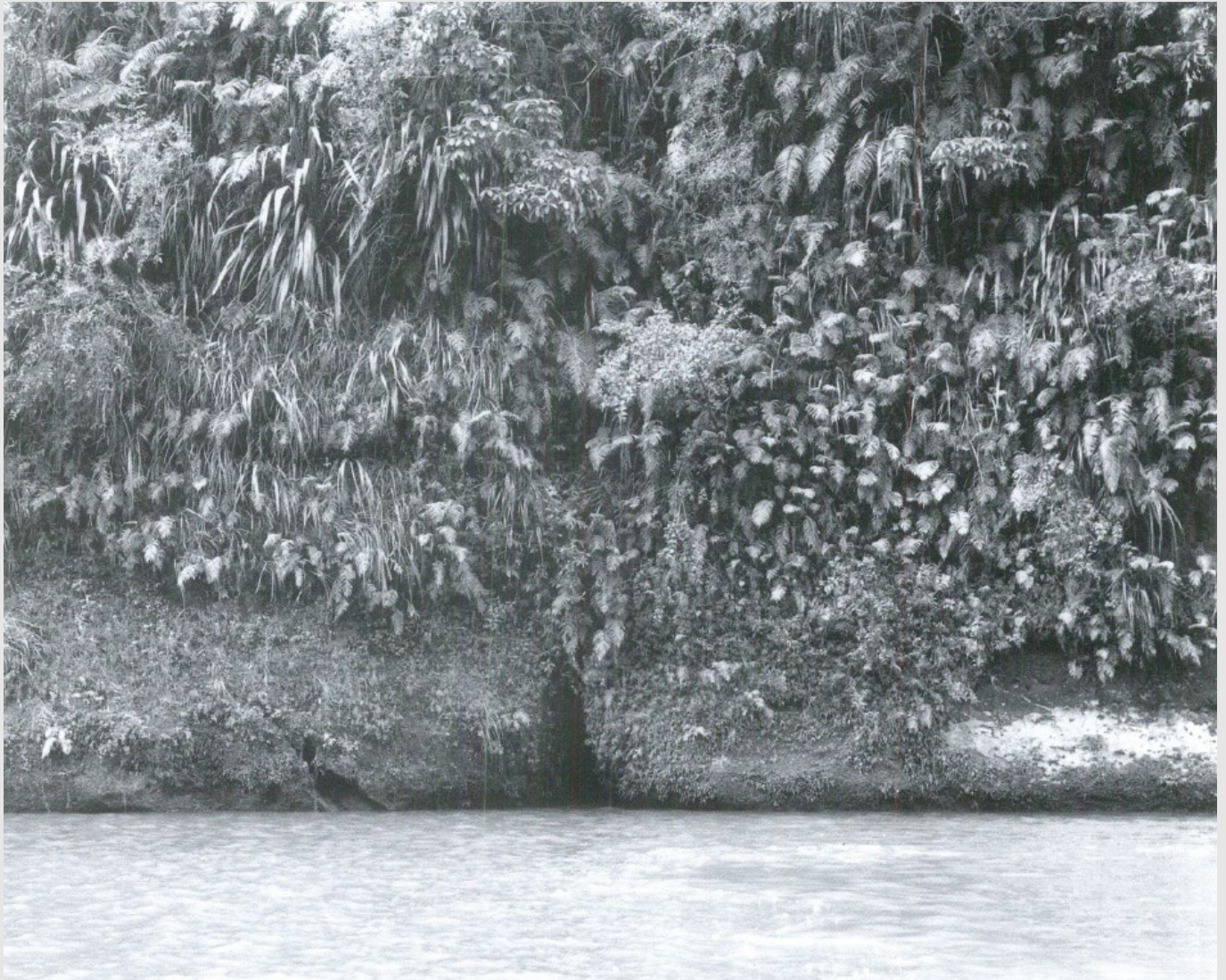




Horizons groundwater quality monitoring optimisation

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ABSTRACT

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 groundwater resources to date. In contrast, national SoE monitoring, also initiated in 1990, has largely remained static. National groundwater quality monitoring is a collaboration between Earth Sciences New Zealand and all regional authorities. Horizons Regional Council (Horizons) commissioned Earth Sciences New Zealand to jointly review both regional and national groundwater quality monitoring programmes in the Manawatū-Whanganui region to ensure it achieves objectives and addresses critiques in respect to national consistency and transparency.

This review is the second case study applying the Surveillance and Evaluative monitoring framework, where Surveillance involves passive characterisation of groundwater quality state and trends. In contrast, Evaluative monitoring is a more targeted approach, notably to assess the efficacy of policies and management initiatives. It is expected that within any given regional network there may be a number of monitoring sites that serve both purposes. In the first case study, undertaken by Earth Sciences New Zealand and Waikato Regional Council, a review methodology was developed with the potential to be applied consistently between regions. The development included extensive consultation with regional councils, relevant Crown Research Institutes (CRIs) and government departments to ensure fitness for purpose. Therefore, the aim of Horizons' joint review is to realign regional and national monitoring, assess the feasibility of applying the methodology in hydrogeological settings different from Waikato's, and clarify differences and limitations between national and regional groundwater quality reporting. This report proposes to replace the current SoE monitoring programme so that there are separate Surveillance and Evaluative networks. Development of an Evaluative network was out of scope for this review.

The existing Manawatū-Whanganui region's SoE monitoring programme consists of 34 wells, three of which are shared with the National Groundwater Monitoring Programme (NGMP) network. The SoE network was reviewed in respect to spatial location, hydrogeological characteristics, availability of information, site access, sampling logistics and, notably, the ability of sampling locations to record changes in groundwater quality that can be statistically assessed. 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 hydrogeologic units provided the basis for informed decisions on the design of the Surveillance regional monitoring network. This uses a variable monitoring site density approach, whereby higher priority areas were assigned greater densities. Priority areas for Evaluative monitoring with nitrate management and seawater intrusion management were also developed to support future network design. 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.

The proposed Surveillance networks involve expansions of both the regional and the national networks with limited changes to the analytical suite and sampling frequency to compensate for the network expansion. Various adjustments will be required involving rationalising some existing sites, while also adding some new monitoring wells, which will require field confirmation of suitability. It is recommended that additional sites involve collaboration with a third party, typically with district councils monitoring drinking-water supplies, which will also generate operational efficiencies.

KEYWORDS

Groundwater quality, monitoring programme, surveillance programme, National Groundwater Monitoring Programme, NGMP, Horizons, Horizons Regional Council, Manawatū-Whanganui

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 groundwater quality context, monitoring activities that aim 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 analyses 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, and (Undifferentiated) where limited data are available.

Surveillance monitoring: in groundwater quality context, monitoring activities aiming to: (1) assess state and trends in groundwater quality, and describe spatial and temporal patterns; (2) associate any trends with potential 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

Horizons Regional Council (Horizons) routinely collects groundwater quality monitoring data as part of both the regional State of the Environment (SoE) and the National Groundwater Monitoring Programme (NGMP), managed by Earth Sciences New Zealand. The main purpose of Horizons' SoE groundwater quality monitoring is to provide an alert in the case of quality deterioration (Zarour 2008).

Horizons' SoE programme collects data for multiple uses:

- Inform on the state and trends of groundwater quality in the region (Daughney et al. 2009). This reporting is a regional council responsibility under the Resource Management Act 1991 (RMA)¹ and is used to inform resource management decision making. State and trends of the monitoring network for groundwater quality indicators (excluding transition metals) have been made publicly available on the Land Air Water Aotearoa (LAWA) website² since 2020.
- State and trends of groundwater quality are also reported at the national scale (Ministry for the Environment and Stats NZ 2026). Note that, at the time of writing this report, the RMA is currently in a multi-year transition phase as the Government moves to repeal and replace it with two new statutes: the Natural Environment Bill and the Planning Bill (Ministry for the Environment 2021; MBIE 2025; Bishop and Court 2026).
- There are also other more locally specific groundwater quality investigations undertaken, such as the recent per- and polyfluoroalkyl substances (PFAS), known as 'forever chemicals', investigation at and around Ohakea Airbase³. These generally respond to locally specific information needs beyond typical baseline characterisation. Additionally, other synoptic surveys of various contaminants were undertaken, such as the 2022 emerging organic contaminants national survey (Banasiak and Close 2025), which are relevant but not routinely part of the monitoring programme.
- SoE and NGMP data underpins government-funded research projects, for instance to calibrate and provide important corroborating data to inform groundwater models.

Since the inception of the SoE and NGMP programmes in the early 1990s, hydrogeological knowledge has considerably grown through council-driven investigations as well as collaborative research projects. However, the regional SoE monitoring programme has not been comprehensively reviewed to incorporate this knowledge, aside from some changes made in response to financial constraints. In addition, past programme reviews have been undertaken separately by Horizons and Earth Sciences New Zealand, resulting in differences in how the region's groundwater resources are represented at regional and national scales.

In parallel, to address current environmental monitoring shortcomings reported by the Parliamentary Commissioner for the Environment (PCE 2019) and limitations of current State of the Environment data to assess policy effectiveness⁴, public groundwater quality monitoring agencies (regional councils, Earth Sciences New Zealand and PHF Science⁵), with support from the Ministry for the

¹ <https://www.legislation.govt.nz/act/public/1991/69/en/latest/#DLM230265>

² <https://www.lawa.org.nz/>

³ <https://www.horizons.govt.nz/environment/water/groundwater/pfas>

⁴ https://ourlandandwater.nz/wp-content/uploads/2024/05/Water_quality_monitoring_for_management_of_diffuse_nitrate_pollution_Final.pdf

⁵ As of 1 July 2025, GNS Science became part of Earth Sciences New Zealand, and the Institute of Environmental Science and Research (ESR) became PHF Science. Articles and information published before this date may reference the former names of these organisations.

Environment⁶, agreed to a set of common principles for groundwater quality monitoring (Moreau 2024). These principles defined high-level objectives to split the current SoE monitoring programmes into Surveillance (i.e. long-term changes) and Evaluative (i.e. management choice driven) programmes, which represents a step-change in New Zealand’s monitoring approach. Between 2023 and 2026, a pilot pragmatic application of these principles, the Waikato case study, was undertaken to develop and apply an optimisation methodology. This work included extensive consultation and numerous interactions with the Groundwater Forum Special Interest Group (Moreau et al. 2026). This case study was successful in proposing two Surveillance groundwater quality monitoring programmes (regional and national) and case studies for regional Evaluative monitoring. The method was designed to enable flexibility between regions and hydrogeological settings. One of the recommendations from the Groundwater Forum was to undertake another case study to test the applicability of the method in other regions. Feedback on the case study received from the Ministry for the Environment included whether national consistency could be achieved.

The proposed work will provide a systematic approach to identify and address gaps in Horizons’ SoE programme aligned with current knowledge. By undertaking a joint review, it will also clarify any difference between national and regional representation, which has relevance to freshwater national reporting.

At the time of writing this report, New Zealand’s environmental legislation, local government structure and science, innovation and technology systems are undergoing significant reforms which may significantly influence future monitoring design and responsibilities (Bishop and Watts 2025; Ministry for the Environment 2024; 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 transparency on the resulting monitoring design, which will facilitate adjustments to potential future requirements.

1.1 This Report

Horizons commissioned Earth Sciences New Zealand to jointly review regional and national groundwater quality monitoring programmes in the Manawatū-Whanganui region, using the Surveillance and Evaluative framework (Moreau 2024) and the methodology developed for the Waikato region (Moreau et al. 2026). The review will provide a second application of this framework in a different hydrogeological setting and management context. It will test the feasibility of using a consistent methodology across regions, and clarify differences and limitations between national and regional groundwater quality reporting. This study was co-funded by the Envirolink Scheme, administered by the Ministry of Business, Innovation and Employment (MBIE Contract HZLC176) and the NGMP (MBIE Strategic Science Investment Fund Contract C05X1701).

The tasks undertaken in this review included:

- Development of a digital map of Horizons’ groundwater priority areas for Surveillance and Evaluative monitoring based on a desktop analysis.
- Development of a revised regional Surveillance monitoring programme that will address any identified gaps in representativeness of the region’s groundwater resources

⁶ Note that on 1 July 2026, The Ministry for the Environment was merged into the new Ministry for Cities, Environment, Regions and Transport (MCERT).

- Development of a revised national Surveillance network in the region, where cost-efficiencies with regional monitoring are identified.
- Drafting of a technical report summarising the methods and dataset used for the review, documenting the Surveillance programmes' design, record necessary compromises between objectives and practical considerations, and make recommendations. It will also provide considerations and recommendations for Evaluative monitoring.
- Presentation of lessons learnt and results of the second case study to the Groundwater Forum.

This report first summarises Horizons' current groundwater monitoring activities and how they evolved over time. This is followed by a description of the network optimisation methods grouped by the following monitoring aspects: objectives and constraints, groundwater monitoring class definition, site distribution, representation at the national scale, and variable and sampling frequency. Next, the resulting optimisation of existing sites, variables and sampling frequencies are presented. Finally, discussion and recommendations are provided.

To review the NGMP requires an iterative process by first assessing each region followed by a national consistency review over the full network. Therefore, to transparently record this process, this technical report is released as part of a series (NGQM Framework Reports), aiming for one report per region.

2.0 Horizons Regional Council's Current Groundwater Quality Monitoring

2.1 Groundwater Resources in the Manawatū-Whanganui

2.1.1 Setting

The Manawatū-Whanganui covers a total area of 22,000 km² (Figure 2.1). The landscape has been primarily shaped by four large rivers: the Whanganui (290 km long), Rangitikei (241 km long), Manawatū (182 km long) and the Whangaehu (161 km long) rivers. The region hosts over 170 lakes, including Punahau (Lake Horowhenua), which is New Zealand's largest dune lake (3.9 km²). Dune lakes are internationally rare ecosystems (Waters et al. 2018).

The region consists mainly of Tertiary and Quaternary marine sediments bisected by a central backbone of Triassic to early Cretaceous greywacke rocks, which form the northeast- to southwest-trending Tararua and Ruahine ranges (Figure 2.1). East of the ranges, Cretaceous to Neogene sediments occur in localised fault-bounded basins, parallel to the ranges' axis. The basins are surface expressions of the fold and thrust belt lying above the Hikurangi subduction zone. West of the ranges, The South Whanganui Basin formed through subsidence during the late Pliocene and Pleistocene, leading to the deposition of the Rangitikei Supergroup. In the north, the currently active Tongariro Volcanic Centre includes andesite lavas, with activity starting in early Quaternary (Begg and Johnston 2000; Bekesi 2001; Townsend et al. 2008).

2.1.2 Overview

Groundwater is used extensively in the region for stock and domestic water supplies, especially in the Manawatū and Horowhenua districts, the alluvial flats in the Tararua District, and in the lower sections of the Rangitikei and Whanganui catchments (Zarour 2008). There are five large hydrogeological systems mapped in the region: the largest is the Whanganui Coastal Basin that extends to the west into the Taranaki region and ends at the Tararua foothills; the South Whanganui Basin that extends to the Wellington region; the Dannevirke and Pongaroa inland basins, and the Taupō Inland Volcanic system, shared with the Waikato region (Figure 2.1). Hydrogeological systems are geographical areas with broadly consistent hydrogeological properties and similar resource pressures and management issues, mapped consistently at the national scale (Moreau et al. 2019).

Most of the region's groundwater resources are hosted in Quaternary (Pleistocene to Holocene) or Tertiary sediments (Figure 2.1). Quaternary sediments consist of marine terraces sand and gravels (extensive in the west) and alluvium deposited adjacent to rivers. These deposits host unconfined aquifers throughout the entire region, with the thickness of these deposits varying from a few metres to over 100 m. Tertiary sediments comprise mudstone, sandstone and limestone of moderate to high permeability, hosting artesian aquifers towards the coast through either fracture-dominated or porous flow. Within the Whanganui Basin these deposits host multiple aquifers, often layered, the distribution of which is controlled by lithology and structural features. Recharge areas are generally located in the high country, but vertical and horizontal anisotropy in the gravel deposits make the delineation of individual aquifers complex (Bekesi 2001 [and references therein]). However, east of the Tararua and Ruahine ranges, tertiary sediments are considered as aquicludes. Unlike the neighbouring Waikato region, karstic features are almost absent in the region, save for two sinkholes close to the Ruahine Hut, within the Matemateaonga Formation (Harrison and Bon 2024). Mesozoic to Early Cretaceous basement consists of weakly to strongly metamorphosed, deep marine sedimentary sequences comprising sandstones, mudstones, siltstone, broken formation and melange. These basement terranes are regarded as aquicludes and the hydrogeological basement in the region (Bekesi 2001; Morgenstern et al. 2017).

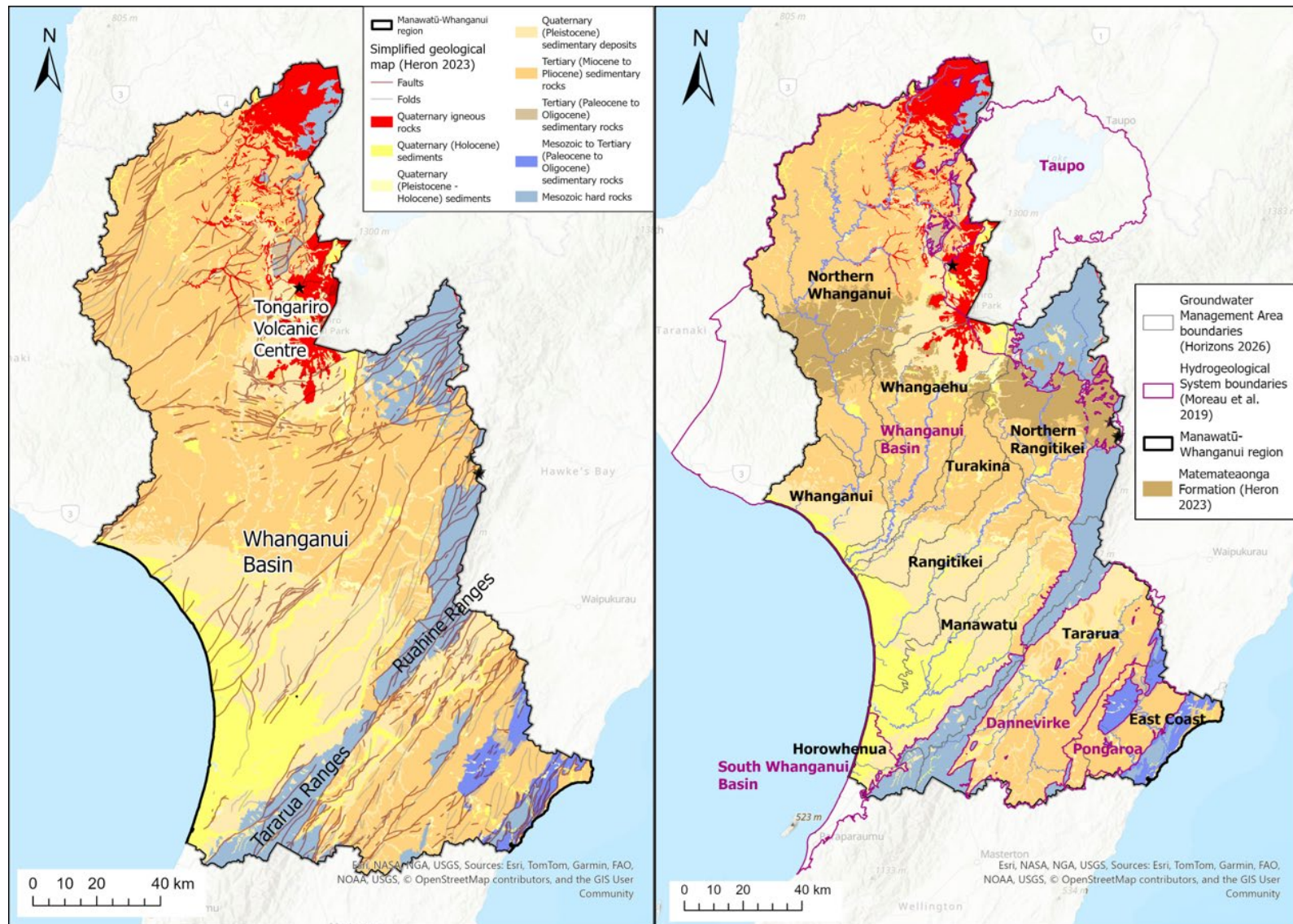


Figure 2.1 Geology (left) and non-basement hydrogeological systems and Horizons' groundwater management areas (right) of the Manawātū-Whanganui region. Note that small linework indicate Basement systems outcrops.

Although the region counts more than 9500 well records, detailed drilling records are often of poor quality and, therefore, limited information is known on aquifer boundaries, which resulted in aquifers being classified by geographical location (Bekesi 2001) or aquifer properties being studied or mapped at the Whanganui Basin level (Morgenstern et al. 2017; Rees et al. 2019). The following sections provide further details on aquifers where they have been associated with specific lithologies or faults.

2.1.2.1 Volcanic Deposits

There is limited information available on groundwater sourced from diverse Quaternary volcanics (e.g. andesitic lava flows, breccia and tuff). In the vicinity of Horokina, at the northern boundary of the Whanganui Basin, three groundwater takes are recorded (up to 1500 m³/d). Available well logs indicate depths ranging from 42 m to 362 m deep. In the Waimarino Plains (Taupō Inland Volcanic system), unconfined aquifers have been identified in bores between 7.7 m and 101.6 m deep, with some elevated nitrate concentrations up to 45 mg/L at shallow depths (Lovett et al. 2014).

Multiple springs occur on Mount Ruapehu, likely from perched aquifers, e.g. the mineralised Silica Springs located on the northwest flank of Mount Ruapehu (Townsend et al. 2008).

2.1.2.2 Quaternary Sediments

In the Whanganui area, sand and gravel deposits host unconfined aquifers recharged by the rivers. The Poroutawhao Fault is a significant structural feature, with an uplifted basement to the west, where sediments may be as thin as 15 m. To the east of the fault, sediments can reach depths of more than 1000 m and groundwater quality varies with depth. Unconfined aquifers also occur within the extensive sand dunes. However, they are often poor in water quality (high iron content, low pH) or due to contamination from storm water and effluent disposal (Begg and Johnson 2000). In the coastal areas, groundwater maintains lake levels (e.g. Lake Horowhenua). East of the Tararua and Ruahine ranges, Quaternary sediments are typically thin (less than 30 m), associated with river valley gravel and regarded as unconfined aquifers. These deposits and some aquifers extend south to the Greater Wellington region.

2.1.2.3 Tertiary Sediments

In the Whanganui area, groundwater is likely recharged in the hill country and flows toward the Whanganui River and the coast. Artesian conditions prevail for deep aquifers at the coast. In the Whangēhau and Turakina coastal areas, deep bores intersect artesian groundwater close to the coast, providing local supplies. In the Manawatū, most groundwater use is located where both unconfined and confined aquifers occur. Confined aquifers are recharged in the Tararua and Ruahine ranges as well as in the Pohangina Anticline. Groundwater flows westwards and discharges to the coast (Bekesi 2001 [and references therein]). East of the Tararua and Ruahine ranges, the tertiary mudstone-dominated sediments are generally regarded as aquicludes. Deep test bores yielded small quantities of brackish waters, possibly linked with the Hikurangi subduction zone (Bekesi 2001).

The following geological formations have been identified as water-bearing (Figure 2.2):

- The Pliocene to Pleistocene Maxwell Group occur in the central part of the region, mostly between the Turakina and the Rangitikei rivers. It comprises sandstone, mudstone, limestone, carbonaceous siltstone and lignite. It has been associated with shallow groundwater in the vicinity of surface water, low hydraulic gradients and water quality issues due to leaching of organic compounds and lignite. (Townsend et al. 2008).
- The Pliocene Mangarere Formation consists of sandstones and siltstones. The formation is generally regarded as an aquitard, except for the basal Te Rimu Sandstone member, which acts as a low-yielding, locally used aquifer from which contact springs arise at the contact with the underlying Paparangi Group (Rees et al. 2019; Townsend et al. 2008).

- The late Pliocene Nukumarū Group, which consists of limestones interbedded with sandstones, is the main aquifer and has been supplying the city of Whanganui for more than 100 years. The Nukumarū Group exhibits transmissivities significantly higher than the surrounding Tertiary sediments, with the latter transmissivities of less than 50 m²/d. Hydrochemical data indicate that the Upokongaro Fault acts as a groundwater divide, with sodium-bicarbonate-type water occurring east of the fault and calcium/magnesium-bicarbonate-type groundwater west of the fault. Beyond the Nukumarū Group, major ion chemistry indicates that Whanganui groundwaters are sourced by five aquifers; however, the poor quality of drilling records hinders classification (Bekesi 2001).

The Miocene to Pliocene Matemateaonga Formation comprises muddy sandstone with interbedded shell beds, siltstone, sandstone and conglomerate. This formation outcrops east–west of the basin and continues in the Taranaki region where it hosts multiple aquifers (Bekesi 2001). In the Whanganui-Manawatū region, there is little information about its potential as a groundwater supply. Warm springs (between 20°C and 27°C) have been recorded along the banks of the Whanganui River at Jerusalem, Upokongaro, Piripiri and Waioara (Townsend et al. 2008). Some records suggest that the Waioara hot spring was part of a larger geothermal area with a bathhouse set up in 1912, later covered by landslide debris (Brown et al. 1987). Cold springs (Ngaporo, Opopo) and mineralised springs (Puraroto Caves, Pokorua, Waitoto), are likely to be linked with discrete aquifers associated with the Miocene Matemateaonga Formation. Chemistry and stable isotope analyses at these springs indicate low temperature at depth and a likely warming by natural geothermal gradient (Brown et al. 1987). Note that the cold (16°C) but mineralised Waitoto Salt Spring recorded east of Whakaroro is sourced from Mount Messenger Formation, which is a spatial variation within the Whangamomona Group to which the Matemateaonga Formation belongs. Water stable isotope analyses from the Waitoto Salt Spring indicate a long residence time and deep circulation (Brown et al. 1987).

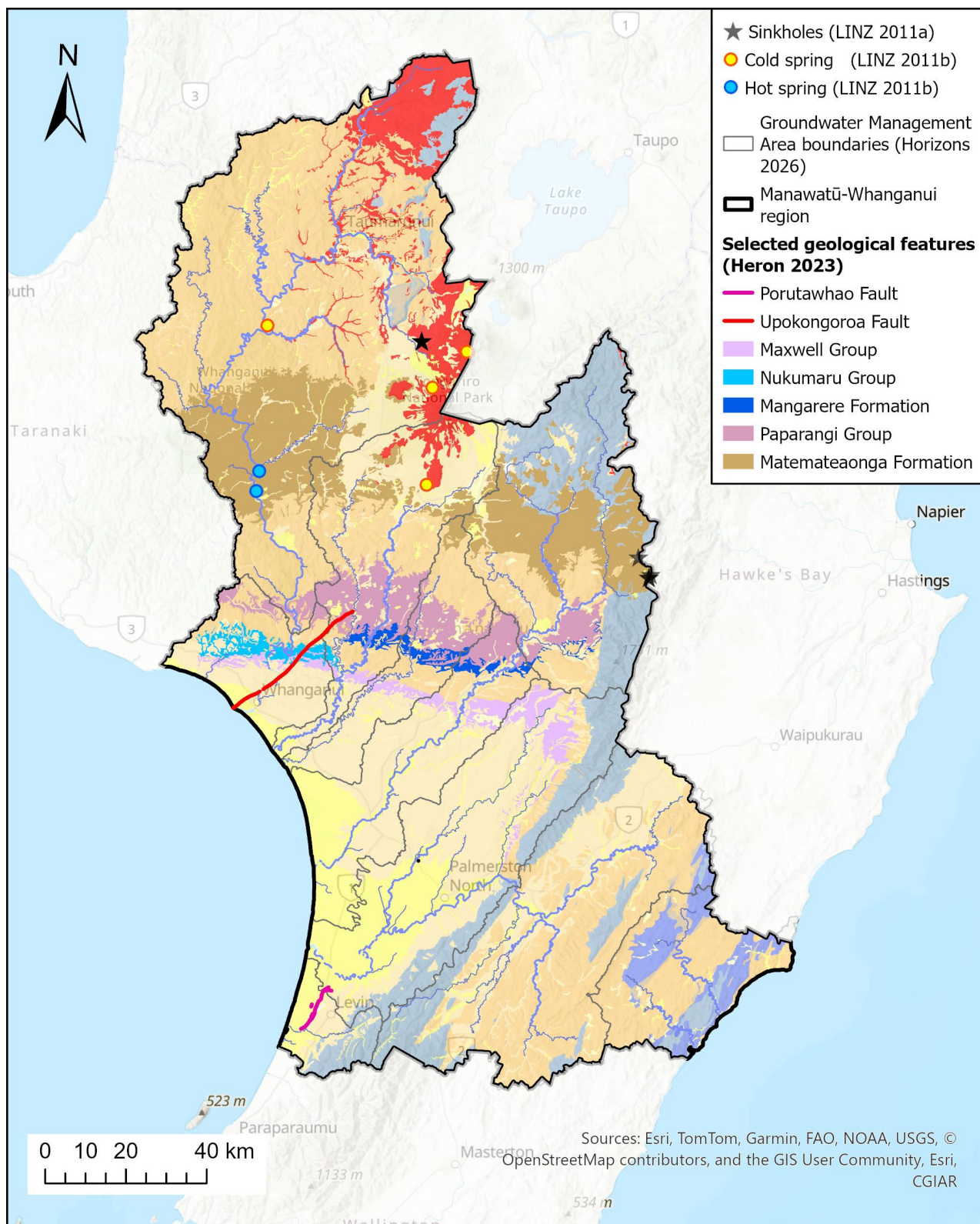


Figure 2.2 Hydrogeological features of the Manawātū-Whanganui region.

2.2 Current Groundwater Quality Monitoring Programmes

2.2.1 Site Distribution of Monitoring Networks

SoE monitoring involves active data collection, which means that networks may undergo modifications with time. This is particularly true for groundwater monitoring where most monitored sites are privately owned and, therefore, site access can become an issue over time, for instance when property ownership changes. It is also common that, within a given monitoring round, the number of monitored sites varies due to unforeseen circumstances (e.g. the pump is not working on the day of the visit). Therefore, collating data for state and trend analysis requires tracking network changes during the time period of interest.

There is limited information available on the SoE programme inception. Prior to 2009, Horizons used a system of ‘rolling sites’, which was modified between 2007 and 2009 (Office of the Auditor General 2011). In 2008, the programme included (Zarour 2008):

- 28 regularly sampled sites forming the SoE network at which field and a range of chemical variables were monitored every seven months.
- Four quarterly sampled NGMP sites.
- Nine quarterly monitored sites at which only nitrate was measured.
- Six telemetered sites at which groundwater levels and electrical conductivity were recorded at 15-minute intervals to monitor saltwater intrusion.
- Occasional science investigations, such as the summer 2008 Horowhenua characterisation sampling campaign during which 55 wells were sampled.

Over the years, multiple reviews were undertaken with strong emphasis on cost effectiveness, resulting in changes over time (Table 2.1). The current SoE programme still combines multiple networks (35 SoE sites and three NGMP sites) and occasional site investigations (Figure 2.3). The NGMP started with a phase of characterisation between 1990 and 2002, and, thereafter, research activities were added to the programme’s monitoring operations.

Table 2.1 State of the Environment (SoE) groundwater quality network evolution over time.

Date	Reported SoE Sites	Sampling Frequency	Source
2008	32 (including four NGMP)	Seven-monthly (SoE) and four-monthly (NGMP)	Zarour 2009
2009	32 (including four NGMP)	Seven-monthly (SoE) and four-monthly (NGMP)	Daughney et al. 2009
2011	25	Seven-monthly (SoE) and four-monthly (NGMP)	Office of the Auditor General 2011
2013	22 (excluding NGMP sites)	Seven-monthly (22 sites)	Hayward et al. 2013
2014	37 (including four NGMP)	Unspecified	Moreau and Daughney 2015
2025	38 (including three NGMP)	Unspecified	Moreau et al. 2024
2026	39 (including three NGMP)	Four-monthly	This report

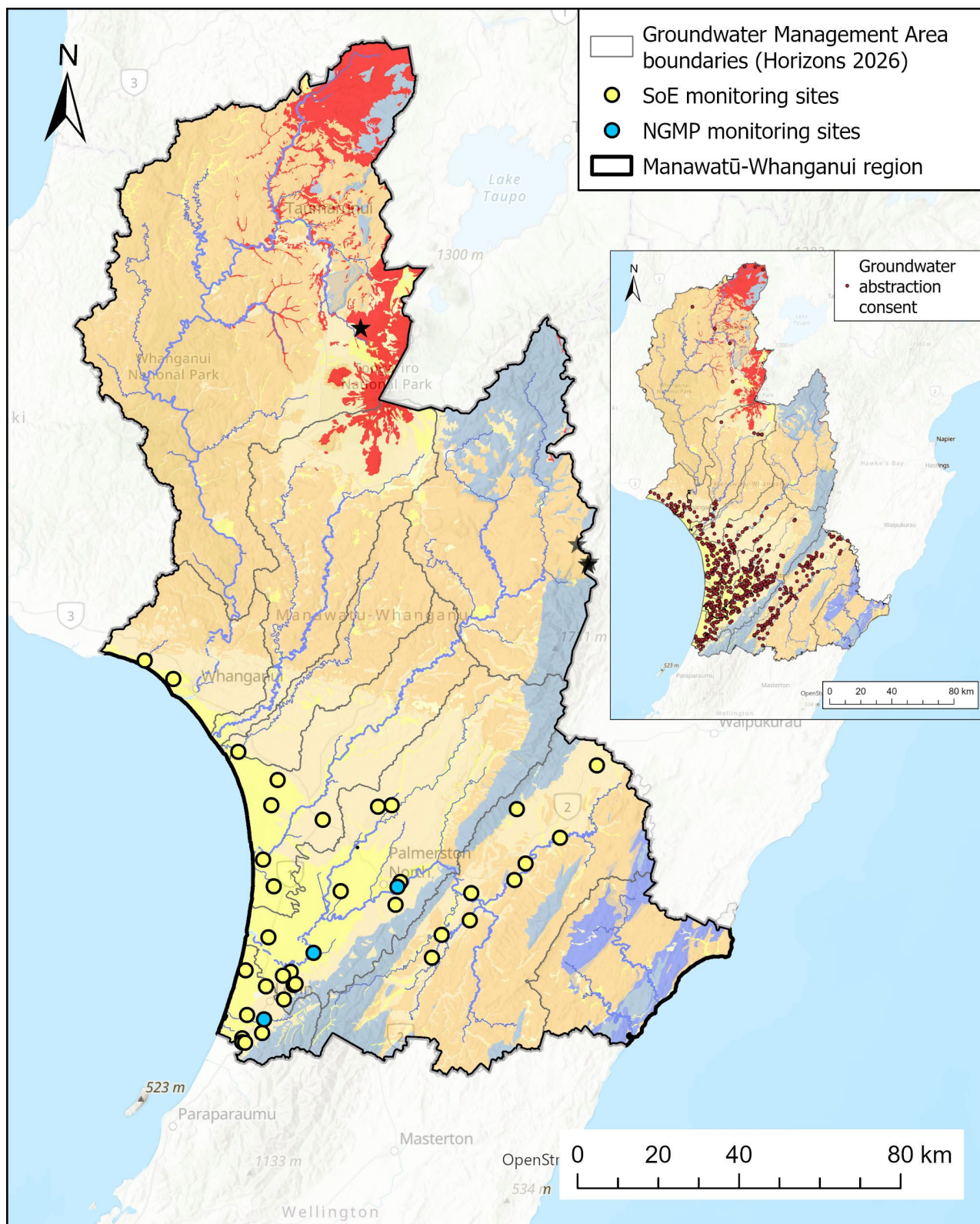


Figure 2.3 Current State of the Environment (SoE) network site locations (National Groundwater Monitoring Programme [NGMP] and SoE) in the Manawatū-Whanganui Region. The inset depicts the spatial distribution of the region's groundwater takes for context.

2.2.2 Variables and Sampling Frequency

Current groundwater quality variables routinely monitored as part of Horizons' SoE programmes include field-measured inorganic chemical and microbial variables (a complete list is provided and discussed in Section 4.3). 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 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 other variables have also been regularly reported by Horizons as indicators, such as nitrate and *E. coli*.

Currently, all SoE sites are routinely monitored at quarterly frequency. The frequency was increased after a 2013 review to meet state and trend statistical minimum data requirements from seven-monthly sampling to quarterly (Table 2.1) (Hayward et al. 2013). The latter sampling frequency was initially selected to provide sampling all seasons in all months with a return period of 12 years for cost-effectiveness (Office of the Auditor General 2011). Higher-frequency monitoring for specific investigation using in-situ probes (e.g. nitrate-nitrogen) can 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's Water Dating Laboratory. As a result, groundwater age samples have been collected over multiple years (from 1982 to current, as repeated age dating is part of the NGMP) to now provide such information at the majority of existing SoE sites. Groundwater age may change over time, reflecting changes in dynamics recharging the sampling points, and therefore repeated measurements are valuable. Repeated age information is available at some of Horizons' SoE sites and for most national monitoring sites.

Alongside routine monitoring operations, both the regional and national programmes also undertake investigations, such as snapshot surveys. For instance, 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 Manawatū-Whanganui region since the 1990s, as part of four-yearly national surveys undertaken by PHF Science (formerly ESR). These surveys are co-funded by participating regional councils. More recently, the monitoring suite of the national surveys 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. The fate of contaminants and their transport in the environment can vary significantly between contaminants and, therefore, to contain the scope of this review, organic variables have not been included.

3.0 Methods

The following section outlines the methods used in this review. Where identical to the Waikato review (Moreau et al. 2026), these are reproduced verbatim and indicated as indented quotations. Note that region-specific mentions have been altered to read 'Horizons' or 'Manawatū-Whanganui' (as appropriate) instead of 'Waikato'; these changes are highlighted using bold, non-italicised font. The development of national consensus involving extensive external consultation and reflections on balancing monitoring objectives and cost are not repeated here. These considerations remain up-to-date and valid for this review and are detailed in Moreau et al. (2026).

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 **Horizons**; 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 Groundwater Classification

To objectively prioritise groundwater monitoring, a designation scheme adapted from the United Kingdom'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 $\text{m}^3.\text{s}^{-1}$) 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, geologically defined surface polygons of New Zealand's hydrological systems map (Moreau et al. 2019) and Horizons' groundwater monitoring areas.

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 Manawatū-Whanganui 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 3.4⁷). In addition, recommendations identifying potential suitable datasets for future inclusion are provided in Section 6.5⁸.

GR Index values in the Manawatū-Whanganui region ranged between zero and 0.012 (Figure 3.1). Unlike in the Waikato region, the GR Index range was not modified to derive classes, because in many areas aquifer boundaries are not known. Instead, these indices were used to guide classification. Where possible, Horizons' Groundwater Management Areas (GWMAs) (Horizons 2026) were combined with the grid and geological polygons where aquifers had been recorded in the literature (see Section 2.1.1). For instance, in the Whanganui Basin, the Maxwell Group, generally regarded as an aquiclude was used to map the northern boundary for the primary areas. Conversely, in the Whanganui GWMA, the Nukumarū Group was mapped as the northernmost primary area. The resulting draft map was evaluated by Horizons' staff familiar with the groundwater resources in the region, which resulted in minor modifications. Finally, classes were reviewed using recent publications related to the region's aquifers to ensure that known aquifers, including those at depth, were represented (Bekesi 2001; White 2001; Zarour 2008).

This approach identified primary areas within the coastal Whanganui, Rangitīkī, Manawatū, Horowhenua and Tararua GWMAs (Figure 3.1; Table 3.1). Quaternary (Holocene) deposits along the main rivers were classed as Secondary A (granular-flow dominated). The Matameatea Formation and Mangarere Formation were classed as Secondary B (fracture-flow dominated). Most of the inland areas of the Northern Whanganui, Whangāehu, Turakina, Northern Rangitīkī as well as East Coast are classed as low-priority secondary undifferentiated. Mesozoic and earlier formations were classed as Tertiary.

⁷ See Section 3.4 in Moreau et al. 2026.

⁸ See Section 6.5 in Moreau et al. 2026.

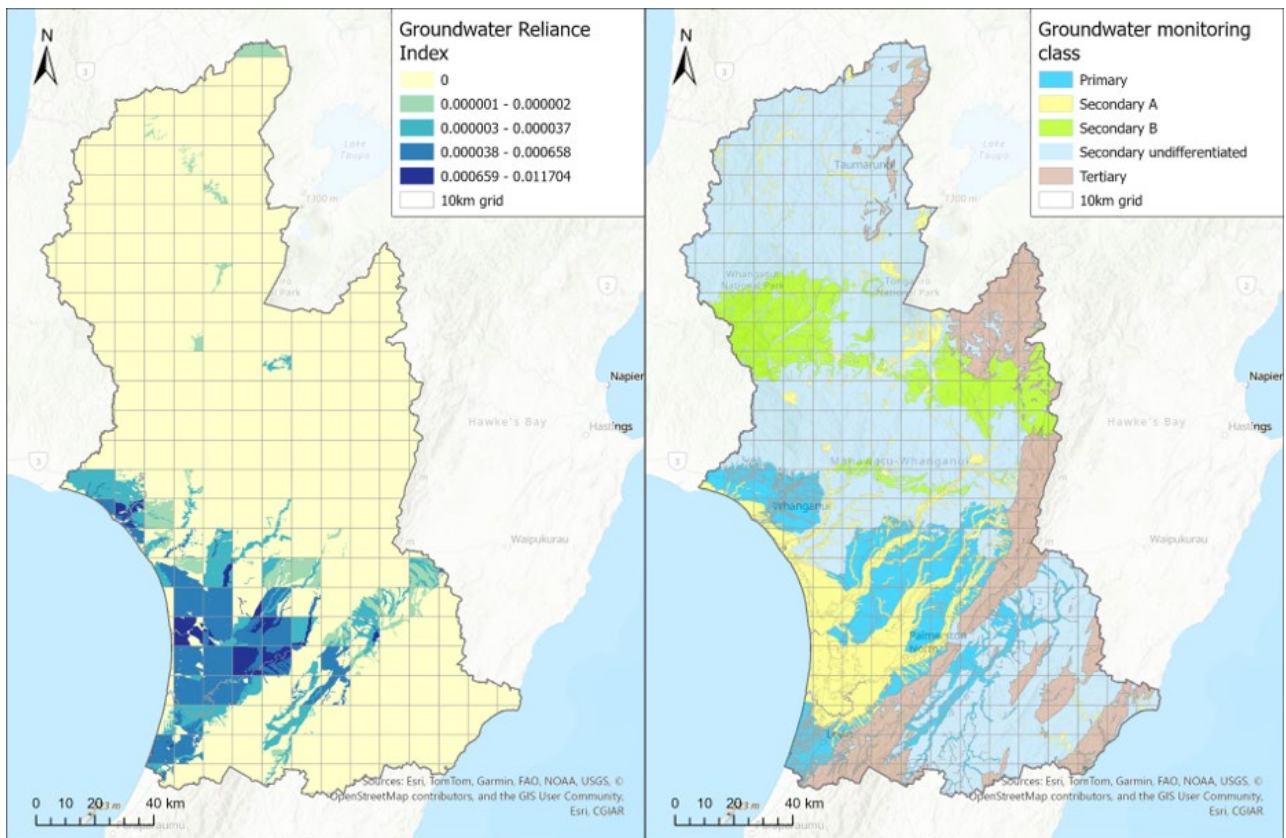


Figure 3.1 Groundwater quality Groundwater Reliance (GR) Index initial values (left) and Groundwater Classes (right) in the Manawatū-Whanganui region after Horizons' review.

Table 3.1 Groundwater Classes in the Manawatū-Whanganui region.

Hydrogeological System Names	Groundwater Monitoring Area	Groundwater Class	Grouped Geology	Aquifer Geological Formation Example
Whanganui Basin	Whanganui	Primary	Tertiary sediments	Nukumarū Group
	Manawatū, Rangitikei,	Primary	Tertiary sediments	Pakihi Supergroup
	Manawatū, Rangitikei, Whanganui	Secondary A	Quaternary sediments	Holocene sediments
	Northern Rangitikei, Turakina, Whangaehu, Northern Whanganui	Secondary B	Tertiary sediments	Matemateaonga Formation
	Rangitikei, Turakina, Whangaehu	Secondary B	Tertiary sediments	Mangere Formation
	Northern Whanganui, Whangaehu	Secondary Undifferentiated	Quaternary volcanics	Whakamaru Group ignimbrite
	Basin-wide	Secondary Undifferentiated	Tertiary sediments	Tangahoe Mudstone, Paparangi Group
South Whanganui Basin	Horowhenua	Primary	Quaternary to Tertiary sediments	Holocene pre-Q2 sediments
	Horowhenua	Secondary A	Quaternary sediments	Holocene Q2 sediments
Dannevirke	Tararua	Primary	Quaternary sediments	Holocene sediments
	Tararua	Secondary Undifferentiated	Tertiary sediments	Mangamaire Group
Pongaroa	East Coast	Secondary A	Quaternary sediments	Holocene sediments
	East Coast	Secondary Undifferentiated	Tertiary sediments	Maui Supergroup
Turnagain	East Coast	Secondary A	Quaternary sediments	Holocene sediments
	East Coast	Secondary Undifferentiated	Tertiary sediments	Palliser Group
Basement infill	Region-wide	Tertiary	Holocene to Tertiary sediments	Te Muna Formation
Basement hard rock	Region-wide	Mesozoic and earlier	Cretaceous and earlier hard rocks	Esk Head Belt, Whangai Formation

3.3 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 Manawatū-Whanganui region, combined with hydrogeologically defined polygons. This resulted in 3210 individual mappable units, which ranged in size from less than 1 km² to 10 km² (median 0.4 km²), to be assessed. The attributes chosen for the relative rating assessment were selected with consideration to the four criteria described in the Environment Aotearoa 2019⁹ synthesis report to provide a “focus on what matters” approach (Table 3.2). 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 3.2).

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 focussed. The equation for determining the GIS-based priority for each grid cell is:

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

Where:

$$A_R = \frac{\text{Area}}{\text{cell parameter rating}} \quad A_R = \text{Area}/(\text{cell parameter rating})$$

and

$$A_W = \frac{\text{Area}}{\text{cell parameter weighting}} \quad A_W = \text{Area}/(\text{cell parameter weighting})$$

The assessment was undertaken in GIS and a detailed description of the assessment and ranking for each attribute is provided in Appendix 1.

⁹ <https://environment.govt.nz/publications/environment-aotearoa-2019/>

Table 3.2 Attributes and weightings used to assess priority areas for groundwater quality monitoring. NA is not applicable. The 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 ¹⁰)	Surveillance Consideration	Weighting (%)	Evaluative Consideration (Nitrate)	Weighting (%)	Evaluative Consideration (Seawater Intrusion)	Weighting (%)
Groundwater class (i.e. primary, secondary, etc.)	1	Yes	55%	Yes	20%	Yes	50%
Vulnerability	3	-	-	Yes	20%	-	-
Land use	1, 3, 4	-	5%	Yes	20%	-	-
Drinking water	4	-	10%	Yes	10%	Yes	10%
Known groundwater quality issues	2, 3	-	5%	Yes	20%	Yes	30%
Groundwater and surface-water interaction	1, 3, 4	Yes	20%	-	10%	-	-
Taonga	3, 4	Yes	-	-	-	-	-
Climate change	3, 4	Yes	5%	-	-	Yes	10%
Other Considerations for Site Selection and Frequency Not Spatially Based							
Distance from coast	3	-	-	-	-	Yes (to include/exclude)	NA
Redox state	2, 3	-	-	Yes (to inform site selection)	NA	-	-
Groundwater age	3	Yes (only to inform frequency)	NA	Yes (to inform site selection)	NA	Potentially	-
Anticipated land-use change	2, 3	-	-	Yes (if available)	NA	Yes (if available)	NA
Policy details (if applicable)	3	-	-	Yes (if available)	NA	Yes (if available)	NA

¹⁰ <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 funding constraints make it important to focus monitoring efforts in aquifers which are most used.

The vulnerability attribute to nitrate contamination was based on a Landscape Subsurface Nitrate-Attenuation Index (LSNAI) assessment undertaken for the region in 2025 (Collins et al. 2025). The LSNAI assessment is a machine-learning, enhanced multivariate statistical analysis based on predicted groundwater redox status probabilities and identified soil drainage and rock types. 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 natural attenuation potential from surface nitrate contamination. Vulnerability was not considered for seawater intrusion Evaluative monitoring because the LSNAI assessment is focussed on nitrate attenuation 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 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 land uses are known to negatively affect groundwater quality in the Manawatū-Whanganui (Zarour 2008). 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 3.4 below.

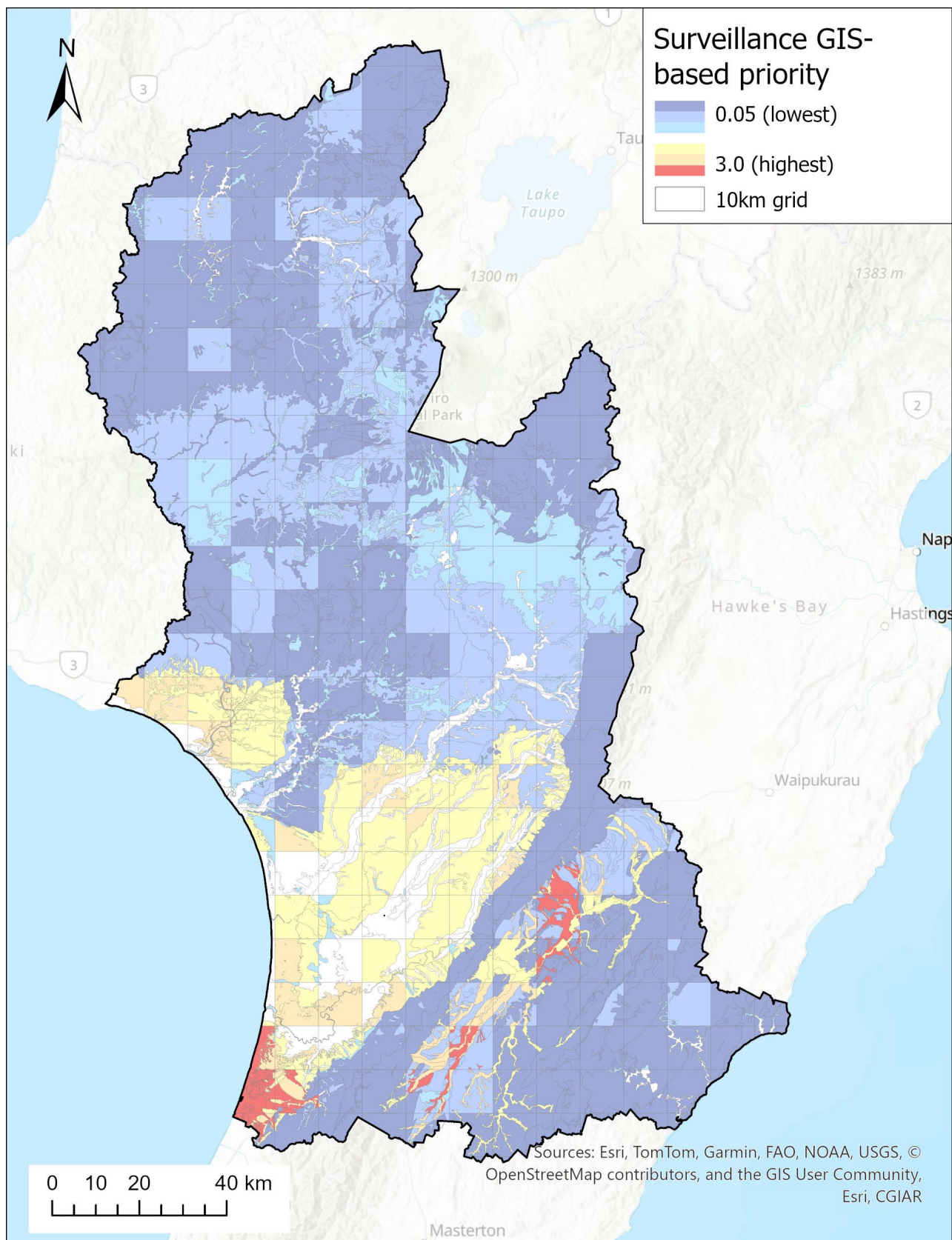


Figure 3.2 Priority ranking for Surveillance monitoring in the Manawatū-Whanganui region.

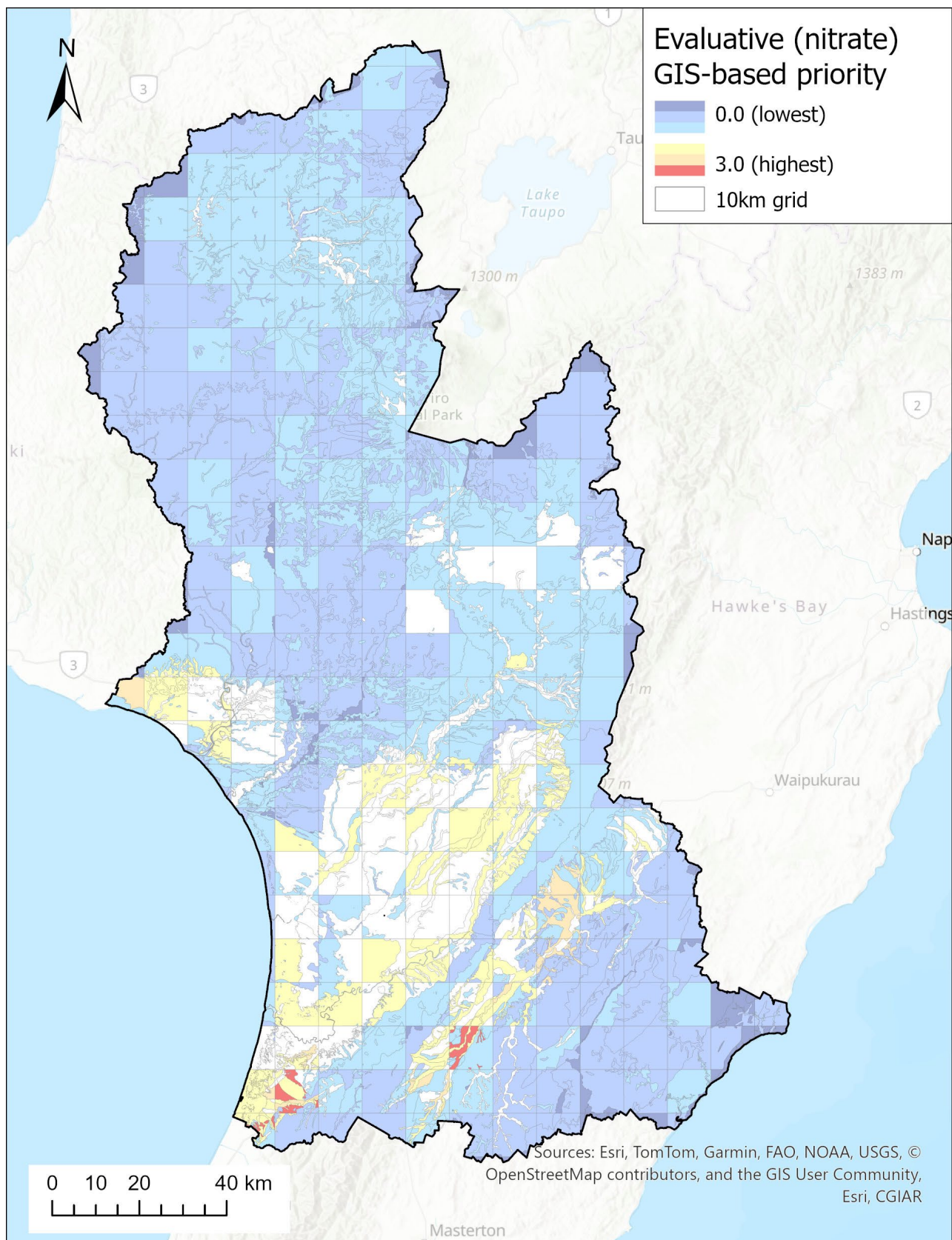


Figure 3.3 Priority ranking for Evaluative (nitrate) monitoring in the Manawātū-Whanganui region.

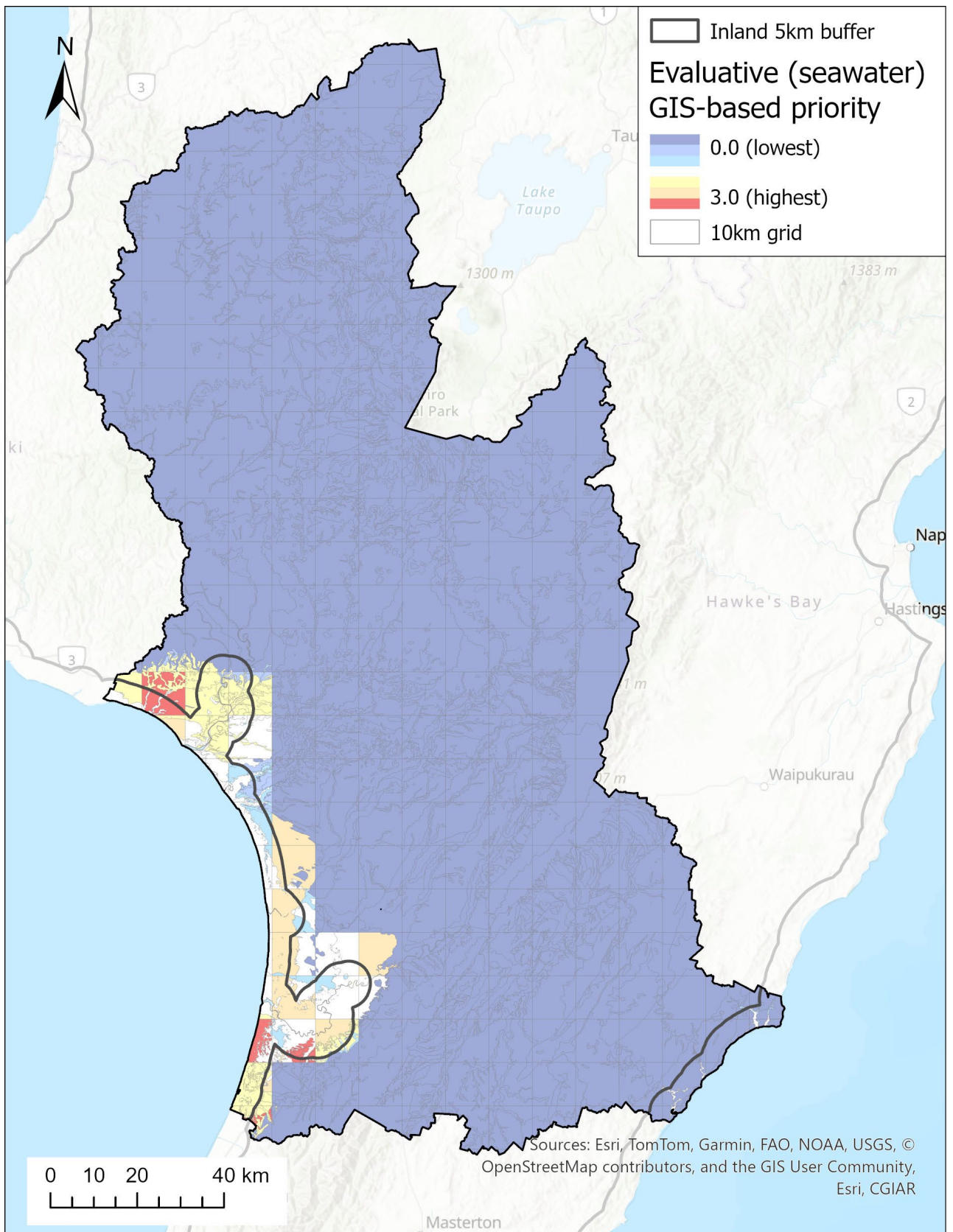


Figure 3.4 Priority ranking for Evaluative (seawater intrusion) monitoring in the Manawatū-Whanganui region.

3.4 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 United States 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]).

3.5 National Groundwater Monitoring Programme

*The number and location of active sites and sampling frequency were reviewed with considerations for: NGMP monitoring objectives, the region's hydrogeological setting, **Horizons'** 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 3.5):

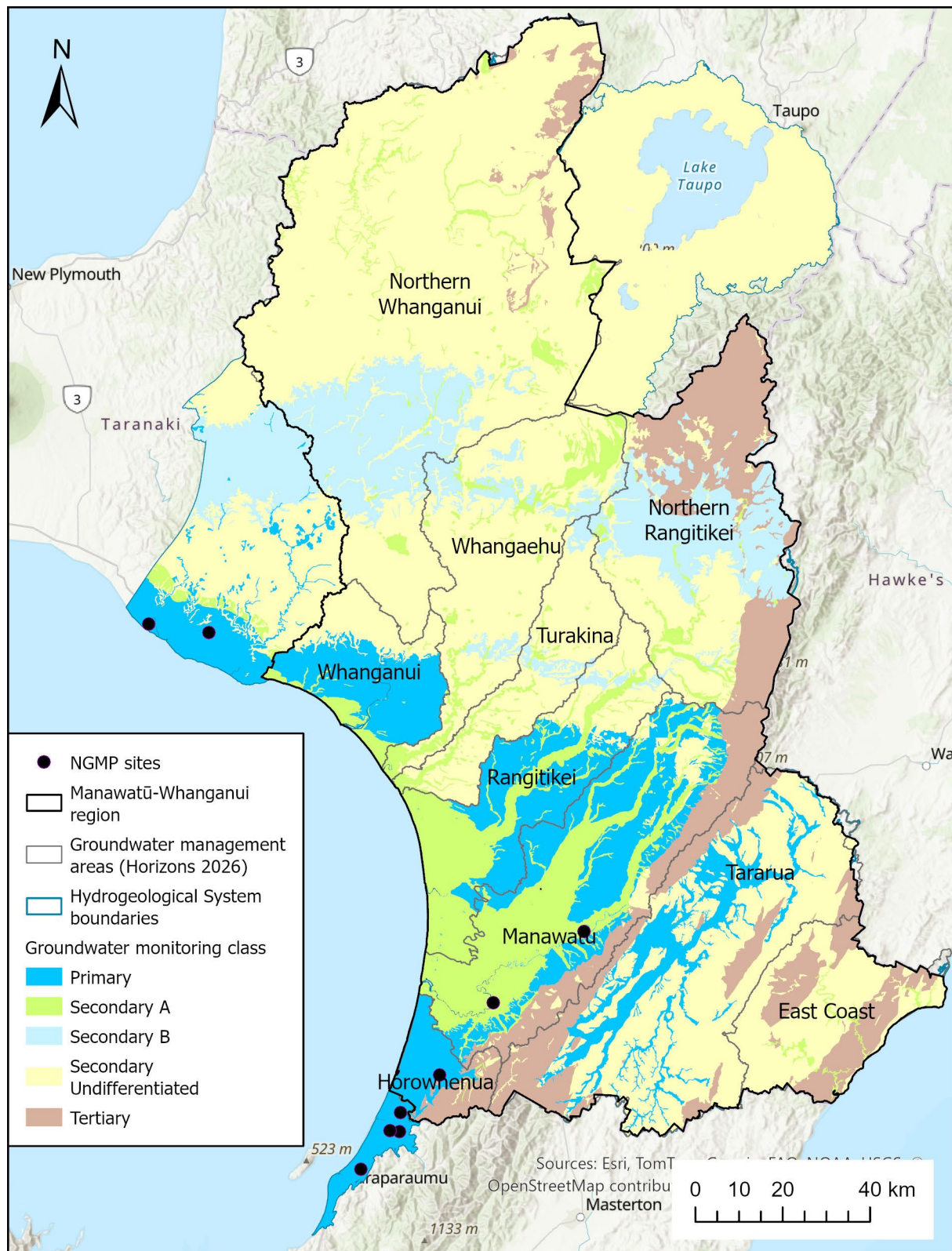
- Three primary aquifer systems: Tertiary sediments of the Whanganui Basin system, all sediments of the South Whanganui Basin system and Quaternary sediments in the Dannevirke system. In the Whanganui Basin system, there are strong geological and structural controls from basin-scale features. The southwest-dipping Tertiary sediments emplaced in a subsiding basin host multiple, distinct aquifers with great thicknesses. These aquifers are recharged in the hill country, exhibiting artesian pressure at the coast and extend across to the Taranaki region (Bekesi 2001 [and references therein]). In the South Whanganui Basin system, Quaternary and Tertiary sediments are amalgamated, as the Tertiary units are significantly thinner than in the larger Whanganui Basin system. These aquifers exhibit strong interactions between groundwater and surface water at shallow depth and extend across to the Wellington region. In the Dannevirke system, Holocene sediments are the main groundwater source (Bekesi 2001).

- Secondary coastal Holocene alluvial and dune sediments within the region, which support surface water features (e.g. Lake Horowhenua, PukePuke Lagoon) and associated dune lake ecosystems. Further inland, these deposits occur within low-producing Tertiary deposits where interactions between groundwater and surface water are limited.
- Mineralised and warm springs associated with geothermal gradient within the Matemateaonga Formation, some of which have local cultural significance (Brown et al. 1987).

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.*

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).



The NGMP programme is organised in three components: operations, research and data management. Under operations, the monitored sites relevant to Horizons' hydrogeological features are located in the Manawatū-Whanganui (three sites), Taranaki (two sites) and Wellington (four sites) regions. Three sites are sourced by primary systems and five by secondary systems, and well depth ranges from 10 m to 186 m. 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, where possible, with other Earth Sciences New Zealand research programmes. This is the same approach used to collect groundwater age data and time series.

To be consistent with the proposed network in the Waikato, two options were developed aiming to include monitoring sites within each of the major hydrogeological features at a range of depths, and for the remote Matamateaonga Formation, manage challenging site access. This 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 Horizons. The two options correspond to a first option that reflects the current funding level, which constrains spatial and temporal coverage, and an aspirational option where cost-efficiency is sought, but a minimal level of monitoring is a driver for all key systems. Both represent a compromise between increasing the breadth of information available for reporting and current resourcing, and, in doing so, better complements the regional monitoring.

4.0 Optimising Regional Monitoring in the Manawatū-Whanganui

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 3.3.

As a general guidance, the density of wells within each area was defined to be (Moreau et al. 2026):

- Two to three wells per 10 km² in the higher priority areas (red areas).
- One well per 10 km² in the medium-high-priority areas (orange areas).
- One well per 20 km² in the medium-priority areas (peach areas).
- One well per 40 km² in the medium-low-priority areas (white areas).
- One well per 80–100 km² in the low-priority areas (blue areas).

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

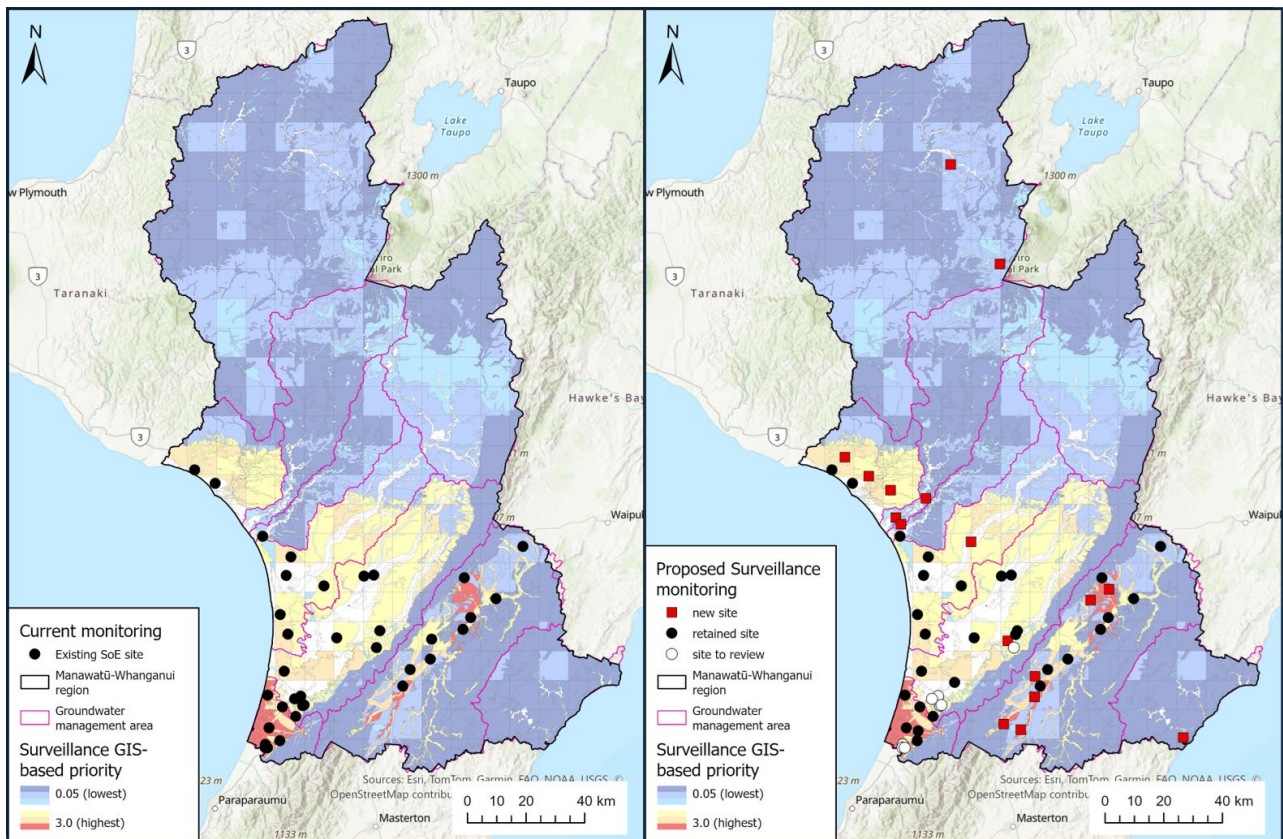


Figure 4.1 Current (left) and proposed (right) Surveillance monitoring sites in the Manawatū-Whanganui region.

4.1.1 East Coast

Groundwater resources in the East Coast are not substantially developed and are of low priority. Land use consists mostly of high- to low-producing (non-dairy) grassland (Appendix 1.3.3). Much of the basement and Tertiary limestone, sandstone and siltstone formations of this area predominantly comprise poor-yielding hydrogeology. There are currently no groundwater quality monitoring sites in this area.

To represent local communities that may depend on limited resources, it is proposed to add the Owahanga Spring Community Water Supply (SourceCode G01819; Birendra 2019) to the network (Figure 4.2). This requires further investigation and collaboration with the local community and/or the Owahanga Catchment Group.

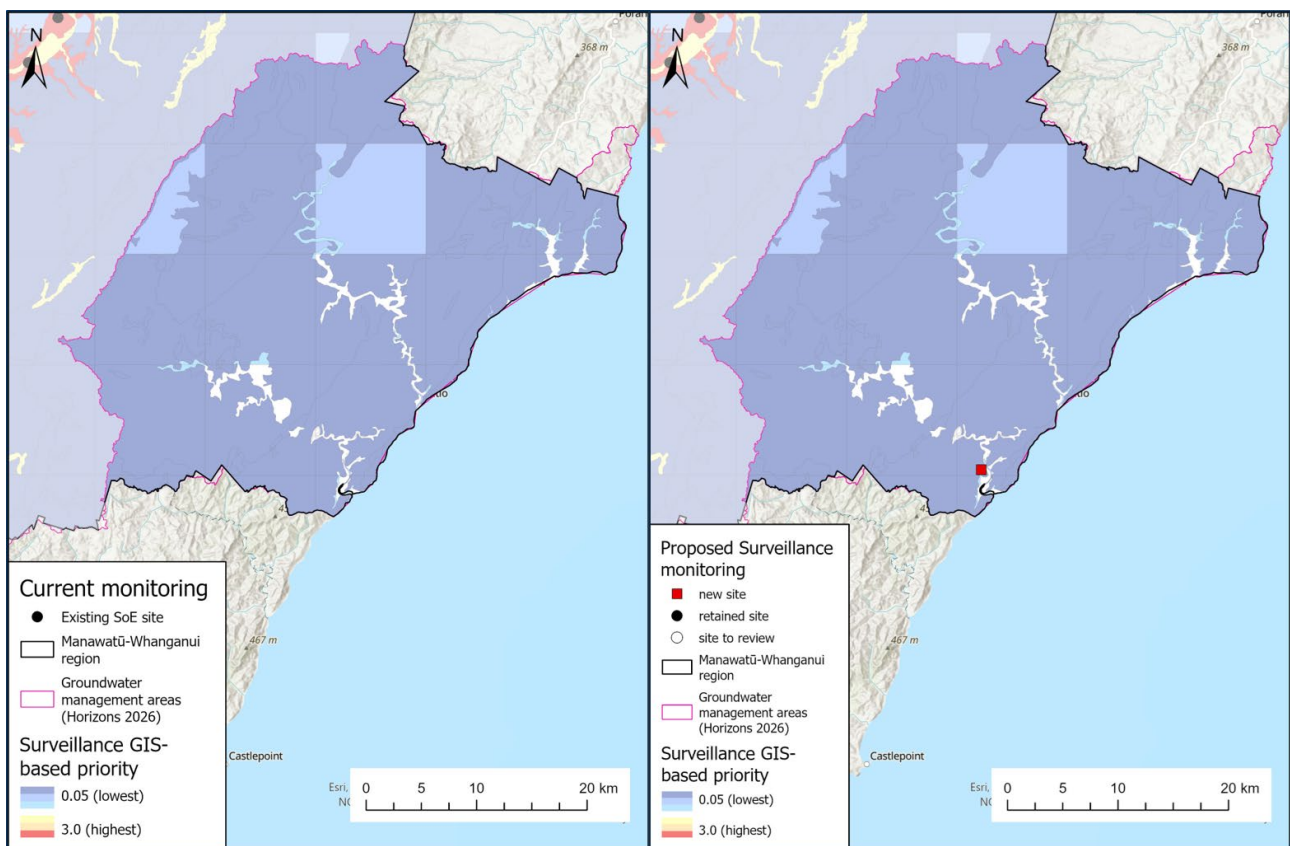


Figure 4.2 Current (left) and proposed (right) Surveillance monitoring sites in the East Coast Groundwater Management Area (GWMA). Note that the location of the proposed site is indicative only, based on the combined drinking-water sources from Birendra 2019. Site suitability and access will need to be assessed.

4.1.2 Horowhenua

In the Horowhenua, groundwaters is sourced by multiple aquifers from Quaternary and Tertiary sediments, with a shallower basement than in the Whanganui Basin. The predominant land use in this area are natural forest and high-producing grassland (dairy and non-dairy). There are currently seven groundwater quality monitoring sites.

It is proposed to retain the existing sites (Figure 4.3), with perhaps a review of data collected from the three-sites cluster located north of Otaki, to check whether one or two sites may be dropped as the wells are screened in a similar depth range (12 m to 19 m). No additional sites are suggested.

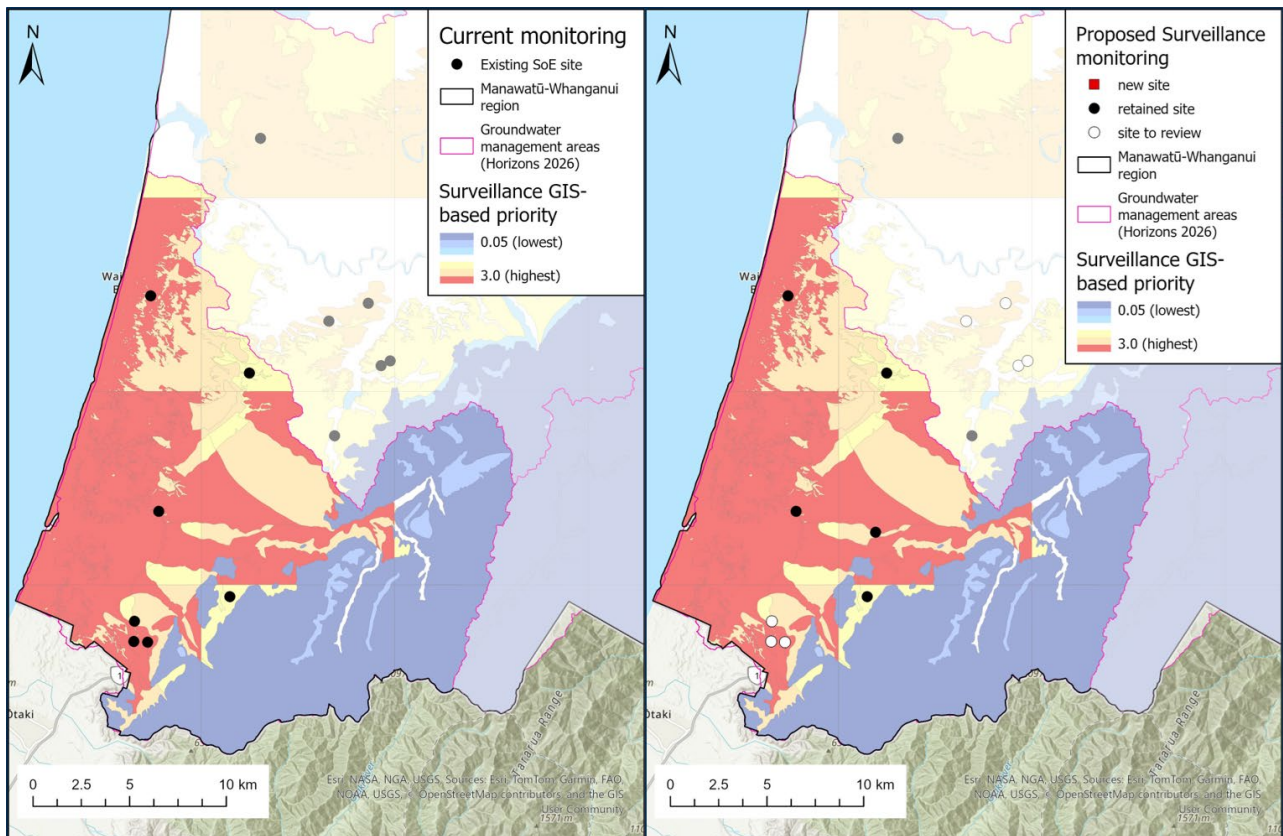


Figure 4.3 Current (left) and proposed (right) Surveillance monitoring sites in the Horowhenua Groundwater Management Area (GWMA).

4.1.3 Manawatū

Groundwater resources in the Manawatū are primarily within the Quaternary alluvial deposits associated with the Manawatū River and Tertiary sediments with strong artesian pressure towards the coast (vertical hydraulic gradient as high as 0.33 [Bekesi 2001]). Land use consists mostly of high-producing (including dairy) grassland (Appendix 1.3.3). There are currently 11 groundwater quality monitoring sites in this area with depths between 12.3 m and 65.5 m.

It is proposed to add a deep site in Palmerston North, at indicative depths of 200 m, and to assess the feasibility of removing two of the four clustered north of Levin, which are sourced at similar depth: 20 m and 40 m, respectively (Figure 4.4). This requires further investigation and collaboration with the local community and/or the Manawatū District Council.

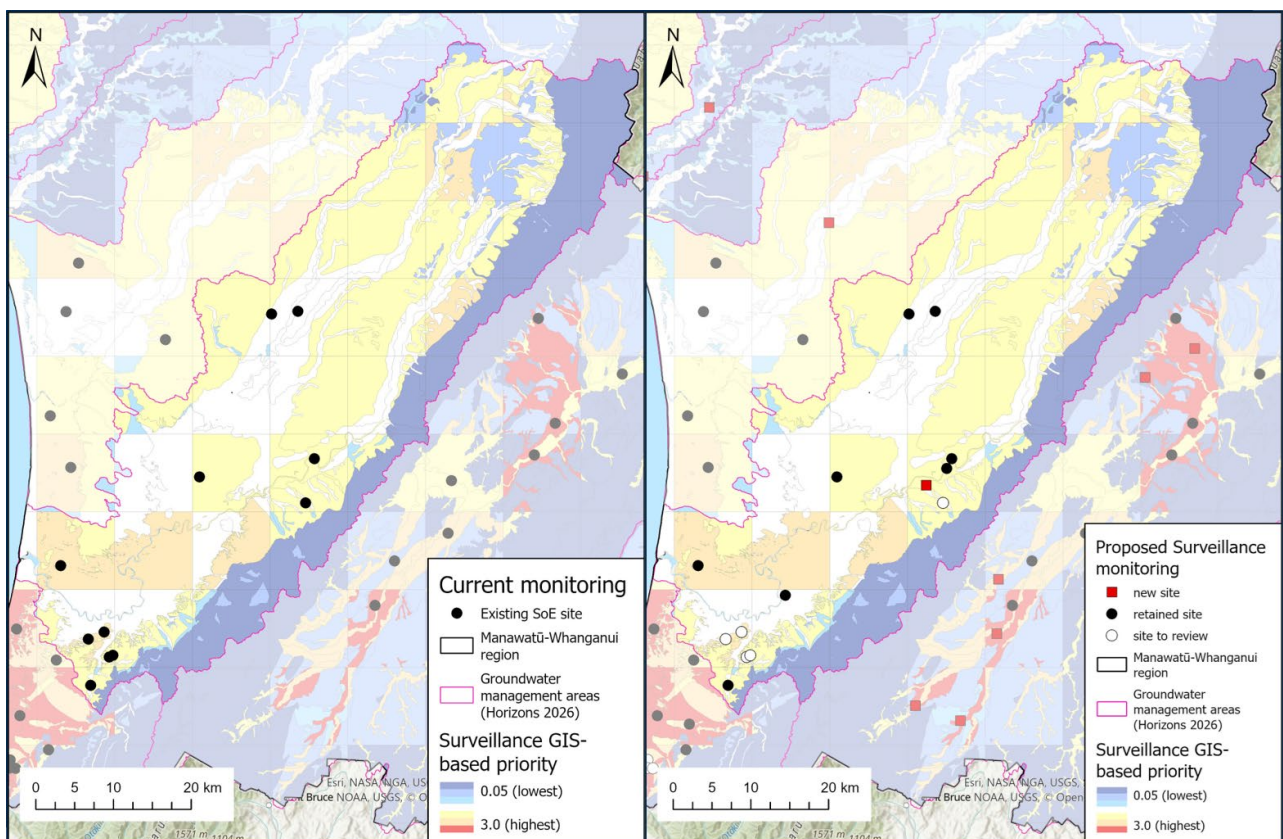


Figure 4.4 Current (left) and proposed (right) Surveillance monitoring sites in the Manawatū Groundwater Management Area (GWMA).

4.1.4 Northern Rangitikei

Groundwater resources in the Northern Rangitikei are not substantially developed and are of low priority. Land use in this area consists of predominantly high- to low-producing grassland (non-dairy) and natural forest (Appendix 1.3.3). There are currently no groundwater quality monitoring sites in this area.

This remote area does not include any consented groundwater takes and only two bores are recorded in Horizons' database (Figure 4.5). It is therefore recommended to keep the existing monitoring unchanged, i.e. without any site in the area.

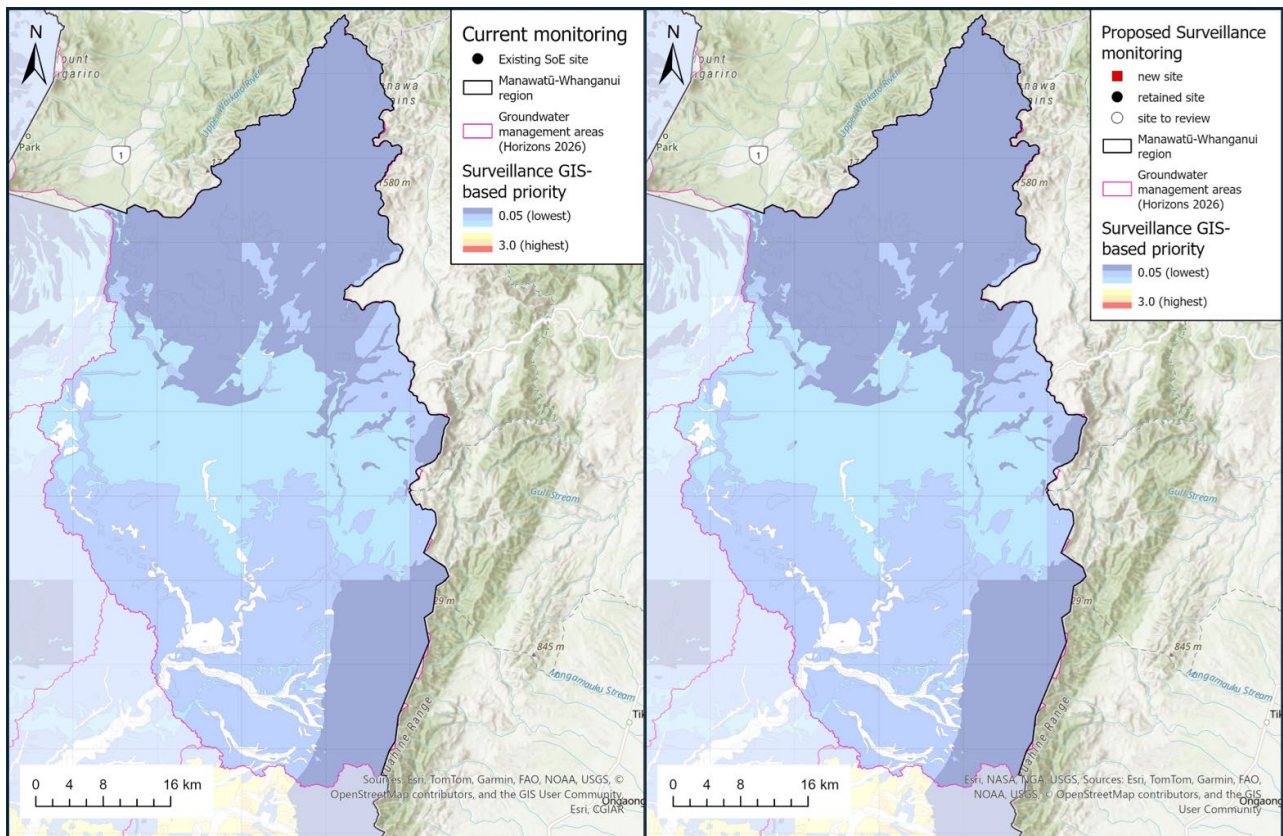


Figure 4.5 Current (left) and proposed (right) Surveillance monitoring sites in the Northern Rangitikei Groundwater Management Area (GWMA).

4.1.5 Northern Whanganui

Groundwater resources in Northern Whanganui are not substantially developed and are of low priority. Land use in this area consists of predominantly natural forest with high- to low-producing grassland (non-dairy) (Appendix 1.3.3). There are currently no groundwater quality monitoring sites in this area.

To represent local communities that may depend on limited resources, it is proposed to add the Piriaka and Waipuna Springs Water Supplies (SourceCode G00385 and G01697; Birendra 2019) to the network (Figure 4.6). This requires further investigation and collaboration with the local community and/or the Ruapehu District Council.

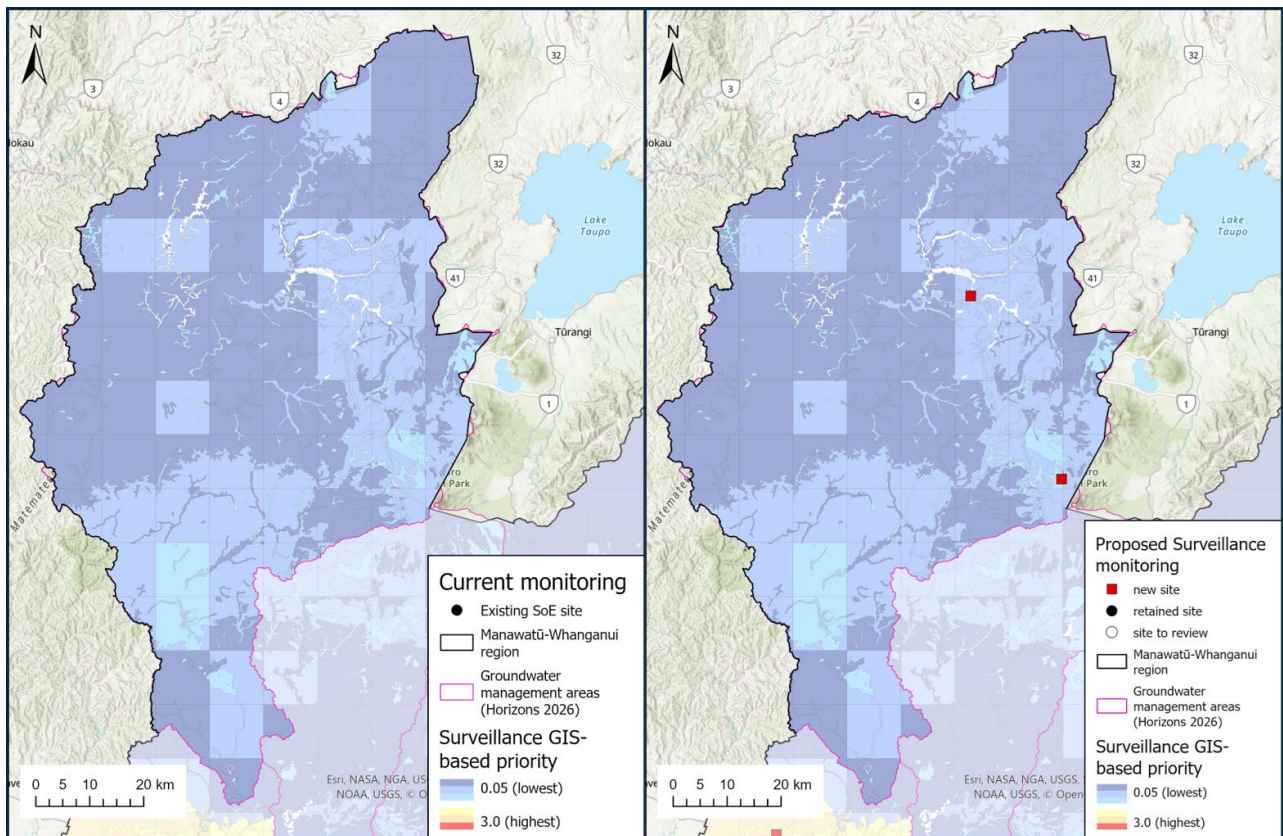


Figure 4.6 Current (left) and proposed (right) Surveillance monitoring sites in the Northern Whanganui Groundwater Management Area (GWMA).

4.1.6 Rangitikei

Groundwater resources in the Rangitikei are primarily within the Holocene alluvial deposits associated with the Rangitikei River. Land use consists mostly of low-producing (non-dairy) grassland and natural forest (Appendix 1.3.3). There are currently five groundwater quality monitoring sites in this area with depths ranging from 18 m to 116.7 m.

The existing network provides good spatial distribution (laterally and with depth). It is proposed to add one monitoring site upgradient (Figure 4.7). This requires further investigation and collaboration with the local community and/or the Rangitikei District Council.

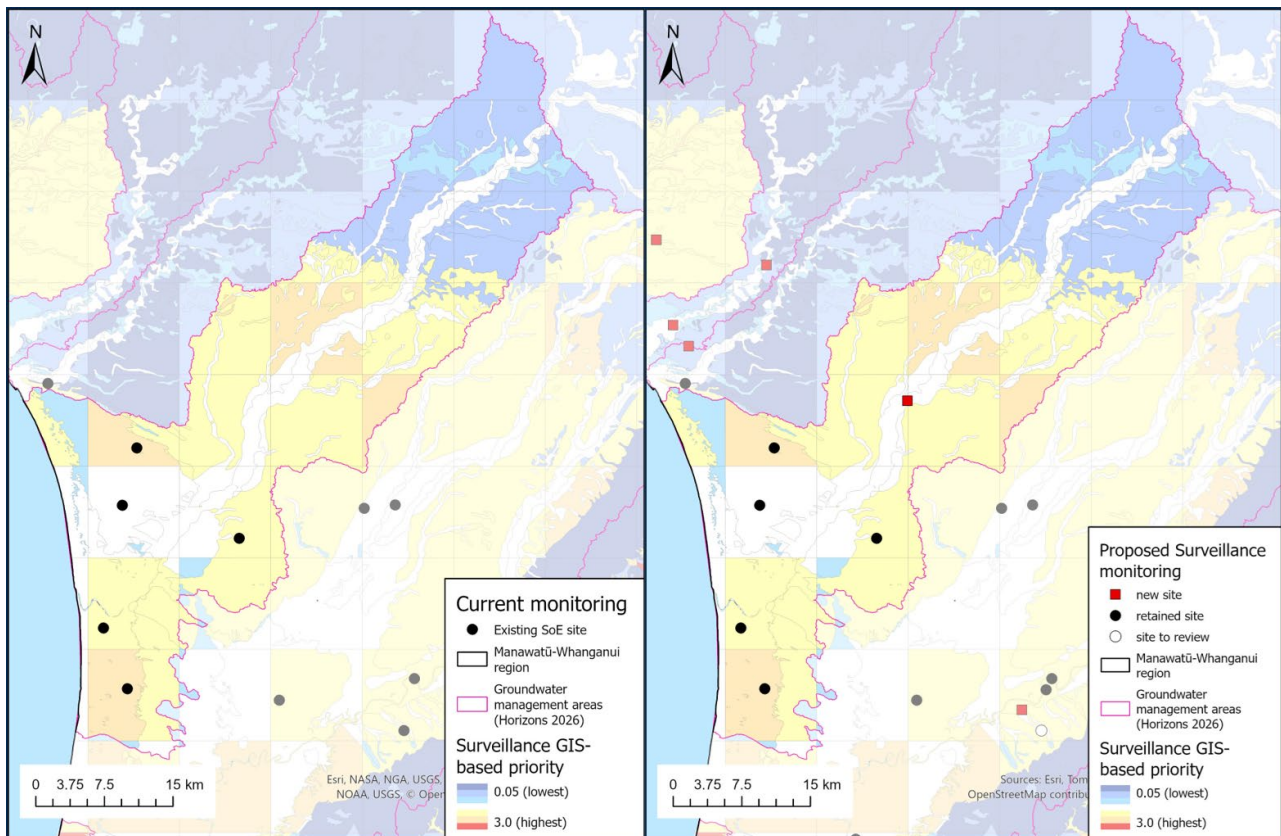


Figure 4.7 Current (left) and proposed (right) Surveillance monitoring sites in the Rangitikei Groundwater Management Area (GWMA). Note that the location of the proposed site is indicative only, based on the Horizons Regional Council's groundwater takes database. Site suitability and access will need to be assessed.

4.1.7 Tararua

Groundwater in Tararua is mostly sourced from shallow Quaternary alluvial gravel (<30 m deep) with intensive land use. It is proposed to retain the existing nine sites and add a further six sites (Figure 4.8). This requires further investigation and collaboration with the Tararua District Council and local communities.

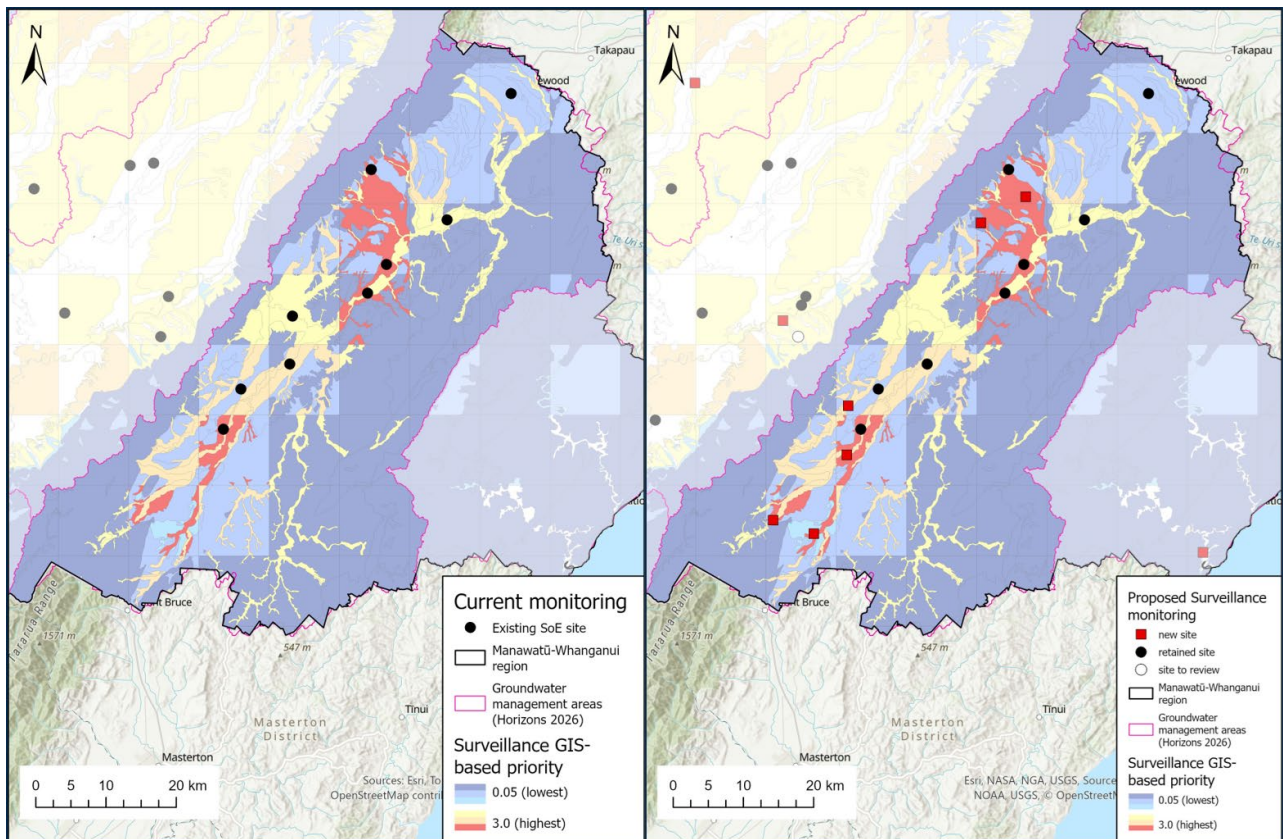


Figure 4.8 Current (left) and proposed (right) Surveillance monitoring sites in the Tararua Groundwater Management Area (GWMA).

4.1.8 Turakina

Groundwater resources in the Turakina are primarily within the Quaternary alluvial deposits associated with the Turakina River. Land use consists mostly of high- to low-producing (non-dairy) grassland (Appendix 1.3.3). Much of the Tertiary limestone, sandstone and siltstone formations of this area predominantly comprise poor-yielding hydrogeology. Currently, there is one groundwater quality monitoring site in this area.

It is proposed to add the Ratana Community Water Supply (SourceCode G00044; Birendra 2019) to the network (Figure 4.9). This requires further investigation and collaboration with the local community and/or the Rangitikei District Council.

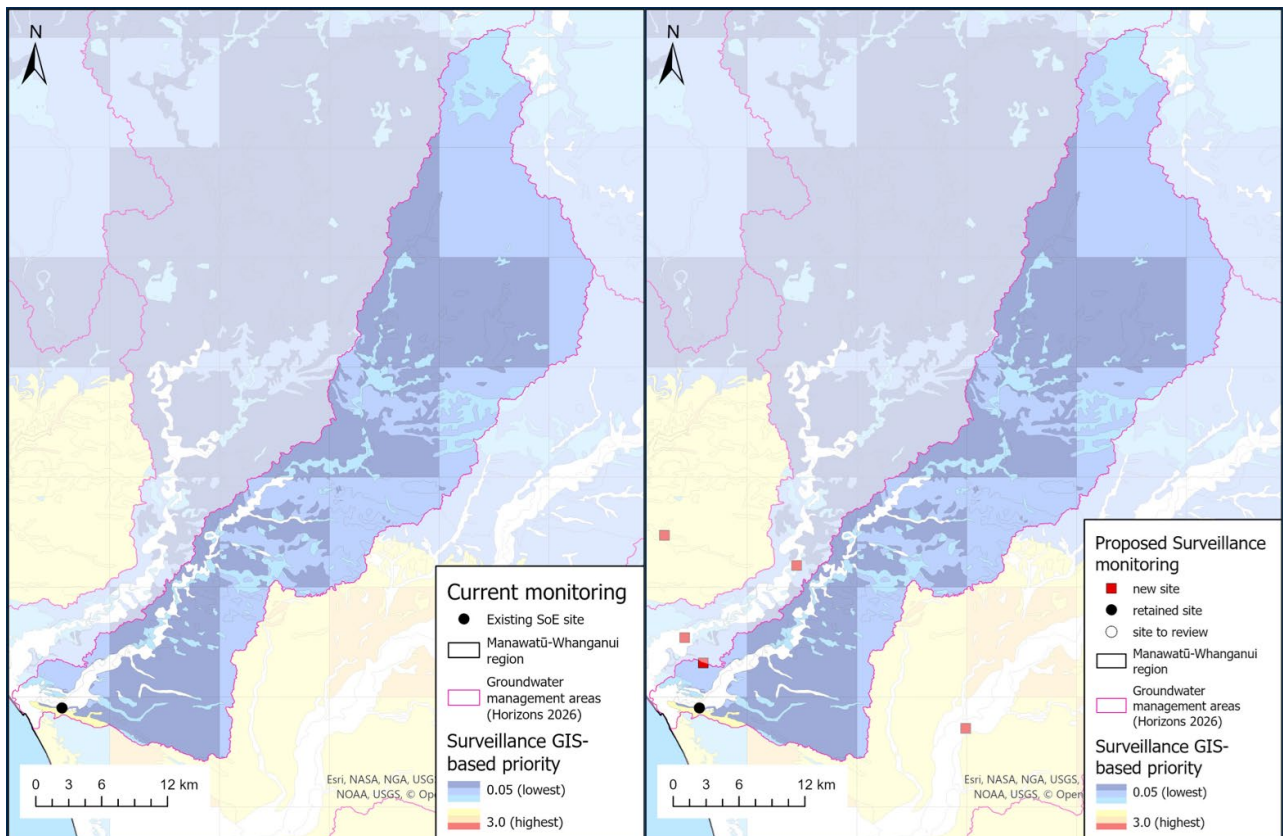


Figure 4.9 Current (left) and proposed (right) Surveillance monitoring sites in the Turakina Groundwater Management Area (GWMA).

4.1.9 Whangaehu

Groundwater resources in Whangaehu are primarily within the Holocene alluvial deposits associated with the Whangaehu River. Land use consists mostly of high- to low-producing (non-dairy) grassland (Appendix 1.3.3). Much of the Tertiary limestone, sandstone and siltstone formations of this area predominantly comprise poor-yielding hydrogeology. There are currently no groundwater quality monitoring sites in this area.

It is proposed to add two sites (at the coast and one up-gradient), which would reflect the abstraction pattern in the area (Figure 4.10). This requires further investigation and collaboration with the local community and/or the Rangitikei District Council.

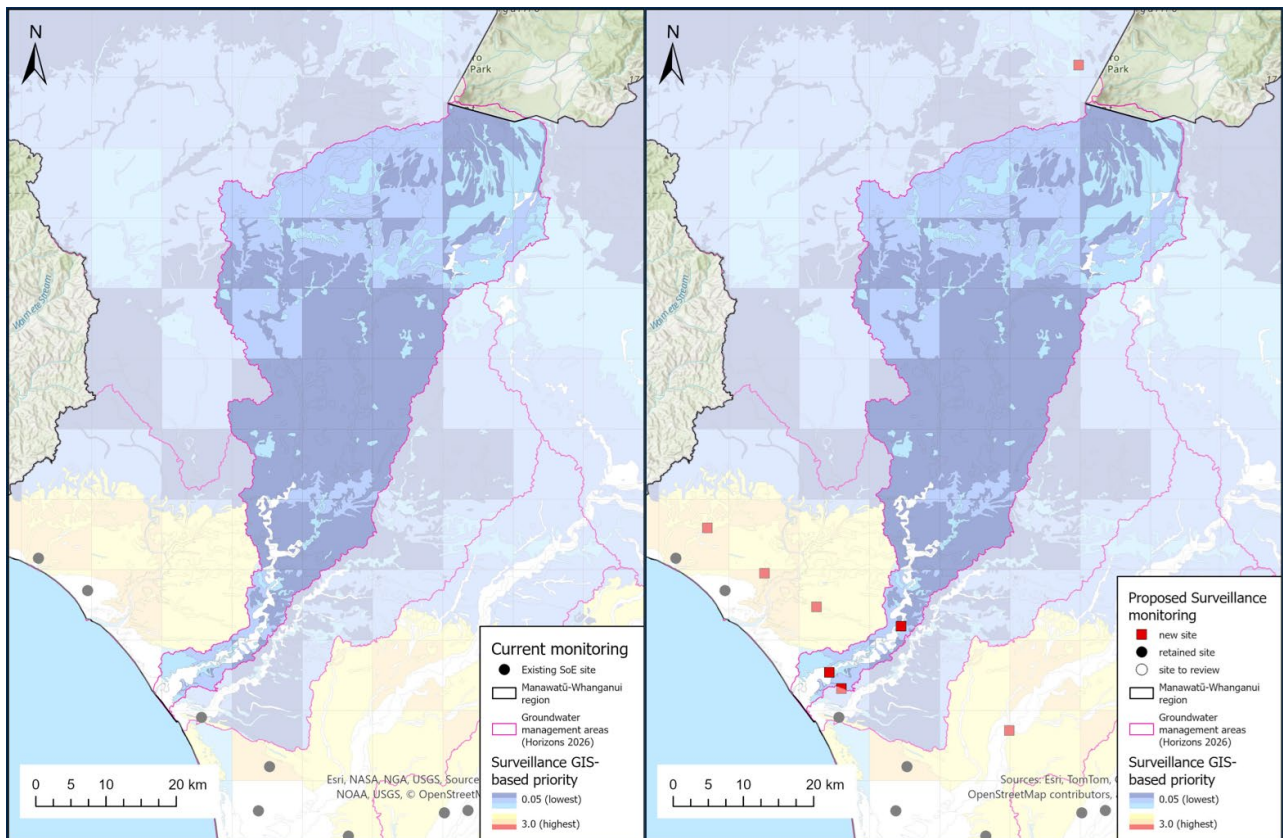


Figure 4.10 Current (left) and proposed (right) Surveillance monitoring sites in the Whangaehu Groundwater Management Area (GWMA). Note that the locations of the proposed sites are indicative only, based on the Horizons Regional Council's groundwater takes database. Site suitability and access will need to be assessed.

4.1.10 Whanganui

Groundwater resources in Whanganui are primarily within the Holocene alluvial deposits associated with the Whanganui River and Tertiary sediments with strong artesian pressure towards the coast (Bekesi 2001). Land use consists mostly of forest (natural and planted) with some high-producing (non-dairy) grassland (Appendix 1.3.3). There are currently two groundwater quality monitoring sites in this area with respective depths of 68.6 m and 128 m.

It is proposed to add three sites further from the coast, which would reflect the abstraction pattern in the area (Figure 4.11). This requires further investigation and collaboration with the local community and/or the Rangitikei District Council.

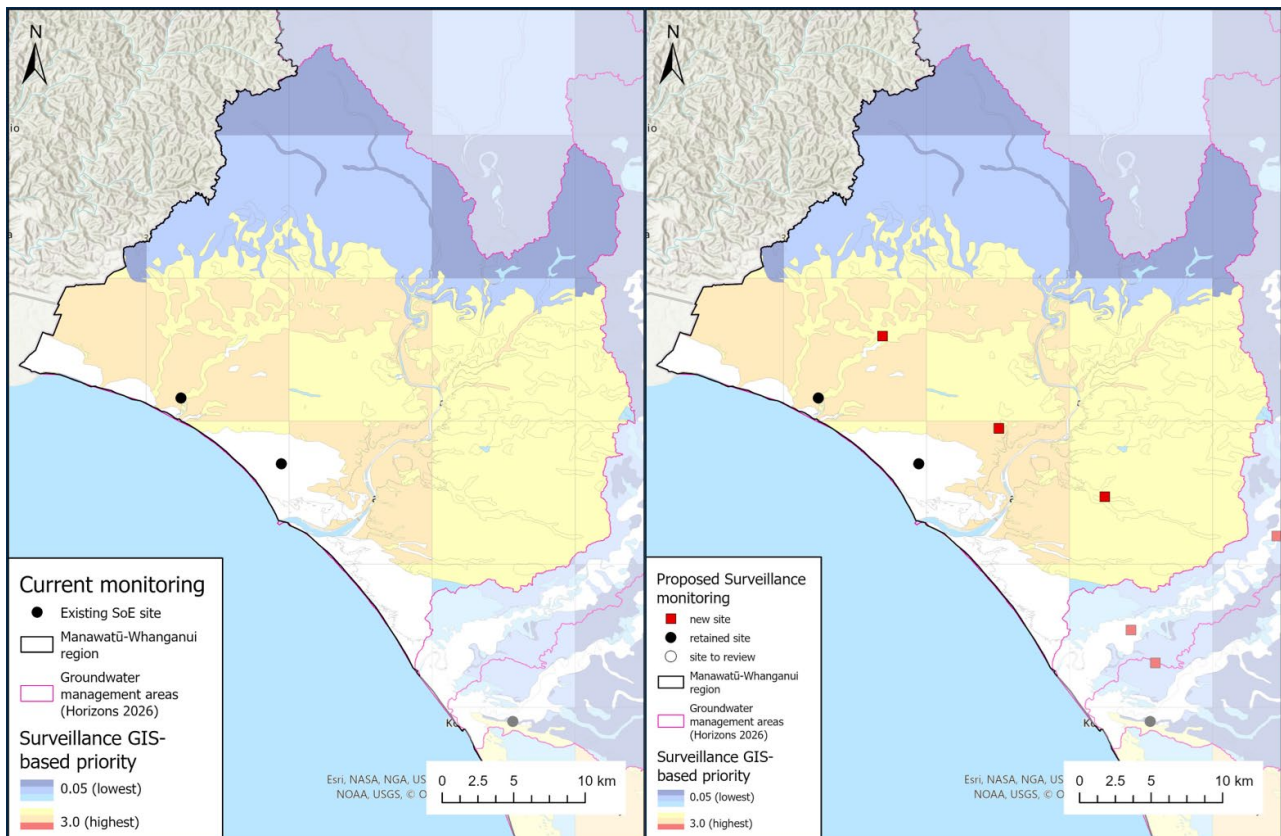


Figure 4.11 Current (left) and proposed (right) Surveillance monitoring sites in the Whanganui Groundwater Management Area (GWMA).

4.2 Surveillance National Groundwater Monitoring Programme

The proposed optimised NGMP includes an expansion of the network (eight sites retained, one site switch and nine new sites) and of the dataset to include significant historical spring water quality analyses. Quality checks will continue to be performed by comparing current analyses with the historical record and charge balance error calculations. The proposed aspirational option would include four more sites (depth >150 m, to be monitored annually). In the proposed network, each primary system includes multiple sites to capture the vertical distribution of aquifers, as well as lateral variability (Whanganui Basin and South Whanganui Basin Tertiary and Quaternary sediments; Dannevirke Quaternary sediments).

Proposed changes to the network for each of the key hydrogeological features of the sub-regions are detailed below (Figure 4.12):

- Whanganui Basin – four existing sites, two sourced by Quaternary sediments (336113 and 354011) and another two sourced by Tertiary sediments (GND2197 and GND2242) in the Taranaki region. It is recommended to assess the feasibility of including a further six sites supplied by Quaternary and Tertiary sediments in the following GWMA: Whanganui with a range of depth (e.g. non-SoE well 790115), Rangitikei with a range of depth (e.g. SoE bores 332039, 332065) and Manawatu with a range of depth (e.g. SoE bore 342051 or non-SoE bores 336213, 336233).
- South Whanganui Basin – five existing sites sourced from Tertiary to Quaternary sediments (362521, S25/5125, S25/5322, S25/5256, R26/6624). Four of these sites are to be retained. It is recommended to assess the possibility of switching one of the existing sites (S25/5125 or S25/5256) for a location further south (e.g. R26/6503). The addition of a site located close to Lake Horowhenua is also recommended (SoE bore 362001).
- Dannevirke – no existing wells; investigate inclusion of two SoE sites supplied by Quaternary sediments (e.g. 357109, 338005).

To assist national reporting on spring features and/or groundwater ecosystems, it is proposed to enhance the NGMP dataset by adding the existing data to the NGMP dataset. 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, 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.

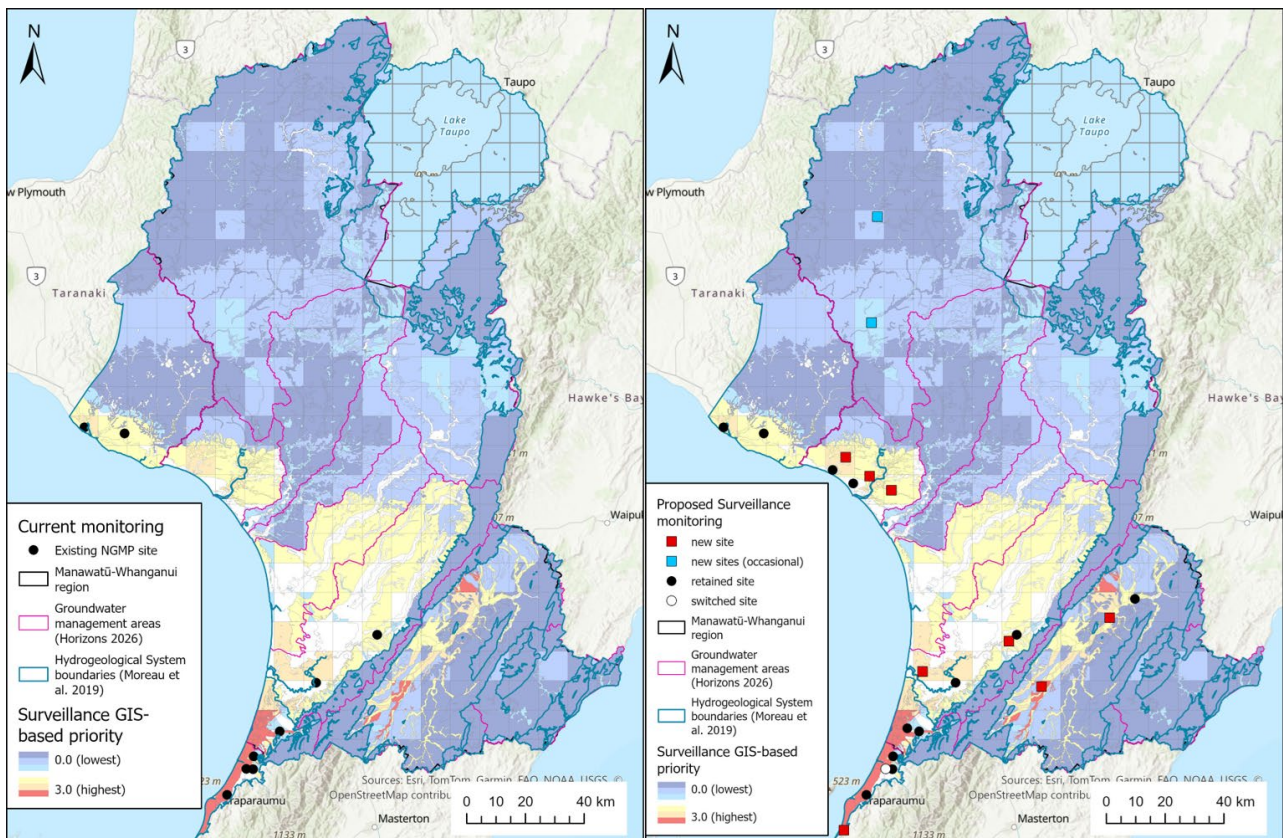


Figure 4.12 Proposed changes to the National Groundwater Monitoring Programme (NGMP): current (left) and proposed NGMP monitoring sites in the region, and proposed dataset enhancement (right). The Taupō system Surveillance priority index was sourced from the Waikato case study (Moreau et al. 2026). At the time of writing this report, the Surveillance priority index has not been developed for the Taranaki region. The GRI was extended to both the Taranaki and the Wellington regions using datasets provided by regional councils.

4.3 Variables and Sampling Frequency

To compensate for the proposed regional network expansion, it is recommended that Horizons reduces the current variable suite to match the Groundwater Forum core suite (Table 4.1).

It is recommended that Horizons uses a combination of quarterly and lower-frequency annual and biennial monitoring that allows greater spatial representation within the same logistical constraints, while including seasonal considerations. Lower frequency should be used at sites where groundwater mean residence time is greater than 50 years. 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). However, at new sites, a quarterly frequency may be used for up to three years to assess suitability. It is recommended to keep the NGMP sampling frequency to quarterly with consideration for minimum data point requirements for national reporting within available resources.

Table 4.1 Comparison between Horizons Regional Council (HRC), Waikato Regional Council (WRC) and National Groundwater Monitoring Programme (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 and the New Zealand Drinking-Water Standard (DWS) requirements.

Variable	HRC	WRC	NGMP	NEMS	GWF	DWS
Alkalinity	TD	TD	TD	-	TD	TD
Ammonia	D/T	T	D/T	-	T	-
Antimony	-	-	-	-	-	T
Arsenic	D	T	-	-	-	T
Barium	-	-	-	-	-	T
Boron	D	T	-	-	-	T
Bromide	D/T	D/T	D	-	-	-
Calcium	D	D	D	-	D	T
Chloride	D/T	D/T	D/T	-	D/T	D/T
Conductivity	TD (field and lab)	TD (field and lab)	TD (field and lab)	TD (field)	TD (lab)	TD (lab)
Copper	-	T	-	-	-	T
Dissolved Inorganic Carbon	D	-	-	-	-	-
Dissolved Inorganic Nitrogen	Meas/calc	-	-	-	-	-
Dissolved Organic Carbon	D	-	-	-	-	-
<i>E. coli</i>	NA	-	-	-	-	-
Fluoride	D/T	-	D	-	-	-
Iron	D	D+T	D	-	D	T
Lead	-	-	-	-	-	T
Magnesium	D	D	D	-	D	T
Manganese	D	D+T	D	-	D	T
Mercury	-	-	-	-	-	T
Nitrate + Nitrite	D/T	-	-	-	-	-
Nitrate	D/T	D/T	D	-	D/T	D/T
Nitrite	D/T	D/T	-	-	D/T	D/T
Oxygen	D (field)	D (field)	D (field)	D (field)	-	-
pH	NA (field and lab)	NA (field and lab)	NA (field and lab)	NA (field)	NA (lab)	NA (lab)
Phosphorus	TD+DR	DR	DR	-	DR	-
Potassium	D	D	D	-	D	T
Silica	D	D/T	DR	-	-	-
Sodium	D	D	D	-	D	T
Sulphate	D/T	D/T	D	-	D/T	D/T
Temperature	NA (field)	NA (field)	NA (field)	NA (field)	-	-

D and T indicate Dissolved and Total form, respectively.

5.0 Recommendations

This review was the first step to practically apply the previously developed Surveillance and Evaluative framework approach, and resulted in the design of a proposed, consistent, regional and national Surveillance network. The next step will be to implement recommended changes and to investigate designs for the Evaluative framework. Therefore, we recommend the following next steps for Horizons:

- Continue regular SoE and NGMP operations until the changes to the network can be effected to ensure the long-term monitoring record is preserved.
- Consultation with the Environmental Monitoring team to communicate potential changes, and work jointly to identify suitable wells and undertake site visits. In areas where there was a lack of monitoring sites, existing private wells were identified for field reconnaissance based on available information. Field visits to potential new sites should include sample collection where possible. Well suitability criteria include the availability of hydrogeological information (i.e. a detailed bore log), completion depth and lithology, location and likely access, with preference given to more recently constructed wells. Any changes to the design should be recorded to continue the transparent documentation of monitoring decisions.
- Assess opportunities for collaboration with district councils and local catchment groups as it is expected that resourcing may also place a limit on the feasibility and size of the regional and national programmes' expansions (Table 5.1). Regular sampling of drinking-water supply could provide a significant cost-efficiency where a modification of the analytical suite may serve both the Surveillance and drinking-water monitoring purposes. This will require assessment of the site sampling point suitability (prior treatment and storage) and possibly training to ensure Surveillance samples are collected following the NEMS standard. Such arrangements will require the development of a formal agreement, for example a Memorandum of Understanding between monitoring agencies.
- Implement recommended changes within the NGMP, in consultation with Earth Sciences New Zealand.
- Review and assess the possibility of alignment between the groundwater level monitoring SoE programme and the groundwater quality Surveillance network.
- Review the current groundwater quality monitoring for organic variables within the Surveillance and Evaluative framework.
- Undertake some technical work to record current and past SoE activities that fit under Evaluative monitoring. For instance, PFAS monitoring at Ohakea Airbase and Palmerston North Airport. It is recommended to prioritise the development of Evaluative monitoring in the Santoft (groundwater level) and PukePuke Lagoon (groundwater quality and levels) areas using the method used in this report. Priority score attributes may require adapting for groundwater level reviews.
- The GIS-based prioritisation scores were based on available data to develop attributes. For the Evaluative nitrate assessment, a regional map of vulnerability was not available; although earlier work from Bekesi and McConchie (2000) provided a basis for it. It is recommended that the feasibility of developing a modern DRASTIC assessment be investigated. Similarly, for the Evaluative saltwater intrusion assessment, the SoE dataset was used. However, if data are available from the saltwater intrusion monitoring network and/or coastal drinking-water supply, this information could be used to revise the Evaluation priority score. Consideration should also be given to use sodium chloride data to identify seawater intrusion.
- The GRI calculation does not currently account for groundwater contribution, due to the lack of a readily available national dataset. It is recommended that the feasibility of developing regional datasets, such as a refined digital spring dataset and/or quantitative information about the interaction of groundwater and surface water, informed by field-based measurements (Stenger and Woodward 2018; Moore et al. 2025), be investigated.

Table 5.1 Summary of proposed changes and indicative resourcing requirements (NA = not applicable). Q, BA and A indicate Quarterly, Biannually and Annually.

Groundwater Management Area	SoE Current	Surveillance (Regional + National)	Surveillance (Regional)	Sites to Review (Regional)	New Sites (Regional)
East Coast	0	1 (BA)	1	-	1
Horowhenua	7	9 (Q)	7	3	-
Manawatu	11	3 (BA) + 11 (Q)	11	4	2
Northern Rangitikei	0	0	-	-	-
Northern Whanganui	0	2 (Q)	2	-	2
Rangitikei	5	2 (A) + 1(BA) + 3(Q)	6	-	2
Tararua	9	14 (Q)	11	-	6
Turakina	1	1(BA) + 1 (Q)	2	-	1
Whangaehu	0	2 (Q)	2	-	2
Whanganui	2	5 (Q)	3	-	3
Outside the region	-	6 (Q)	-	-	-
Total sites	35	61	45	7	19
<i>Total samples per year</i>	<i>140</i>	<i>228</i>	<i>188</i>	<i>NA</i>	<i>NA</i>

6.0 Conclusion

Groundwater quality monitoring in the Manawatū-Whanganui 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 adapted from that used in the Waikato region (Moreau et al. 2026) to reflect the differing hydrogeological settings and available datasets. As in the Waikato, this review represents a step-change from an internally focused and compartmentalised approach to collaborative programme reviews, a switch from traditional SoE monitoring to Surveillance and Evaluative monitoring. The work was conducted in consultation with neighbouring regions and builds on a national framework developed 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), which will require practical reviews with monitoring teams and recommendation 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. It is also expected that some sites will be shared between the Surveillance and Evaluative networks. Recommendations were provided to implement changes and ensure future-proofing of our groundwater quality monitoring programmes in the region.

7.0 Acknowledgements

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APPENDICES

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APPENDIX 1 Detail on Spatial Assessment Methodology

A1.1 Introduction

This Appendix details the methods used to define cells based on geologically defined polygons, (based on the hydrological systems of Moreau et al. [2019], which include the 1:250,000 digital geological map) and a 10 km x 10 km grid overlaid on the Manawatū-Whanganui 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. [2019]).

Spatial analysis was undertaken in GIS software (ArcPro).

A1.2 Groundwater Class Definition

- Clipped the polygon shapes from the GNS Science New Zealand Hydrogeological Systems¹¹ (Moreau et al. 2019).
- Used the “dissolve” tool based on the attributes HS_name and HS_geo_gr to simplify this layer.
- Used the “union” tool to incorporate Horizons’ groundwater management areas.
- Used the “summarise within” tool to calculate the well density and groundwater take (volume) density of each of these polygons. For well density, well locations provided by Horizons were used, and for the groundwater take (volume) density, the attribute Daily (m³/d) was used. Missing values were filled with a nominal value of 50 m³/d, which is the threshold values for consented takes in the region. Where takes combined multiple wells, the consented take was assigned to a single well. Takes for which the “PrimaryPurpose” included “Erosion Protection or Remediation” or “Storm Water or Drainage Management” or “Waste Management | Wastewater Management” were excluded from further analysis because these takes are temporary and do not reflect typical groundwater demand. Two sets of coordinates for takes were manually modified to ensure they plotted with the Hydrogeological Systems shapefiles.
- The well and take ‘densities’ were multiplied together to get the field “DensityCombined” (called the Groundwater Reliance Index or GR Index), which was used to identify the classes described in Section 3.2. The highest GR Index values represented areas of principal class, with lower values representing Secondary A, Secondary B, Secondary Undifferentiated and Tertiary classes. Some minor modifications based on literature and expert judgement were made to adjust classes and/or polygons extents. These are detailed in Section 3.2.

A1.3 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 Manawatū-Whanganui region. The attributes chosen for the relative rating assessment were selected based on the four criteria described in the Environment Aotearoa 2019 synthesis report¹² to provide a “focus on what matters” approach: (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. 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

¹¹ <https://www.gns.cri.nz/data-and-resources/new-zealand-hydrogeological-systems/>

¹² <https://environment.govt.nz/publications/environment-aotearoa-2019/>

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 A1.1). The GIS-based priority is calculated from the attribute 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 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 area is:

$$GIS\text{-based Priority} = \sum A_R A_W \quad \text{Equation A1.1}$$

Where:

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

and

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

Table A1.1 Attributes and their weighting used to derive the GIS-based priority for groundwater quality monitoring (modified from Moreau et al. 2026).

Attribute	Surveillance Consideration	Weighting (%)	Evaluative Consideration (Nitrate)	Weighting (%)	Evaluative Consideration (Seawater Intrusion)	Weighting (%)
Groundwater class (i.e. primary, secondary, etc.)	Yes	55%	Yes	20%	Yes	50%
Vulnerability	-	-	Yes	NA	-	-
Land use	-	5%	Yes	20%	-	-
Drinking water	-	10%	Yes	10%	Yes	10%
Known groundwater quality issues	-	5%	Yes	30%	Yes	30%
Groundwater and surface-water interaction	Yes	20%	-	20%	-	-
Taonga	Yes		-	-	-	-
Climate change	Yes	5%	-	-	Yes	10%
Other Considerations for Site Selection and Frequency Not Spatially Based						
Distance from coast	-	-	-	-	Yes (to include/exclude)	NA
Redox state	-	-	Yes (to inform site selection)	NA	-	-
Groundwater age	Y (only to inform frequency)	NA	Yes (to inform site selection)	NA	Maybe?	-
Anticipated land-use change	-	-	Yes (if available)	NA	Yes (if available)	NA
Policy details (if applicable)	-	-	Yes (if available)	NA	Yes (if available)	NA

A1.3.1 Groundwater Class Attribute

Classes were defined using a combination of groundwater management areas, geology, well density and abstraction density (Table A1.2; Figure A1.1).

Table A1.2 Aquifer type and corresponding scores (source: Moreau et al. 2026).

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

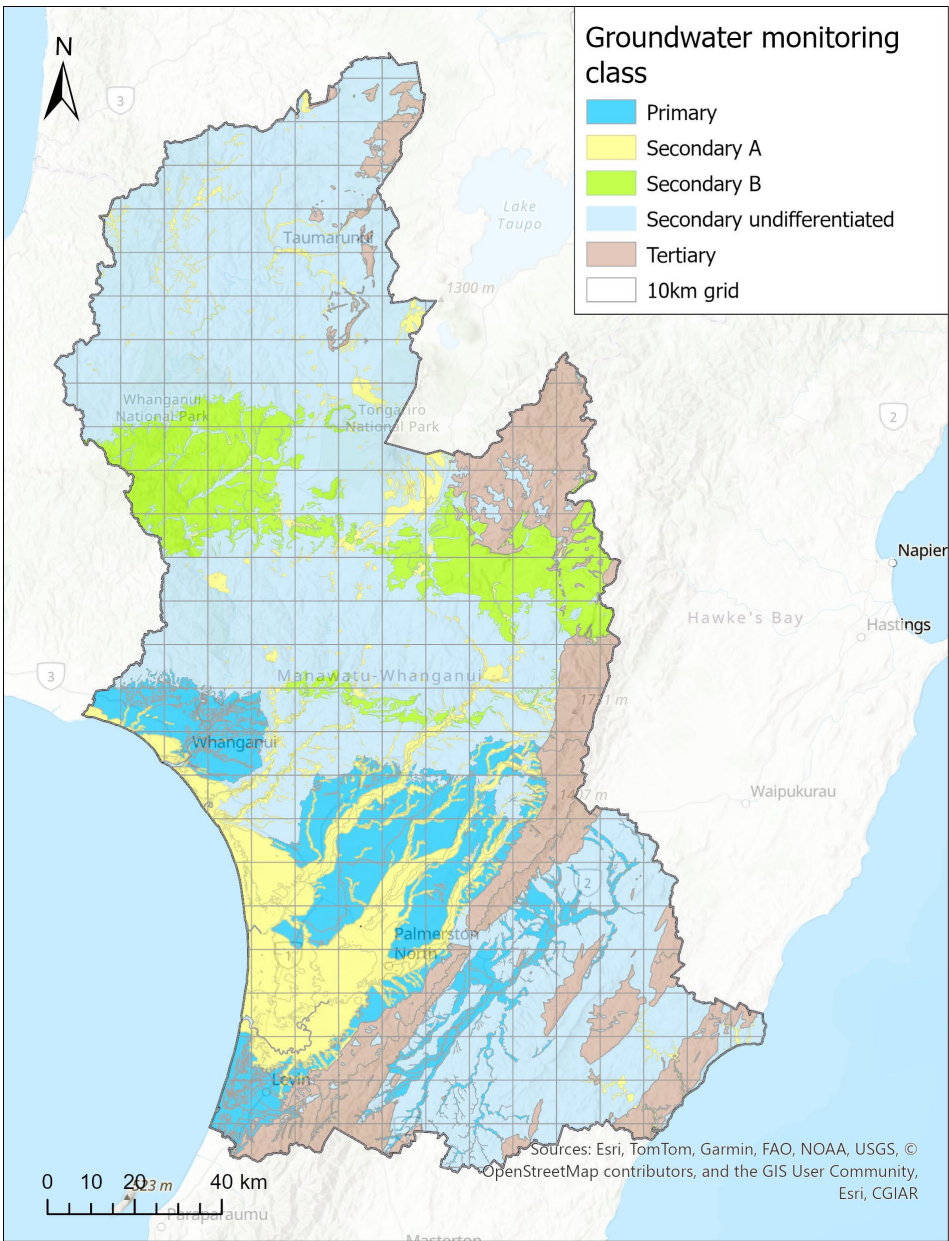


Figure A1.1 Groundwater class designations for the Manawātū-Whanganui region.

A1.3.2 Vulnerability Attribute

Landscape Subsurface Nitrate-Attenuation Index (LSNAI) classes were defined using hierarchical cluster analysis of groundwater redox probability predictions by the XGBoost model and soil drainage and rock type classes for the Manawatū-Whanganui (Collins et al. 2025). The “Zonal Statistics as Table” tool was used to calculate the LSNAI average (mean) for each groundwater class 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 A1.2), 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. Vulnerability score for polygon = $\text{zonal_stats_LSNAI_mean for polygon} \times [\text{three/highest zonal_stats_LSNAI_mean for all polygons}]$).

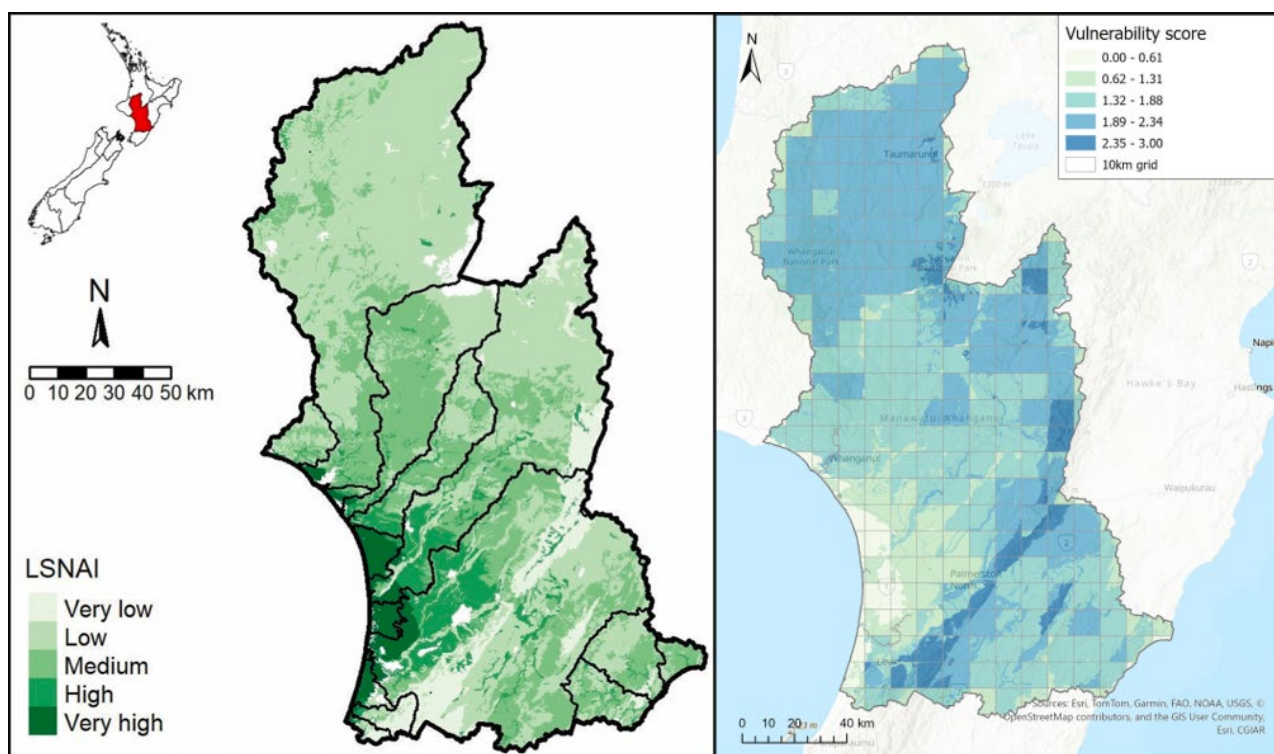


Figure A1.2 Landscape Subsurface Nitrate-Attenuation Index (LSNAI) classes (Collins et al. 2025) (left) and vulnerability to nitrate contamination scores (right) for the Manawatū-Whanganui region.

A1.3.3 Land Use Attribute

Using the LUCAS NZ Land Use Map 2020 v005 dataset (Ministry for the Environment 2024), scores were assigned to particular land uses (Table A1.3; Figure A1.3). 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” tool was used to calculate the average (mean) land-use score (by area) in each polygon. The scores were reclassified using the “Reclassify field” tool to normalise the range from 0 to 3.

The Land Use Map includes 12 land-use classes, with five maps nominally dated at 31 December 1989, 2007, 2012, 2016 and 2020. The mapping methodology is detailed in Harris et al. (2023) and Harrison and Bon (2024).

Table A1.3 Land-use categories and corresponding scores (source: Moreau et al. 2026).

LUCID_2020	LUCID_2020	SUBID_2020	Score
71	Natural Forest	Not used	0.6
72	Planted Forest: pre-1990	Not used	0.6
73	Post-1989 Forest	Not used	0.6
74	Grassland: with woody biomass	Not used	1.2
75	Grassland: high-producing	502 (Grazed: dairy)	3
76	Grassland: high-producing	503 (Grazed: non-dairy)	1.8
75	Grassland: high-producing	504 (Ungrazed)	1.0
76	Grassland: low-producing	Not used	1.2
77	Cropland: perennial	Not used	2.4
78	Cropland: annual	Not used	3
79	Wetland: open water	Not used	0
80	Wetland: vegetated non-forest	Not used	0
81	Settlements	Not used	1.2
82	Other	Not used	1.2

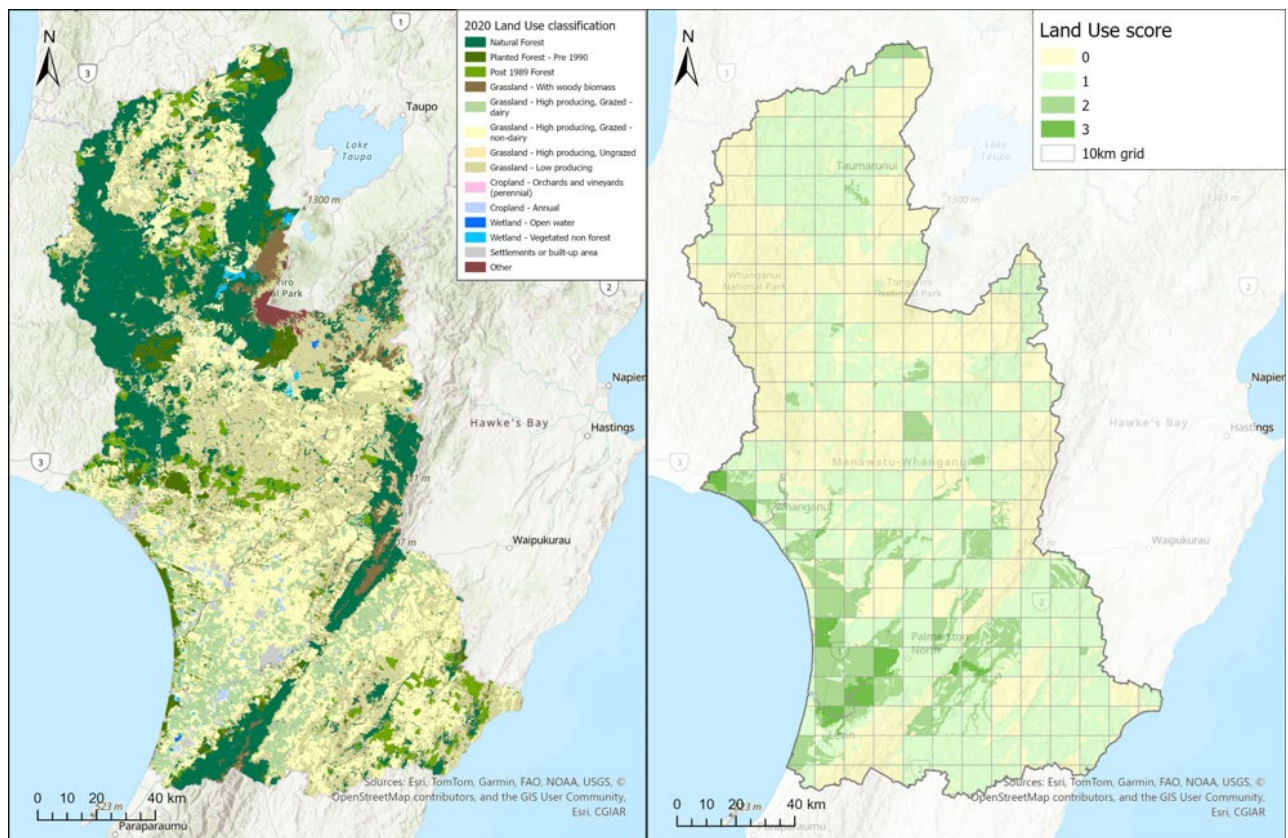


Figure A1.3 Land-use map (left) and land-use scores (right) for the Manawātū-Whanganui region.

A1.3.4 Drinking-Water Attribute

This attribute was assessed using the following datasets (Table A1.4; Figure A1.4):

- The drinking-water supplies identified using the now-archived Drinking-Water online database and Water Information New Zealand database (Birendra 2019).
- Groundwater takes from Horizons’ database where either the primary or secondary purpose include “Municipal or Drinking-Water Supply”.
- Horizons’ current Source Water Risk Management Areas 2.
- Expert knowledge on areas in which widespread private drinking-water bores were located.

Table A1.4 Drinking-water score criteria (adapted from Moreau et al. 2026).

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. Polygons located within a Source Water Risk Management Area 2.
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.

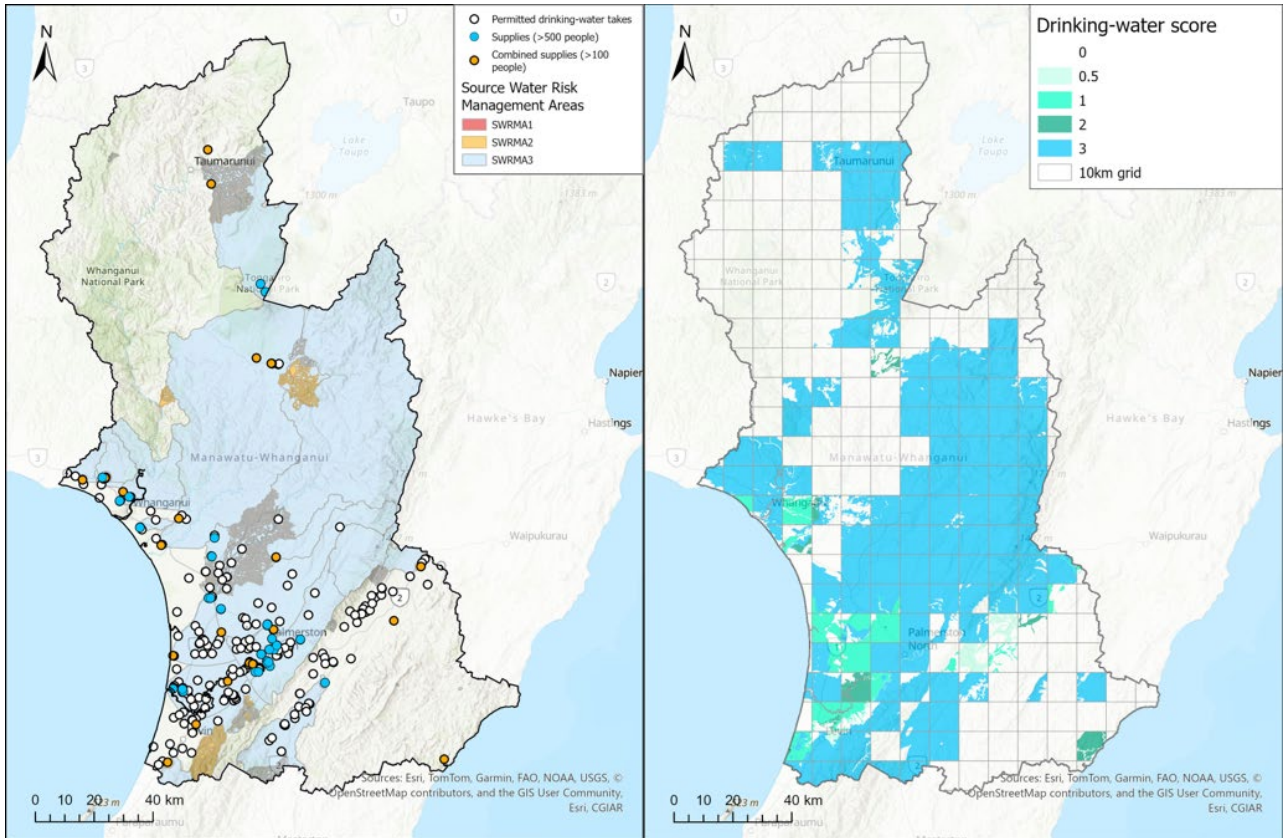


Figure A1.4 Registered drinking water supplies (left) and scores (right) for the Manawātū-Whanganui region.

A1.3.5 Known Nitrate Issues Attribute

Assessment was based on the recent national reporting (Moreau et al. 2025) on groundwater quality that used a combination of regional State of the Environment (SoE) and National Groundwater Monitoring Programme (NGMP) sites. Criteria were developed based on the latest median nitrate concentrations and associated trends at SoE wells to consistently assign a known nitrate issues score (Table A1.5; Figure A1.5).

Table A1.5 Median nitrate concentrations (data range) at State of the Environment (SoE) sites and corresponding scores (source: Moreau et al. 2026).

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.

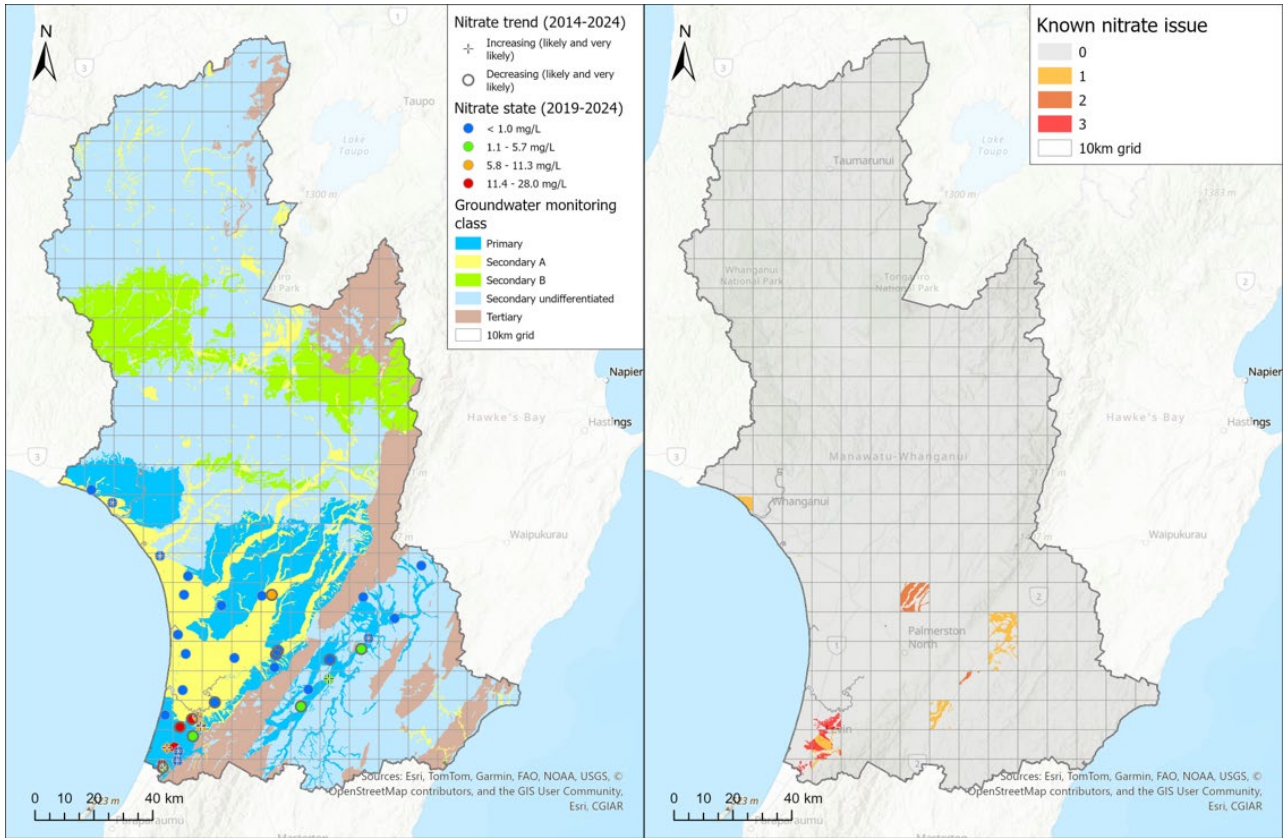


Figure A1.5 Nitrate concentrations and trends (left [from Moreau et al. 2025]) and known nitrate issues score (right) for the Manawatū-Whanganui region.

A1.3.6 Known Seawater Intrusion Issues Attribute

Assessment was based on the recent national reporting on groundwater quality (Moreau et al. 2025) which used a combination of regional SoE and NGMP sites. Criteria were developed based on the latest median nitrate concentrations and associated trends at SoE wells to consistently assign a known salinity issues score (Table A1.6; Figure A1.6).

Table A1.6 Criteria used to assign known seawater intrusion scores at State of the Environment (SoE) sites (source: Moreau et al. 2026).

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

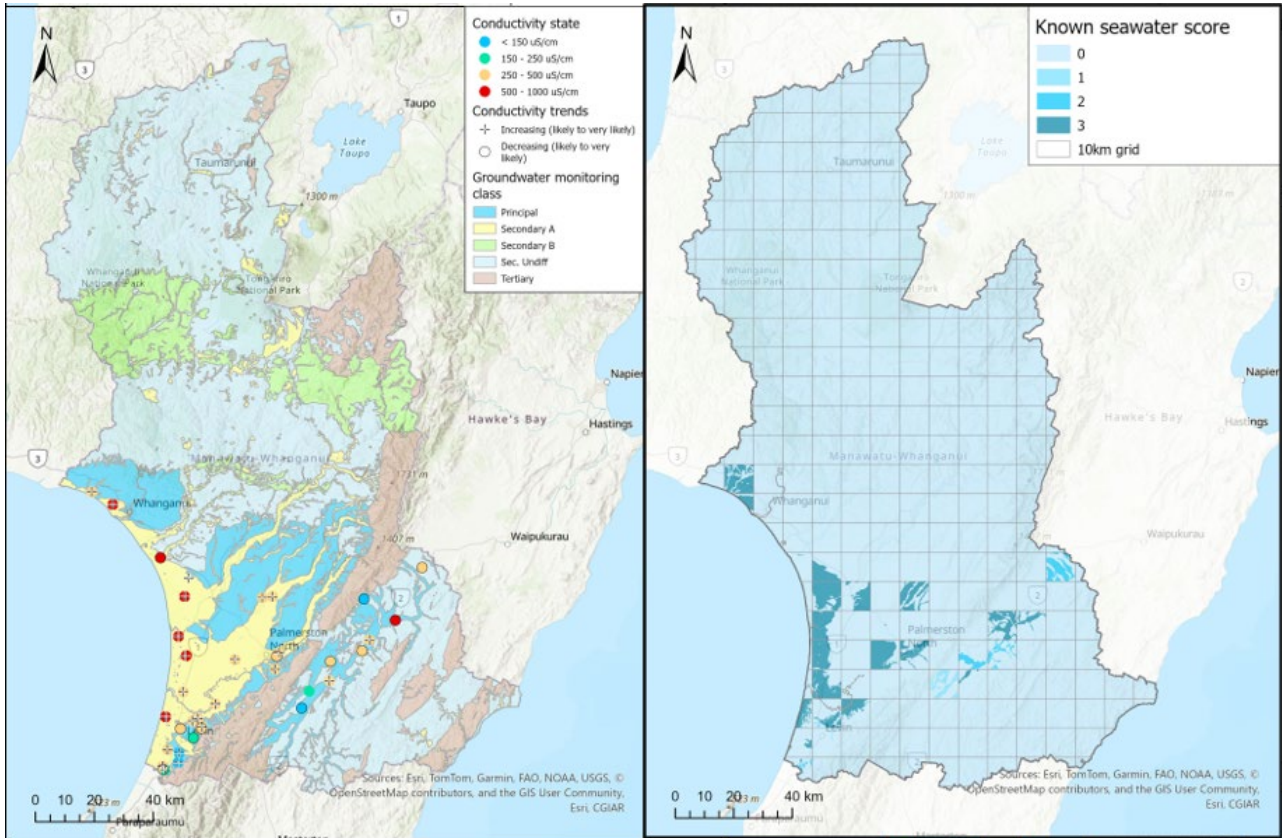


Figure A1.6 Electrical conductivity concentrations and trends (left [from Moreau et al. 2025]) and known seawater intrusion issue score (right) for the Manawatū-Whanganui region.

A1.3.7 Attributes of Interaction between Groundwater and Surface Water

The assessment of the interaction between groundwater and surface water (Figure A1.7) was informed by:

- Previous studies and reports that identified strong interactions with dunes lakes (e.g. Ohua, Horowhenua and Waikawa, and PukePuke Lagoon) along the coast of the Whanganui Basin (Bekesi 2001; Zarour 2008).
- Hydrogeological modelling in the Upper Manawatu (Rawlinson and Begg 2014) and the Santoft areas (Thomas 2017).
- A regional study on groundwater dynamics, source and hydrochemicals using age tracer data (Morgenstern et al. 2017).

Guidance used to assign ratings is summarised in Table A1.7.

Table A1.7 Criteria used to assign groundwater–surface-water interaction scores (adapted from Moreau et al. 2026).

Score Assigned	Description
3	Coastal lakes located within Holocene swamp or dunes deposits. Groundwater age less than one year.
2	Significant spring within polygon or polygon within immediate catchment area of significant spring. Groundwater age between one and five years.
1	Karstic features mapped at the surface. Groundwater age between five and 10 years.
0	Minimal or unknown connection between groundwater and surface water.

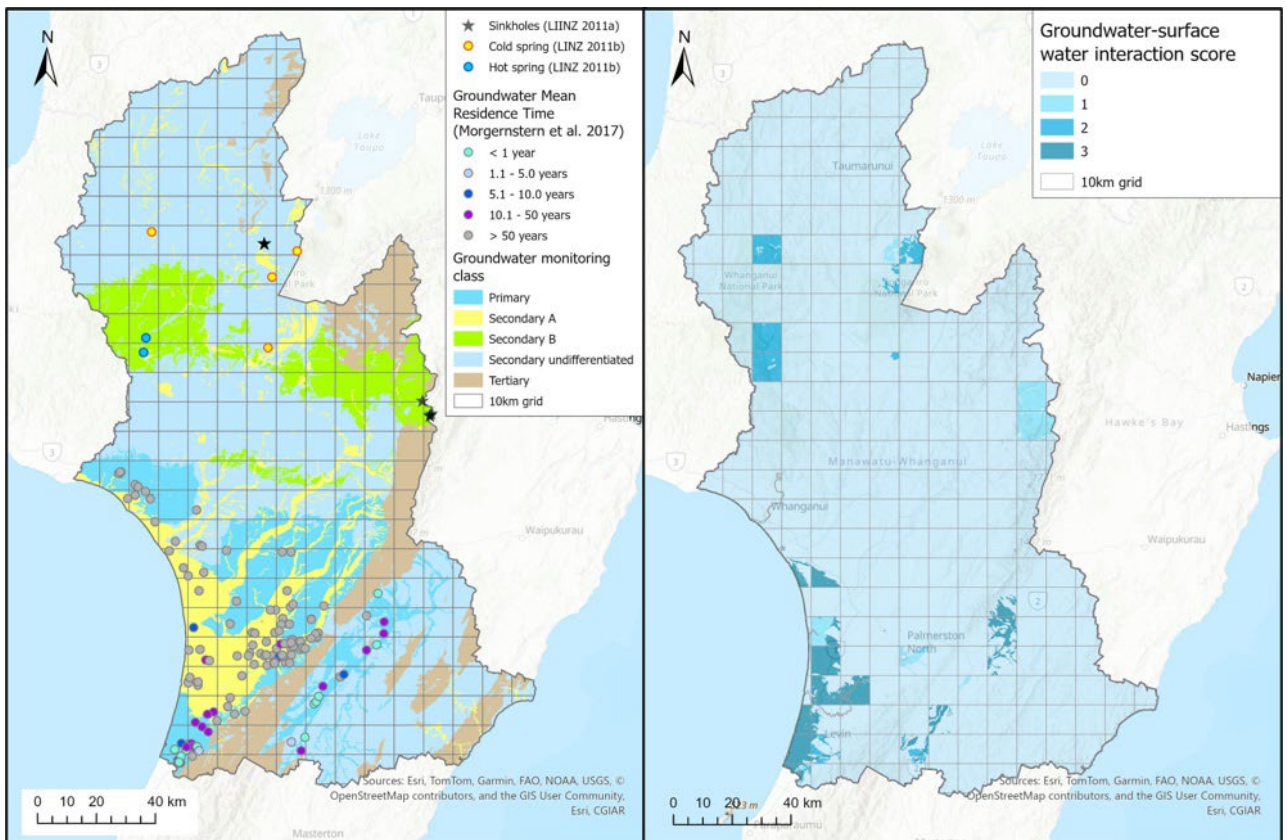


Figure A1.7 Groundwater-surface-water interaction score for the Manawatū-Whanganui region.

A1.3.8 Climate Change Attribute

Coastal inundation and river flooding climate change impact predictions (Holland et al. 2019) were used to identify areas predicted to be the most affected by climate change (Figure A1.8). The most extreme changes to rainfall variables were considered for all future periods.

Key regional climate changes relevant to this attribute:

- Increasing coastal hazards (increasing areas at risk from a 1-in-100-year storm tide).
- Increasing sea level, exacerbated by subsidence at the coast (east and west).
- Larger increases in annual flood and sediment loads.
- Larger increases for the western half of the region in winter, decreases in rainfall for the eastern part of the region (east of the Ruahine Ranges).

Guidance used to assign ratings is summarised in Table A1.8.

Table A1.8 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 increased flood hazards not included in the above.
1	Areas with decreasing precipitation.

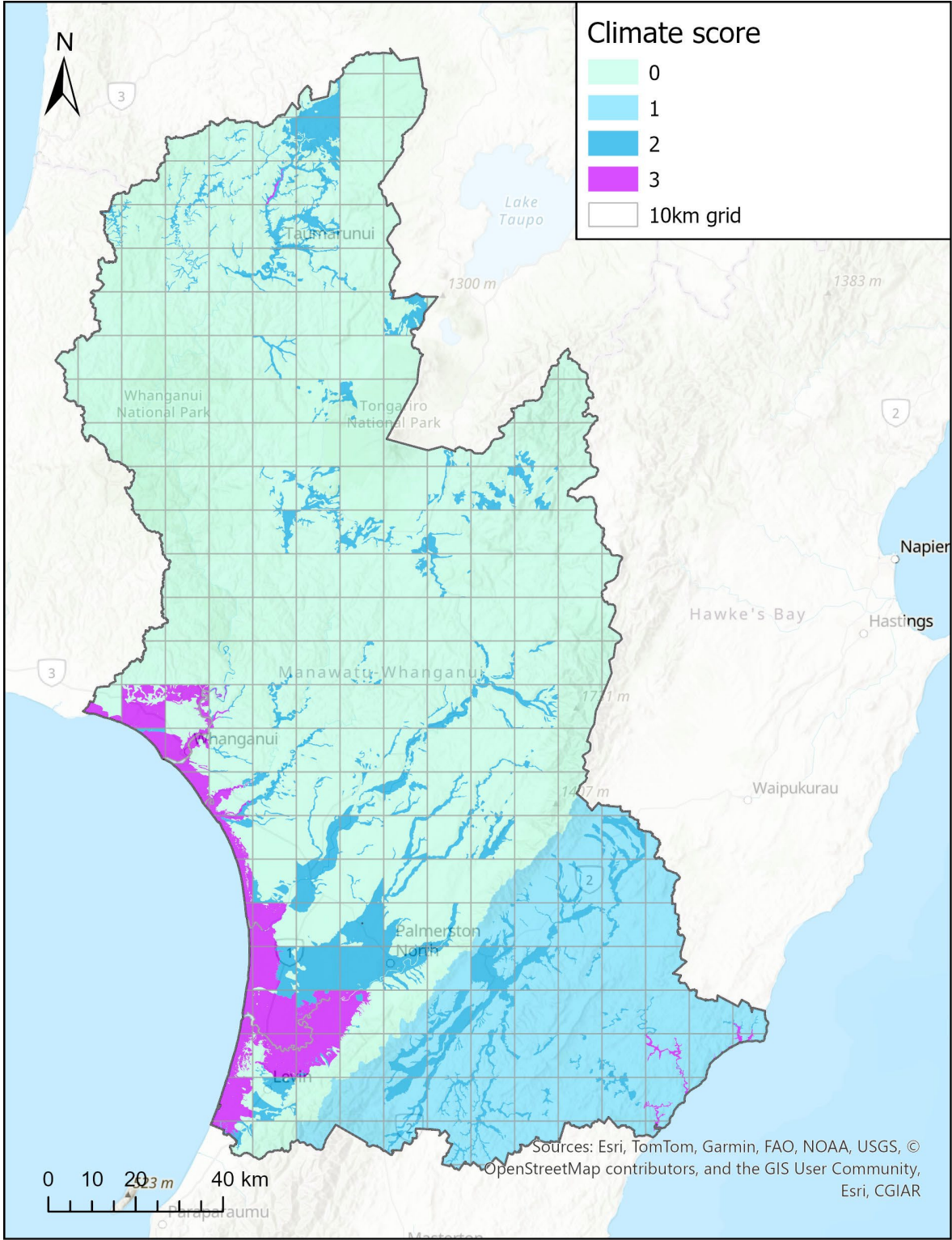


Figure A1.8 Climate change score for the Manawātū-Whanganui region.

APPENDIX 2 The GIS Datasets

The following GIS datasets were developed as part of this project and provided separately to Horizons Regional Council:

- *SR2026_22_monitoring_priority_index.shp* (This dataset is available for public use, subject to the disclaimer below [Section A2.1].)
- *SR2026_22_proposed_surveillance_gwq_network.shp* (The attributes in this dataset identify potential wells for Surveillance monitoring, and the dataset is therefore intended for Horizons Regional Council's use only.)

'Datasets' mean *SR2026_22_monitoring_priority_index.shp* and *SR2026_22_proposed_surveillance_gwq_network.shp* (files or any part of them [shape format *.shp*, shape index *.shx*, attribute *.dbf*, spatial index format *.sbn*, projection *.prj*, character encoding *.cpq* and geospatial metadata *.shp.xml*]).

The attributes in *SR2026_22_monitoring_priority_index.shp* provide the following information within the Manawatū-Whanganui region:

- Hydrogeological system name (HS_name)
- Hydrogeological system type (HS_type)
- Groundwater management area (GWMA)
- Groundwater class (score_gw_class)
- Vulnerability (score_vulnerability)
- Land use (score_land_use)
- Drinking-water (score_drinking_water)
- Known nitrate issue (score_nitrate_isse)
- Known seawater intrusion issue (score_seawater_issue)
- Interaction between groundwater and surface water (score_gw_sw_interaction)
- Climate change (score_climate_change)
- Surveillance GIS-based priority index (index_surveillance)
- Evaluative (nitrate) GIS-based priority index (index_eval_nitrate)
- Evaluative (seawater) GIS-based priority index (index_eval_seawater)

Attribute names, descriptions and values are detailed in Appendix A1.3.

A2.1 Disclaimer

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