trend baselines; (4) identify long-term trends (>five years); (5) provide a national overview of New Zealand groundwater diversity and inform national environmental reporting, and (6) identify emerging risks, and designate sentinel roles for those risks that are not currently a high priority for public or policy processes. These aims were defined collaboratively between central government, regional authorities and CRIs, with a view to replace current SoE monitoring (Moreau 2024).

State of the Environment (SoE) groundwater quality monitoring: monitoring intended to represent a broad range of groundwater characteristics rather than investigate the impacts on quality of specific point-source discharges (Hadfield 2022). The corresponding network is widely distributed throughout the region. Groundwater aquifer systems are three dimensional, and substantial changes in groundwater quality often occur with depth. Groundwater may therefore be monitored at the same location at various depths. At the regional scale, SoE networks are operated by regional authorities; at the national scale, SoE monitoring is undertaken by Public Research Organisations under the National Groundwater Monitoring Programme for inorganic chemistry and the Pesticides and Emerging Contaminants Survey.

Tertiary class: lower permeability layers, which may yield limited amounts of groundwater due to localised features.

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1.0 Introduction

1.1 Why a Step Change in our Monitoring Approach is Required

This collaborative report by Waikato Regional Council (WRC) and Earth Sciences New Zealand[1] reflects the need to review and optimise groundwater quality monitoring for both the region and nationally through a consistent and transparent approach. Both WRC and Earth Sciences New Zealand have been monitoring groundwater quality since the early 1990s as required by the Resource Management Act (1991) under the State of the Environment (SoE) programmes. Both monitoring programmes aimed to characterise groundwater quality, which was achieved. The long-term monitoring data resulting from these programmes have revealed long-standing groundwater quality issues and the variability of Waikato's groundwaters (Hadfield 2001; Rosen 1999; Daughney and Wall 2007; Hadfield 2022).

Under the Environmental Reporting Act (2015), groundwater is reported as part of the Freshwater Domain and Synthesis reports compiled by the Ministry for the Environment and Statistics New Zealand (StatsNZ) (Environmental Reporting Act 2015). These reports are currently informed by the Groundwater Quality, the Water Physical Stocks and the Consented Freshwater Takes Indicator reports (StatsNZ 2024). Regional council reporting of groundwater quality is required by the Resource Management Act (RMA) (1991).

Regular programme reviews are good practice for environmental monitoring (Lovett et al. 2007). Since their inception, the number of monitoring sites has grown considerably, along with the knowledge of groundwater systems. It is now timely for both organisations to re-assess their networks. Notably there have also been three independent reviews which identified the following shortcomings in current groundwater monitoring systems and programmes:

- **Current environmental monitoring data collection is inconsistent and difficult to access**. In 2019, a review of the New Zealand environmental reporting system by the Parliamentary Commissioner for the Environment (PCE 2019) described New Zealand's monitoring systems as:

  > *A passive harvesting system (i.e. designed around what is available rather than purposefully designed); largely fragmented; and having multi-objectives such as State of the Environment (SoE) monitoring, policy development and implementation.*

  Recommendations from this review included: development of a comprehensive environmental monitoring system and, in particular, a comprehensive and representative national monitoring network to ensure systematic, coordinated and consistent monitoring nationwide; and improved data accessibility.

- **There are unresolved challenges in building a consistent national picture from aggregating regional data**. In 2023, site distribution spatial bias and inconsistencies in site and variable selection were identified in a technical review of the 2020 Groundwater Quality Indicator report (Moreau 2023). These issues were attributed to the aggregation of regional data, which is collected for multiple monitoring objectives with variable network density and without common site and variable selection criteria. Note that the 2024 update of the national groundwater quality indicator was co-designed in collaboration with the Ministry for the Environment to address some of these issues (Moreau et al. 2025). Recommendations from this review included the review and consolidation of existing national monitoring programmes and clarification of the Ministry for the Environment and StatsNZ data needs for national reporting, with input from regional councils.

[1] On 1 July 2025, GNS Science and the National Institute of Water and Atmospheric Research (NIWA) merged to form Earth Sciences New Zealand.

- **The groundwater quality dataset from State of the Environment (SoE) networks is not fit for purpose for policy effectiveness assessments**. In 2023, the power of change detection of the aggregated SoE groundwater quality regional datasets was tested (Etheridge et al. 2023). Analysis suggested that the effectiveness of policies intended to reduce nitrate concentrations is unlikely to be identifiable using the existing groundwater monitoring network within effective natural resource management timeframes (Etheridge et al. 2023). For example, an improvement to a 2.4 mg/L target nitrate-nitrogen level would only be detected with a suitable degree of confidence at 40% of the wells over the total network after 30 years of quarterly sampling.

To address nationally consistent data collection, suitable regional to national data aggregation and policy effectiveness monitoring requires a concerted approach, which is a significant departure from the current model of independently undertaken monitoring network reviews by various agencies (Moreau-Fournier and Daughney 2012; PDP 2013; Knottenbelt et al. 2023).

1.2 This Report

To address the aforementioned inconsistency issues identified by the PCE, regional representation at the national scale and the power of detection limitations, WRC commissioned GNS Science (now the GNS Science business unit of Earth Sciences New Zealand) in 2023 to collaborate in the development of an optimisation plan for regional monitoring, aligning regional and national objectives. This study was co-funded by the National Groundwater Monitoring Programme (NGMP) (Ministry of Business, Innovation and Employment's [MBIE] Strategic Science Investment Fund Contract C05X1701).

Initially, the work included the following tasks:

- A review of the current groundwater quality monitoring programmes in the Waikato.
- A literature review of potential optimisation techniques.
- Collaborative application of at least one optimisation technique to WRC's groundwater quality monitoring.
- Preparation and delivery of a virtual workshop with the Groundwater Special Interest Group (the Groundwater Forum) and the Ministry for the Environment. This was to present the approach and to collect feedback. It was also to assess the potential for this work to be extended to other regions either through regional or national networks.
- Presentation at the New Zealand Hydrological Society Conference, as this work has potential for re-use across organisational and environmental domain monitoring with other councils.
- Design of a transparent, optimised groundwater quality network for the Waikato region.

From its inception, this project used a consultative approach aiming to foster enduring pan-organisational change under the current fragmented resourcing situation. The multi-year timeframe enabled a range of concepts from high level to practical applications to be explored. An iterative approach with consultation was found to be fundamental to achieving a focussed, purposeful, cost-effective and pragmatic monitoring design. This concept can be illustrated with sampling frequency. At a high-level, a slow-moving groundwater body (residence time >50 years) under low environmental pressure may only require five-yearly monitoring. Practically, however, most monitoring sites are located on private properties and therefore site access and maintenance are outside of councils' control. Over time periods longer than two years, site conditions may change (e.g. wells replaced or sampling access changed). This may result in the need for a new sampling location (requiring multiple site visits) and incur a data gap. The associated replacement cost and uncertainty created by the data gap is likely to exceed that of routine acquisition of samples at a higher frequency.

The resulting optimised programme aims to inform both future monitoring in the Waikato and nationally. This work was designated as a case study for optimisation by the Groundwater Forum to inform similar reviews in other regions. It is the nature of monitoring design that regular reviews are required to meet future priorities and information needs. Out of scope of this review were: a review of monitoring operations (i.e. how samples are collected, QA/QC process), the monitoring of organic contaminants, and a complete redesign from scratch of the groundwater quality network.

This report first presents WRC's current groundwater monitoring activities and how they evolved over time. Next, agreed optimisation methods are described, grouped by the following monitoring aspects: objectives and constraints, development of a national consensus, aquifer definition, site distribution, representation at the national scale, and variable and sampling frequency. The resulting optimisation of existing sites, variables and sampling frequencies is then presented. This includes revised Surveillance networks and case studies for Evaluative regional monitoring. Finally, discussion and recommendations are provided.

At the time of writing this report, New Zealand's environmental legislation, local government structure and science, innovation and technology system are changing which may significantly influence future monitoring design and responsibilities (Bishop and Watts 2025; Ministry for the Environment 2025; MBIE 2025; Bishop et al. 2025). The timeline and magnitude of these changes are uncertain. This underlines the dynamic aspect of groundwater quality monitoring within resource management.

In the meantime, the environmental monitoring issues mentioned above can be readily addressed to ensure continued collection of groundwater data relevant to New Zealand's current need. This report provides the basis for the resulting monitoring design, which will make it easier to adjust should changes be required in the future. The new transparency provided in this approach is particularly important when considering future change.

2.0 Waikato Current Groundwater Quality Monitoring Programme and Network

2.1 Groundwater Resources in the Waikato

The Waikato region covers a total area of 24,351 km^2 (Figure 2.1). It includes the Waikato River, the longest (425 km) river in the country, and Lake Taupō (616 km^2), the largest lake. The region can be divided into five broad geological units: Triassic to Jurassic basement, Tertiary volcanics (Coromandel Peninsula), Tertiary sediments (Te Kuiti, Mokau), Quaternary volcanics (Taupō and Tokoroa), and Quaternary sediments (Hamilton Basin; Hauraki Plains). Uplift and volcanic activity have strongly shaped the region. Groundwater is a significant resource, comprising about 90% of the region's freshwater volume and is extensively utilised (WRC c2025). The groundwater resource can be characterised in relation to the geological units as follows:

- Mesozoic basement consists of weakly metamorphosed, deep marine sedimentary sequences separated into three fault-bounded blocks. These basement terranes are overlain by a succession of Tertiary to Quaternary sediments and volcanic rocks, and are regarded as aquicludes and the hydrogeological basement in the region (Edbrooke 2001 and 2005; White et al. 2015).
- Tertiary volcanics consisting of andesitic, dacitic and rhyodacitic volcanic rocks (Coromandel and Whitianga groups) emplaced as an active convergence margin propagated through northern New Zealand (Coromandel Volcanic Zone) (Edbrooke 2001). Fractured rhyolites are used for groundwater supply for several coastal settlements on the Coromandel Peninsula despite being poorly transmissive. Large drawdowns and proximity to the coast mean these aquifers are vulnerable to saltwater intrusion. Transmissivities between 10 and 15 m2d-1 have been reported in the Hahei and Whangamata areas (Hadfield 2001).
- Tertiary sediments comprise mainly marine deposits (Te Kuiti Group). In the Early Miocene, marine deposits were progressively replaced by terrestrial sediments, filling rapidly subsiding basins. An Early Miocene uplift caused heterogeneous erosion of these deposits (White et al. 2015). The Otorohanga and Orahiki karstic limestones are a notable aquifer, although of limited extent. These limestones exhibit the highest-density polygonal karst landscape in the world and include the iconic Waitomo Caves. Mean discharges from the largest springs from the limestones range from 86,400 to 260,000 m3.d-1 (Scarsbrook et al. 2008). The Kaawa Formation is regarded as an important and mostly confined aquifer (White et al. 2015). The formation consists of up to 150-m-thick, porous shell beds, sand deposits and sandstones resting unconformably over earlier Tertiary sediments (e.g. Te Kuiti Group). Kaawa aquifer transmissivities were found to range from 37 m2d-1 to 420 m2d-1 in the Waikato region (Petch et al. 1991). Groundwater quality in the Kaawa Formation is typically high (Hadfield 2001).
- Late Tertiary to Quaternary volcanics include back-arc intraplate volcanics (volcanic cones, tuffs rings and lava flows of varying thickness) emplaced during the Pliocene to Early Quaternary (Alexandra and South Auckland volcanics) in the west, and voluminous ignimbrites and tephra deposits from caldera-forming eruptions (Taupō Volcanic Zone [TVZ]) in the east (Edbrooke 2005). The highly fractured basalts of the South Auckland volcanics are regarded as an important aquifer system in the Pukekohe and Pukekawa areas. The basalts demonstrate a range of hydraulic characteristics according to their thickness, degree of fracturing and extent. Their transmissivity in the Pukekohe area was found to range substantially from 7 m2 d-1 to 5,600 m2 d-1 by Petch et al. (1991). Fractured volcanic flows in the Pukekawa area comprise numerous discontinuous aquifers, providing more than 90% of groundwater supply. Hydrogeologic properties are again highly variable, with yields typically between 100 and 1000 m3 d-1 (Bell et al. 1991). Groundwater from ignimbrites is also used for geothermal extraction (Hadfield 2001). Arsenic concentrations can be relatively high in groundwaters with geothermal influence, exceeding the Maximum Admissible Value (MAV) of the New Zealand Drinking-Water Standards (Piper and Kim 2006; Water Services 2022; Hadfield 2022).

- Quaternary sediments comprise heterogeneous gravel, silt, mud, peat and volcanogenic sediments of variable thickness (typically 5–80 m, locally up to 600 m). The main aquifers in this group are found within the Tauranga Group in the Hauraki Plains and the Hamilton Basin (Figure 2.1). The mid-Quaternary Upper Waikato Lake fine-grained lacustrine sediments (Huka Falls Formation) act as aquicludes and a cap rock to several of the TVZ geothermal fields. They are about 140 m thick near Taupō (White et al. 2015). The Tauranga Group comprises heterogeneous sediments, including gravel, silt, mud, peat and volcanogenic sediments of variable thickness (typically 5–80 m and locally up to 600 m). Water-bearing formations from this group include: flood deposits from the Pleistocene Hinuera Formation (Piako Sub-group), Holocene deposits in the Hauraki Plains, and re-worked, non-welded ignimbrite and tephra (Walton Sub-group) in the Hamilton Basin. In this basin, the Piako Sub-group mainly consists of braided river deposits and Holocene swamp deposits, and provides groundwater of variable quality and yield (White et al. 2015). Tauranga Group aquifer thickness ranges from less than 10 m up to 50 m in the plains, but the deposits are commonly thinner (<5 m) in the basin. Transmissivities are greater in the plains (5–25,000 m2.d-1) than the basin (10–1000 m2.d-1) (Hadfield 2001). In the Hauraki Plains, groundwater flows from south to north. Downgradient, the aquifer becomes semi-confined and discharges through artesian upwelling and leakage to surface water, including streams and wetlands (Hadfield 2001). Groundwater quality in the Hauraki Plains varies along the flowpath with stronger reducing conditions in the north (downgradient). In the Hamilton Basin, groundwater quality is highly variable, and age tracer data indicate rapid (MRT <5 years) circulation in the shallow parts of the basin and much slower (thousands of years) at depth (Hadfield 2001). There are reported occurrences of nitrate-nitrogen concentrations above the MAV and the human-impact threshold defined on groundwater age and groundwater quality (Hadfield 2022; Morgenstern and Daughney 2012). Holocene, shallow coastal sand aquifers are locally important for groundwater supply to small communities on the Coromandel Peninsula, such as Pauanui and Cooks Beach. The sands of these localised aquifers have typical hydraulic conductivities of about 15–20 m.d-1 and are vulnerable to saltwater intrusion (Hadfield 2001).

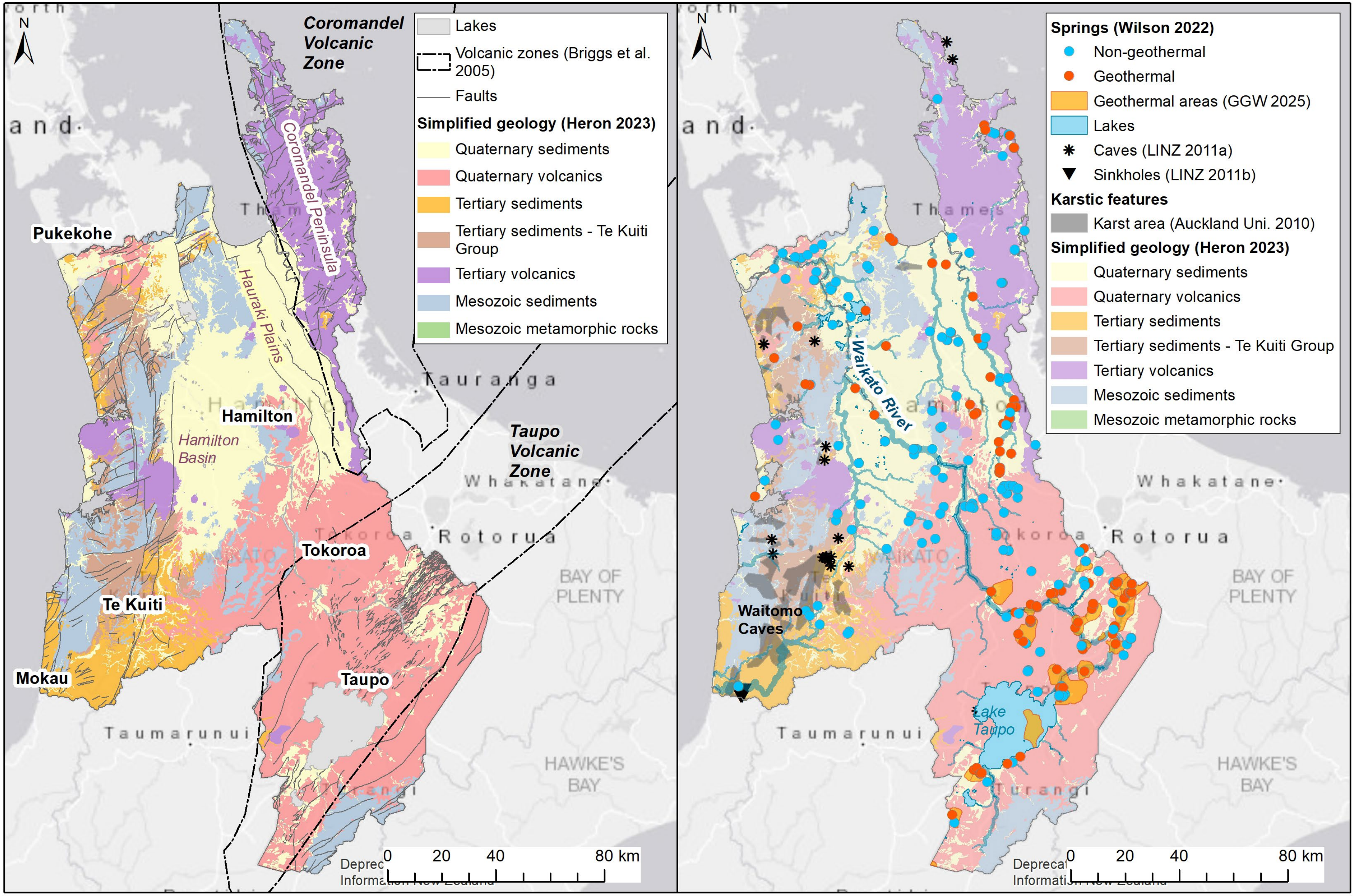

Figure 2.1 Geology (left) and hydrogeology (right) of the Waikato region.

2.2 Current Groundwater Quality Monitoring Programme and Networks

2.2.1 Site Distribution of Monitoring Networks

The state and trends of groundwater quality in the Waikato region were most recently reported in WRC technical report 2022/23 (Hadfield 2022). This reporting is a regional council responsibility under the RMA and is used to inform resource management decision making. The reported monitoring derives information from two region-wide monitoring networks, being an SoE (or regional) network and a Schools (Community) network of rural schools (Figure 2.2). There are also other more locally specific groundwater quality investigations undertaken, such as that reported by Vant and Hadfield (2023) for the Taupō sub-region. These generally respond to locally specific information needs beyond typical baseline characterisation. Additionally, other synoptic surveys of various contaminants were undertaken, such as that by Moreau et al. (2019a) for emerging organic contaminants, which are relevant but not routinely part of the monitoring programme.

The primary network for SoE monitoring reported in 2022 comprises 110 wells, the majority of which are sampled annually (Figure 2.2). A subset of 37 wells are monitored quarterly, 10 of which are part of the national programme, i.e. the NGMP. Routine SoE groundwater quality monitoring in the Waikato commenced in 1995 involving 30 wells and increased to 108 wells within two years.

A second ‘community’ network was established in 2000 following investigation of community supplies and their vulnerability (Hadfield and Nicole 2000). Although there was some monitoring for potability already undertaken at the point of discharge for these supplies, source water and its protection had otherwise been given little consideration. This ‘community’ network currently comprises a minimum of 80 rural schools, which are monitored every two years (Figure 2.2). This monitoring has obvious community interest. It also provides an objectively determined, well-distributed network on public land.

It is noted that, as these supplies are required to meet drinking water guidelines, they tend not to be used once exceedances occur. Some may continue to be used just for non-potable supply and may remain in the network. Many of the school supply wells were drilled long before regional council drilling management or database archiving and thus may have limited information, with only half of the network’s wells having driller’s geological logs.

Small community water supplies, such as schools, will, in future, be required, under the Water Services Act, to monitor their source water as part of a multi-barrier approach for protection (Taumata Arowai 2022). Such information will be supplied to WRC by Taumata Arowai. This will build on the valuable data already collected and promote further collaboration for supply and resource protection.

The current SoE programme was intended to represent a broad range of groundwater characteristics rather than investigate the impacts on quality of specific point source discharges, which are addressed in other compliance monitoring. A reasonably wide distribution of monitoring wells throughout the region is achieved in the networks, particularly with the inclusion of the rural schools.

It is noted that groundwater systems are three dimensional, and substantial changes in groundwater quality often occur with depth. For that reason, groundwater is sometimes monitored at various depths at the same location. Current monitoring network well construction and other details are provided in Appendix 1.

The Waikato region is currently represented by 10 SoE sites in the NGMP, which was established in 1990. In this programme, quarterly groundwater samples are collected by regional councils nationwide (c. 110 sites) and analysed by Earth Sciences New Zealand for a consistent suite of inorganic variables (Rosen 1999; Moreau and Daughney 2021). Samples are sequenced and collected by regional and district council staff to align with regional operations and then dispatched to the Earth Sciences New Zealand laboratory for analysis at Earth Sciences New Zealand’s cost. The NGMP is a collaboration with 16 councils and unitary authorities, and is currently funded as part of Earth Sciences New Zealand's Strategic Science Investment Fund infrastructure programme (Contract C05X1701).

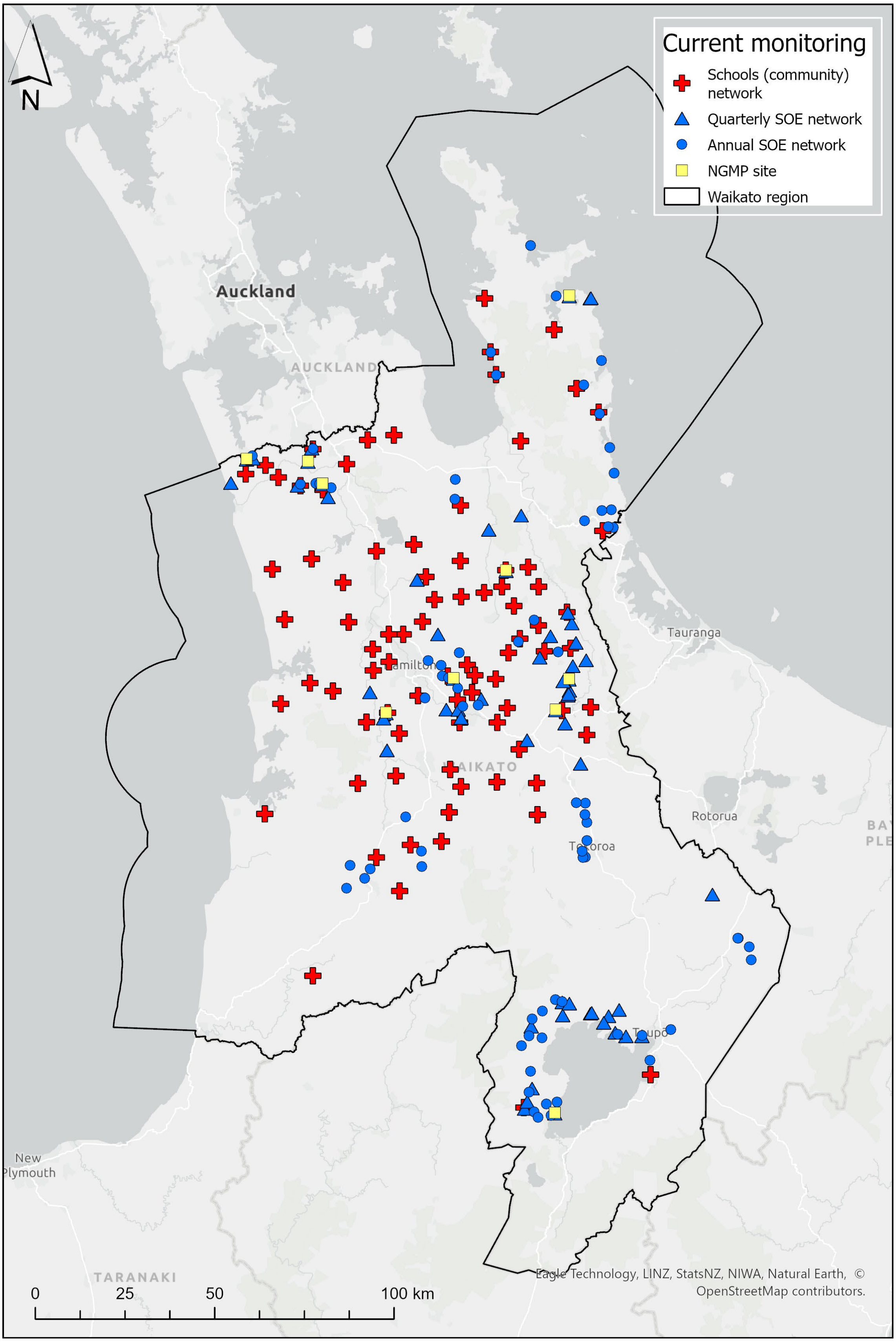

Figure 2.2 State of the Environment (SoE) regional and Schools (Community) groundwater quality monitoring networks.

2.2.2 Variables and Sampling Frequency

Current groundwater quality variables routinely monitored as part of SoE programmes include field-measured, inorganic chemical and microbial variables. Field-measured variables indicate in-situ aquifer conditions and quality of the sample being taken. Field variables are listed as requirements in the National Environmental Monitoring Standard (NEMS) for Discrete Quality (Milne 2019). Inorganic chemistry variables consist of major (>1 mg/L), minor (between 0.001 and 1 mg/L) and trace (<0.001 mg/L) constituents. These variables are monitored to understand a range of hydrogeological processes occurring underground, along a groundwater flow path. Examples of such processes are mineral dissolution and precipitation, mixing, ion exchange and leaching of land surface established contaminants, such as nutrients, to groundwater (Daughney and Wall 2007). Some of these chemical variables can be used to derive other water quality variables. For instance, total hardness can be derived from calcium and magnesium concentrations, total dissolved solids from conductivity, and free carbon dioxide, bicarbonate and carbonate from alkalinity measurements. Some of these variables have been regularly reported by WRC as indicators, such as nitrate, pesticides and *E. coli*.

The current use of some quarterly and lower-frequency annual and biennial monitoring allows greater spatial representation within the same logistic constraints, while including some seasonal consideration. Many trends in groundwater are very long-term and buffered. They therefore may not require as high-frequency monitoring as typically justified for surface waters (Barcelona et al. 1989). Higher-frequency monitoring for specific investigation using in-situ probes (e.g. nitrate-nitrogen) can, however, provide insights for interpretation and greater power for trend detection.

Groundwater dating at monitoring sites provides essential information on time lags and pathways. However, age tracer analyses have a high cost and long turnaround time linked to the analytical process and can only be performed in New Zealand at the Earth Sciences New Zealand Water Dating Laboratory. As a result, groundwater age samples have been collected over multiple years to now provide such information at the majority of existing SoE sites. Groundwater age may change through time, reflecting changes in dynamics recharging the sampling points, and therefore repeated measurements are valuable. Repeated age information is available at some of Waikato's SoE sites and most national monitoring sites.

Alongside routine monitoring operations, both the regional and national programmes also undertake investigations such as snapshot surveys. For instance, a glyphosate regional survey was undertaken in the Waikato (Hadfield 2017), and heavy metals were measured as part of NGMP in March 2001 and December 2022 (Moreau and Cameron 2023). There has been ongoing monitoring of pesticide contamination of groundwater in the Waikato region since initial investigations in the late 1990s (Hadfield and Smith 2000). Subsequent four-yearly surveys have been undertaken and more recently contributed to a national survey coordinated by the Public Health and Forensic Science Institute (formerly known as the Institute of Environmental Science and Research). These surveys are co-funded by participating regional councils. The monitoring suite has grown with increased laboratory capability and, recently, emerging organic contaminants (e.g. PFAS) have been added to the monitoring suite (Close and Banasiak 2023). The pesticide surveys aim to provide a long-term view of selected organic compound occurrence in groundwater. Most of the exceedances of guidelines have related to legacy issues such as the use of dieldrin for historic sheep dipping. Fate and transport in the environment can vary significantly between contaminants and, therefore, to contain the scope of this review, organic variables were deemed out of scope. The have, however, been identified as a future piece of work in the Recommendations (Section 6).

2.3 Evolution of Groundwater Quality Monitoring in the Waikato

Although there is merit in retaining programme and network stability for logistical and other reasons (e.g. length of record for trend detection and comparison), there is inevitably continual minor change. This may be deliberate or forced by factors including loss of access or wells no longer being available. None of the Waikato monitoring wells are on land owned by WRC. Even the Schools (Community) network on public land has seen moderate change as supplies have been replaced or schools closed. Changes to the networks historically have typically been ad hoc, although with the intention of being representative and providing both characterisation and indications of impacts on the groundwater resource. The merits of the programme and network design have perhaps historically been under-recognised, given the previous lack of transparency. Groundwater quality monitoring, as described, is inherently dynamic, involving active data collection. Therefore, reporting on state and trend analysis requires tracking network changes during the period of interest.

Progressively more stringent criteria require that wells are properly documented to inform interpretation. This includes information on both well construction and geology. Some early exceptions have been progressively rectified. The most significant recent change has seen the re-drilling of 17 sites in 2021, predominantly in the Hamilton Basin, to replace wide diameter (~900 mm), shallow, concrete-lined wells. These wells had very limited geological information and were logistically more difficult to sample. The 50-mm-diameter PVC piezometer replacements were logged in detail from continuous core samples. They have also been constructed to account for changes in documented redox conditions. Four sites were found to have redox changes at shallow depth (less than 6 m) and within the interval previously monitored. Both the wide-diameter wells and their replacements have been monitored together to provide an overlap to show differences in chemistry. Given these piezometers are replacements at the same site and have short monitoring records, they have not been included in the review or power of detection analysis to date.

Groundwater chemistry may vary significantly with water level where there are mixed redox conditions. The impacts of land use may also be effectively diluted due to the contribution of anaerobic groundwater (Hadfield 2021). Since the Childs' test has been utilised by WRC during monitoring well drilling over the last 20 years, wells have been designed and constructed to avoid mixing redox conditions (Childs 1981). The Childs' test involves the use of a colour-changing reagent (dypridil in an ammonium acetate solution) that, when applied to a drill core, shows the presence of ferrous iron and therefore anaerobic conditions. This can then guide well construction. It is noted that redox changes result in contrasting chemistry even where there are no other apparent formation changes.

Prior to initial routine regional monitoring, there have been a series of groundwater quality investigations undertaken. Many of the wells still monitored have variously been adopted into the SoE network following such initial investigations. These studies include those undertaken by WRC's predecessor organisations, e.g. the Waikato Valley Authority (later Catchment Board) in the Pukekohe/ Pukekawa and Hamilton Basin areas, and some investigations in the Coromandel and Hauraki areas by the former Hauraki Catchment Board.

More recently, monitoring wells have included some wells from investigations in the Lake Taupō catchment (Vant and Hadfield 2023). A component of 17 wells is currently included from the larger Taupō sub-regional groundwater quality monitoring now predominantly carried out by Tūwharetoa Māori Trust Board for WRC.

Contributions of regional monitoring to national groundwater quality reporting has also evolved. This notably includes a Waikato component to the NGMP, pesticide monitoring contributed to ESR's national surveys, reporting of groundwater quality aggregated nationally via the Land, Air, Water Aotearoa (LAWA) website or contributions to StatsNZ's Groundwater Quality Indicator reports.

2.4 Differences Between Current Regional Networks

It is noted that any selection of groundwater wells is unlikely to fully represent groundwater resources in the Waikato. For example, wells tend to be constructed to avoid low-permeability formations and poor-quality groundwater. Also, due to the cost of drilling, deep wells are less common where shallower aquifers are present. Such influences variously skew representation. This raises questions about what the objectives of monitoring are and what the networks are attempting to represent. One approach to spatial optimisation is to investigate how representative the current network is of a larger set of all available data (acknowledging that this may also be skewed). This may be undertaken using a selected determinant to compare its distribution within a larger dataset with that of the optimised proposed network, as described by Farlin et al. (2019).

Differences between our current SoE network and the Schools (Community) network are indicative of there being multiple possible representations of reality. The SoE network tends to be more representative of more vulnerable aquifers with relatively more young groundwater in aerobic conditions than the Schools (Community) network.

To illustrate differences between the SoE and Schools (Community) networks, nitrate-nitrogen concentrations and well depths are compared using 2020 annual data (Figure 2.3). Nitrate-nitrogen concentrations are significantly higher in the SoE network than in the Schools (Community) network, with medians of 3.60 and 0.91, respectively (Mann Whitney $p < 0.001$). Also, anaerobic conditions are more commonly found in the Schools (Community) network (~23%) than in the SoE network (~5.5%). As a corollary, SoE network wells are more frequently aerobic (~55%) than wells in the Schools (Community) network (34%). Higher nitrate concentrations are consequently more prevalent in shallower wells where aerobic conditions are more likely.

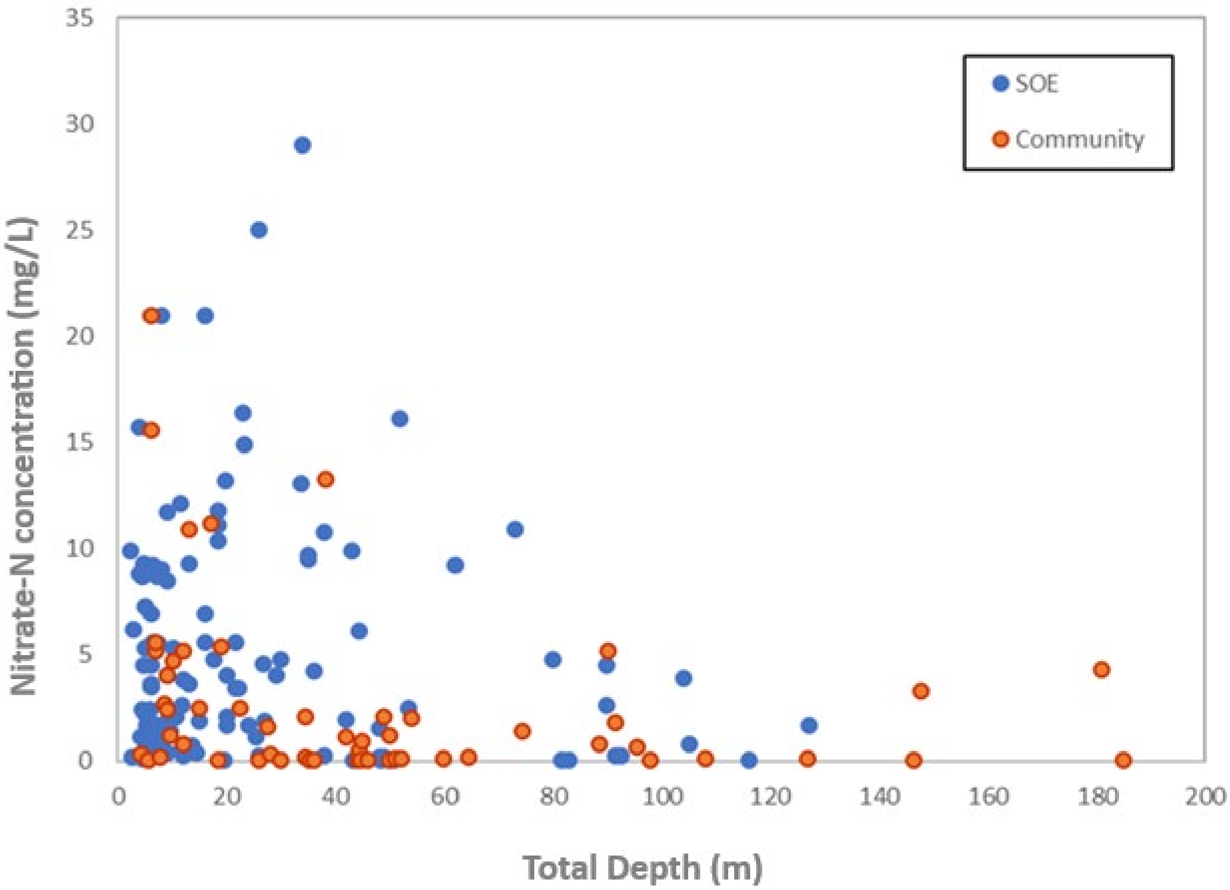

Figure 2.3 Nitrate-nitrogen concentrations in 2020 versus well depth for State of the Environment (SoE) and Schools (Community) network wells.

Differences between the Waikato SoE and Schools (Community) networks are also evident in nitrate-nitrogen state and trends distribution across the region (Figure 2.4). The Schools (Community) network's state and trend map shows a more subdued concentration distribution. This in part reflects that groundwater exceeding the drinking water MAV at schools is not used for potable supply (although they are sometimes still used for other purposes and continue to be monitored). It also, however, reflects differences in network composition, such as well depth and representation of redox categories as described above. Spatially, the overall distribution of higher concentrations in the central region areas follows similar patterns.

In contrast to the SoE network, which has equal portions of wells with increasing and decreasing nitrate-nitrogen concentrations (30.9% each), the Schools (Community) network shows more degrading (increasing concentration) trends (22.5%) than improving (6.25%). The Schools (Community) network records now provide useful trend information despite only being monitored biennially.

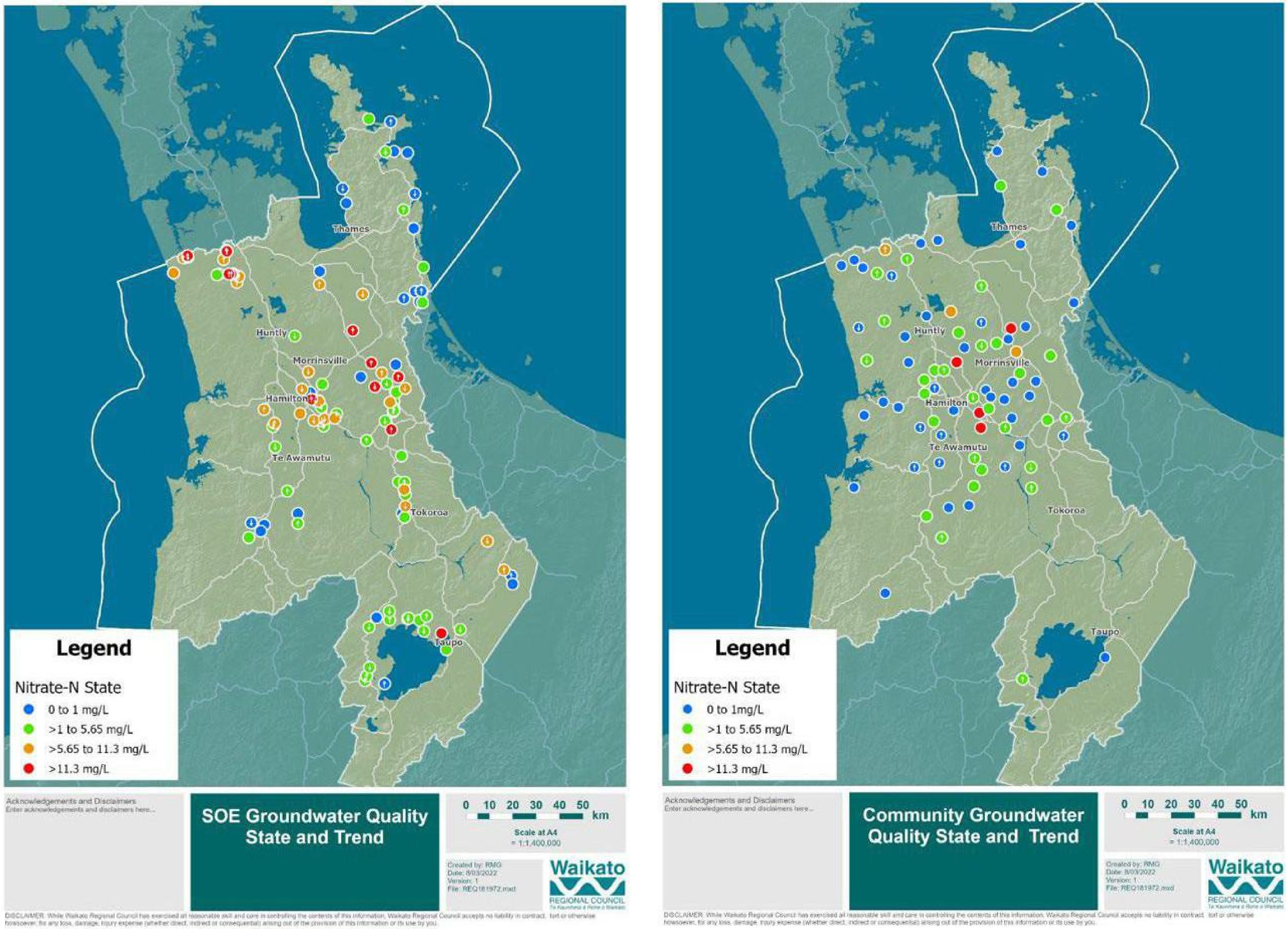

Figure 2.4 Nitrate-nitrogen concentration state and trend for the State of the Environment (SoE) groundwater quality network (left) and the Schools (Community) groundwater quality network (right) (Hadfield 2022). State is identified by the colour of the circle, whereas trend is shown by an arrow in each circle.

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3.0 Methods

The following sections outline the agreed finalised methods, organised by monitoring aspect. These methods were refined iteratively, balancing high-level objectives with practical constraints. Between most iterations, the Groundwater Forum and other relevant parties were consulted as appropriate.

3.1 Optimisation Objectives and Constraints

The optimisation objectives were to: refocus monitoring in the region to address site and analytical variables representation at regional and national level, enhance efficiencies (internally and across organisations), and clarify trade-offs between resourcing and monitoring at regional and national scales. This optimisation is consistent with the PCE's recommendations to: develop a comprehensive and representative national monitoring network; fill data gaps using existing initiatives and past efforts, and provide a shift from passive to active information gathering (PCE 2019).

Differences between the regional and national programmes' constraints on optimisation, arising from the current fragmented resourcing model, were:

- At regional level: maintaining existing programme-level resourcing, such as ongoing data curation and research activities, while adopting practical strategies for cost-efficiency.
- At the national level: consistent approach with WRC; use of nationwide relevant and readily available datasets; nationwide consistency in programme design; a minimum data requirement for statistical analysis used for state and trend national reporting; unchanged operational model; unchanged resourcing at programme level; continuation of data curation and research activities to ensure collected data remain relevant to current and future issues.

3.2 Development of a National Consensus

Initially, a short, targeted literature review was undertaken to select a peer-reviewed monitoring optimisation method. Reviewed materials ranged from technical specific work (e.g. combined use of measured contaminant concentrations and transit time to optimise a network [Farlin et al. 2019]); to large-scale monitoring frameworks (e.g. EU and US approaches) (European Commission 2003; Subcommittee on Ground Water of the Advisory Committee of Water Information 2009).

The two reviewed national approaches were similar, separating monitoring objectives level between "Surveillance" and "Trend"/"Operational" effectiveness (Table 3.1). Each monitoring objective has a bearing on the selection and number of sites, variables, sampling frequency and reporting (e.g. "Surveillance" monitoring uses a low frequency [Table 3.1]). These national approaches are consistent with the PCE and power of detection work recommendations regarding the decoupling of policy effectiveness from SoE monitoring/Surveillance. Both approaches require identification of groundwater bodies. For instance, the UK Environment Agency developed an aquifer designation scheme for groundwater protection purposes (Table 3.2).

Table 3.1 Monitoring programmes and objectives in the EU and the US (European Commission 2003; Subcommittee on Ground Water of the Advisory Committee of Water Information 2013).

Country	Programme	Monitoring Objective(s)	Relative Sampling Frequency
EU	Surveillance	Supplement and validate characterisation and risk assessment procedure with respect to risks of failing to achieve good groundwater chemical status. Establish the status of all groundwater bodies, or groups of bodies, determined as not being at risk on the basis of the risk assessments. Provide information for use in the assessment of long-term trends in natural conditions and in pollutant concentrations resulting from human activity.	Low (e.g. annually)
	Operational	Establish the status of all groundwater bodies, or groups of bodies, determined as being at risk. Establish the presence of significant and sustained upward trends in the concentration of any pollutant.	High (e.g. quarterly and more frequently)
US	Surveillance	Assess long-term natural trends or the effect of slowly changing climate.	Low
	Trend	Provide data to assess both long-term trends and seasonal variations.	High
	Special studies	No monitoring requirement, associated with suspected changes.	Varying

Table 3.2 UK aquifer system definitions for groundwater protection (Environment Agency 2017).

<table>
<tr><th colspan="2">Aquifer Designation</th><th>Aquifer Examples</th></tr>
<tr><td colspan="2">Principal aquifers (high intergranular and/or fracture permeability, may support water supply and/or river base flow on a strategic scale).</td><td>Chalk, Crag, Lower Greensand, Spilsby Sandstone, Oolites, Triassic Sandstone, Corallian Limestone, Magnesian Limestone, Permian limestone, Carboniferous Limestone, Fell Sandstone and Border Group</td></tr>
<tr><td rowspan="3">Secondary aquifers (rock layers with a wide range of water permeability and storage).</td><td>Type A: capable of supporting water supplies at a local rather than strategic scale; may form an important source of base flow to rivers.</td><td>Lower Devonian, Ravenscar Group, Yorkdale group</td></tr>
<tr><td>Type B: may store and yield limited amounts of groundwater due to localised features, such as fissures, thin permeable horizons and weathering.</td><td>Lias Group</td></tr>
<tr><td>Undifferentiated</td><td>Blue Lias Formation</td></tr>
<tr><td colspan="2">Unproductive strata (lower permeability layers which may store and yield limited amounts of groundwater due to localised features).</td><td>West Walton Formation, Oxford Clay, Thames Group</td></tr>
</table>

This framework was initially presented to the Groundwater Forum in November 2023 to gauge interest to adopt a similar approach (Table 3.3). The Groundwater Forum supported the initiative and formed a Working Group to assess the feasibility of developing a New Zealand approach. Over the following months, increasing consultation to represent all monitoring agencies and data users at national level were undertaken. Between April and June 2024, the Ministry for the Environment funded workshops to develop and document common principles for a national monitoring framework for groundwater quality. The following aims were collectively defined (Moreau 2024) and summarised in Table 3.4.

For Surveillance monitoring:

- Assess state and trends in groundwater quality and describe spatial and temporal patterns.
- Associate any trends with causes at a broad scale, such as land use or non-anthropogenic influences.
- Derive reference state and trend baselines.
- Identify long-term trends.
- Provide a national overview of New Zealand groundwater diversity.
- Identify emerging risks and designate sentinel roles for those risks that are not currently a high priority for public or policy processes.
- Inform national environmental reporting.

For Evaluative monitoring:

- Understand, forecast and assess the implications of agreed policy-related management choices.
- Assess whether outcomes (set in public or policy processes) are being achieved.
- Enable assessments of why, if outcomes are not being achieved.
- Inform models and reduce uncertainty.

The optimisation approach presented here represents the first application of these principles in New Zealand. This approach is consistent with recommendations for Evaluative-like river monitoring (Stoffels et al. 2022). Therefore, methods for site and variable selection, as well as sampling frequency, are presented from this point forward within this Surveillance and Evaluative framework.

Table 3.3 External engagement activities undertaken in relation to, or as part of, this project from November 2023 to December 2025, presented in chronological order.

Event	Event Description	Event Outcome
Groundwater quality monitoring optimisation workshop (online, 23 Nov 2023)	This workshop was facilitated by WRC, GNS Science and Komanawa Solutions, and involved 11 councils (between 1 and 10 participants per council). It featured a presentation of the monitoring optimisation approaches literature review and its implication for the Waikato, the findings from a statistical review of the suitability of SoE data to assess policy, and a group discussion.	The Groundwater Forum indicated support to this initiative by tasking a Working Group to further explore the development of a national framework. The Working Group included groundwater scientists from six regions (Gisborne, Bay Of Plenty, Wellington, Northland, Otago and Canterbury).
New Zealand Hydrological Society Annual Conference (Auckland, 28 Nov–1 Dec 2023)	Conference oral presentation of the monitoring framework concept by WRC and GNS Science during which the status quo was presented as the preposterous option.	Generally positive feedback received on the proposed approach.
Groundwater Forum Working Group monthly meetings (online, Dec 2023–Apr 2024)	Discussions facilitated by WRC and GNS Science on the need and desired approach to progress the step change. The Working Group was extended in March 2024 to include ESR, Ministry for the Environment and StatsNZ.	The need to agree on common objectives identified as the first step.
Coalescing towards a groundwater monitoring framework workshops (online, 9 Apr, 30 Apr and 10 Jun 2024)	The workshops were funded by the Ministry for the Environment and prepared and facilitated by Happen Consulting Ltd to ensure objective participation. Participants included regional and national monitoring programme managers (regional councils, GNS Science, ESR), Ministry for the Environment, StatsNZ, Te Uru Kahika Chief Science Advisor, Our Land and Water National Challenge, and Komanawa Solutions. The first two workshops were attended by 32 and 27 participants, respectively. The first workshop provided a stocktake of regional networks and a state of reviews was developed, highlighting variability in the approaches and cycle of network reviews. The second workshop focussed on the value of working together and the proposed monitoring scope and definitions, and the drafting of common principles. A sub-group was designated to work on feedback on principles. The third workshop was held to discuss and collectively action feedback on the principles.	Common national framework principles are agreed and reported (Moreau 2024).
Groundwater Forum (online, 27–28 May 2024)	Northland, Canterbury and Waikato regional councils presented results from the triaging of their existing networks into Surveillance and Evaluative, as defined in the common principles.	The Waikato optimisation case study was designated as a test for a practical application to be reported on at future Groundwater Forum meetings.
Groundwater Forum (Blenheim, 25 Nov 2024)	The Groundwater Forum was attended by Chris Daughney (as Te Uru Kahika Chief Science Advisor), Tim Davie (as Regional Management Group) and Stefan Beaumont (as Surface Water Integrated Management Special Interest Group chair). WRC and GNS Science provided an update on the Waikato Case Study, which was combined with a discussion on monitoring variables between regions.	Continued support and positive feedback from all participants. A common suite of core monitoring variables between regions was agreed between Groundwater Forum members.

Event	Event Description	Event Outcome
New Zealand Hydrological Society Annual Conference (Blenheim, 26–29 Nov 2024)	Conference oral presentation of the initial practical application of the optimisation method for the Waikato region by WRC and GNS Science.	Generally supportive feedback, including from scientists who contributed to the inception of NGMP.
Groundwater Forum Working Group meeting (online, 1 Apr 2025)	Update on current status of the optimisation design. Discussions about applicability on other regions with varying hydrogeological context. It was found that WRC monitoring over time ticked each of the five monitoring objectives tested as part of the Greater Wellington study.	Continued support by the Working Group. Bay of Plenty, Greater Wellington and Northland volunteered to be the next case studies. Suggestion to use the national network to concentrate on a particular question (e.g. volcanic aquifers in New Zealand).
Project alignment meetings (Dec 2024, Mar and May 25)	Project updates between the Waikato pilot study and the GWRC-led the review on monitoring activities.	Cross referencing of initiatives in project report. Scope review of the Waikato Study to focus on Surveillance optimisation and development of Evaluative examples.
Groundwater Forum (online, 29 May 2025)	Participatory session presenting the revised methods and results and lessons learnt.	The following insights were collected through the online poll (number of votes/participants in brackets below): • Agreement with the Surveillance (14/14) and Evaluative approaches (8/8 for saltwater intrusion and 13/13 for nitrate). • Agreement with the proposed national approach (10/10). • Minimum practical sampling frequency by the group range from quarterly (6/12) to six-monthly (6/12).
Draft report feedback meetings and correspondence (Nov 25)	Feedback on an earlier version of this report was sought from the Working Group (five regions), the Ministry for the Environment, StatsNZ and the PCE's office.	All contacted organisations but StatsNZ provided constructive comments and were supportive of the approach which are summarised in Section 5.2.
New Zealand Hydrological Society Annual Conference (Hamilton, 2–5 Dec 2025)	Two conference oral presentations by WRC and Earth Sciences New Zealand on the practical application of the optimisation method for the Waikato region and received feedback.	Other regions indicated willingness to apply this approach to groundwater quality monitoring in their region.

Table 3.4 High-level objectives, sampling frequency and analytical suite guidance for Surveillance and Evaluative programmes as defined by the Working Group.

Programme	Monitoring Objective(s)	Sampling Frequency	Analytical Suite
Surveillance (open-ended monitoring)	• Provide a national overview of New Zealand groundwater quality diversity suitable for setting reference conditions and describing long-term spatial and temporal patterns. • Investigate emerging or currently low-priority risks to groundwater quality.	Quarterly to annually	Core variables
Evaluative (time-bound monitoring)	• Understand, forecast and assess the implications of management choices. • Assess whether defined environmental outcomes are being achieved and, if not, investigate causes where possible. • Inform models and reduce uncertainty.	Typically 15-minute interval to quarterly	Tailored to management choice

3.3 Groundwater Classification

To objectively prioritise groundwater monitoring, a designation scheme adapted from the UK's aquifer designations was developed (Environment Agency 2017):

- Primary Class areas including aquifers with high intergranular and/or fracture permeability that may support water supply and/or river base flow or significant water bodies.
- Secondary Class areas consisting of rock and soil layers with a wide range of water permeability and storage. This class can be further divided into (A) capable of supporting water supplies at a local rather than regional scale, and may form an important source of base flow to rivers, and (B) may store and yield limited amounts of groundwater due to localised features, such as fissures, thin permeable horizons and weathering.
- Tertiary Class areas comprising lower permeability layers, which may store and yield limited amounts of groundwater due to localised features.

To assign a designation to an area, a Groundwater Reliance Index (GR Index) was calculated by multiplying the consented abstraction volume (as the maximum daily rate in $m^3.s^{-1}$) by the density of wells (per km^2) within a given geographical area. Areas assessed were based on a combination of a 10 km x 10 km grid and geologically defined surface polygons of New Zealand's hydrological systems map (Moreau et al. 2019b).

It is acknowledged that the GR Index calculation currently only considers human reliance. This is because there is currently no region-wide (or national) dataset available to objectively assess environmental reliance on groundwater (e.g. base flows to rivers) or cultural reliance. As such datasets become available, these may be factored into the GR Index and classes revised accordingly. In the interim, to address this gap for the Waikato region, environmental considerations were factored into later calculations that determine the appropriate level of monitoring effort in an area – the "GIS-based priority" (see Section 3.4). In addition, recommendations identifying potential suitable datasets for future inclusion are provided in Section 6.5.

GR Index values in the Waikato ranged between zero and 171 (Table 3.5). Initial results were scrutinised by WRC staff familiar with the groundwater resources in the region, which resulted in minor modifications (Table 3.5). Finally, classes were compared with recent publications related to Waikato's aquifers to ensure that known aquifers were represented (White et al. 2015; Hadfield 2022). This approach identified three primary, 19 secondary (seven A, 10 B and two undifferentiated) and three tertiary areas (Figure 3.1;

Table 3.6). The three primary areas are located within the South Auckland Volcanic Field (of the Kerikeri Volcanic Group in the northern areas and the Quaternary Tauranga Group sediments of the Hamilton Basin / Lower Waipa and Hauraki areas). Secondary areas include the fractured Quaternary volcanics in the Upper Waikato and Taupō areas, as well as localised aquifers serving coastal settlements on the Coromandel Peninsula.

Table 3.5 Groundwater Reliance Index (GR Index) modifications incorporating local knowledge.

Groundwater Class	**GR Index Range**		**Adjustment**
	Initial	**Revised**	
Primary	0–171	4.06–171	In small-sized polygons reflecting variations in regional boundary datasets, index was changed from 0 to -1.
Secondary A	0–6.4	0–3	Coromandel Peninsula GR Index re-assigned to 3, as local more than regional importance.
Secondary B	0–0.55	0–0.55	In the Upper Waikato, Quaternary deposits were re-assigned an index of 0.32 to reflect expected hydraulic continuity with underlying ignimbrites (index of 0.32).
Secondary Undifferentiated	0–0.79	0–0.79	Inclusion of Quaternary sediments in the Hauraki northern river valleys (Paeroa to Thames in the east and Patetonga to Miranda in the west), Taharoa and Taupō areas.
Tertiary	0–1.99	0–0.16	Inclusion of andesite dominated in the Coromandel Peninsula; siltstone-dominated Te Kuiti Group in the western areas and siltstone dominated Waitemata Group in the northern areas. GR Index 1.99 value was re-assigned to next highest for this class, 0.16, as in this area no abstractions occur.
Not applicable	0	-1	GR Index for water bodies and grid section outside of Waikato onshore were re-assigned to -1.

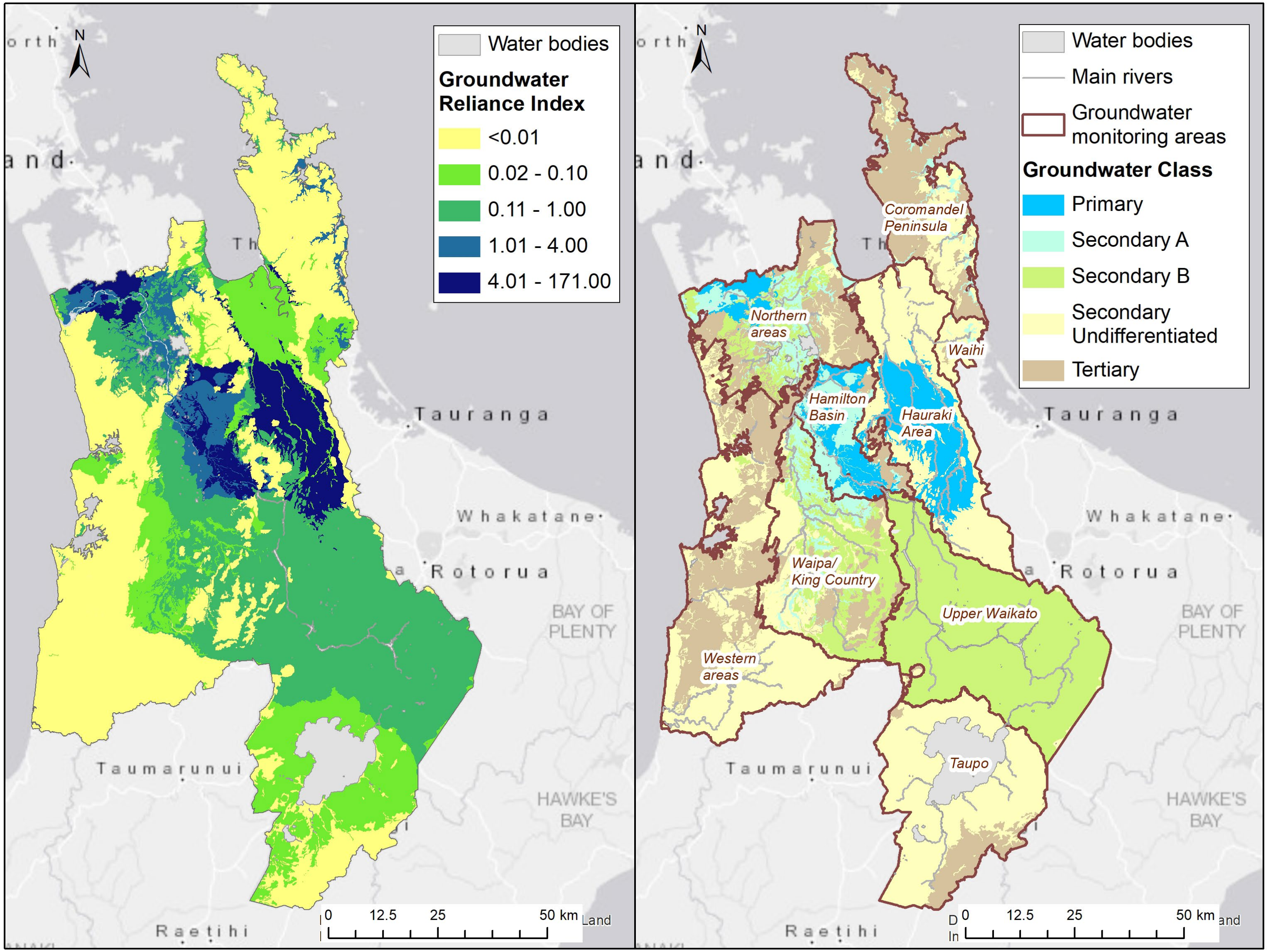

Figure 3.1 Groundwater quality Groundwater Reliance Index initial values (left) and Groundwater Classes (right) in the Waikato region after Waikato Regional Council (WRC) review.

Table 3.6 Groundwater Classes in the Waikato region.

Groundwater Monitoring Area	Hydrogeological System Names	Groundwater Class	Grouped Geology	Aquifer Geological Formation Example
Coromandel Peninsula	Colville, Plenty	Secondary A	Holocene sediments	Tauranga Group, Karioitahi Group
	Colville	Secondary A	Holocene sediments	Holocene sediments
	Coromandel Peninsula	Secondary Undifferentiated	Tertiary volcanics (andesites and rhyolites)	Coromandel and Whitianga Group
Hamilton Basin	Hamilton	**Primary**	Quaternary sediments	Tauranga Group, Hinuera Formation, Piako Sub-group, Walton Sub-group
	Hamilton	Secondary A	Quaternary sediments	Holocene sediments
	Hamilton	Secondary A	Volcanics	Mamaku Ignimbrite, Pakaumanu Group ignimbrites, Waiterariki Ignimbrite
Hauraki Area	Hauraki	**Primary**	Quaternary sediments	Tauranga Group, Hinuera Formation, Piako Sub-group, Walton Sub-group
	Hauraki	Secondary Undifferentiated	Quaternary sediments	Holocene swamp deposits
Lake Taupō Catchment	Taupō	Secondary Undifferentiated	Ignimbrites, rhyolites, basalts	Taupō Ignimbrite, Whakamaru Ignimbrite, Oruanui Ignimbrite
	Taupō	Secondary Undifferentiated	Holocene sediments	Taupō Pumice Alluvium
Northern Areas	South Auckland Volcanics	**Primary**	Quaternary volcanics	Kerikeri Volcanic Group of South Auckland Volcanic Field (shallow and deep units)
	Lower Waikato, Awhitu	Secondary A	Holocene sediments	Tauranga Group
	Limestone Downs	Secondary B	Tertiary sediments	Te Kuiti Group, Miocene sediments
	Lower Waikato, Awhitu	Secondary B	Tertiary sediments	Kaawa Formation, Waitemata Formations sandstones

Groundwater Monitoring Area	Hydrogeological System Names	Groundwater Class	Grouped Geology	Aquifer Geological Formation Example
Upper Waikato River Catchment	Upper Waikato	Secondary B	Quaternary volcanics	Waiotapu Ignimbrite, Whakamaru Ignimbrite, Rangitaiki Ignimbrite, Taupō Ignimbrite, Oruanui Ignimbrite, Waiora Formation, Pakaumanu Group, Mamaku Plateau Formation, Earthquake Flat Formation
	Upper Waikato	Secondary B	Holocene sediments	Tauranga Group
Waihi Basin	Waihi	Secondary A	Holocene sediments	Holocene sediments
	Waihi	Secondary B	Tertiary volcanics	Coromandel Group and Whitianga Group
Waipa Catchment / King Country	Waipa	Secondary A	Holocene sediments	Holocene sediments, Tauranga Group
	Waipa	Secondary B	Quaternary volcanics	Alexandra Volcanic Group, Pakaumanu Group
	Waipa	Secondary B	Tertiary sediments	Te Kuiti Group
West Coast Areas	Marokopa, Limestone Downs	Secondary B	Te Kuiti Group limestone-dominated karstic formations	Otorohanga Limestone and Orahiri Limestones
	Kawhia Harbour, Aotea Harbour, Tararoa, Tirua	Secondary Undifferentiated	Holocene sediments	Karioitahi Group
	Raglan Harbour, Orangiwhao	Secondary Undifferentiated	Quaternary volcanics	Hamilton Ash Formation, Kauroa Ash Formation
Region	Basement Infill	Tertiary	Holocene to Tertiary siltstone-dominated sediments	Glen Massey Formation
	Basement Infill	Tertiary	Tertiary andesite-dominated volcanics	Waiwawa Sub-group, Omahine Sub-group
	Basement Hard Rock	Tertiary	Cretaceous and earlier hard rocks	Manaia Hill Group

3.4 Site Distribution

An index-overlay method has been used to assess priority areas for groundwater quality monitoring. The index-overlay method involves the superposition of a relative rating system over mappable units. The combination of weights and ratings for each attribute assessed produces a GIS-based priority for each mappable unit. The GIS-based priority provides a means of assessing the mappable units relative to each other. This allows informed decisions to be made on the design of the groundwater monitoring network. The DRASTIC model, used to assess the pollution potential in hydrogeologic settings (Aller et al. 1987), is an example of a widely used index-overlay method.

For the purposes of the groundwater quality monitoring network, mappable units were selected to be a 10 km x 10 km grid overlaid across the Waikato region, combined with hydrogeologically defined polygons. This resulted in 3210 individual mappable units, which ranged in size from less than 1 km^2 to 10 km^2 (median 0.4 km^2) to be assessed. The attributes chosen for the relative rating assessment were selected with consideration to the four criteria described in the Environment Aotearoa 2019[2] synthesis report to provide a 'focus on what matters' approach (Table 3.7). Ratings of between 0 and 3 have been assigned for each attribute in each grid cell with respect to the other grid cells (0 being of low priority, 3 being of higher priority). The weightings assigned to each attribute have been assessed with respect to each other to determine the relative importance of each factor with respect to groundwater quality (Table 3.7).

The GIS-based priority is calculated from the attribute ratings and weightings for each grid cell. The GIS-based priority is a number between 0 and 3; the higher the GIS-based priority, the higher priority that area is for groundwater quality monitoring. It should be noted that the GIS-based priority is a relative evaluation and does not give absolute answers, but rather identifies areas that are determined to be of higher priority and thus where groundwater quality monitoring should be focussing. The equation for determining the GIS-based priority for each grid cell is:

$$GIS\text{-}based\ Priority = \sum A_R A_W \qquad \text{Equation 3.1}$$

Where:

$$A_R = \frac{Area}{cell\ parameter\ rating}$$

and

$$A_W = \frac{Area}{cell\ parameter\ weighting}$$

The assessment was undertaken in GIS and a detailed description of the assessment and ranking for each attribute is provided in Appendix 2.

2 https://environment.govt.nz/publications/environment-aotearoa-2019/

Table 3.7 Attributes and weightings used to assess priority areas for groundwater quality monitoring. NA is not applicable. Ministry for the Environment's four criteria are: (1) spatial extent and scale, (2) magnitude of change, (3) irreversibility and lasting effects of change, and (4) scale of effect on culture, recreation, health and economy.

Attribute	Focus Criteria (Environment Aotearoa 2019[3])	Surveillance Consideration	Weighting (%)	Evaluative Consideration (Nitrate)	Weighting (%)	Evaluative Consideration (Seawater Intrusion)	Weighting (%)
Groundwater Class (i.e. primary, secondary, etc and calculated using well density and abstraction volume).	1	Y	65%	Y	20%	Y	50%
Vulnerability	3	-	-	Y	20%	-	-
Land use	1,3,4	-	-	Y	20%	-	-
Drinking water	4	-	-	Y	10%	Y	10%
Known GW quality issues	2,3	-	-	Y	30%	Y	30%
GW-SW interaction	1,3,4	Y	20%	-	-	-	-
Taonga	3,4	Y	10%	-	-	-	-
Climate change	3,4	Y	5%	-	-	Y	10%
Other considerations for site selection and frequency not spatially based.							
Distance from coast	3	-	-	-	-	Y (to include/exclude)	NA
Redox state	2,3	-	-	Y (to inform site selection)	NA	-	-
GW age	3	Y (only to inform frequency)	NA	Y (to inform site selection)	NA	Optional	-
Anticipated land use change	2,3	-	-	Y (if available)	NA	Y (if available)	NA
Policy details (if applicable)	3	-	-	Y (if available)	NA	Y (if available)	NA

3 https://environment.govt.nz/publications/environment-aotearoa-2019/

A single Surveillance weighting distribution was applied to all contaminants, whereas Evaluative weightings were assessed differently, depending on the contaminant of concern – in this case, we considered nitrate and seawater intrusion.

The well density and abstraction volume attributes (i.e the Groundwater Class) were considered in both Surveillance and Evaluative assessments. This is because it is considered important to focus limited monitoring efforts in aquifers which are the most used.

The vulnerability attribute was based on a DRASTIC assessment undertaken in the Waikato in 2003 with respect to the vulnerability of groundwater to contamination from the surface (Brown 2003; Fryer 1999). The DRASTIC assessment is itself an index-based method, and considers several attributes (depth to groundwater, hydraulic conductivity, recharge rate, vadose zone, aquifer media, soil media and topography). Thus, it was sensible to assign a large weighting to this attribute for the nitrate Evaluative network as it represents many sub-attributes and is directly relevant to diffuse nitrate contamination. Vulnerability was not considered for seawater intrusion Evaluative monitoring because the DRASTIC assessment undertaken by Brown (2003) related to land-based contamination and not abstraction-related seawater intrusion. The vulnerability to seawater intrusion is essentially covered by the well density and abstraction volume attributes, and the distance from the coast, which are both factored into this assessment. Vulnerability was not considered for Surveillance monitoring as the purpose of Surveillance monitoring is to provide a general status of groundwater bodies, without any particular focus or bias towards high-risk areas.

Attributes that were considered to have a direct anthropogenic relationship (land use, groundwater use and known groundwater quality issues) were only considered for Evaluative assessment (i.e. they were assigned a 0% weighting for Surveillance). Other weightings were assigned based on their perceived importance to the monitoring objective. For example, land use was given a high weighting (20%) for nitrate Evaluative monitoring as intensive agricultural and horticultural land uses are known to negatively affect groundwater quality in the Waikato (Hadfield 2022). By contrast, the well density and magnitude of groundwater abstraction was given a high weighting (25% each) for seawater intrusion Evaluative monitoring, as over abstraction is known to be a common cause of seawater intrusion (Callander et al. 2011). It should be emphasised that the weightings assigned in this assessment are preliminary and can be easily revised for future network reviews or for changing objectives.

Results of the assessments are shown in Figure 3.2 to Figure 3.5, below.

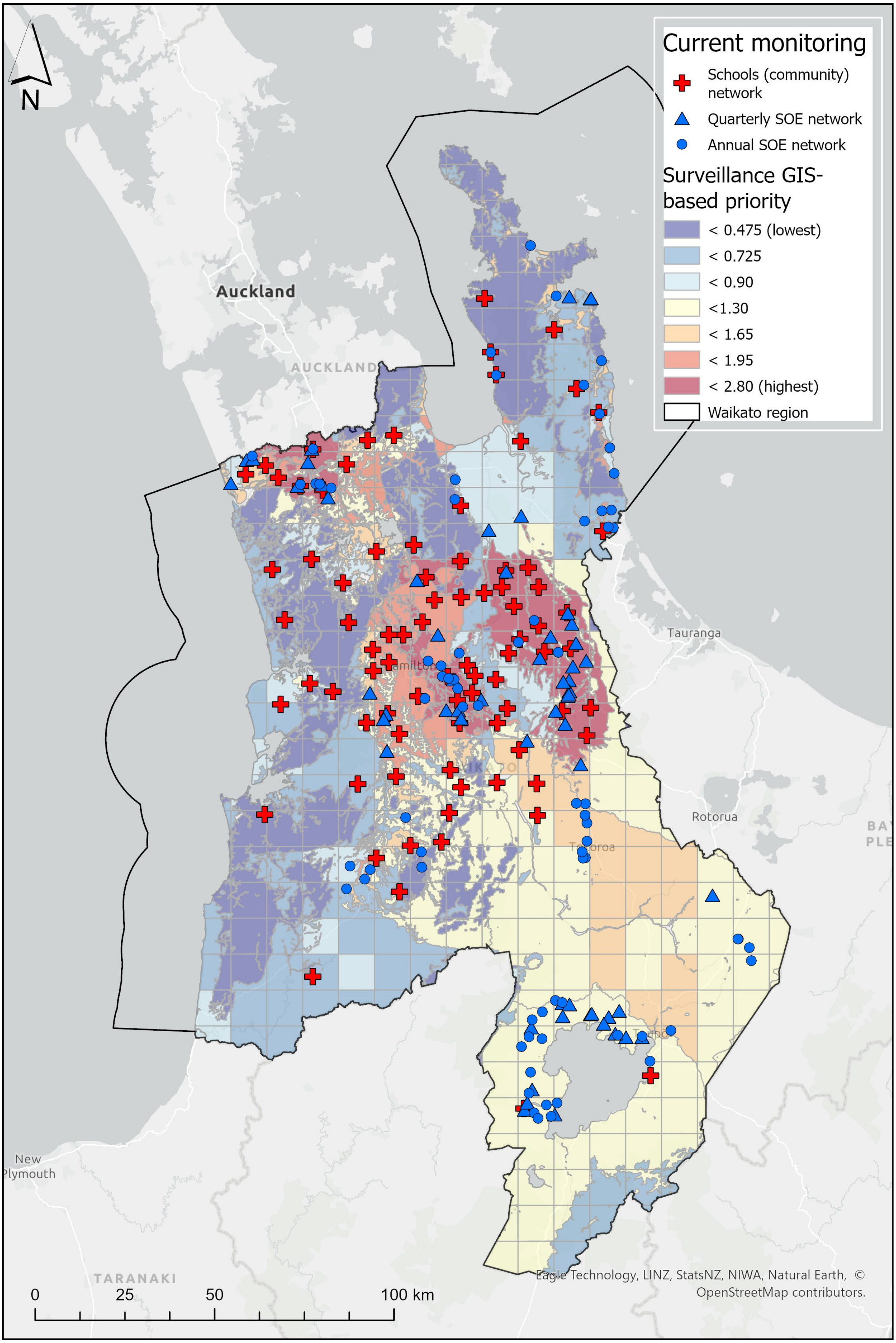

Figure 3.2 Priority ranking for Surveillance monitoring in the Waikato region.

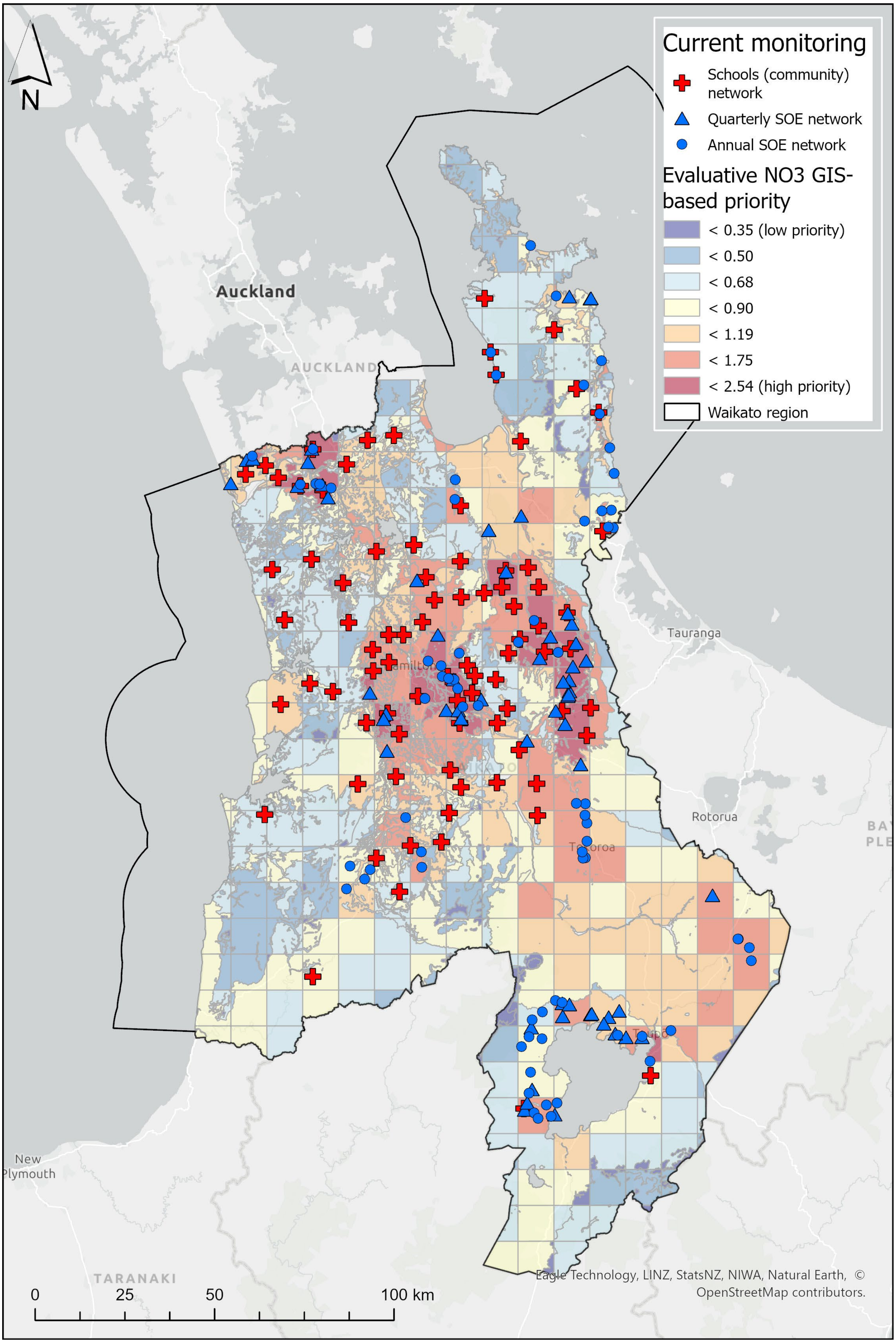

Figure 3.3 Priority ranking for Evaluative (Nitrate) monitoring in the Waikato region.

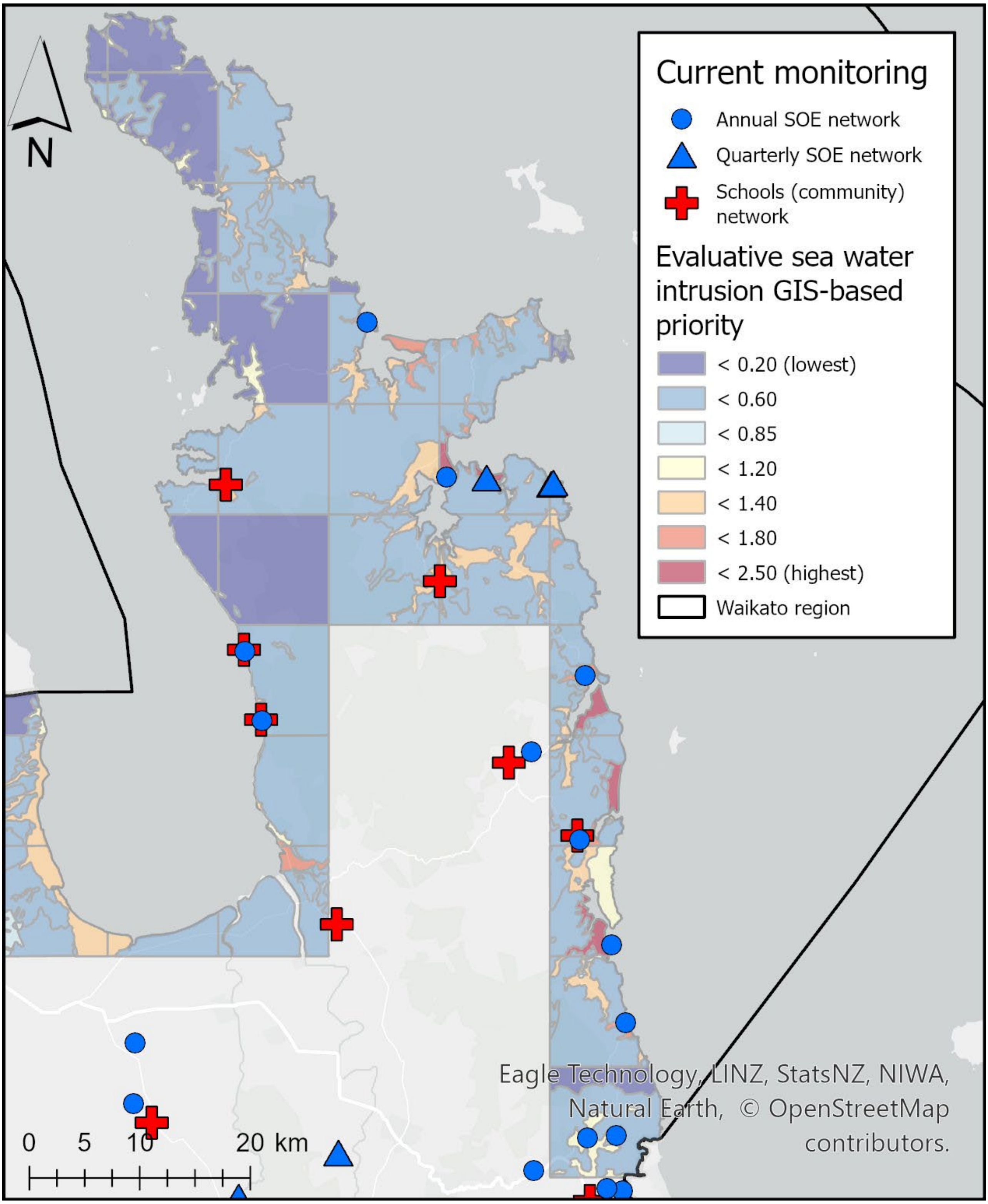

Figure 3.4 Priority ranking for Evaluative (seawater intrusion) monitoring in the Coromandel Peninsula.

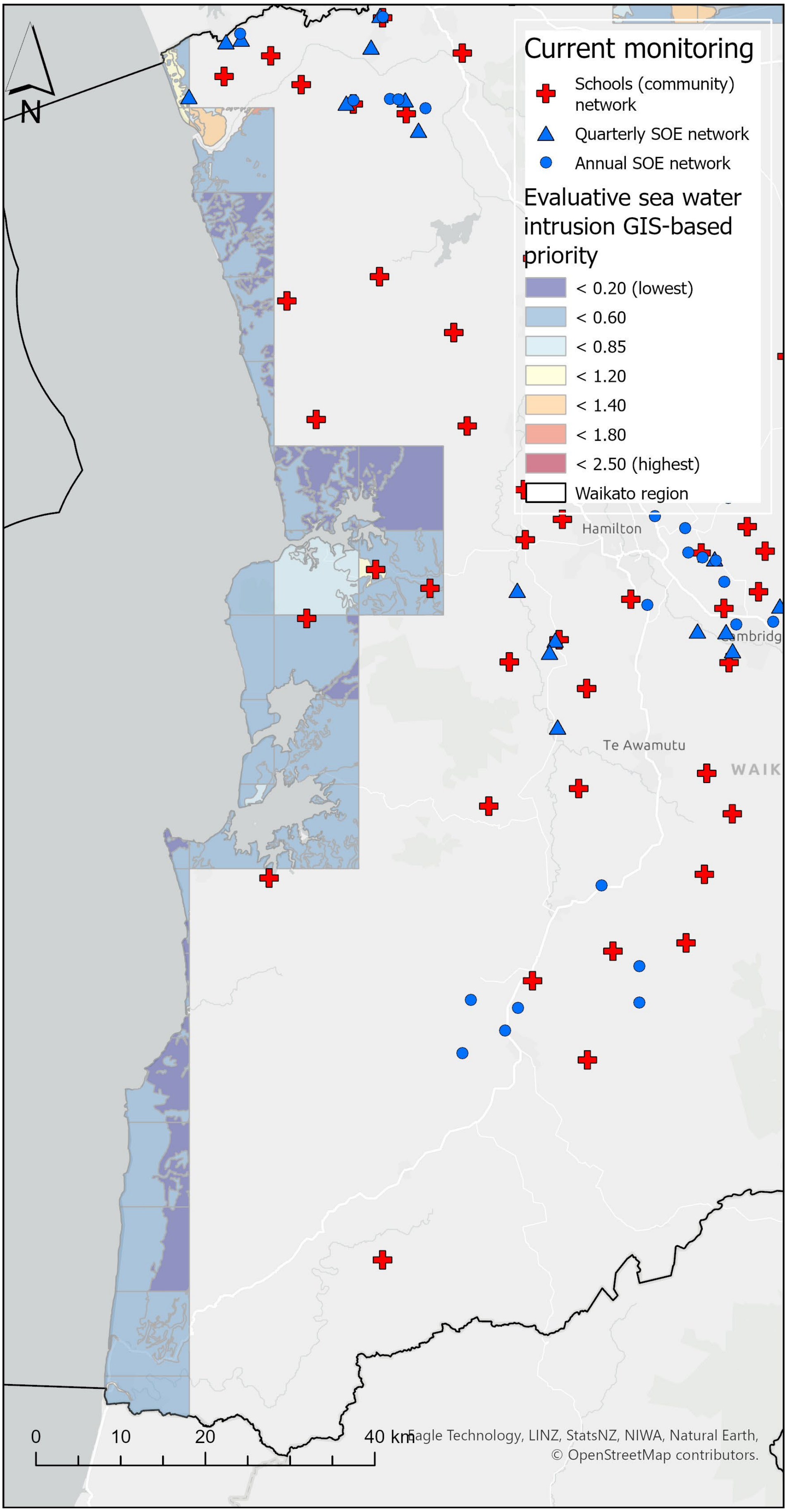

Figure 3.5 Priority ranking for Evaluative (seawater intrusion) monitoring in the west coast of the Waikato region.

3.5 Variables and Sampling Frequency

Analytical suites and sampling frequencies for the regional and national programmes were reviewed against the following:

- The rationale for monitoring each variable.
- Core variables agreed in November 2024 by the Groundwater Forum in parallel with this review (Groundwater Special Interest Group 2024). Reaching this agreement is fundamental to enable aggregation at a national level, thus directly addressing some of the inconsistencies noted by the PCE (2019). It also provides peer-review amongst practitioners.
- The current New Zealand drinking-water analysis requirements (Water Services [Drinking Water Standards for New Zealand] Regulations 2022).
- The monitoring suite undertaken with the US national groundwater quality monitoring framework (Subcommittee on Ground Water of the Advisory Committee of Water Information 2009).
- Insights gained from collected data and practical considerations.

Sampling frequency was reviewed against the monitoring objectives, cost and practical considerations. For NGMP monitoring, the current national reporting requirements under the Environment Reporting Act were also considered. The latter are currently set as a minimum of 10 data points to undertake trend analysis, where time periods of five years and 10 years are used to define ‘state’ and ‘trend’, respectively (Moreau 2023 [and references therein]).

3.6 NGMP Programme

The number and location of active sites and sampling frequency were reviewed with considerations for: NGMP monitoring objectives, the region’s hydrogeological setting, WRC’s Surveillance priority ranking (Section 3.3) and topics required to be reported under the 2015 Reporting Act New Zealand (Ministry for the Environment and Statistics New Zealand 2016).

NGMP monitoring objectives around regular data collection are to provide a long-term perspective on the state and trends in groundwater quality suitable to inform national reporting. Practical efficiencies (e.g. avoid site duplication, data management) with regional programmes are part of NGMP’s operational objectives. Data are used as context for supporting pilot surveys, such as dissolved metals or eDNA (to characterise groundwater microbial communities).

The main hydrogeology features in the region are (Figure 3.6):

- The three main primary systems: Kerikeri Volcanic Group of the South Auckland volcanics system (northern areas), Quaternary sediments in the Hamilton Basin / Lower Waipa, and the Hauraki area. The South Auckland volcanics system hosts multiple, distinct aquifers (Morgenstern et al. 2023) and extends across the regional boundary between WRC and the Auckland Council.
- Four secondary aquifer systems: Taupō, Upper Waikato, Waipa and the Coromandel Peninsula. Taupō, Upper Waikato and Waipa cover each more than 10% of the region, are located upgradient from the Hamilton Basin and support large surface water features (Lake Taupō, Waikato River). Note that the Lower Waikato system is also located along the Waikato River; however, it consists mainly of low-producing Tertiary deposits where groundwater-surface water interactions are limited. The localised, multiple eastern Coromandel Peninsula areas were included as they provide the main water supply for many settlements.
- Large karstic areas within limestone-dominated formations of the Te Kuiti Group (western areas).

- Geothermal areas with associated surface features, such as springs. Approximately 70% of New Zealand geothermal resources are located in the Waikato region (Luketina 2022). High-temperature systems are associated with the TVZ. Most low-temperature systems are located outside of the TVZ, for instance within the Hauraki rift zone (Luketina 2022; Hochstein 1978).

The topics required to be reported nationally fit within a ‘Drivers’, ‘Pressures’, ‘State’, ‘Impact’, ‘Response’ framework, the latter being excluded from environmental reporting (PCE 2019). Topics relevant to groundwater quality monitoring are (Ministry for the Environment and Statistics New Zealand 2016):

- Pressures on the freshwater environment from climatic and natural events, such as rainfall, temperature, volcanic and seismic activity, natural erosion and natural nutrient discharges from the substrate (underlying rock).
- State of Freshwater quality, quantity and flows, which includes geothermal water quality and quantity.
- The impact the SoE has on New Zealand’s biodiversity and ecosystem processes.
- The occurrence of health effects that are related to the SoE.
- The impact the SoE has on the cultural and recreational use of our environment, aesthetic and amenity value.
- How the SoE affects the ability to maintain, develop and transmit traditional Māori knowledge about the environment and maintain tikanga practice.

It should be noted that the RMA (1991) defines geothermal water as any water heated by natural phenomena to a temperature of 30°C and above. WRC conducts regular geothermal monitoring as required under the RMA s35 (Luketina 2022). SoE monitoring and reporting of geothermal waters is conducted separately by WRC owing to the significant differences in monitoring and management between freshwater and geothermal water resources. At the time of writing this report, the proposed changes to the Environmental Reporting Act (2015) include the extension of the pressure-state-impact framework to include a requirement for information on drivers (i.e. factors that cause the pressures on the environment) and outlooks (i.e. how the SoE may change in the future and the likely impact of such changes) (Ministry for the Environment 2021).

Under the current Environmental Reporting Act, each domain must be reported on three-yearly, and the current proposed changes include a change to six-yearly data and a yearly commentary per domain. In Europe, the minimum time period recommended to report on groundwater quality state varies between two and six years, with longer periods applying to time series with seasonal variations, which require quarterly frequency (European Commission 2009). Quarterly frequency is also recommended to assess groundwater quality and environmental impacts in Queensland, Australia (Claus et al. 2021). Analysis of the current NGMP dataset showed that seasonality affected up to 25% of parameter-specific data (Moreau-Fournier and Daughney 2012). Published values for the minimum data point requirements for robust trend detection range between eight and 10 over the trend period (US EPA 2006), and eight data points and at least one data point for 75% of the time period (StatsNZ 2024). The latest Groundwater Quality Indicator consisted of state analysis defined as five years and trend analyses over 10 and 20 years (Moreau et al. 2025).

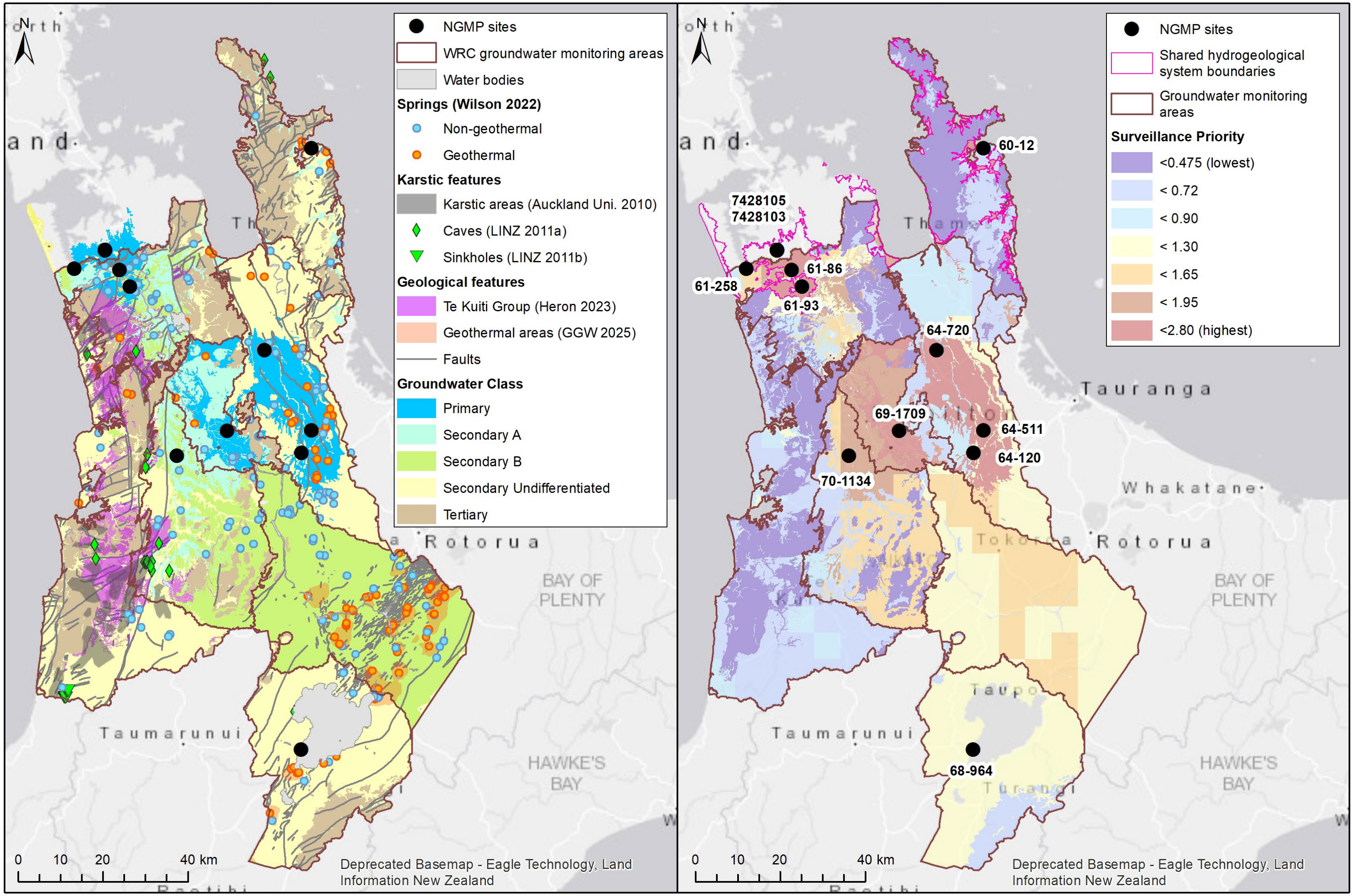

Figure 3.6 National Groundwater Monitoring Programme (NGMP) site distribution in the Waikato region relative to the hydrogeological features (left) and WRC Surveillance priority assessment (right) Hydrogeological systems were delineated using a combination of geological, geomorphological, groundwater, structural, topographic, catchment and arbitrary boundaries (Moreau et al. 2019b). As a result, some systems occur within more than one region. Four systems cross regional boundaries over more than 10% of their areas: Awhitu and South Auckland Volcanics (northern areas); Colville and Plenty (Coromandel and Hauraki).

The NGMP programme is organised in three components: operations, research and data management. Under operations, the monitored sites relevant to Waikato's hydrogeological features are located in both the Waikato (10 sites) and Auckland (two sites) regions. Ten sites are sourced by primary systems and two by secondary systems (Coromandel Sand and Taupō Pumice Alluvium). Monitoring well densities calculated by hydrogeological system area range from one well per 124 km^2 (South Auckland Volcanics) to one well per 3000 km^2 (Taupō). Sampling for microbial eDNA at NGMP and/or SoE sites to characterise groundwater ecosystem diversity and functions is undertaken as part of the research component. Sampling is rotated between regions each year for cost-efficiency and to align with other GNS Science's research programmes where possible. This is the same approach used to collect groundwater age data and time series.

The programme review was undertaken by iteratively trialling to address multiple monitoring objectives. The first option was developed using a uniform site density of one well per 100 km^2 for all primary systems, with at least one monitoring site in each. The resulting network consisted of 45 annually monitored sites. This option was abandoned because some of the major hydrogeological regional features remain unmonitored, the affordable dataset has low statistical power and there is limited added value to the regional network.

A second option was developed to explore a combination of well densities based on systems monitoring priority (one per 500 km^2 for high and one per 1000 km^2 for medium) and a minimal requirement of six data points per primary system, which is the minimum recommended for characterisation of groundwater quality status in the UK (Environment Agency 2022). A site was added to include the Coromandel Holocene sediments, considering their limited extent. The resulting network consisted of 29 sites with varying sampling frequency from quarterly (11 new sites) to biannually (11 existing sites). Some of the major regional hydrogeological features remain unmonitored at the national scale, and the similar criteria means that added value from the regional network remains limited. This option was not retained.

A third option explored a combination of well densities based on systems size: one per 1000 km^2 for areas over 500 km and one per 100 km^2 for areas of less than 500 km^2. The resulting network consisted of 26 biannually monitored sites. This option was not retained as some major regional hydrogeological features remain unmonitored at the national scale, and differences with the regional network were not significant.

A fourth option was devised to include monitoring sites within each of the major hydrogeological features, with at least three sites in high-priority systems (up-, mid- and low-gradient and/or spatially distributed if not applicable). Long-term, regular monitoring of geothermal features or groundwater ecosystems was excluded from the current scope as it will require experts to determine the suitable number of sites, analytical suite and sampling frequency. The resulting network comprised 18 sites with sampling frequency varying from biannually (existing sites) to quarterly (new sites). This option was further refined with considerations for the research and data management components of NGMP to address gaps in national reporting and cost-efficiencies in operations with WRC. It represents a compromise between increasing the breadth of information available for reporting and current resourcing, and, in doing so, better complements the regional monitoring.

3.7 Balancing Monitoring Objectives and Cost

A principal consideration in monitoring-programme design and review are financial and logistic investments. The cost of operating a monitoring programme can be split into three components:

1. Operations that involve sampling preparation (e.g. contacting well owners, field-meter calibration), field data and sample collection, sample dispatch, analysis, QA/QC procedures, data upload to a designated repository, internal reporting and management.

2. Science investigations, which include pilot surveys, low-frequency repeat surveys, data analysis and interpretation, science dissemination and research opportunity alignment.
3. Long-term data curation, including systems upgrades, assessing new technologies, new data standards and user data needs.

Aside from some operational aspects, programme costs are not directly proportional to the size of the network; for instance, data curation includes ensuring modern storage and current data sharing standards are being used, regardless of the dataset size if considering discrete monitoring only. The long-term nature of Surveillance monitoring also means susceptibility to inflation over time. Some cost efficiencies may be realised through the monitoring programme components (e.g. NGMP groundwater ecosystem monitoring characterisation is currently undertaken within the ‘science’ component).

While there is a range of methods to optimise monitoring programmes, practically any modification arising from optimisation requires balancing objectives with resourcing. To illustrate the concept, two NGMP optimisation options are presented in Table 3.8, alongside the monitoring objectives they are seeking to address. Both options provide a fit-for-purpose network and support national reporting, but represent a different response to the monitoring objectives.

Option A aims to increase spatial coverage, using a well density of one well per 200 km^2 for primary areas and a minimal requirement of six data points per Primary Monitoring system, which is the minimum recommended for characterisation of groundwater quality status in the UK (Environment Agency 2022). The initial required number of monitoring sites is 28; however, under fixed resourcing, quarterly sampling is no longer affordable. To remain cost-effective, monitoring sites located in Secondary Monitoring systems must be dropped and sampling frequency dropped to bi-annually in Primary Monitoring systems. In this option, the compromise is increased spatial resolution (i.e. minimum data points is six for each per monitored system) compensated by fewer monitored groundwater bodies (three), fewer objectives achieved (seven out of 12 objectives) and a lower temporal resolution (i.e. the minimum number of data points is lowered to eight per five-year time window).

Option B aims to increase the breadth of information provided: monitoring sites are located within each of the major hydrogeological features of the region. The Hauraki area and the Hamilton Basin each have three monitoring sites (up-, mid- and low-gradient). The Franklin Basalt is monitored at four sites to provide spatial distribution across the regional boundary. The initial number of proposed sites is 18, which, to remain internally cost-effective, has to be revised to quarterly sampling at the seven new sites and bi-annually at the remaining 11 existing sites. In this option, the compromise is increased objectives achieved (nine out of 12 objectives) and groundwater bodies representation (eight) compensated by lower spatial resolution (i.e. minimum data points is one per monitored system) and a lower temporal resolution (i.e. the minimum number of data points is lowered to eight per five-year time window).

A further degree of cost-effectiveness can be achieved by sharing monitoring sites between Surveillance networks and through inclusion of third-party sites. In the case of Option B, which is the proposed NGMP network, by aligning the analytical suite and laboratory needs at the shared sites aligned, quarterly sampling can be maintained at all 18 sites, providing increased statistical power. This efficiency is relying on the overall programme cost and may be revised as the network continues to be optimised in other regions.

Realising pan-organisation efficiencies, however, induced a degree of uncertainty over the long-term, as it relies on site access agreements. These uncertainties may be addressed by formalising the partnership agreement (e.g. MOUs) to ensure trade-offs remain visible between parties and adjusted as agreements require reviews in the future. It may then be appropriate for monitoring agencies to report back to participant organisations regularly to reflect cost alignments.

Table 3.8 Examples of balancing operational costs to optimise NGMP monitoring in a fixed-resource model. Q, BA and A indicate a quarterly, bi-annual and annual sampling frequency, respectively. The asterisk indicates criteria filled through another programme component (e.g. pilot/low-frequency surveys) or relying on third-party agreement. Note that the minimum data points are estimated using the sampling frequency minus two measurements to account for site visit variability (e.g. pump not working or site access denied). Light-grey background highlights change from the current network. Analytical costs are estimated using the current NGMP variable suite at current cost of approximately NZD$400.00 per analysis.

<table>
<tr><th></th><th></th><th colspan="2">Option A
Denser Network</th><th colspan="2">Option B
Increased Breadth</th></tr>
<tr><th></th><th>Current</th><th>Initial</th><th>Cost-Effective</th><th>Initial</th><th>Cost-Effective</th></tr>
<tr><td colspan="6">Network</td></tr>
<tr><td>Number of sites</td><td>13</td><td>28</td><td>28</td><td>18</td><td>18</td></tr>
<tr><td>Sampling frequency</td><td>Q</td><td>Q</td><td>BA</td><td>Q</td><td>Q (7) + BA (11)</td></tr>
<tr><td>Number of analyses per year</td><td>48</td><td>112</td><td>56</td><td>80</td><td>50</td></tr>
<tr><td>Analytical cost (NZD) – Waikato</td><td>20,800.00</td><td>44,800.00</td><td>22,400.00</td><td>32,000.00</td><td>19,200.00</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td>Number of primary systems characterised</td><td>3</td><td colspan="2">3</td><td colspan="2">3</td></tr>
<tr><td>Number of primary systems monitored</td><td>3</td><td colspan="2">3</td><td colspan="2">3</td></tr>
<tr><td>Number of secondary systems characterised</td><td>4</td><td colspan="2">0</td><td colspan="2">5</td></tr>
<tr><td>Number of secondary systems monitored</td><td>4</td><td colspan="2">0</td><td colspan="2">5</td></tr>
<tr><td>Karstic environments monitored</td><td>0</td><td colspan="2">0</td><td colspan="2">yes*</td></tr>
<tr><td>Geothermal water quality characterised</td><td>no</td><td colspan="2">yes*</td><td colspan="2">yes*</td></tr>
<tr><td>Geothermal water quality monitored</td><td>no</td><td colspan="2">no</td><td colspan="2">no</td></tr>
<tr><td>Groundwater ecosystems characterised</td><td>yes</td><td colspan="2">yes</td><td colspan="2">yes</td></tr>
<tr><td>Groundwater ecosystems monitored</td><td>no*</td><td colspan="2">no*</td><td colspan="2">no*</td></tr>
<tr><td>Human health effect can be assessed</td><td>yes</td><td colspan="2">yes</td><td colspan="2">yes</td></tr>
<tr><td>Aesthetic and amenity values assessed</td><td>yes</td><td colspan="2">yes</td><td colspan="2">yes</td></tr>
<tr><td>Māori knowledge, tikanga practice</td><td>limited</td><td colspan="2">limited</td><td colspan="2">limited</td></tr>
<tr><td>Minimum data points per five years</td><td>18</td><td>18</td><td>8</td><td>18</td><td>8</td></tr>
<tr><td>Minimum # sites per primary system</td><td>1</td><td>6</td><td>6</td><td>1</td><td>1</td></tr>
</table>

4.0 Optimising Regional Monitoring in the Waikato

4.1 Surveillance Network

The existing distribution of the groundwater quality monitoring network was assessed with reference to the spatial prioritisation assessment described in Section 3.4. Sites are proposed to be variably added or dropped to reflect priority areas. In areas where there was a lack of monitoring sites, existing private wells were identified for field reconnaissance based on available information (doc 32007561). These included the availability of hydrogeological information (i.e. a detailed bore-log), location and likely access, with preference given to more recently constructed wells. Field visits to potential new sites were undertaken and samples collected for analysis where possible. Site sheets were created for all sites visited. As a general guidance, the density of wells within each area was defined to be:

- Two to three wells per 10 km^2 in the higher priority areas (red areas).
- One well per 10 km^2 in the medium-high priority areas (orange areas).
- One well per 20 km^2 in the medium priority areas (peach areas).
- One well per 40 km^2 in the medium-low priority areas (yellow areas).
- One well per 80-100 km^2 in the low priority areas (blue areas).

A regional overview of the proposed changes is shown in Figure 4.1; area-by-area review of site distribution is detailed in the following sections.

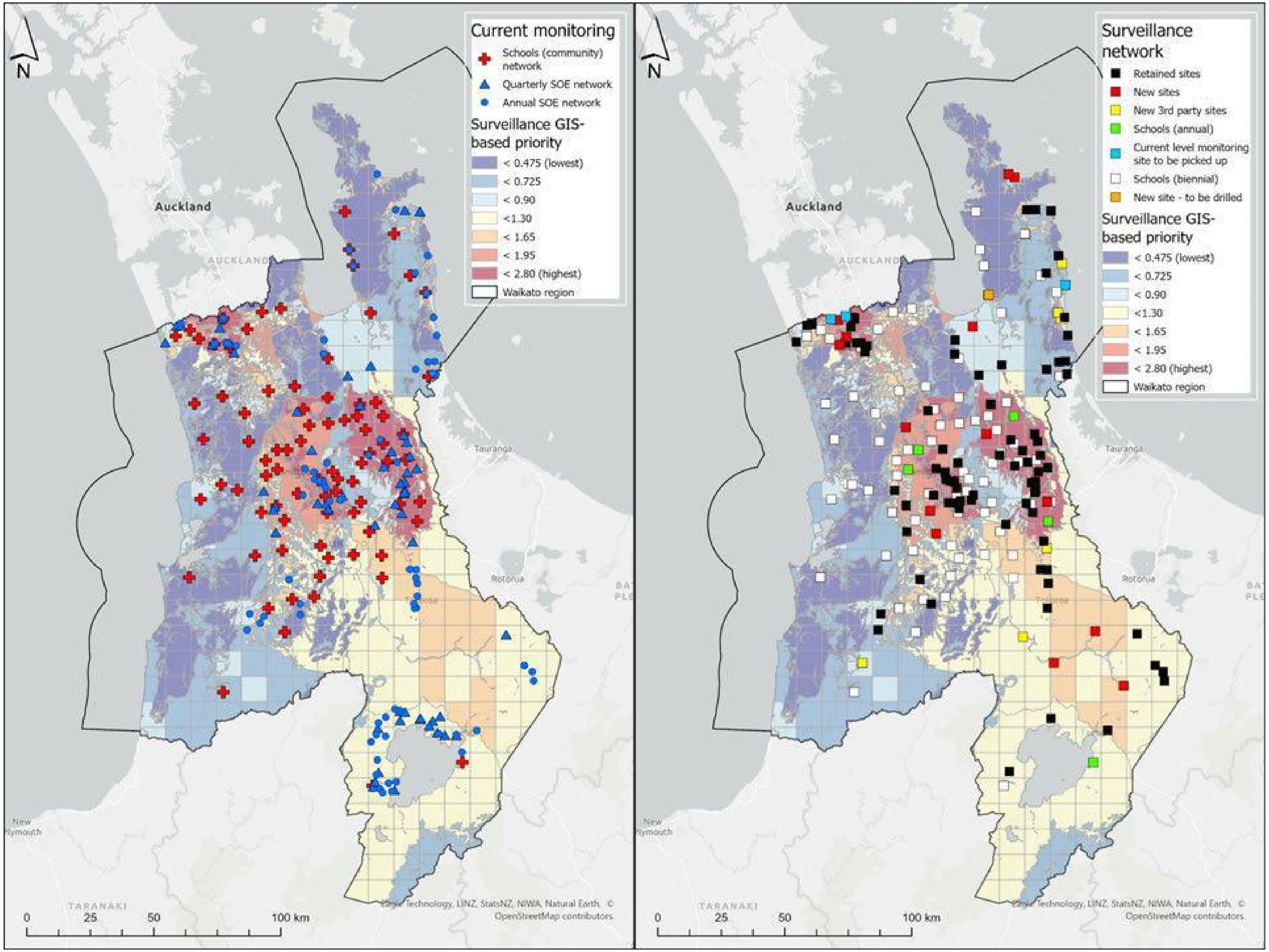

Figure 4.1 Current (left) and proposed (right) Surveillance monitoring sites in the Waikato region.

4.1.1 Lake Taupō Catchment

The Lake Taupō catchment comprises relatively low-yielding, recent volcanic formations. There is already considerable groundwater quality monitoring in this catchment to inform management for the protection of lake water quality. Related policy initiatives included the introduction of a nitrogen cap and trade system. National, regional and district funding was also invested in removing 20% of the manageable nitrogen load to the lake. This was achieved by establishing the Lake Taupō Protection Trust, which essentially bought back nitrogen via reforestation.

The map below (Figure 4.2) shows the current monitoring of 34 sites in the catchment. Half of these (triangles) have been incorporated as part of the current SoE monitoring network (i.e. annual groundwater monitoring), with the other half currently remaining specific to the lake catchment management response (i.e. quarterly groundwater monitoring). Given the relatively low-priority assessment for Surveillance, only a few wells are justified purely from the perspective of monitoring the local aquifers. Only three Surveillance wells are proposed as shown in Figure 4.2. These are wells 72_1087 (west), 68_317 (north) and 68_794 (east), which is Waitahanui School. It should be noted that many of the sites on the western side of the lake are proposed to be retained as part of the Evaluative network.

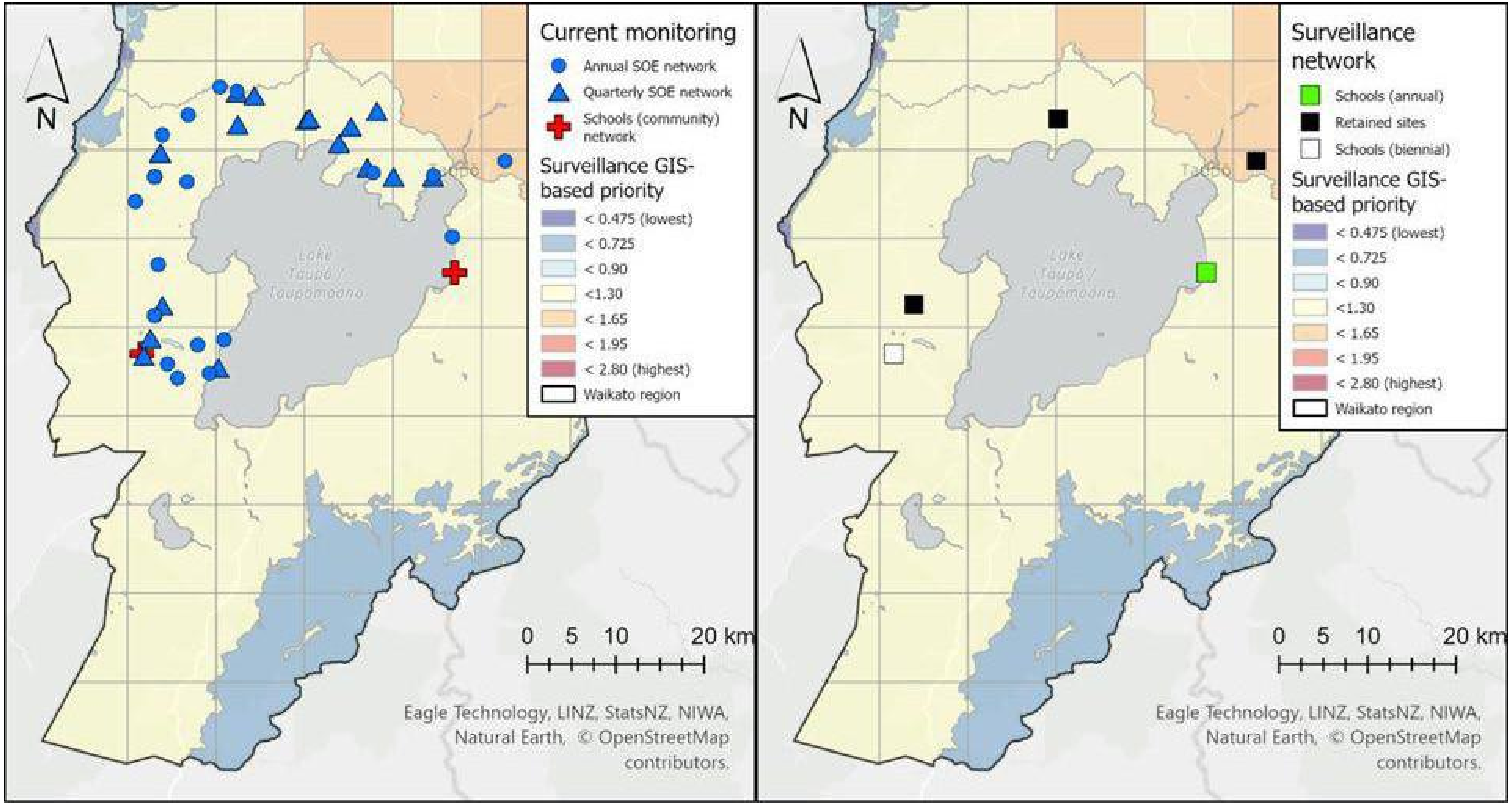

Figure 4.2 Current (left) and proposed (right) Surveillance monitoring sites in the Lake Taupō catchment.

4.1.2 Upper Waikato River Catchment

The Upper Waikato River catchment stretches from the outlet of Lake Taupō to Lake Karapiro. The Upper Waikato has ignimbrite dominated hydrogeology (both fractured and unwelded). It is an area with substantial recent dairy conversion typically involving corporate farming. The GIS-based prioritisation for Surveillance monitoring in this area is modest. Four additional monitoring sites in the Upper Waikato area were identified that would be desirable (Figure 4.3).

Taupō District Council (TDC) was approached and agreed to collaborate with water quality monitoring and data sharing at Maraetai Spring, which is the Mangakino community water supply (Located 1131_87 and Taumata Arowai G00088). TDC undertake monthly source water monitoring for *E. coli*, total coliforms and turbidity. Also, more comprehensive annual monitoring and chemical analysis are carried out, including nutrients, via the Eurofins laboratory in Wellington. Such information for 2024, including other TDC community supply source waters, is available in doc 32012845. It appears that future collaboration with TDC in respect to groundwater quality monitoring at this site will be straightforward.

Six existing private wells were visited and sampled (72_10057, 72_3979, 72_3645, 68_651, 72_9232 and 72_3566). Of these sites, 72_10057, 72_3979 and 72_3645 were chosen as suitable for inclusion in the network.

The four wells in the Reporoa area were retained for the Surveillance network. Four wells (out of eight) were dropped in the Tokoroa area due to an unnecessarily high density of monitoring sites in this area. These were: 67_404, 67_483, 72_10508 and 72_3741.

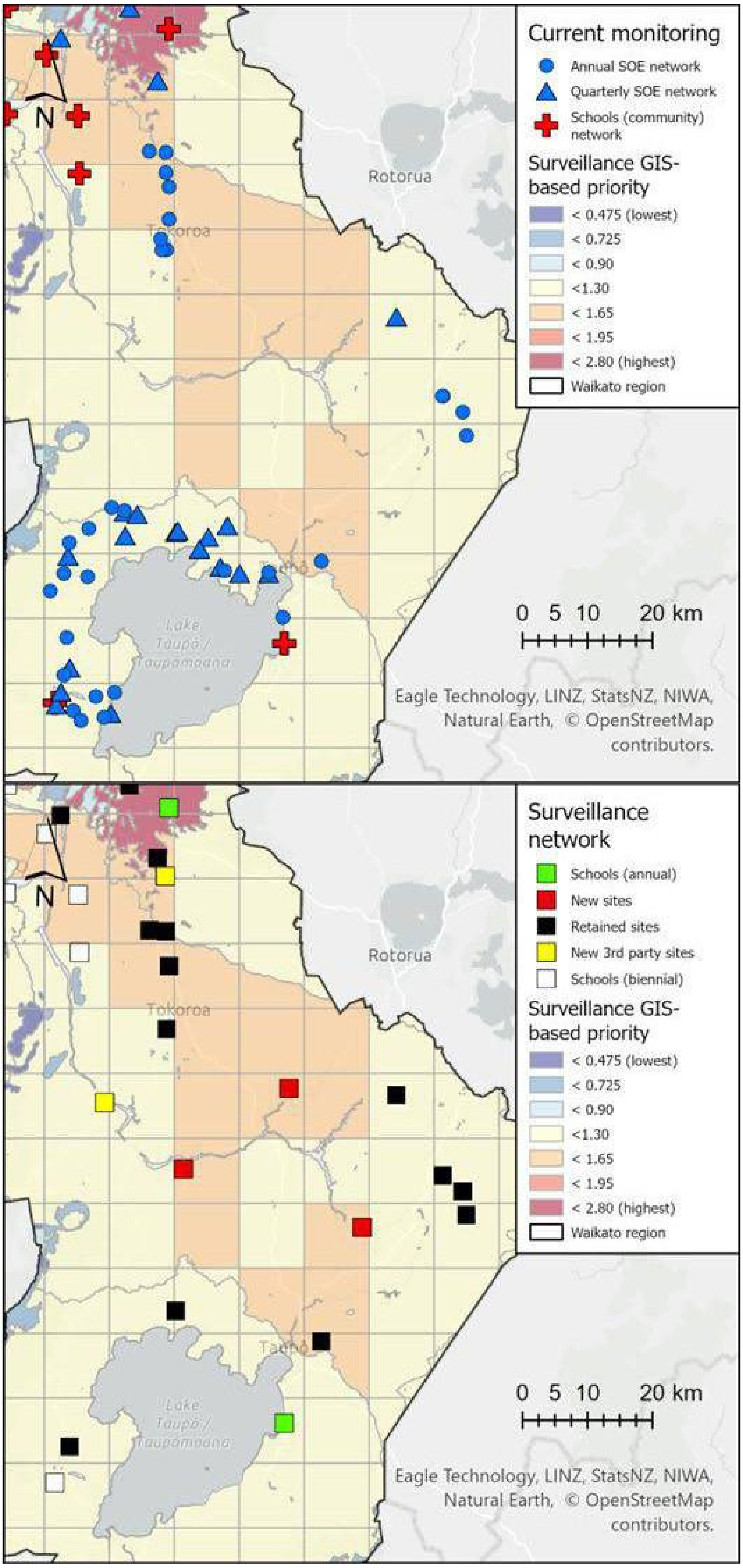

Figure 4.3 Current (top) and proposed (bottom) Surveillance monitoring sites in the Upper Waikato River catchment.

4.1.3 Waipa Catchment / King Country

The Waipa River is the major western tributary of the Waikato River. The thick Quaternary sediments of the alluvial lowlands in the northern and central Waipa catchment graben are developed for dairy farming. Ignimbrites overlay greywacke basement to the south, with some limestone formations providing localised karst groundwater.

Several modifications to Surveillance monitoring in the Waipa catchment have been proposed following the GIS-based prioritisation (Figure 4.4). These are largely to improve the distribution and better reflect aquifers of interest, but also to ensure wells have suitable information and access.

In the King Country area, this involves dropping wells 71_5 and 72_2138 while retaining wells 71_3 and 71_4. In the same general vicinity (east of Te Kuiti), well 71_ 1 is also proposed to be dropped. Well 70_65, closer to Pirongia, which has had access and other issues, will be dropped.

Following identification of potential sites, field visits were undertaken to sites around the Te Awamutu and Ohaupo areas. Two sites were visited and sampled, and have been selected for inclusion in the Surveillance network, namely 72_12284 and 70_795.

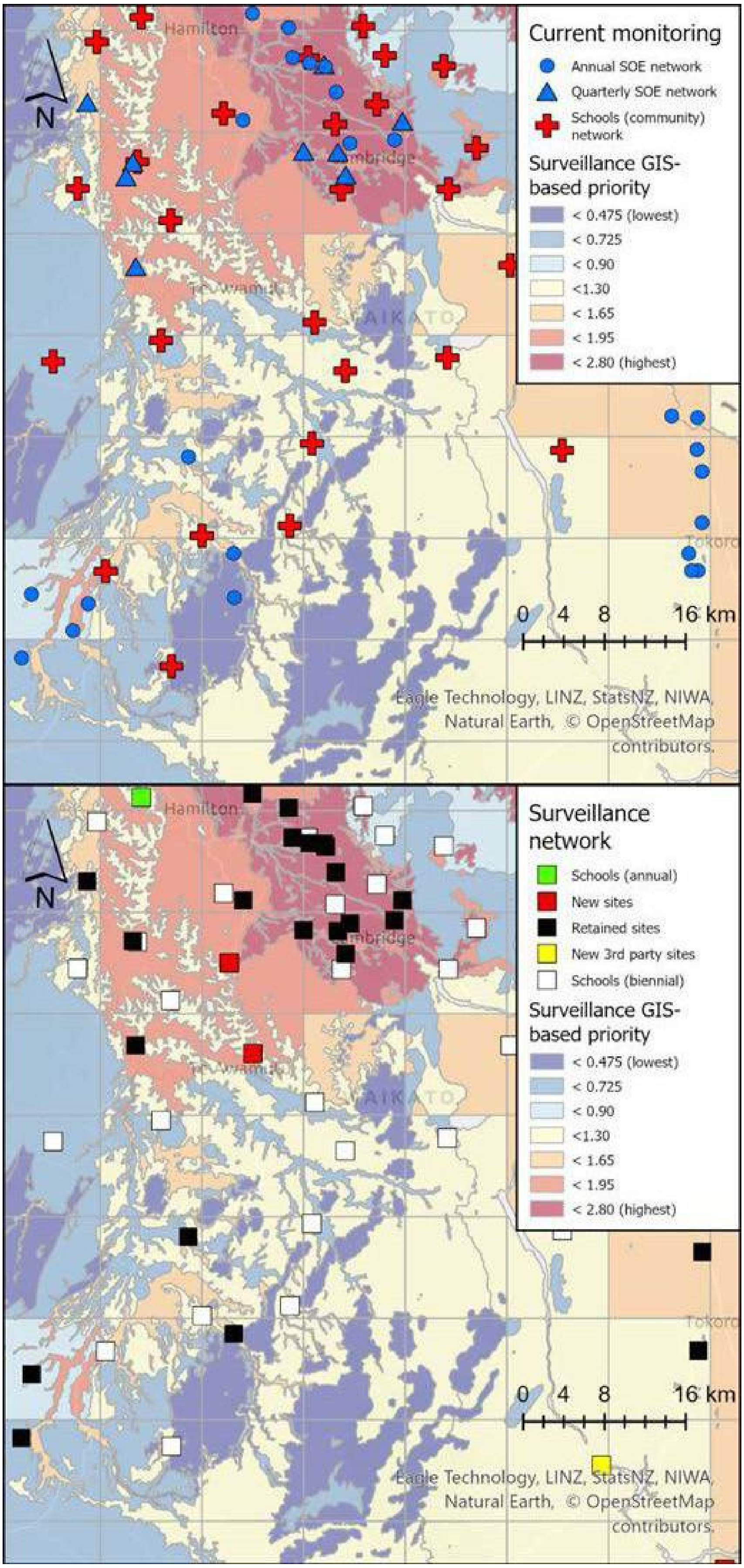

Figure 4.4 Current (top) and proposed (bottom) Surveillance monitoring sites in the Waipa Catchment / King Country.

4.1.4 Hamilton Basin

The Hamilton Basin is a large graben flanked by greywacke ranges. It is infilled by a large thickness of largely alluvial Tauranga Group sediments distributed by the ancestral Waikato River.

Minor changes to Surveillance monitoring in Hamilton Basin are proposed. These involve adopting the Horsham Downs School (69_1349) and Rotokauri School (69_2075) wells for annual Surveillance. Well 72_9908 in the Taupiri area was visited, sampled and will be added to the Surveillance network. Other existing monitoring wells in the Hamilton Basin are to be retained (Figure 4.5).

As mentioned (Section 2.3), existing wide diameter wells, which were predominantly in this sub-region, have been replaced with narrower, better documented piezometers at the same locations. Following overlaps in monitoring to assess differences in chemistry, these changes in the network have been introduced[4].

[4] WRC internal file doc. 20249464, which is hosted by the Environmental Monitoring Team.

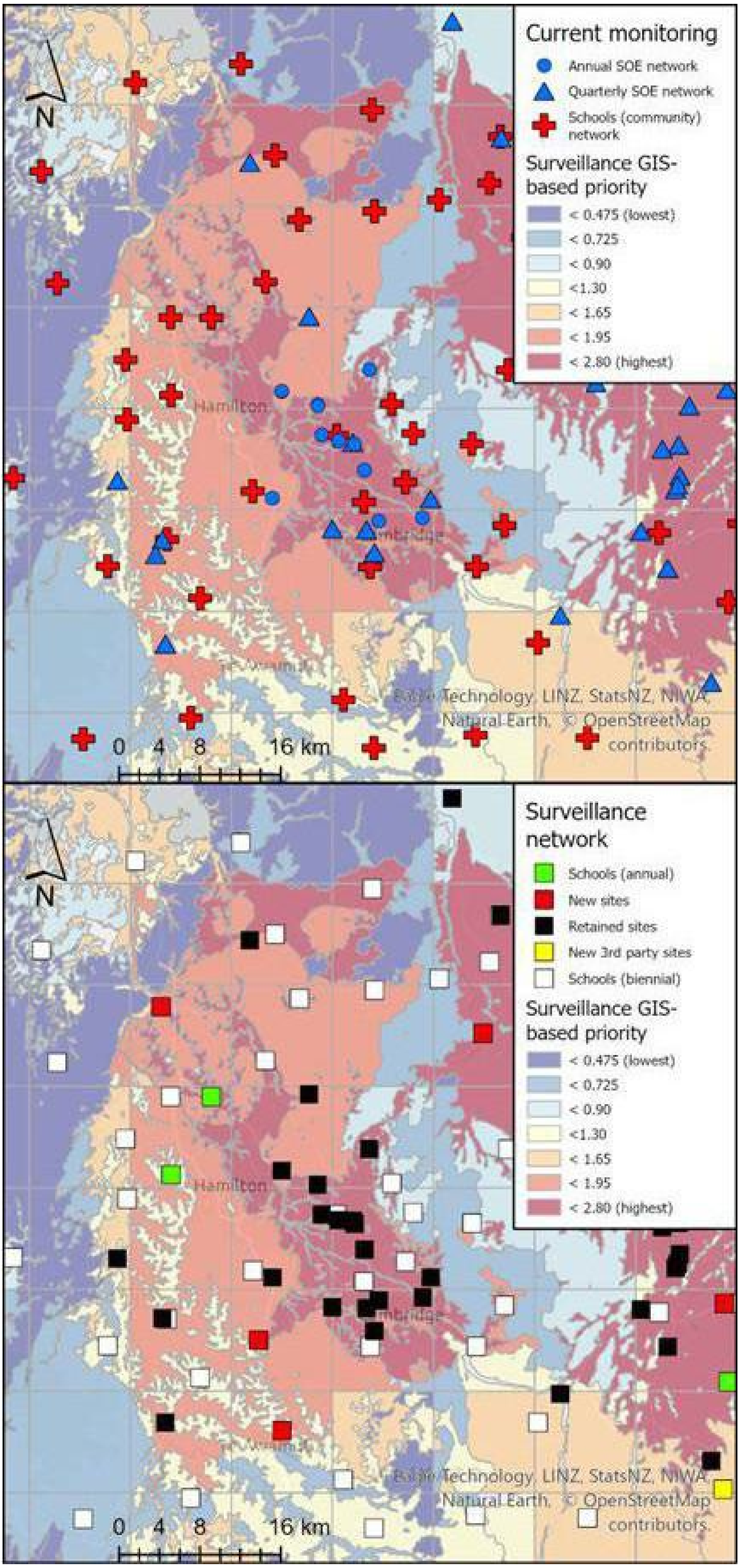

Figure 4.5 Current (top) and proposed (bottom) Surveillance monitoring sites in the Hamilton Basin.

4.1.5 Hauraki Area

The Hauraki Plains form part of a large continental rift structure bounded on either side by major faults. This elongated depression structure is infilled by a large thickness of predominantly Tauranga Group sediments. Further south toward the Mamaku Plateau, a series of ignimbrites form the headwater sub-catchments of the Waihou River.

Two additional sites were selected in the southern Hauraki Plains. One in the Morrinsville area (72_11978) and one near Te Poi (72_9179). Additionally, two current biennial school sites (Okoroire School 67_565 and Waihou School 72_3612) were selected to be transferred to an annual frequency for Surveillance monitoring. It is also proposed to collaborate with South Waikato District Council and add the Blue Spring (3314_3) near Putaruru to the Surveillance network.

Well 72_12749, which is typical for artesian groundwater in the northern Hauraki Plains, was selected to be added to the network. All other sites in the Hauraki sub-region are to be retained (Figure 4.6).

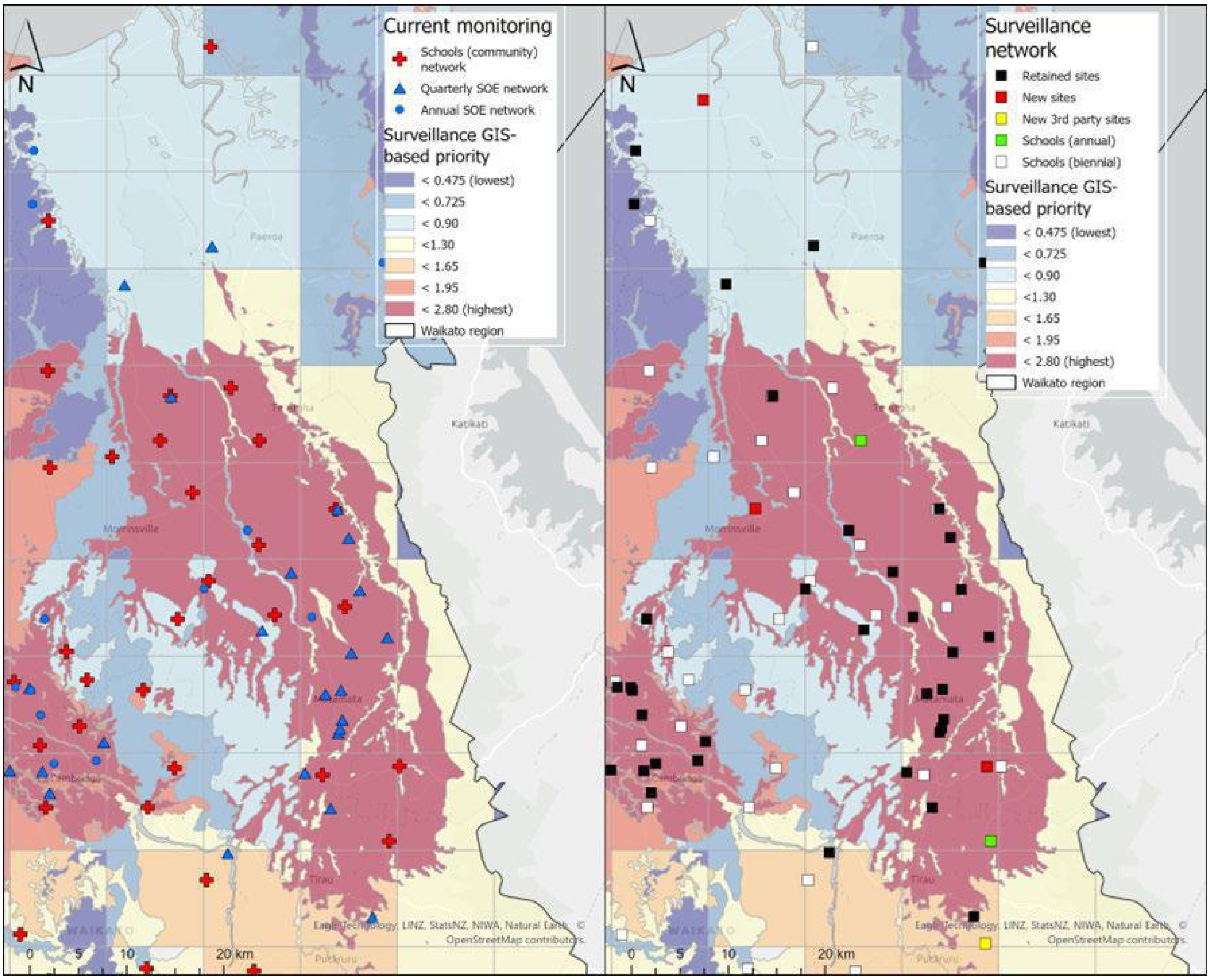

Figure 4.6 Current (left) and proposed (right) Surveillance monitoring sites in the Hauraki area.

4.1.6 Waihi Basin

The Waihi Basin geology is dominated by Tertiary rhyolites and andesites (some notably mineralised) with some alluvial sediment infill. Existing monitoring in the Waihi Basin consists of four annual SoE sites and one biennial rural school. This is more than justified by the GIS-based prioritisation, therefore it is proposed to drop well 63_201 (Figure 4.7).

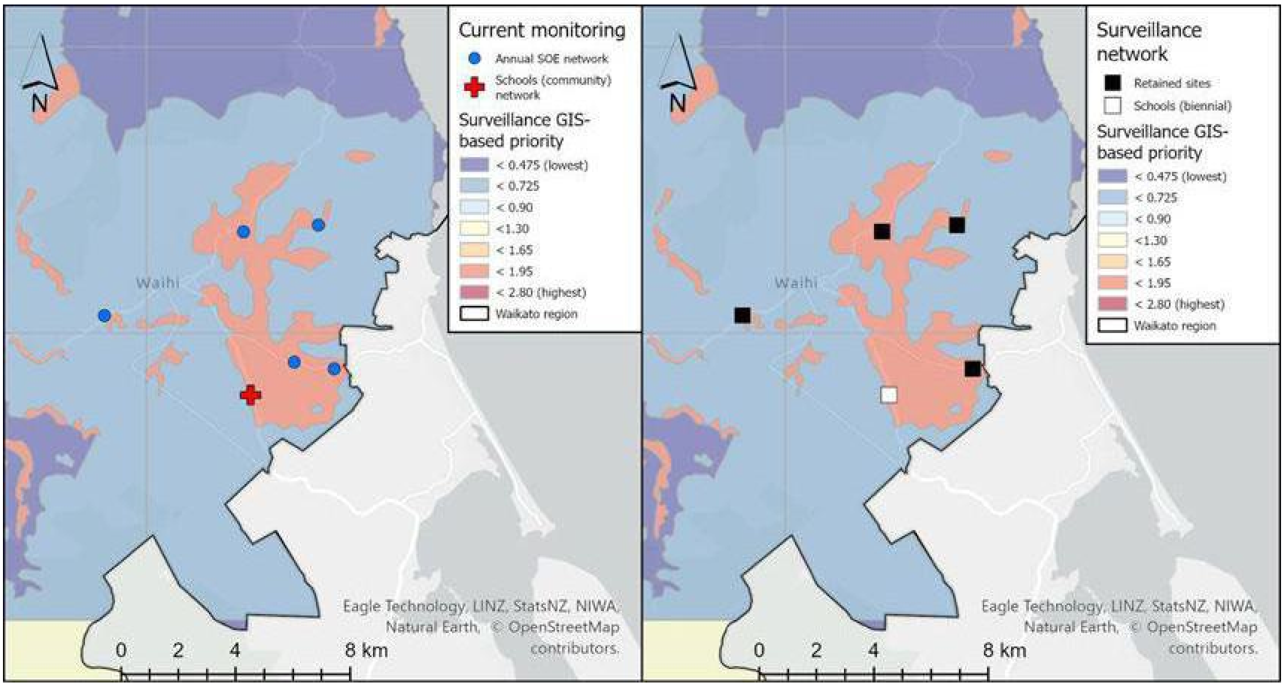

Figure 4.7 Current (top) and proposed (bottom) Surveillance monitoring sites in the Waihi Basin.

4.1.7 Northern Areas

In the Pukekohe area, shallow basalt aquifers overlie deeper aquifers within the Kaawa Formation. At present, all groundwater quality monitoring is limited to the basalt aquifers. To enhance aquifer representation, it is proposed to add a monitoring site within the Kaawa Formation (site 61_46, which is an existing groundwater water-level monitoring site). Additionally, two further sites are recommended in the basalt aquifers to improve spatial distribution: site 61_1343 and site 61_20, also currently a groundwater-level monitoring site. In the Pukekawa area, it is proposed to replace existing monitoring site at 61_59 with a newly identified site, 72_4116, as 61_59 has become inaccessible. Additionally, a site within the Waitemata Sandstone formation is recommended for inclusion for aquifer representation – 72_10829 has been visited, sampled and confirmed as a suitable site. All other sites in the Pukekohe and Pukekawa areas are to be retained (Figure 4.8).

There are currently no monitoring sites within the Whangamarino Wetland, despite its status as a wetland of international importance under the Ramsar Convention[5]. This wetland is likely to have some degree of groundwater dependency. Following likely future investigations, additional sites may be incorporated into the network.

[5] https://www.ramsar.org/

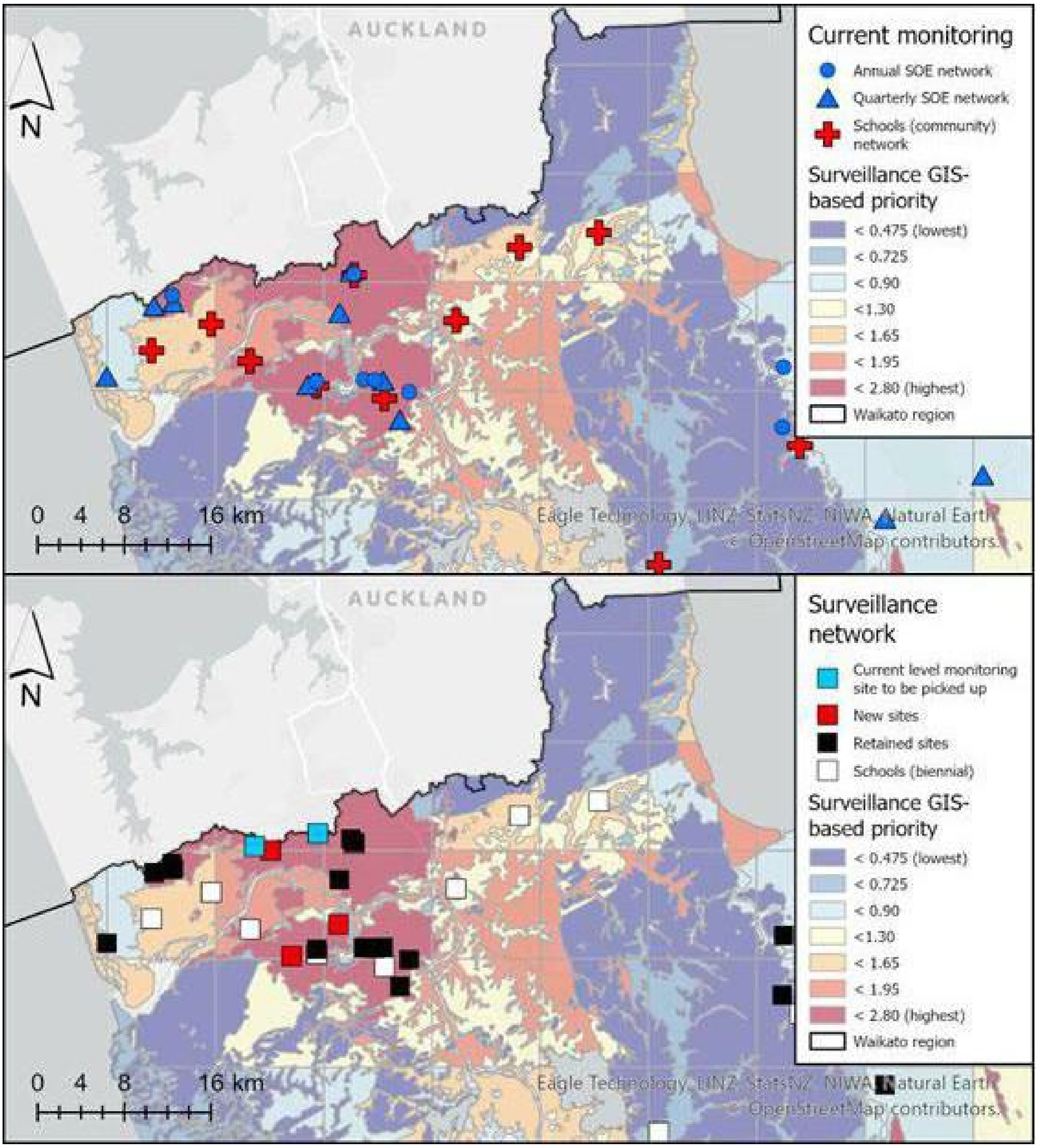

Figure 4.8 Current (top) and proposed (bottom) Surveillance monitoring sites in the northern areas.

4.1.8 Coromandel Peninsula

Groundwater resources of the Coromandel Peninsula are generally derived from pocket coastal sand aquifers and low-permeability fractured volcanics. Typically, the low yielding formations are assessed as being low priority for Surveillance but there are localised exceptions. The current network is also approximately matching, so only requires some minor modification.

The representation of multiple potential seawater intrusion sites poses a challenge. The Thames Coromandel District Council (TCDC) has, however, been approached and there are opportunities to collaborate monitoring efforts with their required source water supply monitoring. It is apparent that the GIS-based prioritisation for Surveillance and Evaluative seawater sites results in similar distributions, largely reflecting the coastal pocket aquifers and localised settlement use. Therefore, the Coromandel network revised distribution will be presented in Section 4.5.3.4.

4.1.9 Western Areas

Groundwater resources in the western sub-region from northern Taranaki to Port Waikato are not substantially developed and are of low priority. Intensive land use is limited to some small alluvial lowlands. Much of the greywacke and Tertiary limestone, sandstone and siltstone formations of the Western Areas predominantly comprises poor yielding hydrogeology. Dissolution of limestone by underground water has led to some notable karst development, particularly in the southwest.

In order to represent karst systems, it is proposed to add the Pio Pio Spring Community Water Supply 774_1 to the network. This requires further investigation and collaboration with the Waitomo District Council. The biennial school monitoring is considered to be sufficient for Surveillance monitoring in the remaining western areas, and no other changes are proposed to sites or frequency (Figure 4.9).

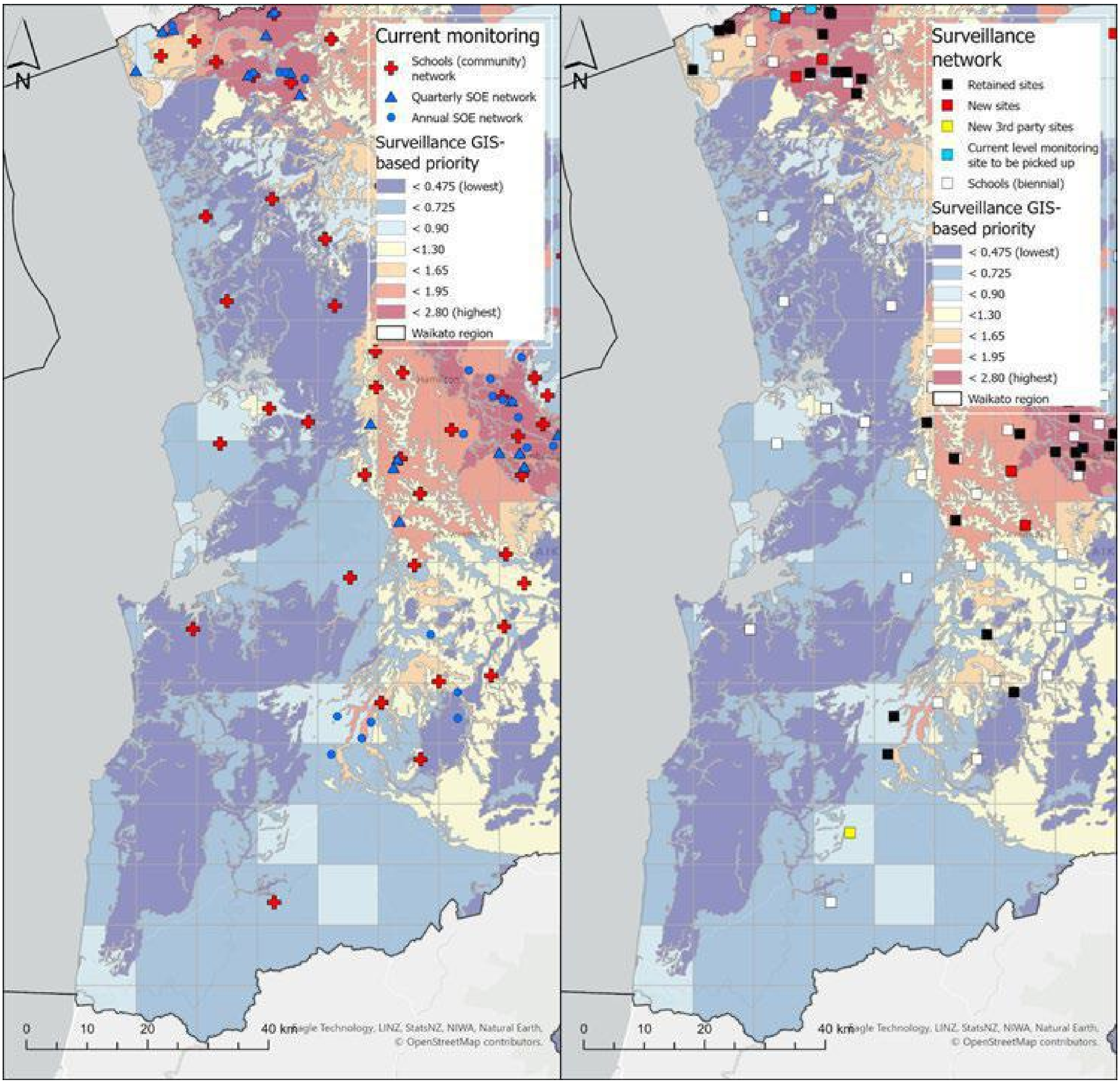

Figure 4.9 Current (left) and proposed (right) Surveillance monitoring sites in the western areas.

4.2 Surveillance Schools (Community) Network

The Schools (Community) network of rural schools is considered an independent Surveillance dataset, at least in the interim. Future source water monitoring at school supplies will be required by Taumata Arowai under the Water Services Act. This is likely to see more involvement of, and potential collaboration with, the Ministry of Education. It is intended in the interim to continue with two-yearly frequency monitoring using the base Surveillance analysis suite. A slightly larger suite of analysis to include some additional Taumata Arowai stipulated parameters could also be considered for some additional characterisation.

The schools network provides good spatial coverage in lower priority areas, so will be retained at the current biennial frequency as a lower-frequency Surveillance network. Some school sites have been identified as filling gaps in higher-priority areas, and will move to an annual frequency for Surveillance (72_3612 – Waihou School, 69_2075 – Rotokauri School, 69_1349 – Horsham Downs School, 68_794 – Waitahanui School and 67_565 – Okoroire School). Colville School (72_1090) was also selected for annual monitoring; however, it will not be included until location and access is resolved.

A further review of our Schools (Community) network will be undertaken, given a few sites have changed supply purpose. There are some which continue to be monitored as part of the Surveillance Schools (Community) network even though they no longer supply schools. There may also be a few school supplies that are currently not included in the network that may be added.

4.3 Surveillance NGMP Programme

The proposed optimised programme includes an expansion of the network (10 sites retained, seven new sites, including one site switch) and of the dataset to include geothermal spring historical water quality analysis. Quality checks will continue to be performed by comparing current analyses with the historical record and charge balance error calculations.

In the proposed network, each primary system includes multiple sites to capture the general flow direction with sites located up-, mid- and down-gradient (Hauraki Quaternary sediments; Hamilton Basin Quaternary sediments) or spatial distribution (South Auckland Volcanics). Proposed changes to the network for each of the key hydrogeological features of the sub-regions are detailed below (Figure 4.10):

- Lake Taupō catchment – one existing well (68_964) installed in Taupō Pumice Alluvium, with some issues raised on representativeness, as the water level fluctuates within a redox changing zone. It is proposed to switch to a new site located closer to Taupō township in fractured volcanics (68_317).
- Upper Waikato – no existing site sourced by fractured Quaternary volcanics. The feasibility of adding either Maraetai Spring (1131_87), currently monitored by TDC and in discussion with WRC, or new WRC surveillance monitoring (72_3979) should be assessed, as well as a site downgradient of the catchment (either 72_10603 and 72_10605, located in the Hamilton Basin).
- Waipa catchment – one existing site (72_10609), replacing a historic site (70_1134) sourced from Quaternary volcanics to be retained.
- Hamilton Basin – one existing well site (69_1709) supplied by the Hinuera Formation to be retained. The proposed network includes two additional sites from WRC's network located up-gradient (72_10603 and 72_10605) and down-gradient (72_9908) from the existing site.
- Hauraki area – three existing sites sourced from the Hinuera Formation (64_511, 64_720, 64_120). Existing sites are to be retained, and the feasibility of including the Blue Spring drinking-water supply (1122_79), sourced by fractured ignimbrites, should be assessed. The Blue Spring is currently monitored by South Waikato District Council for compliance purposes.

- Northern areas. There are currently five wells within the Franklin Basalt: four are less than 50 m deep (61_85, 61_93, 61_258 in the Waikato region; 7428105 in the Auckland region) and one is 90 m deep (7428103 in the Auckland region). It is proposed to keep the existing sites.
- Coromandel Peninsula – one existing well (60_12) supplied by Holocene sediments to be retained.
- Western areas – no existing site; investigate inclusion of the Pio Pio drinking-water supply (774_1), a karstic spring sourced by Te Kuiti Group limestone-dominated formations.

To assist national reporting on geothermal features and/or groundwater ecosystems, it is proposed to enhance the NGMP dataset by conducting a literature review of geothermal groundwater quality focussing on springs and characterisation, rather than geothermal exploitation. This dataset enhancement is in scope of the programme's data management component and built on GNS Science's expertise. Occasional resampling of some unmonitored features may be considered as a snapshot survey within the research component of the programme.

It is also proposed to continue to characterise groundwater microbial ecosystems through sampling undertaken as part of the programme's research component (Houghton 2025; Houghton and Santamaria Cerrutti 2022; Sirisena et al. 2013; Sirisena et al. 2018), completed by a literature review. Groundwater ecosystems are in the characterisation stage in New Zealand (Fenwick et al. 2018; Houghton et al. 2024). While sampling for stygofauna has been undertaken and may continue, it is regarded as cost-effective within the NGMP to assess the potential to use microbial communities as a proxy.

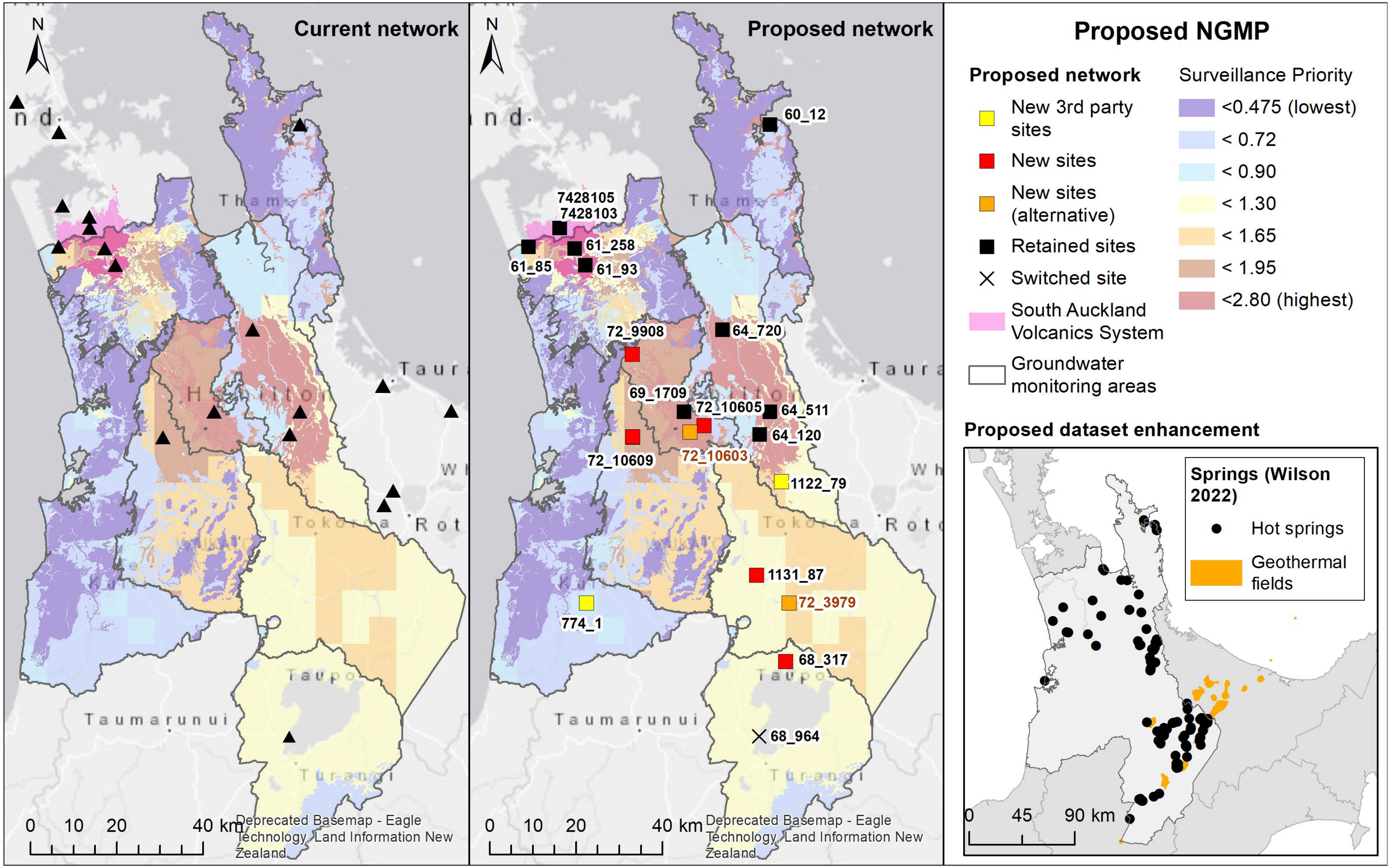

Figure 4.10 Proposed changes to the NGMP programmes: current (left) and proposed (middle) NGMP monitoring sites in the region and proposed dataset enhancement (right).

4.4 Variables and Sampling Frequency

The comparison of monitoring variables requires careful consideration of the variable form (e.g. 'dissolved' or 'total'). Particularly for metals, the dissolved form represents the mobile component whereas total forms might include colloidal forms. Drinking-water requirements generally involve total forms, as being conservative regarding intake, whereas aquifer processes are best informed using dissolved forms, which represent the more mobile fraction. In parallel, analytical methods are selected by laboratories from standard methods considering the sample type (e.g. contaminated site, groundwater), expected concentration range, health and safety, and operational aspects (e.g. equipment available, running costs). Laboratory results are therefore reported in differing forms, depending on the analytical technique used by different laboratories. In turn, these names may be changed or captured differently in databases.

There is a strong alignment between the current regional and national analytical suites (WRC, NGMP and GWF) in terms of variables and forms, and both include the four field-measure variables required by NEMS Standard. (Table 4.1). Current differences are: routine monitoring of total forms for arsenic, boron, copper, iron and manganese by WRC to cover drinking-water requirements, and nationally, routine monitoring of dissolved fluoride. Monitoring of cations in both the dissolved and total forms in the Waikato confirmed significant differences for iron and manganese but less so for other analytes. Both forms for these two metals have therefore been retained and are also useful in consideration of potential treatment and redox significance.

Naturally elevated arsenic and boron have been documented in the Waikato region, associated with geothermal activity and geology particularly in the Reporoa, Taupō and Coromandel areas (Piper and Kim 2006; Hadfield 2022). Fluoride in groundwater is sourced by the dissolution of minerals, such as apatite, in siliceous, igneous formations, and associated compounds are common in geothermal fluids. Fluoride concentrations at NGMP sites vary between regions and are lowest in the Waikato region (Figure 4.11). This is consistent with data collected from SoE monitoring, except in geothermally influenced groundwater (Hadfield 2022).

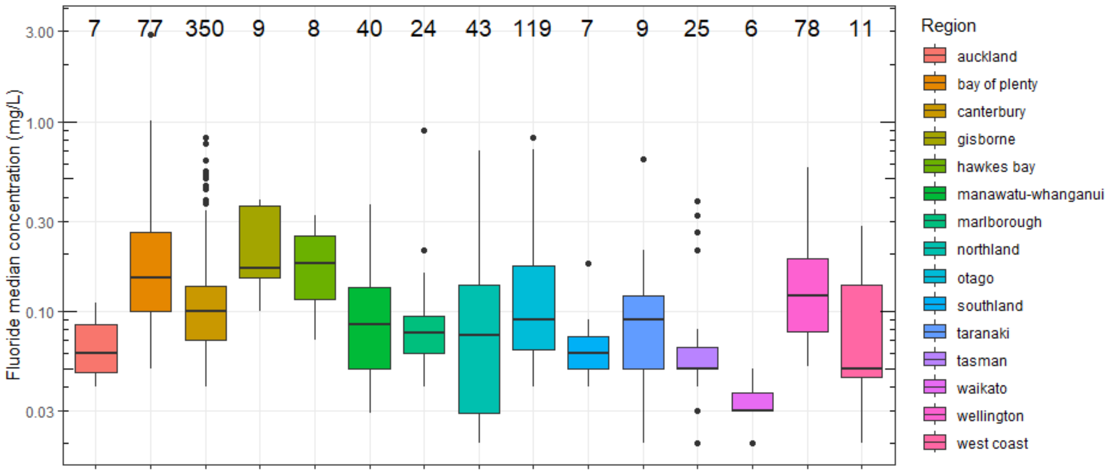

Figure 4.11 Median fluoride concentrations at State of the Environment (SoE) sites nationwide for the 2019–2024 time period. Numbers of monitoring sites for each region at which fluoride measurements were available are shown at the top of each boxplot. Source: Moreau and Cameron (2023).

In the US, the national groundwater quality monitoring framework recommends analytical suites for three types of monitoring: Standard (Trend and Surveillance), Extended (Surveillance only, including Standard variables) and Supplemental (Trend or Surveillance) (Table 4.1) (Subcommittee on Ground Water of the Advisory Committee on Water Information 2009). The difference between WRC and NGMP suites and the US Standard suite is the requirement to measure field-dissolved oxygen concentrations, while field redox potential is recommended instead in the US. Both variables provide information on the physico-chemical status of the aquifer. All variables recommended for Extended monitoring are in the WRC and NGMP suite, except for nitrite, which is only monitored regionally and is part of our drinking-water requirements. Nitrite is an intermediate product of the bacteria-facilitated, nitrification process, by which nitrogen is converted from ammonia to nitrate form under high oxygen conditions. The conversion from one form to another occurs under natural processes and can be reversed in low oxygen conditions. The end-members of this process, ammonia and nitrate, are both monitored regionally and nationally. The Supplemental monitoring is presented as optional and comprises trace metals, synthetic organics, emerging contaminants and selected isotopes. It is to be undertaken following issues of local and state concern, which is a very similar model to the special investigation conducted in both regional and national programmes. The US proposed suite for Supplemental monitoring is consistent with New Zealand practices.

Table 4.1 Comparison between Waikato Regional Council (WRC) and NGMP regularly monitored inorganic water quality variables with national and international guidance. Abbreviations include the National Environmental Standards (NEMS), the Groundwater Forum (GWF) core suite, New Zealand Drinking-Water Standard requirements (DWS) and the US Standard (Std) and Extended (Extd) suites. The asterisk indicates the variable and form considered for inclusion in the next revision of the DWS (Graham 2025).

Variable	WRC	NGMP	NEMS	GWF	DWS	US Std	US Extd
Alkalinity	TD	TD	-	TD	TD	-	TD
Ammonia	T	D/T	-	T	-	-	D/T
Antimony	-	-	-	-	T	-	-
Arsenic	T	-	-	-	T	-	-
Barium	-	-	-	-	T	-	-
Boron*	T	-	-	-	T*	-	-
Bromide	D/T	D	-	-	-	-	-
Calcium	D	D	-	D	T	-	D/T
Chloride	D/T	D/T	-	D/T	D/T	-	D/T
Conductivity	TD (field and lab)	TD (field and lab)	TD (field)	TD (lab)	TD (lab)	TD (field)	TD (field)
Copper	T	-	-	-	T	-	-
Fluoride	-	D	-	-	-	-	-
Iron	D+T	D	-	D	T	-	D/T
Lead	-	-	-	-	T	-	-
Magnesium	D	D	-	D	T	-	D/T
Manganese	D+T	D	-	D	T	-	D/T
Mercury	-	-	-	-	T	-	
Nitrate	D/T	D	-	D/T	D/T	-	D/T
Nitrite	D/T	-	-	D/T	D/T	-	D/T
Oxygen	D (field)	D (field)	D (field)	-	-	-	-
pH	NA (field and lab)	NA (field and lab)	NA (field)	NA (lab)	NA (lab)	NA (field)	NA (field)
Phosphorus	DR	DR	-	DR	-	-	D/T
Potassium	D	D	-	D	T	-	D/T
Silica	D/T	DR	-	-	-	-	
Sodium	D	D	-	D	T	-	D/T
Sulphate	D/T	D	-	D/T	D/T	-	D/T
Temperature	NA (field)	NA (field)	NA (field)	-	-	NA (field)	NA (field)
Zinc	T	D	-	-	-	-	-

Forms are denoted as: D for dissolved, DR for dissolved reactive, T for total, TD for total dissolved, D+T for dissolved and total, D/T for dissolved or total, NA for not applicable.

Coloured backgrounds highlight a change in sampling frequency from July 2025, as a result from this work.

To support this review, a participatory survey was run during the May 2025 Groundwater Forum and provided the following insight based on experience (Table 4.2):

- Although theoretically sampling frequency as low as 10-yearly could be viewed as cost-effective (e.g. slow-moving groundwaters, compounds unlikely to occur, unused groundwater bodies), most councils viewed quarterly to annually sampling as a minimum practical frequency, considering the operational model. Most networks consist of private wells, and access is a regular issue to maintain network integrity. It was noted that the minimum sampling frequency will be specific to an aquifer system.
- Proactive collection of groundwater quality data to support policy development was unanimously perceived as useful for policy effectiveness management.
- Documents like this report are useful to record the design of monitoring networks and could be shared with the public to ensure transparency.

Table 4.2 Survey questions from the May 2025 Groundwater Forum session on sampling frequency and monitoring.

Questions	Number of Responses (Number of Votes)
What should be the theoretical lowest sampling frequency (GW quality)?	10-yearly (1), 5-yearly (1), bi-annually (4), quarterly (4), monthly (2), weekly (1)
What should be the practical minimum sampling frequency (GW quality)?	1-yearly (2), bi-annually (4), quarterly (6)
Should Evaluative monitoring also include 'proactive' assessment to inform/develop policy?	Yes (13) No (0)
How should transparency be communicated, reported and recorded?	Technical reporting and websites. Summary Report and a presentation in GW Forum. Minimum sampling frequency really depends on the aquifer system. Report for initial review and as metadata attached to sites.

Following the review, the following changes were recommended for variables and sampling frequency:

- For Surveillance at regional level, routine monitoring of calcium, magnesium, potassium and sodium in total form ceased, as it is a duplication. Routine iron and manganese will continue to be monitored in both dissolved and total forms, as historical data demonstrates significant differences in measurements between forms. Additional variables will continue to be analysed infrequently or with a much lower frequency, for example, to provide for initial characterisation or to monitor species or compounds that are typically expensive and not frequently detected. Quarterly groundwater sampling will remain the initial frequency recommended to avoid autocorrelation, which might occur at higher frequency, while allowing sample collection to occur in the main climatological seasons upon monitoring setup (Barcelona et al. 1989). This frequency may be revised to a lower frequency once systems are characterised for cost efficiency.
- For Surveillance at the national level, the monitoring suite will remain unchanged; however, analysis frequency will be increased to quarterly for dissolved reactive phosphorous and conductivity measured in the laboratory, for consistency with other variables (Table 4.1). The current quarterly sampling frequency was deemed appropriate to support national reporting requirements and was deemed suitable for research purposes (Moreau-Fournier and Daughney 2012). Age tracers and stable isotopes continue to be repeated over time at varying time intervals, using a rotation across the network for cost efficiency. Similarly to the regional network, additional variables may be analysed, for example, to provide for initial characterisation or specific investigation, and groundwater age will continue to be repeated every couple of years for cost efficiency.

- For Evaluative monitoring, the monitoring suite and sampling frequency is expected to be tailored to the underlying hypothesis to be tested. This monitoring is generally expected to be more targeted in variables and to use higher frequencies. The use of automated loggers is proposed for high frequency (less than three-monthly). For instance, for seawater intrusion monitoring TLC (temperature, water level and conductivity), loggers may be deployed and complemented with a nitrate-nitrogen logger for nitrate investigations. Frequency is likely to be monthly or weekly, but occasionally daily frequency may be justified. The need for Evaluative monitoring at the national scale is yet to be assessed.

4.5 Evaluative Monitoring

4.5.1 Review of Existing Sites

There are numerous ways in which wells may be assessed for suitability for different monitoring purposes. Notably, the ability to detect relevant changes in groundwater quality at these wells may be an important selection consideration. Other factors may include characteristics related to their hydrogeologic setting. There are also practical considerations, such as those related to access, information availability and ease of sampling.

In this section, initial triaging of existing WRC monitoring wells for potential Evaluative and Surveillance purposes is reported based on hydrogeological settings and their 'Power of Detection' (PoD). Thesetwo main purposes of groundwater quality monitoring have been identified from international literature and are considered in the monitoring network and programme design. Surveillance is a more passive component of monitoring for characterisation, whereas the Evaluative monitoring component is more directed for a short-term purpose, such as testing the efficacy of policies. The current definitions and purposes of Surveillance and Evaluative monitoring are described in Section 3.2. It is considered that some wells may be suitable to serve both Surveillance and Evaluative purposes.

In undertaking the triage of existing monitoring sites to Surveillance, Evaluative or both, a pragmatic approach was taken. Firstly, the Schools (Community) (rural school) network of wells was all considered to be Surveillance. This is because the network was adopted as a separate objective dataset without further design consideration. It has inherent attributes of being of high community interest and good spatial distribution. Although some wells within the network may be useful from an Evaluative perspective, these will not be addressed here. Also, for transparency and to allow for future refinement, criteria based loosely on the definitions described in Section 3.2 are used to separate wells considered to have 'potential' as Evaluative sites with the remainder assumed to be suitable for Surveillance ('Unlikely' Evaluative, Appendix 1). PoD analysis was an important consideration (Dumont and Charlesworth 2024). The review results are tabulated for the SoE network (as reported by Hadfield [2022]) with some comment about distribution on a sub-regional basis. It is noted that some minor changes have already been made to the network described in the 2022 SoE report (Section 2.3). The monitoring records for the new or substituted sites introduced are too short to enable similar PoD analysis.

A premise of the Evaluative criteria is that the main quality issue regionally is nitrate contamination. It is noted that other contaminants, although not specifically considered here, also typically enter from the ground surface, and hence, the consideration for nitrate may have some relevance. There is also a separate Evaluative monitoring component focused on potential saltwater intrusion at localised coastal aquifers on the Coromandel Peninsula.

An initial triage of wells was undertaken based on physical setting characteristics. Potentially suitable sites for Evaluative purposes were selected where:

- Well depth is shallow (<30 m).
- Aquifer is known to be unconfined.

- Groundwater age is young (mean residence time [MRT] is <30 years).
- Redox conditions are not anaerobic.
- Nitrate-nitrogen concentration is >0.3 ppm.

The depth criterium for nitrate reflects the prevalence of higher nitrate concentrations in shallow groundwater. This is roughly consistent with groundwater age. Younger groundwater also reflects anthropogenic impacts in a more pragmatic timeframe, justifying higher frequency monitoring. The nitrate criterium excludes sites which to date do not indicate anthropogenic influence.

These ‘potential’ wells for an Evaluative network were considered less isolated from manageable anthropogenic activities and hence likely suitable for evaluating the efficacy of policy initiatives. Those not meeting these criteria were labelled ‘unlikely’ (Appendix 1) and may still be suitable for Surveillance monitoring.

The initial physical setting triaging may also importantly be compared with the estimated PoD analysis in Appendix 1. The confidence in PoD from 20 years of quarterly monitoring where there was a 30% change in nitrogen source concentration over 10 years is tabulated (Dumont and Charlesworth 2024). The PoD work undertaken by Komanawa Solutions Ltd produced a set of reference detection power calculations for the existing monitoring sites in the Waikato. It is noted that the detection power of the network (using these criteria) was found to be generally low, similar to other regions. Some of the sites had no water age information, so a range of ages was used in the analysis. Further water age distribution and MRT information for such sites would improve the estimates. The calculation method for PoD is described in Dumont and Charlesworth (2024). It involves analysing for trend, taking noise into account, estimating source concentration and predicting the receptor concentration. The statistical probably of detecting a given change is then calculated.

PoD analysis of Pukekohe and NGMP monitoring well 61_258 data (Figure 4.12) provides a unique insight into and verification of this approach. This well showed a step change in nitrate-nitrogen concentration in 2017, going from concentrations of 2–3 mg/l to concentrations of about 9 mg/l. Analysis only on the data prior to the step change suggested likely nitrate-nitrogen concentrations at the source within the 4–10 mg/l (median of 7 mg/l). Groundwater age MRT of data prior to the step change had been estimated at 170 years. The most probable explanation for the nitrate-nitrogen step change was a rapid shift to much younger water (perhaps due to changes in well integrity or aquifer changes). Coincidentally, a subsequent age sample was collected from this well and isotope analysis indicated a much younger MRT of 36 years (Morgenstern et al. 2023). Further PoD (BASE) analysis using this additional information about the change in water age showed elevated nitrate-nitrogen concentrations were likely present in the source area prior to 1970.

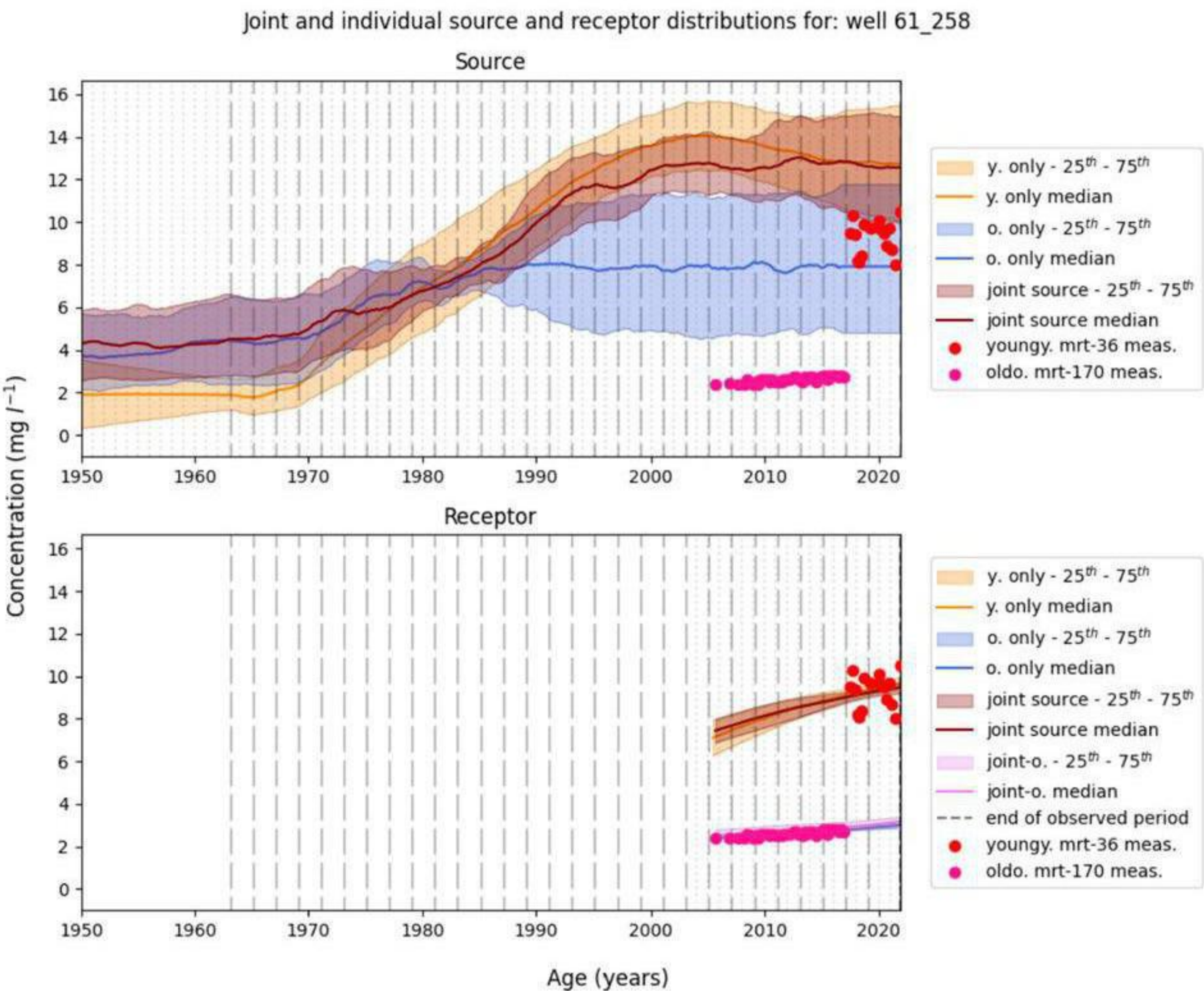

Figure 4.12 Joint and individual source and receptor distributions for well 61_258 (from Dumont and Charlesworth 2024).

The review of the existing SoE network showed that, in general, there was no simple significant correlation between the triaging of the physiochemical settings and the power of detection. This shows the virtue of including PoD analysis when considering monitoring site selection. Aspects, such as the noise in monitoring data records, are otherwise not as readily appreciated. Rather than use PoD and the initial setting criteria as an additive filter, they have been reported separately for more informative consideration.

Although there are notable differences between the wells considered to have Evaluative potential from setting characteristics and those with higher estimated PoD confidence, these differences are often logical. For example, of the 16 wells listed as 'unlikely' but that had PoD confidence >70%, about a third were in the northern basalt areas. Here, depth is less of a physical constraint given the deep water-tables and vertical fracturing. Some others were not considered 'potential' due to unknown confinement or lack of other setting information. Lastly, there are some wells with water age (MRT) >30 years, where the young fraction may still be sufficiently influential.

The estimated minimum detectable change in nitrate-nitrogen concentration from quarterly monitoring over 20 years at an 80% confidence level is also listed for the existing wells in Appendix 1. This also provides some indication of the sensitivity of monitoring at these sites. It is noted that PoD and SoE trend confidence, as reported by Hadfield (2022), are also not simply correlated. This may reflect that actual land-use load changes vary substantially from those assumed in the PoD analysis.

A total of 48 of the 110 current SoE wells were triaged as ‘potential’ for Evaluative purposes using the hydrogeologic setting criteria. There were 32 wells with PoD confidence of 70% or more, using the criteria described.

Of the 11 SoE wells monitored in the Coromandel Peninsula, six are triaged as potential, given most are shallow and unconfined with young waters. Those not triaged as potential include one anaerobic well, with others having deeper and older groundwaters and some being in confined aquifers. Only one of these wells had a PoD >70%. This reflects a lack of some information for half of the wells and also that nitrate concentrations are relatively low in this area.

There are 16 wells monitored in the Hamilton Basin, all of which are shallow and unconfined, with typically young and aerobic groundwater. Most (15) are triaged as having potential for evaluation in respect to the setting criteria, five of which have PoD confidence >70%.

Of the 14 wells monitored in the northern areas (Pukekohe/Pukekawa), only five are triaged as potentially Evaluative with the hydrogeologic setting criteria above. The other sites are ‘unlikely’, predominantly due to their depth or unknown confinement. This northern area is, however, exceptional in that it is the most highly contaminated with nitrate, which continues to increase at the highest rates in the region. This is reflected in the PoD being relatively very high (eight being near 100%). Many of the aquifers monitored are unconfined and predominantly aerobic (no anaerobic conditions being represented), despite some being relatively deep. This is reflective of the basaltic geology and vertical fracturing.

There are 28 wells monitored in the Hauraki area, of which ten are triaged as potential and seven have PoD confidence >70%. Two of the sites are anaerobic and just over half don’t meet setting criteria for confinement. There is a considerable range in character in these predominantly alluvial aquifer sediments. Eight further sites have been noted as potentially warranting reconsideration in respect to their category. Some of these have high nitrate concentrations and many of the criteria not met are in relation to confinement and its uncertainty.

The 17 wells monitored in the Taupō area are part of a larger local network used to investigate nitrate transport to the lake. The triage criteria result in six being in the ‘potential’ category and four have PoD confidence >70%. Half of the sites are either confined or have unknown confinement. Only one monitoring well is installed in anaerobic conditions (as part of dual monitoring above and below the redoxcline). There is one site (68_320) which could be reconsidered for evaluation despite being 62 m deep and reported as having unknown confinement. This reconsideration is based on information from the investigation of point source contamination of the well associated with up-gradient land-use effects near the site.

Of the 11 wells monitored in the Waipa / King Country sub-region, four are triaged as being ‘potential’ for Evaluative sites and two have PoD >70% confidence. The four ‘potential’ sites are the only unconfined aquifers. Although the network in this sub-region has generally low nitrate concentrations, more extensive monitoring may be justified. The sparse monitoring to date reflects, in part, the limited issues prompting groundwater investigation in this area.

Upper Waikato monitoring is currently limited to 13 wells. Only two of these were triaged as ‘potential’ for Evaluative purposes, although five have PoD >70% confidence. Two of the sites are anaerobic and two further wells have very old groundwater with indeterminate redox status or pre-farming-influenced groundwater. More extensive monitoring in this sub-region is likely to be justified and would be helpful in assessing large-scale dairy conversion.

There are 35 piezometers constructed by WRC that are monitored as part of the SoE network sites. These include new replacements of shallow, wide-diameter wells predominantly in the Hamilton Basin. Of these sites, eight are triaged as not having potential for Evaluative sites. Three of these are anaerobic, one is suggested to be reconsidered and two have indeterminate redox chemistry. Some of the new information yet to be updated will assist sites to meet the potential Evaluative criteria.

A more stringent definition of Evaluative monitoring could be contemplated where it is a time-limited component of the monitoring programme, which should relate to specific hypothesis testing. This would enable more robust examination of feasibility to disprove the hypothesis. If not either, then the monitoring would not be justified or further resourcing would be required. Additional resourcing could, for example, be leveraged from the private sector.

It is noted that little or none of the current SoE monitoring in the Waikato would comply with such a stringent definition for Evaluative monitoring. Monitoring in the Lake Taupō catchment, for example, is Evaluative in that it is designed to test the efficacy of policy initiatives to limit nitrogen transport through groundwater to the lake. The time frame to achieve policy targets (by 2080) is, however, relatively long. This reflects the gradual establishment of a modified equilibrium in groundwater.

4.5.2 Policy Considerations

This report focuses on two key issues for Evaluative monitoring to assess the effectiveness of resource-use policy instruments and management on groundwater systems. The first focus is nitrate contamination, which is primarily driven by land-use activities and their cumulative impacts on water quality. Nitrate, which is the most widespread contaminant, is a concern in respect to both human health and environmental effects. High nitrate concentrations have been linked to a blood disorder in bottle-fed babies known as methemoglobinemia (‘blue baby syndrome’), and, as a result, the drinking water guideline for nitrate in New Zealand is 50 mg/L (or 11.3 mg/L as nitrate-nitrogen). Much lower concentrations of nitrate in groundwater can lead to eutrophication of surface waters, such as the growth of nuisance algae and slimes. Sources of excessive nitrate include animal wastes, wastewater treatment disposal fields, nitrogenous fertilisers and domestic effluent.

The second focus is saltwater intrusion, largely resulting from groundwater abstraction. Saltwater ingress can reduce the potability of groundwater and impact the health of plants and fertility of soil. It may be exacerbated by sea-level rise resulting from climate change and ground subsidence. Once saltwater intrusion occurs, it can be difficult to reverse. It is more effective to ensure sustainable abstraction through early detection of salinity increase.

These two issues are considered here in terms of their underlying drivers, policy context, spatial distribution and relevant timeframes. WRC has been, and is required to regularly check whether the policies and methods in its planning documents are achieving the anticipated environmental results. Under Section 35(2)(b) of the RMA 1991, WRC has been required to assess the effectiveness and efficiency of its policies, rules and other methods. Section 35(2A) also required that, at least every five years, WRC publicly reports on the results of this monitoring.

This process supports the identification of changes needed to policies and methods to improve progress toward freshwater objectives. Effectiveness monitoring provides the evidence base for assessing the performance of policy instruments and informing future planning responses. WRC has been reviewing its regional planning documents, with a focus on freshwater and ecosystem health, as part of a Freshwater Policy Review project. It is noted that legislation is currently changing, and policy and related management will be required to evolve as a result.

While there may be other reasons for undertaking Evaluative monitoring to evaluate progress toward achieving community outcomes apart from assessing policy efficacy (e.g. Rotopiko), it is useful to consider here some of the policy context in the Waikato.

Investigation in the Lake Taupō catchment showed the nitrogen load to the lake was increasing, and water age dating indicated further lagged impacts. This led to policy initiatives introduced to protect its water quality predominantly from intensifying pastoral land-use. WRC introduced new rules under Chapter 3.10 of the Regional Plan to control the amount of nitrogen entering Lake Taupō from its catchment. These rules capped manageable sources of nitrogen at their 2001 levels and enabled the establishment of an $80-million public fund to purchase the rights to discharge nitrogen in the catchment, thereby reducing the manageable nitrogen load to the lake by 20%. This fund was aimed at off-setting nitrogen still in transit to the lake from past land use. Central, regional and local government all contributed and, together with local iwi, represented by the Tuwharetoa Maori Trust Board, oversaw operation of the Lake Taupō Protection Trust.

WRC began by ‘benchmarking’ the load of nitrogen discharged during 2001–2005 from all the farms in the catchment, using an on-farm nutrient management model (Overseer). This established the nitrogen discharge allowance (NDA) for each property. By the end of 2012, WRC staff had completed the process of benchmarking and advised the Trust that the combined nitrogen discharge from all the farms considered was about 850 t/yr. By 2013, some 80 consents to farm had been issued by WRC, taking account of each farm’s NDA. During 2008–2015, the Trust purchased NDAs totalling 170 t/yr or 20% of the combined NDAs from the farms in the catchment.

A total of 6675 ha (or 12%) of farmland has been permanently converted to forestry (Figure 4.13). In due course, these former areas of pasture, now in forestry, should discharge less nitrogen. The load of nitrogen is expected to reduce by perhaps half (~170 t/yr of Overseer or unattenuated nitrogen). As a result, the combined load of nitrogen entering the lake in the future may be similar to that estimated in 2008. The Plan aims to ensure that by 2080, water quality in Lake Taupō returns to 1999–2003 levels. To do this, all sources of manageable nitrogen from the catchment are capped at 2001 levels. As mentioned, the load of nitrogen still in transit to the lake has been offset by the Trust reducing the manageable sources. A nitrogen trading system was introduced to provide farmers some flexibility while operating within the nitrogen cap.

Evaluative groundwater quality monitoring has already been established in the Lake Taupō catchment to assess policy efficacy. A minor refinement is recommended to better assess the effectiveness of the public fund to remove nitrogen from pastoral properties (Section 4.5.3.1). The policy evaluation timeframe is relatively long given the 2080 target.

The draft Hauraki Freshwater Management Unit (FMU) stretches from the Mamaku Plateau to the Firth of Thames. Freshwater policy is currently being considered for this area in collaboration with iwi. The Pare Hauraki collective treaty settlement for cultural redress in respect of natural resources, including those associated with the Waihou and Piako catchment areas, is still pending.

A likely key driver for policy development is protecting the sensitive Firth of Thames coastal receiving environment. The Freshwater Policy Review is considering different policy approaches, including restrictions on nitrogen loads to the Firth and land-use management approaches. Current monitoring provides data to support numerical modelling of nitrogen transport in the FMU. In turn, data worth considerations from the modelling can also provide further insight along with power of detection for monitoring optimisation. The modelling and groundwater investigations support the freshwater policy review by informing consideration of land-use management changes, which may be required to meet water quality targets. This work, to date, has included the use of BACH (Bayesian Chemistry-Assisted Hydrograph Separation) modelling (Stenger et al. 2024), SWAT-MODFLOW-RT3D coupled modelling of the Piako catchment (Durney et al. 2025) and MODFLOW / MT3DMS modelling of the larger Hauraki FMU domain (Hemmings et al. 2022).

Policy to improve water quality in the Waikato and Waipā catchments under Plan Change 1[6] is yet to be finalised. There has been an interim Environment Court decision[7] in May 2025. Plan Change 1 changes the Waikato Regional Plan and introduces rules to manage both point source and non-point source discharges. The policy approach includes requirements for farm environmental plans, good management practices and making dairy and dry stock farming a controlled activity where risks of diffuse contamination are more than low.

Dairy farming with low-risk, diffuse discharges of nitrogen, phosphorus, sediment and microbial pathogens to water will be determined based on Nitrogen Risk Scorecard assessments. The higher risk farms will be required to produce Overseer nitrogen leaching loss rate assessments. A tailored, risk-based approach will be used to determine mitigation actions. These will be specified in farm environment plans and resource consent conditions. The plan change is aimed at improving water quality over 80 years to meet the aspirations of Te Ture Whaimana o Te Awa o Waikato (Vision and Strategy for the Waikato River). The policies and rules are not yet operative, and Evaluative monitoring to assess their efficacy for groundwater is likely to be difficult. This is in part due to the currently undefined spatial distribution of mitigation measures and defined targets. Any potential Evaluative monitoring could be considered again once initiatives are better known and may be better undertaken through landholder involvement.

The northern area of Pukekohe is currently the subject of a Ministry for the Environment discussion document[8] that consulted on options to enable commercial vegetable growing. It includes a new objective in the National Policy Statement for Freshwater Management (NPS-FM) to enable the continued domestic supply of fresh vegetables or new national standards that permit commercial vegetable growing. The highest nitrate concentrations in Waikato groundwater occur in this and the neighbouring Pukekawa areas. They also have the highest rates of nitrate concentration increase. Additional targeted monitoring in these areas could be undertaken to evaluate the impact of enabling vegetable production without a resource consent in Pukekohe compared with Pukekawa (where no exemption is currently being considered). Such monitoring could focus on aquifers in the basalt fields where land-use intensity is highest and their aerobic groundwaters provide stream base flows.

The other Evaluative focus is on saltwater intrusion. The focus for this monitoring is the Coromandel Peninsula. Although there are other coastal areas in the Waikato (e.g. Raglan and Kawhia), these currently have no apparent concerning issues. On the Coromandel Peninsula, some aquifers have minor and localised saltwater ingress issues. These typically relate to groundwater abstraction during summer peak demand. Policy for the protection of groundwater resources from saltwater intrusion involves limiting permitted activities near the coast (<600 m distant) and looking to set sustainable aquifer yields for limiting allocation. Areas of saltwater intrusion concern and some elevated salinity include Whangamata, Opoutere, Hahei and Pauanui. Some Evaluative monitoring is proposed to assess the adequacy of current policy and management. Given consented activities are often involved, this also has implications for consent reviews and can utilise some monitoring required in consent conditions.

It is noted that, at the time of writing, there are changes to relevant environmental legislation. The RMA is to be replaced by a Natural Environment Bill and a Planning Bill. These changes will influence future management.

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6 Proposed Waikato Regional Plan Change 1: Waikato and Waipā river catchments.

7 An ‘interim decision’ means the Court wants further input from the parties involved before making a final decision about how Plan Change 1 should be worded.

8 Ministry for the Environment. 2025. Package 3: Freshwater –Discussion document. Wellington: Ministry for the Environment.

4.5.3 Case Studies

4.5.3.1 Lake Taupō Catchment Groundwater Quality Monitoring – A Nitrate Issue

Monitoring was undertaken in response to policy initiatives to protect Taupō lake-water quality. This involved the reduction of the manageable nitrogen load to the lake by 20% and establishment of a nitrogen cap and trade system (Section 4.5.2). The aim and therefore hypothesis to test through monitoring is that nitrate concentrations in groundwater migrating to the lake would not increase in the long term (even though there may be short-term increases associate with lagged impacts).

The current monitoring network is illustrated in Figure 4.13 with the Evaluative prioritisation. Monitoring in this catchment is currently carried out in partnership with the Tūwharetoa Māori Trust Board, who have also been consulted throughout the review process. The proportionate sales of nitrogen to the Lake Taupō Protection Trust and consented transfers are also shown in Figure 4.14. A deficit in monitoring in the southern catchment near Turangi was identified. To address this, one additional well (72_4129) was selected for monitoring. It is proposed to otherwise keep the existing sites but reduce frequency of anaerobic site monitoring substantially, e.g. at least five years.

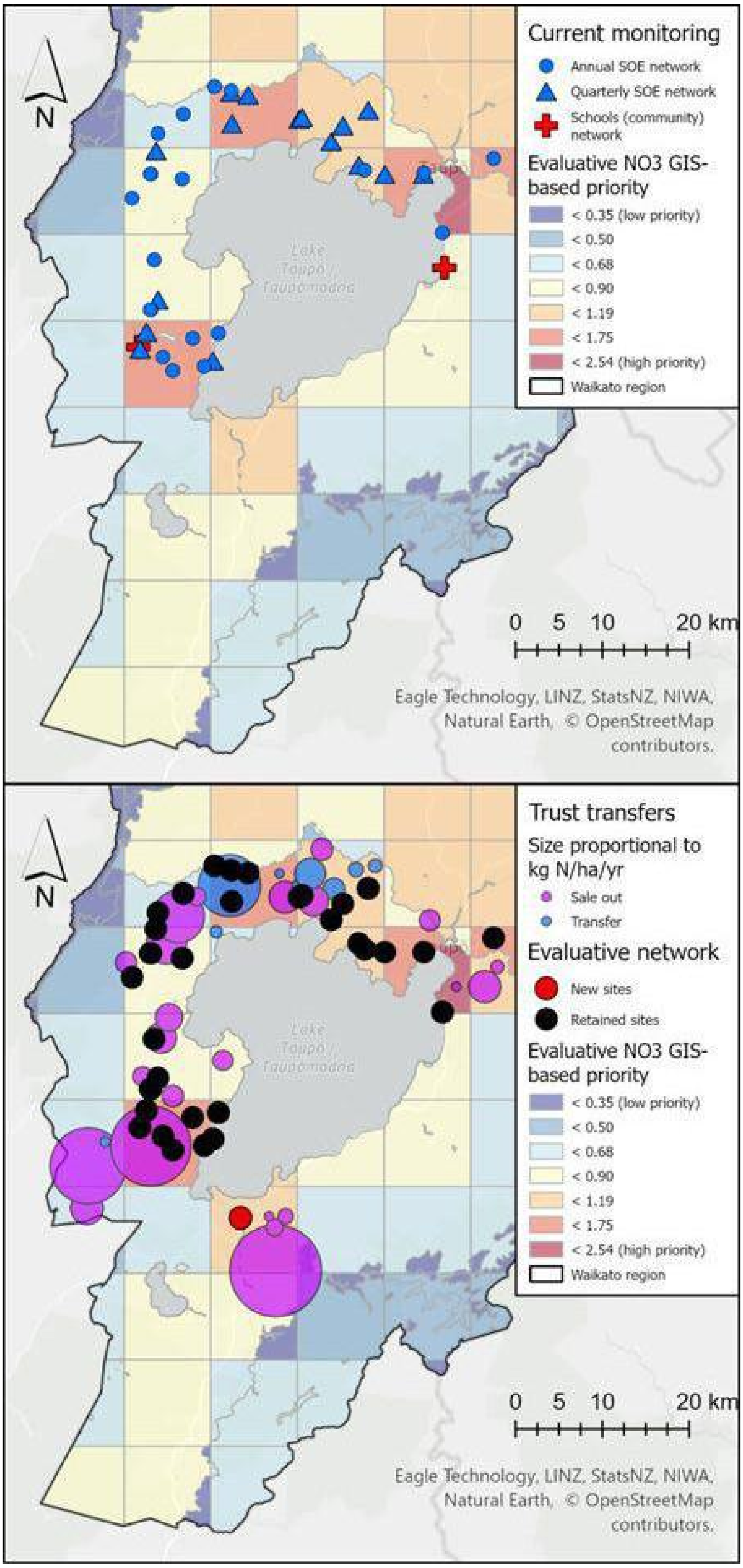

Figure 4.13 Current (top) and proposed (bottom) Evaluative monitoring sites in the Lake Taupō Catchment. The Lake Taupō Protection Trust conversion of land use to forestry is represented under transfers as sales out. Other transfers are nitrogen trading between locations.

4.5.3.2 Hahei Coastal Groundwater Quality Monitoring – A Salinity Issue

Monitoring was undertaken in response to concerns about potential saltwater intrusion resulting from groundwater abstraction for community water supplies (Hadfield 2016). Multiple abstractions have drawn groundwater in the confined fractured rhyolite aquifer down below mean sea level at the coast on a seasonal basis. There is therefore potential for long-term saltwater intrusion. Sentinel monitoring wells (72_3830 and 72_3831) were established by WRC at the coast. There are already some indications of slight salinity elevation at depth near the shoreline and in the vicinity of Wigmore Stream mouth. Recent construction of an additional groundwater supply 2 km inland from the coast was undertaken with the objective of reducing drawdown near the shoreline. It is noted that groundwater quality and level monitoring sites in the Hahei area provide value for Evaluative monitoring of seawater intrusion; as such, these have been recognised on Figure 4.14.

The hypothesis to test is that salinity in groundwater is not increasing as a result of modified abstraction for community water supply. High-frequency (15 minutes) telemetered monitoring of conductivity, water level and temperature has been established at the sentinel wells.

It is noted that Evaluative monitoring may extend into 'medium'-term to support and calibrate model simulation, and to provide context and understanding to underpin policy. Such modelling is involved in Taupō, Hahei and also Hauraki, and likely Pukekohe in future. This type of Evaluative data would be a wider category than site monitoring data, which is intended to show trend confidence directly in a pragmatic timeframe, e.g. 10 years.

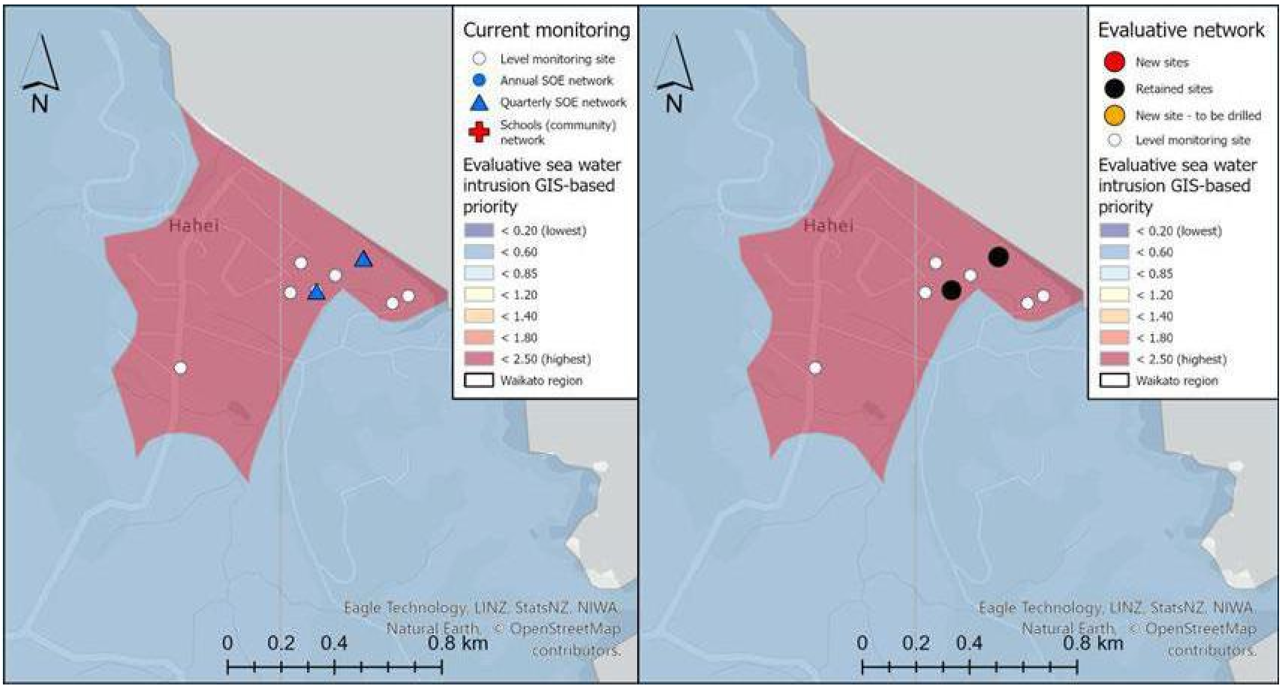

Figure 4.14 Current (left) and proposed (right) Evaluative monitoring sites in the Hahei area.

4.5.3.3 Rotopiko East Lake – A Nutrient and Bacterial Issue

Rotopiko Lakes are a complex of three, small, peat lakes in the Waipa District. Rotopiko East Lake is the smallest of the three and is nationally significant due to the macrophyte community supported by the lake (Sukias et al. 2006). In 2014, a predator-proof fence was constructed around Rotopiko East Lake as part of a larger restoration project (Sandoval et al. 2023). Following the removal of mammalian predators, a dramatic increase in roosting exotic birds established themselves in a kahikatea forest within the predator-free zone.

Nutrient and bacterial inputs to the lake catchment from the deposition of guano from roosting birds within the predator-proof enclosure has led to a range of significant ecological and environmental consequences. These include a significant decline in lake water quality, which has raised concerns about the potential for a regime shift to a turbid state dominated by algal and cyanobacterial blooms (Kelly and Robertson 2022). In addition to lake water quality impacts, the surrounding kahikatea forest has experienced substantial understorey vegetation loss, likely due to nutrient overloading and associated changes in soil chemistry. The accumulation of guano has also produced strong visual and olfactory effects, diminished the aesthetic and recreational value of the site and potential health risks posed to visitors.

In response, a variety of bird deterrent strategies have been implemented, including acoustic, light and smoke disturbances, selective thinning of roosting trees and the reintroduction of mammalian predators (rats) to disrupt roosting behaviour. To assess the effectiveness of these interventions, a targeted network of groundwater and surface water monitoring sites have been established across the lake catchment (Figure 4.15). This included six shallow bores, six piezometers and two surface water sites (in a drain feeding the lake). Groundwater and drain sampling was initially undertaken on a monthly basis to better understand dynamics, but now that this has been established, sampling has recently been reduced to two bores, two piezometers, and one drain sample on a quarterly basis to monitor the effectiveness of management efforts. This monitoring is being conducted in conjunction with lake water quality monitoring and avian population monitoring. These efforts are ongoing and will continue until there is clear evidence of ecological recovery and stabilisation of lake water quality. The hypothesis to test is that management initiatives are reducing nitrogen transport through groundwater to the lake.

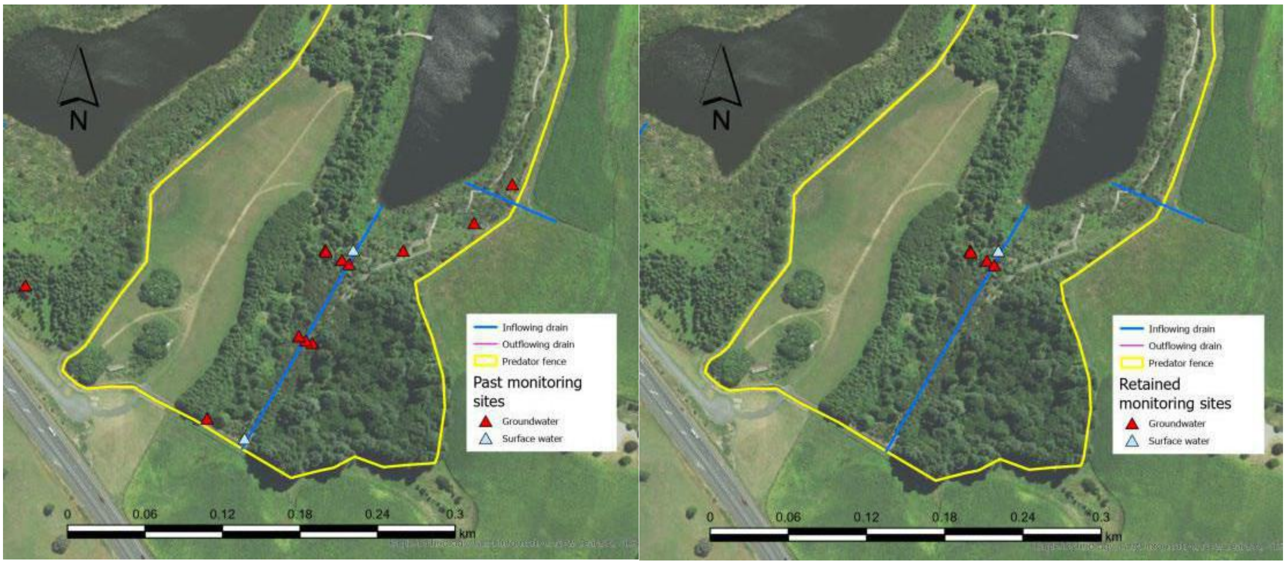

Figure 4.15 Current (left) and proposed (right) Evaluative monitoring sites at the Rotopiko East Lake.

4.5.3.4 Coromandel Peninsula and Seawater Intrusion

Groundwater resources of the Coromandel Peninsula are typically derived from pocket coastal sand aquifers and low-permeability fractured volcanics. Typically, the low-yielding formations are assessed as being low priority for Surveillance, but there are localised exceptions (red areas in Figure 4.16).

The representation of multiple potential seawater intrusion sites poses a challenge, but TCDC has been approached, and there are opportunities to collaborate monitoring efforts with their required source water supply monitoring.

It is apparent that the GIS-based prioritisation for Surveillance and Evaluative seawater intrusion sites results in similar distributions, largely reflecting the coastal pocket aquifers and localised settlement use. The current network is also approximately matching and only requires some minor modification.

Western Coromandel

The western side of the Coromandel Peninsula is of low priority for Surveillance, and localised modest interest for Evaluative seawater intrusion. As a result, wells 60_480 and 60_316 are to be dropped.

There are currently three schools that are monitored on the western side of the Coromandel Peninsula. These are 60_260 (Tapu School), 72_9396 (Te Puru School) and 60_236 (Manaia School). These will be maintained on the usual two-yearly basis. It was intended that Colville School (72_1090) would also be added to the biennial monitoring. The groundwater at Colville School is anaerobic, with elevated chloride (1520 ppm) and sodium (829 ppm) in 2002. There is, however, insufficient information particularly regarding site access (site sheet WRC doc 1235429 and well log WRC doc 1365860) for Colville School to monitor at this stage. The well is reported to be 25 m deep and cased into the top of weathered greywacke. Both the Tapu and Colville schools could be considered Evaluative given their elevated salinity.

The other area on the western side of the Coromandel Peninsula of moderate GIS-based priority is Thames. The principal interest here is in respect to potential groundwater inundation from sea-level rise. Two monitoring wells will be drilled in the near future for this Evaluative purpose (72_13282 and 72_13283). They will be monitored using TLC loggers.

Eastern Coromandel

The following comments are in respect to proposed changes to monitoring on the eastern side of the Coromandel Peninsula, progressing from north to south (Figure 4.16).

The current monitoring well at Whangapoua (60_407) will be substituted by site 72_9235, which has better log information and location closer to the coast.

The ‘current’ monitoring site 72_3559 (Lovegrove) at Kuotunu was recently dropped due to installation of septic soakage in close vicinity. It is not proposed to replace this site.

A monitoring well will be added at Matarangi for Evaluative monitoring. Two sites were visited in Matarangi and sampled – 72_236 (one of the TCDC community supply wells for Matarangi – this well-field is no longer being used, with supply now coming from streamflow), and 72_3472 (one of a series of monitoring piezometers constructed along the foreshore at Matarangi for investigation associated with a proposed wastewater treatment disposal field). Well 72_3472 was considered the more suitable site and is proposed to be added to the network.

It is intended to maintain monitoring of 60_124 (Carter) at Whitianga in the Surveillance monitoring.

Cooks Beach: one Surveillance and Evaluative well retained – 60_12 (Fire Station). There is an adjacent piezometer (72_1878) that WRC installed that could be utilised instead in future. There are also a few further options available, e.g. from the former six-monthly coastal run (in WRC’s Groundwater Quality Calendar), but no change has been recommended at this stage (this may change with further concern about saltwater intrusion which justifies investigation).

Hahei: currently we have 60_190 (Motor Camp tanks) and Hahei Sentinel shallow (72_3831) and Hahei Sentinel deep (72_3830) as Surveillance and Evaluative monitoring wells. These were previously added to quarterly SoE monitoring. Further Evaluative sites could be added to support the modelling being undertaken at Hahei. There are several existing investigative monitoring wells and piezometers we installed to choose from, and their addition to the network would require further justification from modelling.

Tairua will have one Surveillance well 60_348 retained at the golf course.

South of Tairua we carry out Surveillance monitoring at Awapuketea Dairy Farm. We will swap the current well 60_345 to the more conveniently accessed, newly drilled well 72_12022 at this site. Monitoring in December 2024 showed these waters to be essentially identical.

Opoutere – there is a known saltwater interface at the motor camp. It is recommended we monitor the piezometer (72_2375) we installed through the saltwater interface at the motor camp for evaluation of saltwater ingress. Care must be taken when using this piezometer to ensure comparative samples are obtained by using consistent methodology.

The Opoutere School is also monitored biennially as part of the Schools (Community) network. Nearby well 60_167 will be dropped, given it is anaerobic. This well could be resampled again in five to 10 years to check.

Pauanui – collaboration with TCDC is recommended in utilising one (60_310) of the three TCDC community water supply wells for Evaluative monitoring.

There is one shallow coastal piezometer 72_9717 (Pipi Rd) at Whangamata that will be retained for Surveillance. Also, other community water supply wells will be monitored at Whangamata for Evaluative purposes in collaboration with TCDC. The recommended wells are 72_1014 (Manuka Place) and 60_6 (Beverly Hills).

There is one Surveillance well that will be retained at Whiritoa – 63_269 (Cropp).

It is noted that there are still eight schools monitored biennially as part of the Schools (Community) network in Coromandel.

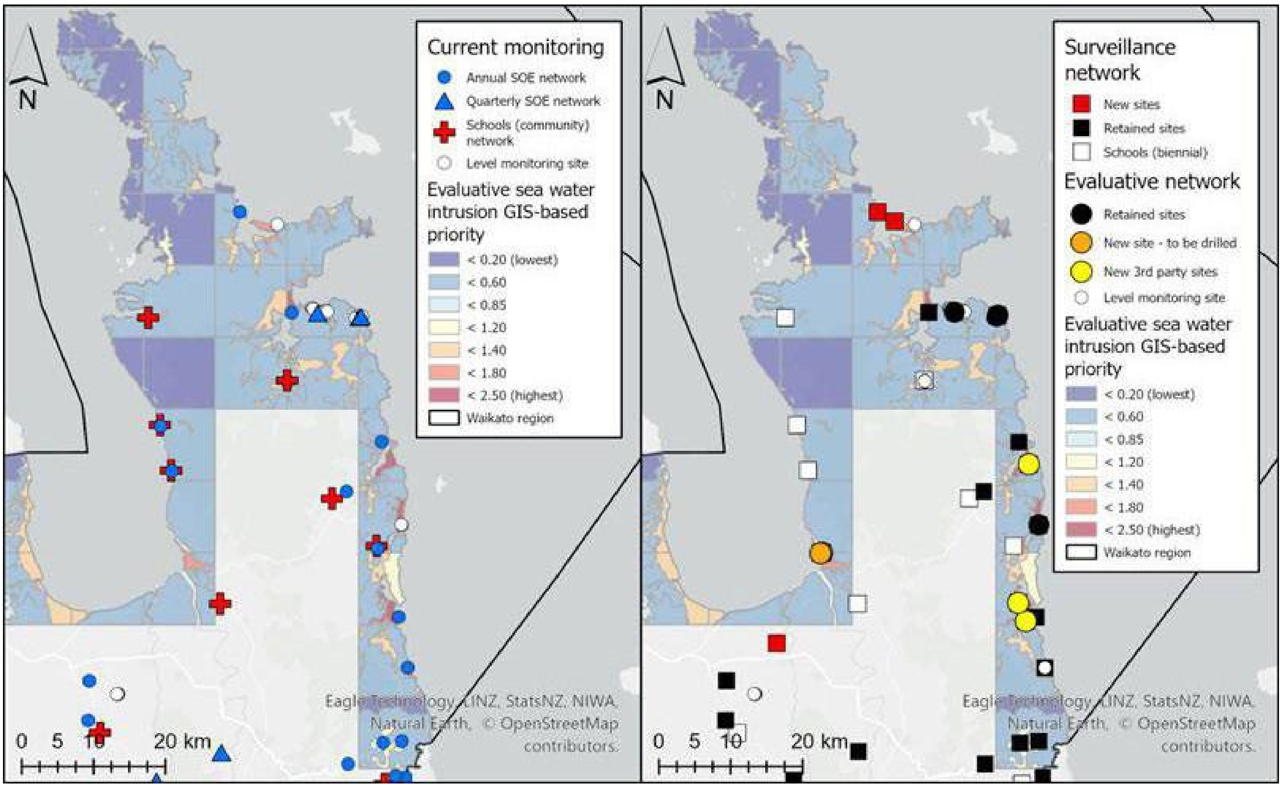

Figure 4.16 Current (left) and proposed (right) Surveillance monitoring sites in the Coromandel Peninsula.

5.0 Discussion

5.1 Lessons Learned

Extensive engagement was undertaken as part of this process (Section 3.2), with the intention that the approach and lessons learned could inform similar efforts elsewhere. A key insight from the consultation was the importance of transparency, particularly given the influence of subjective decisions on final monitoring-programme design. Iterative movement between high-level strategic planning and practical implementation was found to be essential in achieving meaningful improvements. Ongoing communication with field teams is essential to ensure pragmatic network design that can be successfully implemented. Involvement with policy teams is also important for effective evaluation.

The review of the current monitoring network required decisions on whether to retain existing sites or identify new ones. To ensure cost-effectiveness and practicality, it was found useful to apply a set of criteria that allowed assessment on a case-by-case basis. This included the availability of well-log information, site access, health and safety considerations, and sampling feasibility (e.g. issues with large volumes of water required to be pumped before sampling). Preference was given to more recently drilled wells, council-constructed wells and those with longer monitoring records. Sites with strong geothermal influence were also generally avoided. Where there were multiple candidate wells but none meeting all criteria, those meeting most were generally selected. It was found, however, that site access was critical to ensure long-term data acquisition. For example, a well that is suitably located, with a useful data record, may nevertheless be rejected due to access issues. Site access is a common difficulty experienced by groundwater quality monitoring agencies.

Other considerations agreed included the representation of some cold-water springs. Despite the inherent uncertainties of their capture zones, they often hold cultural and community significance. Springs often also support river flows and ecosystems. High-yielding perennial springs can integrate with the land-use signature over large areas.

The three-dimensional nature of groundwater resources requires the consideration of depth as well as mapped, two-dimensional distribution. For Surveillance monitoring, well depths typical of local takes were generally preferred. A change in redox with depth from aerobic to anaerobic conditions is common throughout most of the Waikato. The prioritisation of aerobic groundwater over mixed or anaerobic conditions was discussed and considered appropriate for Evaluative purposes and higher-frequency sampling. It is noted that nitrogen flux to surface waters essentially occurs through aerobic groundwater, which can be constrained to shallow depth. Sites with high-data variability were also considered less desirable for Evaluative purposes, given it reduces the power to detect change.

Groundwater age also needed to be factored into decisions around sampling frequency and Evaluative monitoring. Spatial distribution was guided by GIS-based prioritisation, though some subjective flexibility was necessary, based on well availability. In some cases, lower-frequency monitoring (e.g. two-yearly), could be considered, particularly for sites with older groundwater and anaerobic conditions. That is, however, provided well access was considered reliable with less frequent site visits. Opportunities for collaboration with community water supply monitoring by district councils were explored, and a number of sites were selected for inclusion in the network. The ongoing monitoring of these sites will involve continued collaboration between WRC and those district councils.

It is important to note that the relevance and weighting of these considerations varies depending on whether a site is intended to be monitored for Surveillance or Evaluative purposes.

Although Evaluative monitoring may be targeted at detecting shorter-term change (Etheridge et al. 2023), the lag times in the Waikato are often relatively substantial compared with some other regions. Large variations in lagged effects due to groundwater transport on surface water is evident both regionally and nationally (Stenger et al. 2024). McDowell et al. (2021) reported lags between one and 12 years in surface water catchments nationally from statistical analysis of nitrogen leaching estimates and riverine nitrate-nitrogen loads in 34 catchments. There is, however, potential for substantial hysteresis related to land-use effects. Research in Europe by Ehrhardt et al. (2021) found that, despite management initiatives limiting anthropogenic nitrogen input to many large catchments, there were substantial delays to water quality improvement due to nitrogen retention within the catchment.

At a smaller scale, targeted Evaluative monitoring in the Lake Rotopiko catchment (Section 4.5.3.3) is nevertheless expected to take considerable time to robustly detect change relating to management initiatives. It is important to note that this monitoring is not driven by specific policy obligations but rather initiated in response to targeted management actions and community interest. Although it does address a general policy requirement that the *"health and well-being of degraded water bodies and freshwater ecosystems is improved"* (Policy 5, NPS-FM).

Although significant simple relationships between power of detection and hydrogeologic factors are lacking (Section 4.1), it is obvious that trying to detect change in nitrate concentration in anaerobic groundwater would be futile (nitrate does not occur or is removed in anaerobic conditions). It also appears that wells with older groundwater, lower nitrate concentrations and more scattered data records are less likely to detect change. This suggests that such wells are lower priority for Evaluative purposes, as early changes are likely to be picked up by their inclusion in the Surveillance network. It is noted that random selection of sites has not been adopted in this review, given the pragmatic difficulties that would incur. Rather, the strategy adopted is to be transparent about the decision making involved.

The proposed changes required consultation with, and have implications for, WRC's Environmental Monitoring team. The benefit and importance of considering practical implications on the ground in an iterative fashion with higher-level optimisation has already been mentioned.

There are aspects of monitoring that may not be documented here but which may provide flexibility and efficiencies by small additions of non-routine data collection. Our programmes need to be flexible to allow for reactionary monitoring beyond the normal programme. The requirement for flexibility was echoed by other regions during our May 2024 consultation (Section 3.2).

5.2 Feedback on the Proposed Design

An earlier version of this report was circulated to the GWF Working Group (five regions), the Ministry for the Environment, StatsNZ and the PCE's office. Feedback was sought to: identify major issues in the approach through the peer network, test whether the transparency provided was suitable, and check whether the objectives of the optimisation were achieved. Supportive and constructive feedback was received and addressed (Table 5.1).

Table 5.1 Summarised feedback received on the Waikato pilot study draft report circulated in November 2025 and presented to the Science community in December 2025. Asterisks denotes comments that triggered text revisions beyond this section.

Organisation(s)	Feedback	Author's Response
GWF / Ministry for the Environment / PCE	Valuable transparency gain / Supportive / No substantive issues raised with the approach.	Minor editing of the report, rather than a need to modify the optimisation approach.
GWF / Ministry for the Environment	The GR Index does not account for base flow and environmental contributions, thus emphasising human groundwater use over other uses and 'users', e.g. cultural, spring-fed waterbodies, groundwater dependent ecosystems.*	Considerations for base flow were incorporated subsequently to the GIS-based priority. The GR Index requires nationally consistent and available datasets. Our approach allows us to further develop and integrate more suitable metrics for the next iterations.
PCE	Although specific to groundwater quality, this approach directly addresses multiple environmental monitoring shortcomings.	Acknowledges relevance of aspects of our approach to other environmental domains.
	How does this compare/relate to the recently completed work on prioritising freshwater monitoring objectives in New Zealand?*	The freshwater prioritisation includes wider regulatory monitoring and is high-level, whereas our work focusses on pragmatic groundwater quality monitoring.
	What ability is there to re-evaluate surveillance priorities in the future?	Our approach is designed to enable review, either regularly or as needs arise.
Ministry for the Environment	Should groundwater quality monitoring priorities be ranked consistently in all regions?*	Our GIS-based priority approach allows for some flexibility of design while looking for national consistency. It allows some variation in weighting, reflecting differences between regions (e.g. hydrogeology and management).
	Timing for implementation?*	Changes will be implemented by December 2026, as this timely review is needed both regionally and nationally to ensure we continue to collect relevant data.
	Preferred timing between reviewing national programme and needs?*	A review of national needs is timely. Our approach is transparent and provides a platform from which adjustments can be readily made. In the interim, ensuring data collected is fit-for-purpose is in the interest of monitoring agencies (councils and Crown Research Institutes [at the time of writing this report]) using available guidance.

5.3 Surveillance/Evaluative Framework Linkage to Concurrent Work on National Freshwater Monitoring Priorities

Of relevance to this work, a recently completed project identified national freshwater monitoring priorities using structured expert elicitation (12 policy and planning experts) (Stoffels et al. 2025). Within this work, several types of long-term monitoring were considered, including: SoE monitoring, compliance monitoring (i.e. tied to consent conditions) and monitoring for adaptive management. The work identified five objectives for monitoring:

1. To assess progress towards broad policy and planning objectives.
2. To make state-dependent decisions, where specific action to take is dependent on the state of the environment in a specific place or time.

3. To assess the effects of ‘interventions’, which include policy and plan changes, as well as on-ground mitigation and rehabilitation actions, on environmental outcomes.
4. To predict outcomes of interventions, to aid their design or selection.
5. To engage stakeholders in water resource management.

The next phase of this work is currently underway and aims to develop a framework to support councils in adapting their environmental information plans, such that those plans may more effectively and efficiently fulfil the five monitoring objectives prioritised by Stoffels et al. (2025).

This prioritisation approach encompasses any environmental monitoring (e.g. air quality, groundwater quality) and therefore addresses high-level issues. Work reported in this report aims to provide a pragmatic approach targeted to groundwater quality transparently separating Surveillance (i.e. long-term, capturing broad-scale phenomenon such as climate-change) and Evaluative (i.e. enabling the assessment or forecasting of a management choice) monitoring. There are no contradictions between the five priority objectives from Stoffels et al. (2025) and the framework used in this report; these objectives variably contain elements of Surveillance and Evaluative objectives.

5.4 Extending Optimisation Approach to Other Regions

There are more groundwater bodies than can be monitored in the region, and the GIS-based priority method presented here provides a flexible framework for prioritisation, which is necessary for councils to operate. It is expected that if this method is extended to other regions, there will be differences in both GR Index values (differences in aquifer system size and use) and GIS-based priority ranking (varying hydrogeological context and pressures). It follows that the threshold used to differentiate between primary and secondary systems in the Waikato may need revision when applying nationwide for consistency. Alternative options include the use of a distribution threshold value on the GR Index to attribute class and/or using region-specific thresholds. Assessing the impact of varying the classification threshold type and value will require undertaking other case studies to test differences in GR Index and ranking.

While undertaking this case study, institutional knowledge was used to retrace the evolution of networks and regional groundwater understanding, and disentangle Surveillance from Evaluative. It is possible that, due to staff movement, this task may be less straightforward in other regions. Should the situation arise, it is proposed to continue working with the Groundwater Forum Working Group to support the optimisation, using the collective experience. This is consistent with the “establish pathways to transferring knowledge” aim of the National Groundwater Quality Monitoring Framework (Moreau 2024).

Groundwater resource management base units are aquifer or aquifer systems. However, in New Zealand, aquifer 3-D delineation and, therefore, attribution to individual monitoring sites remain a challenge in parts of the country. In the Waikato, where sedimentary and volcanic aquifers occur over large areas, with alternating deposition and reworking of volcanic material over geological time, this is particularly difficult. It was therefore addressed by monitoring surface areas combined with well depth and, in places, redox conditions. This was complemented by comparing the Groundwater Classification to reported aquifers, and adding wells to the network to represent some well-known aquifers of limited outcrop (e.g. Kaawa Formation aquifer). In regions where it is possible to unequivocally attribute aquifers to monitoring sites (existing and potential), it might be possible to develop the classification using aquifers as base units. This situation also made the use of random well selection complex; however, provided the well network is sufficiently dense and includes aquifer attribution, stratified random well selection may be trialled, with the caveat that site access may remain a limiting factor.

Historically, springs have been monitored in some regions but are not typically included in SoE networks with some exceptions (e.g. Tasman District). In the Waikato, an in-house spring dataset (Wilson 2022) was used to identify potential sites. Although the LINZ digital dataset provides spring locations nationwide, it is lacking information of their suitability as long-term sampling sites (e.g. access, indication of flow rate, perennial/intermittent flow). The inclusion of springs to the network in other regions may require either site visits or the use of adequate site investigations (Green 2022).

The method used to review Surveillance NGMP monitoring in the Waikato relied on datasets available nationwide, regional expert reviews and published national reporting topics (Section 3.6). However, cost-efficiencies were a significant factor in network optimisation. The number of sites per region varies in the network and, although some monitored groundwater bodies extend across regional boundaries, like the South Auckland Volcanics, it is also expected that the optimisation may identify the need for a denser network. As changes will be implemented on a region-by-region basis, a final iteration nationwide will be required to finalise NGMP optimisation.

Transparency will be key to understanding variation between regions, and between regional and national views. This report aims to capture optimisation decisions to provide such transparency. Reporting was identified during the May 2024 Groundwater Forum consultation as a suitable format. A peer-review step by the Groundwater Forum Working Group was therefore built to test this format in other regions, albeit that some sections may simply be cross-referenced in potential future report for efficiency.

5.5 Regional Changes

Implementing the changes outlined in this report marks a significant shift in how regional groundwater monitoring is conducted in the Waikato. The optimised approach directly addresses several limitations of the current monitoring systems and programmes, including:

- Some inconsistencies in data collection.
- Unclear monitoring objectives.
- Lack of systematic, coordinated and consistent monitoring at the national level.
- Spatial bias in site distribution.
- Inconsistencies in site and variable selection.
- Insufficient data for assessing policy effectiveness.
- Challenges with data accessibility.

This revised approach is aligned with international best practices, such as those used in the EU and US (European Commission 2003; Subcommittee on Ground Water of the Advisory Committee of Water Information 2009). While overall improvements to the network are limited by existing financial and logistical resources, the recommended changes are designed to maintain a neutral net effort (Table 5.2). This has been achieved by expanding spatial coverage while reducing sampling frequency and density in areas where this is appropriate.

An overall increase in monitoring sites has been made possible by integrating third-party monitoring required by drinking water providers under the Water Services Act. In this context, district councils have been invited to collaborate on source water monitoring for municipal supplies.

Table 5.2 Overall network changes by area (includes the Schools (Community) network). Site visits per year are the number of times a site is visited in each calendar year. For example, a site visited quarterly has four site visits per year and a site visited biennially has 0.5 site visits per year.

<table>
<tr><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2">Current Network</th><th colspan="2">Revised Network</th></tr>
<tr><th>Surveillance</th><th>Evaluative</th></tr>
<tr><td rowspan="11">Number of Sites</td><td>Northern areas</td><td>28</td><td>32</td><td>-</td></tr>
<tr><td>Hamilton Basin</td><td>39</td><td>34</td><td>-</td></tr>
<tr><td>Hauraki</td><td>44</td><td>47</td><td>-</td></tr>
<tr><td>Coromandel</td><td>20</td><td>12</td><td>11</td></tr>
<tr><td>Waihi</td><td>6</td><td>5</td><td>-</td></tr>
<tr><td>Waipa / King Country</td><td>32</td><td>25</td><td>5</td></tr>
<tr><td>Upper Waikato</td><td>18</td><td>16</td><td>2</td></tr>
<tr><td>Taupō</td><td>43</td><td>4</td><td>40</td></tr>
<tr><td>Western areas</td><td>8</td><td>9</td><td>-</td></tr>
<tr><td rowspan="2">Regional Total</td><td rowspan="2">238</td><td>184</td><td>58</td></tr>
<tr><td colspan="2">242</td></tr>
<tr><td rowspan="11">Site Visits per Year</td><td>Northern areas</td><td>45.5</td><td>52</td><td>-</td></tr>
<tr><td>Hamilton Basin</td><td>58.5</td><td>53.5</td><td>-</td></tr>
<tr><td>Hauraki</td><td>91.5</td><td>91</td><td>-</td></tr>
<tr><td>Coromandel</td><td>29</td><td>9</td><td>29</td></tr>
<tr><td>Waihi</td><td>5.5</td><td>4.5</td><td>-</td></tr>
<tr><td>Waipa / King Country</td><td>51</td><td>26.5</td><td>20</td></tr>
<tr><td>Upper Waikato</td><td>22.5</td><td>22</td><td>1.5</td></tr>
<tr><td>Taupō</td><td>102</td><td>9</td><td>80.5</td></tr>
<tr><td>Western areas</td><td>4</td><td>4</td><td>-</td></tr>
<tr><td rowspan="2">Regional Total</td><td rowspan="2">409.5</td><td>271.5</td><td>131</td></tr>
<tr><td colspan="2">402.5</td></tr>
</table>

5.6 National and Regional Programmes Comparison

The key differences between optimised Surveillance programmes are:

- At the regional scale, the network is based on a fixed density criteria per monitoring priority rating and continued pro-active data collection to support upcoming regional policies.
- At the national scale, the Surveillance network aims to represent regional hydrogeological features and meet statistical requirements for national reporting without consideration of policy effectiveness. The database and research components of the programme aim to continue building national datasets, including geothermal features or groundwater ecosystem diversity. The collected data has been used to complement regional overview of groundwater resources, where monitoring is not routinely undertaken (e.g. West Coast [Moreau et al. 2021]).
- The proposed regional networks remain significantly denser that the proposed NGMP network. The use of a consistent optimisation approach combined with site sharing between networks enhanced consistency (Figure 5.1). The proposed changes do not affect the research alignment opportunities between programmes.

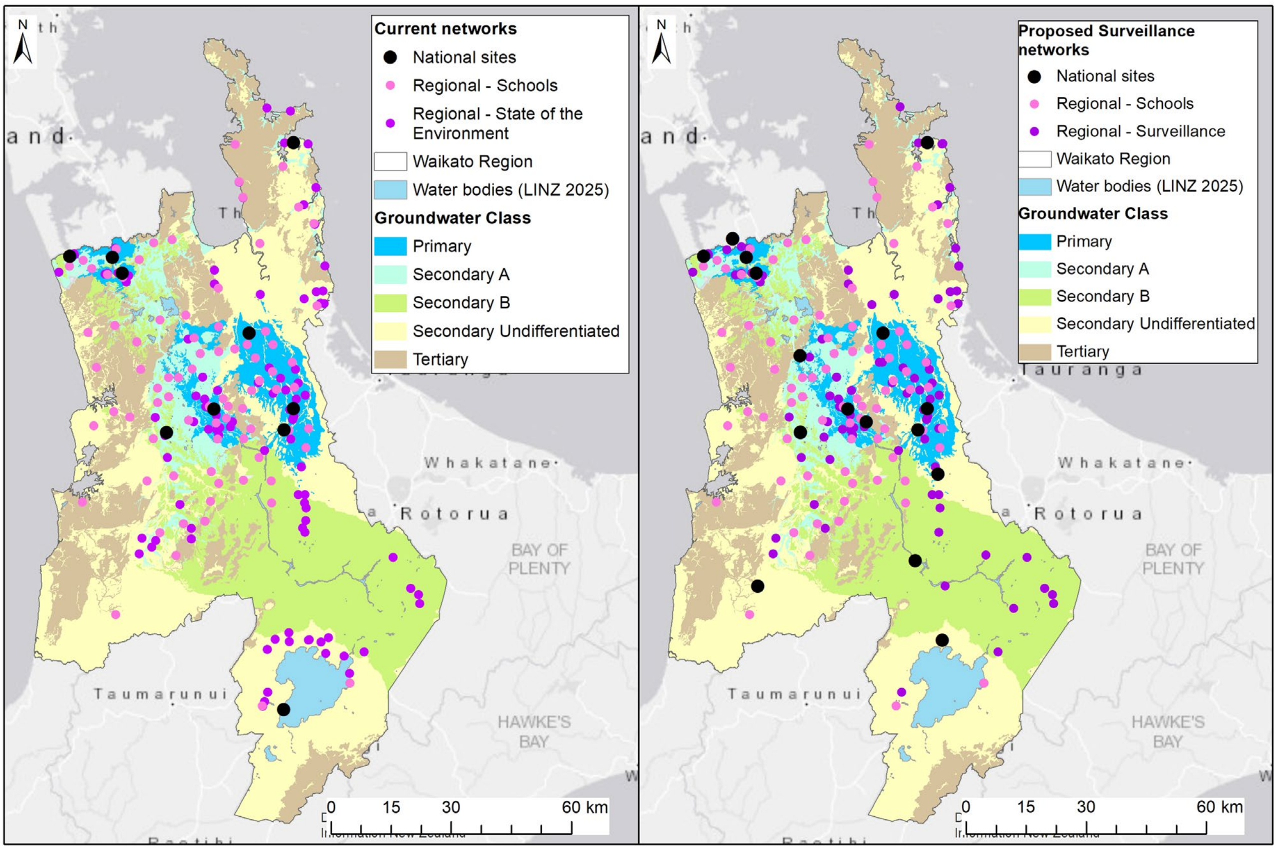

Figure 5.1 Current and proposed Surveillance network for the Waikato region.

5.7 Environmental Reporting on Groundwater Quality Nationally

While reviewing NGMP, the topics in scope for environmental reporting (Ministry for the Environment and Statistics New Zealand 2016) were reviewed, and both the accessibility and availability of key groundwater data key were found to be limited, in particular for geothermal water quality and groundwater ecosystems.

Geothermal features (which include high and low temperatures) occur nationwide (Figure 5.2); however, their monitoring is currently undertaken only in the Waikato and Bay of Plenty regions, and is constrained by site access and limited resourcing (Luketina 2022; Zuquim and Box 2023). Historic geothermal quality data are currently curated under Earth Sciences New Zealand's Natural Thermal Feature springs dataset, which is not linked to the NGMP dataset (Geothermal and Groundwater Database 2025). In light of current requirements, we are proposing to enhance the linkage to the NGMP, leveraging from in-house expertise and enhancing its visibility. However, this excludes any data acquisition. NGMP is not currently resourced to design and undertake long-term monitoring of geothermal features or ecosystems at the national scale. Developing such a programme will require resourcing experts to determine a suitable number of sites, analytical suites and sampling frequency, quality assurance and a long-term operation and data management plan. It will also require consultation with iwi and councils as geothermal features can have significant cultural values and associated data sovereignty.

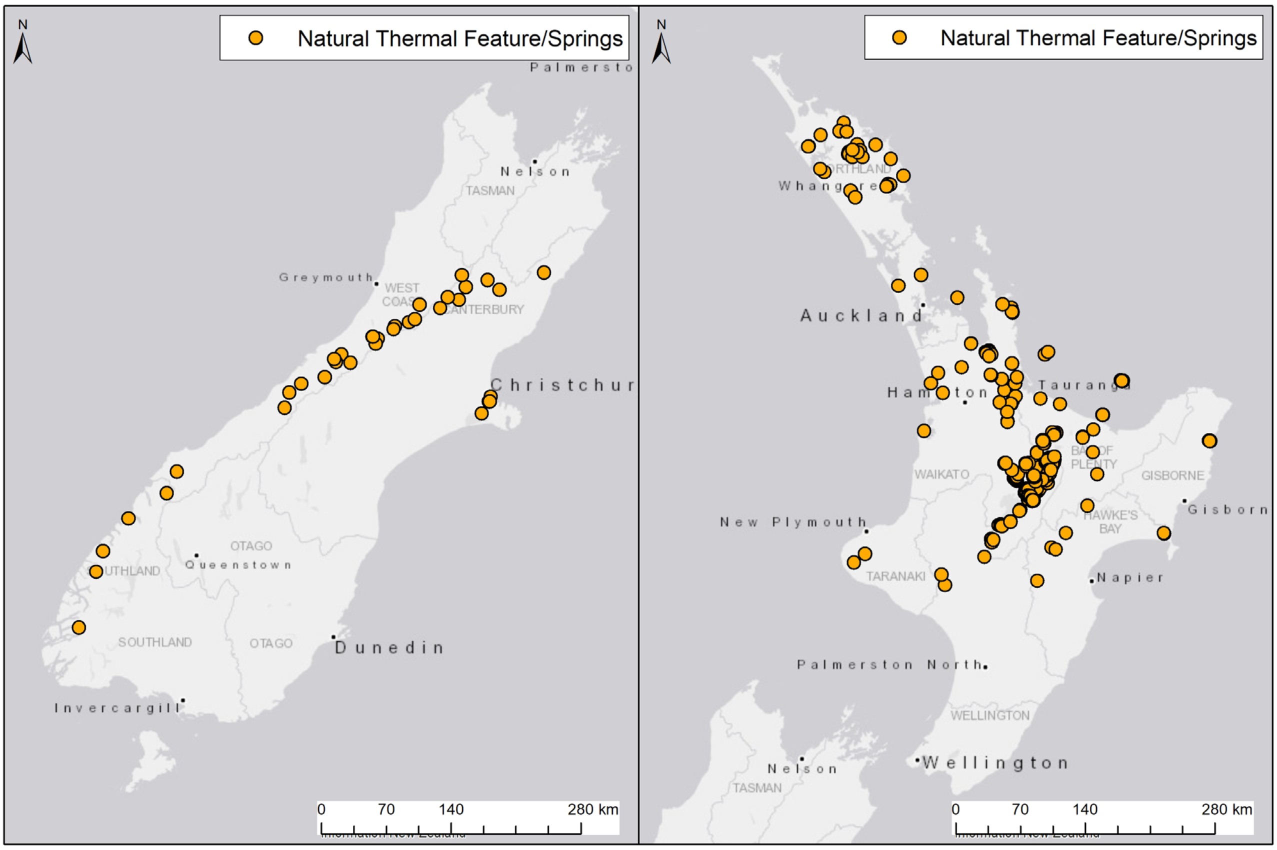

Figure 5.2 Extent of the Natural Thermal Feature springs dataset (Geothermal and Groundwater Database 2025).

Groundwater ecosystems are in the characterisation stage in New Zealand (Fenwick et al. 2018; Weaver et al. 2023; Houghton et al. 2024) and actively researched by multiple organisations. This characterisation is a prerequisite to develop a suitably representative groundwater ecosystems monitoring programme or, alternatively, the use of environmental proxies. Developing a suitable monitoring programme for groundwater ecosystems will require experts to determine suitable site numbers, analytical suite and sampling frequency, and may also require consultation with iwi.

6.0 Recommendations

6.1 Implement Proposed Changes

To enhance the provision of robust monitoring information to underpin policy development and groundwater management, it is recommended that WRC and Earth Sciences New Zealand (GNS Science business unit):

- Implement the proposed changes to their regional and national programmes within 12 months of the publication of this report. For regional monitoring, this entails modification of the current monitoring runs to implement the network changes described in Section 4.0 and summarised in Table 6.1. This will include some initial setup of new sites involving installation of override switches and sampling taps. For national monitoring, it includes actioning network changes in the Waikato and modifications to the dataset. Undertaking similar collaborative reviews in other regions to gradually cover the full national network will require a longer timeframe, likely to be multiple years. As it progresses, proposed changes may be required. At the time of writing of this report, changes to the RMA (1991) have been proposed and may result in amendments or revoking of the Act. This, in turn, may impact multiple policies that currently drive monitoring needs (e.g. National Policy for Freshwater Management, topics to be reported on as part of the Environmental Reporting Act). However, the need for both monitoring and effecting a step change in our approach remain valid. Proposed changes have been informed by groundwater quality monitoring experts to provide a framework that enables further reviews and pragmatic adjustments either after a set period or following a specific event.
- Review regularly (ideally annually) the regional network to record any changes. These reviews should be shared with the NGMP manager to ensure networks continue to be aligned.
- Use WRC internal database systems to record new metadata for each monitoring site (i.e. record the monitoring objective [Surveillance or Evaluative] for each site in WISKI).
- Instigate and run further trials of continuous monitoring for nitrate and conductivity at selected sites for Evaluative purposes. For nitrate, it is recommended to establish a trial at site 69_173 to better understand the redox relationship before considering the transition to the newer piezometer (72_10613). For conductivity, it has been recommended to implement continuous monitoring at Hahei (72_3830 and 72_3831), in conjunction with the establishment of a new telemetered groundwater level site in this bore (Wilson 2025).
- Ensure long-term monitoring programmes continue to provide valuable context for shorter-term investigations. This may involve: undertaking pilot surveys; determining whether an event is unusual or extreme; and providing independent observations to calibrate or assess models, and to address climate change (Lovett et al. 2007).
- Contribute monitoring information to research programmes. The flexibility built within these programmes has been and should continue to be used to support research initiatives as well as occasional maintenance. Ongoing collaboration through research programmes building on long-term monitoring demonstrates these are effective to align science opportunities across organisations. Regular programme reviews are good practice (Lovett et al. 2007), and a frequency of five to 10 years may be suitable.
- Develop MOUs between WRC and Earth Sciences New Zealand, and third parties, to formalise collaboration and make parties aware of efficiencies gained. This would also reduce the risk of losing sites over time through internal reviews.
- Consider the SoE reporting and monitoring of cross-regional boundary aquifers jointly with neighbouring regions.
- Continue engagement with the Groundwater Forum for mutual benefit.

- Further evolve Evaluative monitoring at the regional scale as required. This task may require testing or establishing monitoring targets collaboratively during policy development.
- Engage with groundwater level and surface water quality monitoring, where there may be further opportunities for alignment.
- Review monitoring needs for organic compounds to ensure cost efficiencies and suitable regional representation at the national scale. This topic was excluded from the initial scope to enable development of the optimisation method and will require consultation with the New Zealand Institute for Public Health and Forensic Science. It is recommended that a consistent approach be adopted to that presented in this report.
- Engage with other special interest groups to discuss the optimisation approach. The shortcomings identified by the PCE, rooted in changing scope and fragmented resourcing, were reported across all environmental domains. Extensive consultation was undertaken while developing this approach and, at the time of writing this report, this is the first practical application proposing changes that address these shortcomings without additional resourcing. The approach presented has potential to be applied elsewhere. In the first instance, the work may be presented to the Surface Water Integrated Management SIG.

Table 6.1 Summary of site changes.

	Site	Locality	Current Run	Reason	
Drop	60_167	Coromandel	Annual Coromandel	Dropped in frequency as anaerobic – could be resampled again in five to 10 years to check.	
	60_316	Coromandel	Annual Coromandel	Western Coromandel low priority and has enough spatial coverage – not justified.	
	60_345	Coromandel	Annual Coromandel	Dropped in favour of new bore at same location.	
	60_407	Coromandel	Annual Coromandel	Substituted for a site (to be determined) with better information and location.	
	60_480	Coromandel	Annual Coromandel	Western Coromandel low-priority and has enough spatial coverage – not justified.	
	61_59	Northern areas	Quarterly 1	No longer able to access.	
	63_201	Hauraki	Annual Waihi	Enough spatial coverage in Waihi – not justified.	
	63_57	Hauraki	Quarterly 4	Wide bore dropped in favour of new piezo.	
	67_404	Upper Waikato	Annual Tokoroa	Enough spatial coverage in Tokoroa – not justified.	
	67_483	Upper Waikato	Annual Tokoroa	Enough spatial coverage in Tokoroa – not justified.	
	69_19	Hamilton Basin	Annual Hamilton	Wide bore dropped in favour of new piezo.	
	69_248	Hamilton Basin	Annual Hamilton	Wide bore dropped in favour of new piezo.	
	69_295	Hamilton Basin	Annual Cambridge/Waipa	Wide bore dropped in favour of new piezo.	
	69_374	Hamilton Basin	Annual Hamilton	Wide bore dropped in favour of new piezo.	
	70_47	Hamilton Basin	Quarterly 3	Wide bore dropped in favour of new piezo.	
	70_50	Hamilton Basin	Annual Cambridge/Waipa	Wide bore dropped in favour of new piezo.	
	70_65	Waipa	Quarterly 5	Issues with access and enough coverage in the area.	
	71_1	Waitomo	Annual Otorohanga/Waitomo	Enough spatial coverage in area – not justified.	
	71_5	Waitomo	Annual Otorohanga/Waitomo	Enough spatial coverage in area – not justified.	
	72_10508	Upper Waikato	Annual Tokoroa	Enough spatial coverage in Tokoroa – not justified.	
	72_2138	Upper Waikato	Annual Otorohanga/Waitomo	Enough spatial coverage in area – not justified.	
	72_3559	Coromandel	Annual Coromandel	Septic tank installed in close vicinity.	
	72_3741	Waikato	Annual Tokoroa	Enough spatial coverage in Tokoroa – not justified.	
Pick Up	1131_87	Upper Waikato	-	Gap Filling	Surveillance – monitoring undertaken by third party (Taupō DC – Mangakino Spring).
	3314_3	Hauraki	-		Surveillance – monitoring undertaken by third party (South Waikato DC – Blue Spring).
	60_310	Coromandel	-		Surveillance – monitoring undertaken by third party (TCDC – Pauanui).
	60_6	Coromandel	-		Surveillance – monitoring undertaken by third party (TCDC – Whangamata).
	61_1343	Northern areas	-		Surveillance monitoring.
	61_20	Northern areas	-		Surveillance monitoring (part of current groundwater level network).
	61_46	Northern areas	-		Surveillance monitoring (part of current groundwater level network).
	67_565	Hauraki	-		Surveillance – existing school site proposed to move to annual.
	68_794	Taupō	-		Surveillance – existing school site proposed to move to annual.
	69_1349	Hamilton Basin	-		Surveillance – existing school site proposed to move to annual.
	69_2075	Hamilton Basin	-		Surveillance – existing school site proposed to move to annual.
	70_795	Waipa	-		Surveillance monitoring.
	72_10057	Upper Waikato	-		Surveillance monitoring.
	72_1014	Coromandel	-		Surveillance – monitoring undertaken by third party (TCDC – Whangamata).
	72_10829	Northern areas	-		Surveillance monitoring.
	72_11978	Hauraki	-		Surveillance monitoring.
	72_12284	Waipa	-		Surveillance monitoring.
	72_12749	Hauraki	-		Surveillance monitoring.
	72_13282	Coromandel	-		Surveillance (to be drilled in Thames).
	72_13283	Coromandel	-		Surveillance (to be drilled in Thames).
	72_2375	Coromandel	-		Surveillance monitoring (part of current groundwater level network).
	72_3472	Coromandel	-		Surveillance monitoring.
	72_3612	Hauraki	-		Surveillance – existing school site proposed to move to annual.
	72_3645	Upper Waikato	-		Surveillance monitoring.
	72_3979	Upper Waikato	-		Surveillance monitoring.
	72_4116	Northern areas	-		Surveillance monitoring (replacement for 61_59).
	72_4129	Taupō	-		Evaluative monitoring – Taupō.
	72_9179	Hauraki	-		Surveillance monitoring.
	72_9235	Coromandel	-		Surveillance monitoring.
	72_9908	Hamilton Basin	-		Surveillance monitoring.
	774_1	Western areas	-		Surveillance – monitoring undertaken by third party (Waitomo DC – Pio Pio Spring).

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6.2 Streamline Data Management

As sites and associated data will be shared between WRC and Earth Sciences New Zealand, it is recommended to:

- Develop in-house data-harvesting scripts between existing data systems to enable two-way flow. This requires a testing phase and clarifying requirements on QA/QC processes to ensure consistent quality coding. Because NGMP is only starting its optimisation, it will need to maintain operations and, therefore, require its own data system while other regions are sequenced. Once the NGMP optimisation is complete, there may be opportunities to address system duplication.
- Develop a framework to maintain site and variables data vocabularies between WRC and Earth Sciences New Zealand.
- These recommendations are consistent with the federated data system, recently proposed by the PCE (PCE 2025). Streamlining the ability to update the dataset will ensure that any QA/QC undertaken as part of the monitoring programmes beyond operations is reflected in the dataset.

6.3 Ensure Long-Term Connection between National Reporting and Data Collection

To enhance National Environmental Reporting of groundwater quality, it is recommended that:

- Earth Sciences New Zealand continue to work with the Groundwater Forum to undertake additional case studies in other regions under NGMP, while it remains active. The outcomes should be then shared with the Ministry for the Environment and StatsNZ to assess suitability of using consistent priority attributes and ranking between regions. This approach was designed for flexibility, acknowledging natural variations in hydrogeological settings and management between regions. This assessment is required as environmental reporting is informed by a collection of distinct monitoring programmes.
- Ministry for the Environment and StatsNZ to clarify their reporting needs on groundwater quality Evaluative monitoring at the national scale. Ministry for the Environment and StatsNZ to review the list of topics in scope for environmental reporting. If this list is reviewed rapidly (e.g. within two years), the new requirements could be used immediately to apply the Surveillance/Evaluative framework to other regions, reducing the need for later reviews. For the Waikato, the transparency provided through this optimisation process will enable rapid adjustments, if required. For topics such as geothermal water quality or groundwater ecosystems, clarifying our needs will enable relevant organisations to seek resource to develop or enhance current monitoring programmes.
- The design of the Ministry for the Environment and StatsNZ national reporting would be strengthened by collaboration with monitoring programme managers (regional councils and PROs). This should include criteria for data and site inclusion with the intention of reducing the current spatial bias.
- Once reporting needs are reviewed, feasibility of adequately resourcing them may be required at central government level. In the current funding model, there is a disconnect between national programme funders, monitoring agencies and data users. In this report, the necessary compromises between monitoring objectives, practical decisions and costs have been recorded. This transparency was intended to inform monitoring resourcing decisions and data use. It is recommended that this work be extended to all the remaining regions to provide a national view. This task will be sequenced but may be accelerated through funding injection. Completing this task will ensure that, if needs are identified, adequate resourcing will be provided to meet them.

However, it is recommended that an opportunity to discuss upcoming changes in national reporting needs and data requirements arising from central government, particularly regarding statistical minimum requirements, is given to monitoring programme managers. Early communication will avoid delay in implementing changes in data collection. This could result in data gaps or setting unsuitable requirements that may lead to exclusion of a significant amount of data, and therefore misrepresentation of the monitoring effort. In the current system, both the Groundwater Forum and the national programme provide regular opportunities to central government for consultation. Expert advice provision is part of these monitoring programmes.

6.4 Develop Nationwide Metrics for Environmental Groundwater Contributions

To enhance groundwater quality monitoring, it is recommended that suitable metrics be developed to represent groundwater contributions to our environment for inclusion in the GR Index. These may include:

- Quantify base flow contribution to river flow at a suitable scale. Groundwater-surface-water interactions were factored in this review using base flow contributions to streams (Stenger et al. 2024; Woodward and Stenger 2018), and the location of known springs in the Waikato region (Wilson 2022). This base flow separation method has recently been applied at selected river quality sites nationally to quantify base flow contribution to river flow (Moore et al. 2025). It will require a finer resolution for inclusion in the GR Index. The provision of groundwater-surface-water quantitative information derived from field-collected data make these datasets more suitable than qualitative and prediction-based datasets, such as the national gaining and losing streams dataset (Yang et al. 2017).
- A nationally consistent digital spring dataset mapped at a suitable scale. In the first instance, the New Zealand cold springs (Scarsbrook et al. 2007) dataset could be digitised. However, a stronger dataset should be developed using consistent spring selection criteria and recording ancillary information, such as spring temperature, spring type (e.g. contact, fracture), flow rate and flow conditions (e.g. perennial). This dataset should build on existing spring information held by councils, but may require field campaigns and could be integrated in the GR Index in its simplest form as a count of features. Any robust national or regional Springs datasets could be incorporated alongside the Wells Aotearoa[9] database as a future development. The existing LINZ spring point dataset (at the 1: 50,000 by LINZ) is not considered as suitable for this purpose.

[9] https://wellsnz.teurukahika.nz/

7.0 Conclusion

Groundwater quality monitoring in the Waikato started in the 1990s at both regional and national scale. These programmes have successfully characterised groundwater resources and provide essential data to inform the management of relevant issues to date.

This report documents a timely, joint review of both monitoring programmes to address current shortcomings and data limitations to assess policy effectiveness. This report also provides transparency on the necessary compromises between objectives, practical considerations and resources within monitoring programmes. The optimisation method was developed in consultation with experts from the Groundwater Forum, providing a nationally consistent framework. It represents a step-change from an internally focused and compartmentalised approach to collaborative programme reviews. It notably also proposes a switch from traditional SoE monitoring to Surveillance and Evaluative monitoring. The work was conducted over multiple years to enable wide consultation to ensure national consistency. It was also complemented by the parallel development of a national framework with support from the Groundwater Forum and Ministry for the Environment.

The outcome of this optimisation are two proposed Surveillance groundwater quality monitoring programmes (regional and national) and case studies for Evaluative monitoring. By nature, it is expected that Evaluative monitoring may require wider consultation (e.g. between policy makers, scientists and community groups) to identify evaluation targets. Recommendations were provided to implement changes and ensure future proofing of our groundwater quality monitoring programmes in the Waikato.

8.0 Acknowledgements

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Most importantly, this work rests on countless hours of field work undertaken by the Waikato Regional Council Environmental Monitoring team. We especially acknowledge John Hughey's wise advice, based on long years of monitoring, and his input into site selection.

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APPENDICES

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APPENDIX 1 Initial Triage Summary

Table A1.1 Assessment of current State of the Environment (SoE) wells in the Surveillance/Evaluative framework. Grey shading is for wells with anaerobic redox conditions, median nitrate-nitrogen concentrations exceeding the drinking water MAV and >70% estimated power of detection confidence.

Well	Well Depth (m)	Confinement	Water Age (y MRT)	Redox	Nitrate-Nitrogen (mg/L)	Evaluative Category	Power Detection	MDC 80 (mg/l)
60_12	9	Unconfined	1.5	Indeterminate	0.41	Potential	16.7	0.6
60_124	6	Unconfined	-	Aerobic	0.69	Potential	22.2	0.8
60_167	19.5	Semi-confined	280	Anaerobic	0.05	Unlikely	-	-
60_190	43.4	Confined	160	Indeterminate	0.025	Unlikely	-	-
60_316	7	Unconfined	17	Indeterminate	0.78	Potential	-	0.6
60_345	27	Unconfined	65	Aerobic	1.87	Unlikely	0	-
60_348	13.5	Unconfined	7	Indeterminate	0.7	Potential	-	0.4
60_407	5	Unconfined	-	Aerobic	2.2	Potential	2.8	1.1
60_480	7.7	Unconfined	-	Indeterminate	0.35	Potential	-	0.6
61_113	13	Unconfined	4	Indeterminate	9.3	Potential	11.9	0.8
61_126	6.09	Unconfined	4.5	Mixed	6.9	Potential	100	1.1
61_135	51.82	Unconfined	19	Aerobic	16.1	Unlikely	100	3
61_143	34	Confined	9	Aerobic	29	Unlikely	100	3.2
61_208	18.3	Unconfined	9	Aerobic	11.1	Potential	100	1.8
61_221	44.5	Unconfined	22	Aerobic	6.1	Unlikely	100	4.6
61_230	43	Unconfined	50	Mixed	9.9	Unlikely	26.5	-
61_245	14.5	Unconfined	4	Indeterminate	0.42	Potential	-	0.4
61_258	35	Unknown	130	Aerobic	9.7	Unlikely	0	-
61_280	23.2	Confined	10	Aerobic	14.9	Unlikely	100	1.1
61_54	19.8	Unconfined	13	Aerobic	13.2	Potential	100	0.8
61_59	26.6	Confined	28	Mixed	4.6	Unlikely	31.9	-

Well	Well Depth (m)	Confinement	Water Age (y MRT)	Redox	Nitrate-Nitrogen (mg/L)	Evaluative Category	Power Detection	MDC 80 (mg/l)
61_85	35	Confined	22	Aerobic	9.5	Unlikely	99.5	1.1
61_93	26	Unconfined	49	Aerobic	25	Unlikely	0	-
62_5	6.2	Unconfined	-	Aerobic	4.5	Potential	3.7	2
63_201	48	Unknown	125	Anaerobic	0.16	Unlikely	-	-
63_240	91.5	Confined	240	Indeterminate	0.24	Unlikely	-	-
63_269	20	Confined	25.5	Aerobic	2.1	Unlikely	100	1.1
63_328	49	Confined	230	Indeterminate	0.18	Unlikely	-	-
63_43	73	Confined	14	Aerobic	10.9	Unlikely	27.7	2
63_57	5	Unconfined	11	Mixed	7.3	Potential	100	2.2
63_74	50.8	Confined	160	Indeterminate	0.06	Unlikely	-	-
63_78	24	Confined	12	Mixed	1.68	Unlikely	100	0.2
64_108	23	Confined	62	Aerobic	16.4	Unlikely	82.2	-
64_111	83	Confined	250	Anaerobic	0.025	Unlikely	-	-
64_117	16	Unconfined	7	Aerobic	21	Potential	4.7	-
64_12	11.5	Unconfined	7	Mixed	12.1	Potential	95.6	1.1
64_120	22.2	Unconfined	3.5	Aerobic	3.4	Potential	28.2	1.8
64_20	9	Unconfined	21	Aerobic	11.7	Potential	33.9	-
64_43	21.6	Unconfined	50	Indeterminate	5.6	Unlikely	2.5	-
64_46	12.1	Unconfined	37	Aerobic	3.8	Unlikely	92.8	3
64_50	16.1	Unconfined	32	Aerobic	6.9	Unlikely	99.8	3.6
64_511	21.5	Unconfined	51	Aerobic	3.4	Unlikely	2.5	-
64_7	7.92	Unconfined	50	Aerobic	21	Unlikely	14.4	-
64_70	11.8	Unconfined	38	Indeterminate	0.56	Unlikely	-	1.4
64_720	6	Unconfined	48	Aerobic	25	Unlikely	0	-

Well	Well Depth (m)	Confinement	Water Age (y MRT)	Redox	Nitrate-Nitrogen (mg/L)	Evaluative Category	Power Detection	MDC 80 (mg/l)
64_831	9	Unconfined	20	Aerobic	1.87	Potential	37.1	5.2
65_6	13	Unconfined	-	Aerobic	3.6	Potential	20.2	0.4
66_58	38	Unconfined	170	Indeterminate	0.24	Unlikely	-	-
66_6	38	Unconfined	30	Mixed	10.8	Unlikely	37.2	-
66_92	48.5	Unconfined	73	Anaerobic	0.025	Unlikely	-	-
66_93	8	Unconfined	37	Mixed	9	Unlikely	35.7	9.4
66_96	116	Unconfined	200	Indeterminate	0.025	Unlikely	-	-
67_11	18.5	Unconfined	2.5	Aerobic	10.4	Potential	0	-
67_15	20	Unconfined	45	Aerobic	4	Unlikely	33.7	6.6
67_404	9	Unconfined	15	Aerobic	8.5	Potential	99.9	2.4
67_483	53.6	Confined	29	Anaerobic	0.05	Unlikely	-	-
67_55	127	Confined	-	Indeterminate	1.7	Unlikely	-	2.8
67_573	90	Confined	-	Aerobic	4.5	Unlikely	0	-
67_83	80	Unknown	-	Aerobic	4.8	Unlikely	14.6	1
68_301	53.6	Confined	80	Aerobic	2.5	Unlikely	52	-
68_317	104	Unknown	40	Aerobic	3.9	Unlikely	-	-
68_320	62	Unknown	21	Mixed	9.2	Unlikely	71.9	-
68_912	53.6	Unknown	-	Aerobic	2.8	Unlikely	99.5	1.4
68_964	5	Unconfined	1	Indeterminate	0.55	Potential	0	0.2
69_163	4	Unconfined	-	Mixed	8.8	Potential	51.7	3
69_1709	5	Unconfined	0.2	Aerobic	5.3	Potential	0	2.4
69_173	6	Unconfined	3	Indeterminate	3.5	Potential	27.2	6.8
69_19	4.3	Unconfined	-	Aerobic	15.7	Potential	4.5	3.4
69_248	2.75	Unconfined	-	Aerobic	0.2	Unlikely	13	0.4

Well	Well Depth (m)	Confinement	Water Age (y MRT)	Redox	Nitrate-Nitrogen (mg/L)	Evaluative Category	Power Detection	MDC 80 (mg/l)
69_295	6.35	Unconfined	-	Aerobic	5.6	Potential	95.1	1.1
69_365	6	Unconfined	2	Mixed	3.6	Potential	91.4	0.8
69_374	4.16	Unconfined	-	Aerobic	6.2	Potential	8.6	3
69_62	9.15	Unconfined	-	Aerobic	4	Potential	4	3.2
69_81	2.25	Unconfined	1	Aerobic	9.9	Potential	77.9	3.2
69_97	4.71	Unconfined	-	Aerobic	4.5	Potential	2.7	1
70_1134	10.6	Unconfined	0.3	Aerobic	2.1	Potential	0	0.8
70_22	6.42	Unconfined	5	Aerobic	9.2	Potential	50	2.6
70_31	5.2	Unconfined	-	Mixed	9.3	Potential	100	0.6
70_44	18.3	Unconfined	39	Aerobic	11.8	Unlikely	-	-
70_47	4.5	Unconfined	1	Aerobic	2.4	Potential	36.7	0.8
70_50	7.3	Unconfined	-	Aerobic	8.7	Potential	98.4	1.6
70_56	8	Unconfined	7	Aerobic	8.7	Potential	79.2	3.6
70_65	4.3	Unconfined	6	Aerobic	1.12	Potential	17.1	1.6
70_74	6.71	Unconfined	1	Aerobic	1.72	Potential	33.2	1.6
70_76	30	Unconfined	31	Aerobic	4.8	Unlikely	87.8	1.4
71_1	10	Confined	3.6	Indeterminate	5.3	Unlikely	-	0.4
71_3	26	Confined	9.5	Indeterminate	0.25	Unlikely	-	0.2
71_4	90	Unknown	6	Aerobic	2.6	Unlikely	100	0.4
71_5	81.6	Confined	58	Indeterminate	0.025	Unlikely	-	-
72_1006	5.43	Semi-confined	75	Indeterminate	0.07	Unlikely	-	-
72_1008	8	Unconfined	15.5	Mixed	0.72	Potential	37	3.4
72_1011	5.88	Unconfined	-	Aerobic	2.4	Potential	100	-
72_1069	11.7	Unconfined	4	Indeterminate	2.6	Potential	5.4	0.8

Well	Well Depth (m)	Confinement	Water Age (y MRT)	Redox	Nitrate-Nitrogen (mg/L)	Evaluative Category	Power Detection	MDC 80 (mg/l)
72_1072	21	Confined	62	Anaerobic	0.06	Unlikely	-	-
72_1081	4.6	Unconfined	1	Indeterminate	0.12	Unlikely	-	0.4
72_1082	7.98	Unconfined	-	Aerobic	1.5	Potential	28.7	0.2
72_1087	6.6	Unconfined	3	Aerobic	1.03	Potential	74.8	0.4
72_1089	36.2	Confined	22	Aerobic	4.2	Unlikely	6.2	-
72_1223	92.5	Confined	260	Indeterminate	0.22	Unlikely	-	-
72_2138	105	Confined	38	Indeterminate	0.8	Unlikely	-	0.6
72_2895	16	Unconfined	7.5	Aerobic	5.6	Potential	91.5	3
72_2896	17.5	Unconfined	25	Aerobic	4.8	Potential	37.5	9
72_3559	12	Unconfined	6.5	Indeterminate	0.25	Unlikely	-	0.4
72_356	42	Confined	-	Aerobic	1.94	Unlikely	7.2	0.8
72_3741	78	Unknown	-	Aerobic	7.6	Unlikely	100	-
72_392	93	Unconfined	34	Aerobic	2.435	Unlikely	60.8	-
72_431	48	Confined	-	Aerobic	1.53	Unlikely	56.8	3.4
72_4500	29.1	Unconfined	5	Aerobic	4	Potential	88.9	1.4
72_5510	9.5	Unknown	-	Indeterminate	1.38	Unlikely	-	1.1
72_9095	10	Unconfined	-	Aerobic	1.65	Unlikely	98.2	0.4

APPENDIX 2 Detail on Spatial Assessment Methodology

A2.1 Introduction

This Appendix details the methods used to define cells based on geologically defined polygons, (based on the hydrological systems of Moreau et al. [2019b], which include the1:250,000 digital geological map) and a 10 km x 10 km grid overlaid on the Waikato region. The polygons were used to assess the groundwater class and subsequently perform a priority assessment for groundwater monitoring.

The groundwater class involved the definition of areas into either Primary, Secondary A, Secondary B, Secondary Undifferentiated or Tertiary. This was based on well density and abstraction density in geologically defined polygons (based on the hydrological systems of Moreau et al. [2019b]).

Spatial analysis was undertaken in GIS software (ArcPro).

A2.2 Groundwater Class Definition

- Clipped the polygon shapes from the GNS Science New Zealand Hydrogeological Systems[10] (Moreau et al. 2019b).
- Used "dissolve" tool based on the attributes HS_name and HS_geo_gr to simplify this layer.
- Used "summarise within" tool to calculate the well density and groundwater take (volume) density of each of these polygons. For well density, well locations from National Wells (internal Waikato Regional Council [WRC] GIS layer WELLS_UNIQUE) were used, and for the groundwater take (volume) density, the attribute MAXRATEDERVIVED_NET25HR from the internal WRC GIS layer ALLOC_IRIS_AUTH_TAKE_SEASONAL was used with a definition query to that selected only GW take consents.
- These two 'densities' were multiplied together to get the field "DensityCombined" (called the Groundwater Reliance Index or GRI), which was used to identify the classes described in Section 3.3. The highest GRI values represented areas of principal class, with lower values representing Secondary A, Secondary B, Secondary Undifferentiated and Tertiary classes. Some minor modifications based on expert judgement were made to adjust classes and/or polygons extents. These are detailed in Table 3.3 of the report.
- The resulting file was combined (UNION) with the New Zealand Karst digital dataset[11], which consists of polygons recording location of known karst features with an unrecorded spatial resolution (University of Auckland 2010).

A2.3 Priority Assessment for Groundwater Quality Monitoring

For the purposes of the groundwater quality monitoring network, mappable units were selected to be a 10 km x 10 km grid overlaid on the class layer (described above) across the Waikato region. The attributes chosen for the relative rating assessment were selected based on the four criteria described in the Environment Aotearoa 2019 synthesis report[12] to provide a "focus on what matters" approach (Table A2.1). Ratings of between 0 and 3 have been assigned for each attribute in each area with respect to the other grid cells (0 being of low priority; 3 being of higher priority). The weightings assigned to each attribute have been assessed with respect to each other to determine the relative importance of each factor with respect to groundwater quality. The GIS-based priority is calculated from the attribute

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[10] https://www.gns.cri.nz/data-and-resources/new-zealand-hydrogeological-systems/

[11] https://koordinates.com/layer/717-new-zealand-karst/

[12] https://environment.govt.nz/publications/environment-aotearoa-2019/

ratings and weightings for each polygon. The GIS-based priority is a number between 0 and 3; the higher the GIS-based priority, the higher priority that area is for groundwater quality monitoring. It should be noted that GIS-based priority is a relative evaluation and does not give absolute answers, but rather identifies areas that are determined to be of higher priority and thus where groundwater quality monitoring should be focussing. The equation for determining the GIS-based priority for each area is:

$$\mathit{GIS\text{-}based}\ Priority = \sum A_R A_W \qquad \text{Equation A2.1}$$

Where:

$$A_R = \frac{Area}{cell\ parameter\ rating}$$

and

$$A_W = \frac{Area}{cell\ parameter\ weighting}$$

Table A2.1 Attributes and their weighting used to derive the GIS-based priority for groundwater quality monitoring.

Attribute	**Surveillance Consideration**	**Weighting (%)**	**Evaluative Consideration (Nitrate)**	**Weighting (%)**	**Evaluative Consideration (Seawater Intrusion)**	**Weighting (%)**
Groundwater class (i.e. primary, secondary, etc.)	Y	65%	Y	20%	Y	50%
Vulnerability	-	-	Y	20%	-	-
Land use	-	-	Y	20%	-	-
Drinking Water	-	-	Y	10%	Y	10%
Known GW quality issues	-	-	Y	30%	Y	30%
GW-SW interaction	Y	20%	-	-	-	-
Taonga	Y	10%	-	-	-	-
Climate change	Y	5%	-	-	Y	10%
Other Considerations for Site Selection and Frequency Not Spatially Based						
Distance from coast	-	-	-	-	Y (to include/exclude)	NA
Redox state	-	-	Y (to inform site selection)	NA	-	-
GW age	Y (only to inform frequency)	NA	Y (to inform site selection)	NA	Maybe?	-
Anticipated land-use change	-	-	Y (if available)	NA	Y (if available)	NA
Policy details (if applicable)	-	-	Y (if available)	NA	Y (if available)	NA

A2.3.1 Groundwater Class Attribute

Classes defined above (by a combination of geology, well density and abstraction density) were assigned the following scores:

Table A2.2 Aquifer type and corresponding scores.

Groundwater Class	Score Assigned
Principal	3
Secondary A	2
Secondary B	1
Secondary undifferentiated	0.5
Tertiary	0

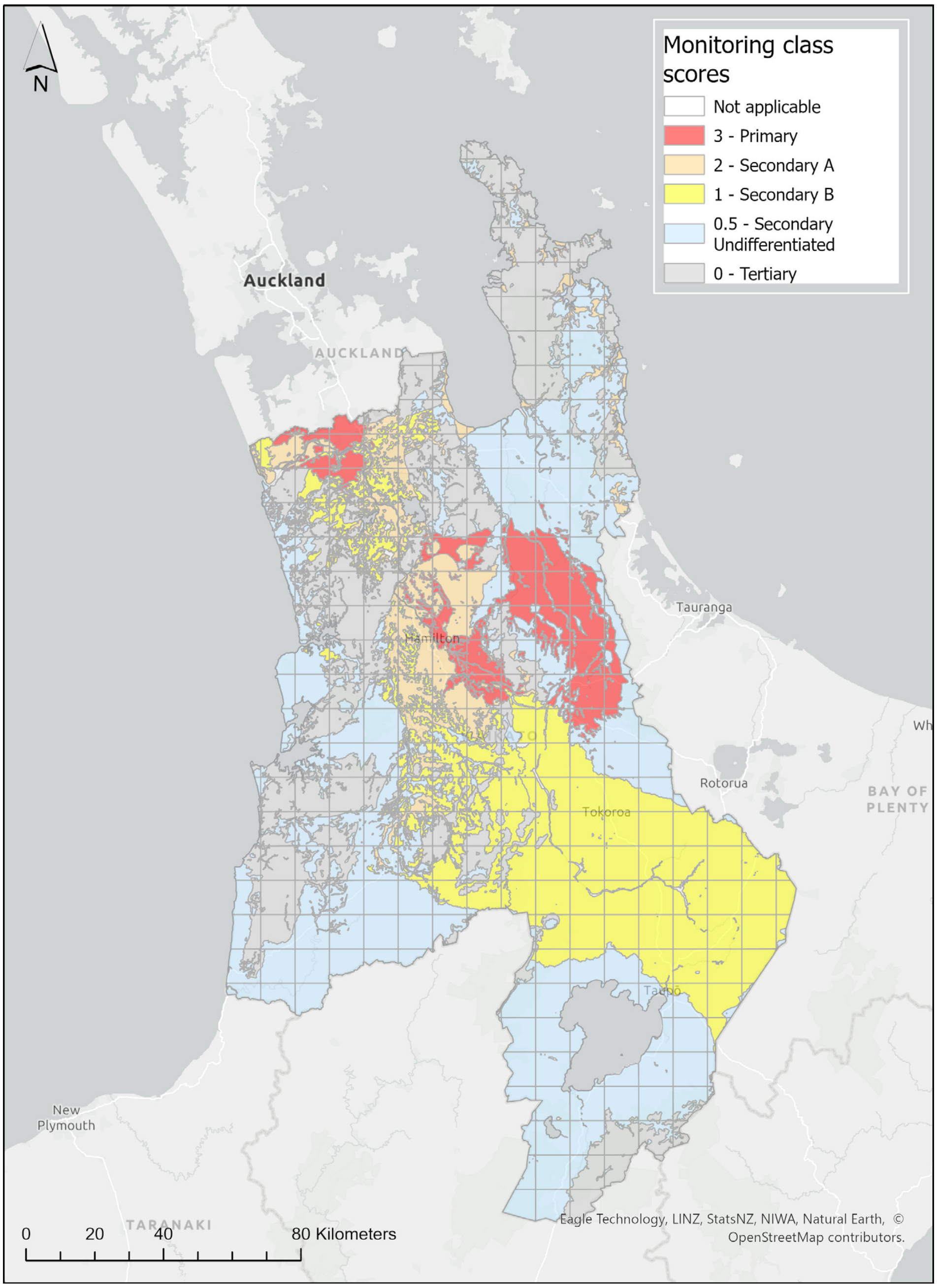

Figure A2.1 Groundwater class designations for the Waikato region.

A2.3.2 Vulnerability Attribute

Vulnerability was assessed using the DRASTIC raster layer (Figure A2.2) created for the Waikato (Brown 2003; Fryer 1999). The “Zonal Statistics as Table” tool was used to calculate the average (mean) of the Drastic Pollution Potential for each GWQ polygon. This zonal statistics table was then joined to the vector layer of polygons and exported to save the results. To assign scores for vulnerability (Figure A2.2), a score of three was assigned to the polygon with the highest mean score, and then the remainder of the polygon scores were calculated as a percentage of this (i.e. Land Use score for polygon = zonal_stats_drastic_mean for polygon* [three/highest zonal_stats_drastic_mean for all polygons]).

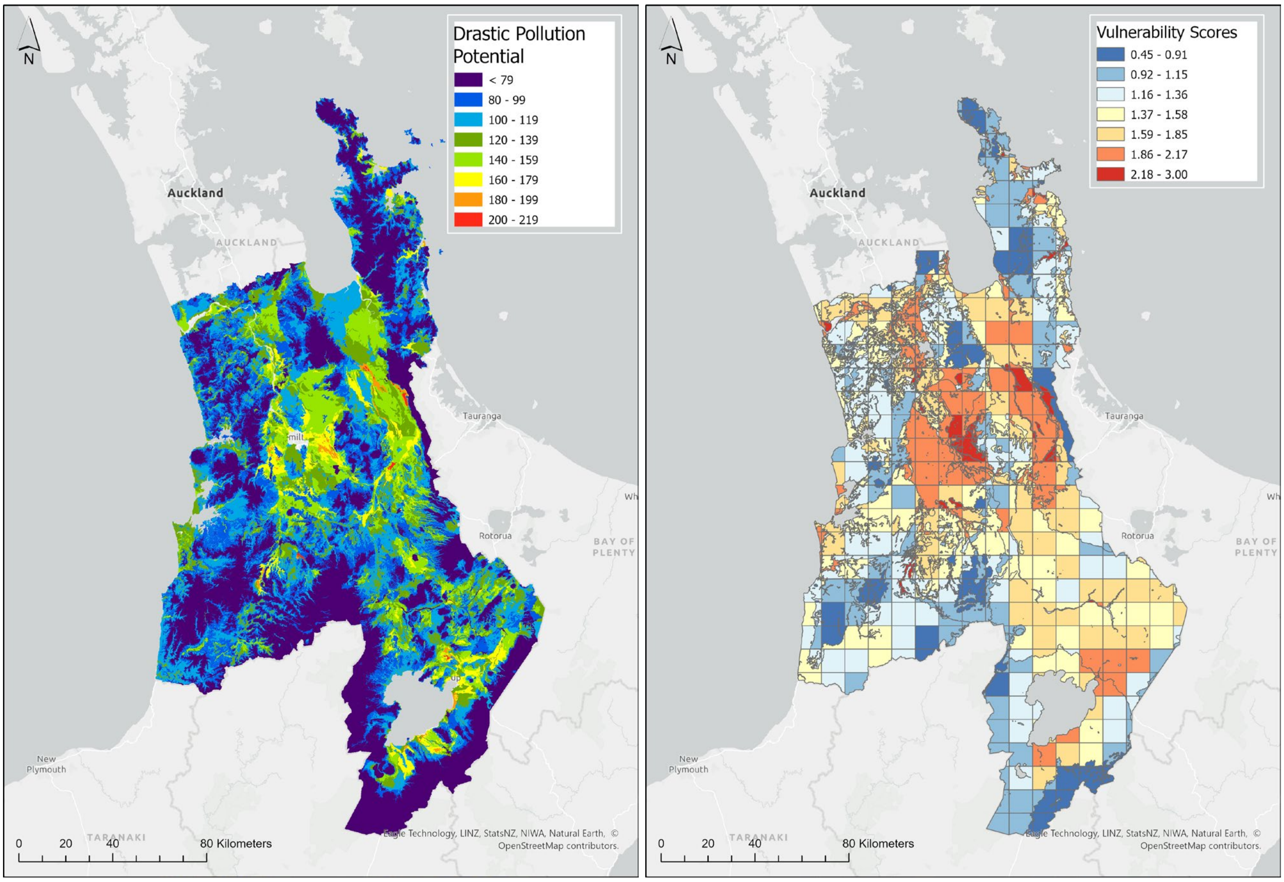

Figure A2.2 DRASTIC map (Brown 2003; Fryer 1999) (left) and vulnerability scores (right) for the Waikato region.

A2.3.3 Land Use Attribute

Using the WRC layer LANDUSE_LUCAS_WRC_2016.lyrx, scores were assigned to particular land uses (Table A2.4). Higher scores were assigned to land uses contributing the more nutrient inputs to the land (sub-categories were used only for high-producing grassland).

The “Summarise within” geoprocessing tool was used to calculate the average (mean) of land-use score (by area) in each polygon. As the final scores for this only ended up being around 0–1.5, it was multiplied by two to ‘normalise’ it. Anything over three (which were only a handful) was set to three.

Table A2.3 Land-use categories and corresponding scores.

LUCID_2016	LUCNA_2016	SUBID_2016	SUBNA_2016	Score
71	Natural Forest	-	-	0.6
72	Planted Forest – Pre-1990	-	-	0.6
73	Post-1989 Forest	-	-	0.6
74	Grassland – With woody biomass	-	-	1.2
75	Grassland – High-producing	502	Grazed – dairy	3
75	Grassland – High-producing	503	Grazed – non-dairy	1.8
75	Grassland – High-producing	504	Ungrazed	1.0
75	Grassland – High-producing	0	Unknown	1.8
76	Grassland – Low-producing	-	-	1.2
77	Cropland – Perennial	-	-	2.4
78	Cropland – Annual	-	-	3
79	Wetland – Open water	-	-	0
80	Wetland – Vegetated non-forest	-	-	0
81	Settlements	-	-	1.2
82	Other	-	-	1.2

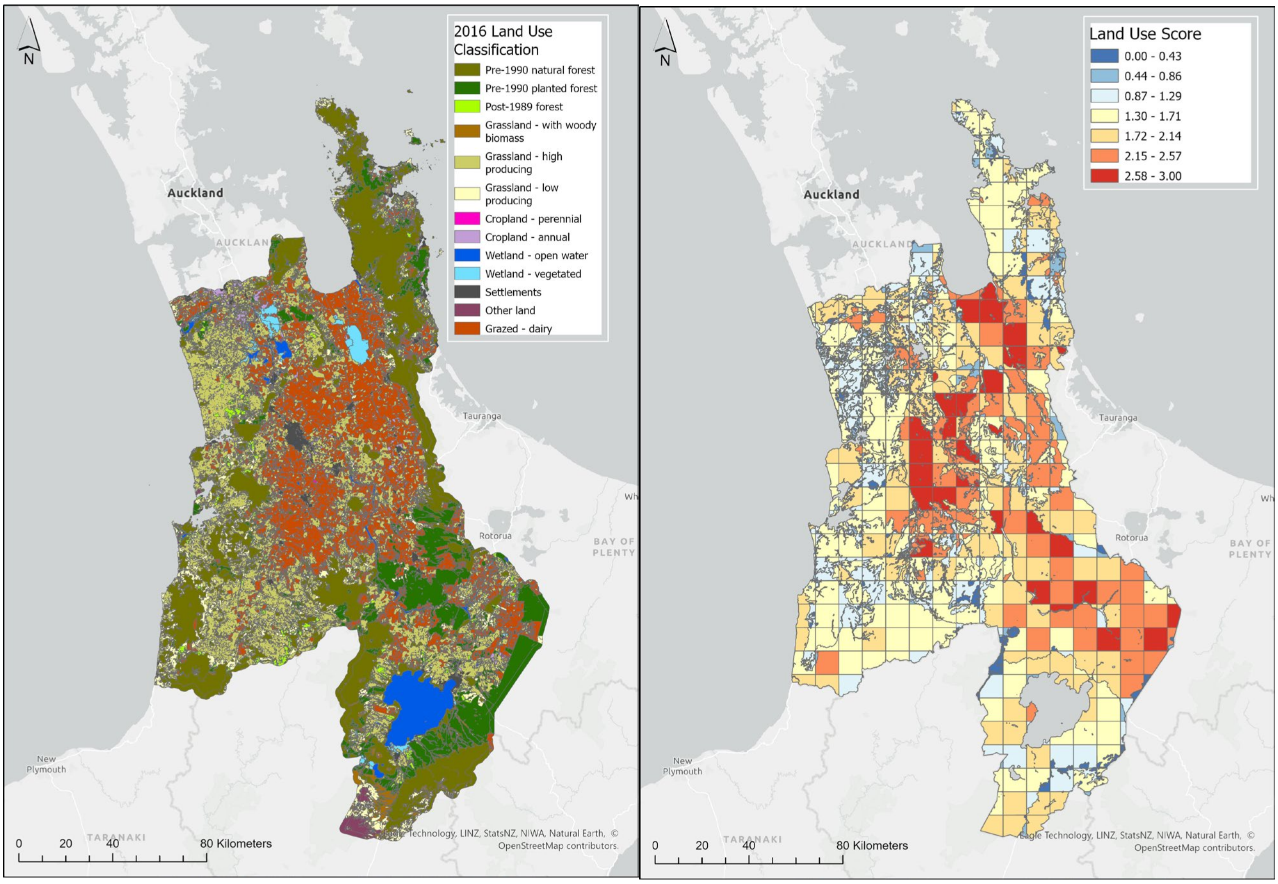

Figure A2.3 Land-use map (left) and land-use scores (right) for the Waikato region.

A2.3.4 Drinking Water Attribute

Drinking water supplies registered with Taumata Arowai were used in the assessment, in addition to expert knowledge on areas where widespread private drinking water bores were (e.g. Cooks Beach).

Table A2.4 Drinking water score criteria.

Score Assigned	Description
3	Minor, medium or large (>500, >5000 and >10,000 population supplied, respectively) registered drinking water supply from a bore or spring source within a polygon, or widespread private drinking water supplies with few alternatives.
2	Small (101–500 people supplied) registered drinking water supply from a bore or spring source within a polygon.
1	Neighbourhood (25–100 people supplied) registered drinking water supply from a bore or spring source within a polygon.
0.5	Minimal use, permitted use.
0	No use.

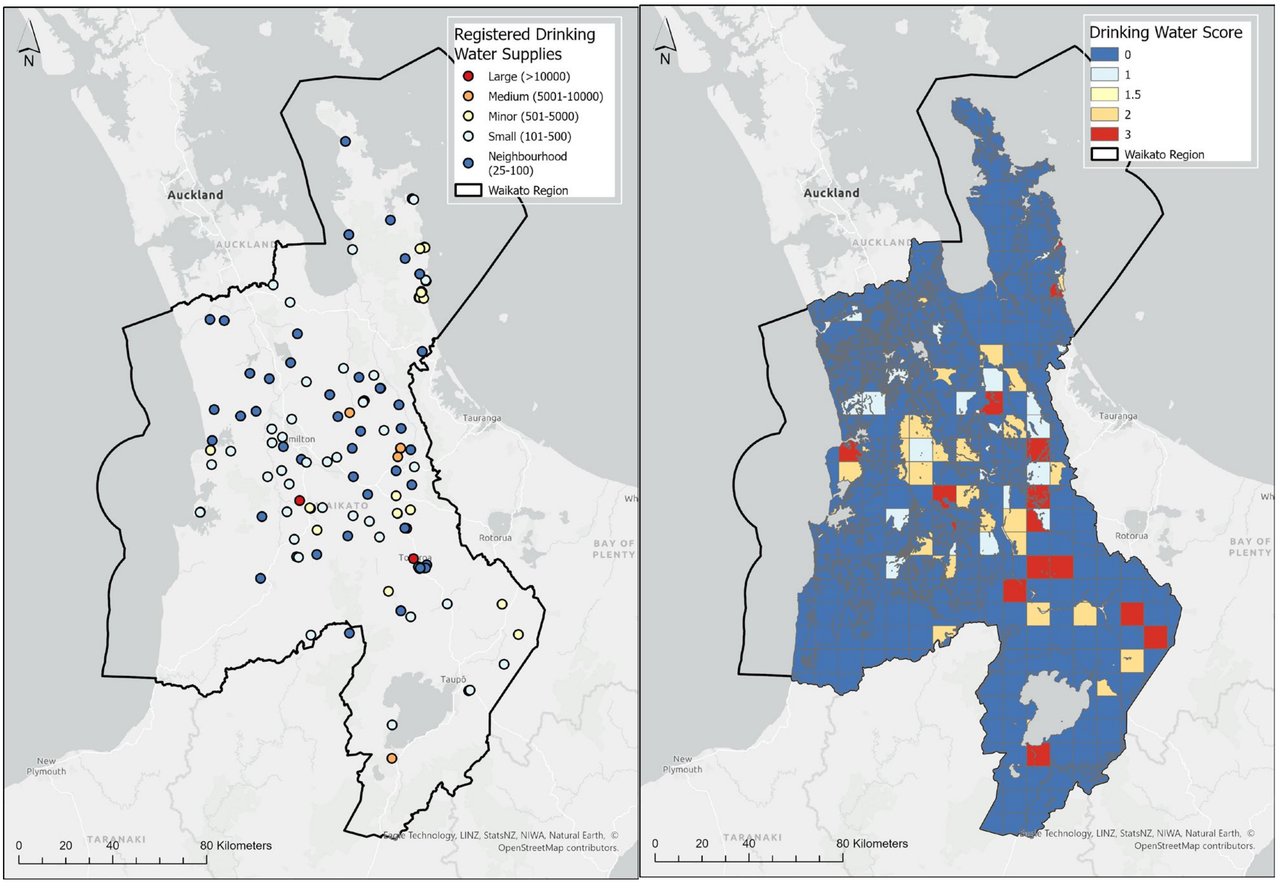

Figure A2.4 Registered drinking water supplies (left) and scores (right) for the Waikato region.

A2.3.5 Known Nitrate Issues Attribute

Assessment was based on recent WRC's State of the Environment (SoE) reporting on groundwater quality (Hadfield 2022). Criteria were developed based on the latest median nitrate concentrations and associated trends at WRC wells to assign consistently a known nitrate issues score (Table A2.5).

Table A2.5 Median nitrate concentrations (data range) at State of the Environment (SoE) sites and corresponding scores.

Score Assigned	Description
3	NO_3 concentrations >11.3 mg/l or >5.65 mg/l with an increasing trend.
2	NO_3 concentrations >5.65 mg/l or >1 mg/l with an increasing trend.
1	NO_3 concentrations >1 mg/l or <1 mg/l with an increasing trend.
0	NO_3 concentrations <1 mg/l.

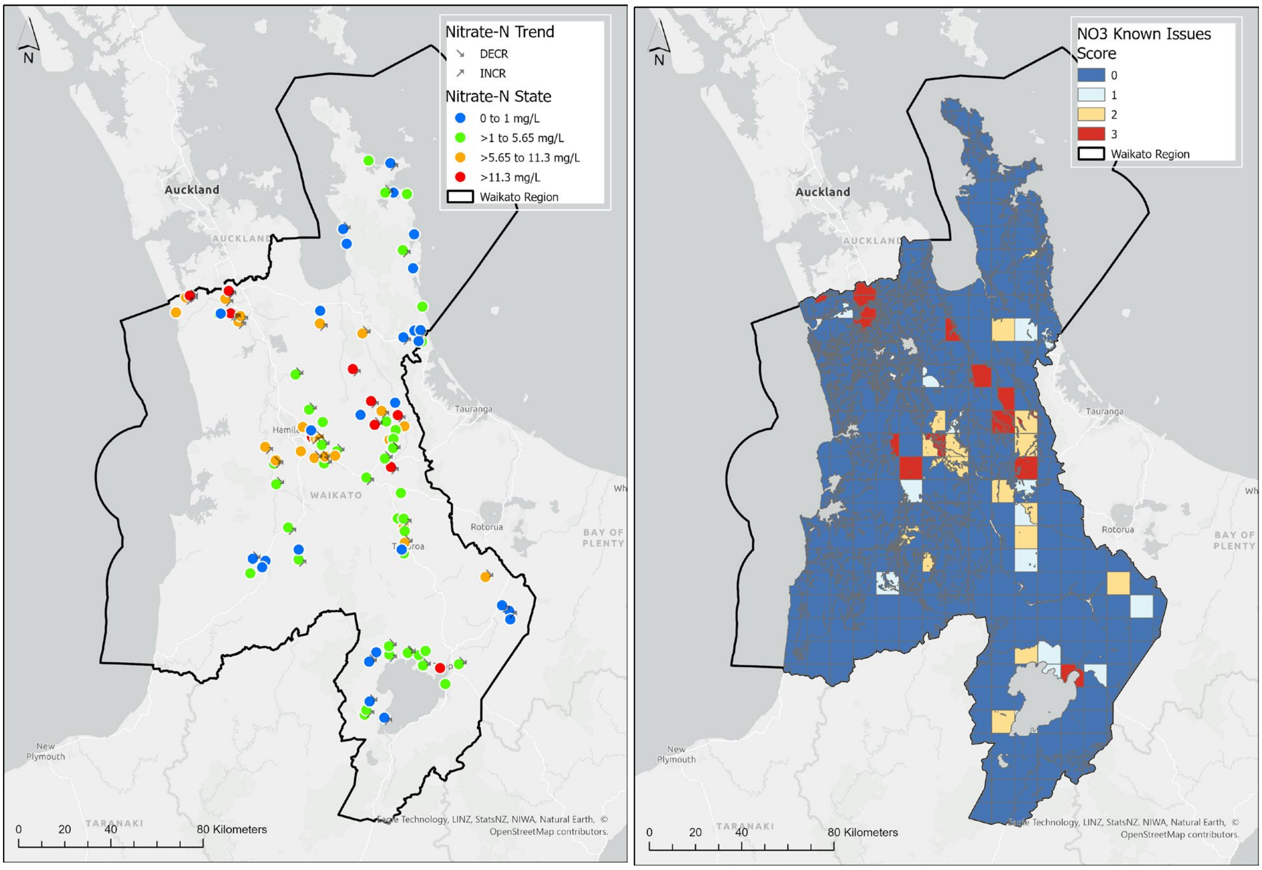

Figure A2.5 Nitrate concentrations and trends (left [from Hadfield 2022]) and known nitrate issue score (right) for the Waikato region.

A2.3.6 Known Seawater Intrusion Issues Attribute

Assessment was based on recent WRC's SoE reporting on groundwater quality (Hadfield 2022). Conductivity trends were categorised in WRC monitoring wells (Table A2.6). In addition, expert knowledge on areas where seawater intrusion has had a heightened risk (i.e. Opoutere, Whangamata, Hahei) or groundwater inundation is a threat due to rising sea levels (i.e. Thames) was considered. For the purposes of this assessment, the following categories were assigned:

Table A2.6 Criteria used to assign known seawater intrusion scores at State of the Environment (SoE) sites.

Score Assigned	Description
3	Conductivity concentrations >500 uS/cm, >250 uS/cm with an increasing trend, or known seawater intrusion issues or concern for groundwater inundation.
2	Conductivity concentrations >250 uS/cm, >150 uS/cm with an increasing trend, or known seawater intrusion issues or concern for groundwater inundation.
1	Conductivity concentrations >150 uS/cm, <150 uS/cm with an increasing trend, or known seawater intrusion issues or concern for groundwater inundation.
0	Conductivity concentrations <150 uS/cm.

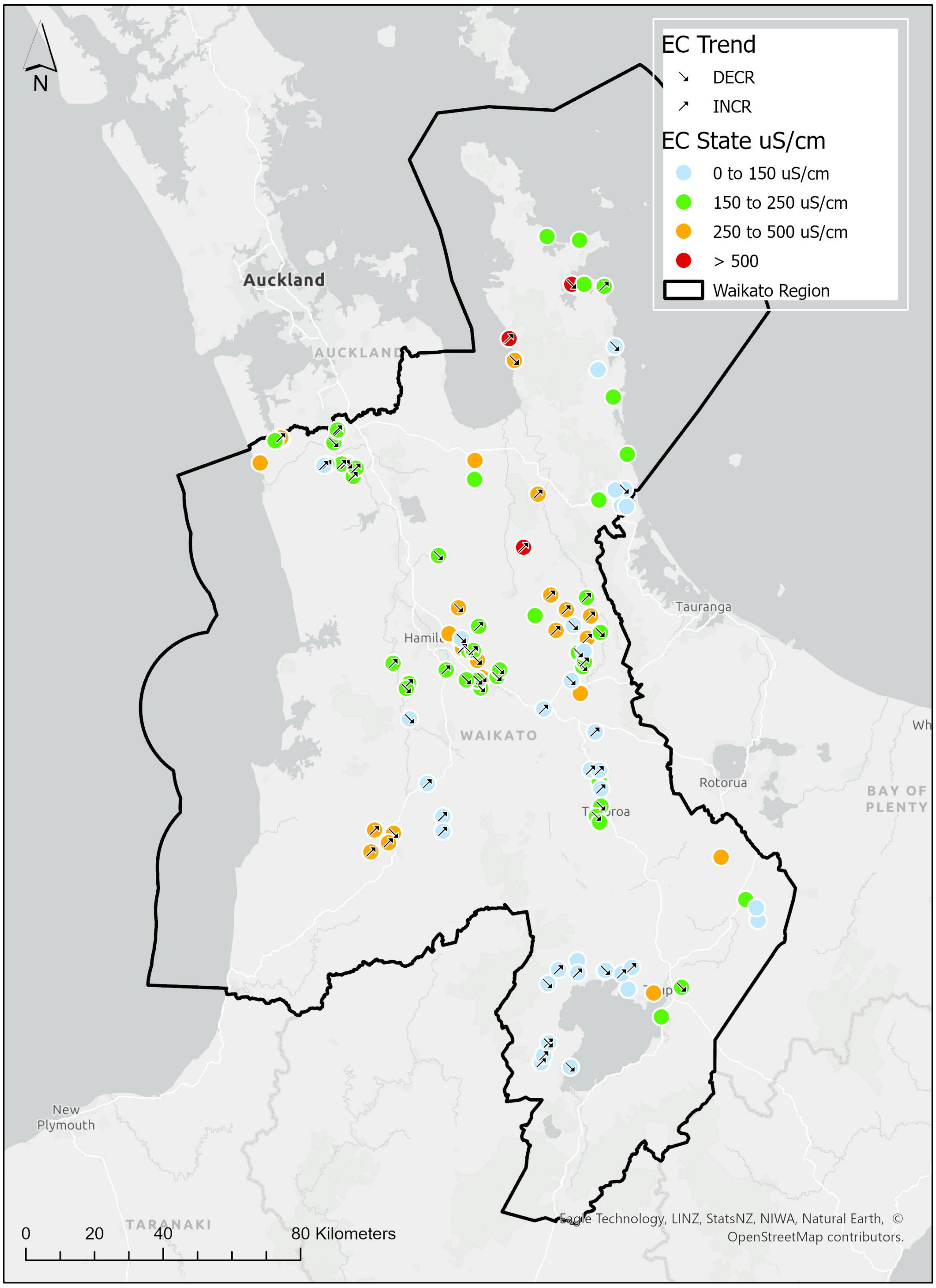

Figure A2.6 Electrical conductivity (EC) concentrations and trends (from Hadfield 2022) for the Waikato region.

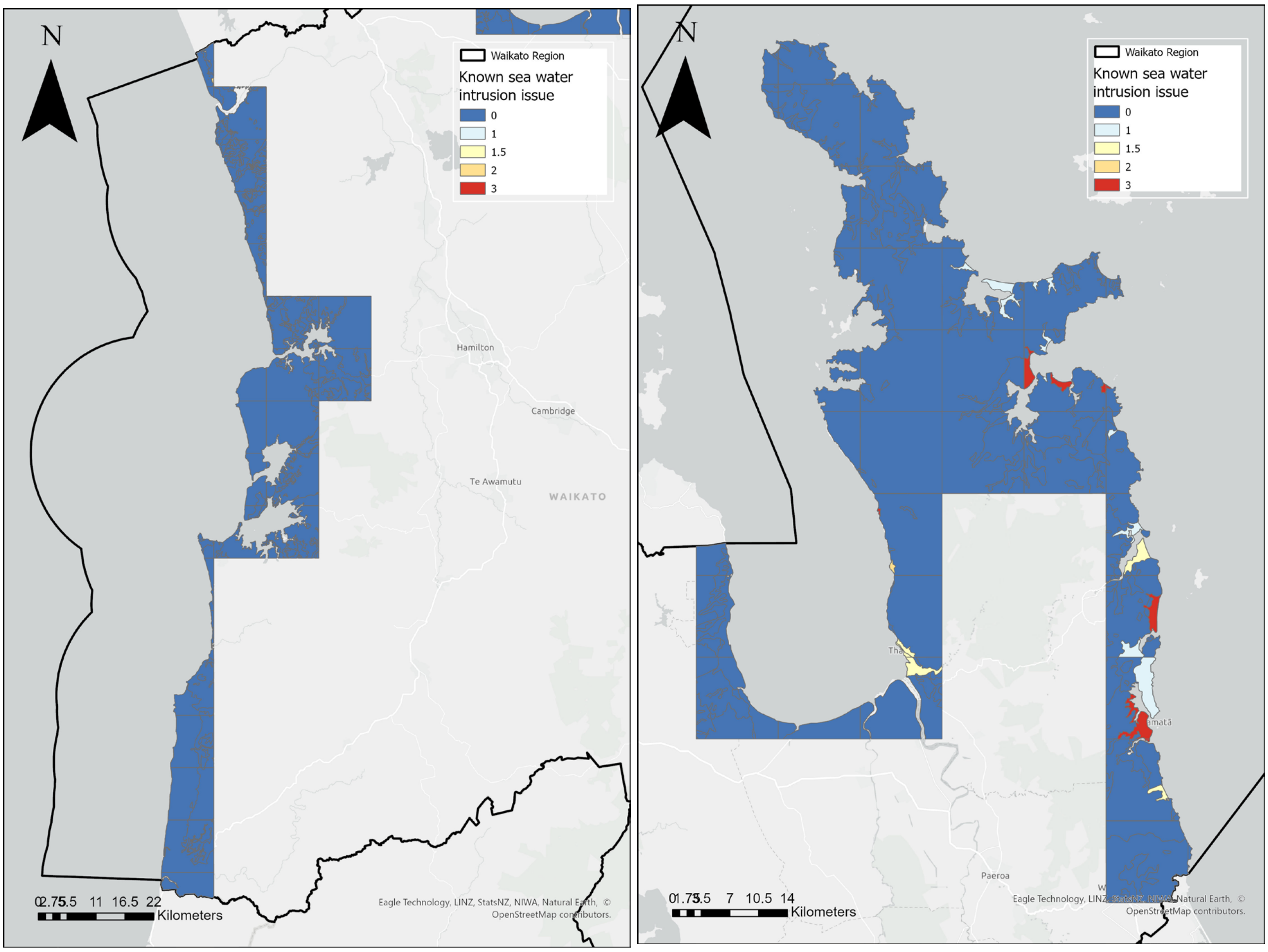

Figure A2.7 Known seawater intrusion issue scores for the Waikato region – West Coast (left) and Coromandel (right).

A2.3.7 Groundwater-Surface Water Interaction Attribute

The assessment on groundwater-surface-water interaction was informed by the recent work undertaken by Lincoln Agritech on base flow contributions to streams (Stenger et al. 2024; Woodward and Stenger 2018), in addition to the location of known springs in the Waikato region. The following guidance was used to assign ratings:

Table A2.7 Criteria used to assign groundwater-surface-water interaction scores.

Score Assigned	Description
3	High connection between groundwater and surface water (i.e. streams with a high base flow component and/or groundwater supported ecosystems and springs). Everything in the Waikato River catchment above Lake Karapiro.
2	Moderate connection between groundwater and surface water.
1	Low connection between groundwater and surface water.
0	Minimal connection between groundwater and surface water.

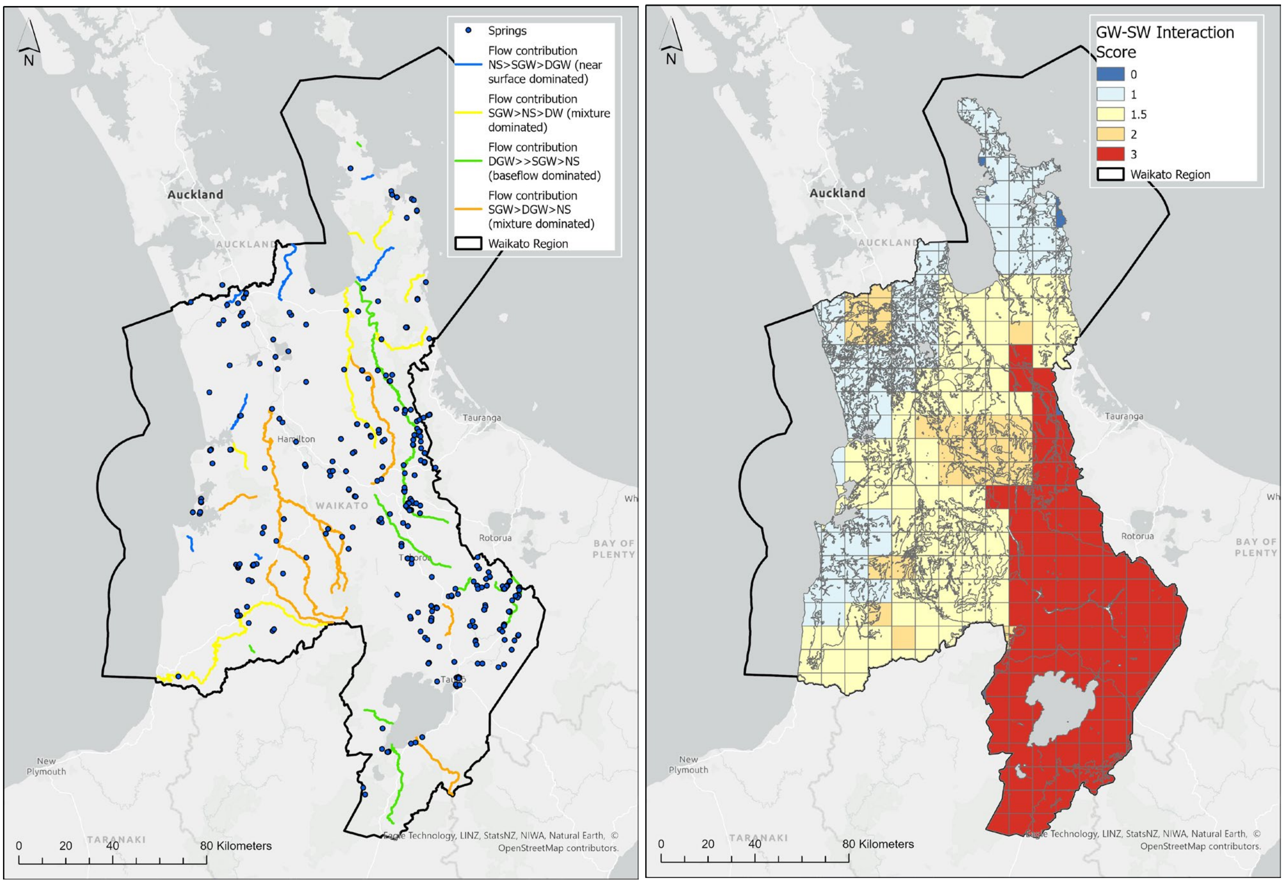

Figure A2.8 Groundwater-surface-water interaction score for the Waikato Region. NS = near surface groundwater, SGW = shallow groundwater, DGW = deep groundwater.

A2.3.8 Taonga Attribute

The locations of significant springs (e.g. the Waihou/Blue Spring), significant wetlands (e.g. Kopuatai and Whangamarino), peat lakes and significant geothermal features (as identified in the Waikato Regional Plan) were used to determine areas where the groundwater resource was supportive of Taonga. Only geothermal features with some connection to groundwater (e.g. geysers) were considered for this assessment. This resulted in features within the Atiamuri, Horohoro, Ngatamariki and Wairakei (Tauhara, Mokai and Tokaanu) geothermal systems being included in the assessment. The following guidance was used to assign ratings:

Table A2.8 Criteria used to assign known Taonga scores at State of the Environment (SoE) sites.

Score Assigned	Description
3	Significant spring within polygon or polygon within immediate catchment area of significant spring.
2	Immediate catchment of significant surface water body (i.e. Lake Taupō).
1.5	Significant groundwater-supported geothermal feature within polygon.
1	Significant wetland or peat lake within polygon, or polygon within immediate catchment of significant wetland or peat lake.
0	Minimal connection between groundwater and surface water.

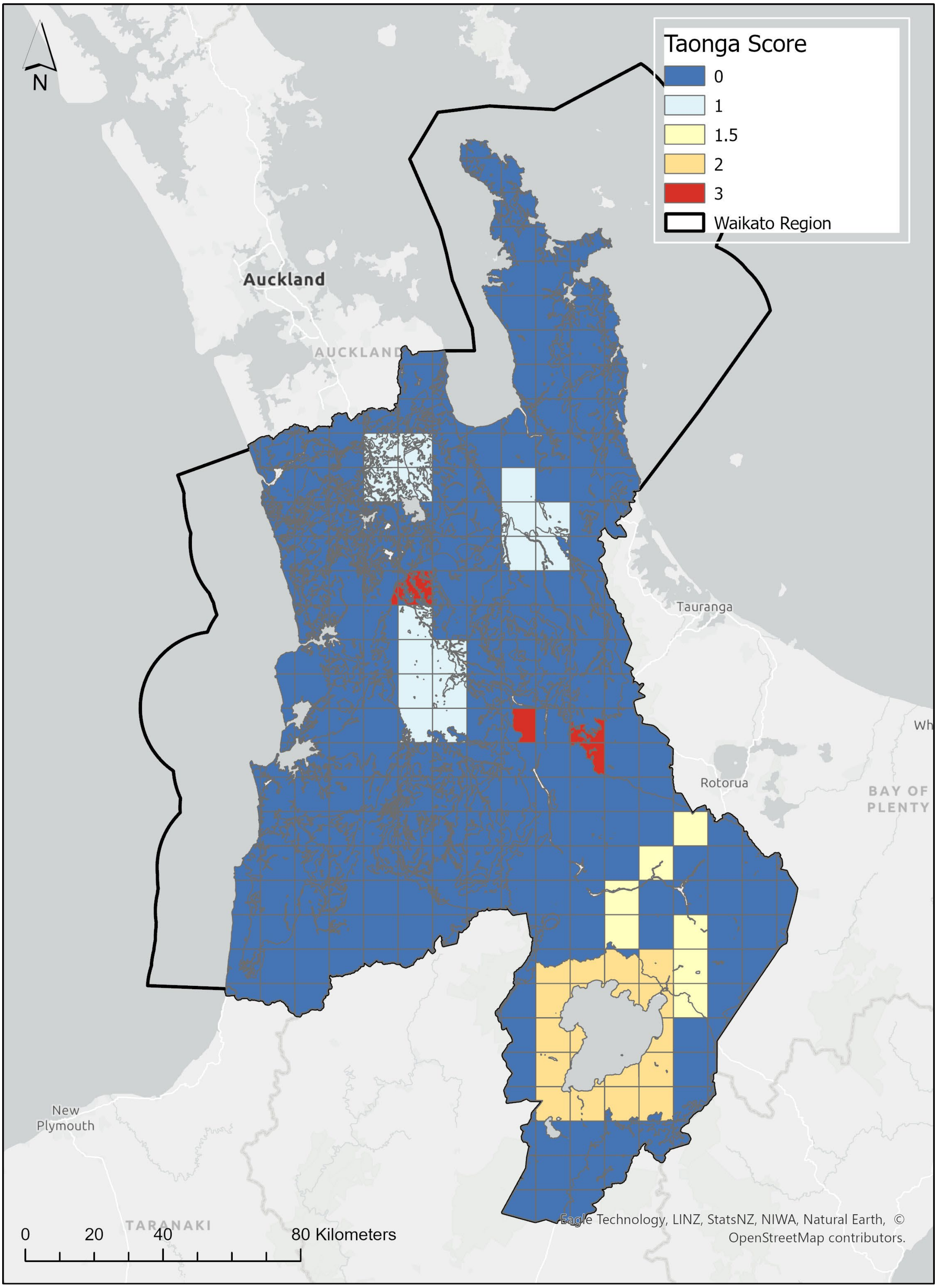

Figure A2.9 Taonga score for the Waikato region.

A2.3.9 Climate Change Attribute

Earth Sciences New Zealand (NIWA business unit)[13] New Zealand climate change prediction maps[14] were used in conjunction with the WRC coastal inundation tool to identify areas predicted to be the most effected by climate change. The most extreme changes to rainfall variables were considered for all future periods. Guidance used to assign ratings is summarised in Table A2.2.

Table A2.9 Guidance to assign climate change scores.

Score Assigned	Description
3	Coastal areas with a sea level rise of 2 m or greater predicted.
2	Areas with relatively high changes to precipitation predicted either seasonally and/or annually.
1	Areas with relatively low changes to precipitation predicted either seasonally and/or annually.

[13] On 1 July 2025, the National Institute of Water and Atmospheric Research (NIWA) and GNS Science merged to form Earth Sciences New Zealand.

[14] https://map.climatedata.environment.govt.nz/

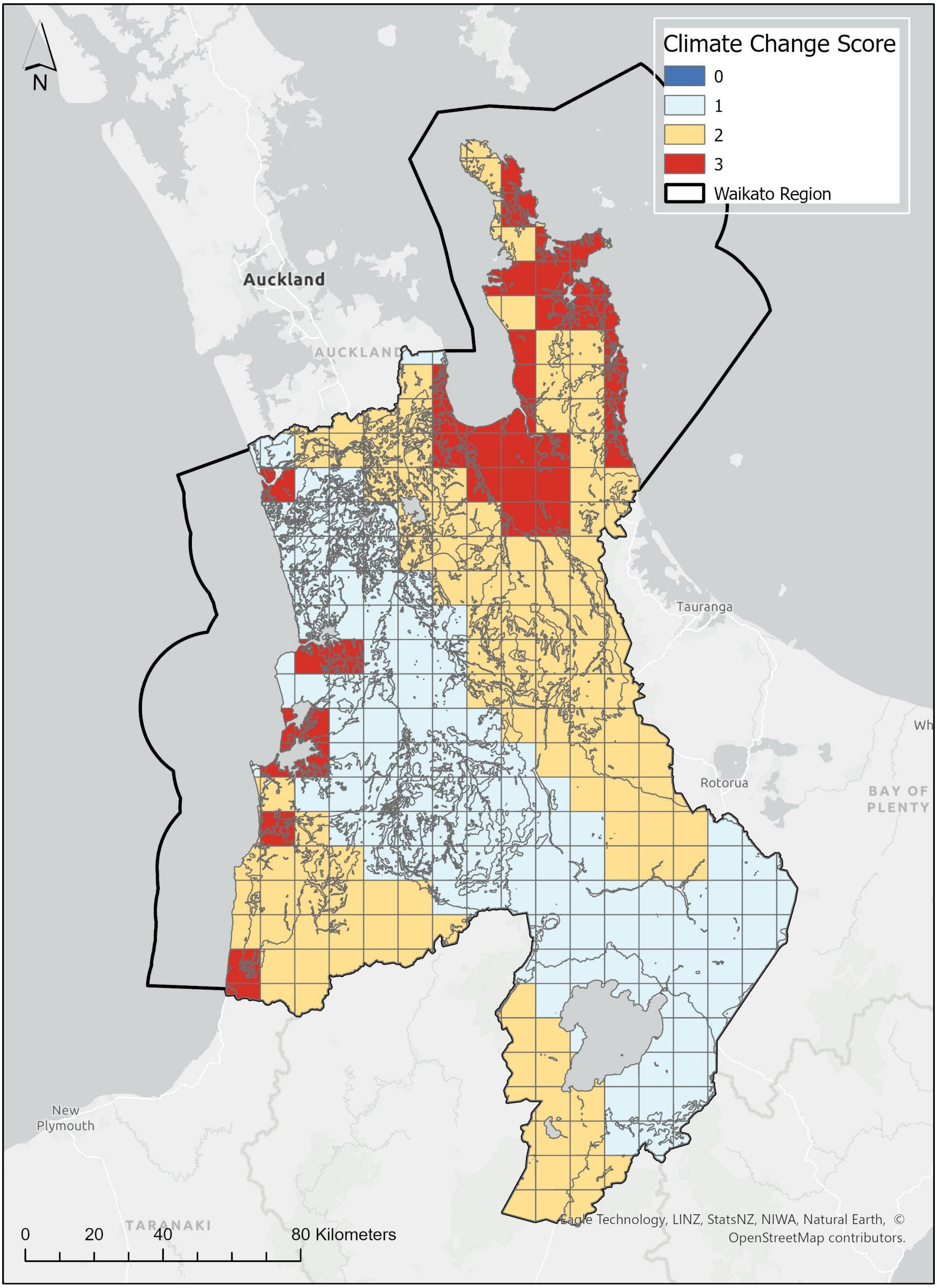

Figure A2.10 Climate change score for the Waikato region.

earthsciences.nz